SEDIMENTOLOGY AND ICHNOLOGY OF ESTUARINE CHANNELS IN THE LOWER CRETACEOUS BLUESKY FORMATION: THE EDSON GAS RESERVOIR, WEST-CENTRAL ALBERTA, CANADA

BY

ALESSANDRO TERZUOLI

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree

Master of Science

McMaster University

May 1996

MASTER OF SCIENCE (1996) **McMASTER UNIVERSITY**

(Geology) **Hamilton, Ontario, Canada**

TITLE: **Sedimentology and Ichnology of Estuarine Channels in the Lower Cretaceous Bluesky Formation: Edson Gas Reservoir, West-Central Alberta, Canada**

AUTHOR: **Alessandro Terzuoli, Laurea (University of Siena, Italy)**

SUPERVISOR: **Dr. Roger. G. Walker**

NUMBER OF PAGES: xii, 174

ABSTRACT

The Bluesky Formation at Edson consists of a complex of six incised channels trending SW-NE. A SE-NW oriented shoreline is implied, and the open sea lay to the NE. The channels cut into the underlying continental sediments of the Gething Formation and are filled by transgressive estuarine sediments 20-25 m thick. The complex is capped by transgressive shoreface deposits which pass up into marine mudstones of the Wilrich Member of the Spirit River Formation.

The estuarine channel fills consist of three main facies: mudstones, sandstones, and interbedded mudstones and sandstones. The mudstone fill of Channel 1 becomes sandier-upward, and also contains basal cross-bedded sandstone bodies interpreted as preserved fluvial sand bars.

The sandstone-filled Channels 2, 3, 4 and 5 display cross-bedded, parallel laminated and structureless beds with almost no mudstone interbeds. In Channels 2 and 3 there is a lateral northeastward transition from sandstones to mudstones; Channel 5 also has mudstones at the northeastern end.

The fill of Channel 6 consists of thinly interbedded sandstones and mudstones.

All of these filling sediments are characterized by a stressed trace fossil assemblage that shows an upward increase in species diversity and density.

The sandstone facies are interpreted as the fluvially-dominated inner part of a bay-head delta. The mudstones represent the central estuary turbidity maximum, and the interbedded mudstones and sandstones were deposited in the

distal part of a bay-head delta located at the transition between the previous two facies. Marine sandstones, the third component of the tripartite estuary fill, are less common in the study area.

The three different types of filling and the relationship between channels suggest three cycles (fall/rise) of relative sea-level change. Incised channels were formed during falling stages of relative sea-level. During subsequent transgressions, wave scouring modified most of the original incisions, reworking most or all of the evidence of fluvial sedimentation. Eventually, the channels were back-filled as estuaries. The final transgression affected the entire study area allowing the deposition of transgressive shoreface sandstones and the establishment of fully marine conditions (Wilrich Member).

ACKNOWLEDGMENTS

It is not an exaggeration to say that this experience at McMaster University marked a very significant step in the development of my life. I deeply thank Prof. Roger Walker not only for his precise supervision and his constant availability, but also because for me he was a "professor model" and reinforced my love for geology.

I would also like to thank the University of Siena (Italy), and especially Professors A. Lazzarotto and A. Costantini for their financial support and encouragement. Part of funding for the project was provided by an Ontario Graduate scholarship. The Ontario government is also thanked for the Fee Waiver Award that contributed to make this experience possible.

Chevron Canada Resources, and in particular Jamie D. Doig are thanked for providing me the well log data base for this study.

I would also like to thank Professors James MacEachern and Guy Plint for their help in identifying trace fossils and macro fossils.

A special thank goes to my " lab companions" student colleagues Jhonny Casas, Jin-Hyung Lee, Nicoleta Badescu, Jamie Burton and Vicki Hunter. Their friendship and the fun time spent together will never be forgotten.

I would like to express my gratitude to my parents and my sister Silvia for their constant phone call support.

Finally, I would like to dedicate this thesis to my wife Simona with endless love. She decided to share difficulties and joys, staying by my side in this unforgettable experience in a foreign country.

> "The journey from Kamakura to Kyoto takes twelve days. If you travel for eleven but stop on the twelfth how can you admire the moon over the capital?"
>
> Nichiren Daishonin
>
> Great Buddhist sage of the 13^{th} century

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDIX

CHAPTER 1: INTRODUCTION

1.1. The geological problem

In western Alberta, the Bluesky Formation represents the basal part of Fort St. John Group and it is considered a transitional phase between the continental Lower Mannville (Gething Formation, Fig. 1) and the marine Upper Mannville (Wilrich Member of the Spirit River Formation, Fig. 1). In general, the Bluesky contains transgressive lag deposits or shallow marine to brackish sediments deposited during regressive pulses in a continuing southward transgression of the Boreal sea (Jackson, 1984; Smith, 1994). Shorelines were believed to trend eastnortheast/westsouthwest, with the open Boreal sea to the north northwest.

In the Deep Basin area (Fig. 2), 6 prolific Bluesky gas reservoirs have been discovered (Masters, 1984). They are relatively narrow (10-30 km), elongate (about 100 km) and trend roughly SW-NE or WSW-ENE. Among them, the southern Hoadley and the northern Elmworth gas fields have been recently studied by Rosenthal (1988) and Strobl (1988), and O'Connell (1988), respectively. In these studies, shoreline orientations are generally interpreted to trend WSW-ENE and the Bluesky deposits are divided into stratigraphic units produced by transgressive/regressive events.

The study area of this thesis includes the Pine Creek (eastward extension of Wild River belt, not named in Fig. 2) and Edson gas pools, which have not

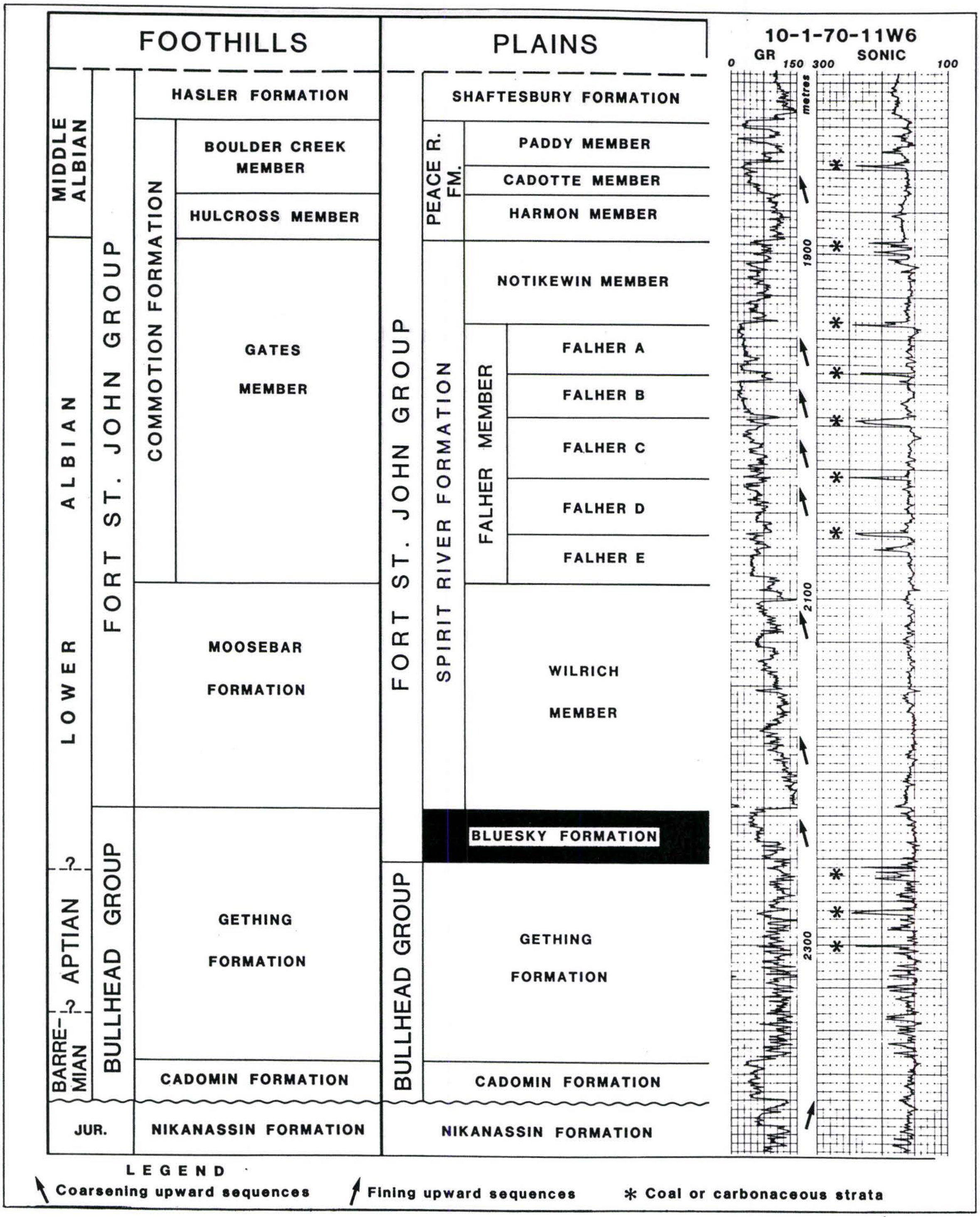


Fig. 1. Lower Cretaceous stratigraphic chart for the Foothills outcrop belt in British Columbia and the Plains of Western Alberta. The type log is from the Elmworth field, about 200 km NE of the study area (Modified after Smith et al., 1984). The studied section is shown in black.

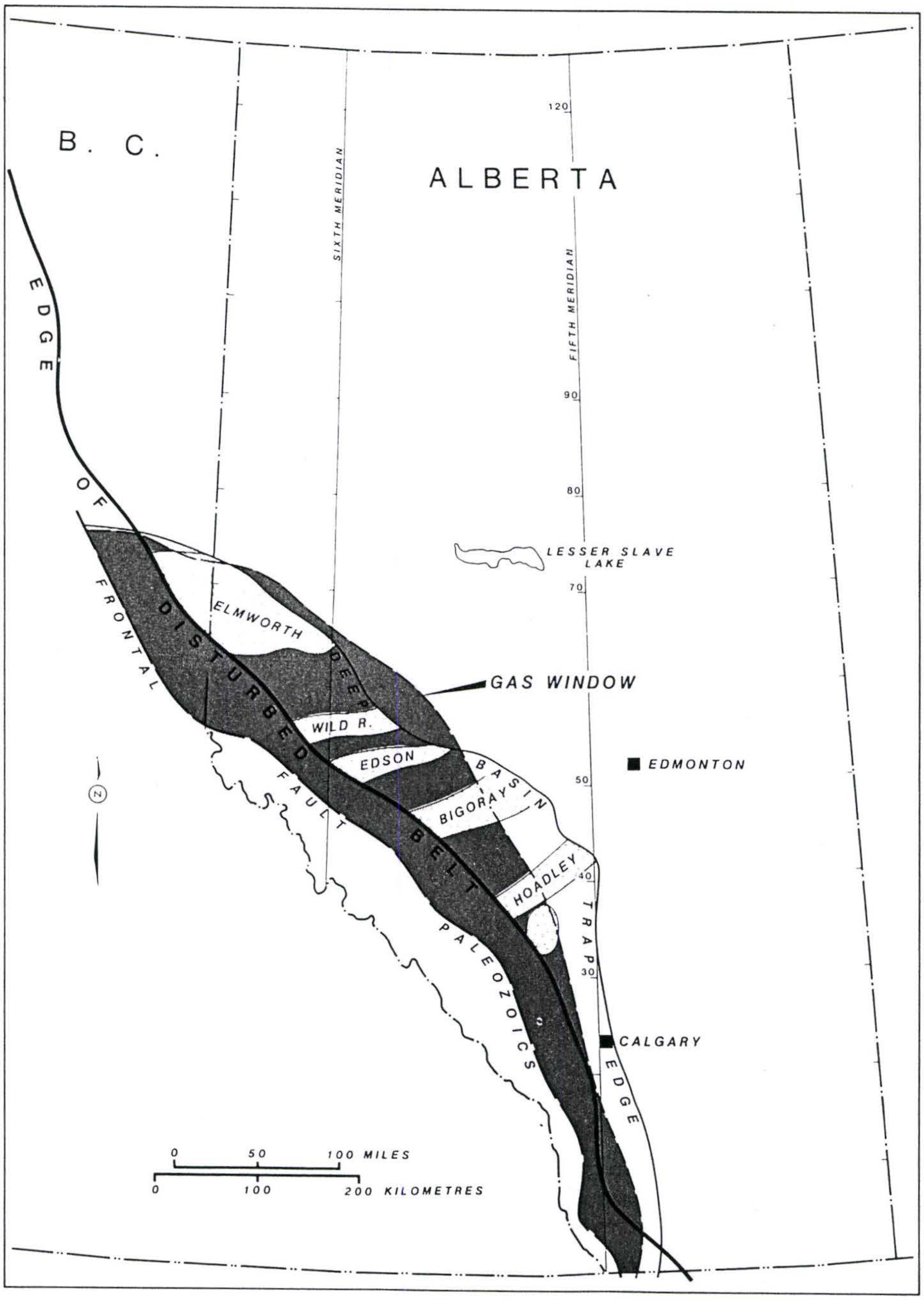


Fig. 2. Reservoir sand belts in the gas-saturated Deep Basin. After Masters (1984)

been described in detail. To simplify, this study area will be referred to as Edson.

The main purpose of this research is to determine the exact nature and geometry of the Bluesky deposits at Edson, and to place the interpretation in the context of the adjacent Bluesky deposits to the north and south.

The new estuarine channel complex interpretation proposed in this thesis leads to a series of geological problems related to relative sea level changes:

i) What is the relationship between the northeast trending estuarine channels and the SW-NE shoreline orientation as presently interpreted at Hoadley and Elmworth ?

ii) How are channel incision and filling related to a period of overall transgression?

iii) Can a transgressive systems tract contain a complex system of estuarine channels consisting of repeated and/or superimposed channel incisions?

iv) Are there any longitudinal changes in the fills of the channels and what is their relationship with sea level fluctuations?

v) What is the temporal scale of sea level fluctuations?

vi) What are the possible controls on relative sea level fluctuations?

1.2. The study area

The study area is located in the "Deep Basin", of western Alberta, about 200 km west of the city of Edmonton and about 100 km east of the thrust and fold belt (Fig. 3). It encompasses Townships 52 to 57 and Ranges 16 to 20, west of the Fifth Meridian, an area of 28 townships or about 2600 km^2 (Fig. 4).

Within the study area, the Bluesky Formation occurs entirely in the subsurface. It has been extensively drilled, especially in the gas producing Edson and Pine Creek pools. The database used in this study consists of 358 geophysical well logs and 63 cores (Fig. 4).

1.3. Method of study

The excellent core and well log control offered by the study area allowed detailed analysis of the Bluesky Formation. All cores were examined at the Energy Resources Conservation Board in Calgary. They were analyzed in detail to determine lithologies, grain size, grain size trends, physical sedimentary structures, trace fossils, trace fossil trends, and facies contacts. Detailed photographs of individual facies, facies contacts and trace fossils were taken. Photographs of the whole core boxes were also taken from most of the cored well locations to show vertical facies distributions and variations.

The 358 geophysical logs consists of both gamma ray and resistivity logs. They were used to calibrate cores with their log responses, and for the construction of cross-sections.

Both gamma ray and resistivity logs were used for correlation purposes. Gamma ray log responses reflect subtle lithological changes more accurately; the

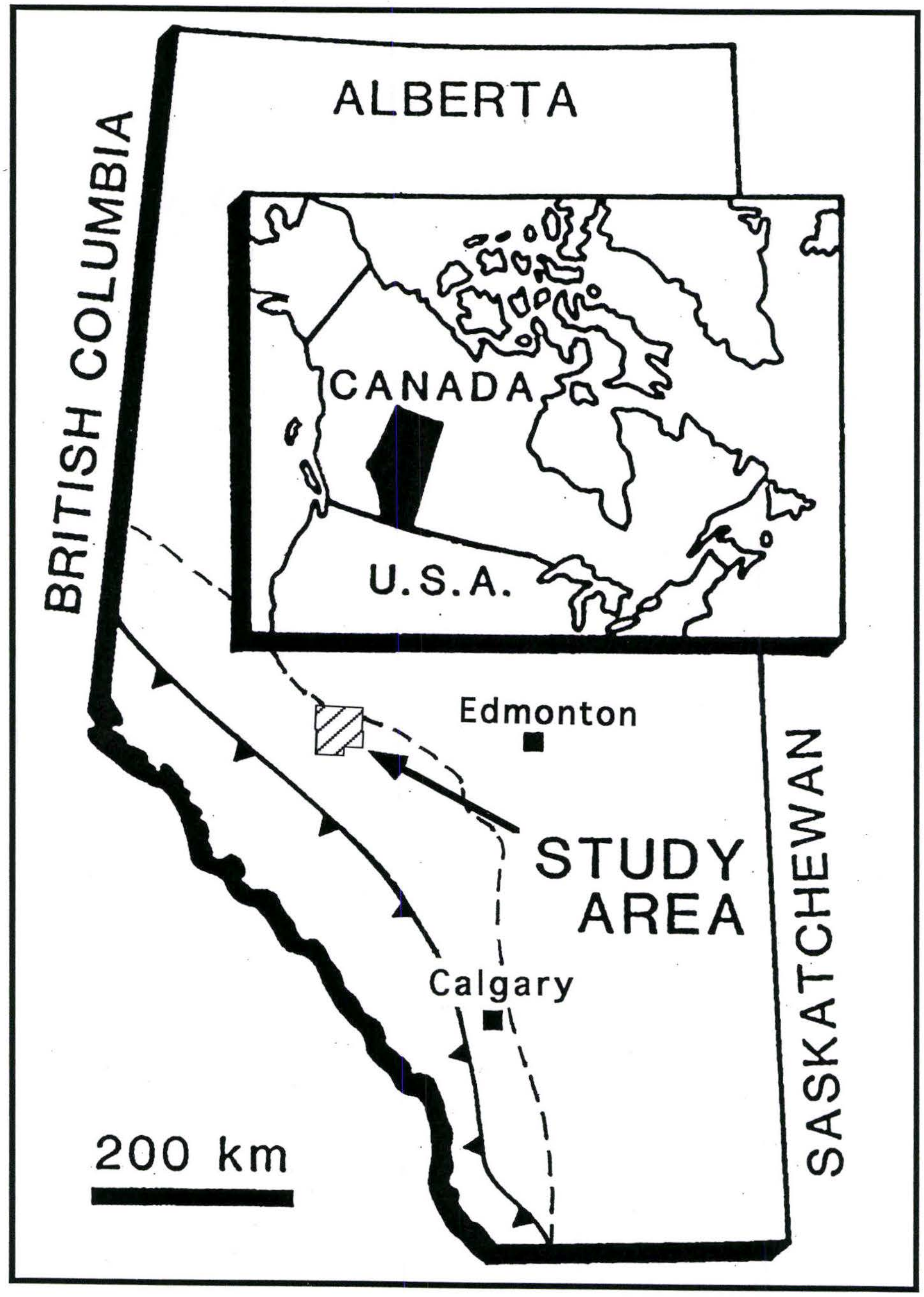


Fig. 3. Index map showing location of study area in the plains of western Alberta, Canada. Toothed line indicates the eastern limit of Cordilleran deformation; dashed line shows the Deep Basin edge. Modified after Wood and Hopkins, 1992).

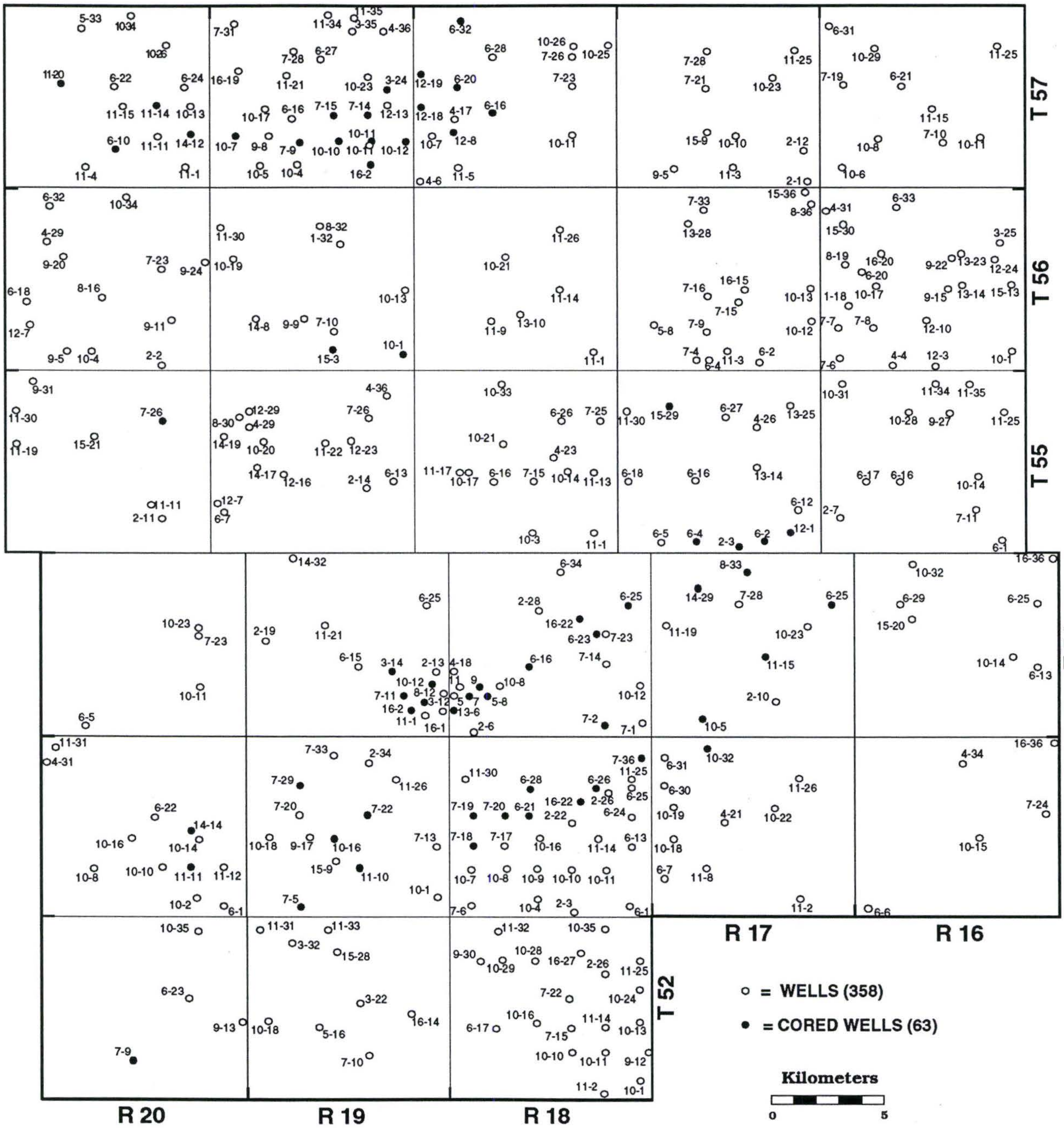


Fig. 4. The index map of the study area showing the location of wells and cored wells.

resistivity logs were also extremely useful for correlations and provided an unequivocal datum. All cross-sections are hung on this datum, a regionally extensive marker located about 25-30 m above the top of the Bluesky, within the mudstones of the Wilrich Member. This marker is an extremely low resistivity kick (about 12 ohm-m).

All grain size estimates were made using a Canstrat card, and are quoted as vfU (very fine Upper), fL (fine Lower), fU (fine Upper), mL (medium Lower), vcL (very coarse Lower), etc.

CHAPTER 2: STRATIGRAPHY AND GEOLOGICAL SETTING

2.1. Structural setting

The Western Canada Foreland Basin fill comprises the younger part of the Phanerozoic rocks of the Western Canada sedimentary basin. The Foreland Basin developed in response to arc collision and lithospheric loading that began roughly in the middle Jurassic.

Monger (1989) discussed the geology and the evolution of the western Canadian Cordillera. He attributed the Cordilleran building processes to Mesozoic accretion of several distinct terranes to Ancestral North America and crustal thickening above subduction zones, involving a multi-collision mechanism. The 5 morphogeological belts recognizable in the actual Cordillera were mainly due to these Middle Jurassic to Early Tertiary convergence processes.

Van der Hayden (1992) proposed a different interpretation for the regional tectonic features of the Western Canadian Cordillera. He suggested the accretion of a single composite superterrane to Ancestral North America in a single collision event, during Middle Jurassic time. His Andean arc model relates to prolonged east dipping subduction of Pacific Ocean lithosphere beneath the accreted superterrane.

Within the Alberta Foreland Basin, there are two major northeast trending structural elements, the Peace River Arch and the Sweetgrass Arch (Cant and O'Connell, 1988, Fig. 5). In the Peace River Arch, granitic rocks are uplifted about 1000 m above their regional position in the basement (Cant and O'Connell, 1988).

These basement structures formed in Paleozoic time, but also influenced basin sedimentation during Cretaceous time.

The study area is part of the tectonically undeformed portion of the basin. The Bluesky Formation occurs approximately 2200 to 3050 m below the surface and has a regional southwest dip of about 0.8°.

2.2. Regional stratigraphy and depositional evolution

The Early Albian Bluesky Formation and equivalents are transitional units between the Lower and Upper Mannville Group, which consists of an unconformity bounded clastic wedge that built into the Western Canada basin during Early Cretaceous (Fig. 6).

In western Alberta, the Bluesky Formation also comprises the basal part of the Fort St. John Group and occurs entirely in the subsurface.

Bluesky equivalents are the Glauconitic Member or Glauconite Formation (redefined by Rosenthal, 1988) in central and southern Alberta, the Wabiskaw in northeastern Alberta and the Cummings in eastern Alberta.

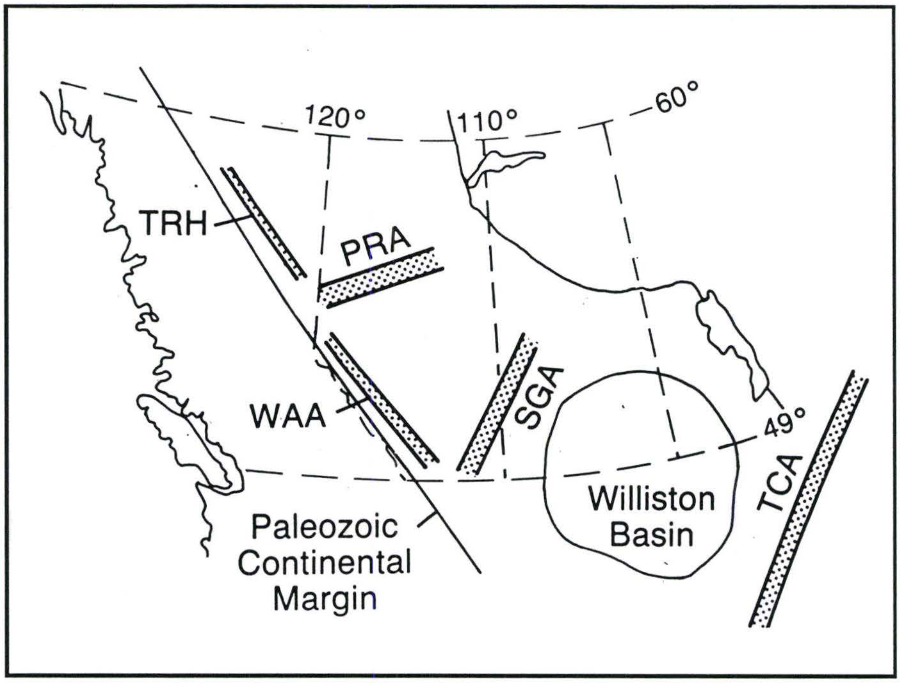


Fig. 5. Regional tectonic elements in the Paleozoic. PRA - Peace River Arch; TRH - Toad River High; WAA - West Alberta Arch; SGA - Sweetgrass Arch; TCA - Transcontinental Arch. After Cant and O'Connell (1988).

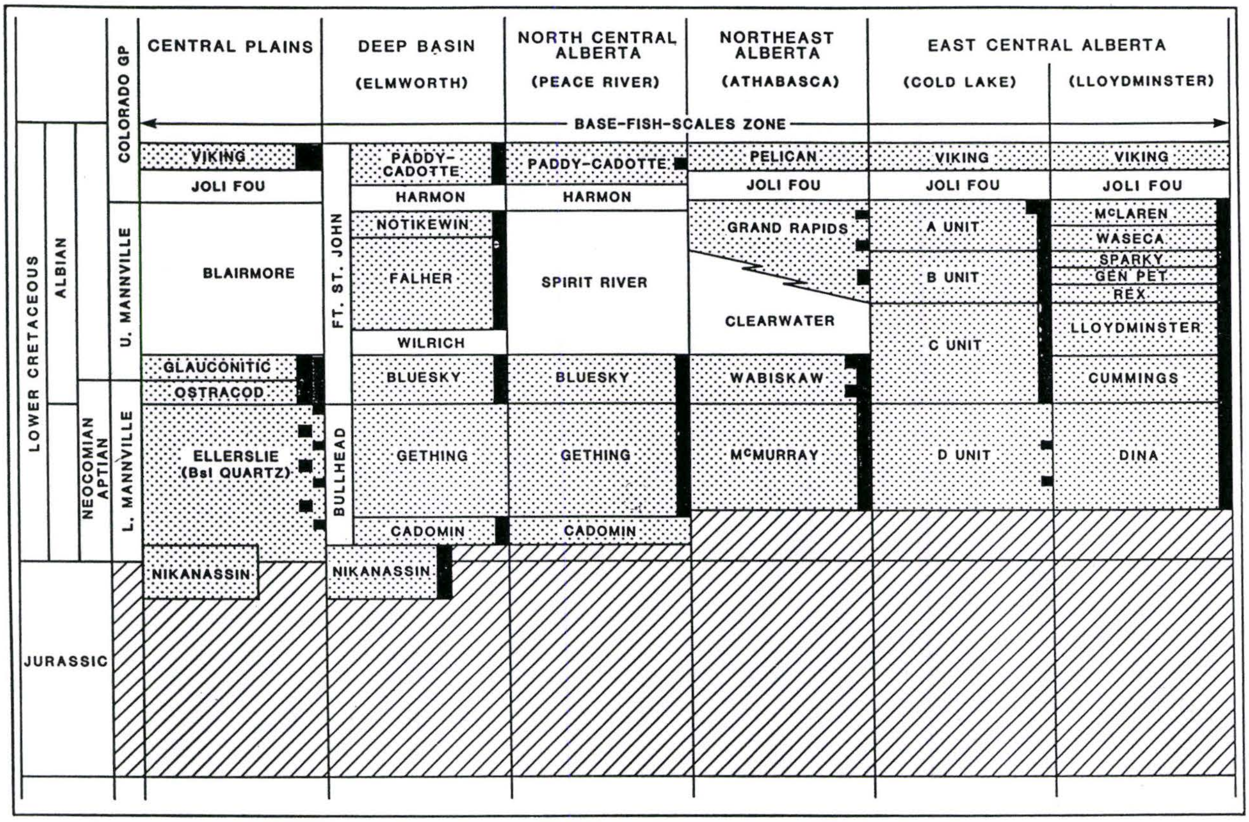


Fig. 6. Correlation chart of Lower Cretaceous-Jurassic formations showing principal oil and gas zones. Reservoir beds stippled. Source-seal beds blank. After Masters (1984).

Following the sub-Cretaceous unconformity (Fig. 6), alluvial fan and braid-plain conglomerates of the Cadomin Formation were deposited. Fluvial and delta plain sediments of the Gething Formation and equivalents were then deposited in the developing subsiding trough during Aptian time. The Lower Mannville Gething Formation consists of dark, organic-rich mudstones and siltstones with coal interbeds and *in situ* roots, and is interpreted as coastal plain deposits. Despite the general continental nature of these sediments, fresh- to brackish-water clams and other bivalve shells have been observed in some parts of the study area. The Gething Formation is always defined by a very irregular log response (Fig. 1).

In Early Albian time, a strong southward advance of the Boreal sea occurred and the Bluesky Formation and equivalents were deposited during the continuing transgression (Jackson, 1984). Continued subsidence of the basin resulted in deepening of the advancing Boreal sea and marine shales of the Clearwater Formation and equivalents (Fig. 6) were deposited over the Bluesky Formation. In the study area, the Bluesky Formation is overlain by the open marine mudstones of the Wilrich Member (Fig. 1 and 6).

These marine conditions did not persist for long, because during Middle to Late Early Albian, there was renewed supply of clastic sediments to the basin, restoring continental conditions (Smith et al., 1984). The rate of sedimentation was higher than the relative sea level rise and the shoreline started to move northward. The coastal/deltaic sediments of Falher and Notikewin Members (Spirit River Formation) are part of this overall regression.

In Middle Albian time, a second major transgression of the Boreal sea allowed the deposition of marine shale of the Harmon Member (Peace River Formation). Within this overall transgression, coastal plain to shallow marine sediments of the Paddy and Cadotte Members represent two well-developed regressive pulses.

A later northward transgression of the Gulfian sea joined the Boreal sea, forming the Western Interior Seaway of North America (Jackson, 1984).

2.3. Previous work and interpretations of the Bluesky Formation and equivalents

There are relatively few papers that discuss the Bluesky in any detail. The Alberta Study Group (1954) first defined the Bluesky Formation in the Peace River region of Alberta as a "salt and pepper" marine sandstone overlying the Bullhead Group strata. This formation takes its name from well 4-29-81-1 W6 (Pugh, 1960).

Jackson (1984) discussed the depositional history of the Lower Cretaceous of Western Canada, using a series of paleogeographic maps. In this regional study, the Bluesky Formation and equivalents are informally defined as "Middle Mannville", as they represent the transition from the Lower Manville southward transgression and the Upper Manville major northward regression. In the paleogeographic map of Fig. 7, most of the Bluesky sandstone bodies have linear shapes and trend either northeastward or northwestward. Bluesky

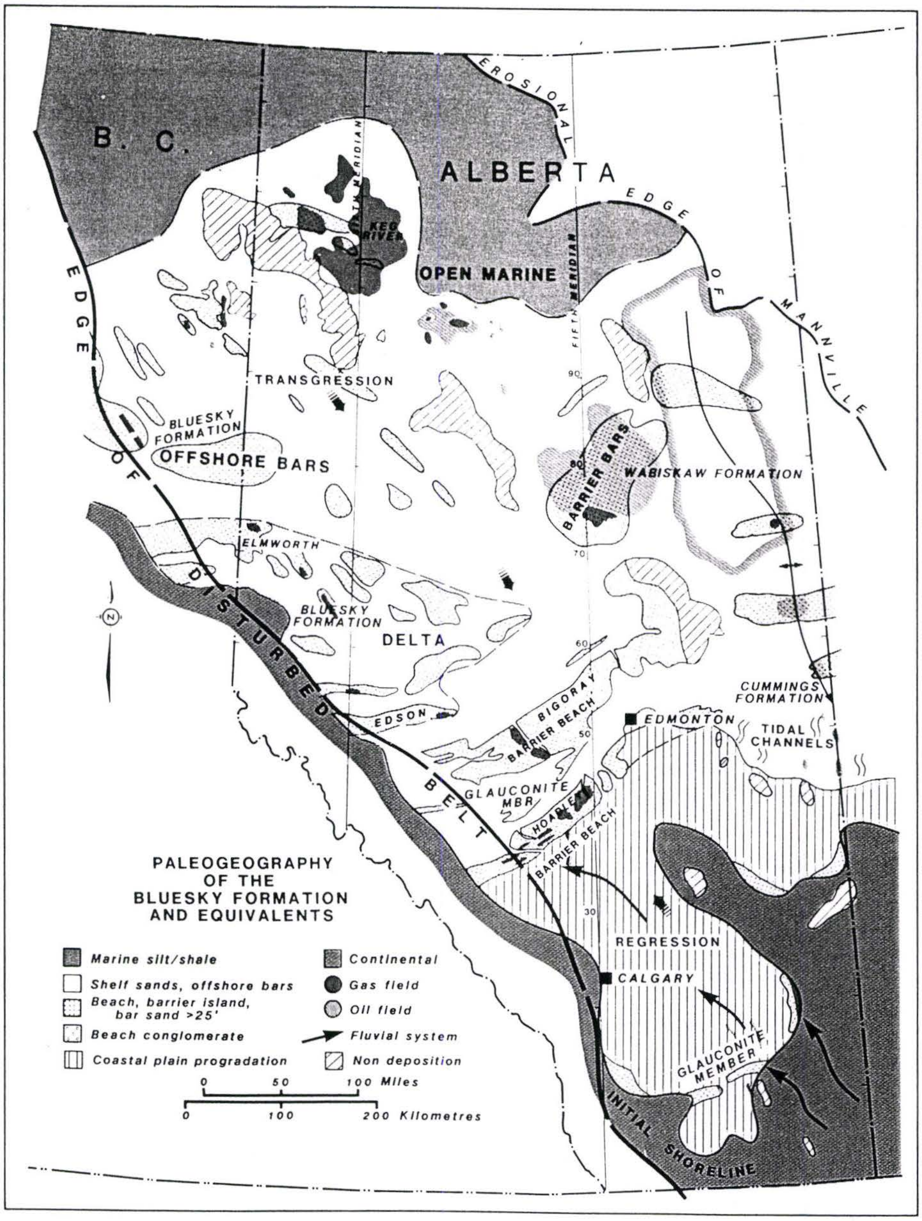


Fig. 7. Paleogeography of the Bluesky Formation and equivalents. After Jackson (1984).

sandstones of the northern part of the basin were interpreted as transgressive lag deposits or shallow marine sandstones deposited as "regressive pulses" during the Early Albian southward transgression of the Boreal sea. In southern and central Alberta, the Glauconitic member (Bluesky equivalent) was mainly deposited as two northeast trending barrier complexes (Hoadley and Bigoray) during a northward coastal progradation (Jackson, 1984).

The Hoadley gas field was interpreted by Chiang (1984) as a marine barrier complex. A series of sand barriers and interbar lagoons were described, and interpreted as forming by repeated emersions and submersions of the barrier during its northward progradation.

In a study on Lower Cretaceous oil and gas, Masters (1984) defined 6 reservoir sand belts in the gas saturated deep-basin (Fig. 2). Each of these sand belts implies a northeast trending shoreline. The Edson gas field is one of these 6 sand belts.

In northeastern British Columbia and western Alberta, Bluesky coarsening-upward sandstones, partly capped by lagoonal deposits, were discussed by Smith et al. (1984). In the Elmworth area, two large northeastward trending sandstone bodies were interpreted to be the result of a northward prograding barrier bar/offshore bar system (Fig. 8). As the barrier bar prograded, the landward bay-lagoon also prograded seaward. A transgressive lag deposit capped all the underlying facies, suggesting a renewed final transgression.

In 1988, new sedimentological, ichnological and stratigraphic studies were conducted on the Bluesky Formation, especially in the equivalent Glauconitic

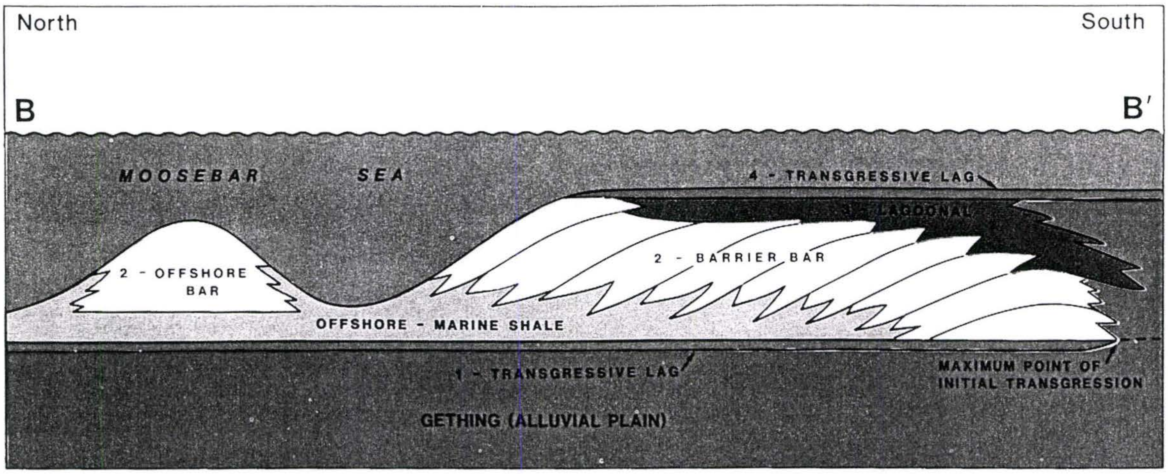


Fig. 8. Schematic cross section illustrating a prograding Bluesky barrier bar/offshore bar system. As the barrier progrades seaward, a bay/lagoon develops landward of the barrier. After Smith et. al (1984).

Member. It follows from these new data that Bluesky shoreline trends are controversial.

Opplet (1988) defined two different depositional settings for the Bluesky sandstones of Northern British Columbia. In the northern part of his study area (the Peace River plains, T 78-85 in Fig. 7), glauconitic bioturbated and cross-bedded sandstones were interpreted as offshore shelf bars. In contrast, coarsening-upward sandstones and burrowed mudstones of the Foothills (southern part of his study area, T 72-77 in Fig. 7) were considered delta front and prodelta sediments deposited in a brackish water setting during a northward progradation. These two elongate deposits formed at about the same time and the paleoshoreline orientation was about east-west, as indicated by Smith et al. (1984).

Also in 1988, O'Connell published a study of the Bluesky Formation of northwestern Alberta, an area (T 70-75, R 1-13, Fig. 7) that almost coincided with the eastern part of the area studied by Smith et al. (1984). Two main facies were identified: 1) marine offshore and shoreface deposits and 2) tidally dominated inshore sediments. The latter are confined to the eastern part of the study area and consist of channel and brackish bay sediments. The two eastward trending sandstone bodies (named Northern and Southern Bluesky sands, Fig. 9), interpreted by Smith et al. (1984) as a contemporaneous barrier bar/offshore bar system (Fig. 8), were considered by O'Connell (1988) as two northward prograding offshore to shoreface deposits, each followed by a renewed southward transgression.

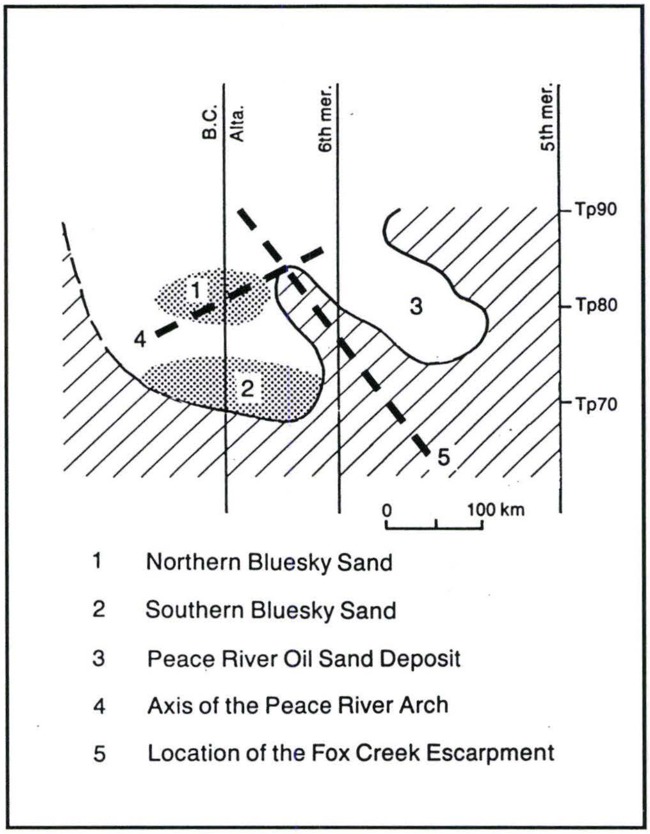


Fig. 9. Proposed paleogeography of the Bluesky marine embayments, with the location of the underlying structural elements. After O'Connell (1988).

The channel and brackish bay sediments were interpreted as deposited on the eastern shoreline of a large marine embayment (Fig. 9). This eastern shoreline was formed by a structurally elevated area overlying the Fox Creek Escarpment.

In West-central Alberta, Rosenthal (1988) recognized three distinct transgressive/regressive successions within the redefined Glauconite Formation. Each succession consists of basal shales overlying by coarsening-upward, coal-capped marine sandstones deposited during a marine regression. The tops of these successions are locally incised by deep channels filled with fluvial or estuarine sediments (Fig. 10). The basal Glauconite sandstone succession is cut by a northeast trending channel (the Caroline Channel, Fig. 11), which implies a northeastward dipping paleoslope. In contrast, the second and third Glauconite sandstone successions (Hoadley and Bigoray) are cut by northwest trending channels which suggest a paleoslope dipping to the northwest. Rosenthal (1988) then suggested the occurrence of a dramatic change in basin geometry between the deposition of the first Glauconite sandstones and the two others. The Edson gas field is part of Rosenthal's study area. It is interpreted as a northeast trending channel system, but it is not discussed in any detail, as the exact stratigraphic position is unknown.

The Hoadley field has also been studied by Strobl (1988). He defined the Glauconitic Member as two northward prograding shallowing upward marine to non marine deposits, both incised by valleys at their tops. The Hoadley sandstones are one of these two northeast trending shorelines (Fig. 12) and are interpreted to have been deposited in a regressive barrier island system. The incised valleys at the tops formed during major relative sea level drops and were

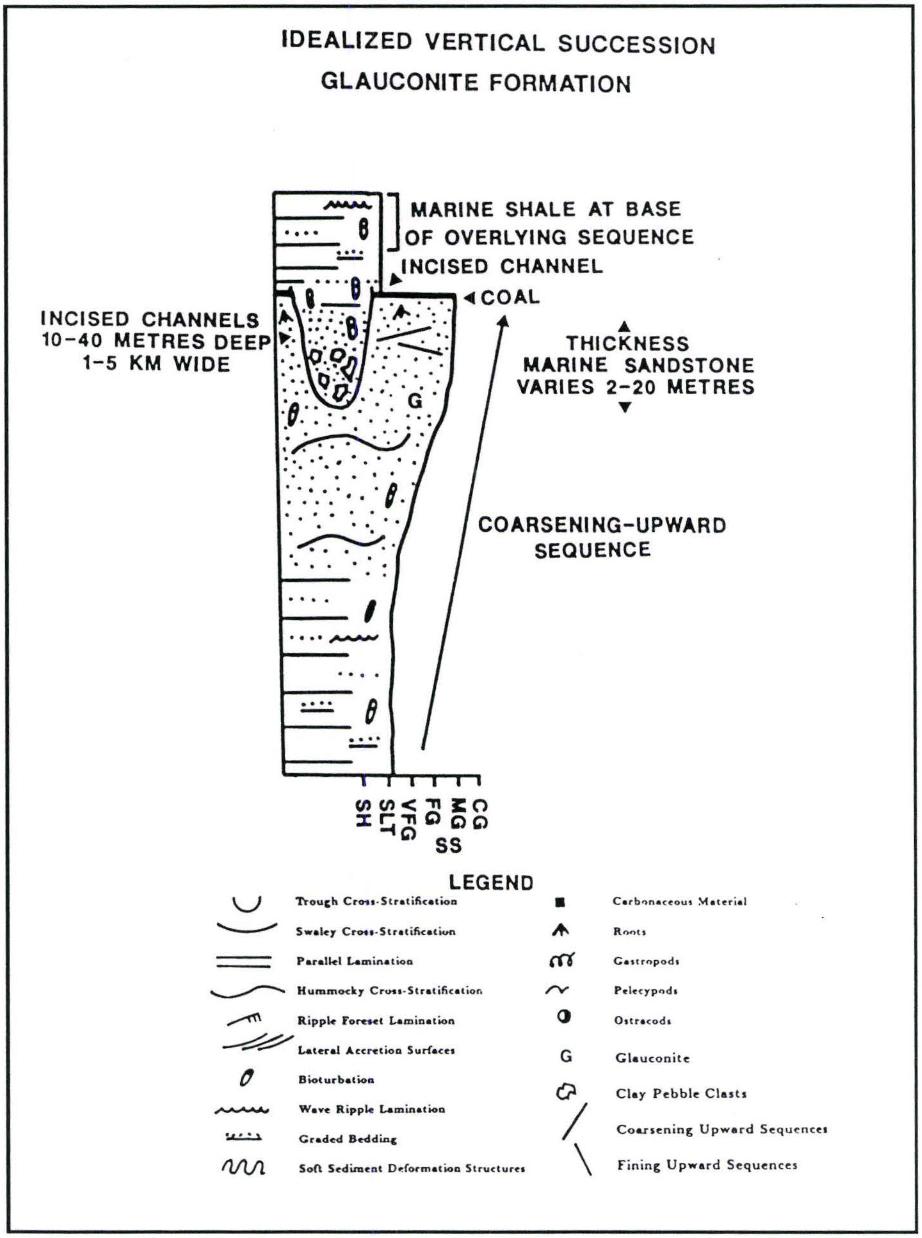


Fig. 10. Typical depositional succession, Glauconite Formation, west-central Alberta, showing regressive marine sandstone, capped by coal. This sandstone is locally incised by deep, narrow channels that are infilled with fluvial and estuarine sediments. After Rosenthal (1988).

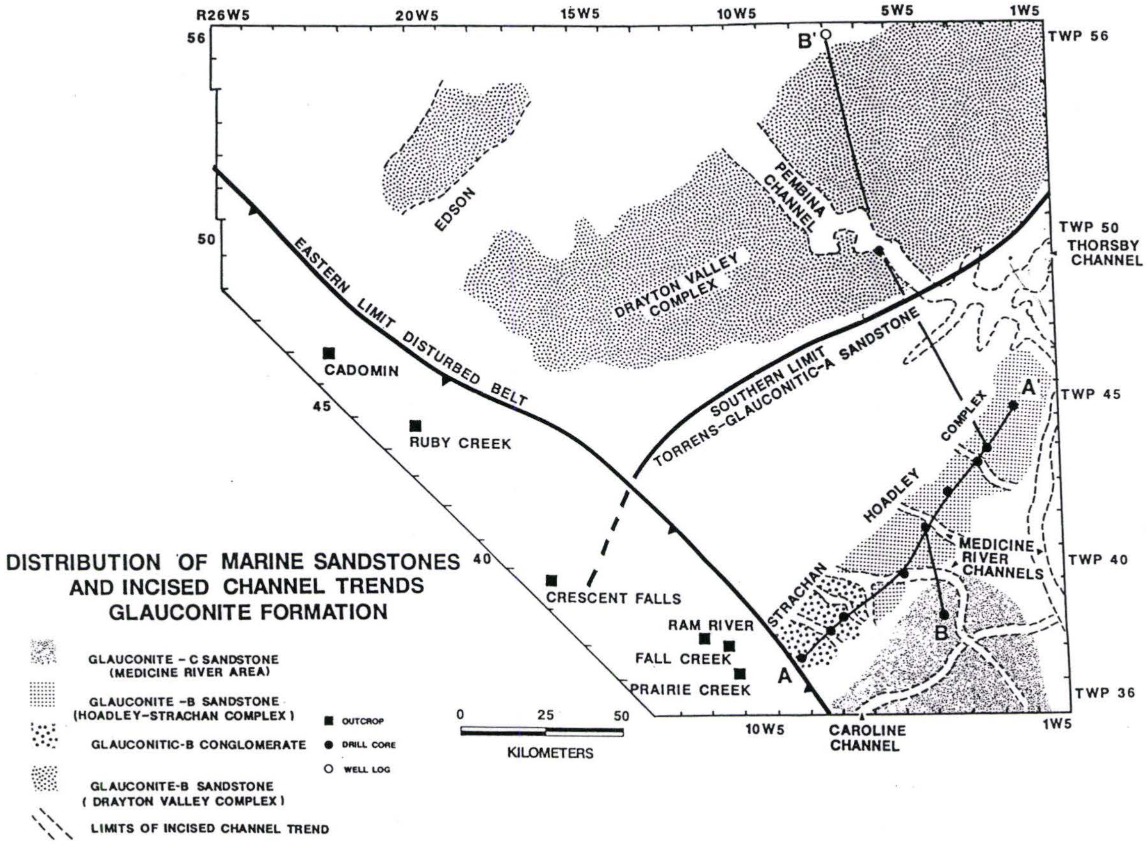


Fig. 11. Spatial distribution of marine and channel sandstones within the Glauconite Formation. After Rosenthal (1988).

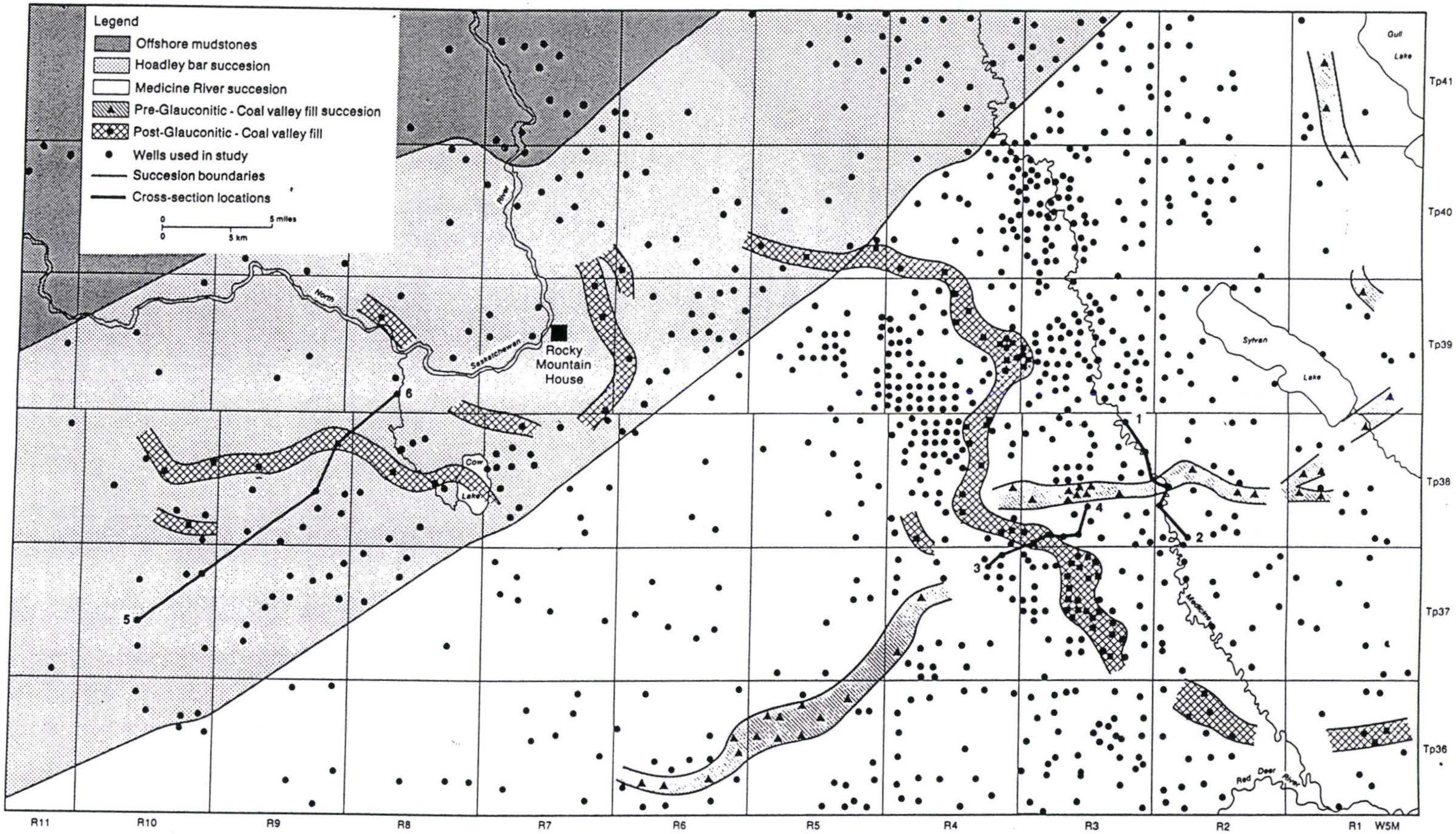


Fig. 12. Distribution of major shoreline and valley-fill successions in the medicine River field and Hoadley areas. After Strobl (1988).

filled by estuarine sediments during following sea level rises. The anomalous northeast trend of one of these estuarine valleys (Fig. 12) suggests that it must has been a shoreline-parallel channel.

Further work on the Glauconitic Member was published by Wood and Hopkins (1989, 1992). In southern Alberta, 8 paleovalleys filled by estuarine and fluvial sediments, and correlative adjacent inter-valley strata, have been mapped across the study area (Wood and Hopkins, 1992). These valleys have an overall northward trend and occur at different stratigraphic levels. In part of the same area, Wood and Hopkins (1989) conducted detailed sedimentological studies of the estuarine valleys fills. Three main lithofacies (very similar to those described in the present thesis) were identified: 1) locally highly bioturbated shale, 2) cross-bedded sandstones and 3) interbedded sandstones and shales.

Recently, further sedimentological and ichnological studies on Bluesky facies have been conducted by Ranger and Pemberton (1991), Male (1992), and Brekke and Pemberton (1994). These authors interpret Bluesky sandstone bodies as the depositional expression of repeated transgressive and regressive phases occurred during an overall marine transgression.

In the paleogeographic evolution of the Western Canada sedimentary basin proposed by Smith (1994, p. 283), the Bluesky depositional environment is characterized by SW-NE shorelines with the open sea to the NW.

2.4. The proposed interpretation of the Bluesky Edson gas pool: transgressive estuarine channels

In 1984, the Bluesky Formation and equivalents were interpreted as transgressive lag deposits or shallow marine sandstones. These sediments were deposited during northward regressive pulses of east or northeast trending shorelines. These pulses occurred during the overall southward transgression of the Boreal sea (Jackson, 1984; Masters, 1984; Smith et al., 1984; Chiang, 1984).

By 1988, publications give more attention to relative sea level fluctuations as depositional controlling factors. Bluesky sandstones and equivalents were generally divided into units separated by repeated transgressive/regressive phases. As mentioned in the previous paragraph, some shoreline orientations in the 1988 studies differ from those proposed in 1984, with a 90° change in trend proposed by Rosenthal (1988) and a 180° change in trend proposed by O'Connell (1988).

At present, detailed published studies on Bluesky sediments of the Edson area do not exist. Their interpretation as east or northeast trending shoreline deposits proposed in 1984 studies appear to be widely accepted (Smith, 1994).

In this thesis, calibration of cores with well logs gave a good understanding of the well logs responses. These responses were then mapped regionally. The resulting linear east-northeast trending bodies are shown in Fig. 13.

NW-SE cross-sections (Fig. 14; Appendix C1, C2, C3, C10 described in Chapter 4) clearly indicate an overall incision of the Bluesky sediments into the

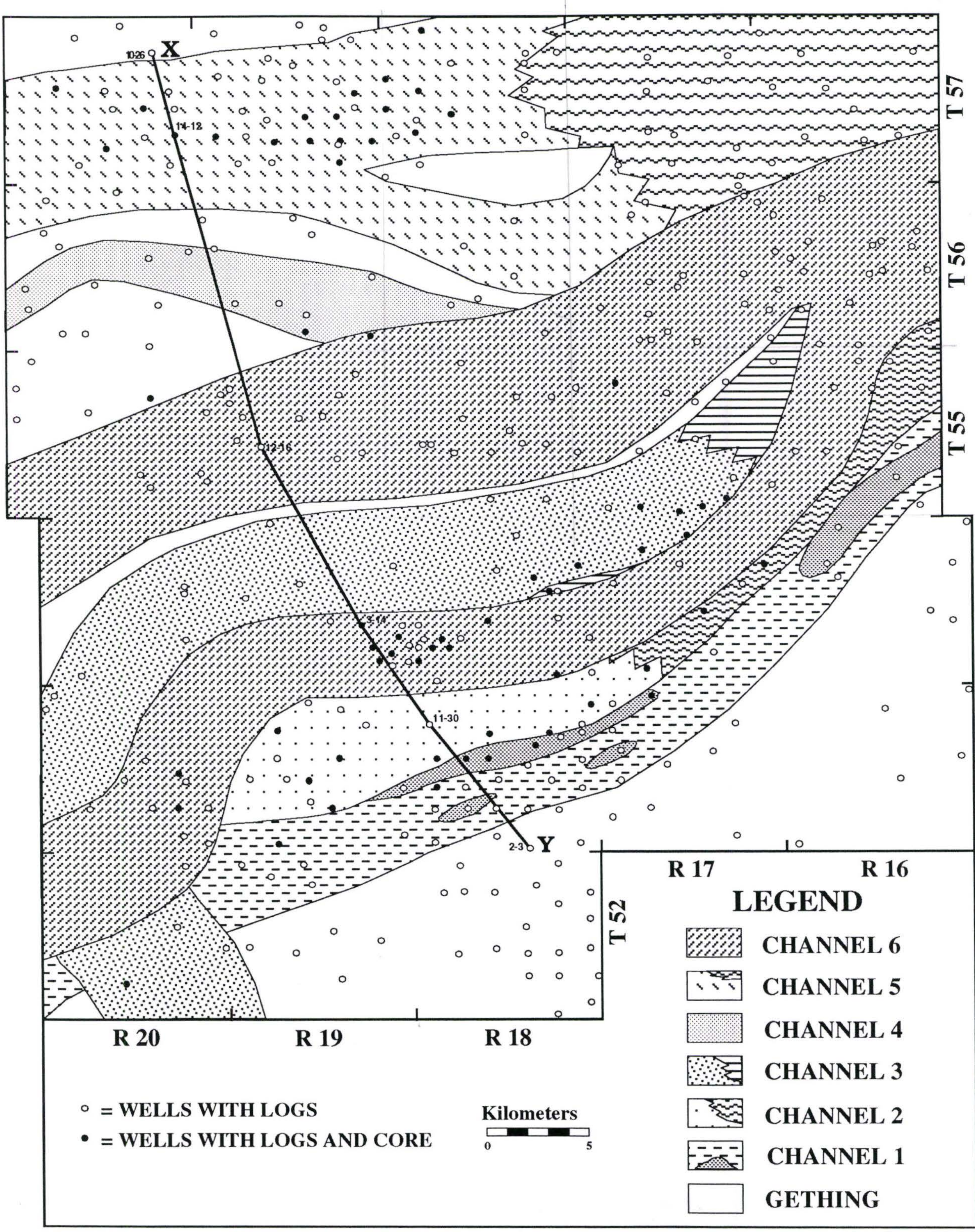


Fig. 13. Paleogeographic map of the study area showing the linear east and northeast trending Bluesky channels. XY is the location of the general log cross-section of Fig. 14.

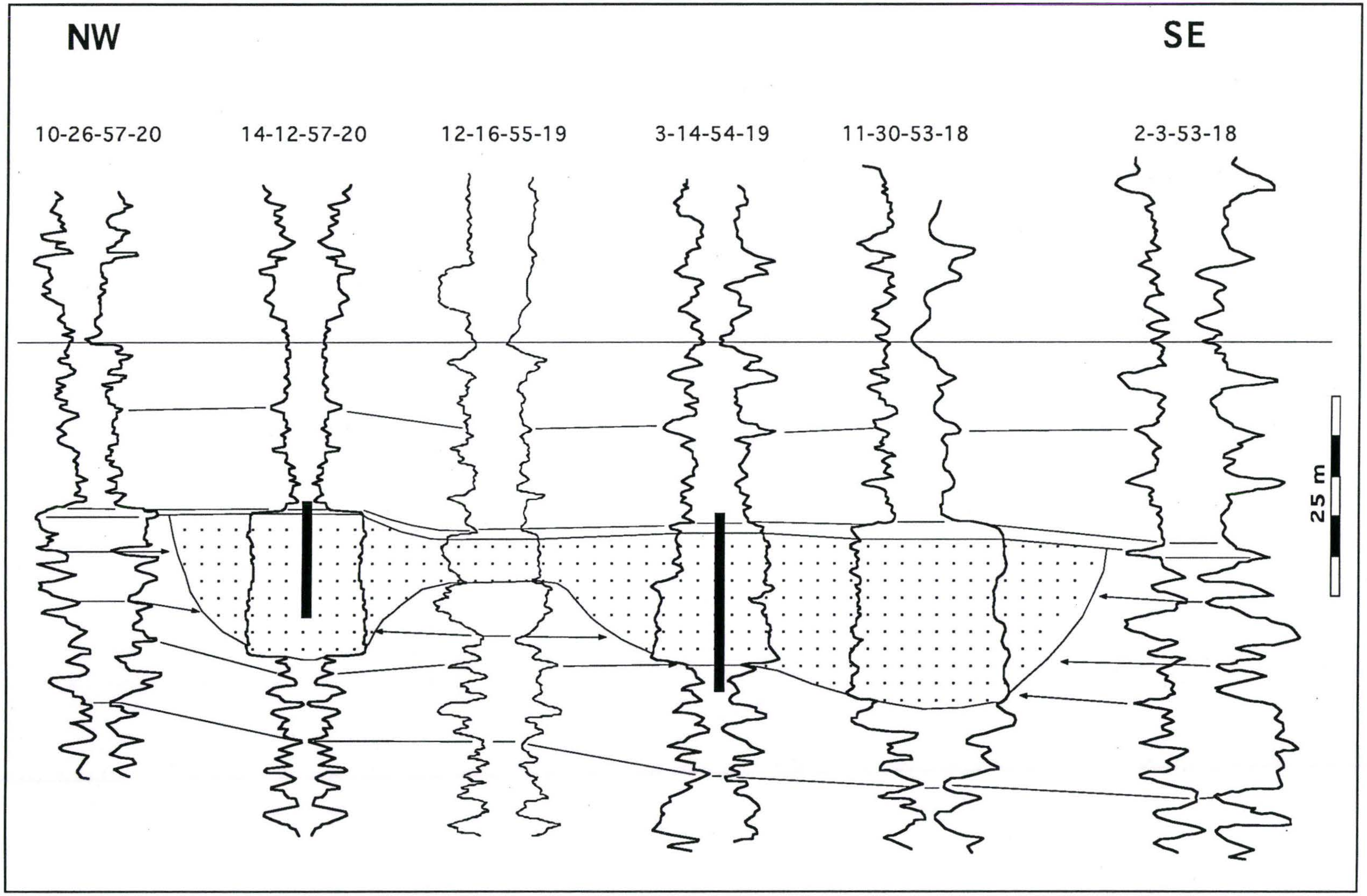


Fig. 14. General NW-SE log cross-section XY showing the overall incision of Bluesky sediments (stippled) into the Gething Formation. See Fig. 13 for location.

underlying Gething Formation. Furthermore, from well log pattern correlations, it has been possible to show a series of incisions nested within the overall incision. SW-NE cross-sections (Appendix C4, C5, C6, C7, C8, C9) show that in some of these linear Bluesky deposits, there is a lateral northeastward transition from sandstones to mudstones.

Thus the overall interpretation, developed in this thesis, is that the Bluesky Formation in the Edson area is a complex of fluvial channels filled by transgressive estuarine sediments. The open sea lay to the northeast.

CHAPTER 3: SEDIMENTOLOGICAL DESCRIPTIONS AND INTERPRETATIONS

3.1. Introduction

In this chapter Bluesky channels fills 1 through 6 will be described and interpreted.

Evidence for incised valleys eroding the underlying sediments of the Gething Formation is displayed in the SE-NW cross-sections (Appendix C1, C2, C3, C10). Despite the generally irregular gamma ray and resistivity log signatures of the Gething Formation, some extensive (tens of km) markers are cut by Bluesky deposits (see as example, the correlatable coarsening-upward marker in cross-section A, Appendix C1). These same markers are preserved and correlatable beyond the southeastern and northwestern margins of the incision.

Channel 1 is the first Bluesky channel to incise into the Gething Formation and is eroded by Channels 2 and 3.

As shown in Fig. 15, Channel 2 cuts Channel 1 in T52-53, R19. The fill of Channel 2 consists mainly of sandstones, whereas the dominant fill of Channel 1 is a sandier-upward succession of mudstones.

In T52 R20, Channel 3 also incises into Channel 1 (Fig. 15). It is also filled by sandstones.

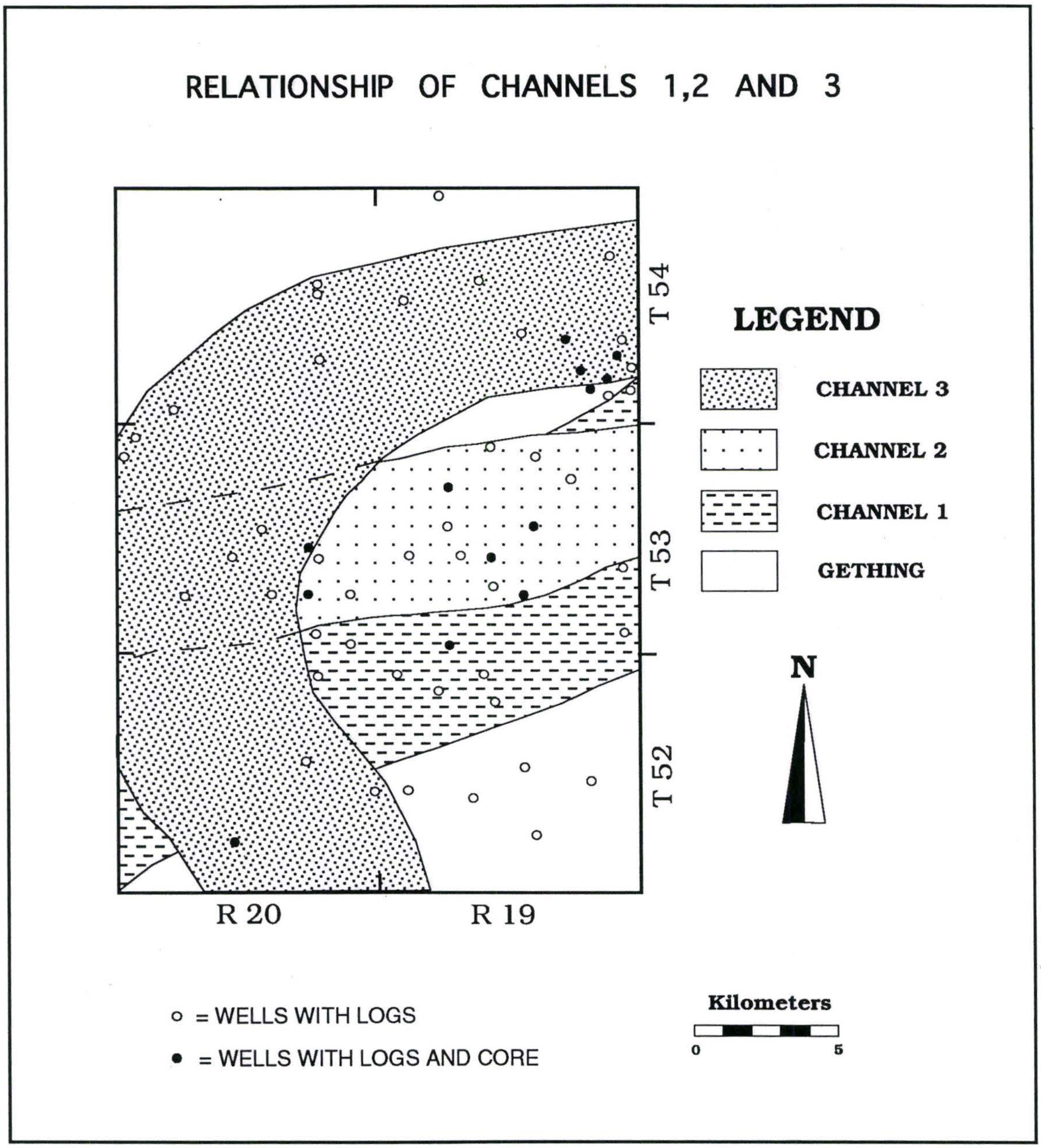


Fig. 15. Paleogeographic map of the southwestern part of the study area showing the relationship between Channels 1, 2 and 3.

However, is not clear whether Channel 3 cuts into Channel 2 (solid channel boundaries, Fig. 15), or whether Channel 2 cuts into Channel 3 (dashed channel boundaries, Fig. 15).

Where Channels 2 and 3 intersect (T53 R20), they are both largely cut out by Channel 6 (not shown in Fig. 15), making determination of the exact succession difficult. Furthermore, the fills of Channel 2 and 3 are very similar (see descriptions later) and even without extensive erosion by Channel 6, it would have been difficult to determine the exact sequence of events.

The preferred order of channeling is 1, cut by 2, cut by 3, but the precise channel succession in T52-54, R19-20 does not influence the broader aspects of interpretation.

Channels 4 and 5 neither intersect each other nor Channels 2 or 3, but they are both cut by Channel 6 (see Fig. 13). Also in this case, it is difficult to establish a precise channel succession, except that they are both older than Channel 6. As the sandstone fills of Channels 4 and 5 are similar to those of Channels 2 and 3, it is assumed that these 4 channels are quasi-contemporaneous, older than Channel 6 and younger than Channel 1.

In conclusion, there are 3 main types of channel fills: 1) mudstone (Channel 1), 2) sandstone (Channels 2,3,4,5) and interbedded mudstones and sandstones (Channel 6).

3.2. Channel 1

This is the first Bluesky channel to incise into the underlying continental Gething Formation (Fig. 16). It is about 50 km long and up to 8 km wide. The fill averages about 16 m thick, with a maximum of 23 m at the southwestern end and a minimum of 8 m at the northeastern end. The fill is variable, but in general consists of sandier-upward successions of mudstones bioturbated by a limited number of trace fossil species. The base of the channel is normally floored by 2-3 m thick sandstones bodies, observed in few cores and recognizable from log responses. In places, these sandstones can be mapped as localized elongate sandstones bodies about 2 km wide and 7-8 km long. They have an average preserved thickness of 10 m (maximum 17 m in core 7-20-53-18).

The sandier-upward trend is easily identifiable as a funnel shaped signal in the 35 gamma ray and resistivity logs that penetrate the fill of Channel 1 (Appendix C4). A blocky signal is characteristic of the elongate sandstone bodies. There are six cores within the Channel 1 fill.

The sandier-upward responses map in a linear form that trends 060-240° (Fig. 16). The southern edge of the channel is almost totally preserved, but the northern edge has been completely eroded by Channel 3 (dashed channel boundary, Fig. 16), except for a short 2-3 km stretch that allowed an estimate of the local channel width.

The fill of Channel 1 can be subdivided into 4 facies distinguished by their lithology, sedimentary structures, log responses and trace fossils.

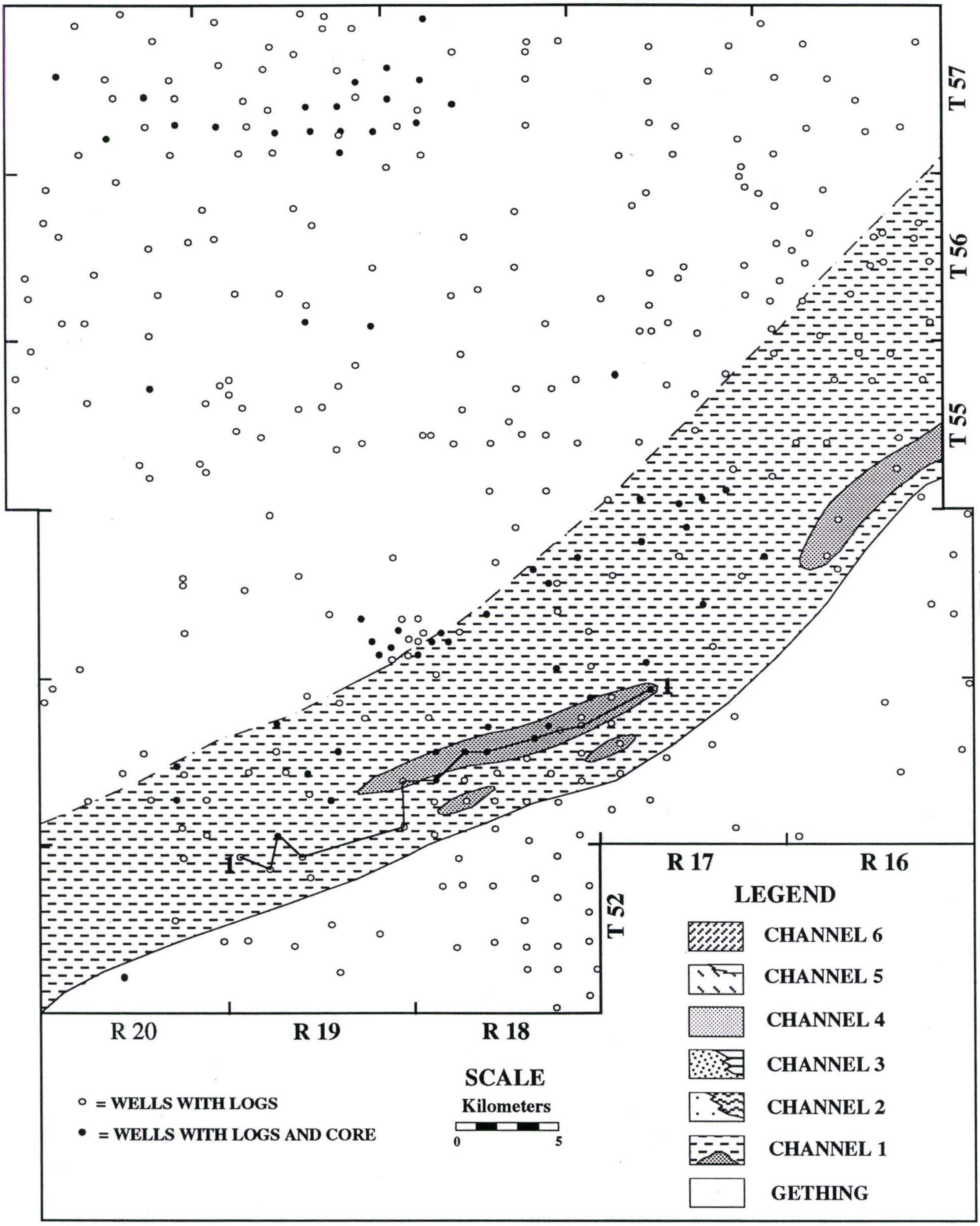


Fig. 16. Paleogeographic map of the mudstone filled Channel 1 with location of log cross-section 1 (Appendix C4).

3.2.1. Facies 1a: Cross-bedded sandstones

Description - Where present, Facies 1a occurs at the base of Channel 1 and is 2 to 17 m thick. It rests very sharply on the underlying Gething Formation, and is overlain by the mudstones of Facies 1b and 1c (Appendix C4). It is characterized by a well defined blocky log pattern.

The rocks consist of cross-bedded sandstones in sets 15 to 30 cm thick. Between sets there may be mm-scale mudstone partings or stylolitic surfaces. The grain size is fU to mL, but no specific vertical trends were observed. In core 10-32-53-17, the sandstones are almost structureless.

The cross laminations are angle of repose or steeper (up to 35° in core 7-20-53-18) and are commonly poorly defined. They indicate both planar-tabular and trough cross-bedding. Mudstone partings are very rare, irregular, 1-2 mm thick and difficult to study because the cores usually break where they occur.

The sandstones also contain rare sideritized ripped-up mud clasts (up to 10 cm) and a few coalified plant fragments. No trace fossils were observed.

The passage into the overlying mudstones of Facies1b is very sharp, as seen in core 10-32-53-17 and by the abrupt convergence of resistivity and gamma ray log responses. In well 7-20-53-18, there is a direct sharp contact between Facies 1a and 1c.

Interpretation - The combination of sedimentological characteristics, geometry, and the location of these sandstones within an incised valley, suggests that this facies represents high-energy channel deposits, such as longitudinal channel bars. The monotonous vertical occurrence of cross-bedding, the absence of grain size trends and the scarcity of mud partings is consistent with aggrading bed forms under fairly steady hydrodynamic conditions. The total absence of biogenic structures is probably not only due to the high energy of the environment, but also suggests dominant freshwater conditions. Sideritized ripped-up mud clasts and coalified plant fragments are interpreted as channel-lag material.

3.2.2. Facies 1b: Weakly-bioturbated sandier-upward mudstones

Description - These sediments are 4-10 m thick and either overlie the Gething Formation (log 10-1-53-19, Appendix C4) or rest on the cross-bedded sandstones of Facies 1a (from well 7-13-53-19 to 7-18-53-18 and from well 6-21-53-18 to 10-32-53-17, Appendix C4). The basal contact is always very sharp, but pebbles were not observed.

The facies consists of dark bioturbated mudstones alternating with a few thin very-fine-grained sandstone beds which show a slight upward increase in thickness and frequency. Sandstones beds are always thinner than 5 cm. In places, bedding is commonly reworked by bioturbation and the sand is concentrated into burrows. Rarely ripple cross-lamination is preserved.

The sandier-upward trend of Facies1b is clearly identifiable from the “funnel” shape of all log responses.

The trace fossil assemblage is characterized by a very limited number of species. It consists of abundant *Planolites*, few *Thalassinoides* and rare *Teichichnus* and *Paleophycus*. A single example of *Zoophycos* was also observed.

The weakly bioturbated sandier-upward mudstones are overlain either by Facies 1c or 1d, with sharp contacts (Appendix C4, C8).

Interpretation - The dominant mudstone lithology with few interbedded fine-grained sandstones beds and the very restricted trace fauna (mostly *Planolites*) is indicative of low-energy brackish water conditions. This channel fill is interpreted as deposited in the quiet turbidity maximum zone characteristic of the central area of an estuary. The interpretation of this facies will be elaborated later in the text.

3.2.3. Facies 1c: Strongly bioturbated sandier-upward mudstones

Description - These rocks rest sharply on Facies 1a or 1b, or directly on the Gething Formation (at the southwest end of the channel, Appendix C4, C8; Fig. 17). The basal contact with Facies 1a is characterized by 60 cm of almost structureless fU sandstones which contain one 0.60 cm chert pebble and ripped-up mud clasts (in core 7-20-53-18, Appendix, C8). Where Facies 1c rests directly on the Gething Formation, coarse sand grains are present at the contact (Fig. 17). Facies 1c thickens southwestward from 2 m to 19 m (in well 7-5-53-19).

Fig. 17. Basal contact of Channel 1 between the mudstones of Facies 1c (above) and coal (below) of the Gething Formation. The contact is characterized by coarse sand grains interpreted as transgressive lag. (Well 7-5-53-19W5 depth 9144 feet, 3" core diameter).

The overall sandier-upward succession can be subdivided into 4 parts: 1) a muddier-upward succession at the base, 2,3) two superimposed sandier-upward successions in the middle, and 4) a muddier-upward succession at the top.

The basal muddier-upward succession is preserved in the first 6-7 m of core 7-5-53-19 and in core 7-20-53-18 (Appendix C4, C8). It consists of bioturbated sandy mudstones grading up into pure black mudstones. The corresponding log response of this pure black mudstone has a distinctive "box shaped" gamma ray signal that can be used to correlate (dashed line in Appendix C4, C8).

The basal part of this facies is highly bioturbated, but by a limited number of species (abundant *Planolites, Teichichnus* and fewer *Thalassinoides* (core 7-5-53-19, Appendix B1). A single example of the ostracod *Melania* has been found in the pure black mudstones of core 7-20-53-18. The two overlying sandier-upward mudstone successions are separated by a horizon of granules, pebbles and angular chert or sandstones clasts up to 0.4 cm, mud clasts, and coalified plant fragments scattered through the mudstones (cores 13-6-54-18 and 7-5-53-19). The lower succession is muddy, whereas the upper sandier-upward succession is sand-dominated, with the sandstones coarsening from fL to mL upward.

In the two superimposed sandier-upward successions, the rocks become gradually more marine with traces such as *Rosselia* (cores 7-5-53-19, 7-18-53-18, 13-6-54-18), *Asterosoma*, *Paleophycus*, *Terebellina* and *Helminthopsis* (cores 7-5-53-19 and 7-18-53-18).

The upper muddier-upward succession is not cored and is only inferred from log responses (see upper part of wells 11-31-53-19 to 11-33-53-19, Appendix C4).

Interpretation - Facies 1c is interpreted to have been deposited in the relatively low-energy central zone of an estuary (Dalrymple et al. 1992). The overall sandier-upward succession of the mudstones suggests an upward increase in current activity. The basal part of this bioturbated mudstones displays a very low trace fossil diversity and high density of the traces *Planolites* and *Teichichnus*, part of the Cruziana ichnofacies assemblage. This ichnological character reflects restricted environments (Pemberton and Wightman, 1992). The higher diversity and the more marine character of the Cruziana and Skolithos assemblage of the upper part of Facies 1c is indicative of an increase in water salinity. This interpretation will be elaborated later when the facies are placed in context.

3.2.4. Facies 1d: Bioturbated sandstones

Description - This Facies is 1 to 2.5 m thick and overlies sediments of Facies 1b and 1c with a sharp basal contact (Appendix C4, C8). In some cases, this contact is characterized by a lag of medium to coarse sand grains, mud clasts and chert pebbles up to 0.5 cm. In core 7-18-53-18 a 3 cm diameter *Thalassinoides* burrow occurs at the basal contact.

This facies is mainly composed of vfU to fU thoroughly bioturbated sandstones with a very low mudstone content which usually decreases upward (core 7-18-53-18). Rarely, a few scattered glauconite grains are present.

Most original sedimentary structures have been totally destroyed by biogenic activity, except for rare poorly defined low-angle to flat sets of laminations (cores 10-32-53-17 and 7-18-53-18).

Facies 1d is characterized by a higher diversity of trace fossils compared with the underlying deposits in the Channel 1 fill. This ichnofaunal diversity increases upward (e.g. core 7-20-53-18). Nine ichnogenera have been recognized, including abundant *Terebellina, Paleophycus* and *Planolites*, fairly abundant *Ophiomorpha* and *Asterosoma,* few *Syphonichnus*, rare *Teichichnus*, *Conichnus*, *Macaronichnus simplicatis* and some mud lined vertical burrows.

This bioturbated sandstone represents the uppermost facies of Channel 1 fill. As in the other Bluesky channels, it is overlain with a sharp contact by the Transgressive Shoreface sediments (discussed below).

Interpretation - This upper facies of the Channel 1 fill consists of thoroughly bioturbated sandstones, with a relatively high diversity of trace fossils of the Cruziana and Skolithos assemblages. The combination of these sedimentological and ichnological aspects of this channel fill deposit suggests that facies 1d was deposited in the high-energy marine-dominated environment characteristic of the outer portion of an estuary. A more accurate interpretation of this facies will be discussed later in the text.

3.3. Channel 2

Bluesky Channel 2 cuts into the sediments filling Channel 1 (Fig. 18), and can also erode through Channel 1 into the Gething Formation (e.g. cross-section A, Appendix C1).

The fill of Channel 2 contains two distinct lithologies; sandstones in the southwestern part and a muddier-upward bioturbated succession of sandstones in the northeastern part. A good example of the lateral transition between these two lithologies is shown in core 10-5-54-17 (Appendix C5, C9).

In the study area, Channel 2 has about the same orientation and length as Channel 1 (060-240° and 50 km) and is about 5-8 km wide. The fill thins from 33 m in the southwest to 8.5 in the northeast (Appendix C5). The southern wall of Channel 2 is almost totally preserved, but part of the northern wall and all of the southwestern part of the channel have been eroded by Channels 3 and 6 (Fig. 18 and 33).

Twenty-three wells with gamma ray and resistivity logs penetrate the Channel 2 fill, and 11 cores are available.

Two distinct units (Facies 2a and Facies 2b) were identified in the Channel 2 fill, on the basis of their lithology, sedimentary structures, trace fossils and log responses.

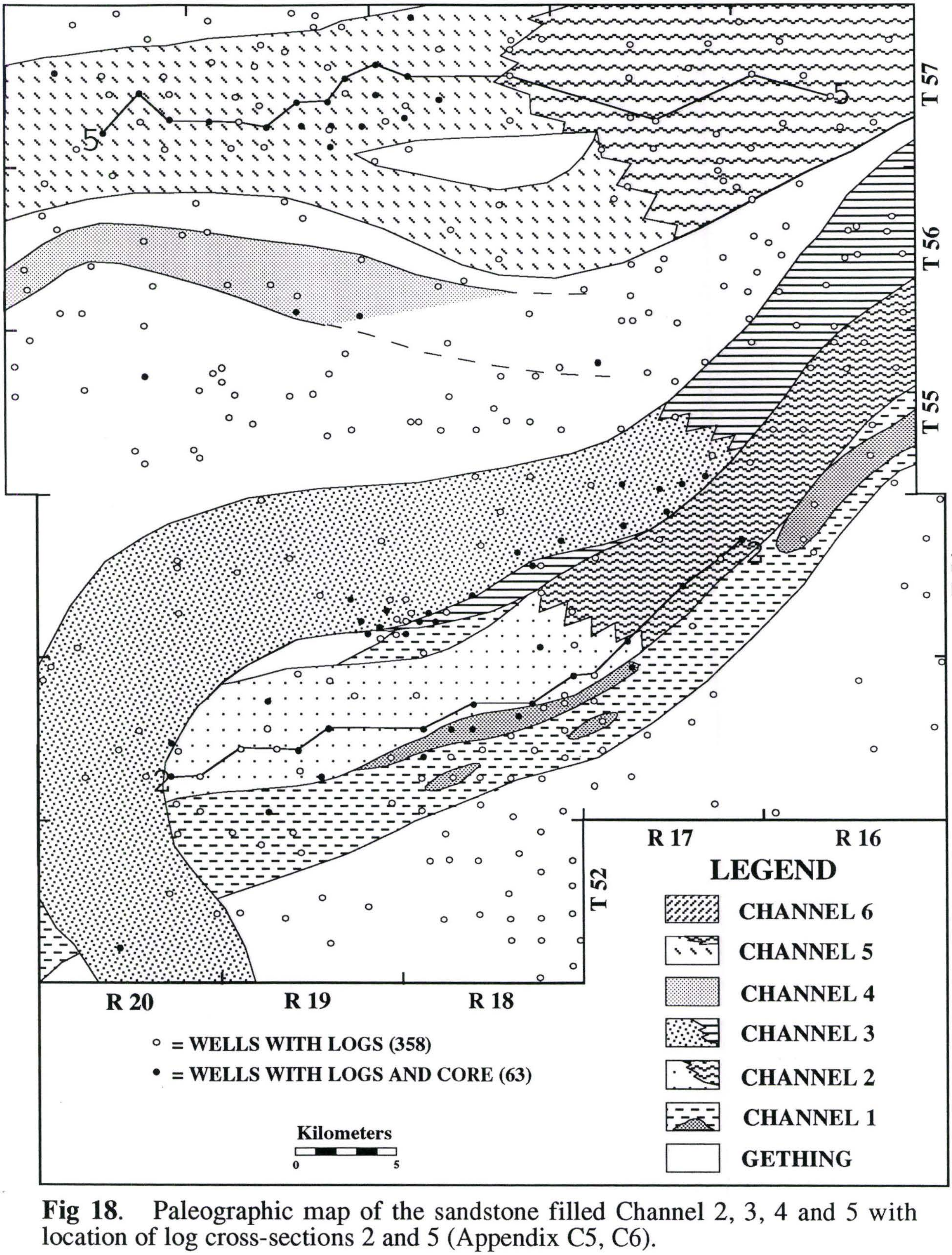


Fig 18. Paleographic map of the sandstone filled Channel 2, 3, 4 and 5 with location of log cross-sections 2 and 5 (Appendix C5, C6).

3.3.1. Facies 2a: Cross-bedded and crudely flat laminated to massive sandstones

Description - This Facies is 10 to 33 m thick and rests with a sharp basal contact on the sediments of the Gething Formation. The sharp nature of the contact is indicated by an abrupt change in lithology (e.g. cores 10-5-54-17, 6-28-53-18, 7-19-53-18 (Appendix C9) and divergence of log responses (Appendix C5).

The rocks consist almost exclusively of sandstones and show a typical blocky-shaped signal in gamma ray and resistivity logs. In most cases, these sandstones have an overall fining-upward trend, ranging from mL to fL in grain size. They are commonly planar-tabular or trough cross-bedded, less commonly crudely flat laminated to structureless.

In core 7-19-53-18 (Fig. 19), the base of the channel is characterized by coalified plant fragments, mud clasts and 2-3 mm chert pebbles. However, in most cases a basal lag was not observed.

In places, this sandstone body can be subdivided into subtle 1 to 8 m thick amalgamated fining-upward successions (e.g. core 6-28-53-18) characterized by two distinct facies: 1) cross-bedded sandstones and 2) crudely flat laminated and/or structureless sandstones. The successions are difficult to define because they are amalgamated together without a distinct grain size or lithological contrast. In some cases, an abrupt change of sedimentary structures occurs (cores 6-28-53-18 and 7-36-53-18).

Fig. 19. Basal contact of Channel 2 between the sandstones of facies 2a (above) and coal of the Gething Formation (below). Notice coal fragments and chert granules (arrow) at the base of Facies 2a (well 7-19-53-18W5 depth 8611 feet, 3" core diameter).

The cross-bedded sandstones are similar to facies 1a of the Channel 1 fill. They range from mL to fU in grain size and are organized into amalgamated 15-30 cm thick sets. In places, set boundaries are marked by stylolitic surfaces, mm-scale irregular mudstone partings or coal laminae. Cross-laminations are usually poorly defined and at angle of repose. Bioturbation is absent.

The change to the crudely flat laminated and/or structureless sandstones is usually defined by an abrupt change of sedimentary structures (cores 10-16-53-19 and 7-36-53-18). These fL to fU sandstones are characterized by beds up to 40 cm thick (core 7-36-53-18) alternating with mudstone partings or stylolitic surfaces. Sedimentary structures in the sandstones can show any stage in the transition from structureless to poorly defined flat laminations. In core 10-16-53-19 a few ripple cross-laminated sandstones beds were observed. Mud clasts (in places sideritized), ripped-up mud laminae and coalified plant fragments are commonly contained in these sandstones.

Mudstones partings range from 1 mm to 3 cm thick and are usually irregular and undulating. In core 10-5-54-17 they increase upward in frequency.

These rocks are characterized by a very poorly developed bioturbation. Trace fossils consist of a few *Paleophycus* (core 6-28-53-18, Fig. 20) and mud-lined *Skolithos* and *Diplocraterion* burrows (cores 10-5-54-17 and 10-16-53-19). A few *Planolites* traces were observed within the mudstone partings.

Facies 2a is overlain by Facies 2b with a gradational contact (as indicated in core 10-5-54-17, Appendix B4, C9), and then by the Transgressive Shoreface sediments (discussed below) with a sharp contact. As shown in cross-section 2 (Appendix, C5), sandstones of Facies 2a thin eastward, from the top downward.

Fig. 20. Poorly developed bioturbation in structureless sandstones of Facies 2a. A *Paleophycus* trace is indicated by the arrow. Well 6-28-53-18W5 depth 8498 feet, 2" core diameter.

Fig. 21. Basal contact of Channel 2 (Facies 2b) represented by lag of abundant bivalve shells (coquina), chert pebbles (Ch), sideritized mud pebbles (S) and mud clasts. Well 11-15-54-17W5 depth 2373 m, 3" core diameter.

Interpretation - The medium-grained sandstones with an overall fining-upward trend, the physical sedimentary structures, and the presence of ripped-up mud laminae and coal fragments are indicative of high energy channel fill deposits such as sand bars or sand flats. The presence of a very low density and low diversity trace fauna of the Skolithos ichnofacies is compatable with an high-energy stressed environment. Facies 2a is interpreted as the inner river-dominated portion of an estuarine bay-head delta.

3.3.2. Facies 2b: Bioturbated muddier-upward sandstones

Description - These sediments either overlie the Gething Formation with a sharp basal contact (well 11-15-54-17, Appendix C9) or rest on the crudely flat laminated to massive sandstones of Facies 2a with a gradational basal contact (see core 10-5-54-17, Appendix B4, C9). Their thickness ranges from 5 to 8.5 m (Appendix C5).

This facies consists of bioturbated muddier-upward interbedded mudstones and sandstones showing a "bell shaped" signal in the resistivity and gamma ray logs (Appendix C5).

Where the rocks overlie the Gething Formation in core 11-15-54-17, they are characterized by a 1 m thick basal lag consisting of abundant bivalve shells (coquina), ripped up thin mudstone clasts, sideritized mud clasts, chert pebbles up to 2 cm, and a coarse sand matrix (Fig. 21).

The muddier-upward trend is due to a progressive thinning-upward of the sandstone beds, from 7 cm at the base to mm-scale at the top (where the sand is mostly concentrated in burrows). Sandstone beds fine upward from mL to vfU, are structureless to crudely flat laminated, lenticular, and commonly reworked by bioturbation. Rarely, ripple cross-laminations were observed. Mudstone beds thicken upward from mm-scale at the base, to exclusively dark bioturbated mudstones at the top (Fig. 22).

In core 10-5-54-17 Facies 2b overlies the sandstones of Facies 2a (Appendix, B4, C9). In this case, bioturbation is better developed and the interbedding of mudstone and sandstone is not preserved. The muddy sandstones are very-fine-grained and grade up into bioturbated dark mudstones at the top.

Trace fossil assemblage of Facies 2b is characterized by a limited number of species consisting of *Thalassinoides*, *Planolites* (Fig. 22), few *Terebellina*, *Helminthopsis* and a single example of *Syphonichnus* (core 11-15-54-17).

The rocks are overlain by the Transgressive Shoreface (discussed below) with a sharp basal contact.

Interpretation - The muddy nature of this facies associated with low diversity trace fossils of the Cruziana Ichnofacies suggests a stressed and relatively quiet environment, within Channel 2. The basal interbedding of sandstones and mudstones is interpreted as an estuarine point bar located in the transition between the inner sand-dominated part of the bay-head delta and the central mud-dominated zone of the estuary. The muddier-upward trend suggests

Fig. 22. Dark bioturbated mudstones of Facies 2b. Bioturbation is dominated by *Planolites* traces. Well 11-15-54-17W5 depth 2362 m, 3" core diameter.

Fig. 23. Basal contact of Channel 3 (Facies 3a). The basal lag contains chert pebbles up to 3 cm, mud clasts and shell fragments. Well 6-4-55-17W5 depth 2342 m, 3" core diameter.

deposition under transgressive conditions. This interpretation will be elaborated later in the text.

3.4. Channel 3

Bluesky Channel 3 erodes the southwestern part of the fills of Channels 1 and 2. The channel trends northward (T53-T54, R20), turning to the northeast in T54 R20 (Fig. 18). In the central part of the study area, it also incises directly into the Gething Formation.

The fill of Channel 3 is very similar to that of Channel 2 and consists mostly of sandstones. In cores 7-7-54-18 and 5-8-54-18 (Appendix C7), a thin muddier-upward succession of bioturbated sandstones rests on the main sandstone facies with a gradational contact, as in core 10-5-54-17 of Channel 2 fill (Appendix C5).

Channel 3 is 60 km long, about 5-7 km wide and the thickness of the fill is 20 m at the southwestern end, 25 m in the middle and 6 m in the northeastern end. The orientation of most of the channel is 060-240°. The southern wall and the northeastern end of the channel are partially eroded by Channel 6 (Fig. 33). Channel 6 also erodes through the southwestern part of the Channel 3 fill into the Gething Formation.

There are 42 wells in the fill of Channel 3, and 18 of them are cored.

The fill of Channel 3 can be divided into 2 main facies: Facies 3a and Facies 3b.

3.4.1. Facies 3a: Cross-bedded, crudely flat laminated and structureless sandstones

Description - The fill of Channel 3 is almost exclusively represented by Facies 3a, which has lithological, sedimentological and biogenic aspects similar to those of Facies 2a.

Facies 3a is 4 to 20 m thick and overlies the Gething Formation with a sharp basal contact. This contact is commonly characterized by a basal lag consisting of well rounded chert pebbles up to 3 cm (Fig. 23, core 6-4-55-17), mud clasts and shell fragments. In cores 3-14-54-19 and 6-23-54-18, *Thalassinoides* traces were also observed at the contact.

Facies 3a consists of an overall fining-upward succession of sandstones with cross-bedding, crude flat laminations and structureless beds. It is characterized by a blocky-shaped log signal. Within these mL to fL sandstones, it is possible to recognize subtle 0.70 to 4 m thick amalgamated fining-upward successions which are characterized by cross-bedding, flat lamination and structureless beds. In places, these subtle successions are defined by a trend of sedimentary structures from cross-bedding at the base to crude flat laminations and/or structureless beds at the top (cores 2-3-55-17 and 3-12-54-19) and are floored by a lag of coarse sand grains and/or chert pebbles up to 0.6 cm (core 6-25-54-18).

The fU to mL cross-bedded sandstones show poorly defined 15-30 cm sets of planar-tabular or trough cross-laminations (core 12-1-55-17, Fig. 24). In places, irregular mm-scale mudstones laminae or stylolitic surfaces define the sets

Fig. 24. Poorly defined cross-bedding in fU sandstones of Facies 3a. Well 12-1-55-17W5 depth 2323 m, 3” core diameter.

Fig. 25. Gradual transition between crude flat laminations to structureless fU sandstones within Facies 3a. Well 3-12-54-19W5 depth 2597.5 m, scale bar 2 cm.

boundaries. Mudstones clasts and coal fragments were observed, but bioturbation is absent.

The crudely flat laminated fL to fU sandstones occur in beds up to 30 cm thick, generally separated by mudstones partings. In some cases, low-angle laminated beds were also observed. The mudstone partings can be irregular or flat, up to 2 cm thick. In rare places, they drape the gently inclined top surfaces of some sandstones beds (core 12-1-55-17). In core 12-1-55-17 an asymmetrical scour (similar to a *flute cast* in cross-section) was observed. Ripped-up mud laminae, mud clasts and coal fragments are common.

The structureless beds generally consist of 10 cm to 1 m thick fL to fU sandstones beds. Rarely, crude ripple cross-laminations are preserved (core 6-25-54-18). In core 6-23-54-18, the structureless sandstones contain sideritized mud clasts up to 7 cm.

The contacts between cross-bedded and flat laminated sandstones are generally characterized by an abrupt change of sedimentary structures, without the interposition of mudstones partings (core 3-14-54-19, Appendix B5). In contrast, a gradual transition from poorly defined flat laminations to structureless sandstones was usually observed (core 3-12-54-19, Fig. 25).

In the upper parts of cores 7-9-52-20, 6-23-54-18, 6-16-54-18 and 3-12-54-19, the structureless sandstones have a different aspect: they can be mL in grain size, up to 8 m thick and, in places, characterized by a basal lag of pebbles up to 0.7 cm (cores 7-9-52-20 and 6-23-54-18).

Within Facies 3a, a few glauconite grains were observed at different stratigraphic levels, but more commonly in the upper part of these sandstones.

Facies 3a shows scarce evidence of biogenic activity, mostly restricted to the flat laminated sandstones. The trace fossils recognized consist of *Macaronichnus,* (core 6-2-55-17, Fig. 26), *Paleophycus*, few sand filled *Arenicolites* or *Skolithos* burrows (core 12-1-55-17) and a few *Planolites* traces within the mudstone partings.

Facies 3a is sharply overlain by the Transgressive Shoreface (discussed below) and may also be gradationally overlain by Facies 3b.

Interpretation - The combination of the overall fining-upward trend of the sandstones and the scarce and stressed fauna of the Skolithos Ichnofacies, suggest that Facies 3a represents high-energy sand bars to sand flat deposits of the inner fluvial-dominated part of the estuarine bay-head delta. Similar successions have been described by Dalrymple et al. (1990) in an overall regressive setting. The presence of *Thalassinoides* traces and shell fragments at the basal contact, suggests reworking of the original fluvial incision by wave action. A more detailed explanation of this interpretation will be discussed later.

3.4.2. Facies 3b: Bioturbated muddier-upward sandstones

Description - This Facies is 1.5 to 7 m thick and overlies Facies 3a with a gradational contact (core 5-8-54-18). It is preserved only in a restricted central area (wells 5-8-54-18, 7-7-54-18 and 10-8-54-18, Fig 18) and in the northeastern end of Channel 3, where is inferred from the bell-shaped signal of gamma ray and

Fig. 26. *Macaronichnus* traces in almost structureless sandstones of Facies 3a. Well 6-2-55-17W5 depth 3014m, 3" core diameter.

Fig. 27. Basal sandstones of Facies 3b completely bioturbated by *Rosselia*(R), *Asterosoma* (A) and *Paleophycus* (P). Well 5-8-54-19W5 depth 2556 m, 3" core diameter.

resistivity logs. A lateral transition from blocky to bell-shaped signals occurs between well 6-12-55-17 and 10-31-55-16 (Fig. 18).

The rocks consist mainly of muddier-upward bioturbated sandstones. The muddier-upward trend occurs with the progressive decrease of sand content which is fL to mU in grain size, mostly reworked by bioturbation at the base and concentrated in burrows at the top (core 7-7-54-18). Nevertheless, in core 7-7-54-18, the sand contained in the succession is coarsening up from fU to mU. Rarely, flat laminated sandstone beds up to 5 cm are preserved (core 5-8-54-18).

Facies 3b is generally completely bioturbated by *Rosselia, Asterosoma, Teichichnus, Paleophycus, Planolites* (core 5-8-54-18, Fig. 27)*, Helminthopsis*, a few sand filled vertical burrows (core 7-7-54-18) and *Thalassinoides.*

This facies is similar to Facies 2b of Channel 2. It is sharply overlain by the sediments of the Channel 6 fill and by the Transgressive Shoreface (discussed below). The sharp contact with the overlying fill of Channel 6 is characterized by a lag of mud clasts and chert pebbles (up to 1 cm in core 7-7-54-18), or by bioturbated pebbly muddy sandstones (with chert pebbles up to 1.5 cm), *Thalassinoides* burrows up to 4 cm and mud clasts up to 5 cm (core 5-8-54-18).

Interpretation - The dominant mudstone lithology associated with the presence of the Cruziana-Skolithos trace assemblage indicates that this channel filling facies was deposited in the low-energy central area of the estuary (similar to Facies 2b). This interpretation will be elaborated when the facies are placed in context.

3.5. Channel 4

This channel incises into the Gething Formation in the northern part of the study area (Fig. 18). Its sandstone fill is very similar to that of both Channels 2 and 3. It is not possible to determine its exact chronological relationship with respect to Channels 2 and 3, because it cuts only into the Gething Formation, and its eastern part is totally eroded by Channel 6 (Fig. 33).

Channel 4 has a preserved length of about 20 km; it is 2-4 km wide and its fill is about 4-8 m thick. The orientation of this channel is roughly east-west.

Nine wells penetrate the fill of Channel 4, but only 1 of them is cored.

The fill of Channel 4 consists of a single facies: Facies 4

3.5.1. Facies 4: Cross-bedded, crudely flat laminated and structureless sandstones

Description - Facies 4 is very similar to Facies 2a and 3a of the fills of Channels 2 and 3. It is 4-8 m thick and it rests on the Gething Formation with a sharp basal contact. This contact is characterized by a pebble lag with chert pebbles up to 2 cm.

The rocks consist of cross-bedded, crudely flat laminated and structureless sandstone beds interbedded with a few mudstone partings. The fU to mL cross-bedded sandstones contain 10-20 cm sets of planar-tabular cross-bedding.

The fL to fU flat laminated sandstone beds are up to 25 cm thick. In places, they are sharply superimposed on the cross-bedded sandstone beds without the interposition of mudstones partings.

The fL to fU structureless sandstone beds are up to 70 cm thick and are mostly concentrated in the basal part of the channel. None of the sandstones beds in Channel 4 is bioturbated.

Mudstone partings average 2-3 mm thick (up to 2 cm), are commonly irregular and bioturbated by a few *Planolites* burrows.

Facies 4 is sharply overlain by the Transgressive Shoreface (discussed below).

Interpretation - The combination of the sandstone lithology filling Channel 4 and the physical sedimentary structures observed, suggests high-energy sand bar to sand flat deposits. The presence of a few *Planolites* traces within the few mudstone partings is the only evidence of biogenic activity. This is indicative of extremely low salinity conditions such as those of freshwater-dominated inner estuaries. Further details will be explained later.

3.6. Channel 5

Bluesky Channel 5 is located in the northern end of the study area and cuts into the Gething Formation (Fig. 18).

This channel is oriented east-west, and bifurcates locally in T57 R19-18. Channel 5 is about 50 km long, 7 km wide at its western end and at least 9 km wide at the eastern end. The Channel 5 fill is 8-20 m thick and consists mainly of sandstones, except for a thin (about 2m) mudstone deposit located at the eastern end (Appendix C6).

The southern part of the eastern end of the Channel 5 fill has been eroded by Channel 6 (Fig. 33).

Seventy-four well logs penetrate the fill of Channel 5, and 19 cores have been described.

The analysis of lithology, sedimentary structures, ichnology and log responses suggests that the fill consists of two facies: Facies 5a and 5b.

3.6.1. Facies 5a: Slightly bioturbated cross-bedded, flat laminated and structureless sandstones

Description - Facies 5 is 8-20 m thick and overlies the Gething Formation with a sharp basal contact. The base of this sandstone body is commonly characterized by a lag of chert pebbles up to 1.5 cm (core 6-20-57-20), in places poorly rounded (cores 11-14-57-20, Fig. 28; core 10-10-57-19). This lag may also contain sideritized mud clasts and glauconite grains. In cores 16-2-57-19 and 6-10-57-20, *Thalassinoides* and *Skolithos* burrows were observed at the contact. The rocks consist of an overall fining-upward succession of mL/mU to fL/vfU

Fig. 28. Basal contact of Channel 5 between the sandstones of Facies 5a (above) and black mudstones of the Gething Formation. The contact is characterized by a lag of chert pebbles and mud clasts. Well 11-14-57-20W5 depth 2512 m, 3" core diameter.

sandstones characterized by flat laminated beds, structureless beds, and less commonly by cross-laminated beds. Coal fragments and mud clasts (sideritized or not) are commonly contained within these sandstones (core 10-12-57-19). Some scattered glauconite grains were also observed, especially in the upper part of Facies 5 (core 16-2-57-19).

The log responses of these sandstones generally show blocky-shaped curves (Appendix C6). In some well logs these curves display a slightly bell-shaped signal (e.g. log 11-14-57-20, Appendix C6).

In places, the overall sandstone body can be divided into subtle 1 to 8 m thick fining-upward successions. These subtle successions fine upward from mL/mU to fL/vfU and, in some cores, they have a basal pebble lag with chert pebbles up to 1 cm (cores 6-16-57-18, 6-10-57-20 and 16-2-57-19).

The cross-bedded mL sandstones occur in 15-25 cm sets of planar-tabular or trough cross-bedding (cores 6-20-57-18 and 6-16-57-18) mostly localized in the lower part of Facies 5 (core 3-24-57-19, Fig. 29 and Appendix B6).

The flat laminated fL to mL sandstone beds average 10 cm thick (range 5-20 cm). Laminations can be well or poorly defined. Rarely, 2-3 cm ripple cross-laminated sandstone beds were intercalated within the flat laminated beds (core 3-24-57-19).

The structureless sandstones occur in 2 to 10 cm thick mL to fU sandstone beds (core 10-11-57-19).

The contacts between sandstone beds with different sedimentary structures can be variable: 1) in core 3-24-57-19 (Fig. 29), the upward change from trough cross-bedded to structureless sandstones occurs with the

Fig. 29. Contact between structureless and trough cross-bedded sandstones of Facies 5a. Well 3-24-57-19W5 depth 2650 m, 4" core diameter.

Fig. 30. Gradational and irregular contact between poorly defined cross-bedded (below) and structureless (above) sandstones of Facies 5a. Well 10-12-57-19W5 depth 2664 m, 4" core diameter.

interposition of 1 mm thick mud laminae, 2) in core 10-12-57-19 (Fig. 30), the same upward change is gradational, but with irregular contacts, and 3) in core 12-19-57-18 (Fig. 31), structureless sandstones change abruptly upward to crudely flat laminated sandstones.

In general, all sandstone beds of Facies 5 show a thinning-upward trend from about 20-30 cm at the base to an average of 3 cm at the top (core 11-14-57-20).

The boundaries of most of the sandstones beds of Facies 5 are defined by irregular, mm-scale to 2 cm thick mudstones partings. These thin beds thicken and increase upward in number.

This facies is slightly bioturbated, mostly in the flat laminated sandstones, with the amount of bioturbation increasing upward. The trace fossils observed were: 1) *Paleophycus*, abundantly concentrated within a 1-2 m thick level in the upper part of Facies 5 (core 3-24-57-19, Fig. 32), 2) fairly abundant *Skolithos* and/or *Arenicolites* sand filled burrows (core 3-24-57-19), 3) common escape structures (cores 3-24-57-19, 10-12-57-19 and 12-19-57-18), and 4) a few *Ophiomorpha* and *Diplocraterion* (core 6-10-57-20). Commonly, mudstones partings are bioturbated by *Planolites*.

Facies 5 is sharply overlain by the Transgressive Shoreface (discussed below).

Interpretation - The overall interpretation of this facies is similar to those of Facies 2a, 3a and 4. The dominant flat laminations of the sandstones suggests a

Fig. 31. Abrupt change from structureless to crudely flat laminated fL sandstones of Facies 5a. Well 12-19-57-18W5 depth 2444 m, 3" core diameter.

channel sand flat as the most likely depositional environment. The upward increase of the Skolithos Ichnofacies assemblage reflects a progressive upward increase in water salinity, probably related to transgressive conditions. This interpretation is elaborated later in the text.

3.6.2. Facies 5b: Mudstones

Description - This facies is 1 to 2 m thick and overlies Facies 5a with a sharp contact at the eastern end of the channel (Fig. 18). No cores penetrate Facies 5b and its muddy nature is inferred from the abrupt deflection above the blocky-shaped gamma ray and resistivity log response visible from well 7-23-57-18 to 11-15-57-16 (Appendix C6). Similarly, Channels 2 and 3 also have mudstone facies at their eastern ends. Facies 5b is sharply overlain by the Transgressive Shoreface (discussed below).

Interpretation - The muddy lithology inferred from log responses and the stratigraphic position (overlying sandstone facies as in Channels 2 and 3) suggest deposition in the low-energy central area of the estuary (similar to Facies 2b and 3b). The sharp nature of the basal contact probably indicates that fluvial sediment input was abruptly reduced, at time of Facies 5b deposition.

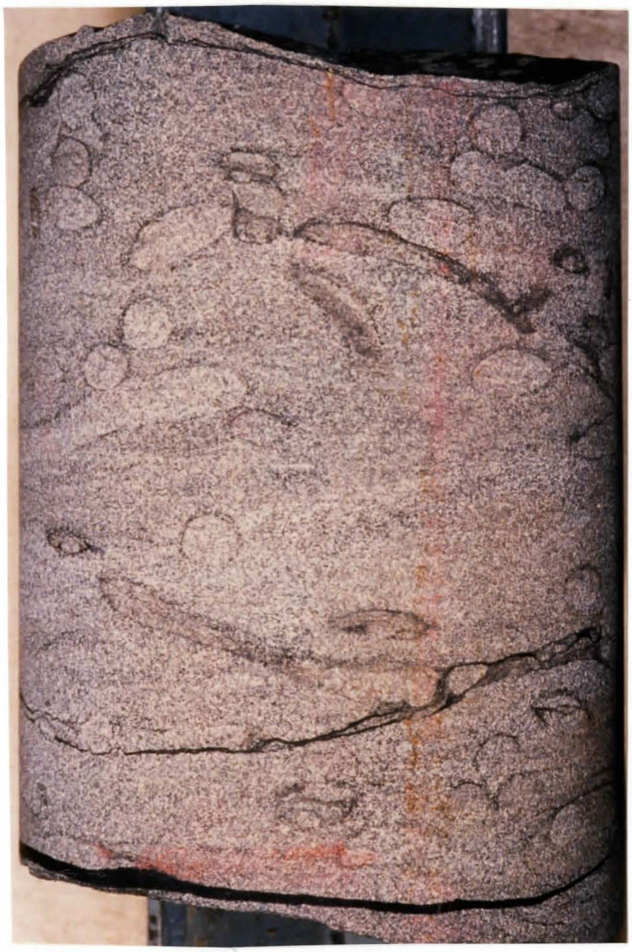


Fig. 32. Fine-grained sandstones of Facies 5a abundantly bioturbated by traces of *Paleophycus*. Well 3-24-57-19W5 depth 2642 m, 4" core diameter.

3.7. Channel 6

In the study area, Channel 6 consists of two distinct branches that merge at the northeastern end (Fig. 33).

The northern branch incises into the Gething Formation and erodes the eastern part of Channels 4, 3 and the southern part of the eastern end of Channel 5 (Fig. 33). It is fairly straight and trends SW-NE. It is about 7-10 km wide and 45 km long. Its fill is 7 m thick at the southwestern end, 15 m in the middle part and 7 m in the northeastern end.

The southern branch of Channel 6 is sinuous. It incises into both Channels 2 and 3 and cuts down into the sediments of the Gething Formation (e.g. wells 16-2-54-19, Appendix C1, C10, C7) and into the fill of Channel 1 (wells 13-6-54-18 and 2-6-54-18, Appendix C1, C7). It also erodes the southern wall of Channel 3, the northern wall of Channel 2, and cuts right through the southwestern part of the fill of Channel 3 into the Gething Formation (Appendix C7).

The southern branch is about 3-7 km wide, 65 km long, and its fill thins from about 27 m at its southwestern end to 4-7 m at its northeastern end.

Both northern and southern branches have a general orientation of 060-240°.

The fill of Channel 6 generally consists of a basal muddier-upward succession of weakly bioturbated interbedded mudstones and sandstones, overlain by a sandier-upward succession of more intensely bioturbated interbedded mudstones and sandstones.

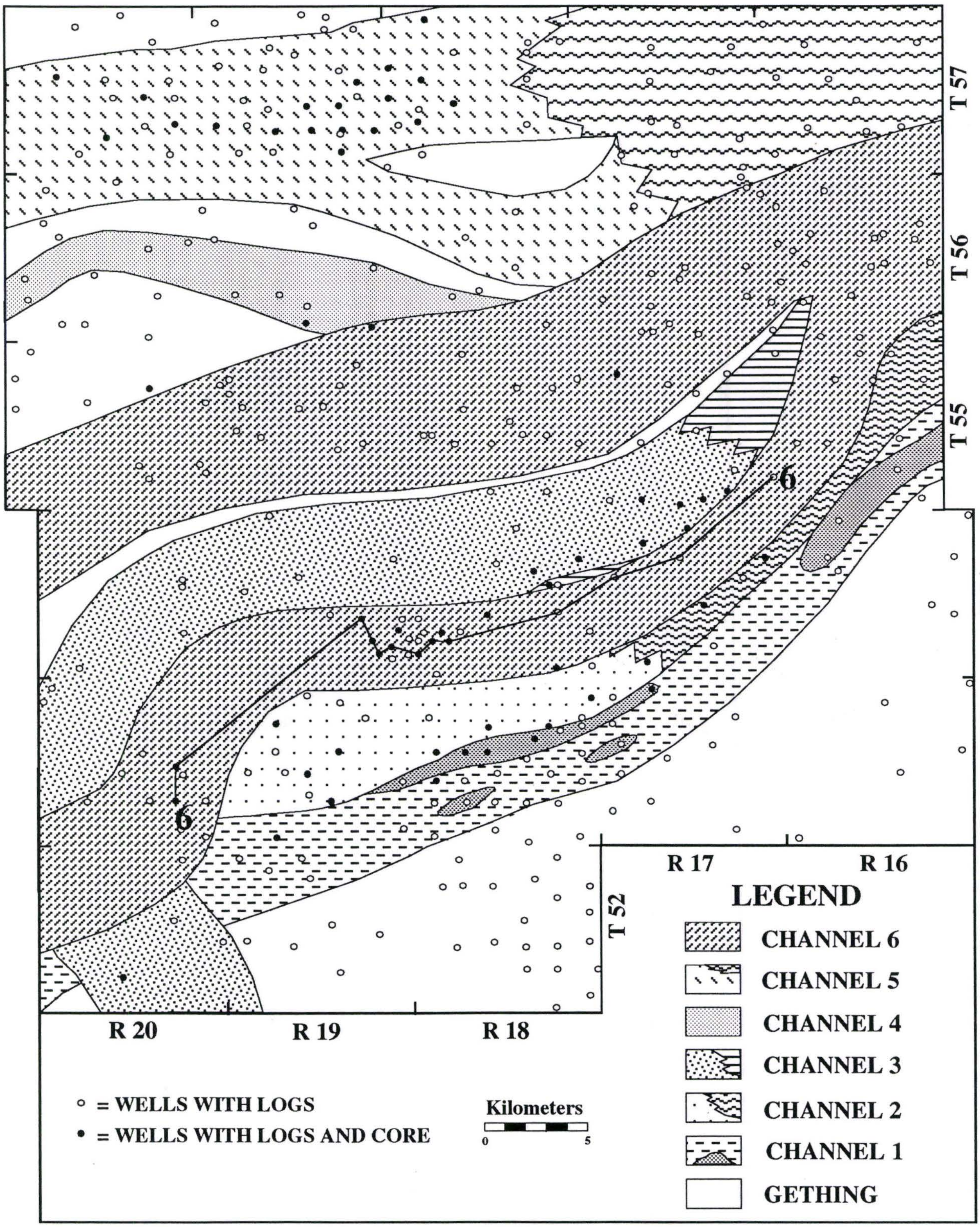


Fig. 33. Paleogeographic map of the interbedded mudstones and sandstones filled Channel 6 with location of the log cross-section 6 (Appendix C7).

The typical shape of the log curves of the fill of Channel 6 shows a symmetrical trend. It is characterized by a basal convergence of gamma ray and resistivity logs (muddier-upward) followed by an upward divergence (sandier-upward), (e.g. well 11-11-53-20, Appendix C7). The well logs of the northern branch have a dominant sandier-upward trend ("funnel shape"), whereas "bell-shaped" muddier-upward log responses are better developed in the southern branch.

Forty-eight well logs and thirteen cores are available in the southern branch, and sixty-two well logs and two cores are available in the northern branch.

The fill of Channel 6 has been subdivided into 2 distinct facies: a basal muddier-upward succession (facies 6a) and an upper sandier-upward succession (facies 6b).

3.7.1. Facies 6a: Muddier-upward interbedded mudstones and sandstones

Description - In the northern branch, Facies 6a is 0-3 m thick in its western part, up to 10 m between T 55 and T 56 (R17), thinning to 0 m at the eastern end. In the southern branch, it thins eastward from about 20 to 4 m (Appendix C7). This facies sharply overlies either the Gething Formation or the fills of Channels 1, 2 and 3.

The basal contact is always characterized by a lag of pebbly sandstones with chert pebbles up to 2 cm and sand grains up to cL (core 13-6-54-18, Fig. 34). In places, it also contains mud clasts (cores 11-11-53-20 and 14-14-53-20), coal fragments and abundant glauconite grains (core 10-1-56-19, Fig. 35). *Thalassinoides* (core 10-1-56-19, Fig. 35), *Arenicolites* and *Skolithos* burrows were also observed at the basal contact.

Facies 6a consists of an overall fining- and muddier-upward succession of thinly interbedded bioturbated mudstones and sandstones. Sandstone beds average about 2-5 cm thick (core 3-12-54-19, Fig. 36). They form a general thinning-upward trend from a maximum of 20-25 cm at the base (core 14-14-53-20) to mm-scale (core 11-11-53-20, Fig. 37) at the top. The sandstones also fine upward from mL/fU to vfU/fL. In the first 1-2 m of the succession, a few scattered pebbles may also be contained within the basal portions of the sandstone beds. These beds are commonly lenticular and slightly bioturbated. The thicker beds have a crude low angle to flat lamination (core 7-7-54-18, Fig. 38) whereas the thinner beds commonly contain ripple cross-laminations (cores 16-2-54-19 and 3-12-54-19, Fig. 36). In the basal part of the succession, rare large-scale cross-bedding was observed (sets up to 10 cm thick, cores 7-7-54-18 and 10-1-56-19). Totally structureless sandstones are uncommon.

Mudstone beds thicken upward from about 1 mm to 5 cm. They are commonly irregular, undulating and heavily disturbed by bioturbation. In places, load structures due to the overlying sandstone beds were observed. Pyrite is present in cores 15-29-55-17 and 11-11-53-20.

Fig. 34. Sharp contact between the mudstones of Facies 1b (Channel 1, below) and the basal pebbly sandstone lag of Facies 6a (Channel 6, above). Well 13-6-54-18W5 depth 2565 m, 3" core diameter.

Fig. 35. The basal contact of Channel 6 is defined in this case by black mudstones of the Gething Formation (below) abruptly overlain by a glauconite rich pebbly sandstones representing a transgressive lag. *Thalassinoides* traces of the Glossifungites Ichnofacies are present within the mudstones (black arrows). Well 10-1-56-19W5 depth 2569 m, 3" core diameter.

Fig. 36. Thinly interbedded mudstones and sandstones of Facies 6a. Some fL sandstone beds show ripple cross-laminations, mudstones partings have few *Planolites* traces. Well 3-12-54-19W5 depth 2586 m, 3" core diameter.

Fig. 37. Black mudstones with very fine sand laminae of the upper part of Facies 6a. A *Teichichnus* trace indicated by the arrow. Well 11-11-53-20W5 depth 2831 m, 3" core diameter.

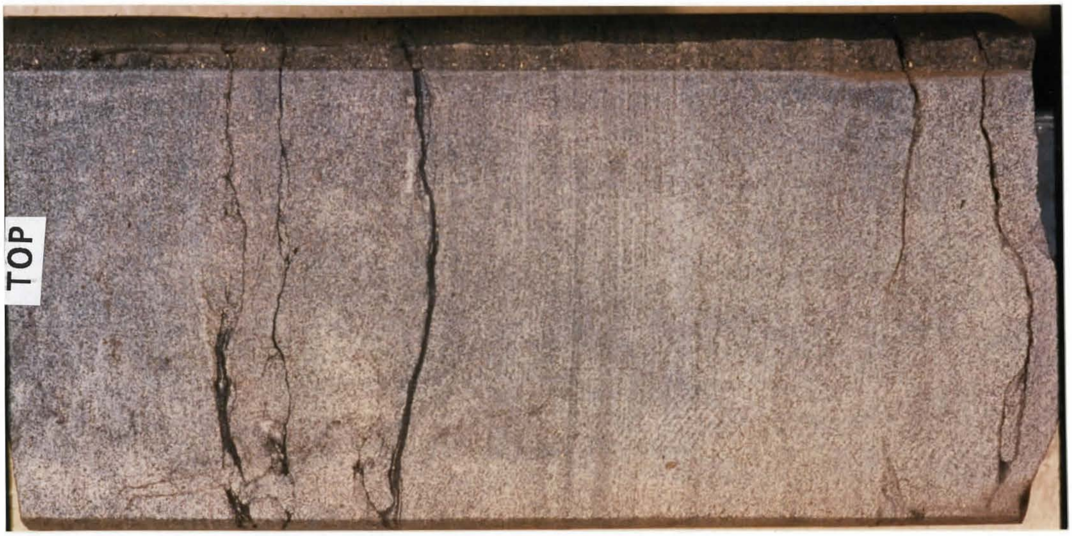


Fig. 38. Crudely flat laminated fine sandstones of the basal part of Facies 6a. Well 7-7-54-18W5 depth 2543 m, 4" core diameter.

Fig. 39. Fine-grained sandstones of the upper part of Facies 6b abundantly bioturbated by traces of *Macaronichnus*. Well 14-14-53-20W5 depth 2833 m, 3" core diameter.

In core 11-11-53-20 (Appendix C7, C9), the top of the succession is characterized by a strong convergence in the resistivity and gamma ray log curves. In this interval the core is missing, but an almost pure mudstone is inferred from the log responses.

In general, the rocks are moderately bioturbated. The amount of bioturbation and number of ichnogenera increase upward and, in places, the original interbedding is almost totally reworked (cores 11-11-53-20, 15-29-55-17 and 10-1-56-19). The trace fossils observed within the sandstone beds consist of a few small (1-2-cm wide) *Asterosoma* (core 13-6-54-18), 1.5 cm wide *Rosselia* (core 3-12-54-19), fairly abundant mud lined *Skolithos* and *Arenicolites* (cores 3-12-54-19 and 10-1-56-19), rare *Terebellina*, *Teichichnus* (core 11-11-53-20, Fig. 37) and *Paleophycus*. (core 11-11-53-20) A better developed bioturbation of Facies 6a is due to *Planolites* traces. These are abundant, up to 2-3 cm in diameter (core 14-14-53-20) and almost exclusively concentrated within the mudstone partings (Fig. 36).

Facies 6a is gradationally overlain by Facies 6b. In the southern branch of Channel 6 (Appendix C7), it may also be sharply overlain by the Transgressive Shoreface (discussed below).

Interpretation - The interbedding of thin mudstones and sandstones filling a channel and the low density and reduced size of the Skolithos-Cruziana Ichnofacies, suggest deposition in the bay-head delta of an estuary in the transition between the sand-dominated inner zone and the mud-dominated turbidity maximum central zone. Similar facies have been previously described by several authors (Reinson et al., 1988; Boreen and Walker, 1991; Pattison, 1992; Pattison and Walker, 1994; Walker, 1995)

3.7.2. Facies 6b: Sandier-upward interbedded mudstones and sandstones

Description - Facies 6b is better developed in the northern branch of Channel 6, where it thickens eastward from about 5 m to 12 m. In the southern branch, this facies is about 15 m thick at the western end, thins eastward to 0 m (T 54, R 18) and is about 3m thick in well 7-14-54-18 and 11-19-54-17 (Appendix C7).

Facies 6b usually overlies Facies 6a with gradational contacts (e.g. well 11-11-53-20, Appendix C7). The rocks consist of a sandier- and coarsening-upward succession of interbedded and pervasively bioturbated mudstones and sandstones. The sandier- and coarsening-upward trends show thickening of sandstone beds up to 27 cm, and increase of the sand grain size from vfU to fU. The sedimentary structures are generally poorly preserved due to bioturbation and commonly consist of ripple cross-lamination in the thinner sandstone beds, or crude flat to low-angle laminations or structureless sandstones within the thicker beds. In the upper part of core 10-1-56-19, a few 20-25 cm thick sandstone beds show a poorly defined trough cross-bedding.

Mudstone beds become less common upward, but their thickness is fairly constant in the mm to 2 cm range (cores 10-1-56-19 and 14-14-53-20). These beds are always highly disturbed by bioturbation and, in places, almost completely reworked into a muddy sandstone (core 15-29-55-17).

The sandier-upward trend is generally shown by the “funnel-shaped” gamma ray logs, whereas resistivity logs have, in places, a “blocky-shaped” curve. In core 11-11-53-20, the whole sandier-upward succession consists of bioturbated muddy sandstones containing scattered chert pebbles up to 0.5 cm and mud clasts up to 2 cm.

Facies 6b has a higher diversity of trace fossils compared with the underlying Facies 6a. This ichnofacies diversity also increases upward in the succession. The traces recognized are: abundant *Planolites* (mostly concentrated within mudstones partings), *Thalassinoides*, *Rosselia*, *Diplocraterion* (core 10-1-56-19), mud filled *Skolithos*, mud-lined sand-filled *Skolithos*, *Terebellina* (core 14-14-53-20), *Teichichnus* (core 7-11-54-19), *Macaronichnus* (core 14-14-53-20, Fig. 39), *Arenicolites*, one example of *Bergaueria* (core 10-1-56-19) and a few *Helminthopsis*.

Facies 6b is sharply overlain by the Transgressive Shoreface (discussed below).

Interpretation - The sandier-upward trend of Facies 6b, associated with the upward increase in the amount and diversity of ichnospecies, indicates that this sediments were deposited close to the seaward end of the estuary and were transgressed landward. This interpretation will be explained later in the text.

3.8. Transgressive Shoreface

This unit overlies all of the previously described channel fills, and overlies adjacent parts of the Gething Formation. It is present across the entire study area as an areally extensive sheet-like deposit. The facies of the rocks is variable, but normally consist of bioturbated sandstones to sandy mudstones.

All the wells available penetrate these rocks, and 25 of them have cored in this interval.

3.8.1. Facies 7: Bioturbated glauconitic sandstones to sandy mudstones

Description - Facies 7 is 50 cm to 6 m thick, with an average thickness of about 1.5 m (see all cross-sections). It has a sharp basal contact normally characterized by granules, chert pebbles up to 1 cm (core 13-6-54-18; core 12-18-57-18, Fig. 40), sideritized cm-scale mud layers and/or clasts (cores 10-5-54-17, Fig. 41 and 7-20-53-18). There are also trace fossils of the Glossifungites Ichnofacies such as *Skolithos* (core 13-6-54-18), *Thalassinoides* (cores 10-5-54-17, Fig. 41 and 11-15-54-17), *Diplocraterion* (cores 11-15-54-17, 7-7-54-18 and 10-32-53-17). Rarely, the basal surface consists of a simple sharp and abrupt lithological contrast (core 14-14-53-20).

The rocks generally consist of bioturbated sandstones, muddy sandstones and sandy mudstones that in places display scattered granules, pebbles (core 14-

Fig. 40. Sharp contact between the bioturbated glauconitic sandstones of Facies 7 (above) and the flat laminated fine-grained sandstones of Facies 5a. The contact is characterized by chert pebbles and glauconite grains (Gl). Well 12-18-57-18W5 depth 2456 m, 3' core diameter.

Fig. 41. Sharp contact between the medium-grained sandstones of Facies 7 (above) and the mudstones of Facies 2b (below). In this case the contact is characterized by sideritized mudstones and a *Thalassinoides* burrow suggesting Glossifungites Ichnofacies (the burrow is filled with the sandstones of Facies 7). Well 10-5-57-17W5 depth 8027 feet, 4" core diameter.

14-53-20) and sideritized mud clasts. If preserved from bioturbation, the mL to mU sandstones beds are up to 50 cm thick, normally cross-bedded, more rarely structureless, and in places, they are bounded by mud partings or layers up to 5 cm thick, normally sideritized.

The general spiky log signature of these rocks can normally be distinguished from the mudstones of the Wilrich Formation, but, in places, it is not distinguishable from the underlying sandy channel fills.

In core 11-11-53-20, a 5.5 m thick fining- and muddier-upward succession of interbedded sandstones and mudstones with *Diplocraterion* traces and pebbles up to 0.5 cm at the base, was also observed. The fU to fL sandstone beds thin upward from 10 to 5 cm and display hummocky-cross-stratification (HCS).

In general, this facies is characterized by a high proportion of glauconite grains.

Bioturbation is common; the trace fossils observed include abundant *Diplocraterion* (core 7-18-53-18, Fig. 42) and *Skolithos*, common *Teichichnus*, *Paleophycus*, *Rosselia*, *Thalassinoides*, *Cylindrichnus* (core 7-22-53-19, Fig. 43), *Ophiomorpha* (core 2-3-55-17) and *Planolites*, and rare *Macaronichnus*, *Arenicolites*, *Bergaueria* (core 13-6-54-18) and *Asterosoma*.

The Transgressive Shoreface is sharply overlain by the mudstones of the Wilrich Member. This upper contact is generally characterized by the presence of scattered sand grains and sideritization. Pebbles were not observed.

Interpretation - The geometry of this unit, the stratigraphic position, its sedimentological characteristics and the fully marine character of the trace fossils

Fig. 42. Medium-grained sandstones of Facies 7 with *Diplocraterion.* Well 7-18-53-18W5 depth 8647 m, 3" core diameter.

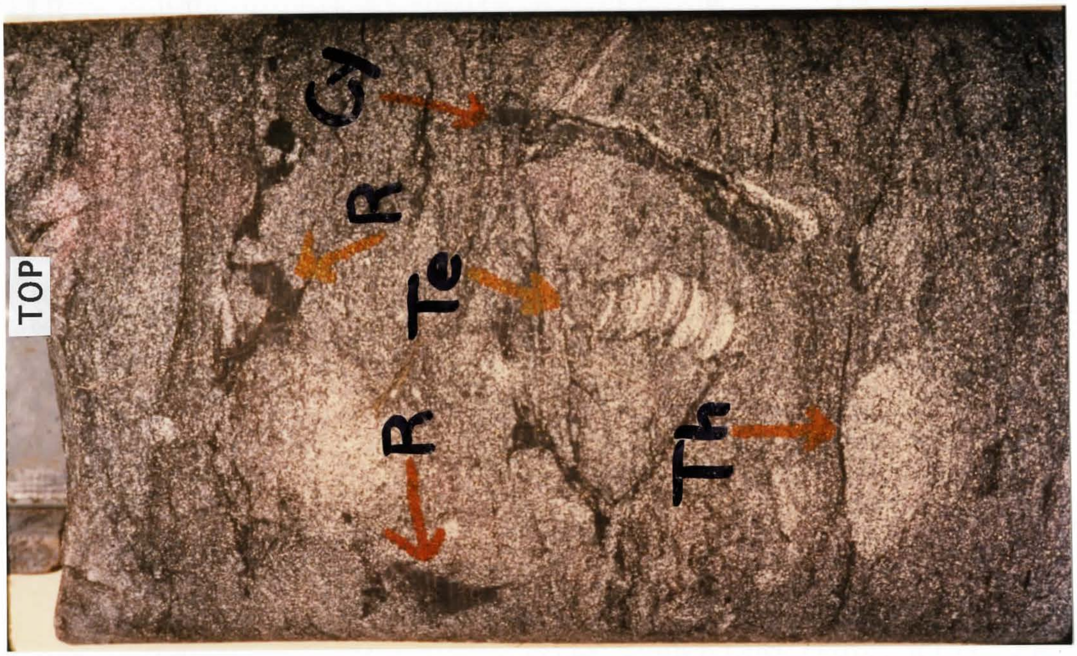


Fig. 43. Muddy sandstones of Facies 7 completely bioturbated by traces of *Teichichnus* (Te), *Rosselia* (R), *Cylindrichnus* (Cy) and *Thalassinoides* (Th). Well 7-22-53-19W5 depth 8785 feet, 4" core diameter.

observed, suggests that it was mainly deposited as transgressive lag in shoreface settings. During transgression, 5 to 15 m of the sediments behind the shoreface are eroded. Mud and fine sediments are washed out into the shelf, the coarsest sediments are deposited in the shoreface. The sharp basal contact, typically characterized by pebbles and Glossifungites ichnofacies, is consistent with the nature of a transgressive surface of erosion. The occasional presence of a muddier-upward succession of interbedded mudstones and sandstones with HCS is indicative of local upward development of storm-dominated offshore settings, under relatively slow transgressive conditions. An elaborated version of this interpretation will be given later.

CHAPTER 4: CORE AND WELL LOG CORRELATIONS

4.1. Introduction

Bounding Surfaces - Individual facies within the Bluesky are bounded by areally extensive surfaces. In this section a brief definition of all the bounding surfaces is given, and a more elaborate interpretation will be discussed later in this chapter and in chapter 5.

All the basal surfaces of the Bluesky channels are defined by fluvial incisions (Surfaces of Erosion, SEs) that are partially (TSE_{1a} in Channel 1) or probably totally modified by subsequent Transgressive Surfaces of Erosions (TSEs(SEs)) in Channels 2 to 6.

The sharp contact between the inner estuarine sandstones of Facies 5a and the central estuarine mudstones of Facies 5b (Channel 5, Appendix C6) is defined by Flooding Surface FS_5. In contrast, the contact between the inner estuarine sandstones of Channels 2 and 3 (Facies 2a and 3a) and the overlying central estuarine mudstones (Facies 2b and 3b) are gradational (labelled by a dashed line in log and core cross-sections, Appendix C5 and C9). A gradational contact is also defined in Channel 6 between the muddier-upward (6a) and sandier-upward (6b) successions (Appendix C7).

Within Channel 1 there are two additional TSEs (TSE_{1b} and TSE_{1c}) which define the sharp contact between Facies 1a and 1b and the base of the estuarine-mouth sandstones of Facies 1d, respectively (Appendix C4, C8).

The final TSE (TSE_7) cuts across the entire study area and defines the base of the Transgressive Shoreface (Facies 7). The boundary between the Bluesky deposits and the mudstones of the Wilrich Member is defined by a Maximum Flooding Surface (MxFS), as discussed later.

All the SW-NE cross-sections (Appendix C4, C5, C6, C7, C8, C9) show channel bases, with some of the TSEs dipping southwestward (upstream). The steepest upstream dipping surface (TSE_{1a}, Appendix C4, C8) is inclined at about 0.38°. This apparent upstream inclination of a channel base can be transformed into a horizontal surface if the assumed horizontal datum (within the Wilrich Member) actually dipped northeastward (seaward) with an angle of 0.38° during deposition.

Correlations - Seven log cross-sections (Fig. 44) and three core cross-sections (Fig. 45) have been constructed across the study area. For the log cross-sections, both the gamma ray and resistivity log responses of each well were traced onto transparent paper, covering an interval from about 50 m above to 30 m below the Bluesky. Correlations were achieved by overlaying adjacent traced log signatures. The datum used consists of a regionally extensive low resistivity kick (about 12 ohm-m) located about 25-30 m above the top of the Bluesky, within the Wilrich Member mudstones.

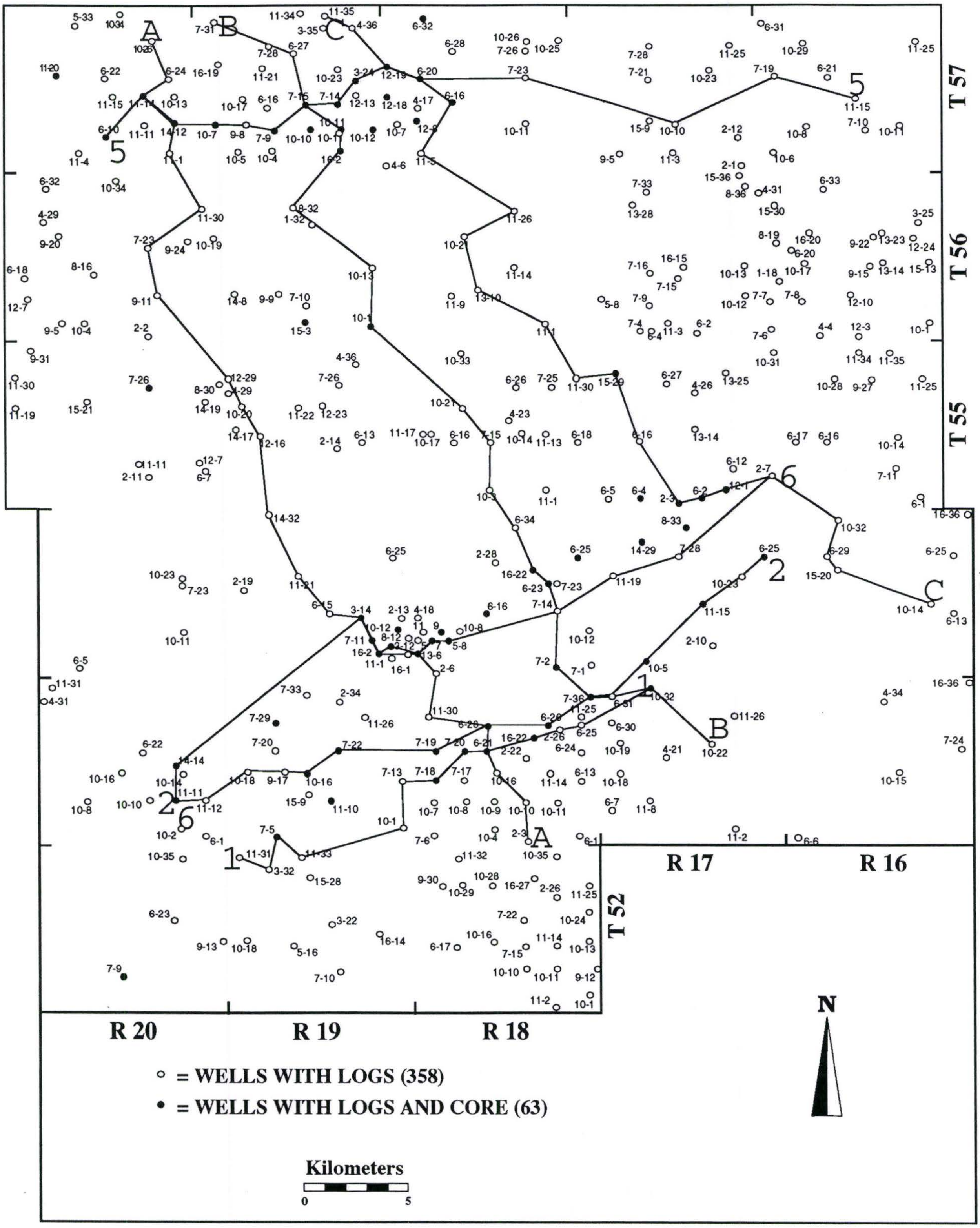


Fig. 44. Location map of the 7 log cross-sections across the study area (Appendix C1, C2, C3, C4, C5, C6, C7).

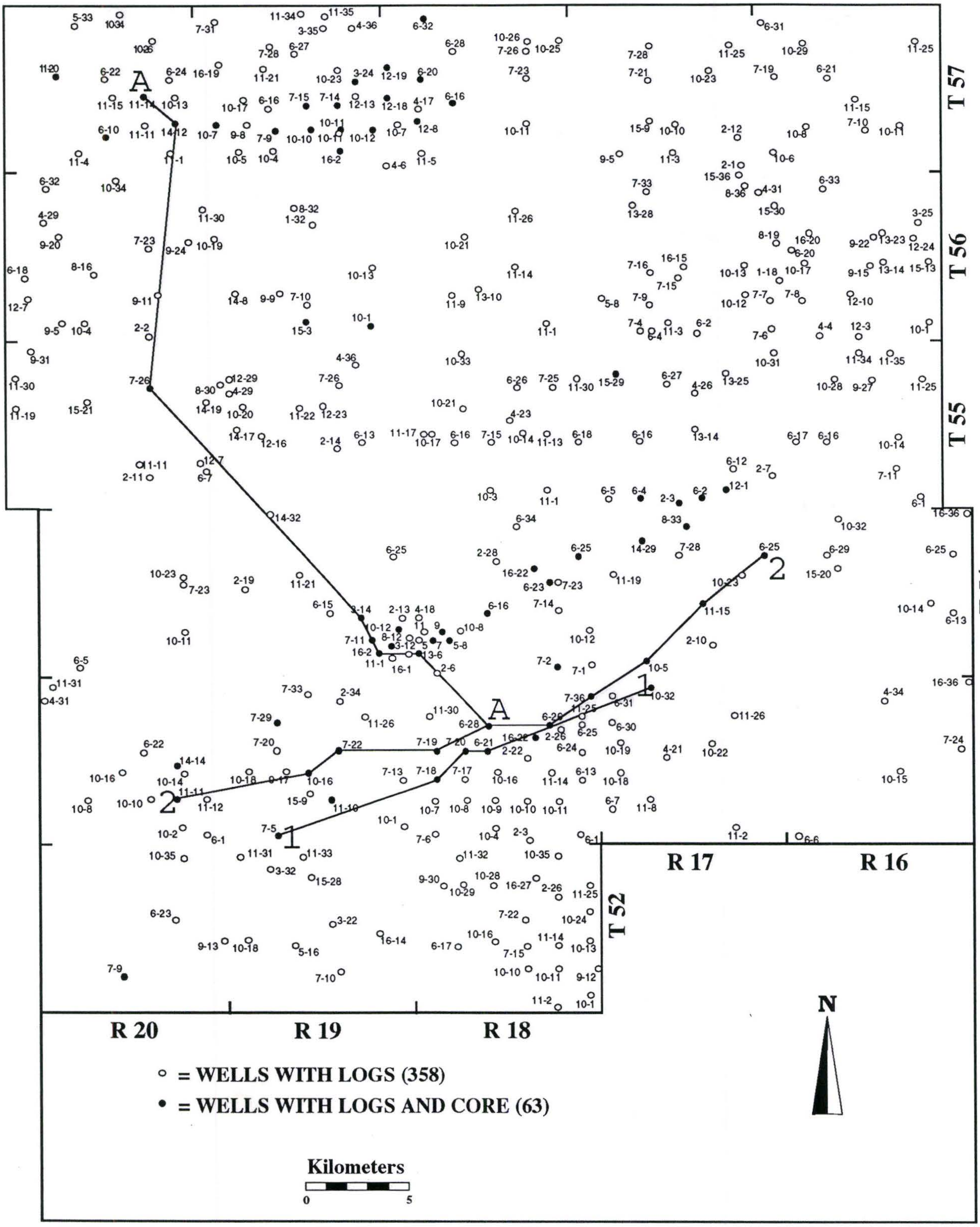


Fig. 45. Location map of the 3 core cross-sections across the study area (Appendix C8, C9, C10)

The four NW-SE cross-sections (Appendix C1, C2, C3, C10) emphasize the contrast between the “irregular” Gething Formation log responses and the more systematic Bluesky log responses. The channellized nature of Bluesky deposits is well displayed. There are three different channel-fill log responses (discussed later), suggesting at least three generations of superimposed channels. In detail, it will be shown that within the overall Edson channel complex, there are six individual channels that cut into each other. Channel six consists of two separate branches.

The six SW-NE cross-sections (Appendix C4, C5, C6, C7, C8, C9) show the longitudinal variations in channel filling within (1) the mudstone fill of Channel 1, (2) the sandstone fills of Channels 2 and 5, and (3) the interbedded mudstone and sandstone fill of Channel 6.

The fills of Channels 3 and 4 closely resemble those of Channels 2 and 5, and cross-sections are not presented.

A cross-section along the northern branch of Channel 6 is not presented because of its similarity with the southern branch, and the scarcity of cored wells in the northern branch.

The following text is largely descriptive, but the initial facies interpretations from Chapter 3 are used to help integrate facies geometries (as shown by the cross-sections).

4.2. NW-SE cross-sections

The NW-SE cross-sections are perpendicular to the six Bluesky channels. The underlying Gething Formation generally consists of coastal plain deposits represented by a variety of lithofacies such as coal layers, small sandstone-filled channels, flood plain siltstones and mudstones and lacustrine mudstones. This variable lithological assemblage generally produces a very irregular signal in the gamma-ray and resistivity logs. However, there are some sandier-upward and muddier-upward successions, and some coals, that are laterally persistent and can be easily correlated. For example, the sandier-upward marker of Appendix C1 (labelled with curved arrows) is correlatable from wells 10-26-57-20 to 11-14-57-20. South of 11-14-57-20, the sandier-upward Gething marker is cut out by blocky log signals of the Bluesky (14-12-57-20), but the Gething signal reappears in 11-1-57-20 and can be correlated to 14-32-54-19. It is then cut out again by blocky log signals representing Bluesky channels. A sandier-upward Gething response reappears at the southeastern end of the cross-section (2-3-53-18).

The Wilrich marker (datum), the top of the Bluesky, and markers in the Gething are parallel to sub-parallel. This emphasizes the channellized nature of the base of the Bluesky.

The bases of Bluesky channels are clearly defined by the truncation of the "irregular" Gething log responses and the abrupt occurrence of more systematic, commonly blocky Bluesky log responses. These systematic log responses consist of : 1) **blocky-shaped** log signals typical of the sandstone fills of Channels 2, 3, 4 and 5 (e.g. wells 14-12-57-20 and 6-28-53-18, Appendix C1, C10), 2) **funnel-**

shaped log signals of the mudstone fill of Channel 1 (e.g. lower part of well 10-16-53-18, Appendix C1 and well 15-20-54-16, Appendix C3), 3) **bell-shaped** log signals of the northeastern mudstone-filled part of Channel 2 (e.g. well 2-7-55-16, Appendix C3; well 11-15-54-17, Appendix C5), and 4) **symmetrical muddier- and sandier-upward** log signals of the interbedded mudstones and sandstones filling Channel 6 (e.g. well 11-11-53-20, Appendix C6, C9).

Evidence for superimposed channels is also displayed in the NW-SE cross-sections. In Appendix C1, the blocky log responses of Channel 2 sandstones (wells 11-30-53-18 and 6-28-53-18) clearly cut through the funnel-shaped log responses of the Channel 1 mudstones (the basal sand body in 6-21-53-18, labelled 1a, will be discussed later). Similarly, the basal muddier-upward responses of the interbedded mudstones and sandstones of Channel 6 (Facies 6a) erode into the sandier-upward mudstones (funnel-shaped log signal) of Channel 1 (wells 13-6-54-18 and 2-6-54-18, Appendix C1). Note the abrupt deflection of the well logs at the base of Channel 6. Channel 6 also cuts into the blocky responses of Channel 3 sandstones (between wells 6-15-54-19 and 7-11-54-19, Appendix C1) and into the bell-shaped log signal of the Channel 2 mudstones (well 7-14-54-18, Appendix C2; well 2-7-55-16, Appendix C3).

The transition between Bluesky channels and the overlying marine mudstones of the Wilrich Member is represented by bioturbated muddy sandstones and sandstones of the Transgressive Shoreface (Facies 7). These sheet-like transgressive sediments cover all of the study area and are characterized by gamma-ray values ranging from 30 to 105 API units and resistivity values ranging from 40 to 200 ohm-m. This variable log response is due to differences in mudstone and sandstone content within these deposits. Without core control, the common spiky log response of Facies 7 is hard to distinguish from the blocky log response of the sandstone-filled channels (e.g. well 6-28-53-18, Appendix C1). However, it can be distinguished from the underlying mudstone fill of Channel 2 (e.g. wells 10-5-54-17 and 11-15-54-17, Appendix C5).

Where the Gething Formation is not cut by Bluesky channels the Transgressive Shoreface is the only Bluesky deposit interposed between Gething and Wilrich sediments (e.g. well 2-3-53-18, Appendix C1; well 7-26-55-20 Appendix C10).

4.3. Mudstone fill (Channel 1)

Channel 1 fill consists of four different facies (described in Chapter 3; Appendix C4, C8): 1) basal localized sandstone bars (Facies 1a), 2) weakly bioturbated mudstones (Facies 1b) at the northeastern end, 3) strongly bioturbated mudstones (Facies 1c) at the southwestern end, and 4) bioturbated sandstones (Facies 1d) at the northeastern end. Of the six channels, only Channel 1 has a dominantly mudstone fill.

Sandstone bars of Facies 1a - Northeastward from well 7-13-53-19 (Appendix C4 and Fig. 16), the base of Channel 1 (Surface of Erosion 1, SE_1) is in places characterized by longitudinal sand bars of Facies 1a. These lenticular sandstone bodies display a blocky log response (e.g. 7-13-53-19 and 7-20-53-18,

Appendix C4) with gamma ray values of about 30 API units and resistivity values of about 200 ohm-m. This blocky response is sharply overlain by a much muddier, slightly sandier-upward log response (e.g. 16-22-53-18, Appendix C4) which represents the weakly bioturbated sandier-upward central estuarine mudstones of Facies 1b.

Mudstones of Facies 1b - Where the sandstone bars do not occur (well 10-1-53-19 in Appendix C4, and all wells lateral to the bars shown in Fig. 16), Facies 1b forms the basal deposits of Channel 1. These sandier-upward mudstones are correlatable with those over the sand bars (wells 7-13-53-19 and 7-18-53-18; 6-21-53-18 to 10-32-53-17, Appendix C4).

The sandier-upward trend is indicated by the upward decrease of gamma ray values from 120 to 95 API units (e.g. wells 6-21-53-18 and 7-18-53-18, Appendix C4). Facies 1b blankets the lenticular sandstone bars and the floor of Channel 1 from wells 10-1-53-19 to 7-18-53-18 and from wells 6-21-53-18 to 10-32-53-17; it is not preserved above the sandstone bar of well 7-20-53-18. The basal surface of this facies (TSE_{1a}) becomes co-planar with SE_1 southwest of well 7-13-53-19 (Appendix C4).

Mudstones of Facies 1c - The strongly bioturbated sandier-upward mudstones (Facies 1c) occur at the southwestern end of the cross-section (11-31-52-19 to 10-1-53-19), and can be correlated northeastward as far as 7-20-53-18 (Appendix C4, C8). They have been interpreted as a central estuarine deposit with a stronger marine influence than Facies 1b. The basal part of this facies is generally characterized by a pure black mudstone (seen in cores 7-5-53-19 and 7-20-53-18) that displays a small "box-shaped" gamma-ray signal with higher API values (about 105 API units; dashed line in Appendix C4 and C8, especially in well 10-1-53-19). This "box-shaped" log signal is better developed between wells 10-1-53-18 and 7-18-53-18. The "box" occurs above Facies 1a in well 7-20-53-18 and above Facies 1b between wells 7-18-53-18 and 10-1-53-19. Similar black mudstones facies probably occur immediately above the Gething in well 11-33-52-19 and just above the Gething (maximum gamma ray and minimum resistivity responses) in 7-5-53-19, where the facies can be seen in core. The correlation of TSE_{1b} was made possible by the distinctive shape of this "box" in the gamma ray logs. TSE_{1b} dips 0.28° southwestward and becomes co-planar with TSE_{1a} southwest of well 10-1-53-19 (Appendix C4).

The four parts of the overall sandier-upward mudstone succession (see description of Facies 1c, Chapter 3) are completely preserved only southwest of well 10-1-53-19, whereas from wells 10-1-53-19 to 7-20-53-18 only the two basal parts are preserved. The sandier-upward trend of these central estuarine mudstones is represented by the upward decrease of gamma-ray values from 105 API units at the base to 60 API units at the top and by the upward increase of resistivity values from 40 ohm-m at the base to 120 ohm-m at the top.

Bioturbated sandstones of Facies 1d - From well 10-1-52-19 northeastward, the bioturbated sandstones of Facies 1d overlie Facies 1c as far as well 7-20-53-18 and Facies 1b from well 6-21-53-18 northeastward. Facies 1d has been interpreted as transgressing estuarine-mouth sandstones. Its basal surface of erosion ($TSE1_c$) is represented by an abrupt increase of resistivity values and decrease of gamma-ray values. This log signal contrast is clearly evident at the northeastern end of the cross-section, where gamma-ray logs form a prominent spike with a value of about 50 API units (well 10-32-53-17). At the southwestern end, Facies 1d gamma-ray values increase to 70 API units. This lateral change indicates a southwestward decrease of sand content and is consistent with the interpretation of estuarine-mouth sandstones building up-estuary over the central estuarine mudstones.

4.4. Sandstone fills (Channels 2, 3, 4 and 5)

Channels 2, 3, 4 and 5 are characterized by fills which are dominantly sandstone, with mudstone facies preserved at their northeastern end (except for Channel 4 that is eroded by Channel 6; Fig. 33). Only the SW-NE cross-sections within Channels 2 and 5 are described (Appendix C5, C6, C9). From about T18 westward and southwestward, these channels are characterized by the distinct "blocky" log response of the fluvially dominated inner estuarine sandstones (Facies 2a and 5a). Their gamma-ray and resistivity values are about 35 API units and 200 ohm-m, respectively. The overall fining-upward and slightly muddier-upward trend of these facies is displayed in only a few log responses (e.g. wells 11-14-57-20 and 12-19-57-20, Appendix C6). In places, the channel bases (defined by TSE_2(SE2) and TSE_5(SE_5)) are floored by pebble lags. These lags are recognizable only in cores; their log responses are identical to those of sandstones.

Within the Channel 2 fill, the blocky sandstones of Facies 2a pass northeastward into the central estuarine mudstones of Facies 2b. This lateral transition is well displayed in well 10-5-54-17 (Appendix C5, C9) where a bell-shaped log response takes the place of the blocky responses of the wells to the southwest. This bell-shaped log signal is defined by the upward-increase of gamma-ray values from 35 API units at the base to 90 API units at the top. Northeast of well 10-5-54-17, the log response of Facies 2b is definitely muddier.

Within Channel 5 (7-23-57-18 and eastward, Appendix C6), mudstones (Facies 5b) sharply overlie the blocky sandstones of Facies 5a. No core control is available and the muddy nature of these rocks is inferred by the abrupt convergence of gamma-ray and resistivity log responses. The basal surface of these mudstones (Flooding Surface, FS_5) is not preserved in Channels 2 and 3 and it has probably been eroded by TSE_7 of the Transgressive Shoreface (Facies 7). A gradational surface separates the mudstones above the blocky sandstones of Channel 3 (see dashed line in wells 7-7-54-18 and 5-8-54-18, Appendix C7).

The lateral northeastward transition from sandstones to mudstones of Channel 2 (Appendix C5) was not observed in Channel 5, where the mudstones sharply overlie the sandstones (e.g. 10-10-57-17, Appendix C7). There may be a lateral transition from sandstones to mudstones east of well 11-15-57-16, beyond the study area.

4.5. Interbedded mudstone and sandstone fill (Channel 6)

This type of channel fill is characteristic of the two branches of Channel 6 and consists of a basal muddier-upward succession (Facies 6a) and an upper sandier-upward succession (Facies 6b), showing symmetrical resistivity and gamma ray log responses (e.g. wells 11-11-53-20 and 7-14-54-18). The basal surface of this channel, TSE_6 (SE_6), is always characterized by pebble lags. It is defined by sharp deflections in both the gamma ray and resistivity log responses (Appendix C7), particularly where Channel 6 erodes into the muddy fill of Channel 1 (cored well 13-6-54-18), Channel 2 (from wells 7-14-54-18 to 2-7-55-16) and Channel 3 (cored well 5-8-54-18). Facies 6a appears to be progressively muddier-northeastward (Appendix C7).

The upper sandier-upward succession (Facies 6b) is preserved at the southwestern end of the channel (from wells 11-11-53-20 to 3-12-54-19, Appendix C7), and it is inferred toward the northeast from log responses of wells 7-14-54-18 and 11-19-54-17. This sandier-upward log response appears to have been eroded by TSE_7 from wells 13-6-54-18 to 5-8-54-18, and in wells 7-28-54-17 and 2-7-55-16 (Appendix C7). The sandier-upward succession is interpreted to represent estuarine-mouth sandstones that built landward, up the incised valley. The mudstone tongue present in well 11-11-53-20 forms the upper part of the lower muddier-upward succession (Facies 6a), separates it from the upper sandier-upward succession (Facies 6b), and correlates northeastward with a transitional surface (dashed line, wells 14-14-53-20, 7-14-54-18 and 11-19-54-17, Appendix C7) that defines the limit between Facies 6a and Facies 6b.

CHAPTER 5: DISCUSSION, INTERPRETATION AND DEPOSITIONAL HISTORY

5.1. Discussion

5.1.1. Prograding Barrier or Estuarine Channels ?

The estuarine channel complex interpretation of the SW-NE trending Bluesky sedimentary bodies proposed in this thesis differs from the current idea of a prograding barrier (see Chapter 2 of this thesis). This new interpretation introduces a series of related scientific and economic questions, such as shoreline orientation, relative sea level changes, reservoir characteristics and associated depositional environment (discussed later) which involve not only the Edson study area, but also the adjacent Bluesky (or Glauconitic) deposits at Hoadley and Elmworth (Fig. 7).

5.1.2. Evidence supporting the estuarine channel interpretation

There are three main lines of evidence supporting the estuarine channel interpretation 1) the channellized nature of Bluesky deposit, 2) the facies, and 3) the longitudinal facies changes within the channel fills.

1. Channellized nature of the Bluesky - All the NW-SE log and core cross-sections (Fig 14; Appendix C1, C2, C3, C10) clearly indicate incisions into the Gething Formation and truncation of Gething well log markers (see discussion in Chapter 4). This channellized nature is also emphasized by the occurrence of parallel to sub-parallel markers above (Wilrich datum; top of the Bluesky deposits) and below (Gething markers) the Bluesky interval.

In the inter-channel areas (e.g. cored well 7-26-55-20), no Bluesky facies were observed, and the coastal plain sediments of the Gething Formation extend right up to the Transgressive Shoreface (Facies 7). Thus the Bluesky deposits appear to represent the filling of 6 nested incised valleys trending SW-NE (Fig. 13).

The presence of different superimposed channel fill facies (e.g. Facies 6a overlying Facies 1b and 3a, Appendix C1, C10) separated by sharp contacts with pebble lags (see base of Channel 6) also suggests different generations of superimposed channel fills.

2. Estuarine channel facies - In this channellized context, the three dominant channel fill types (described in Chapter 3) display lithological and biogenic characteristics compatible with an estuarine interpretation. The thinly interbedded sandstones and mudstones within Channel 6 (Facies 6a) are very similar to the bay head-delta facies interpreted in the Ricinus and Crystal estuaries (Reinson, 1988; Pattison, 1992; Pattison and Walker, 1994; Walker, 1995). In Crystal, particularly, this facies occurs at the geographic "bay head" end of the valley, and passes northward into central estuary mudstones, and thence into marine sandstones.

A very important aspect, common to all three channel fill types, is the highly stressed trace fauna observed. A limited number of trace fossils species, a general reduced size, and the dominance of specific traces of the Skolithos-Cruziana ichnofacies typically represent brackish-water deposits (Pemberton and Wightman, 1992).

3. Longitudinal channel fill facies changes - Longitudinal facies changes occur within Channels 2 and 3. This change was seen in cores within the channel 2 fill and is inferred from well log responses within Channel 3 fill (see description of Channels 2 and 3, Chapter 3). The sandstone-dominated southwestern facies (3a and 2a) gradually passes into the mudstones facies (3b and 2b) at the northeastern end of the channels. This transition is well displayed in core and log cross-sections (Appendix C5, C9) and is compatible with an estuarine channel interpretation with an inner, fluvially dominated estuarine bay-head delta gradually building into the quiet central estuarine mudstones (see next chapter for details).

5.1.3. Evidence against the prograding barrier interpretation

If the Bluesky sedimentary bodies at Edson formed a prograding barrier with a shoreline oriented SW-NE, typical shoreface sandstone facies should be present, grading seaward into marine mudstones. Neither of these facies was observed.

1. Absence of shoreface sandstones - Prograding shoreface sandstone bodies have been described in many parts of the Western Interior Seaway, and their sedimentological characteristics have been well established (Walker and Plint 1992). A typical vertical succession shows a coarsening-upward trend with storm-deposited SCS sandstones at the base, passing upward into trough cross-bedded sandstones of the upper shoreface longshore bars and troughs, flat-laminated sandstones representative of the beach, possibly with *in situ* root traces indicating final emergence (Walker and Plint, 1992). The bases of the shorefaces may be gradational (normal regression) or sharp (forced regression). Sand body geometries at Edson are not consistent with a progressive northwestward progradation.

2. Absence of shoreface to offshore marine mudstones - Marine mudstones commonly lie offshore from the sandy shoreface. In typical vertical transitions from offshore via shoreface to beach, mudstone facies occupy the basal offshore to lower shoreface portion and consist of fully marine bioturbated mudstones (MacEachern and Pemberton, 1992) interbedded with fine-grained HCS sandstones interpreted as storm-emplaced beds (Harms et al. 1975). No such mudstones exist at Edson, neither at the bases of sandier-upward successions, nor north of the sand bodies where an open marine setting is predicted by a shoreface interpretation.

3. Presence of incisions parallel to the sedimentary bodies - Marine mudstones were never observed north of the southernmost sand bodies (Channel 2). In contrast, a series of incisions also trending SW-NE and filled with different sedimentary facies were mapped (Channels 1 to 6, Fig. 13). These incisions trend perpendicular to tidal inlet predicted by the barrier interpretation (inlets would trend NW-SE).

4. Preservation of strips of Gething Formation - In several parts of the study area, north of the supposed shoreface/barrier sand bodies (Channel 2), coastal plain sediments of the Gething Formation were found (e.g. cores 16-2-54-19 and 7-26-55-20, Appendix C10; 13-10-56-18, Appendix C3; 8-32-56-19, Appendix C2; Fig. 13). This evidence is incompatible with an open marine setting, where a progressive northwestward deepening of the shelf profile is predicted, without preserved portions of Gething floodplain.

The evidence discussed above strongly suggest that the Bluesky at Edson was deposited as a series of six SW-NE trending channels filled by transgressive estuarine sediments. The channels are truncated by transgressive shoreface deposits.

In the following detailed interpretation, facies and geometries will be referred to estuary models (Dalrymple et al., 1992; Reinson, 1992). In the existing estuary models (Dalrymple et al., 1992; Reinson, 1992), wave-dominated estuaries commonly show well defined tripartite zonations that consist of: 1) marine estuarine-mouth sandstones, 2) mudstones or fine-grained sediments of the central estuary (turbidity maximum), and 3) estuary bay-head delta.

Turbidity maxima and associated central estuarine mudstones are generally not observed in tide-dominated estuaries (Dalrymple et al., 1992) where tidal energy penetrates along the length of the estuary and redistributes sediments.

In river-dominated estuaries (Cooper, 1993) central estuarine mudstones are also not observed.

The fact that 1) all the Bluesky channel fills are at least partially characterized by central basin mudstones (except in Channel 4 where they were probably eroded by Channel 6, Fig. 13), 2) the facies distributions within channels suggests bay head deltas passing down-channel into mudstones, and 3) there is no evidence of tidal currents suggests that the Bluesky estuaries were wave-dominated.

5.2. Detailed interpretation and depositional history of Bluesky deposits

5.2.1. First incision-filling event

The Bluesky has generally been regarded as a transgressive deposit. However, at Edson, the first Bluesky event was the incision of Channel 1, with a minimum depth of about 15 m (Appendix C4).

5.2.1.1. Fluvial incision (SE_1) and deposition

The deposition of the Gething coastal plain sediments was interrupted by a major drop of sea level. Erosional conditions began to be dominant and Gething coastal plain sediments at Edson were dissected by a single fluvial incision, forming SE_1 of Channel 1. The sediments eroded were probably transported to a shoreline northeast of the study area (Fig. 16).

The filling of Channel 1 started during the initial stage of a subsequent rise of relative sea level. The fU to mL cross-bedded sandstones observed in localized areas of the channel base (Appendix C4) are interpreted as fluvial longitudinal sand bars (Fig. 46a). Both two and three-dimensional dune bedforms were migrating and depositing in some portion of the channel, while erosion was probably still active in other parts. The monotonous vertical facies distribution is probably indicative of steady sediment supply and water depth during bedform aggradation (Miall, 1992). The absence of bioturbation suggests fresh-water conditions.

5.2.1.2. Flooding stage (TSE_{1a})

Continuing transgression caused flooding of Channel 1 and cut off fluvial sediment input. Quiet conditions allowed mud deposition in the sandier-upward mudstone succession (Facies 1b, Appendix C4; Fig. 46b). The sharp contact between the cross bedded sandstones of Facies 1a and the mudstones of Facies 1b (Appendix C4) is considered to define TSE_{1a} (also observed in core 10-32-53-17). This TSE planed-off the tops of the fluvial sand bars (Facies 1a) and probably reworked the base of the channel (southwest of well 7-13-53-19, Appendix C4), becoming co-planar with SE_1 (Fig. 46b). Its apparent upstream dip (0.38°) is due to the assumption of an horizontal datum (see discussion in Chapter 4).

Wave-winnowing at the channel-mouth probably formed a subaerial barrier or a submerged bar which prevented most of the wave energy from

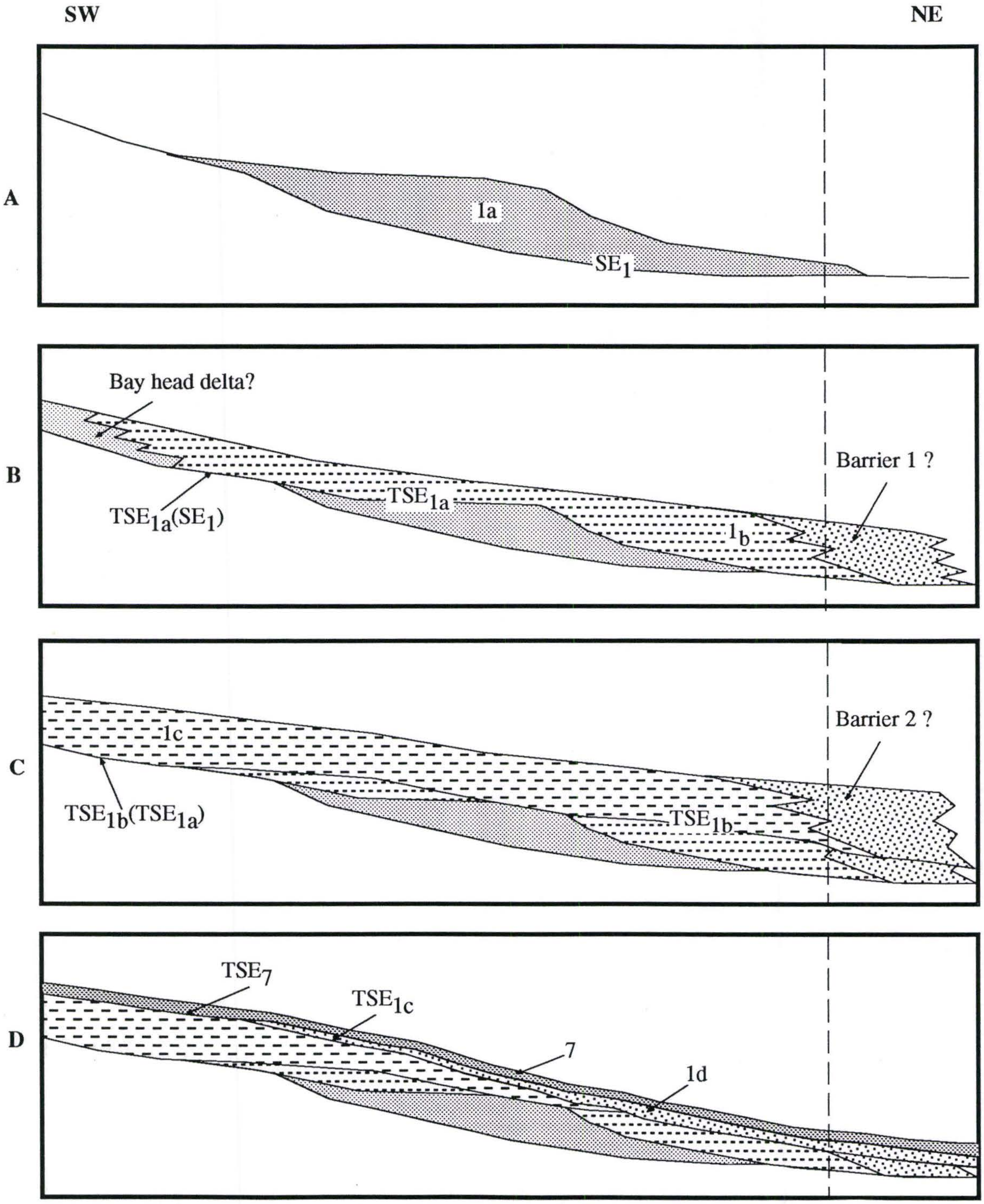


Fig. 46. Schematic depositional evolution of Channel 1. A) Fluvial incision (SE_1) and sand bars deposition of Facies 1a; B) transgression (TSE_{1a}) and deposition of Facies 1b; C) continued transgression (TSE_{1b}) and deposition of Facies 1c; D) continued transgression (TSE_{1c}), deposition of Facies 1d, final transgression (TSE_7) and deposition of Facies 7. Vertical dashed line is the eastward limit of the study area.

entering the channel (Dalrymple et al., 1992). An estuarine tripartite zonation was probably established and the central basin mudstones of Facies 1b were deposited. The restricted trace fauna of Facies 1b is dominated by *Planolites*, indicating brackish-water conditions (Beynon and Pemberton, 1992). Trace fossil diversity does not increase upward. However, the sandier-upward trend observed (e.g. wells 7-18-53-18 and 6-21-53-18, Appendix C4) is probably the result of a continuing transgression that caused an increase of the amount of sand supplied from the seaward end of the estuary.

5.2.1.3. Transgression (TSE_{1b} (SE_1))

In Appendix C4 and C8, Facies 1c overlies Facies 1a and 1b; it also directly overlies sediments of the Gething Formation. Its basal surface (TSE_{1b}) is characterized by structureless sandstones, mud clasts, one chert pebble (core 7-20- 53-18, top of the sand bar) and coarse sand grains (core 7-5-53-19, Fig. 17). A new pulse in the transgression probably caused scouring in the upper part of Facies 1b and again 1a (core 7-20-53-18; Appendix C4), and southwest of T53-52, R19 (Appendix C4, C8). The base of Channel 1 was again reworked. TSE_{1b} became co-planar with TSE_{1a} and with the original fluvial incision SE_1 (named $TSE_{1b}(TSE_{1a})$ in Appendix C4, C8 and Fig. 47c; Ainsworth and Walker, 1994). Similar to TSE1a, TSE_{1b} has an apparent landward dip of 0.28° (Fig. 46c). The structureless sandstones, mud clasts and the one chert pebble are interpreted as lag material produced by reworking during the transgression, with coarser material being introduced from the open end of the estuary.

With continued deepening, limited fluvial input and the probable formation of a new barrier at the seaward end of the estuary, a large central basin area developed in which the deposition of the black mudstones took place (dashed line in Appendix C4, C8). These pure black mudstones (seen in cores 7-5-53-19 and 7-20-53-18) are preserved from T53 R19 to T52 R20 (Fig. 16 and Appendix C4, C8) and indicate a minimum preserved length of about 20 km for the central estuarine mudstones. The two superimposed sandier-upward mudstone successions reflect continuing transgression and the influence of landward migration of the estuarine-mouth sandstones over the central estuarine mudstones. The break between the two successions is characterized by a thin horizon of granules, pebbles and plant fragments (core 7-5-53-19, Appendix C8) probably introduced from the seaward end of the estuary. The beginning of a new sandier-upward succession suggests a pulse of fluvial flooding producing a slight seaward shift of the central estuarine mudstones, during the overall transgression.

The upward-increase in trace fossil diversity and the occurrence of more marine species (*Asterosoma, Rosselia, Helminthopsis, Terebellina*) is consistent with overall transgression.

The final muddier-upward succession visible in some of the log responses (Appendix C4) can be explained by a more gradual seaward shift of the central estuarine mudstones, possibly due to increased river flow.

5.2.1.4. Continuing transgression (TSE_{1c})

Facies 1b and 1c are overlain by the bioturbated sandstones of Facies 1d. The bioturbation suggests estuary mouth rather than bay head-delta environments, and Facies 1d therefore indicates continued transgression, with migration of estuary mouth sandstones facies up the estuary.

Generally, the marine sand body of wave-dominated estuaries consists of flood-tidal delta facies (Dalrymple et al., 1992). Except for a few sets of flat laminations, Facies 1d is thoroughly bioturbated and most of the original sedimentary structures have been destroyed. The strong bioturbation probably occurred at times of reduced tidal-current velocities (Nichols, 1991). The landward backstepping is indicated by the upward decrease of mudstone (observed in cores) and by the southwestward decrease in mudstones displayed by the progressively less pronounced kicks in the gamma ray and resistivity log responses (Appendix C4). The high diversity of trace fossils of the Cruziana and Skolithos assemblage is consistent with the higher salinity of the outer portion of an estuary.

Facies 1d sharply overlies Facies 1b at the northeastern end, and Facies 1c at the southwestern end of Channel 1 (Appendix C4, C8). The erosive nature of TSE_{1c} is suggested by the presence of mud clasts and chert pebbles (core 6-21-53-18). Farther southwestward, TSE_{1c} rests on the upper part of Facies 1b, TSE_{1b}(TSE_{1a}), and the upper part of Facies 1c (Appendix C4, C8, Fig. 46d). In T53 R18 it was subsequently eroded by the Transgressive Shoreface (discussed below). Tidal energy and erosive power were probably decreasing southwestward. A similar scenario is described by Boyd and Honig (1992) in the Lawrencetown Lake estuary of Nova Scotia.

5.2.2. Second incision-filling event

During this second event four active fluvial channels (2, 3, 4, and 5; Fig. 18) were formed and back-filled with estuarine sandstones in their southwestern and central portions, and with estuarine mudstones in their northeastern ends.

5.2.2.1. Fluvial incisions (SE_2, SE_3, SE_4 and SE_5)

After the partial or total filling of estuarine Channel 1, a second major fall of relative sea level occurred. The top of the Channel 1 fill was subaereally exposed, and partly removed by new fluvial erosion. Four active SW-NE trending fluvial channels, either separate or part of a branching river, cut into the Channel 1 fill and the Gething sediments of the study area and probably fed a shoreface located northeast of the study area.

5.2.2.2. Transgression and channel base reworking ($TSE_2(SE_2)$, TSE_3 (SE_3),TSE_4 (SE_4), TSE_5 (SE_5))

After incision, sea level started to rise again and the bases of the channels were rapidly inundated by sea water. Wave scouring probably modified the original fluvial incisions (SEs), reworking any evidence of fluvial sedimentation. Wave scouring at the channel bases and reworking of possible fluvial sediments are suggested by the following evidence: 1) presence of basal lags of chert pebbles and shell fragments in several places immediately above the channel bases and 2) presence of a few *Glossifungites* traces (*Thalassinoides* in Channel 3 and 5, *Skolithos* in Channel 5) at the channel bases.

Chert pebbles up to 2 cm diameter are common, particularly at the bases of Channels 3, 4, and 5. They have been found as far west as R 20 (Fig. 18, Channel 5). In the cored interval penetrating the Gething Formation, chert pebbles have never been observed, and the source of the pebbles was probably from the marine end of the estuary (Walker, 1995). If a hypothetical shoreline were located at the eastward end of the study area, the pebbles would have to be transported landward by waves or tide- generated currents for over 40 km.

Bivalve shells reworked as lag deposits are more commonly observed in the northeastern part of the channels (e.g. core 11-15-54-17, Fig. 21).

The Glossifungites ichnofacies is a substrate-controlled assemblage of trace fossils excavated into semiconsolidated (firmground) substrates. It reflects pauses in sedimentation commonly accompanied by erosion (MacEachern et al., 1992). This type of bioturbation has been observed exclusively in marine or marginal marine settings and supports the interpretation of sea water flooding over the original fluvial incision, development of the Glossifungites assemblage on a scoured firmground surface, and their burial by deposition of sand.

5.2.2.3. Estuarine filling: sandstone (Facies 2a, 3a, 4, 5a)

Continuing transgression and wave-winnowing at the mouths of the channels probably formed partial sand-barriers at the wave-dominated estuary mouth. At that time, the four fluvial channels probably evolved into estuaries with tripartite zonations (Dalrymple et al., 1992; Reinson, 1992). In the study area, estuarine sediments of the sand-dominated inner bay-head delta (Facies 2a, 3a, 4, and 5a) were observed in the southwestern and central parts of Channels 2 and 3 and throughout Channels 4 and 5 (Fig. 18). A large amount of sand was supplied from the fluvial end. The commonly observed overall fining upward trends of cross-bedded and flat-laminated sandstones suggest channel filling. Two- and three-dimensional dune bedforms migrated and aggraded, forming sand bars and sand flats. Flat-laminations reflect periods of upper-flow regime conditions. The subtle fining-upward successions are compatible with fluvial flooding and sand bar reincision and filling. The millimetre-scale mud partings, normally interbedded with the laminated sandstones sets, represent pauses in fluvial flooding activity, mud deposition and preservation from the erosion of the subsequent flooding. In general, angle of repose cross-bedded sandstones are dominant in the lower part of the succession, whereas flat-lamination is more common in the upper part (core

3-24-57-19). The cross-bedding represents sedimentation by dunes in the deeper part of the channel (Flach and Mossop, 1985), whereas upper flow regime conditions more likely occurred as the channels were filling with sediments and water depth was decreasing. The presence of decimetre-scale angular clasts indicates lateral erosion of the muddy channel walls, collapse, and rapid burial. Within the sandstones, glauconitic grains can be found, mainly in the upper part of the successions. Glauconite is believed to be formed by quiet deposition in a distal offshore environment and its presence within channels indicates introduction from the open end of the estuary. Its presence within the fluvially-dominated inner estuary sandstone, many km "up-estuary", remains an unsolved problem.

Some sandstones show a completely structureless aspect up to 10 m thick without breaks (Channel 5) and with almost no vertical grain size variation. Most of the laminated sandstones display diffuse structures and can show any stage in the transition from structureless to a poorly defined structure (Fig. 24, 25). The completely or partially structureless aspect is here interpreted as being due to cryptobioturbation (Cullen, 1973; Saunders et al., 1994). The alternative interpretation of rapid deposition from suspension is considered less probable. Cryptobioturbation can be abundant in estuarine valleys and is produced by meiofauna such as *nematodes*, *gammaridean amphiopods*, *Copepods* and juveniles of the *Macaronichnus* tracemakers (J.A. MacEachern, pers. com., 1996).

The trace fossil assemblage is poorly developed and limited to the Skolithos Ichnofacies. With the exception of the Channel 5 fill, the few species observed are concentrated exclusively in the upper part of the successions and are absent in the lower parts. This evidence and the slight muddier-upward trend observed in some cores suggest an increase in water salinity, and hence deposition under transgressive conditions.

The presence of trace fossils and glauconite grains in the lower part of Channel 5 is indicative of more marine water than in Channels 2, 3, and 4.

Similar inner estuarine sandstones have been described by several authors (Flach and Mossop, 1985; Reinson et al., 1988; Pattison and Walker, 1994; Allen, 1991; Nichols, 1991)

5.2.2.4. Estuary filling: mudstones (Facies 2b, 3b, 5b)

While sand was deposited in the inner bay-head delta, quiet mud deposition occurred to the northeast, in the central estuarine turbidity maximum.

Channel 2 best displays the sand-mud lateral transition (see core 10-5-54-17 and 11-15-54-17; Appendix C5, C9). The basal part of core 11-15-54-17 is characterized by thinly interbedded mudstones and sandstones showing fining- and muddier-upward trends. This facies is interpreted as the distal part of the bay-head delta, and is similar to the bay head-delta facies at Crystal (Pattison and Walker, 1994; Reinson et al., 1988). It is overlain by landward-migrating central estuarine mudstones. Continuing transgression probably caused farther headward shifting of the central estuarine mudstone resulting in mud deposition over the inner bay-head delta sandstones. However this mud was preserved only in localized lower areas (T54, R18, Fig. 18; core 5-8-54-18, Appendix 7); elsewhere, it was eroded by the Transgressive Shoreface (discussed later).

The lateral sand-mud transition observed in Channel 2 is not present in Channel 5, where the mudstone (Facies 5b) sharply overlies the sandstones (Facies 5a) and rests on a flooding surface (FS_5, Appendix 6). A lateral transition possibly exists farther eastward, beyond the study area.

The trace fossils of the central estuarine mudstones are represented by a limited number of species of the Cruziana Ichnofacies, suggesting a stressed environment.

5.2.3. Third incision forming event

During this event, the branching Channel 6 was formed during a relative sea level fall (Fig. 33); it was subsequently filled with the estuarine sediments of facies 6a and 6b.

5.2.3.1. Fluvial incision and channel base reworking (TSE_6(SE_6))

After the partial or total filling of Channels 2, 3, 4, and 5, there was another major drop of relative sea level, leaving the study area subaereally exposed. Fluvial incision took place, and the SW-NE trending branches of Channel 6 (Fig. 33) were formed. All of the previous estuarine fills, as well as the sediments of the

Gething Formation were incised by Channel 6. A new shoreface was probably fed somewhere northeastward, beyond of the study area.

Fluvial deposits probably formed during this time, but they are not preserved, probably because of extensive reworking during the subsequent transgression. The floor of the incised valley was reworked into a TSE ($TSE_6(SE_6)$, Appendix 7) representing a transgressively modified sequence boundary (Walker, 1992).

The base of Channel 6 is characterized by abundant chert pebbles, glauconite grains (Fig. 34 and 35) and Glossifungites traces (*Thalassinoides, Arenicolites, and Skolithos*). Pebbles and glauconite grains were probably introduced by storms from the marine open end of the estuary during modification of the valley floor.

The Glossifungites ichnofacies is typical of firmground substrates The firmground surface formed at the base of Channel 6 was colonized by trace-maker organisms during transgression (Pemberton et al., 1992).

5.2.3.2. Estuary filling: initial deposition (Facies 6a)

Continuing sea-level rise caused flooding of the estuary and sand barriers probably formed at the mouth of Channel 6. Wave-energy within the estuary was reduced and the sediments supplied by the river started to build a bay-head delta over the quiet central estuarine mudstones (Dalrymple et al., 1992).

The basal part of the Channel 6 fill (Facies 6a) consists of a muddier-upward succession of interbedded mudstones and sandstones. Sandstone beds show a clear thinning-upward trend and are generally flat or ripple cross-laminated. In places, mainly in the southwestern part of the channel fill (core 11-11-53-20), the basal thicker sandstone beds (up to 25 cm thick) display large scale cross-bedding and resemble the sand-dominated inner bay-head delta of facies 2a, 3a,4, and 5a. Better developed inner bay-head delta facies are probably preserved farther southwestward, beyond the study area.

The muddier-upward trend of Facies 6a is progressively more pronounced northeastward (Appendix 7) suggesting that central estuary mudstones were probably deposited at this time, but beyond the study area.

The trace fossil assemblage of Facies 6a shows all of the typical characteristics of brackish-water deposits: 1) a relatively low diversity of species, 2) forms typically found in marine environments but with reduced sizes, and 3) horizontal and vertical traces of the Skolithos and Cruziana Ichnofacies (Pemberton and Wightman, 1992). Bioturbation and trace diversity increase upward.

The sedimentological and ichnological character of Facies 6a is indicative of distal bay-head delta deposits. These sediments have been described in estuarine environments by several authors (Reinson et al., 1988; Pattison, 1992; Boreen and Walker, 1991; Walker, 1995; Pattison and Walker, 1994, Allen, 1991). The adjective “distal” is here used to differentiate them from the landward sandier correlative “inner” bay-head delta (Facies 2a, 3a, 4 and 5a).

5.2.3.3. Estuary filling: upper deposits (Facies 6b)

With continued transgression wave and tidal currents appear to have driven the estuarine-mouth sandstones landward up the estuary. Sea level rise created new accommodation space, and the consequent landward shift of facies changed the muddier-upward succession into a sandier-upward succession (Facies 6b). Facies 6b also coarsens-upward (pebbles up to 0.5 cm were observed in the upper part) and shows a less distinct mud/sand interbedding than Facies 6a. Pebbles were probably introduced by storms or stronger tidal-currents from the advancing marine end of the estuary; the less pronounced interbedding reflects the higher degree of sediment reworking by bioturbation.

Facies 6b has a gradational contact with the underlying Facies 6a (dashed line, Appendix C7).

The upward increase of species displayed by the restricted trace fossil assemblage (mainly Skolithos ichnofacies) of Facies 6b is consistent with the interpreted transgressive conditions.

While the sandstones were migrating headward, farther up-estuary (part of R20 T53) quiet deposition of central estuarine mudstones occurred and pure black mudstones were deposited (core 11-11-53-20, Fig. 37; Appendix C7). The superimposition of a sandier-upward succession over these black mudstones in core 11-11-53-20 suggests a sea-level rise with creation of new accommodation space and continued up-estuary migration of the flood-tidal delta.

The symmetrical trend (basal muddier-upward and upper sandier-upward) formed is typical of the evolution of wave-dominated estuaries under transgressive conditions (Pattison, 1992; Dalrymple et al., 1992; Reinson, 1992).

5.2.3.4. Preservation of a Transgressive System Tract and Transgressive Shoreface deposition

Transgressive Surface of Erosion (TSE_7) - After channel 6 had been filled transgressively, the shoreface that originally presumably lay at the northeastern end of the channel, beyond the study area, continued to move southwestward. This formed a TSE (TSE_7, Fig. 40, 41). During the passage of the shoreface, some part of the estuary fills was removed by wave erosion, possibly as much as 5 to 15 m of sediment (Walker and Eyles, 1991). The upper portion of the Channel 6 estuarine deposits and the subaereally exposed Gething were truncated by TSE_7. The degree of preservation of estuarine deposits depends upon the amount of erosional shoreface retreat versus rate of inundation (Reinson, 1992). A slow sea level rise and a high rate of landward erosion will result in destruction of most of the estuarine system. The preservation of the Bluesky transgressive system tract is indicative of erosional retreat accompanied by significant sea level rise.

The extensive localized erosion of Facies 6b (Appendix C7) suggests that in detail TSE_7 forms an irregular surface due to variation in the rate of sea-level rise during transgression.

The chert pebbles that overlie TSE7 represent lag material formed during transgression. The abundance of Glossifungites traces is typical of firmground surfaces. Stiff substrates are generally created by erosional exhumation, and siderite cemented portions are also common (MacEachern et al., 1992). The firmground surface was colonized by trace-making organisms and their burrows were passively filled during the deposition of the next unit.

Transgressive shoreface deposition (Facies 7) - Extensive transgression across the entire study area allowed the deposition of the sheet-like deposits of Facies 7. The coarse nature of these marine bioturbated sandstones, the partial preservation of cross-bedding, and their context overlying a TSE suggest deposition in a shoreface setting and reworking during transgression (Boreen and Walker, 1991). Mud, silt and very-fine grained sand were more likely washed out onto the shelf.

The fining- and muddier-upward succession of interbedded bioturbated mudstones and HCS sandstones observed in core 11-11-53-20 are indicative of slow transgressive phases which allowed the local development of storm-dominated offshore settings.

The marine character of the trace fossils observed and the presence of abundant glauconite support the interpretation of the establishment of fully marine conditions.

5.2.4. Maximum Flooding Surface (MxFS) and establishment of a Highstand System Tract

The overlying Wilrich mudstones are generally characterized by a sharp basal contact with common sideritization. Above this contact there is a sandier-upward trend for about the first 25 m (see all well log responses and core 6-28-53-18 as e.g.). Fining-upward transgressive mudstones were never observed. The sandier-upward succession is indicative of progradational distal offshore sediments probably deposited during sea level highstand. The basal surface of the Wilrich Member is therefore interpreted as a Maximum Flooding Surface (MxFS) separating the transgressive from the highstand system tract (Walker, 1992).

CHAPTER 6: DEPOSITIONAL CONTROL OF BLUESKY DEPOSITS

The three incision-filling events interpreted to control Bluesky channel fill deposition appear to be controlled by fluctuations of relative sea level.

Changes of relative sea level (RSL) depend on both global and local controls and include the interplay of eustasy, local tectonics and sedimentation rate (Plint et al., 1992). From the sedimentary record, it is only possible to infer variations in water depth, and it is generally very difficult to isolate these three controlling factors and determine their influence on RSL fluctuations. As the influence of tectonics and eustasy probably work on different time scales, a rough estimate of the absolute time duration of each RSL cycle is one general way to speculate on the effects of eustasy, tectonic, and sedimentation rate.

6.1. Temporal scale of RSL changes for Bluesky deposits

The foraminiferal zonation of Caldwell et al. (1993, p. 492) places the Bluesky Formation in the *Trochammina mcmurrayensis* subzone (Lower Albian). This subzone cannot be dated precisely as no ammonites have been found, but it is believed to correspond to the *Lemuroceras cf. indicum* subzone of the Albian molluscan biostratigraphy (Caldwell et al., 1978). Based on radiometric dating of the Upper Aptian-Middle Albian interval, Kauffman et al. (1993; p. 409) give an equal time duration of about 650,000 years to the Lower Albian biozones (the *Lemuroceras* subzone is included). If the correlations of Caldwell et al. (1993) and Caldwell et al. (1978) stated above are correct, the temporal scale for the deposition of Bluesky interval will be about 650,000 years. As there is no way of determining the exact duration of each cycle, an equal time duration is assumed for each of the three Bluesky cycles, about 216,660 years. This probably corresponds to the fourth-order cycles of Van Wagoner et al. (1990) and Plint et al. (1992).

6.2. Possible Controls

In the following text, possible eustatic and/or tectonic controls of the Bluesky deposition at Edson are briefly discussed.

The sedimentation rate is not considered a possible control in the context of an estuarine channel system if base level is not rising within the channel. In fact, sedimentation affects sea-level by sea floor aggradation and reduction in water depth (Plint et al., 1992).

Autocyclic mechanisms such as channel switching are also excluded at Edson. If the 6 Bluesky channels were created by switching of a single river, the abandoned valley would probably be filled with mudstones with no evidence of marine bioturbation. The only way to fill a channel with estuarine sediments is probably by a rise of RSL.

6.2.1. Eustatic controls

Eustatic (or global) sea level fluctuations basically depend on three main factors: 1) volume changes of oceanic spreading centers, 2) growth and decay of continental ice sheets, and 3) changes in the volume of groundwater storage (refer to Plint et al., 1992 for details).

The controls of the 5 order of cycles of Van Wagoner et al. (1990) and Plint et al. (1992) depend largely on the time scale of the cycles. The first and the second order cycles (200-400 my and 10-100 my, respectively) are both related to volume changes of oceanic spreading ridges.

Third order cycles (1-5 or 1-10 my.) have problematic and controversial controlling factors that are reviewed by Plint et al. (1992). The third-order cycles defined in the Phanerozoic sea level curves published by Haq et al. (1988) are considered to be controlled by eustatic mechanisms. However, assuming that this is correct, the fourth-order cycles of Bluesky deposits at Edson have a frequency one order of magnitude higher than the Haq curves. The easiest way to explain fourth and fifth-order cyclicity is by Milankovitch cycles. These reflect cyclical variations of incoming solar radiation which in turn may affect either the growth and decay of glacial ice sheets or the variation of groundwater storage (Plint et al., 1992). The Milankovitch-induced glacio-eustatic sea level variations are debatable, because during the Cretaceous there is very limited evidence of glacial features (Frakes and Francis, 1988, in Wadsworth and Walker, 1991). The climatically-induced groundwater storage variations may be a possible candidate for a controlling-factor.

6.2.2. Local tectonic controls

Possible local tectonic controls of RSL in the Alberta Foreland Basin are probably directly associated with thrusting and loading of the Cordillera to the west. During periods of active thrusting, crustal loading and associated subsidence created a rise of RSL. At times of less active thrusting, there would be reduced subsidence, erosion of the Cordillera, and fall of RSL due to basin infilling.

Wadsworth and Walker (1991) suggested that the 300,000-350,000 years cyclicity of their Cardium cycles was too rapid for tectonic mechanisms. If their suggestion is valid, it would be even more difficult to explain tectonically the 216,660 year Bluesky cyclicity.

6.3. Sea level control conclusions

The above discussion is highly speculative and deals very briefly with the possible mechanisms controlling relative sea level changes during the deposition of Bluesky sediments. Groundwater storage variations due to Milankovitch cyclicity is possible and local tectonic mechanisms can not be totally excluded. The combined effect resulting from the interplay of the two mechanisms has also to be taken into account. However, no definite answer seems possible at this time.

CHAPTER 7: CONCLUSIONS

1. The Bluesky at Edson consists of a complex of six incised channels trending SW-NE. The channels cut into the underlying continental sediments of the Gething Formation and are about 50-60 km long, 15-20 m deep and 5-10 km wide.

2. The six channels are filled with three main types of facies: 1) the Channel 1 fill mainly consists of mudstones and contains a few basal sandstones bodies; 2) Channels 2, 3, 4 and 5 are mainly filled with sandstones; 3) Channel 6 is filled with interbedded sandstones and mudstones. A lateral northeastward transition from sandstones to mudstones occurs in Channels 2 and 3. The three main types of channel fills are characterized by a stressed trace fossil assemblage that show an upward increase in species diversity and density. The entire study area is capped by transgressive shoreface sandstones.

3. There is no evidence of shoreface sandstones or offshore mudstones facies in the SW-NE oriented sedimentary bodies.

4. The SW-NE channel trends, perpendicular to the Cordillera to the southwest, suggest SE-NW oriented shorelines, with the open sea to the NE.

5. The six channels are interpreted as lowstand incisions formed by rivers. During subsequent transgressions, channel bases were generally extensively modified and fluvial sediments reworked (except for the basal sand bodies of Channel 1, which are interpreted as fluvial sand bars preserved from reworking). Continued transgression allowed the channels to be filled with estuarine sediments and eventually, the entire study area was transgressed and capped by the Transgressive Shoreface.

6. The three different types of filling and the relationship between channels suggest three incision-filling events (A, B, C in Fig. 47, representing three cycles (fall/rise) of RSL change. Bluesky deposition did not occur during a single transgression.

7. The time-duration of these three sea level fluctuations has been estimated to be approximately 216,660 years, corresponding with fourth-order cycles.

8. Milankovitch cyclicity and/or local tectonics may have controlled the relative sea level fluctuations. However, these possible controlling mechanisms remain highly speculative.

9. The SE-NW shorelines implied by the new Bluesky estuary interpretation at Edson are difficult to relate to the SW-NE shorelines of the adjacent Hoadley and Elmworth Bluesky shorefaces. The relationship between Bluesky deposits at Edson, Hoadley and Elmworth remains problematic.

10. The bounding discontinuities, implying 3 RSL changes, may be a way of achieving a correlation with a similar succession of key surfaces at Hoadley and Elmworth.

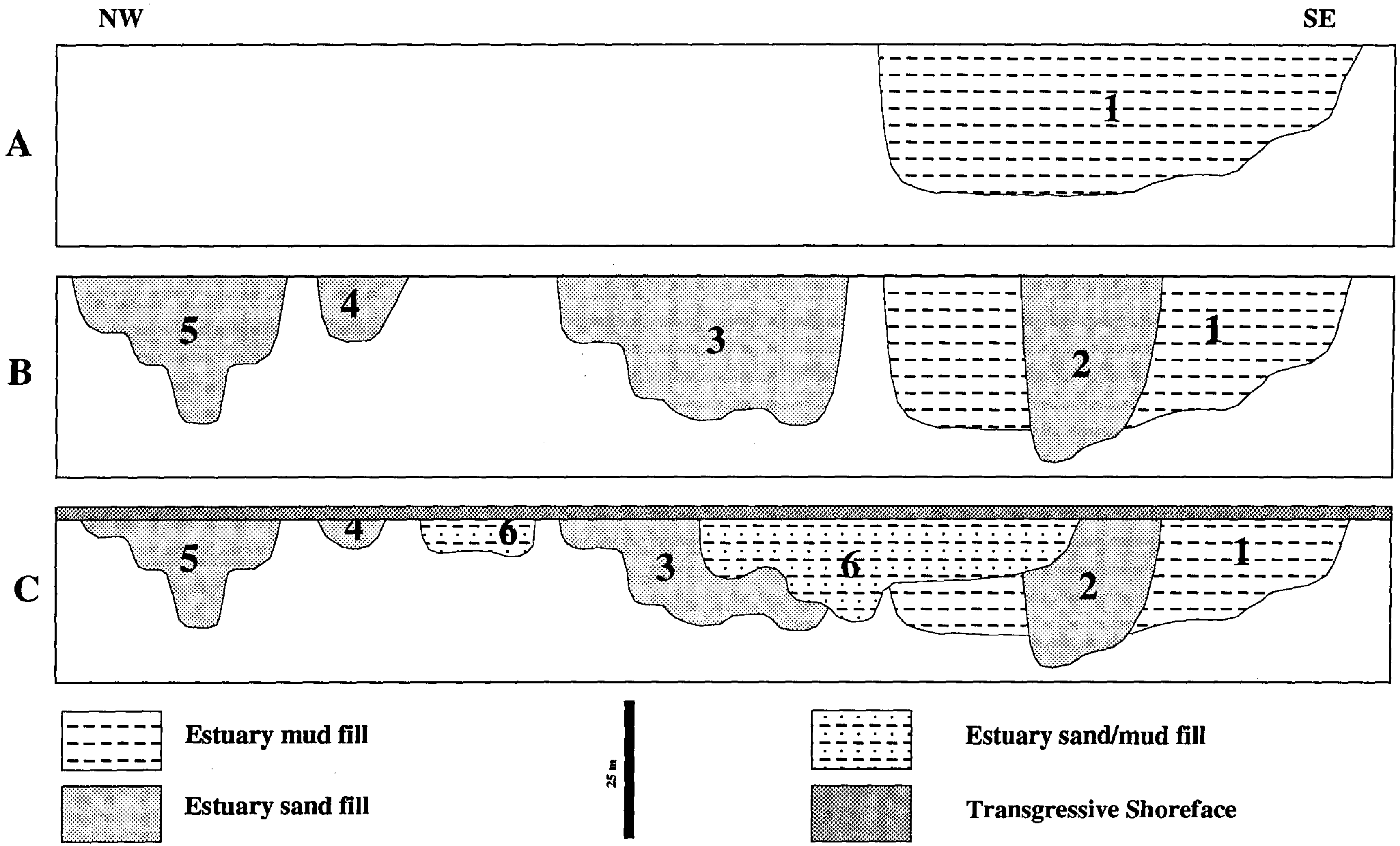


Fig. 47. Summary depositional evolution of the Bluesky deposits at Edson. A, B, C are the three incision-filling events (see text for details). Horizontal scale is not implied.

REFERENCES

Ainsworth, R.B and Walker, R.G., 1994. Control of estuarine valley-fill deposition by fluctuation of relative sea-level, Cretaceous Bearpaw-Horseshoe Canyon Transition, Drumheller, Alberta, Canada. In: Dalrymple, R.G., Zaitlin, B.A. and Boyd, R., eds., Incised-valley systems: Origin and Sedimentary Sequences. Society of Economic Paleontologists and Mineralogists, Special Publications 51, p. 159-174.

Alberta Study Group, 1954. Lower Cretaceous of the Peace River Region. In Clark, L.M. ed., Western Canada Sedimentary Basin, Rutherford Memorial Volume. American Association of Petroleum Geologists, p.268-278.

Allen, G.P., 1991. Sedimentary processes and facies in the Gironde estuary; a recent model for macrotidal estuarine systems. In: Smith, D.G., Reinson, G., Zaitlin, B. and Rahmani, R.A., eds., Clastic Tidal Sedimentology. Canadian Society of Petroleum Geologists, Memoir 16, p. 29-39.

Beynon, B.M. and Pemberton, S.G., 1992. Ichnological signature of a brackish water deposit: an example from the Lower Cretaceous Grand Rapids Formation, Cold Lake oil sands area, Alberta. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 199-222.

Boreen, T.D. and Walker, R.G., 1991. Definition of allomembers and their facies assemblages in the Viking Formation, Willesden Green area, Alberta. Bulletin of Canadian Petroleum Geology, vol. 39, p. 123-144.

Boyd, R. and Honig, C., 1992. Estuarine sedimentation on the eastern shore of Nova Scotia. Journal of Sedimentary Petrology, v. 62, p. 569-583.

Brekke, H.G. and Pemberton, S.G., 1994. Paleoenvironmental reconstruction of the Bluesky Formation in the Sinclair Field, west-central Alberta: an integrated ichnological and sedimentological approach. In: Pemberton, S.G., James, D.P, and Wightman, D.M. Mannville core conference. Canadian Society of Petroleum Geologists, p. 57-71..

Caldwell, W.G.E., Diner, R., Eicher, D.L., Fowler, S.P., North, B.R., Stelck, C.R. and von H. Wilhelm, L., 1993. Foraminiferal biostratigraphy of Cretaceous marine cyclothems. In: Caldwell, W.G.E. and Kauffman, E.G., eds., Evolution of the Western Interior Basin: Geological Association of Canada, Special Paper 39, p. 477-520.

Caldwell, W.G.E., North, B.R., Stelck, C.R. and Wall, J.H., 1978. A foraminiferal zonal scheme for the Cretaceous system in the interior plains of Canada. In: Stelck, C.R. and Chatterton, D.E., eds., Western and Artic Canadian Biostratigraphy. Geological Association of Canada, Special Paper 18, p. 497-575.

Cant, D. and O'Connell, S., 1988. The Peace River Arch: its structure and origin. In: James, D.P., and Leckie, D.A., eds., Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. Canadian Society of Petroleum Geologists, Memoir 15, p. 537-542.

Chiang, K.K., 1984. The giant Hoadley gas field, south-central Alberta. In: Masters, J.A. ed., Elmworth - Case Study of a Deep Basin Gas Field. American Association of Petroleum Geologists, Memoir 38, p.297-315.

Cooper, J.A.G., 1993. Sedimentation in a river dominated estuary. Sedimentology, v. 40, p. 979-1017.

Cullen, D.J., 1973. Bioturbation of superficial marine sediments by interstitial Meiobenthos. Nature, v. 242, p. 223-324.

Dalrymple, R.W., Knight, R.J., Zaitlin, B.A. and Middleton, G.V., 1990. Dynamic and facies model of a microtidal sand-bar complex, Cobequid Bay-Salmon River Estuary (Bay of Fundy). Sedimentology, v. 37, p. 577-612.

Dalrymple, R.W., Zaitlin, B.A. and Boyd, R., 1992. Estuarine facies models: conceptual basis and stratigraphic implications. Journal of Sedimentary Petrology, v. 62, p. 1130-1146.

Flach, P.D. and Mossop, G.D., 1985. Depositional environments of Lower Cretaceous McMurray Formation, Athabasca oil sands, Alberta. American Association of Petroleum Geologists Bulletin. v. 69, p. 1195-1207.

Haq, B.U., Hardenbol, J. and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. In: Wilgus, C.K., Hastings, B.S., Kendal, C.G.St.C., Posamentier, C.A., Ross, C.A. and Van Wagoner, J.C., eds., Sea-level changes - An Integrated Approach. Society of Economic Paleontologists and Mineralogists, Special Publication 42, p. 71-108.

Harms, J.C., Southard, J.B., Spearing, D.R. and Walker, R.G., 1975. Depositional environments as interpreted from primary sedimentary structures and stratification sequences. Society of Economic Paleontologists and Mineralogists, Short Course 2, 161p.

Jackson, P.C., 1984. Paleogeography of the Lower Cretaceous Mannville Group of western Canada. In: Masters, J.A., ed., Elmworth - Case Study of a Deep

Basin Gas Field. American Association of Petroleum Geologists, Memoir 38, p. 49-79.

Kauffman, E.G., Sageman, B.B., Kirkland, J.I., Elder, W.P., Harries, P.J. and Villamil, T., 1993. Moluscan biostratigraphy of the Cretaceous Western Interior Basin, North America. In: Caldwell, W.G.E. and Kauffman, E.G., eds., Evolution of the Western Interior Basin: Geological Association of Canada, Special Paper 39, p. 397-434.

MacEachern, J.A. and Pemberton, S.G., 1992. Ichnological aspects of Cretaceous shoreface successions and shoreface variability in the Western Interior Seaway of North America. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p.57-84.

MacEachern, J.A., Raychaudhuri, I. and Pemberton, S.G., 1992. Stratigraphic applications of the *Glossifungites* ichnofacies: delineating discontinuities in the rock record. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 169-198.

Male, W.H., 1992. The sedimentology and ichnology of the Lower Cretaceous (Albian) Bluesky Formation in the Karr area of west-central Alberta. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 33-55.

Masters, J.A., 1984. Lower Cretaceous oil and gas in western Canada, In: Masters J.A. ed., Elmworth - Case Study of a Deep Basin Gas Field. American Association of Petroleum Geologists, Memoir 38, p. 1-35.

Miall, A.D., 1992. Alluvial deposits. In: Walker, R.G. and James, N.P., eds., Facies model: response to sea level change. Geological Association of Canada, p.119-142.

Monger, J.W.H., 1989. Overview of Cordilleran geology. In: Ricketts, B.D., ed., Western Canada Sedimentary Basin: A Case History . Canadian Society of Petroleum Geologists, p. 9-32.

Nichol, S.L., 1991. Zonation and sedimentology of estuarine facies in an incised valley, wave dominated, microtidal setting, New South Wales, Australia. In: Smith, D.G., Reinson, G., Zaitlin, B. and Rahmani, R.A., eds., Clastic Tidal Sedimentology. Canadian Society of Petroleum Geologists, Memoir 16, p. 41-58.

O'Connell, S.C., 1988. The distribution of Bluesky Facies in the region overlying the Peace River Arch, Northwestern Alberta. In: James, D.P., and Leckie, D.A., eds., Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. Canadian Society of Petroleum Geologists, Memoir 15, p. 387-400.

Opplet, H., 1988. Sedimentology and Ichnology of the Bluesky Formation in Northeastern British Columbia. In: James, D.P. and Leckie, D.A., ed., Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. Canadian Society of Petroleum Geologists, Memoir 15, p. 401-416.

Pattison, A.J., 1992. Recognition and interpretation of estuarine mudstones (central basin mudstones) in the tripartite valley-fill deposits of the Viking Formation, central Alberta. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 223-250.

Pattison, A.J. and Walker, R.G. 1994. Incision and filling of a lowstand valley: Late Albian Viling Formation at Crystal, Alberta, Canada. Journal of Sedimentary Research, v. B64, N.3, p. 365-379.

Pemberton, S.G. and Wightman, D.M., 1992. Ichnological characteristics of brackish water deposits. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 141-168.

Pemberton, S.G., Reinson, G.E. and MacEachern, J.A., 1992. Comparative ichnological analysis of Late Albian estuarine valley-fill and shelf-shoreface deposits, Crystal Viking field, Alberta. In: Pemberton, S.G., ed., Application of Ichnology to Petroleum Exploration. Society of Economic Mineralogists and Paleontologists, Core Workshop 17, p. 291-317.

Plint, A.G., Eyles, N., Eyles, C.H. and Walker, R.G., 1992. Control of sea level change. In: Walker, R.G. and James, N.P., eds., Facies model: response to sea level change. Geological Association of Canada, p.15-25.

Pugh, D.C., 1960. The subsurface Gething and Bluesky Formations of northeastern British Columbia. Geological Survey of Canada, Paper 60-1.

Ranger, M.G. and Pemberton, S.G., 1991. Multivariate analysis of ichnofossil associations in the subsurface of Bluesky Formation (Albian, Alberta, Canada). Paleogeography, Paleoclimatology, Paleoecology, v.85, p. 169-187.

Reinson, G.E., Clark, J.E., and Foscolos, A.E., 1988. Reservoir geology of Crystal Viking field, Lower Cretaceous estuarine tidal channel-bay complex, south-central Alberta. American Association of Petroleum Geologists Bulletin, v. 72, p. 1270-1294.

Reinson, 1992. Transgressive barrier island and estuarine systems. In: Walker, R.G. and James, N.P., eds., Facies model: response to sea level change. Geological Association of Canada, p. 179-194.

Rosenthal, L., 1988. Wave dominated shorelines and incised channel trends: Lower Cretaceous Glauconite Formation, west-central Alberta. In: James, D.P. and Leckie, D.A., ed., Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. Canadian society of Petroleum Geologists, Memoir 15, p. 207-220.

Saunders, T.S., MacEachern, J.A. and Pemberton, S.G., 1994. Cadotte Member sandstone: Progradation in a Boreal basin prone to winter storms. In: Pemberton, S.G., James, D.P, and Wightman, D.M. Mannville core conference. Canadian Society of Petroleum Geologists, p. 331-349.

Smith, D.G., Zorn, C.E., and Sneider, R.M., 1984. The paleogeography of the Lower Cretaceous of western Alberta and Northeastern British Columbia in an adjacent to the deep basin of the Elmworth area. In: Masters, J.A., ed., Elmworth - Case Study of a Deep Basin Gas Field. American Association of Petroleum Geologists, Memoir 38, p. 79-115.

Smith, D.G., 1994. Paleogeographic evolution of the western Canada foreland basin. In: Mossop, G., and Dixon, J., eds., Geological Atalas of the Western Canada sedimentary basin. Canadian Society of Petroleum Geologists, Alberta Geological Survey, p. 277-298.

Strobl, R.S. 1988. The effect of sea-level fluctuations on prograding shorelines and estuarine valley-fill sequences in the Glauconitic Member, Medicine River field and adjacent areas. In: James, D.P. and Leckie, D.A., ed., Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. Canadian Society of Petroleum Geologists, Memoir 15, p. 221-236.

Van der Hayden, P., 1992. A Middle Jurassic to Early Tertiary Andean-Sierran arc model for the Coast Belt of British Columbia. Tectonics, v. 11, p. 82-97.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M. and Rahamanian, V.D., 1990. Siliciclastic sequence stratigraphy in well logs, cores and outcrops. American Association of Petroleum Geologists, Method in Exploration Series 7, 55p.

Wadsworth, J.A. and Walker, R.G. 1991. Morphology and origin of erosion surfaces in the Cardium Formation (Upper Cretaceous, Western Interior Seaway, Alberta) and their implications for rapid sea level fluctuations. Canadian Journal of Earth Sciences, v. 28, p. 1507-1520.

Walker, R.G. 1995. An incised valley in the Cardium Formation at Ricinus, Alberta: reinterpretation as an estuary fill. In; Plint, A.G., ed., Sedimentary

Facies Analysis. International Association of Sedimentologists, Special Publication 22, p. 47-74.

Walker, R.G., 1992. Facies models and modern stratigraphic concepts. In: Walker, R.G. and James, N.P., eds., Facies model: response to sea level change. Geological Association of Canada, p.1-14.

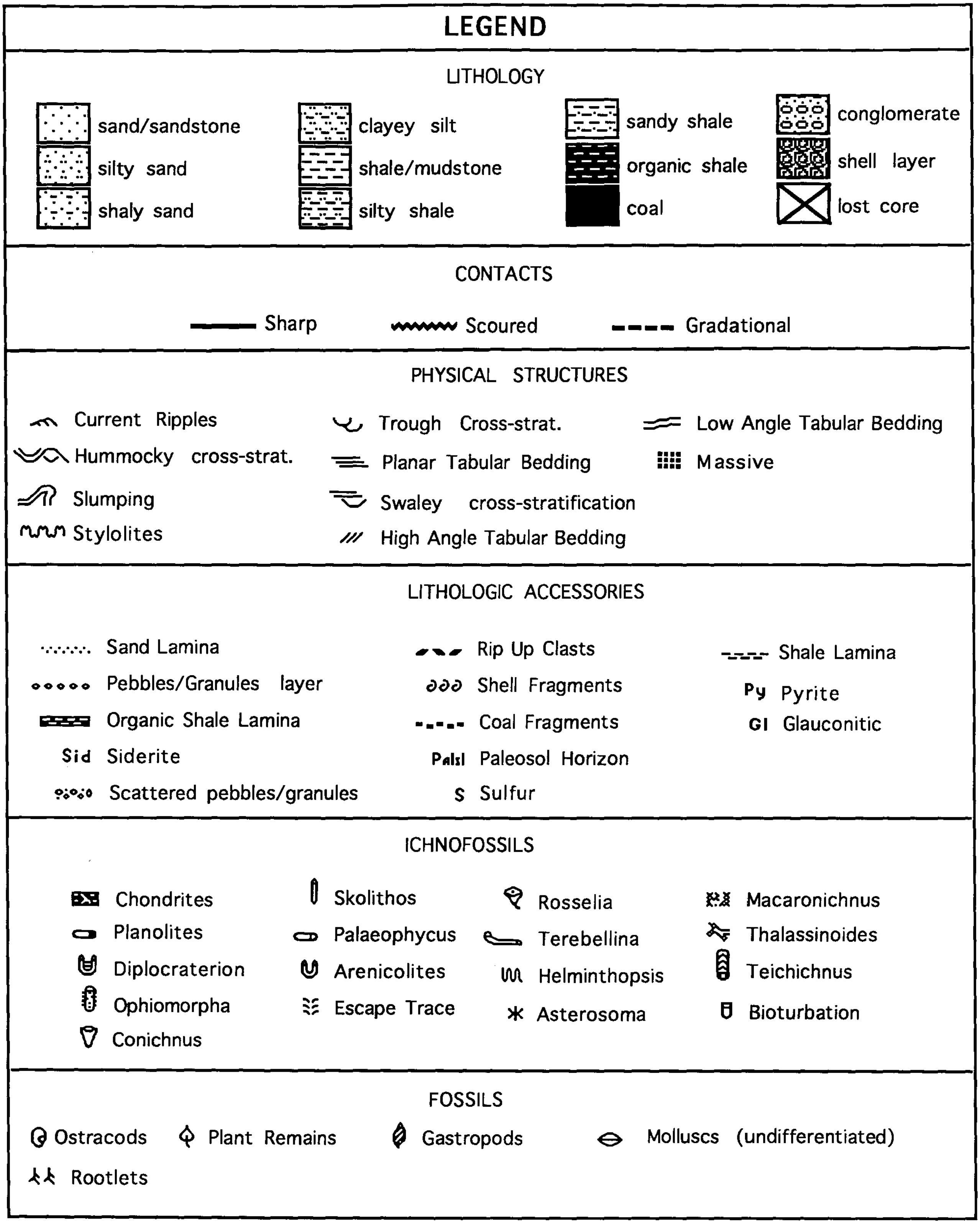
Walker, R.G. and Plint, A. G. 1992. Wave- and storm dominated shallow marine systems. In: Walker, R.G. and James, N.P., eds., Facies model: response to sea level change. Geological Association of Canada, p. 219-238.

Walker, R.G. and Eyles, C.H., 1991. Topography and significance of a basin-wide sequence-bounding erosion surface in the Cretaceous Cardium Formation, Alberta, Canada. Journal of Sedimentary petrology, v.61, p. 473-496.

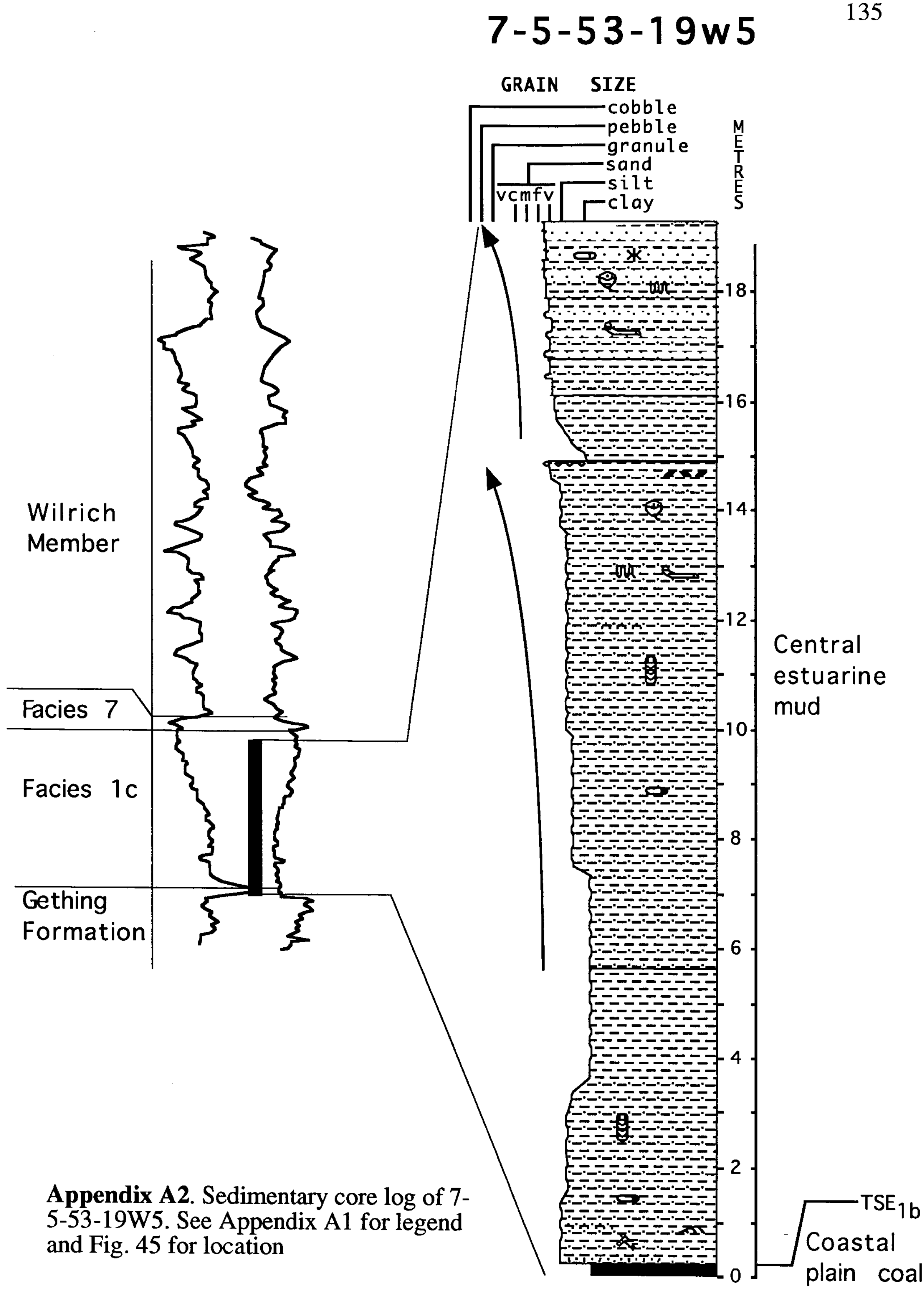
Wood, J.M. and Hopkins, J.C. 1992. Traps associated with paleovalleys and interfluves in an unconformity bounded sequence: Lower Cretaceous Glauconitic Member, southern Alberta, Canada. American Association of Petroleum Geologists Bulletin. v. 76, p. 904-926.

Wood, J.M. and Hopkins, J.C. 1989. Reservoir sandstone bodies in estuarine valley fill, Lower Cretaceous Glauconitic Member, Little Bow field, Alberta, Canada. American Association of Petroleum Geologists Bulletin, v. 73, p. 1361-1382.

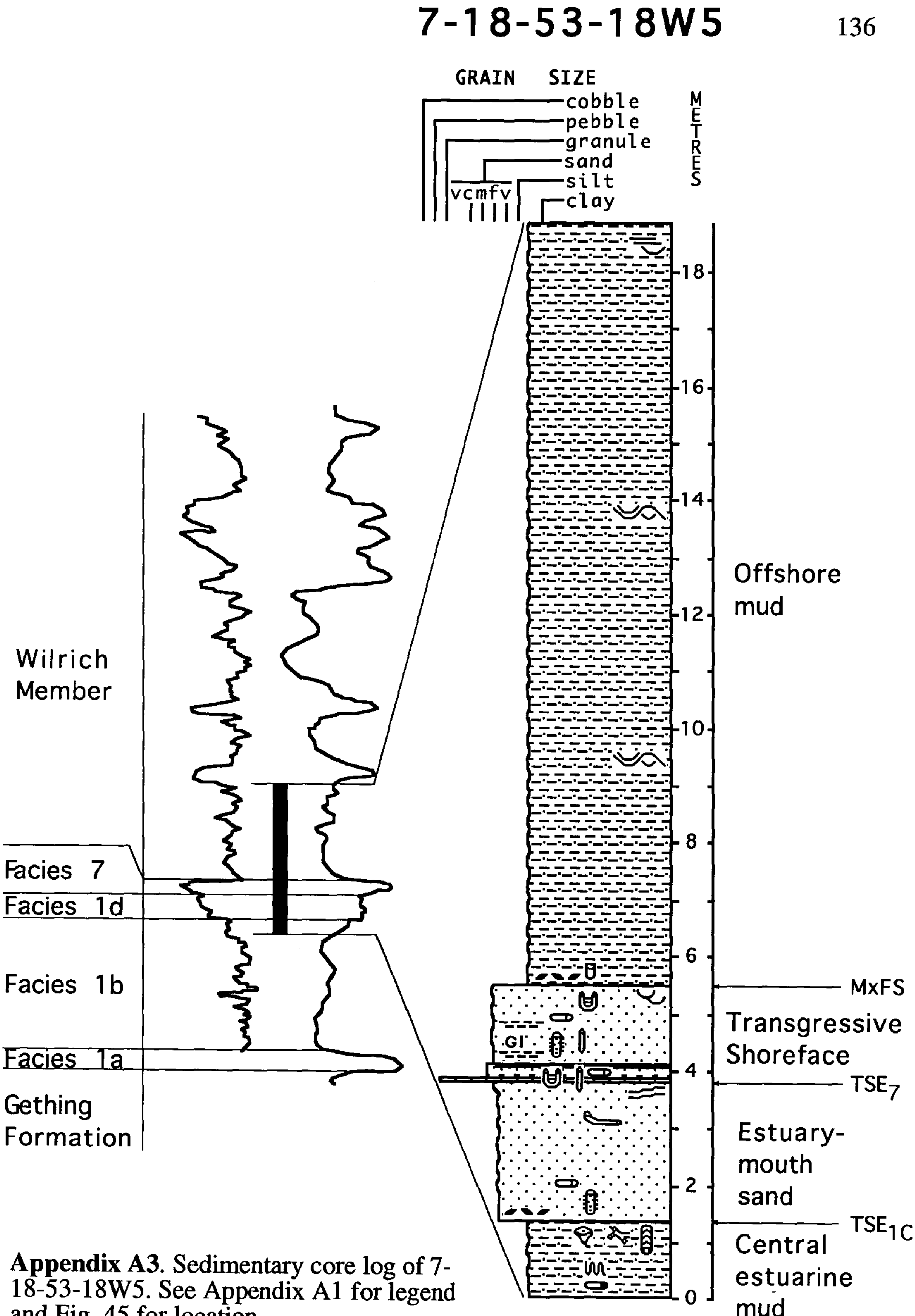
APPENDIX A



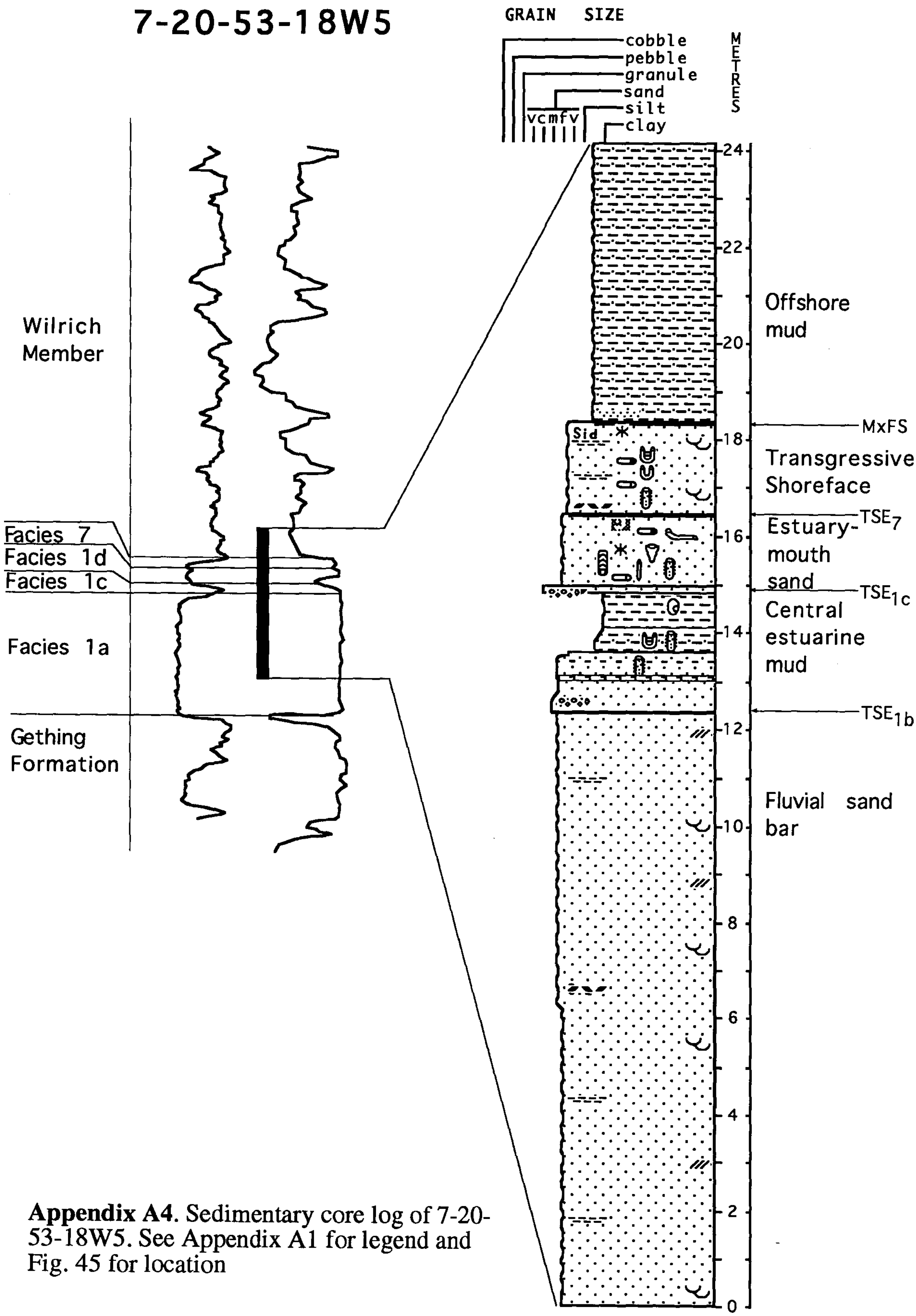
Appendix A1. Legend for the sedimentary core logs and core cross-sections



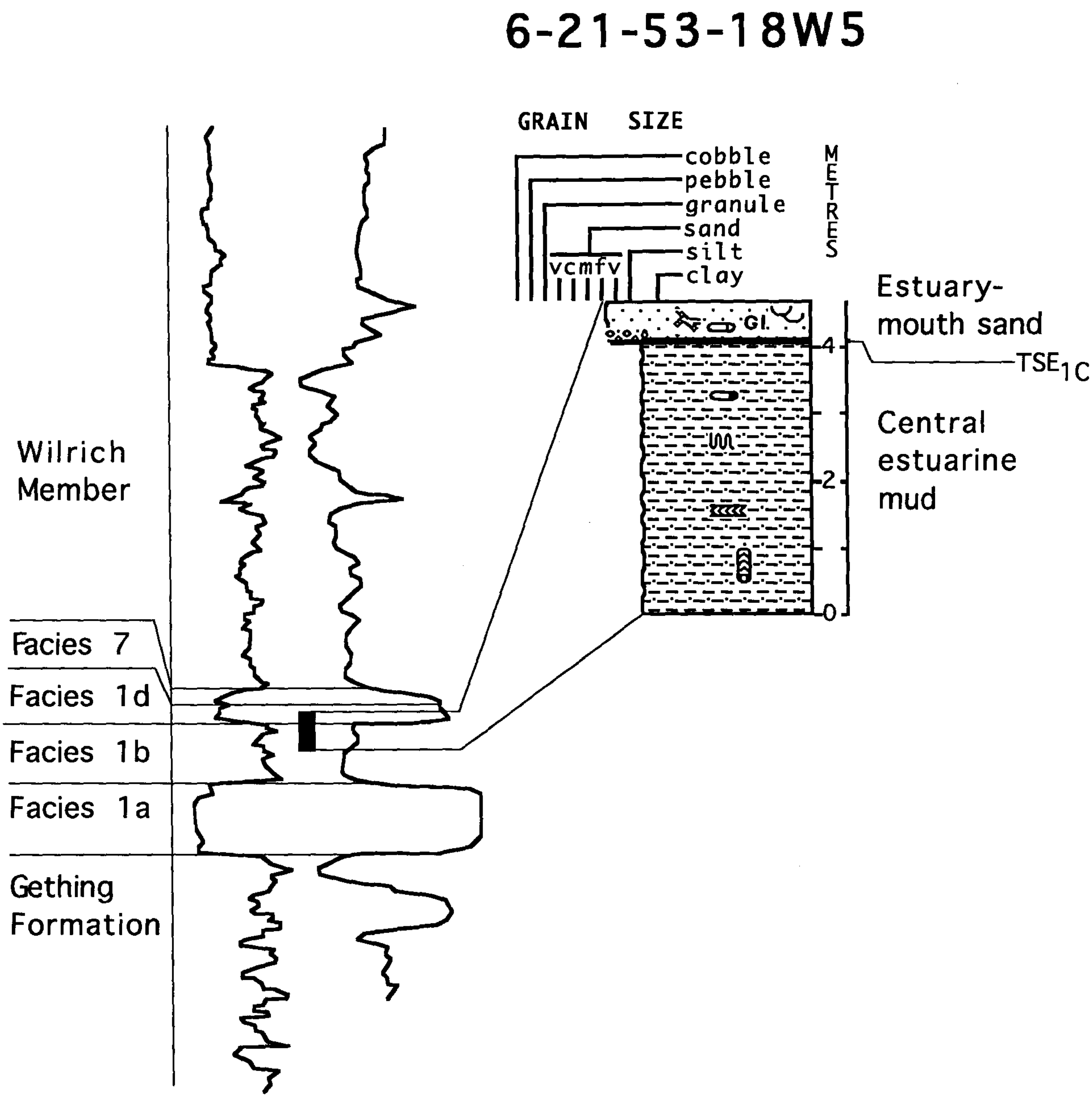
Appendix A2. Sedimentary core log of 7-5-53-19W5. See Appendix A1 for legend and Fig. 45 for location



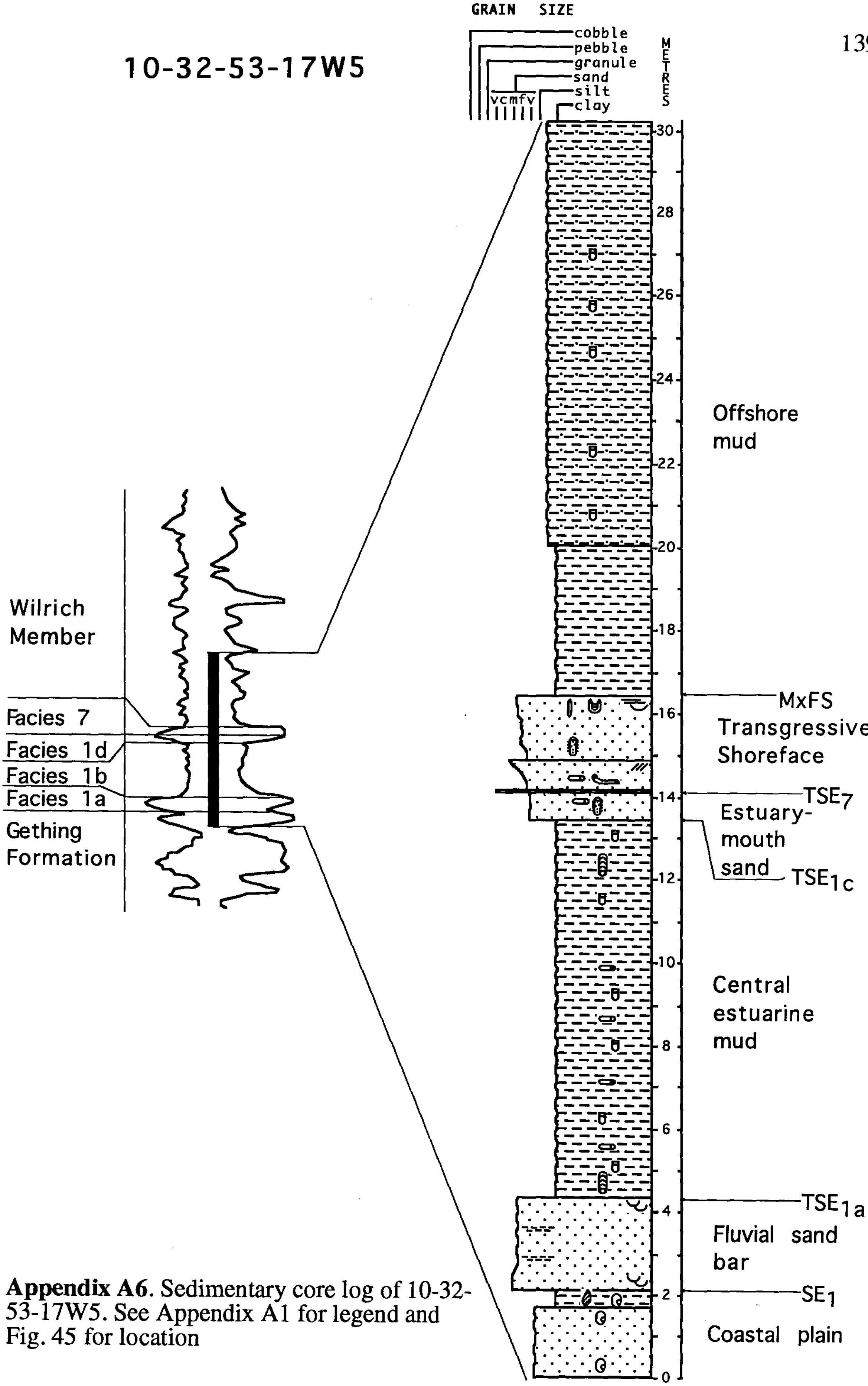
Appendix A3. Sedimentary core log of 7-18-53-18W5. See Appendix A1 for legend and Fig. 45 for location



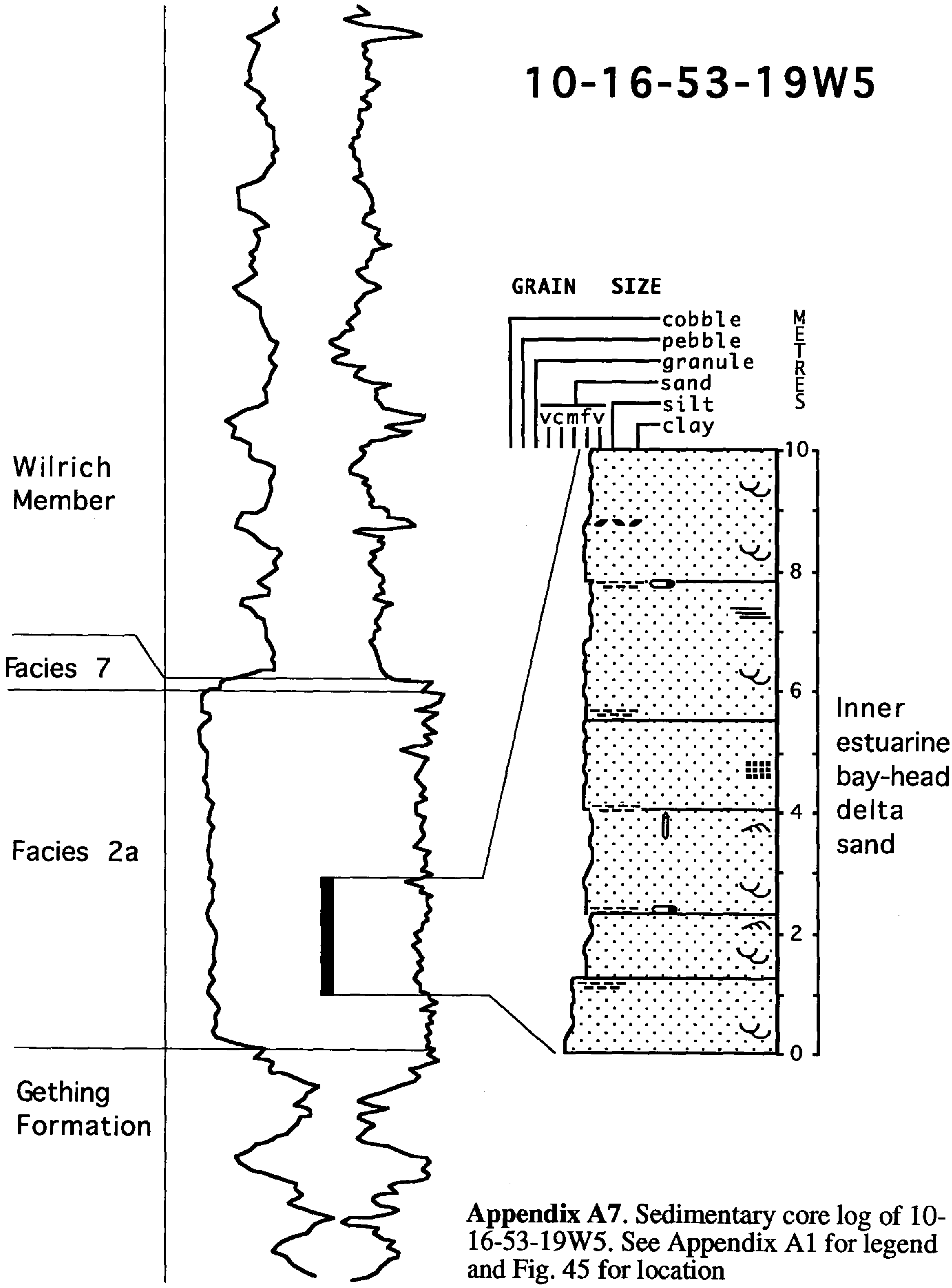
Appendix A4. Sedimentary core log of 7-20-53-18W5. See Appendix A1 for legend and Fig. 45 for location



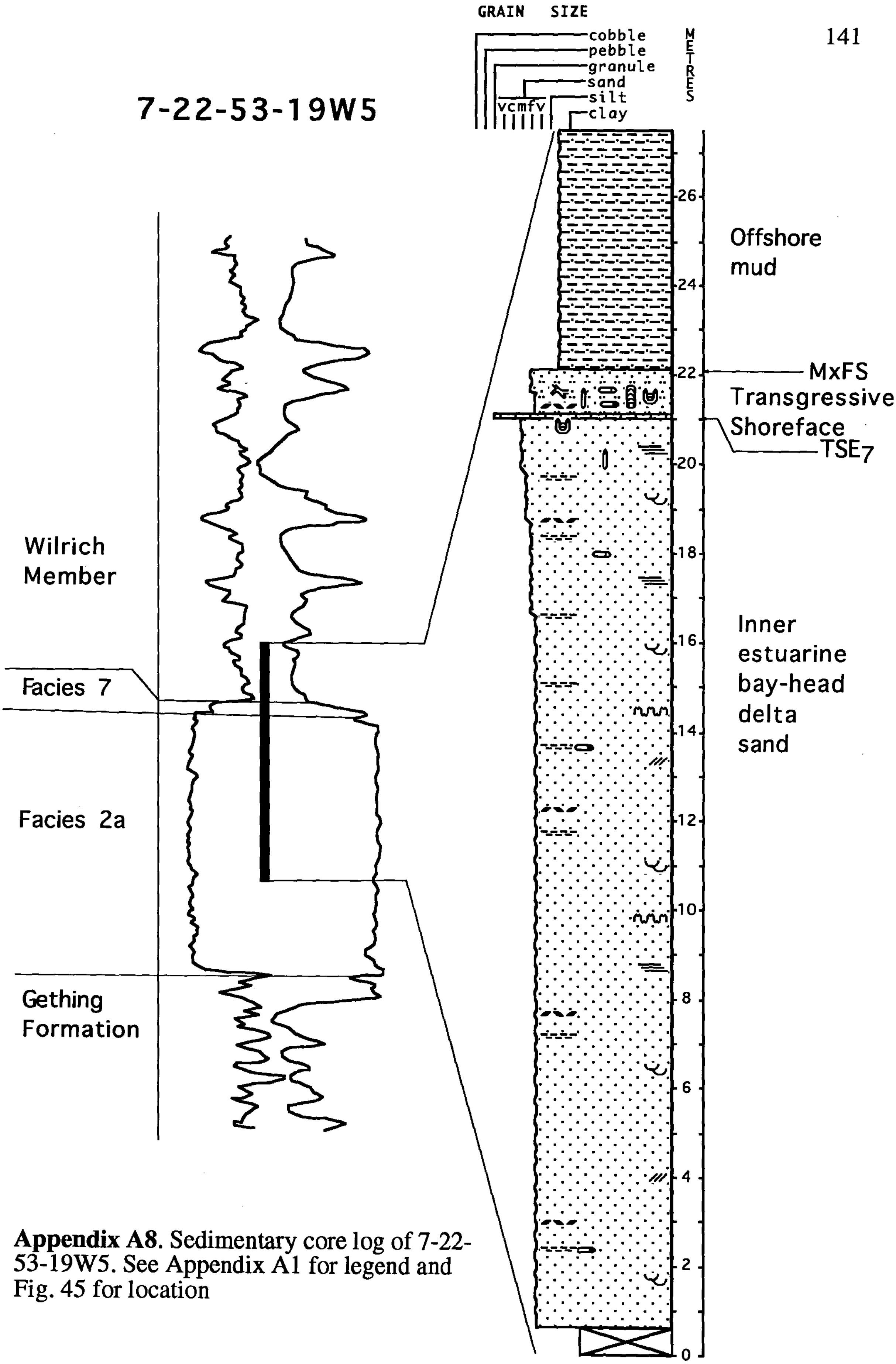
Appendix A5. Sedimentary core log of 6-21-53-18W5. See Appendix A1 for legend and Fig. 45 for location



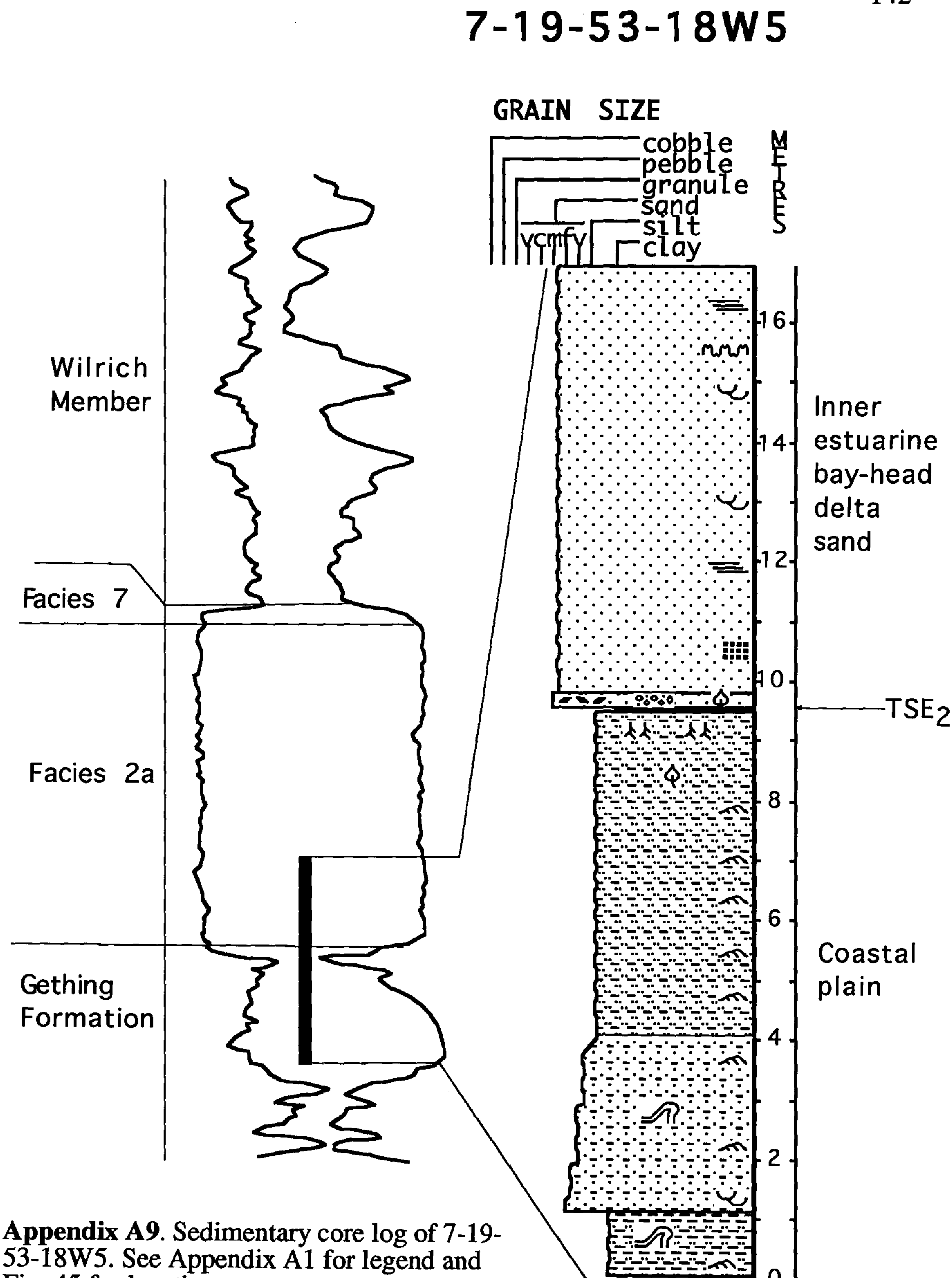
Appendix A6. Sedimentary core log of 10-32-53-17W5. See Appendix A1 for legend and Fig. 45 for location



Appendix A7. Sedimentary core log of 10-16-53-19W5. See Appendix A1 for legend and Fig. 45 for location

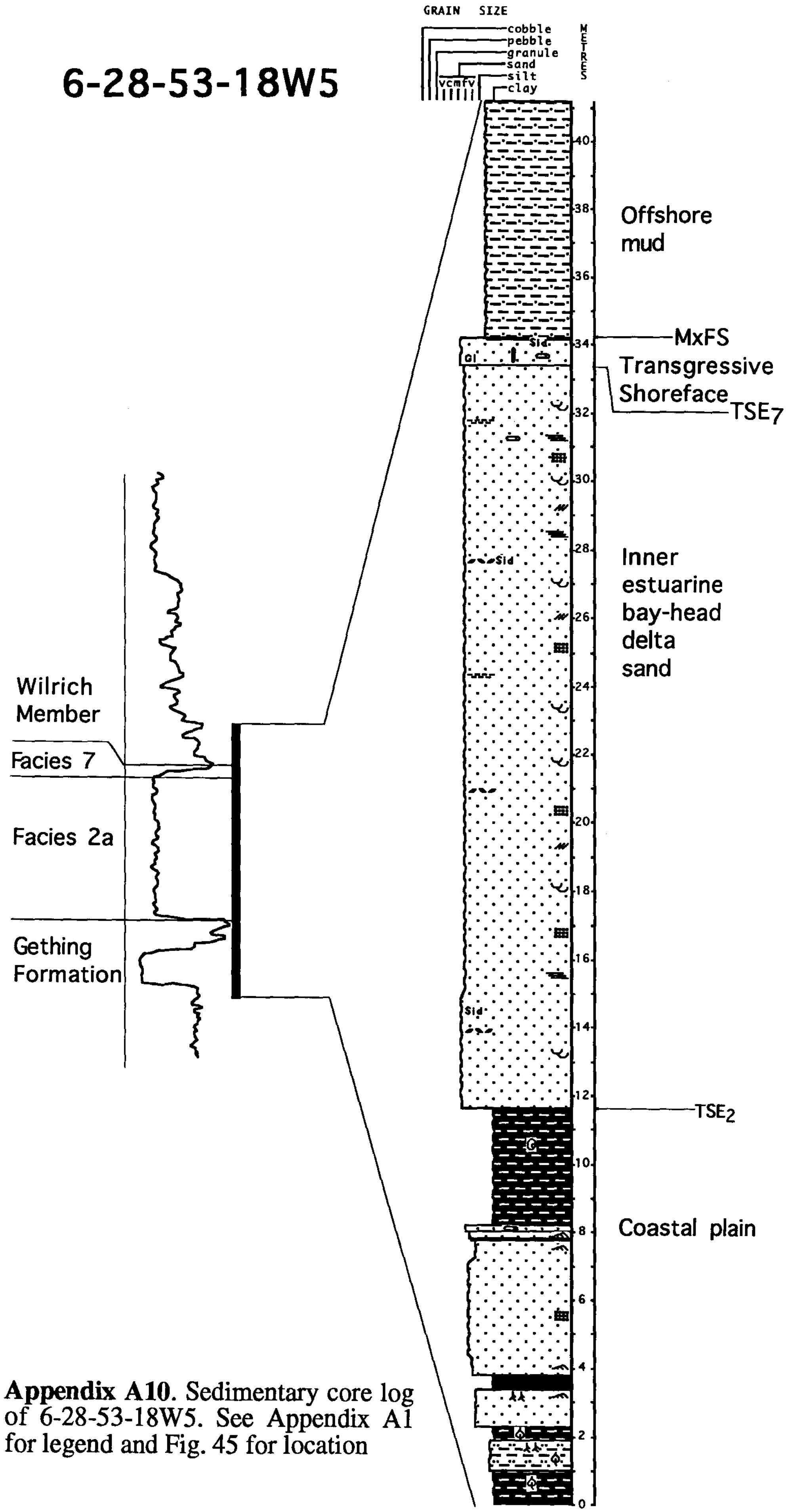


Appendix A8. Sedimentary core log of 7-22-53-19W5. See Appendix A1 for legend and Fig. 45 for location



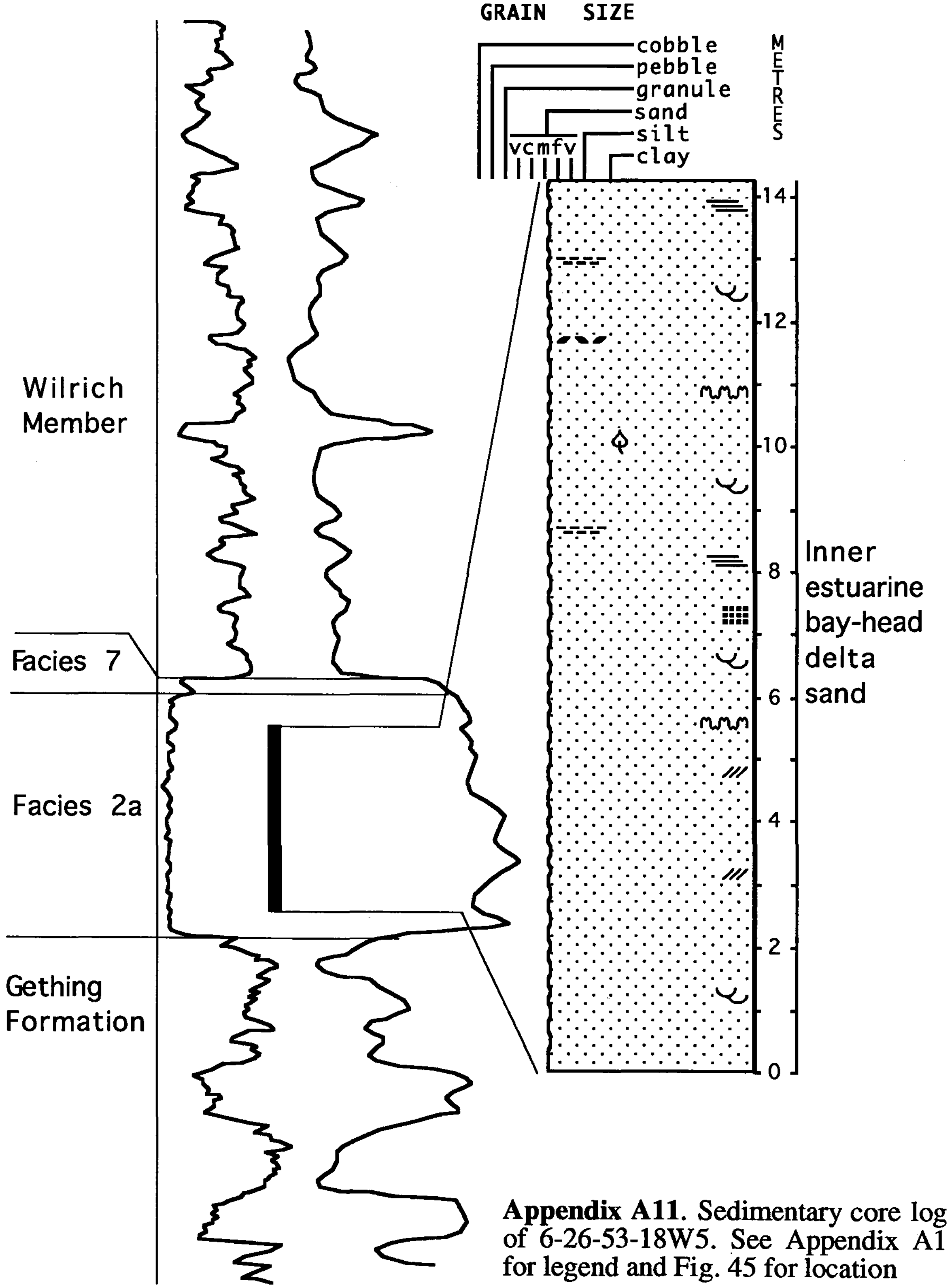
Appendix A9. Sedimentary core log of 7-19-53-18W5. See Appendix A1 for legend and Fig. 45 for location

6-28-53-18W5



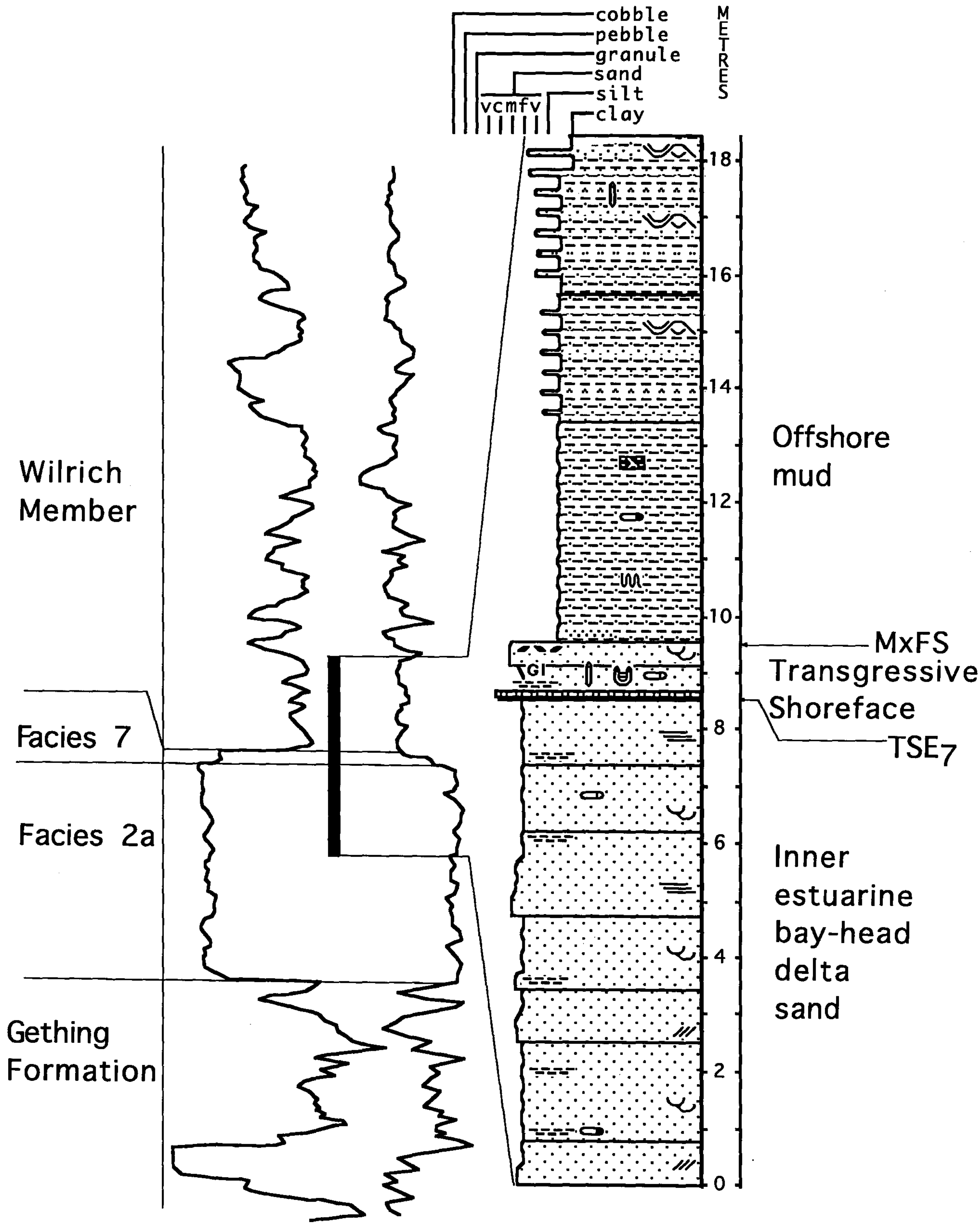
Appendix A10. Sedimentary core log of 6-28-53-18W5. See Appendix A1 for legend and Fig. 45 for location

6-26-53-18W5

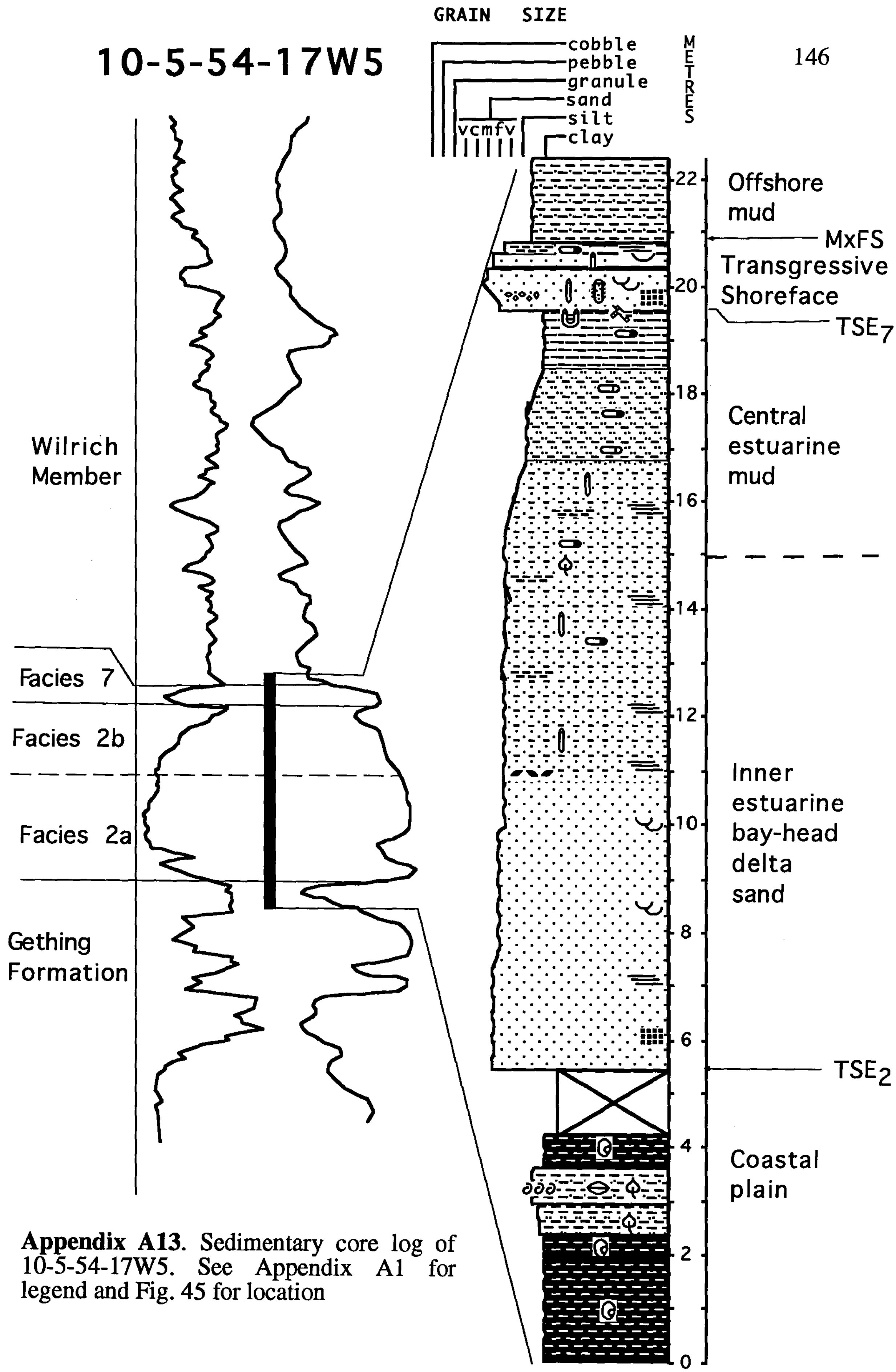


Appendix A11. Sedimentary core log of 6-26-53-18W5. See Appendix A1 for legend and Fig. 45 for location

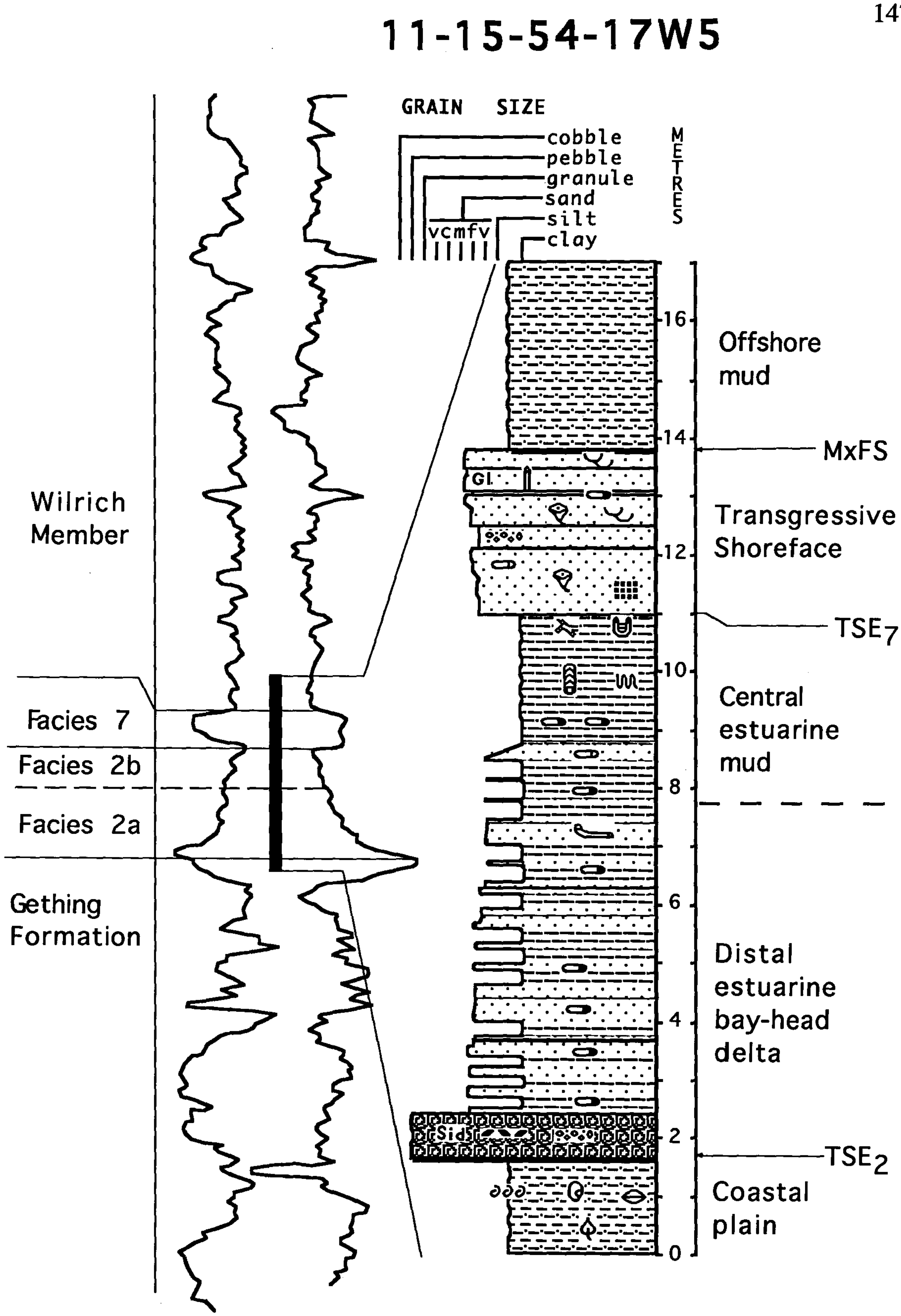
7-36-53-18W5



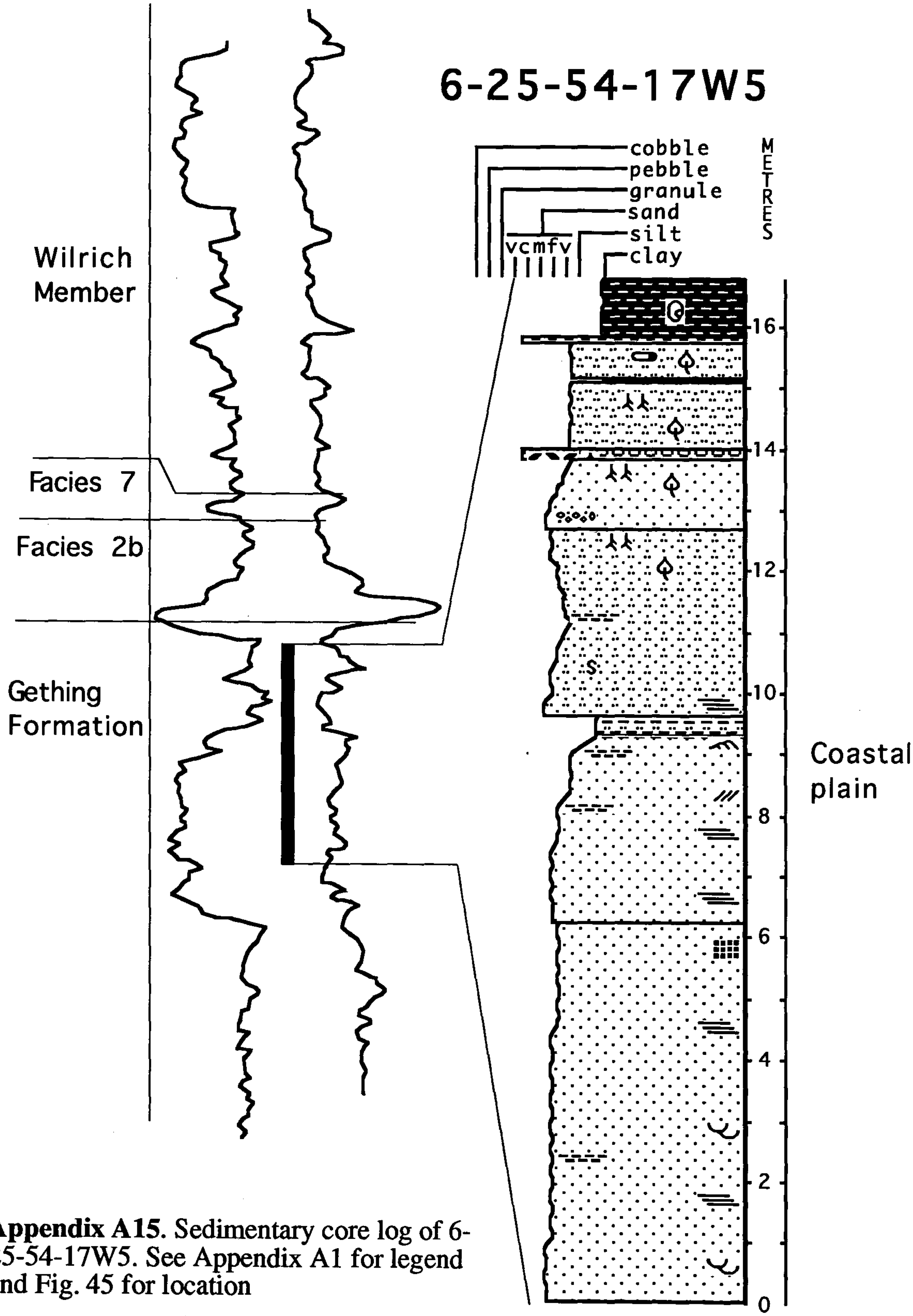
Appendix A12. Sedimentary core log of 7-36-53-18W5. See Appendix A1 for legend and Fig. 45 for location



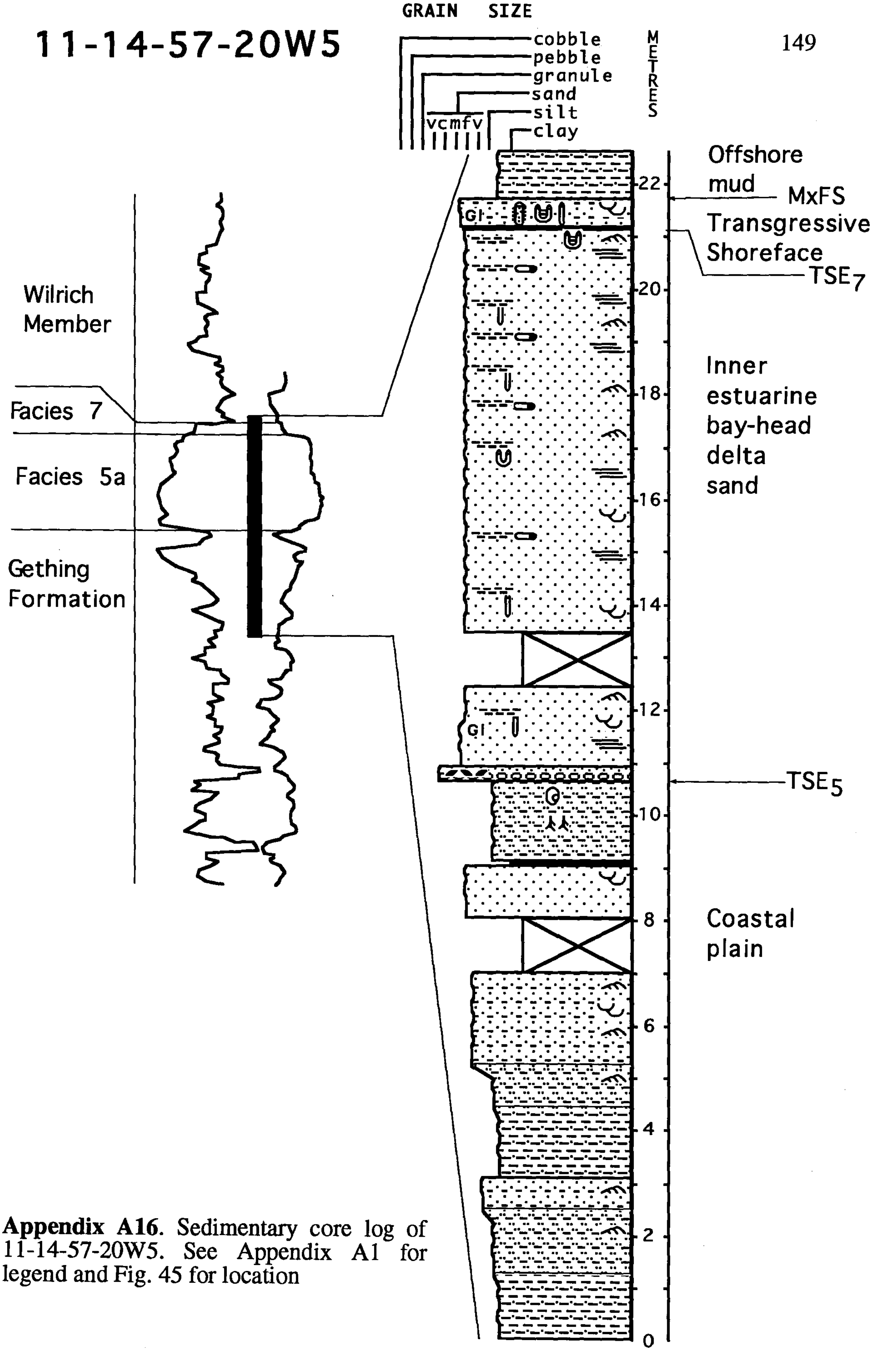
Appendix A13. Sedimentary core log of 10-5-54-17W5. See Appendix A1 for legend and Fig. 45 for location



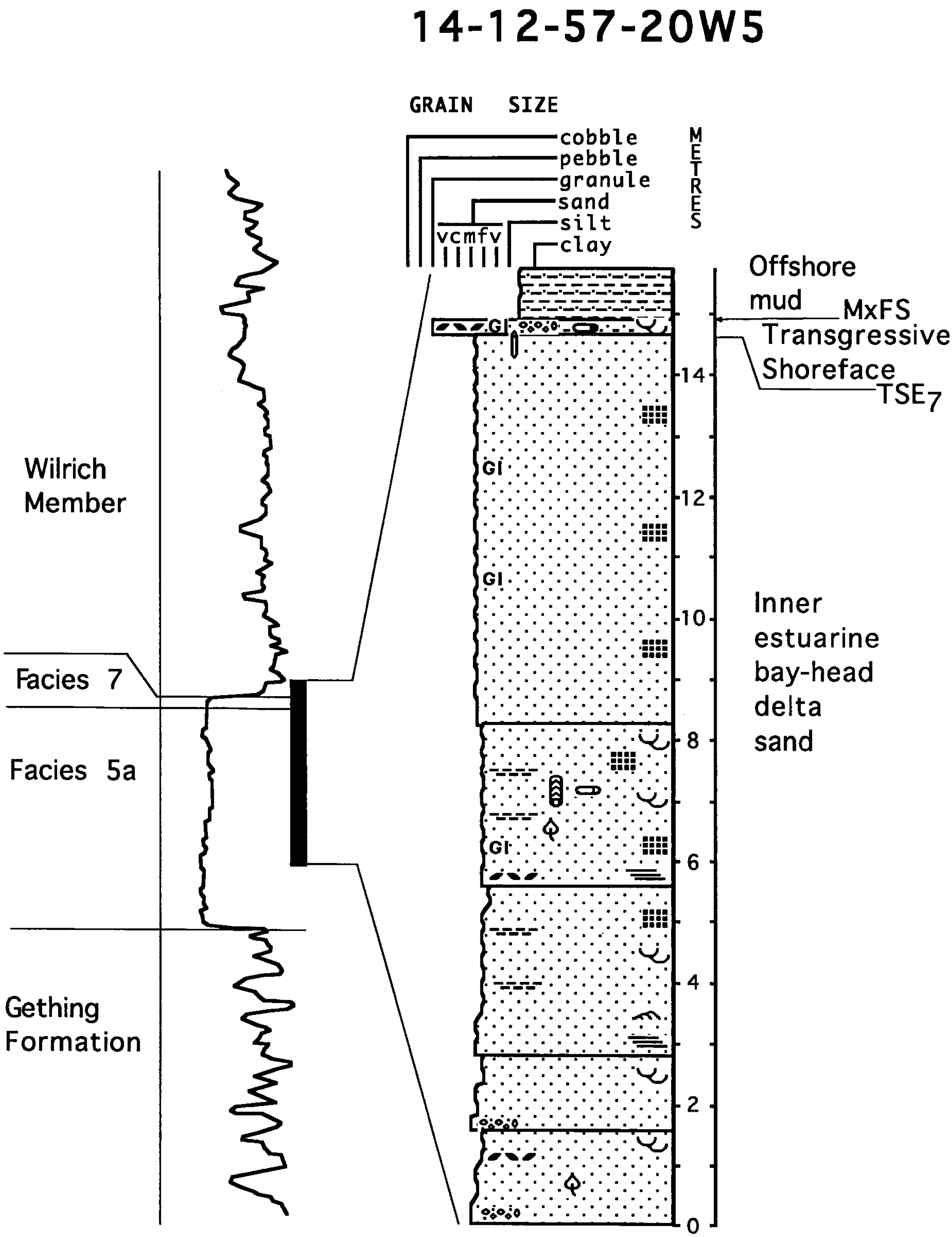
Appendix A14. Sedimentary core log of 11-15-54-17W5. See Appendix A1 for legend and Fig. 45 for location



Appendix A15. Sedimentary core log of 6-25-54-17W5. See Appendix A1 for legend and Fig. 45 for location

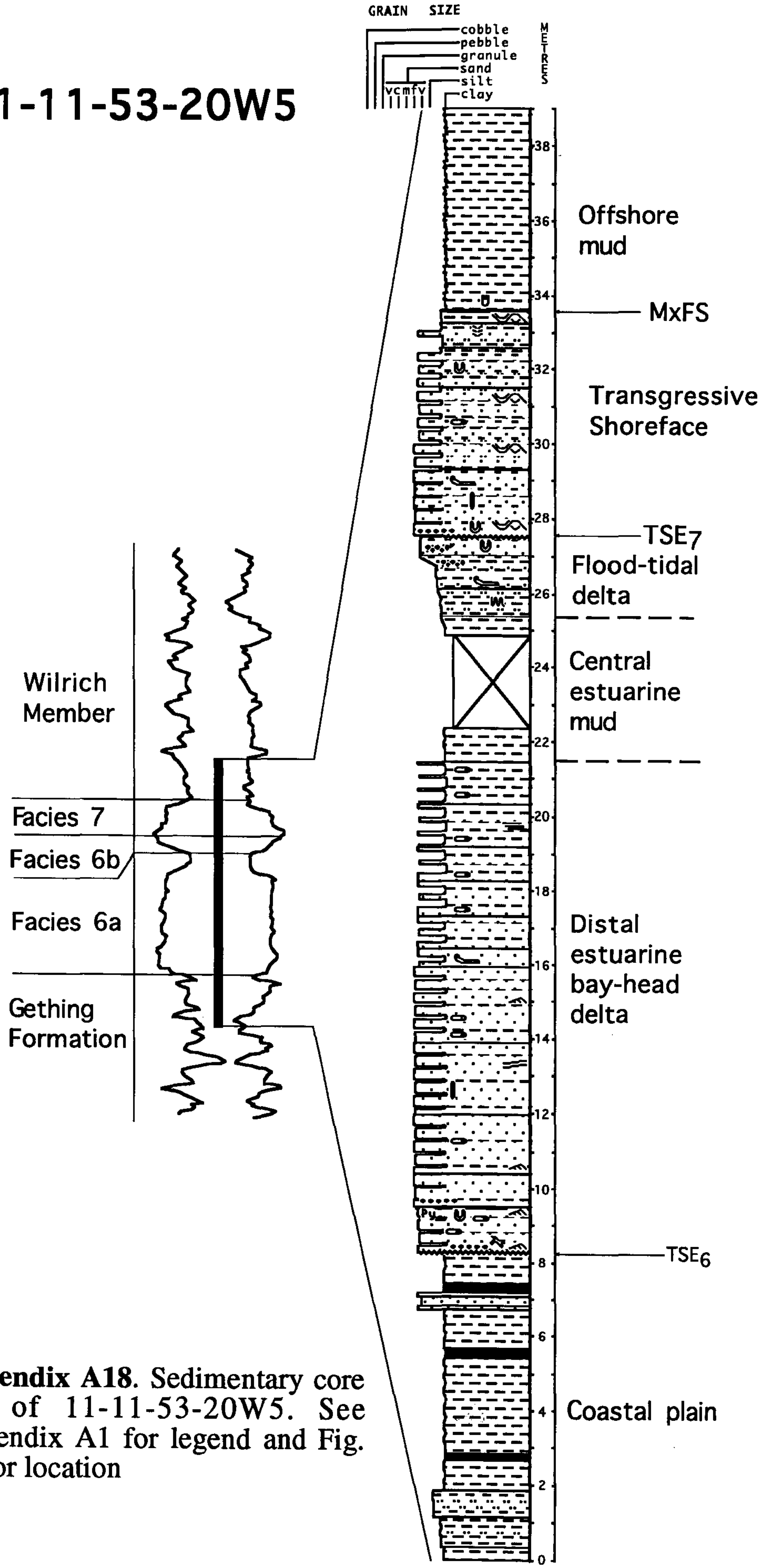


Appendix A16. Sedimentary core log of 11-14-57-20W5. See Appendix A1 for legend and Fig. 45 for location



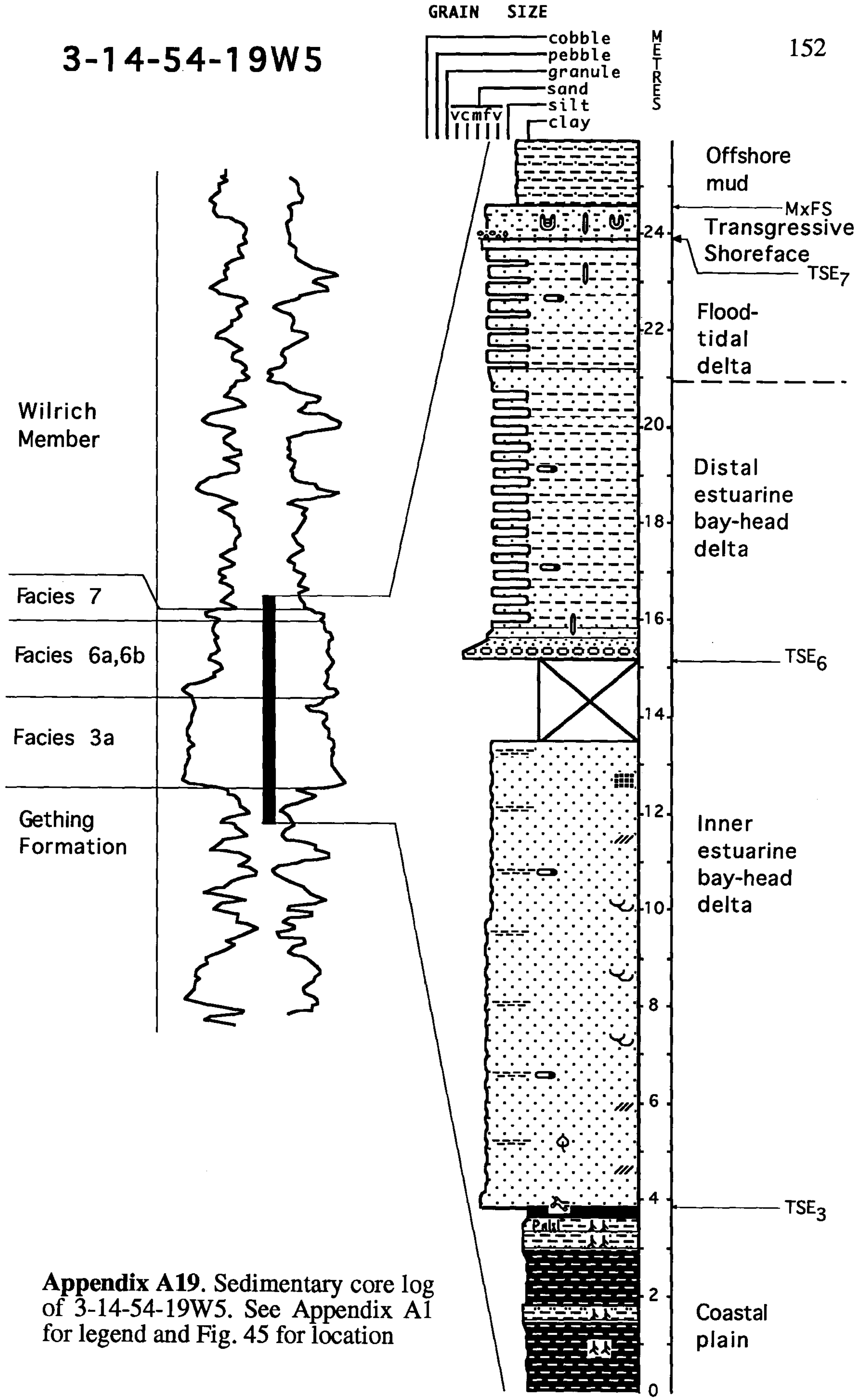
Appendix A17. Sedimentary core log of 14-12-57-20W5. See Appendix A1 for legend and Fig. 45 for location

11-11-53-20W5

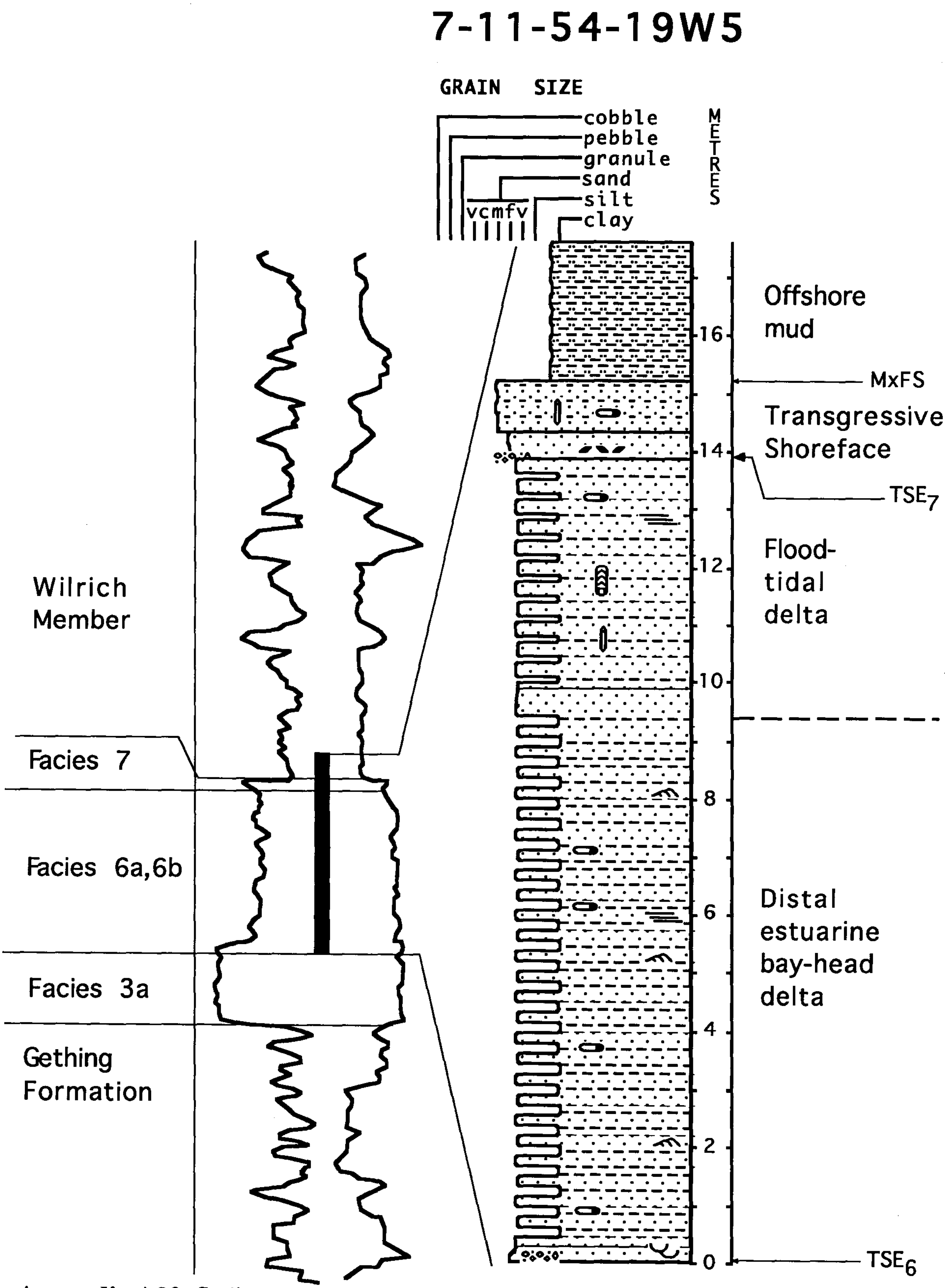


Appendix A18. Sedimentary core log of 11-11-53-20W5. See Appendix A1 for legend and Fig. 45 for location

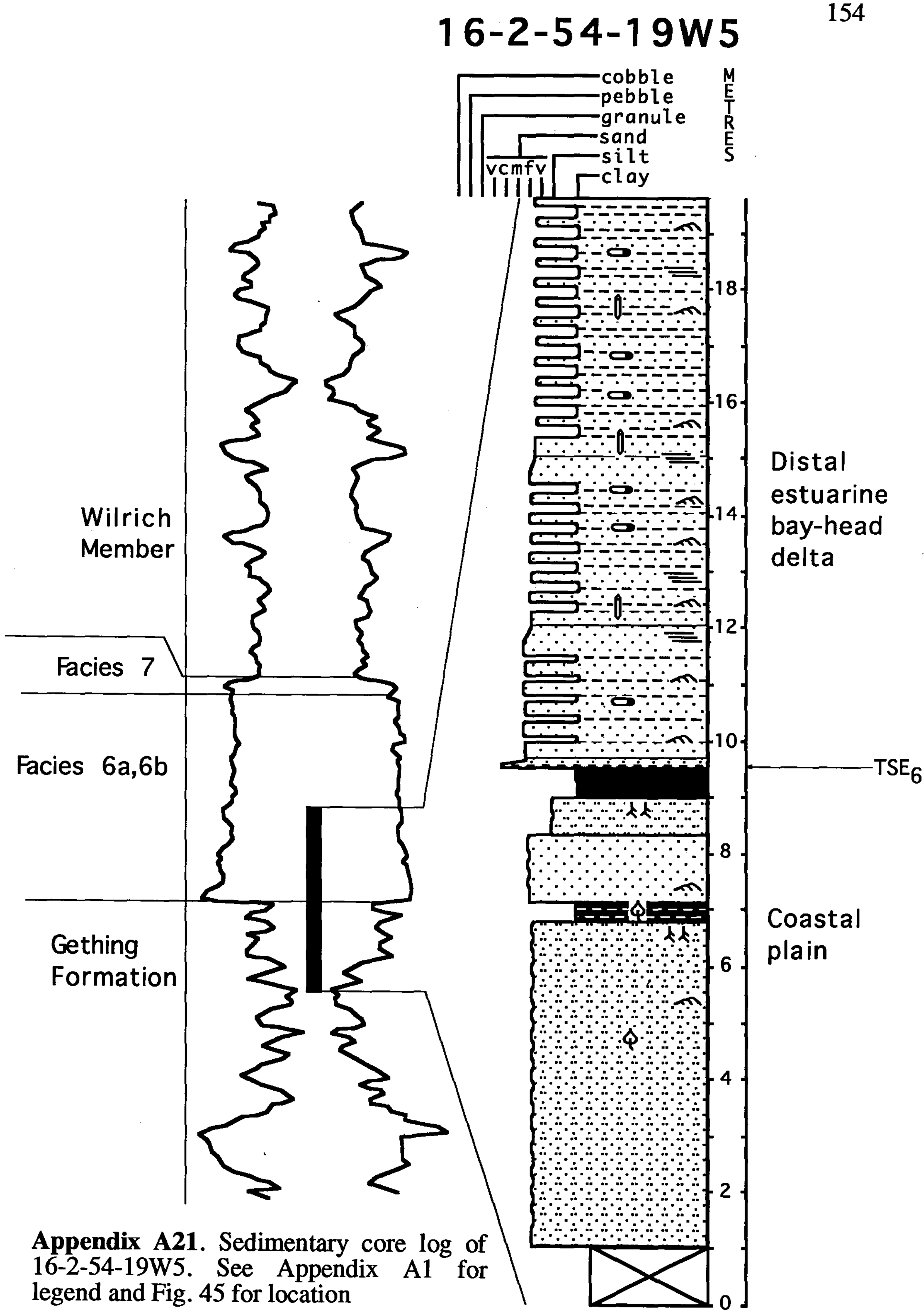
3-14-54-19W5



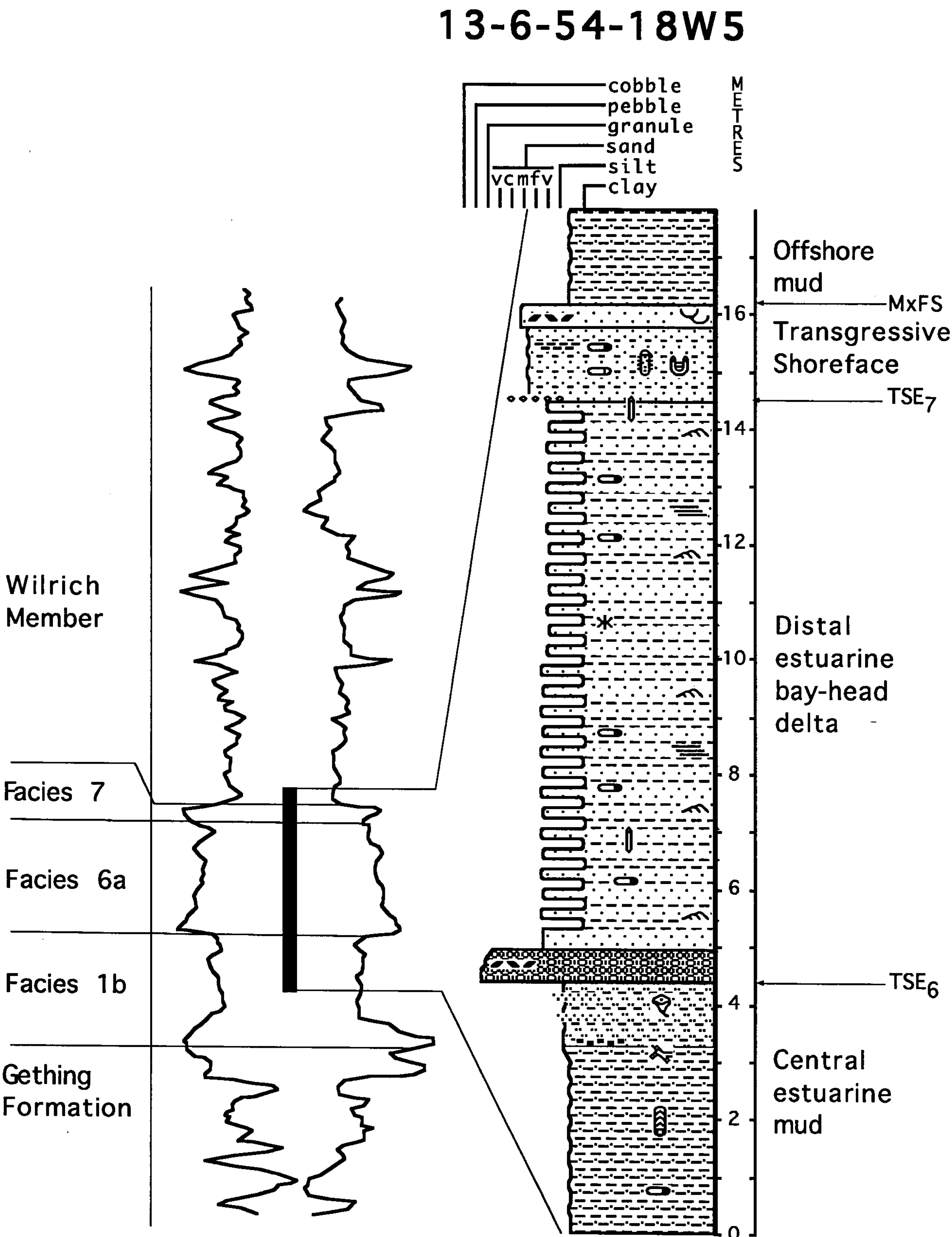
Appendix A19. Sedimentary core log of 3-14-54-19W5. See Appendix A1 for legend and Fig. 45 for location



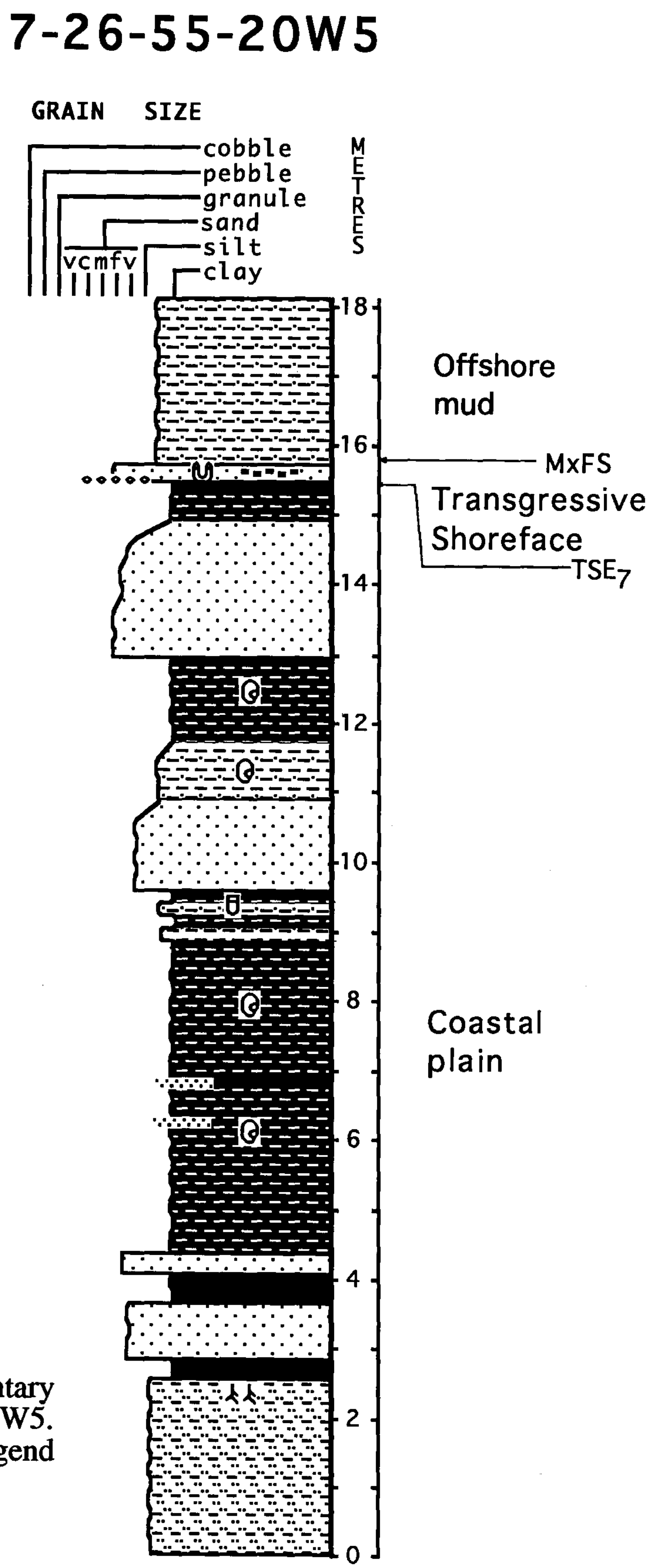
Appendix A20. Sedimentary core log of 7-11-54-19W5. See Appendix A1 for legend and Fig. 45 for location



Appendix A21. Sedimentary core log of 16-2-54-19W5. See Appendix A1 for legend and Fig. 45 for location

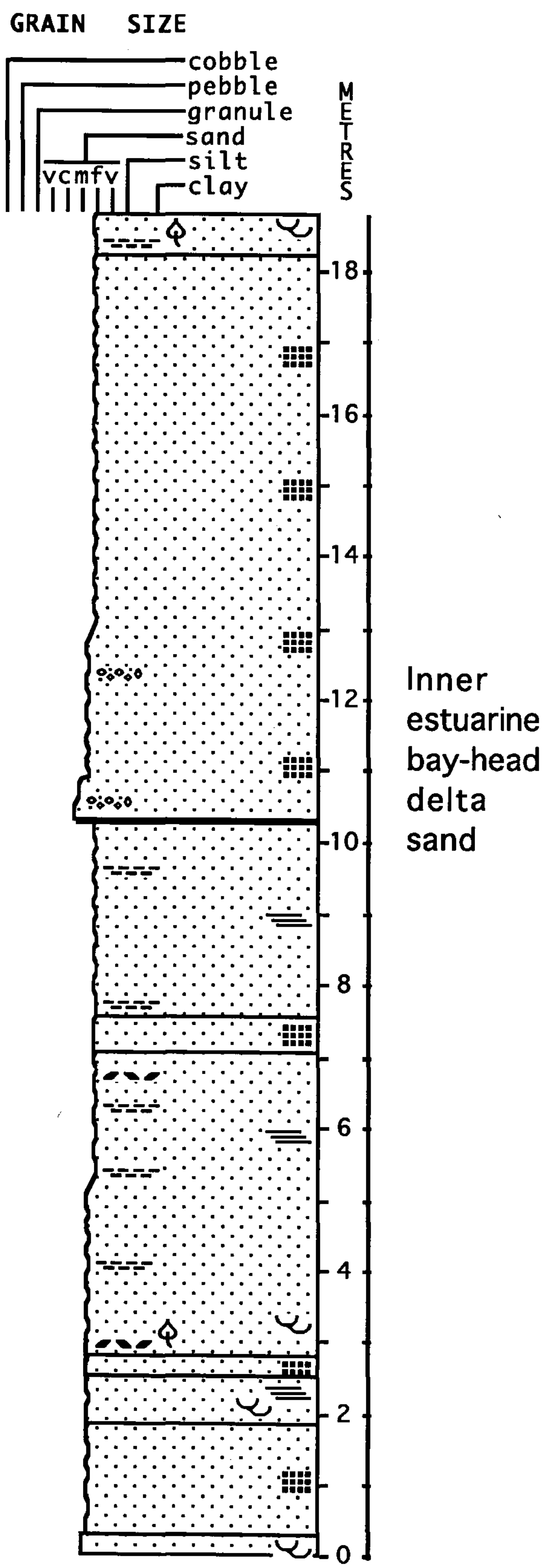


Appendix A22. Sedimentary core log of 13-6-54-18W5. See Appendix A1 for legend and Fig. 45 for location



Appendix A23. Sedimentary core log of 7-26-55-20W5. See Appendix A1 for legend and Fig. 45 for location

7-9-52-20W5



Appendix A24. Sedimentary core log of 7-9-52-20W5. See Appendix A1 for legend and Fig. 45 for location

APPENDIX B

APPENDIX B1

7-5-53-19W5

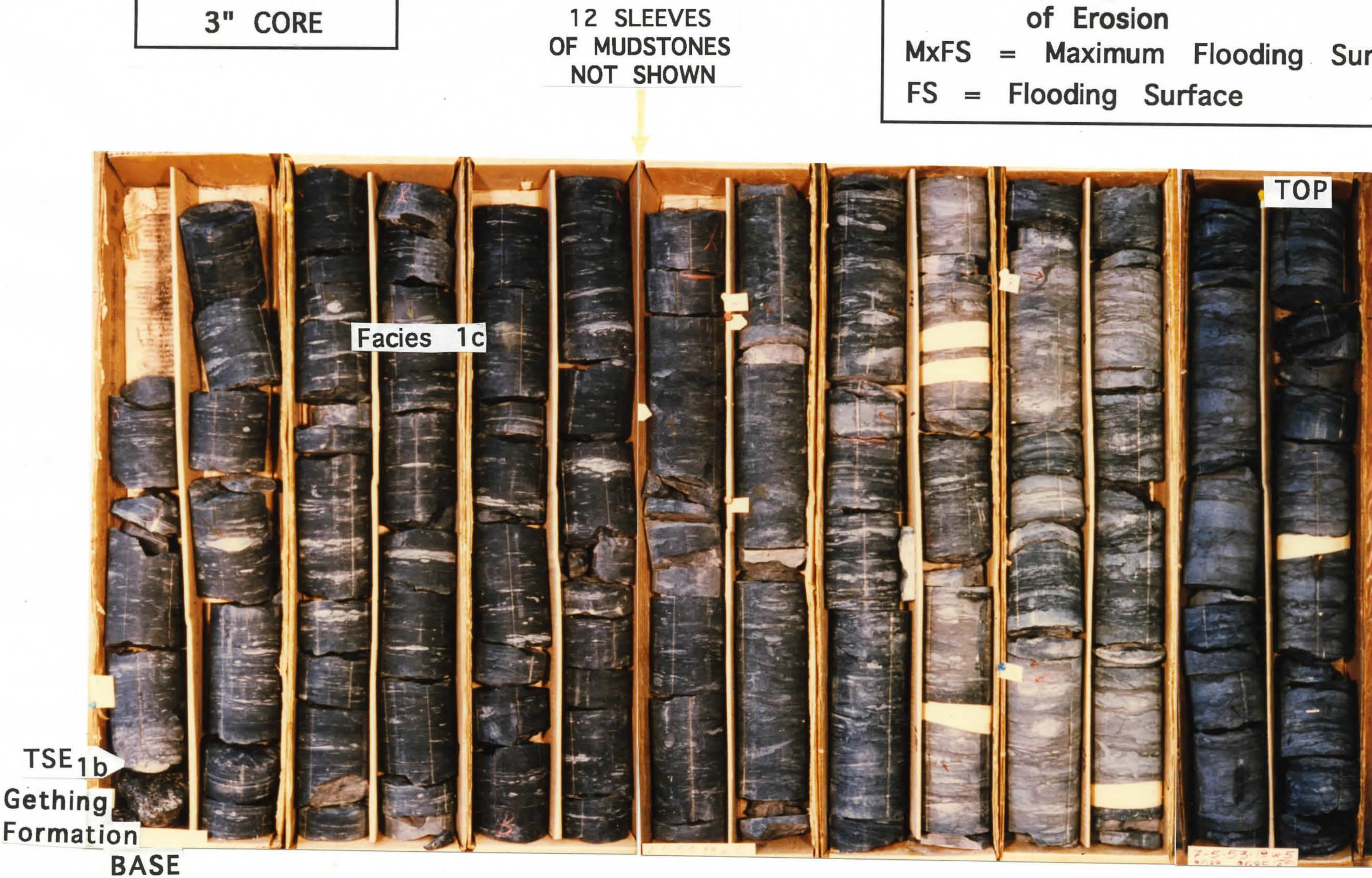
3" CORE

SE = Surface of Erosion

TSE = Transgressive Surface of Erosion

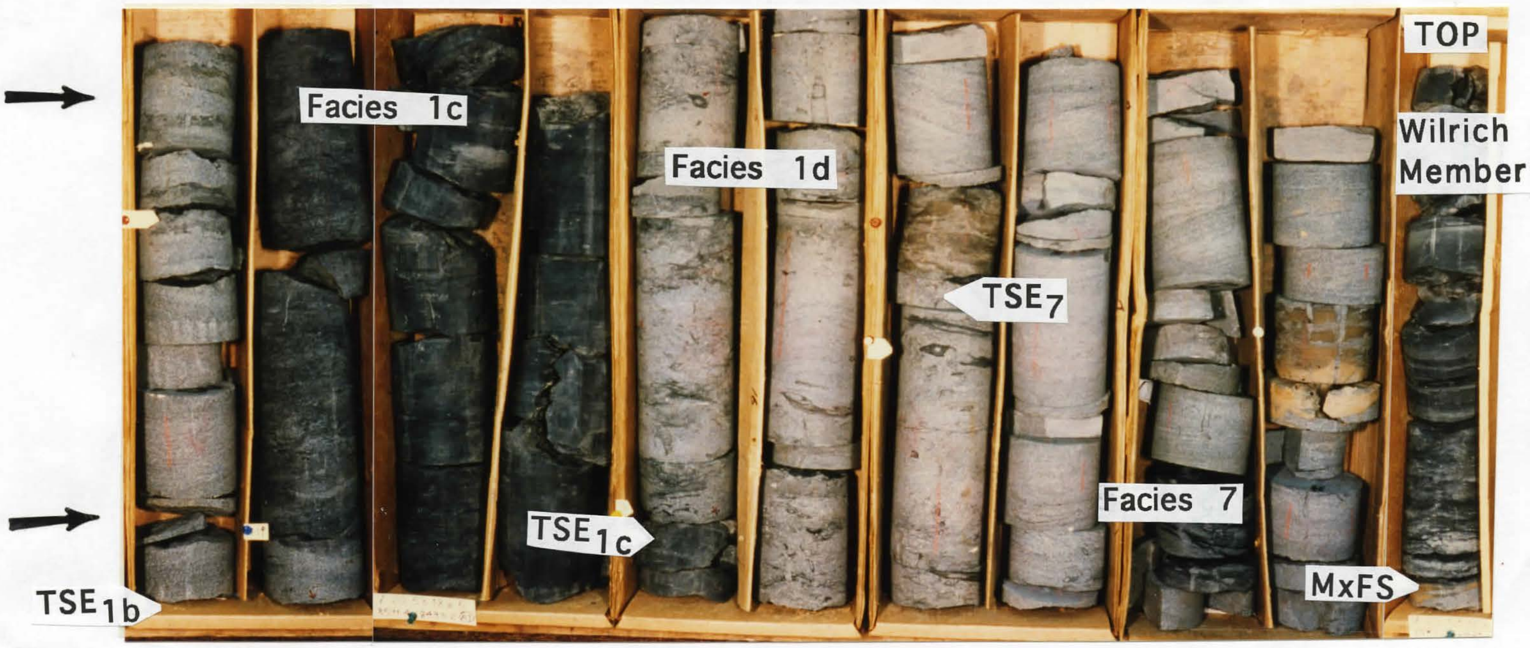
MxFS = Maximum Flooding Surface

FS = Flooding Surface



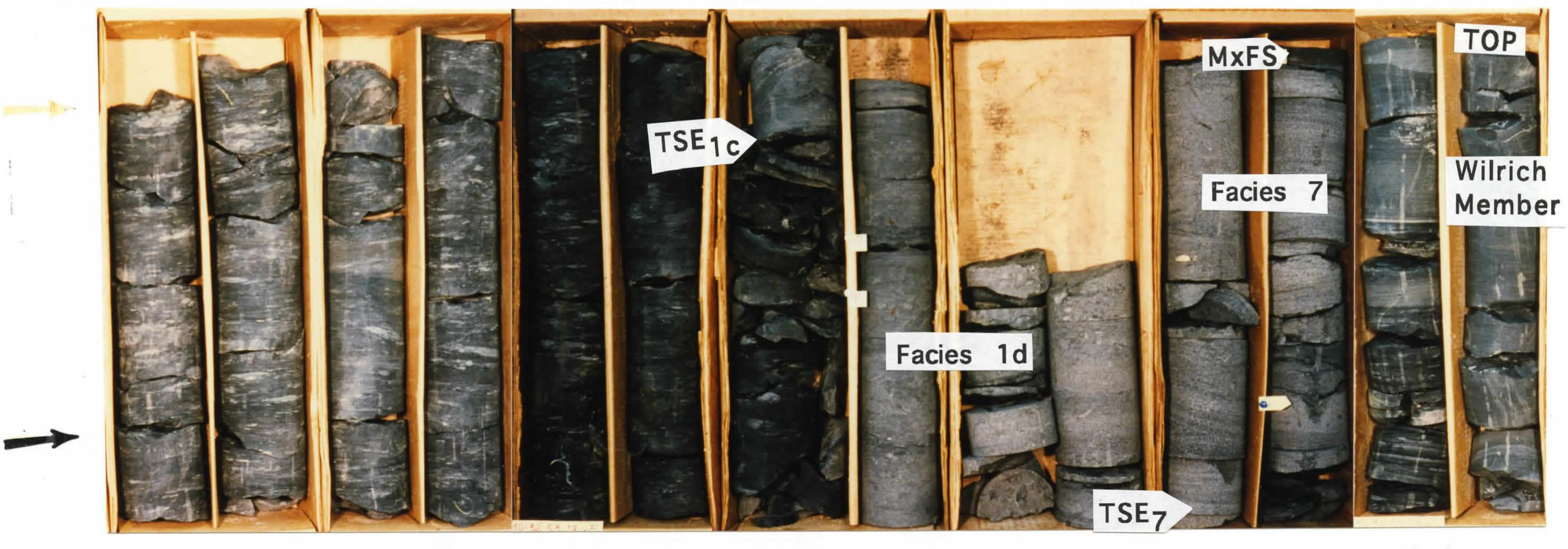
APPENDIX B2
7-20-53-18W5
4" CORE

SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
MxFS = Maximum Flooding Surface
FS = Flooding Surface



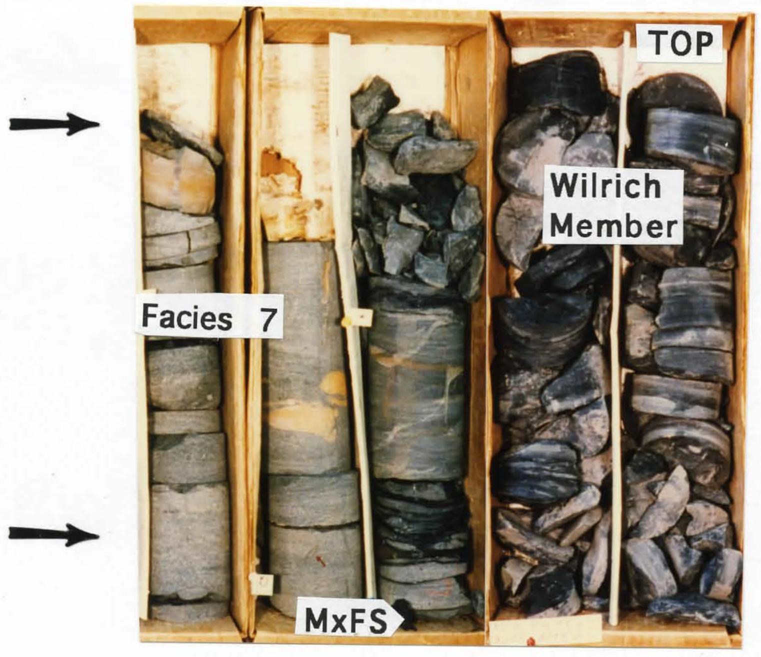
APPENDIX B3
10-32-53-17W5
4" CORE

SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
MxFS = Maximum Flooding Surface
FS = Flooding Surface



APPENDIX B4
10-5-54-17W5
4" CORE

SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
MxFS = Maximum Flooding Surface
FS = Flooding Surface



APPENDIX B5

3-14-54-19W5

3" CORE

SE = Surface of Erosion

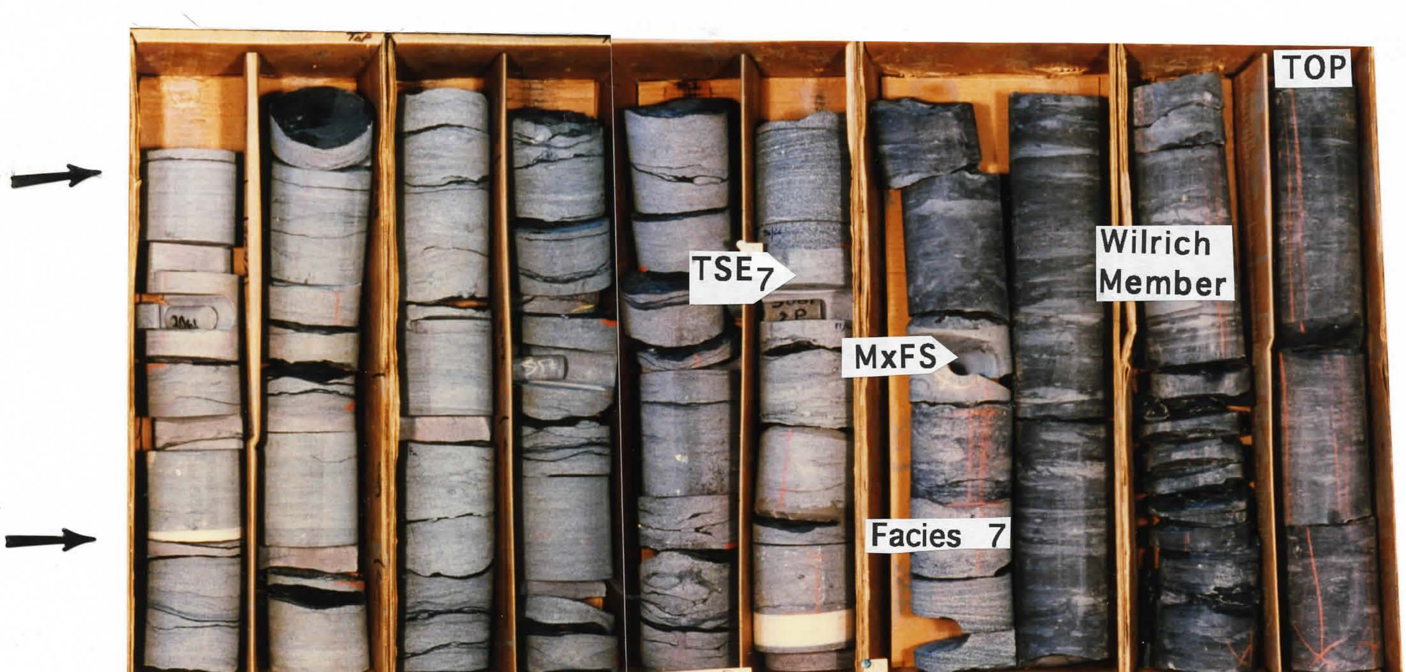
TSE = Transgressive Surface of Erosion

MxFS = Maximum Flooding Surface

FS = Flooding Surface

APPENDIX B6
3-24-57-19W5
4" CORE

SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
MxFS = Maximum Flooding Surface
FS = Flooding Surface



APPENDIX B7
14-14-53-20W5
4" CORE

SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
MxFS = Maximum Flooding Surface
FS = Flooding Surface

APPENDIX C


NW
SE
10-26-57-20
6-24-57-20
11-14-57-20
14-12-57-20
11-1-57-20
11-30-56-19
7-23-56-20
9-11-56-20
12-29-55-19
10-20-55-19
12-16-55-19
14-32-54-19
11-21-54-19
6-15-54-19
3-14-54-19
7-11-54-19
16-2-54-19
13-6-54-18
2-6-54-18
11-30-53-18
6-28-53-18
6-21-53-18
10-16-53-18
10-10-53-18
2-3-53-18
WILRICH MEMBER
DATUM
MxFS
TSE7
25 m
APPENDIX C1
NW-SE Log Cross-section A
All gamma ray and resistivity logs
See Figure 44 for location
SANDSTONE FACIES (1a,2a, 4, 3a and 5a)
TRANSGRESSIVE SHOREFACE (FACIES 7)
INTERB. MUD & SAND FACIES (6a and 6b)
MUDSTONE FACIES (1b, 1c, 2b, 3b and 5b)
ESTUARINE MOUTH-SAND FACIES (1d)
= Cored interval
SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
FS = Flooding Surface
MxFS = Maximum Flooding Surface
= Sandier-upward Gething marker

APPENDIX C2

NW-SE Log Cross-section B
All gamma ray and resistivity logs
See Figure 44 for location

APPENDIX C3

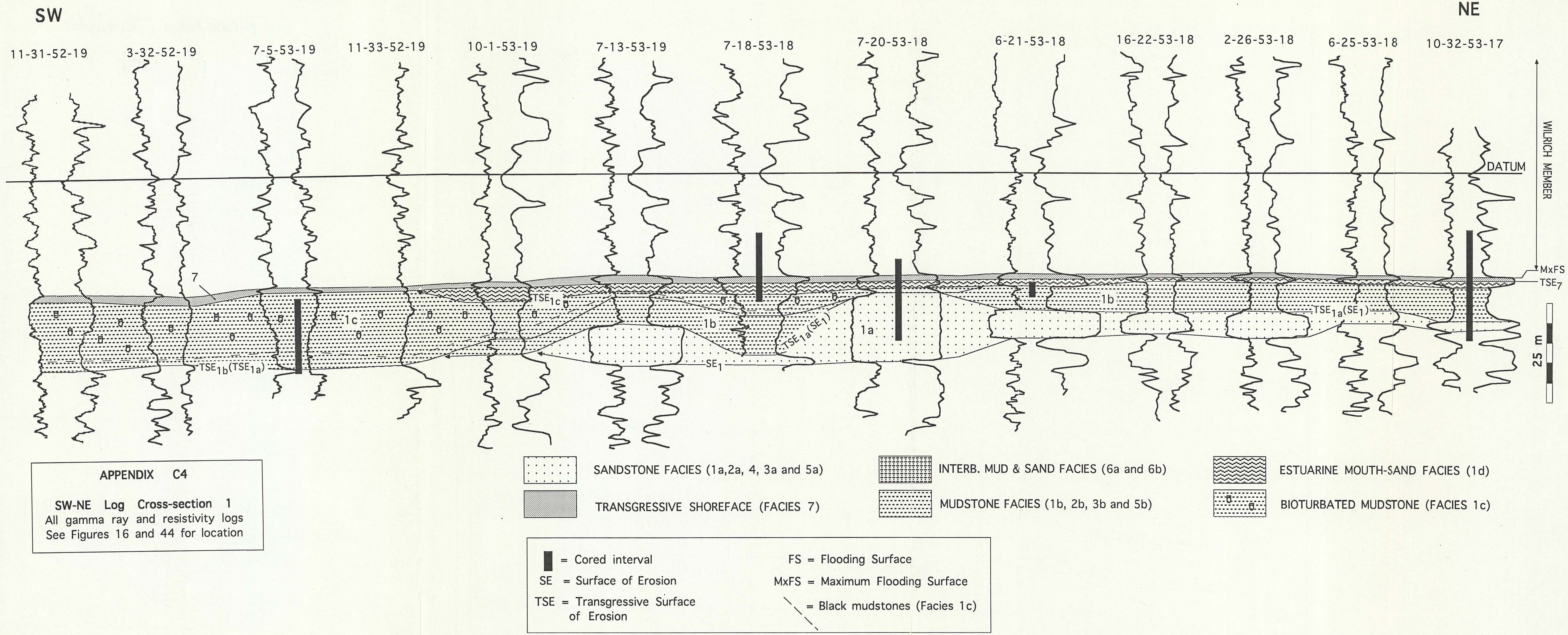
NW-SE Log Cross-section C
All gamma ray and resistivity logs
See Figure 44 for location

SANDSTONE FACIES (1a,2a, 4, 3a and 5a)
TRANSGRESSIVE SHOREFACE (FACIES 7)
INTERB. MUD & SAND FACIES (6a and 6b)
MUDSTONE FACIES (1b, 1c, 2b, 3b and 5b)
ESTUARINE MOUTH-SAND FACIES (1d)

▌ = Cored interval
SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
FS = Flooding Surface
MxFS = Maximum Flooding Surface
= Gradational contact

APPENDIX C4

SW-NE Log Cross-section 1
All gamma ray and resistivity logs
See Figures 16 and 44 for location

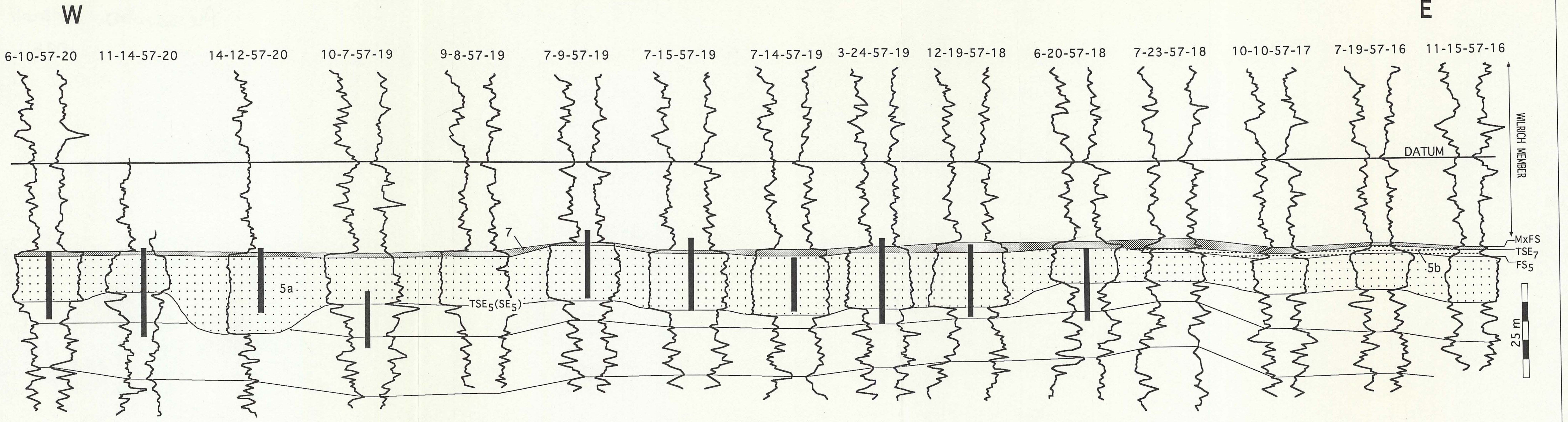


APPENDIX C5

NW-SE Log Cross-section 2
All gamma ray and resistivity logs
See Figures 18 and 44 for location

SANDSTONE FACIES (1a,2a, 4, 3a and 5a)
TRANSGRESSIVE SHOREFACE (FACIES 7)
INTERB. MUD & SAND FACIES (6a and 6b)
MUDSTONE FACIES (1b, 1c, 2b, 3b and 5b)
ESTUARINE MOUTH-SAND FACIES (1d)

▮ = Cored interval
SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
FS = Flooding Surface
MxFS = Maximum Flooding Surface
= Gradational contact



SANDSTONE FACIES (1a,2a, 4, 3a and 5a)

TRANSGRESSIVE SHOREFACE (FACIES 7)

INTERB. MUD & SAND FACIES (6a and 6b)

MUDSTONE FACIES (1b, 1c, 2b, 3b and 5b)

ESTUARINE MOUTH-SAND FACIES (1d)

APPENDIX C6

NW-SE Log Cross-section 5
All gamma ray and resistivity logs
See Figures 18 and 44 for location

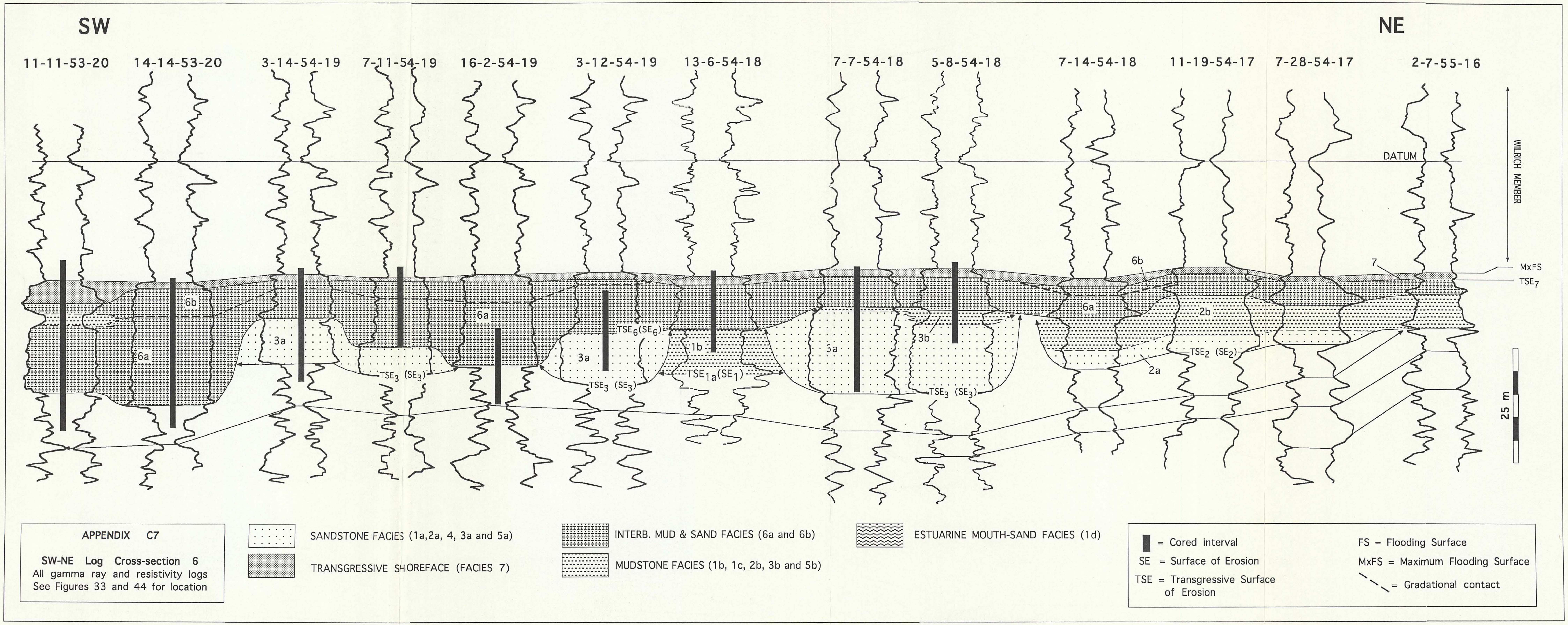
▮ = Cored interval

SE = Surface of Erosion

TSE = Transgressive Surface of Erosion

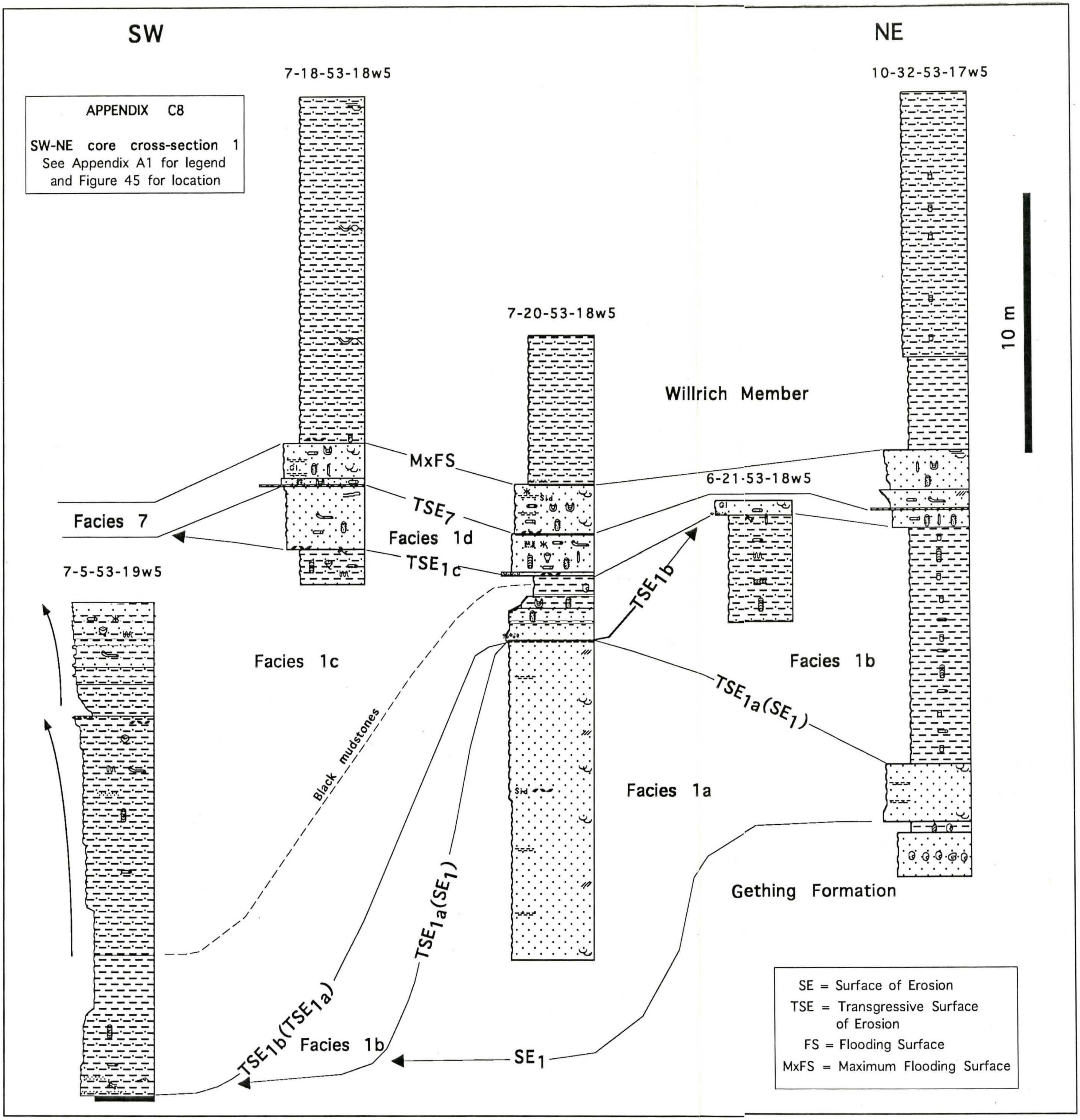
FS = Flooding Surface

MxFS = Maximum Flooding Surface

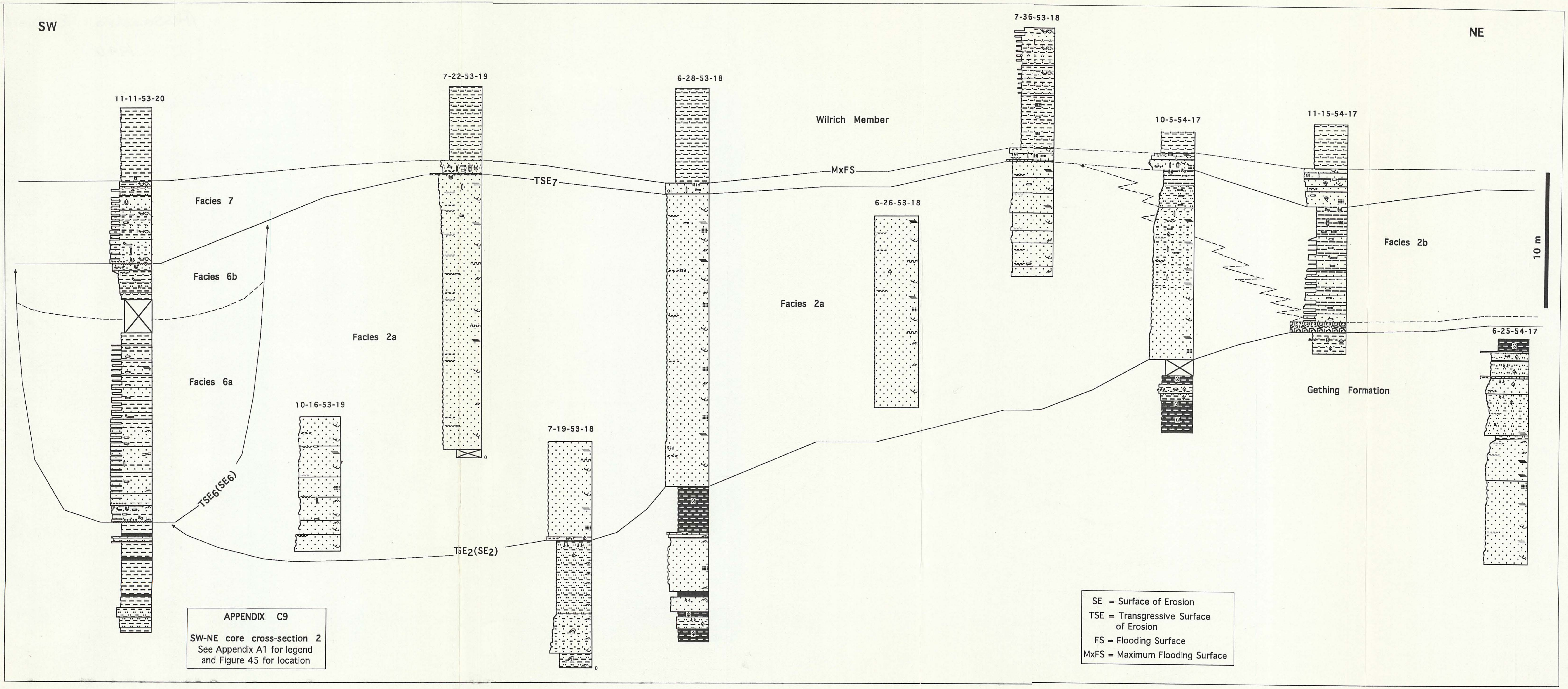


APPENDIX C7

SW-NE Log Cross-section 6
All gamma ray and resistivity logs
See Figures 33 and 44 for location

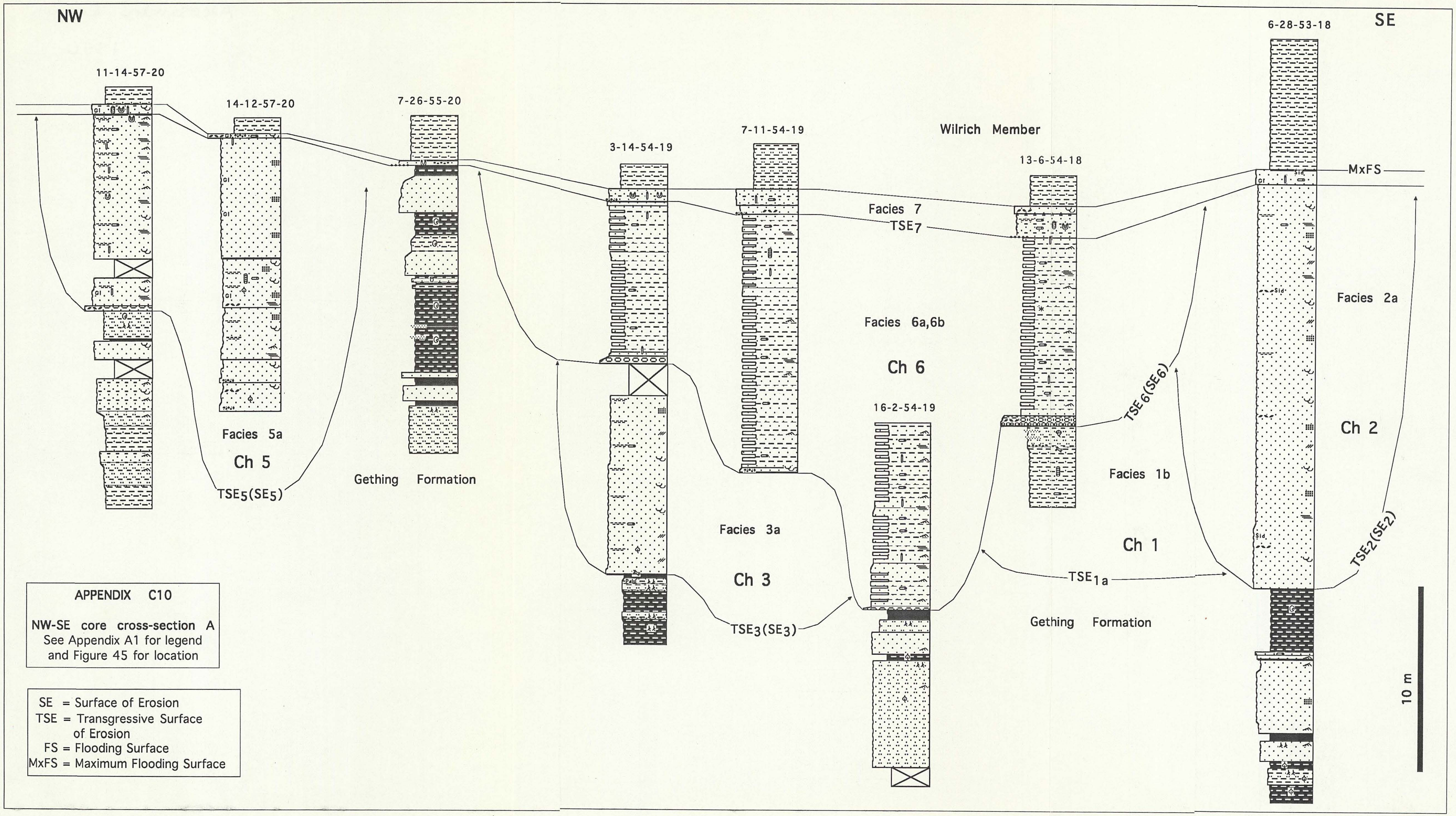


SW
NE
APPENDIX C8
SW-NE core cross-section 1
See Appendix A1 for legend and Figure 45 for location
7-18-53-18w5
10-32-53-17w5
7-20-53-18w5
6-21-53-18w5
7-5-53-19w5
10 m
Willrich Member
MxFS
TSE7
TSE1c
TSE1b
TSE1a(SE1)
TSE1b(TSE1a)
SE1
Facies 7
Facies 1d
Facies 1c
Facies 1b
Facies 1a
Black mudstones
Gething Formation
SE = Surface of Erosion
TSE = Transgressive Surface of Erosion
FS = Flooding Surface
MxFS = Maximum Flooding Surface



APPENDIX C9

SW-NE core cross-section 2
See Appendix A1 for legend
and Figure 45 for location



APPENDIX C10

NW-SE core cross-section A
See Appendix A1 for legend
and Figure 45 for location