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Evolution of Late Cretaceous-Early Tertiary depositional sequences in the Beaufort-Mackenzie Basin; Canada

Myers, Mark D., Ph.D.

University of Alaska Fairbanks, 1994

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EVOLUTION OF LATE CRETACEOUS-EARLY TERTIARY DEPOSITIONAL SEQUENCES IN THE BEAUFORT-MACKENZIE BASIN; CANADA

A

THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

By

Mark D. Myers, B.S., M.S.

Fairbanks, Alaska

May 1994

EVOLUTION OF LATE CRETACEOUS-EARLY TERTIARY DEPOSITIONAL SEQUENCES IN THE BEAUFORT-MACKENZIE BASIN; CANADA

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ABSTRACT

The Maastrichtian to Lower Eocene rocks of the Fish River and Aklak sequences of Arctic Canada's Beaufort-Mackenzie basin were deposited during the northward migration of a fold and thrust belt across a north-facing passive margin. Detailed outcrop analysis performed in this study has resulted in delineation of the depositional processes, environments and history of systems tracts contained within the Fish River sequence.

The Fish River sequence contains Maastrichtian to Lower Paleocene rocks of the Tent Island and Moose Channel Formations of the Fish River Group. This 1900 m thick terrigenous clastic succession consists of channelized conglomerate, sandstone and siltstone overlain by mudstone and capped by a large scale coarsening-upward package of interbedded mudstone, sandstone and conglomerate. Regional unconformities separate the Fish River Group from both the underlying shale of the Cenomanian to Turonian Boundary Creek Formation and the overlying conglomerate, sandstone, mudstone, and coal of the Paleocene to Eocene Aklak Member of the Reindeer Formation. The Fish River Group records a systematic vertical succession of depositional environments including submarine canyon, slope to outer shelf, prodelta, delta front and lower and upper delta plain. The succession of paleoenvironments, regional stratigraphic correlations and relationships, thickness and age control, and bounding unconformities suggest that the Fish River Group records the evolution of a complete type-1, second order, depositional sequence.

The Cuesta Creek Member at the base of the Fish River sequence consists of stacked fining-upward channel fills consisting of conglomerate, sandstone and siltstone. The channel fills contain a complex assemblage of high and low density turbidites, current deposits, debris flows, slumps, and slide blocks. These deposits record the complex fill history of a coarse-grained lowstand submarine canyon system.

The internal stratigraphic organization of the Fish River sequence records alternating periods of uplift and subsidence in the Beaufort-Mackenzie basin. The scale and timing of these episodes, combined with the environments of deposition and lithologic character of the rocks, suggests that the driving mechanism was alternating episodes of subsidence due to thrusting followed by flexural rebound.

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ACKNOWLEDGMENTS

Many people have contributed to this project and have provided support from inception to completion. I wish to thank my advisory committee of Dr. Keith Crowder, Dr. Wes Wallace, Dr. Don Triplehorn, Dr. Joe McGowen, Mr. Charles (Gil) Mull and Dr. Keith Watts. I gratefully acknowledge the field support provided to this project by ARCO Alaska which allowed me to use the preliminary field data that I gathered in 1985 while being employed as a exploration geologist. The project greatly benefited from the field observations of ARCO Alaska geologists Mr. Jim Gonziewski, Ms. Julie Houle, and ARCO research advisor Dr. Joe McGowen. Dr. McGowen's willingness to serve as a member of my advisory committee has greatly enhanced this dissertation. Field work during the summer of 1987 was supported by the State of Alaska, Divisions of Oil and Gas (DOG) and Geological and Geophysical Surveys (DGGS), the Canadian Institute of Sedimentary and Petroleum Geology (ISPG) and the University of Alaska, Department of Geology and Geophysics Tectonics and Sedimentation Research Group. I am grateful for assistance in the field during the 1987 field season from Dr. John Decker and Mr. Tom Smith. Support and equipment for petrographic analysis was provided by Dr. Ken Helmold of ARCO Research, Mr. Moe Lynch of the Minerals Management Service and Dr. John Decker of DGGS. A special thanks to Mr. Tom Smith, Mr. Richard Kornbrath and Mr. James Hansen of the Resource Evaluation Section of the Division of Oil and Gas for the employment and constant support provided me throughout my degree program.

This dissertation benefited greatly from discussions with Dr. Jim Dixon and Dr. Larry Lane of the ISPG, Mr. Giles Morrell of the Canadian Oil and Gas Lands Administration and Dr. John Decker and Mr. Gil Mull of DGGS.

INTRODUCTION

Objectives of this Study

Exposed clastic sedimentary rocks in Arctic Alaska and Canada are commonly complexly deformed within fold and thrust belts. Field studies are commonly limited by structural complications and poor quality exposures. The coastal plain outcrops of the Boundary Creek Formation, Cuesta Creek and mudstone member of the Tent Island Formation and sandstone and Ministicoog members of the Moose Channel Formation are some of the best exposures of Upper Cretaceous to Lower Tertiary rocks in western arctic Canada or northern Alaska. They also encompass a full spectrum of environments of deposition ranging from deep marine to nonmarine. The main goal of this study has been to describe and interpret in detail the sedimentology of these units, including their internal organization and the processes by which they were deposited. A particularly important objective of this study is to describe in detail the internal organization and sedimentary structures and to interpret the depositional processes within submarine canyon deposits of the Cuesta Creek Member of the Tent Island Formation. Submarine canyons are an important element in deep water turbidite systems, yet they are very poorly understood and rarely identified in outcrop. Most literature on canyon-fan systems has been devoted to the fans with little attention spent on the canyon. This study provides a well documented example of a canyon system.

Sequence stratigraphy is an important tool for making more accurate basin analyses, paleogeographic reconstructions, geologic history interpretation and resource evaluations of sedimentary basins (Vail and others, 1991). This study uses regional subsurface and high resolution outcrop data to divide Upper Cretaceous and Lower Tertiary rocks of the Beaufort-Mackenzie basin into depositional sequences and systems tracts. Previously published sequence stratigraphic studies in Arctic Alaska and Canada have relied almost exclusively on subsurface data and have provided a reasonable framework but very little detail. By integrating high resolution outcrop description (detailing a complete suite of deep water to nonmarine depositional environments) with regional subsurface correlation, this study is the first to delineate systems tracts within these sequences. The Upper Cretaceous and Lower Tertiary rocks which are the focus of this study were deposited in a setting where the leading edge of a fold and thrust belt migrated northward across a north-facing passive continental margin. There are no published detailed sequence stratigraphic studies or models for this tectonic setting. The well constrained systems tracts delineated by this study provide a detailed framework for analyzing the depositional history, reservoir continuity and reservoir distribution in this and other similar tectonic settings.

A final goal of this study has been the examination of the petrographic and diagenetic history of the Fish River Group. An understanding of the composition and diagenetic history of these immature sandstones is critical to the prediction of reservoir quality in the subsurface. It also provides important information on the post-burial history of the study area.

Study Area and Methods of Study

In this study 54 localities were examined and 30 detailed stratigraphic sections (Appendix 1) of the Upper Cretaceous Boundary Creek Shale, the Upper Cretaceous and Lower Tertiary Fish River Group and Aklak Member of the Reindeer Formation were measured from outcrops on the coastal plain just west of the modern Mackenzie River delta in the

Yukon and Northwest Territories of Arctic Canada (Figure 1). Field work for this project was accomplished in Canada in the summers of 1985 and 1988. Field work during the 1985 field season was accomplished while I was employed by ARCO Alaska Inc. During that field season I was the principal field geologist (party chief) and worked in conjunction with three other ARCO geologists who provided valuable expertise and assistance for varying periods of time in the field. Those geologists are Jim Gonsiewski, Julie Houle and Joe McGowen. Dr. McGowen has continued to provide expertise through his role as a valued member of my dissertation committee. The 1985 field party worked as a single team and I described all measured sections and localities in this study. During the 1988 field season, I was employed as a student intern for the State of Alaska, Division of Oil and Gas. During the 1988 field season, I received assistance while measuring sections from Division of Oil and Gas petroleum geologist Tom Smith (1 week) and Division of Geological and Geophysical Surveys geologist John Decker (2 days). I performed supporting field work on the North Slope of Alaska in the summers of 1988-1990 in conjunction with the Division of Geological and Geophysical Surveys and supported by the Division of Oil and Gas. Stratigraphic sections were measured using a Jacob staff or a tape measure and Brunton compass.

I performed petrographic and scanning electron microscope (SEM) analyses on thin sections from outcrops to determine composition, compositional variations, diagenetic history and petroleum reservoir potential. In this study I examined 120 thin sections from outcrops within the field area. All thin sections were impregnated with blue epoxy and stained for K-feldspar with a sodium cobaltinitrate solution. Twenty-four of these thin sections were selected for quantitative point count analysis (Plate 1). I performed the SEM analysis at the Minerals Management Service laboratory in Anchorage.

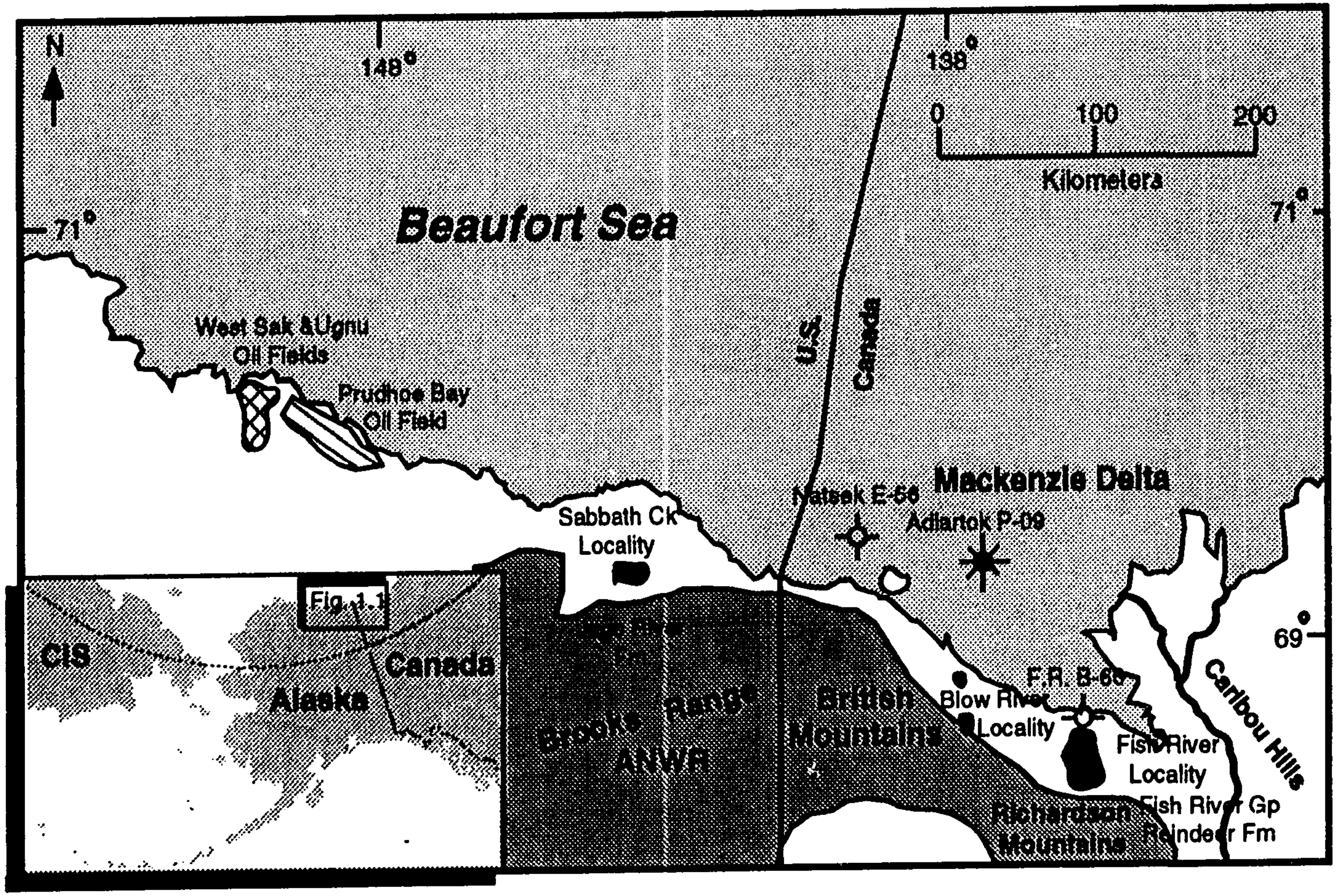


Figure 1. Location maps.
1.1. General locality map displaying the location of key outcrops and wells examined for this study.

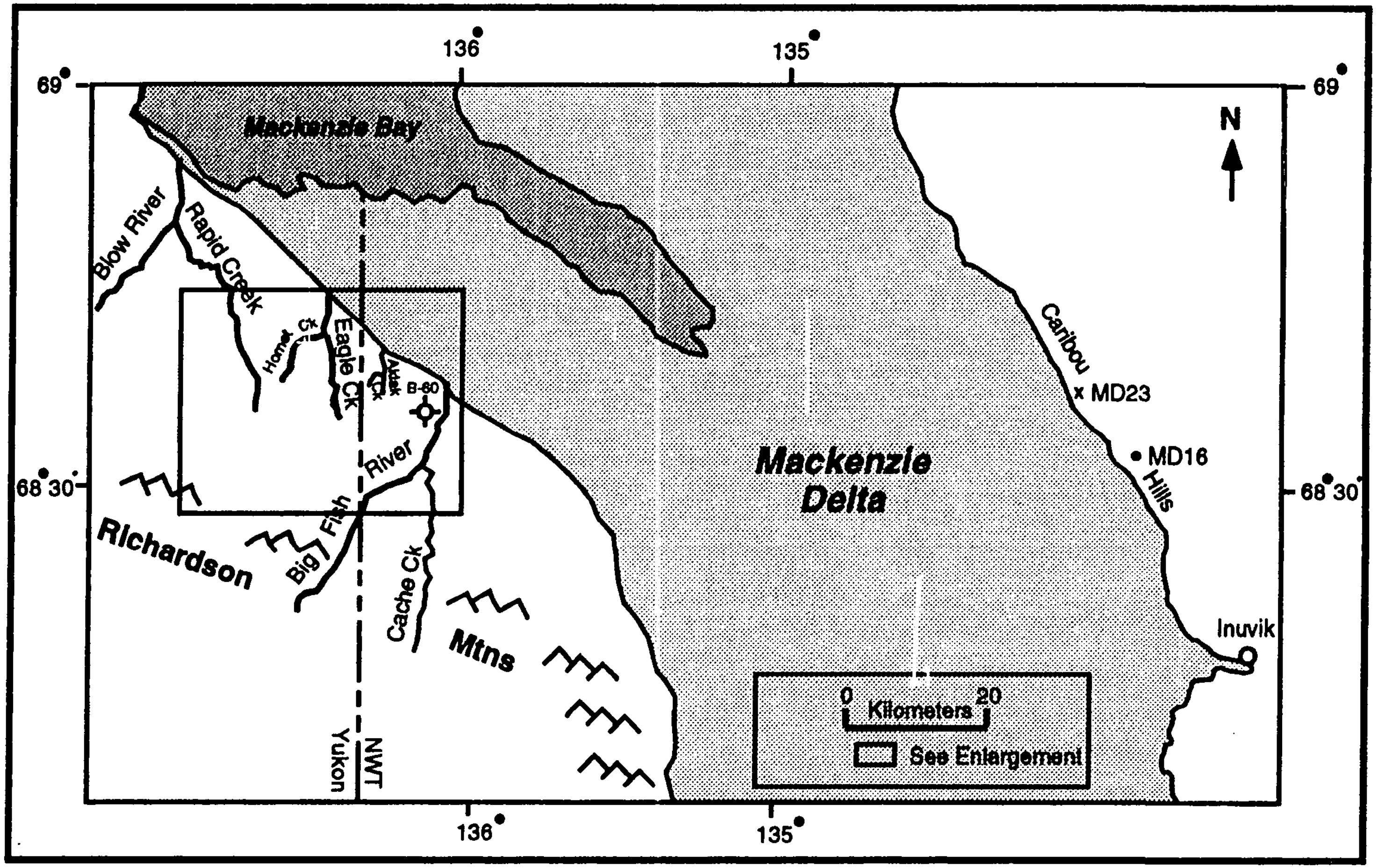


Figure 1.2. Location of Canadian Study Area. **x** = measured section, •= field locality (no measured section). Area in box is enlarged in Figure 1.3.

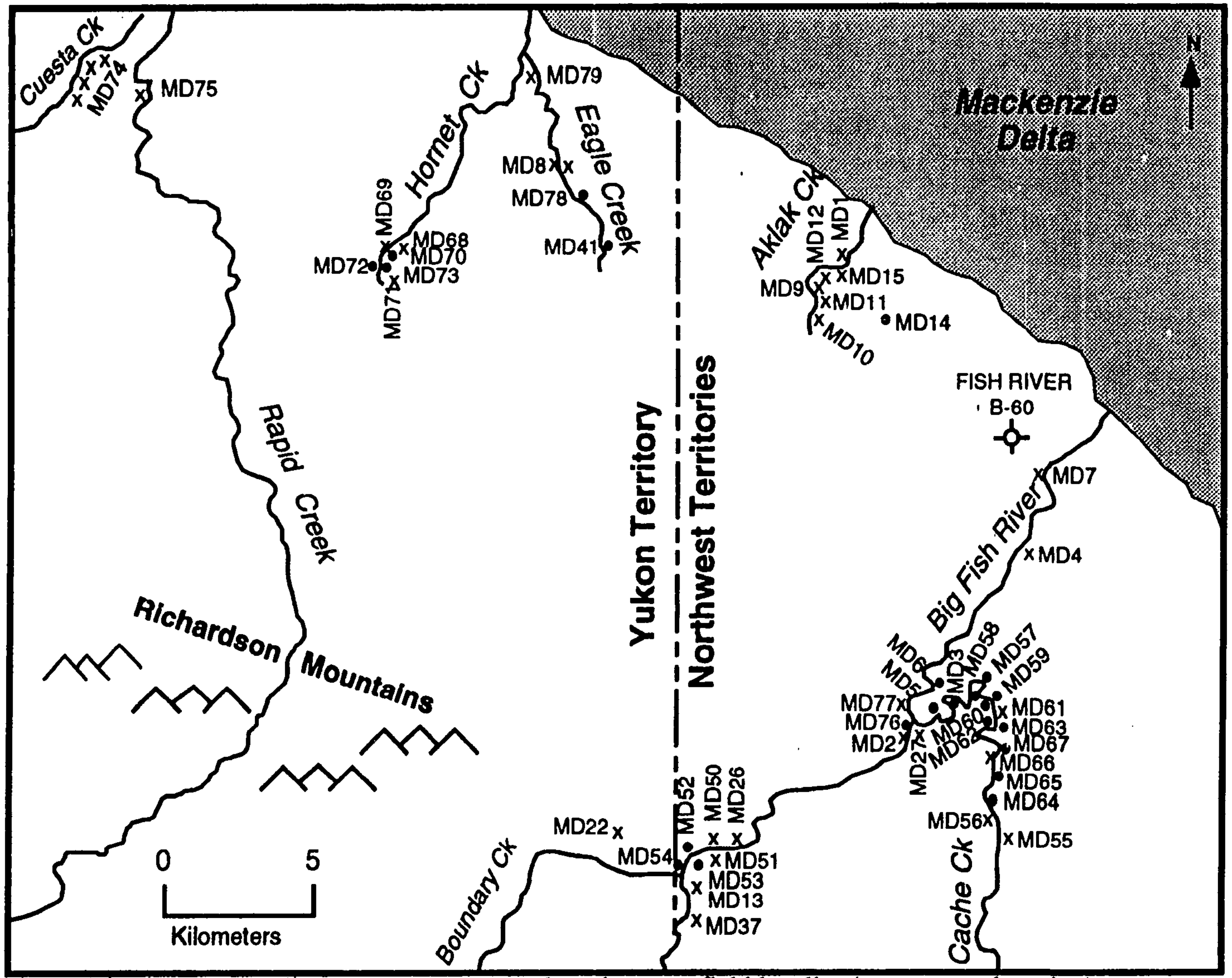


Figure 1.3. Outcrop locality map. x = measured section, ● = field locality (no measured section).

Subsurface information discussed in this study comes from publicly available well and seismic data, as well as from published and unpublished reports made available to the author and cited throughout the dissertation. In particular, the Chevron Canada Pex et al. Fish River B-60 and Dome Pacific Pex et al. Natsek E-56 wells and the Dome Petroleum D-38 and D-47 reflection seismic lines were heavily relied on for interpreting regional stratigraphic relationships and correlation.

Other studies have addressed the regional distribution of the Boundary Creek, Tent Island, Moose Channel and Reindeer Formations using a much larger regional grid of offshore seismic data and well control supported by age control (Dietrich and others, 1989a & b; Dixon, 1986; Dixon and others, 1985, 1988, and 1989; Kyer, 1987; McMillen and O'Sullivan, 1992). Greater reliance on regional subsurface correlation as an interpretation tool was not attempted in this study due to the lack of availability of reliable age control in most publicly available wells. This created a general lack of confidence in the ability to differentiate the Moose Channel Formation from the overlying Reindeer Formation in many wells. The ability to perform this analysis would require extensive access to proprietary oil industry seismic, well, and paleontological data not available to me.

Regional Geologic Setting

The stratigraphic succession of Arctic North America from the Mackenzie delta to the western North Slope of Alaska has been divided into four major sequences based on contrasting tectonic style, provenance, and lithology. These sequences are Inuvikian (Proterozoic), Franklinian (Cambrian to Devonian), Ellesmerian (Mississippian to Lower Cretaceous) and Brookian (Lower Cretaceous to present) (Lerand, 1973; Young, 1978;

Norris and Yorath, 1981; Grantz and May, 1982; Dietrich and others, 1985; Hubbard and others, 1987).

Rocks of the Inuvikian and Franklinian sequences (Figure 2) are commonly referred to as pre-Mississippian "basement" (Bird and Molenaar, 1987; Grantz and May, 1982). The Inuvikian sequence contains carbonates, clastic rocks, basic volcanic rocks and quartzites (Bird and Molenaar, 1987; Dietrich and others, 1985). The Franklinian sequence consists of a variable assemblage of rocks including deformed and weakly metamorphosed shale, quartzite, graywacke, platform carbonate, radiolarian chert, graptolitic shale, scattered granitic plutons, and mafic to intermediate volcanogenic sedimentary rocks (Hubbard and others, 1987). Structural deformation during the mid-Paleozoic Ellesmerian orogeny consolidated Franklinian and Inuvikian rocks.

Following uplift and widespread regional erosion, a thick succession of platform carbonate and terrigenous clastic rocks of the Ellesmerian sequence buried the Arctic platform (Grantz and May, 1982; Hubbard and others, 1987; McMillen and O'Sullivan, 1992; Wood and Armstrong, 1975). These rocks record deposition along a slowly subsiding continental margin in which the land area was to the north and the ocean to the south (Bird and Molenaar, 1987). Sandstone and conglomerate of the Ellesmerian sequence are compositionally and texturally mature, in contrast to the overlying compositionally immature terrigenous clastic rocks of the Brookian sequence (Crowder, 1990).

Initiation of rifting that created the Beaufort continental margin began in the Jurassic, with actual break-up in the early Cretaceous. Sea floor spreading in the Canada basin continued until the Maastrichtian (Grantz and others, 1987; Hubbard and others, 1987; Dixon and others, 1992b). Jurassic and Lower Cretaceous sedimentary rocks associated with the

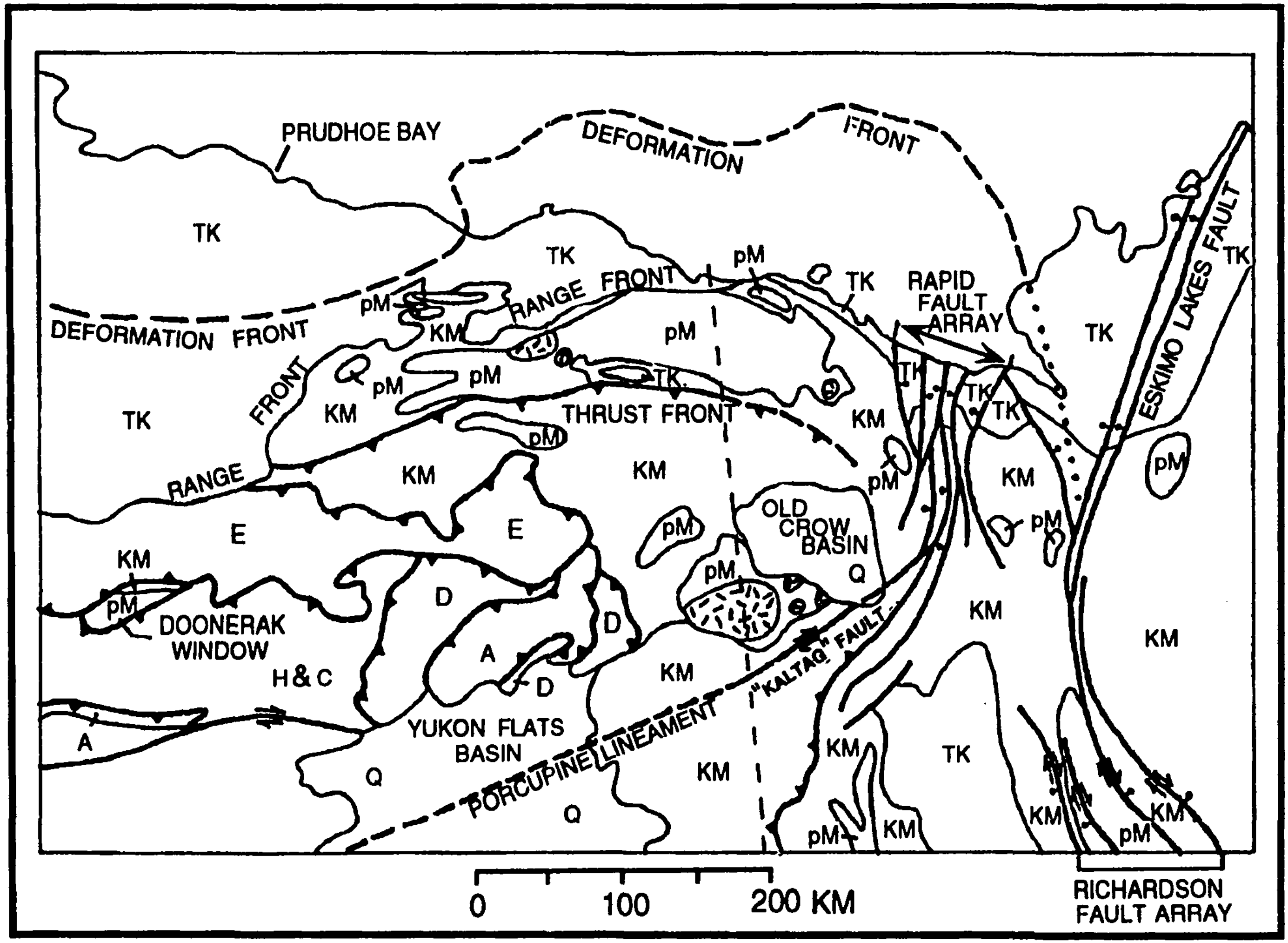


Figure 2. Generalized geologic map of northeastern Alaska and northwestern Canada. Unpublished map compiled by W. Wallace.

Autochthonous and parautochtonous rocks

Q	Quaternary deposits-undifferentiated
TK	Brookian Sequence: Tertiary and Cretaceous sedimentary rocks
KM	Ellesmerian Sequence: Cretaceous to Mississippian sedimentary rocks
pM	Inuvikian and Franklinian Sequences: Pre-Mississippian rocks
▨	Granitic Intrusive rocks

Allochthonous rocks of the Brooks Range

D	Delong Mountains Subterrane: Cretaceous to Mississippian sedimentary rocks
A	Angayucham Terrane: Jurassic to Devonian basalts and pelagic metasedimentary rocks and Middle Jurassic ultramafic and gabbroic rocks
H & C	Hammond and Coldfoot Subterranes: Metasedimentary and metaigneous rocks of Paleozoic to Proterozoic protolith age
E	Endicott Mountains Allochthon: Lower Cretaceous to Devonian sedimentary rocks

Figure 2.1. Key for general geologic map of northeastern Alaska and northwestern Canada.

creation of the passive continental margin are either included within the Ellesmerian sequence or placed into a separate "Beaufortian" sequence. (Hubbard and others, 1987).

The Brookian sequence records a reversal of basin polarity and a complete change in structural and stratigraphic style from the underlying Ellesmerian sequence. It includes all sedimentary rocks derived from the Brooks Range orogenic belt to the south (Hubbard and others, 1987). Uplift and deformation in the central and southern Brooks range, beginning in the Jurassic, created a southern source area for the thick synorogenic and postorogenic clastic deposits that flooded the Arctic platform during late Mesozoic and Tertiary time (Grantz and May, 1982). The evolution of the Brookian sequence records a progressive migration of the thrust front and associated foredeeps to the north and east. This migration continues today in the eastern Beaufort Sea, where the passive margin bounding the Canada basin is being overridden by the thrust front (Hubbard and others, 1987).

Organization of Cretaceous to Holocene Strata in the Beaufort-Mackenzie Basin

In the northern Yukon Territory and the northwestern District of Mackenzie, Hauterivian to Albian strata are separated from Upper Cretaceous to Holocene strata by a major regional unconformity. This unconformity marks a significant change in tectonics and sedimentation in the area (Dixon and others, 1985; Young, 1973). Underlying the unconformity are Hauterivian to Albian deposits associated with both extensional and compressional tectonics; overlying it are Upper Cretaceous to Holocene deposits primarily associated with compressional tectonics (Dixon and others, 1985).

During Hauterivian to Aptian time, extensional tectonics associated with the origin of the Canada basin resulted in normal faulting and associated folding throughout the Mackenzie delta region (Dixon, 1992b). This resulted in the creation of numerous local structures, including the Cache Creek uplift, Eskimo Lakes arch and the Tununuk high (Figure 3). During Hauterivian to Aptian time, significant accumulations of nonmarine sediment derived from the east and southeast were deposited in the Mackenzie delta and Anderson basin areas (Figure 3). Late Aptian to Albian extension created the Kugmallit, Blow, and Keele bathymetric troughs (Figure 3; Dixon and others, 1985; Dietrich and others, 1989a). During Albian time, Cordilleran compressional structures began to control sedimentation. The Blow and Keele troughs became foredeeps that were filled with sediments from the rising Cordillera and ancestral Brooks Range to the south and west (Dixon, 1992b).

The Late Cretaceous to Pliocene history of the Beaufort-Mackenzie area reflects post-rift sea-floor spreading in the Canada basin, thermal subsidence of the continental margins and the dominance of the Cordilleran orogen as a clastic source area and a prominent tectonic influence. By Cenomanian time, the Canada basin had opened and Late Cretaceous to Early Tertiary orogenesis gave rise to the major thrust faults and folds in the mountains south and southwest of the Beaufort-Mackenzie basin, as well as associated normal and strike-slip faults. This orogeny tended to overprint the "pre-Late Cretaceous" tectonic elements, but in many instances the effect was to rejuvenate them (Dixon, 1986). This change in tectonic regimes is marked by a major regional sub-Cenomanian unconformity (Young, 1973; Dixon and others, 1985; Dixon, 1986).

The Tertiary structural history of the Beaufort-Mackenzie basin included multiple periods of compressional and gravity-induced tectonics. Deformation reached its peak in the Middle Eocene and continued to the Late Miocene with the creation of a major fold and thrust belt in the northern Yukon Territory and adjacent offshore areas (Dixon and others, 1992b).

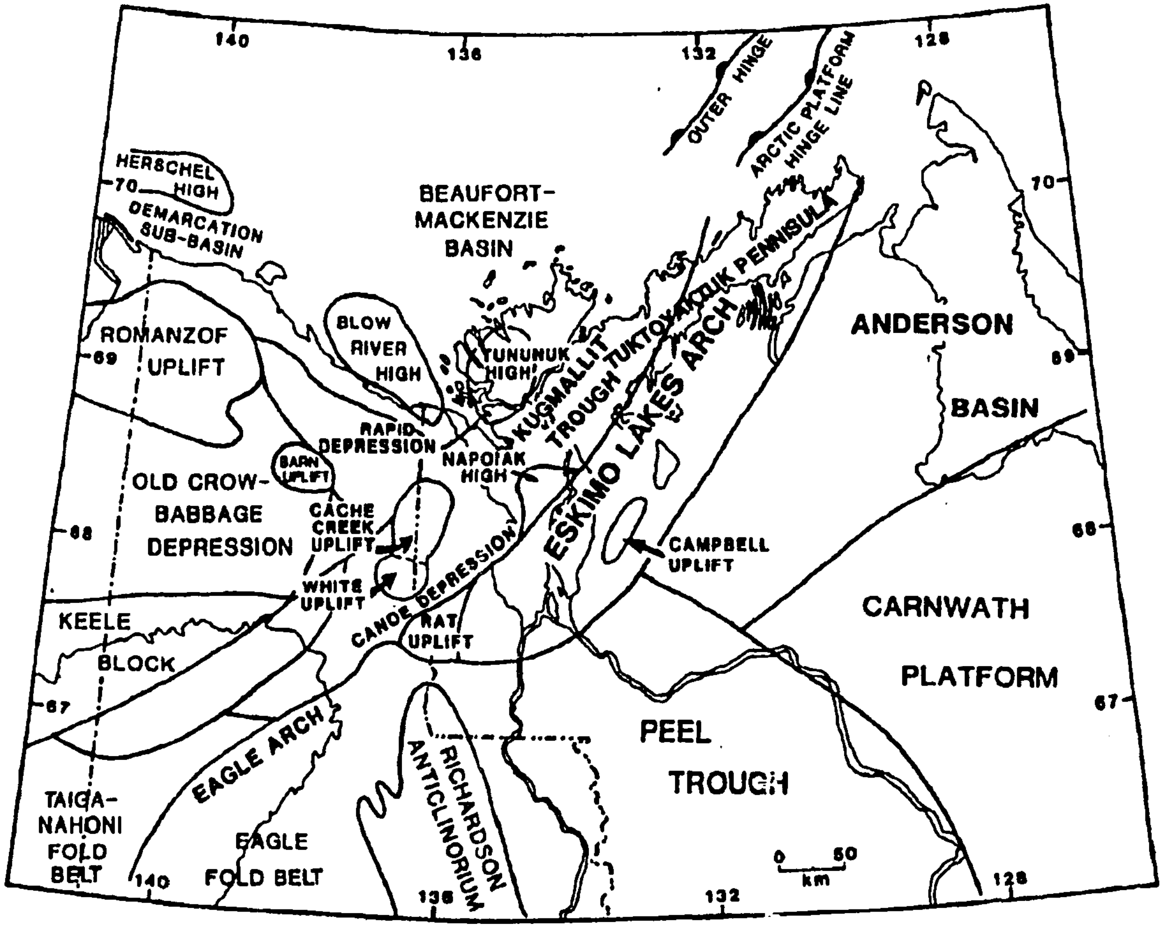


Figure 3. Tectonic elements of northwestern Canada. From Dixon and others (1985).

Major tectonic elements created by this deformation include the Rapid depression, Blow River high, the Herschel high and the Demarcation subbasin (Figure 3). The fold and thrust belt dies out to the east and northeast, where shale diapirs, listric growth normal faults, and associated roll-over anticlines are the dominant structural elements (Nentwich and Yole, 1982; Lane, 1988; Dietrich and others, 1989a & b; Dietrich and Lane, 1992). Since the Pliocene, deformation has been minimal, although in northeastern Alaska deformation continues today (Dietrich and others, 1989a).

The depositional history of the Beaufort-Mackenzie Basin has been divided into four "tectonostratigraphic phases," each terminating with the development of a regional unconformity (Figure 4; Dixon and others, 1992b). The first tectonostratigraphic phase occurred during the Cenomanian to Campanian, when deep water sediments of the Boundary Creek and Smoking Hills Formations were deposited in the Beaufort-Mackenzie area. Dixon (1992a) interprets these formations to be the basinward equivalents of nonmarine to shelf clastic successions that are present 200-250 kilometers to the south and southwest in the Eagle arch and Peel trough areas (Figure 3). In the Beaufort-Mackenzie basin, the Boundary Creek and Smoking Hills Formations rest unconformably on Albian flysch (Dixon, 1992b). This unconformity separates dense, highly compacted, brittlely fractured Middle Albian strata from less dense, less compacted, plastically deformed Upper Cretaceous strata (Dixon, 1992b). The unconformity marks the boundary betwen the upper and lower divisions of the Brookian in the Beaufort-Mackenzie basin.

The second tectonostratigraphic phase was initiated when Late Cretaceous Cordilleran orogenic activity caused a significant northward migration of shoreline/deltaic sedimentation. By the Maastrichtian, shallow marine sediments were being deposited on the Beaufort Sea continental margin (Dixon, 1986). On the southern margin of the

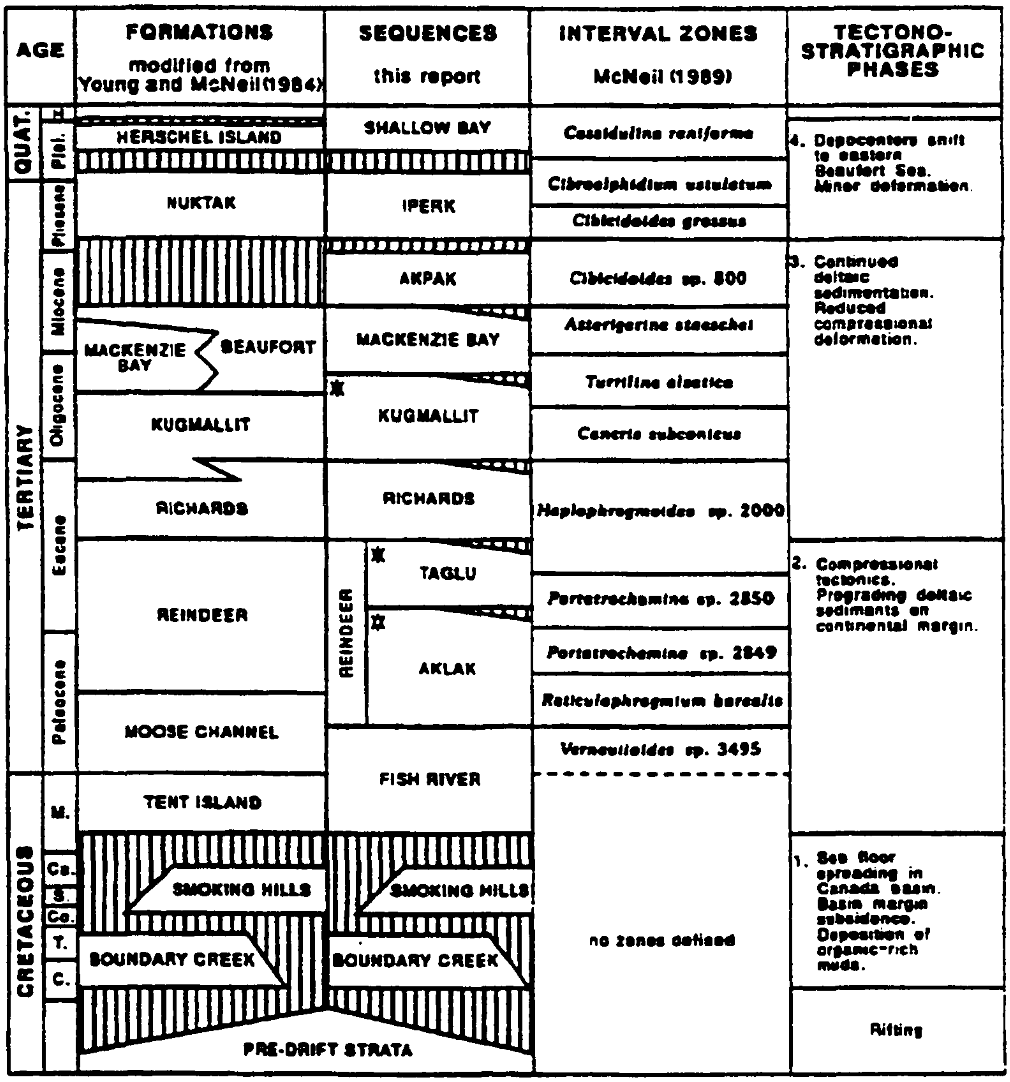


Figure 4. Stratigraphic nomenclature and summary of tectono-stratigraphic phases for the Beaufort-Mackenzie basin. From Dixon and others (1992b).

Beaufort-Mackenzie basin, this large shift in sedimentation is marked by a type-1 unconformity (Van Wagoner and others, 1988) that separates the Boundary Creek and Smoking Hills Formations from the overlying Tent Island Formation (Figure 4; Myers, 1992; Dixon and others, 1992a & b). The Fish River Group (consisting of the Tent Island and Moose Channel Formations) was the first of at least six documented deltaic successions and nine transgressive-regressive sequences which, based on well and reflection seismic data, deposited a maximum basin fill of 12-16 km (Willumsen and Cote, 1982; Dixon and others, 1992b). Deposition from the late Maastrichtian to the Middle Eocene was centered in the southwestern part of the Canadian Beaufort Sea in the region of the modern Mackenzie Delta. A regional Middle Eocene unconformity marks the boundary between the Reindeer and Richards Formations (Figure 4; Dixon and others, 1992b). This unconformity has been documented throughout the eastern Beaufort Sea in both Canada and Alaska and is interpreted to represent the culmination of a major compressional event (Hubbard and others, 1987; Dixon and others, 1992b; McMillen and O'Sullivan, 1992).

During the third tectonostratigraphic phase (Late Eocene to Late Miocene), compression continued but with progressively decreasing intensity. Depocenters migrated northward in the Oligocene and westward in the Miocene. These depocenters underlie the central Canadian Beaufort Sea (Dixon and others, 1992b). The fourth "tectonostratigraphic phase" is represented by Pliocene, and possibly lower Pleistocene, strata which were deposited during a period of only minor deformation. The depocenter during this phase had shifted back to the eastern Canadian Beaufort Sea (Dixon and others, 1992b).

The focus of this study are the Upper Cretaceous-Lower Tertiary sedimentary rocks of the Upper Brookian division. The lithostratigraphy of these rocks has been previously described by Mountjoy (1967), Holmes (1972), Holmes and Oliver (1973), and Young

(1972, 1973, 1975). Young (1975) identified rocks of Late Cretaceous and Early Tertiary age which crop out along the Big Fish River, Cache Creek, Eagle Creek and other streams and rivers on the coastal plain north of the Richardson Mountains and west of the Mackenzie delta (Figure 1.3). These rocks include, in ascending stratigraphic succession: (1) the Boundary Creek Formation, (2) the Cuesta Creek and mudstone members of the Tent Island Formation, (3) the sandstone and Ministicoog members of the Moose Channel Formation and (4) the Aklak Member of the Reindeer Formation (Figure 5). As has been previously mentioned, the Fish River Group is composed of the Tent Island and Moose Channel Formations.

As summarized above, the Upper Cretaceous-Lower Tertiary sedimentary rocks of the upper Brookian division which are the focus of this study were deposited in a very complex tectonic setting. These rocks were deposited in response to accommodation created by both thermal subsidence on the southern passive continental margin of the Canada basin and structural loading from a northward-and eastward-verging fold and thrust belt. The sedimentary rocks of the Fish River Group record deposition influenced by this unusual interplay between passive margin and fold and thrust belt tectonic settings. Understanding the depositional history of the Fish River Group is important in understanding the overall depositional history of the Beaufort-Mackenzie Basin.

Comparison of Nomenclature Between Arctic Alaska and Canada

In Arctic Alaska, the Brookian sequence of Lerand (1973) has been divided into three depositional megaseqences by Hubbard and others (1987). The middle Brookian megasequence is Middle Cenomanian to Early Eocene in age. Lithostratigraphic units

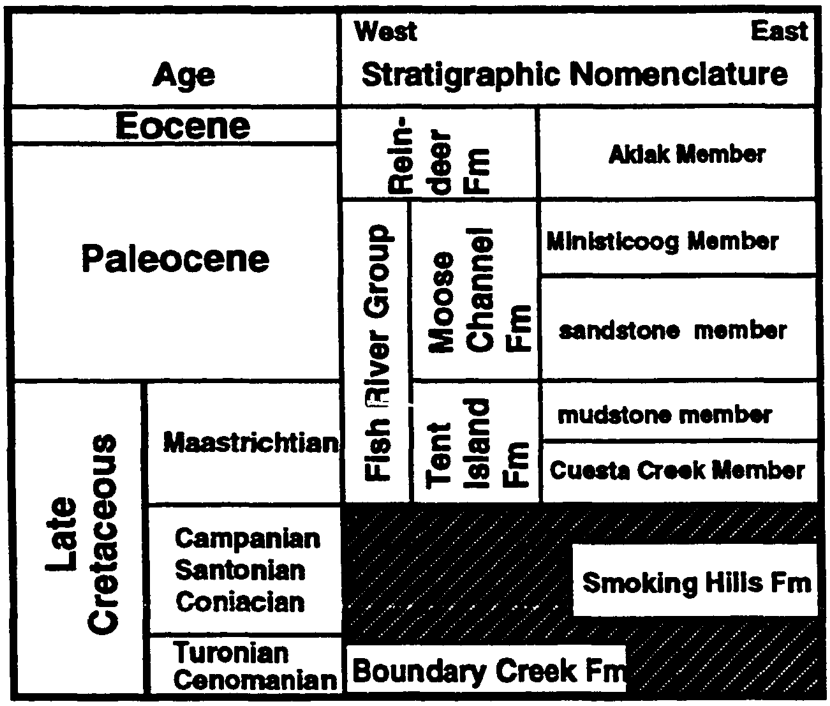


Figure 5. Upper Cretaceous and Lower Tertiary lithostratigraphy of the Beaufort-Mackenzie basin. After Dixon and others (1992a).

included within the middle Brookian depositional megasequence include the Colville Group and the Sagwon Member of the Sagavanirktok Formation on the central North Slope, and the Hue Shale, Canning Formation, Jago River Formation, and the Sagwon Member of the Sagavanirktok Formation on the eastern North Slope (Figure 6). The age equivalent lithostratigraphic units in the Beaufort-Mackenzie basin are the Boundary Creek, Tent Island, Moose Channel and Reindeer Formations (Figure 6). The unconformities which bound the middle Brookian depositional megasequence in Alaska are time equivalent to those that bound the second tectonostratigraphic phase of Dixon and others (1992b).

Petroleum Potential

The Mackenzie delta-Canadian Beaufort Sea region of Canada is a major petroleum province and among the most promising areas for exploration in North America. Discovered resources in the region are estimated to be 1.5 to 2.0 billion barrels of oil (BBO) and 10.4 to 12.6 trillion cubic feet of gas (TCF) from 49 discoveries. The mean estimate of potential resources is 7.1 BBO and 68 TCF of gas (Dixon and others, 1988). Although over 200 wells have been drilled in this region, it is still a frontier petroleum province. Most of the undiscovered hydrocarbon potential is likely to occur within the Brookian sequence. Economic interest in the Fish River Group and Aklak Member of the Reindeer Formation as a hydrocarbon reservoir has been greatly increased by the discovery of an estimated 226 million barrel oil field in these reservoirs by the Adlartok well (Dixon and others, 1988).

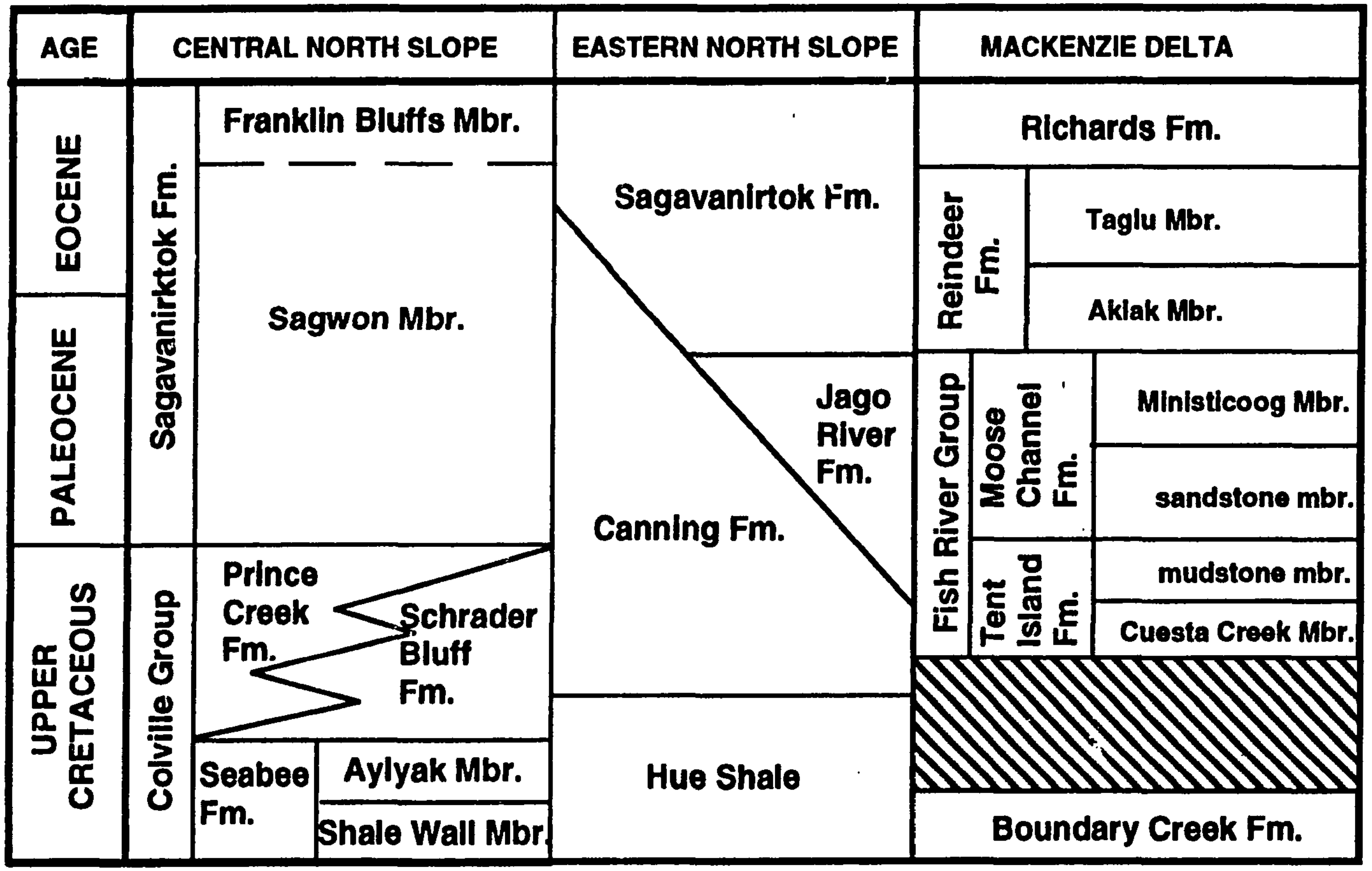


Figure 6. Comparative stratigraphic columns of the Beaufort-Mackenzie basin and the North Slope of Alaska.

Additionally, the geology of the Mackenzie delta-Canadian Beaufort Sea region is central to the evaluation of the petroleum potential to the west on the coastal plain of the Arctic National Wildlife Refuge (ANWR) of Alaska and the adjacent Beaufort Sea.

DEPOSITION OF THE BOUNDARY CREEK AND SMOKING HILLS FORMATIONS

The Boundary Creek Formation underlies the Fish River Group. It is significant both as a key to understanding the depositional history of the overlying Fish River Group and as a potential petroleum source rock. The Boundary Creek Formation consists of up to 1100 meters of organic rich bentonitic shale which unconformably overlies ironstone and shale of Albian age (Young, 1975). The Boundary Creek Formation was examined in outcrops on Boundary, Hornet, Rapid and Cache Creeks on the west side of the Mackenzie delta (Figure 1.3). The lithologically similar, but slightly younger, Smoking Hills Formation was briefly examined at one locality in the Caribou Hills on the east side of the delta (Section MD16; Figure 1.2). Based upon field observations, the Smoking Hills Formation on the east side of the Mackenzie delta appears to be indistinguishable from the Boundary Creek Formation on the west side of the Mackenzie delta. However, the formations have been differentiated by regional subsurface correlation (Dietrich and others, 1985). Dixon and others (1985) estimate the thickness of the Smoking Hills Formation to be 130 meters in outcrop in the Caribou Hills along the east margin of the Mackenzie delta and several hundred meters in subsurface. Based on palynology (pollen, spores and dinoflagellates), the Boundary Creek Formation has been dated as Late Cenomanian to Turonian and the Smoking Hills Formation as Santonian to Campanian (McIntyre, 1985). Pelecypods and ammonites from the Boundary Creek Formation also indicate a Cenomanian to Turonian age (Jeletzky, 1960).

Both the Boundary Creek and Smoking Hills Formations are excellent source rocks for petroleum and are lumped into a single "Bituminous zone" by Snowdon and Brooks (1985). They found that the total organic carbon of these formations is greater than 3 percent and that it commonly exceeds 4 percent. Organic material from the "Bituminous zone" is composed of a mixture of Type II (marine planktonic) and Type III (terrestrial) material deposited in an oxygen depleted environment. Similarly, Creaney (1980), based on a detailed petrographic study of the organic material from thirteen wells, concluded that the Boundary Creek Formation received both marine and terrestrial input under predominantly anaerobic conditions.

The Boundary Creek Formation consists of black fissile shale containing abundant thin bentonite beds ranging from 2 millimeters to 8 centimeters thick. Large siderite cemented septarian nodules up to 1 meter in diameter are also present. The lithology of the Boundary Creek Formation shows no vertical changes in outcrop at the localities examined by this study.

In this study, the Boundary Creek Formation is interpreted to represent a period of low, steady-state deposition. Due to the uniformly very fine-grained lithology and general lack of definitive sedimentary structures, the Boundary Creek Formation could have been deposited in environments ranging from outer shelf (below storm wave base) to basin floor. The high content and mixture of terrestrial and planktonic organic material indicates anoxic conditions with slow constant hemipelagic sedimentation.

DEPOSITION OF THE FISH RIVER GROUP

Introduction

The lithostratigraphic units formalized by Young (1972, 1973, 1975) for the Fish River Group are based on observable rock characteristics and stratigraphic position. Formations, formal members, and informal members are mappable throughout the outcrop belt and were used without revision in this study. I have further subdivided the mudstone member of the Tent Island Formation and sandstone member of the Moose Channel Formation into informal units. These units are based on variations in lithology and sedimentary and biogenic structures within these members. Sedimentary and biogenic structures are used in this study to determine depositional processes and interpret depositional environments for these rock units.

Depositional sequences and systems tracts defined in this study are based on bounding unconformities, genetically related successions of beds, bedsets and parasequences, presence of marine flooding surfaces and the vertical relationship of interpreted depositional environments. The systems tract boundaries defined in this study do not directly correlate with lithostratigraphic units.

In the Fish River area, the Fish River Group is 1800-1900 meters thick. This thickness estimate is based both on outcrop data (Young, 1975; Holmes and Oliver, 1973) and subcrop data from the Chevron Pex et al Fish River B-60 well immediately north of the field area.

Tent Island Formation

The Tent Island Formation overlies the Boundary Creek Formation, and forms the lower part of the Fish River Group. The Tent Island Formation was defined by Young (1975) and includes a lower Cuesta Creek Member whose dominant lithologies are conglomerate, sandstone, and siltstone and an upper member (informally named the mudstone member) that consists of mudstone with lesser siltstone and sandstone. In the Fish River area, the Tent Island Formation is approximately 850 meters thick (Young, 1975). Based on terrestrial palynoflora and limited dinoflagellates, both members of the Tent Island Formation have been assigned a Maastrichtian age (McIntyre, 1985; Sweet, 1978). In addition, reworked Early Devonian, Carboniferous, probable Permo-Triassic and Early Cretaceous palynomorphs are present within the Cuesta Creek Member (Sweet, 1978).

Cuesta Creek Member

The contact between the Cuesta Creek Member and the Boundary Creek Formation is an erosional unconformity where examined along Hornet Creek (Sections MD69 and MD71) and Rapid Creek (Section MD 75; Figure 1.3). Localized relief on the unconformity surface ranges from 20 cm to 3 m. The basal Cuesta Creek member is composed of channel fills of deformed pebbly mudstone, sandstone or conglomerate. Individual channel fills typically fine and thin upward on a scale of a few meters to tens of m. The contact is exposed along Hornet (Sections MD69 and MD71) and Rapid Creeks (Section MD 75). Along Hornet Creek, the basal Cuesta Creek consists of up to 12 m of deformed pebbly mudstone. This mudstone contains abundant rounded black chert pebbles up to 6 cm in diameter. The pebbly mudstones are overlain by channel fill sandstones, siltstones and shale. On Rapid Creek, the pebbly mudstone is absent and fissile parallel bedded black shale is directly overlain by an ungraded clast supported conglomerate. This pebble conglomerate is poorly sorted and contains clasts of up to 13 cm in diameter. The matrix of the conglomerate is fine-to medium-grained sandstone. The 1 m thick conglomerate is channelized, pinching out over a distance of 30 m along depositional strike. It is overlain by 5 m of thick to very thick bedded fine-to medium-grained sandstone containing interbedded conglomerate lenses and zones of shale rip-ups.

In this study, a similar contact relationship to that described above is interpreted from the well logs of the Fish River B-60 well. In this well, the Boundary Creek/Cuesta Creek contact is an abrupt change in lithology from shale to sandstone. The log character of the basal 8 m thick sandstone interval of the Cuesta Creek Member in the B-60 well is indicative of a fining-upward sequence typically associated with channel fills.

The Cuesta Creek Member consists of a highly variable succession of sandstone, siltstone, pebbly mudstone and conglomerate. The dominant lithology is fine-to very fine-grained sandstone. Most sandstone is poorly to moderately sorted and subangular. Dominant grain types in sandstones are, in descending order of abundance; polycrystalline quartz, monocrystalline quartz, chert and cherty argillite, metamorphic rock fragments, shale/slate and argillite. Only minor amounts of igneous rock fragments and feldspar grains are present. Conglomerate clasts are dominantly chert, with lesser amounts of quartz, quartzite, sandstone and metamorphic rock fragments. Clasts range from very fine pebble to cobble and rare boulder size. Most clasts are rounded to well rounded. Angular to rounded brown and black clay rip-ups and mud balls are also common.

Based on measurements taken in this study, the thickness of Cuesta Creek Member is highly variable and reaches its maximum known thickness of 151 m in outcrops at the type section near the junction of the Big Fish River and Boundary Creek. In the Fish River B-60 well, to the north of the type section, the Cuesta Creek is 96 m thick.

Internal organization of the Cuesta Creek Member is extremely complex and most beds and bedsets are discontinuous on an outcrop scale. The most striking feature of the Cuesta Creek Member in outcrop is that it is entirely confined laterally within channels defined by the underlying erosional surface and is internally organized into multiple channel fill successions of a variety of scales. Internal channels within the member are vertically stacked, with channels commonly cutting underlying or laterally equivalent channels.

In this study, hierarchy of channel fill successions have been recognized within the Cuesta Creek Member, based on scale and geometry of the bounding erosional surface. In order to describe the complex architecture of the Cuesta Creek Member, this study uses a modified version a classification developed for fluvial channels (Figure 7; Miall, 1985a). First order channel fills are bounded by large-scale erosional surfaces and record significant erosional relief at the scale of a paleovalley, or canyon. At the type section, I interpret the entire 151 m section of the Cuesta Creek Member as a first order channel fill. Based on continuous outcrop control at the type section, minimum width for the first order canyon at this locality is several kilometers. Second order surfaces define the basal scour surface of a major channel or channel complex within the first order channel fill. Second order channel fills within the Cuesta Creek Member range from 7-60 m in thickness. In outcrop, second order channels are of up to several hundred meters wide. The internal fill of second order channels typically displays a fining-and thinning-upward succession. Third order surfaces bound genetically related lithofacies assemblages, bedding cosets or amalgamated event deposits. Third order channel fills are typically 1-3 m thick. Third order channels commonly pinch out laterally after distances of meters to tens of m and may or may not

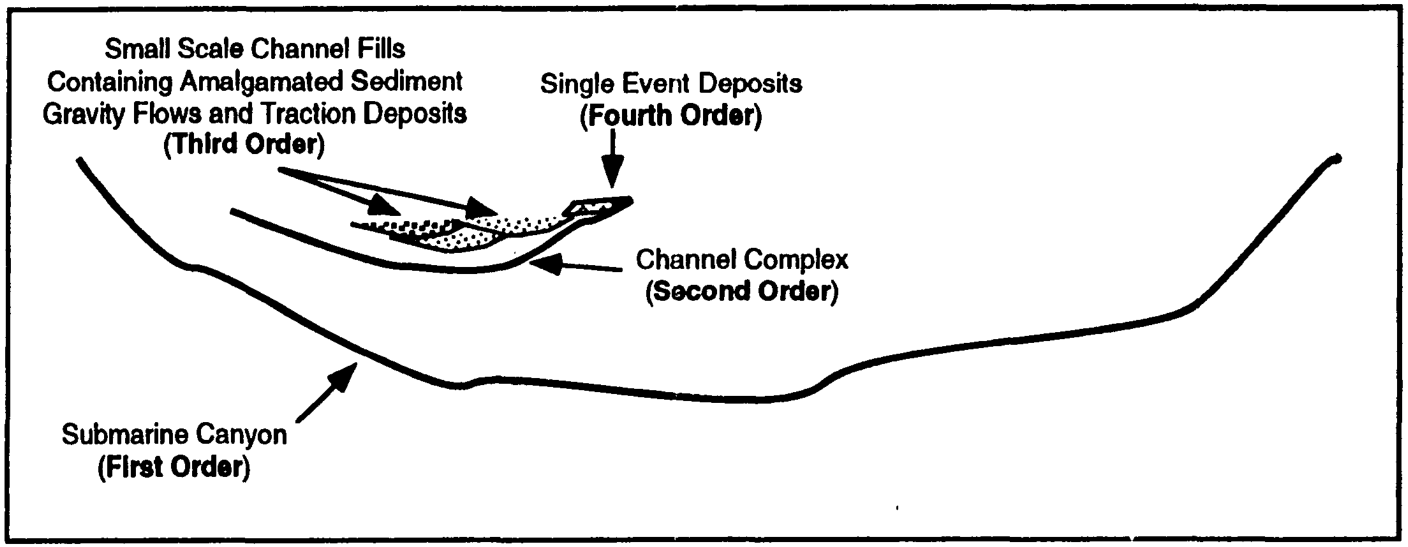


Figure 7. Channel hierarchy within submarine canyon deposits of the Cuesta Creek Member of the Tent Island Formation. Concept after that used by Miall (1985a) for fluvial systems.

contain fining-upward sequences (Figure 8). Fourth order surfaces bound individual cross bed sets or single event deposits.

Sandstone in the Cuesta Creek Member normally contains one of two stratification types: (1) beds of sinuous asymmetrical ripple laminae and wavy bedding, or (2) partial Bouma sequences. Individual beds commonly display load casts and a few well developed flute and groove casts on their bases.

Amalgamated sandstone beds commonly consist of repeated successions of 2-30 cm thick partial Bouma sequences. Medium-to coarse-grained sandstones commonly consist of a basal massive or graded interval (Bouma Ta) overlain by a planar laminated sandstone interval (Bouma Tb). Stacked Ta sequences are also common. The bases of individual Ta or Ta-b sequences commonly have up to several cm of erosional relief. Amalgamated sandstone beds containing Ta or Ta-b sequences range from 10 cm to several m in thickness (Figure 9.1). The base of amalgamated Ta-b beds commonly contain elongate angular shale clasts and soft sediment deformation. The beds are laterally discontinuous, normally pinching out or thinning dramatically over less than 10 m. These beds commonly occur in the basal one-half of fining-upward channel successions. Amalgamated fine-grained sandstone and siltstone beds reach a maximum thickness of 50 cm and commonly consist of repeated thin couplets of asymmetrically rippled sandstone (Bouma Tc) which is capped by ripple laminated to planar laminated siltstone (Bouma Td). Individual couplets are typically less than 4 cm in thickness and pinch out laterally in less than 10 m, whereas amalgamated Tc-d beds may extend for 10s of m (Figure 9.1). The bases of both amalgamated beds and couplets are sharp and planar. Beds consisting of Bouma Ta-c and Ta-d sequences are also present.

Figure 8. Photographs displaying channeling within the Cuesta Creek Member. (A) Stacked second order channel fills. Note the truncation at the base the upper channel. Scale bar is 64 m. (B) Fining-upward sequence in a large third order intraformational channel. Note the smaller scale internal channels in sandstone and conglomerate and numerous small faults. The section in photo is 94 m thick. (C) Third order channels with coarse-grained fill. Scale bar is 1 m. Photographs A, B, and C are from sections MD37, MD53 and MD51 respectively.

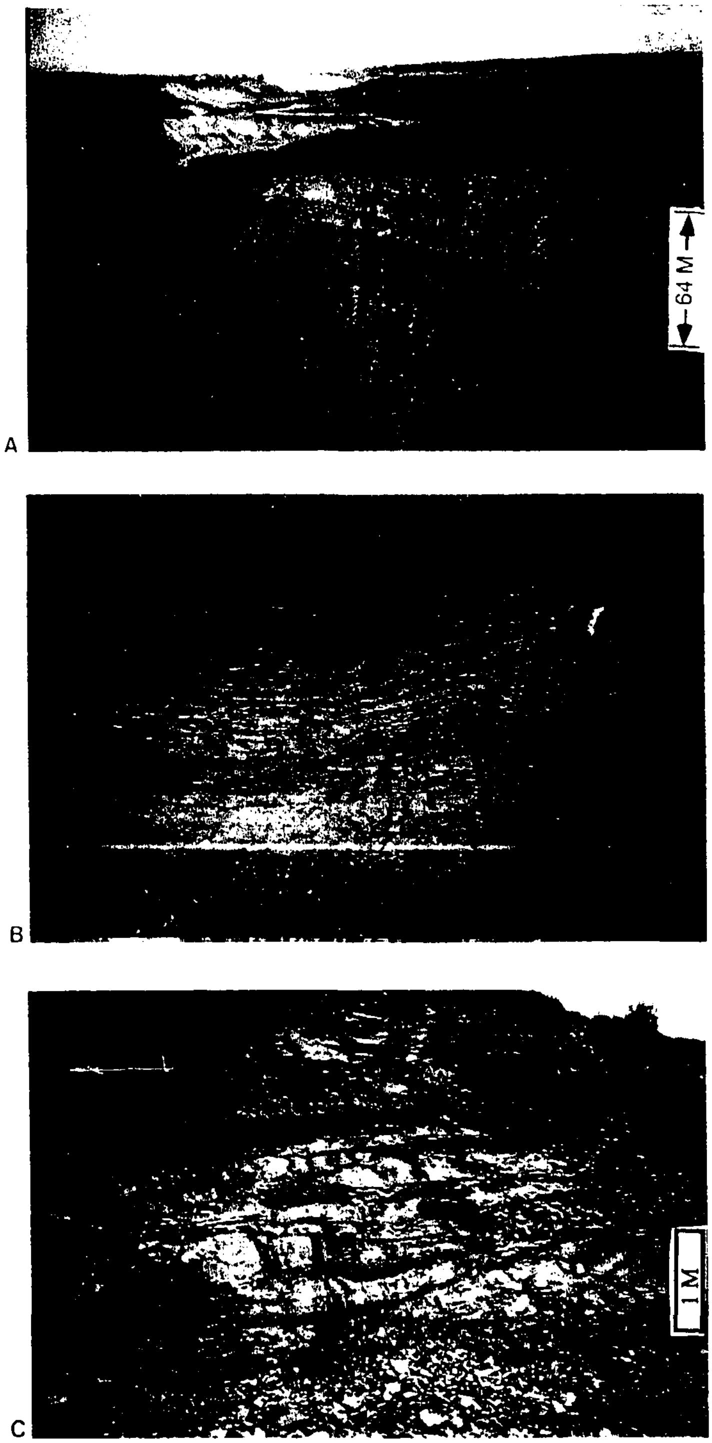


Figure 8.

Figure 9. Photographs of the internal sedimentology of the Cuesta Creek Member.

9.1. Internal sedimentology of the Cuesta Creek Member. (A) Alternating very thin- to thin-beds of fine-to very fine-grained ripple laminated sandstone and siltstone (Bouma Tc-d). Interpreted as stacked low density turbidites. (B) Interbedded conglomerate (inversely graded or ungraded) and pebbly sandstone. Interpreted as traction carpet deposits and high density turbidites. Scale is 15 cm. (C) Amalgamated very coarse-to fine-grained sandstone bed consisting of truncated successions of graded and planar bedded sandstone (Bouma Ta-b or S3Tt divisions of Lowe, 1982). Interpreted as stacked high density turbidites. Photographs A, B and C are from sections MD37, MD13 and MD51 respectively.

9.2. Internal sedimentology of the Cuesta Creek Member. (A) Succession of alternating flaser and lenticular bedded sandstones interpreted as low energy traction deposits. (B) Bedding plane view of lingoid current ripples in fine-grained sandstone. Lingoid ripples are the dominant bedform in flaser bedded intervals. Both photos are from section MD69, Hornet Creek.

9.3. Internal sedimentology of the Cuesta Creek Member. (A) Syndepositional normal fault (1 m displacement at base of fault). (B) Block consisting of interbedded sandstone, siltstone, and mudstone. Block is 2 m high. Note the sharp basal contact at the base of the block. Interpreted as a slide block consisting of collapsed channel margin material. (C) Amalgamated unit of disorganized conglomerate containing large rounded clay balls (note hammer for scale). Interpreted as multiple small debris flows. Photographs A, B, and C are from section MD54, locality MD53 and section MD54 respectively.

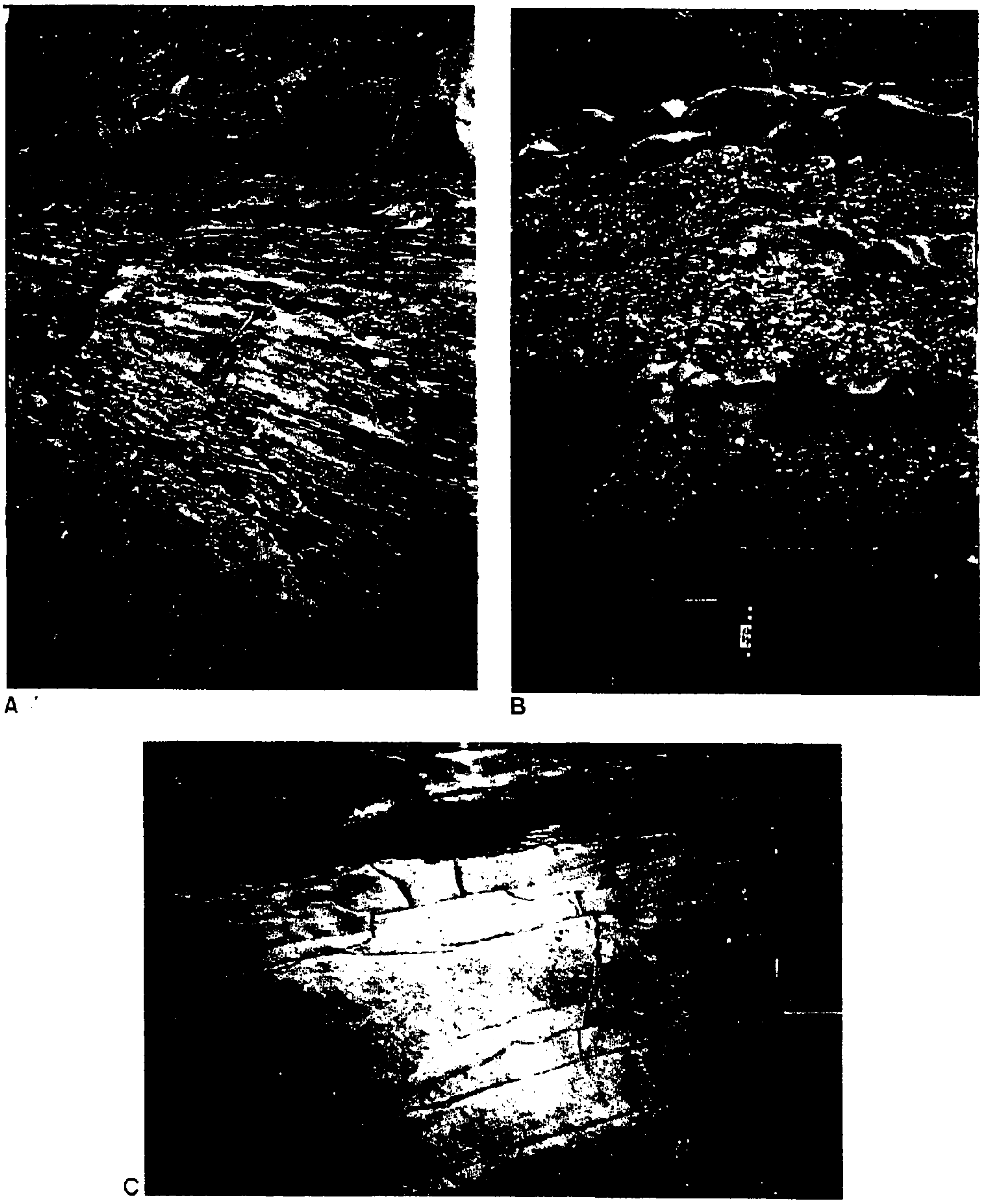


Figure 9.1.

Figure 9.2.

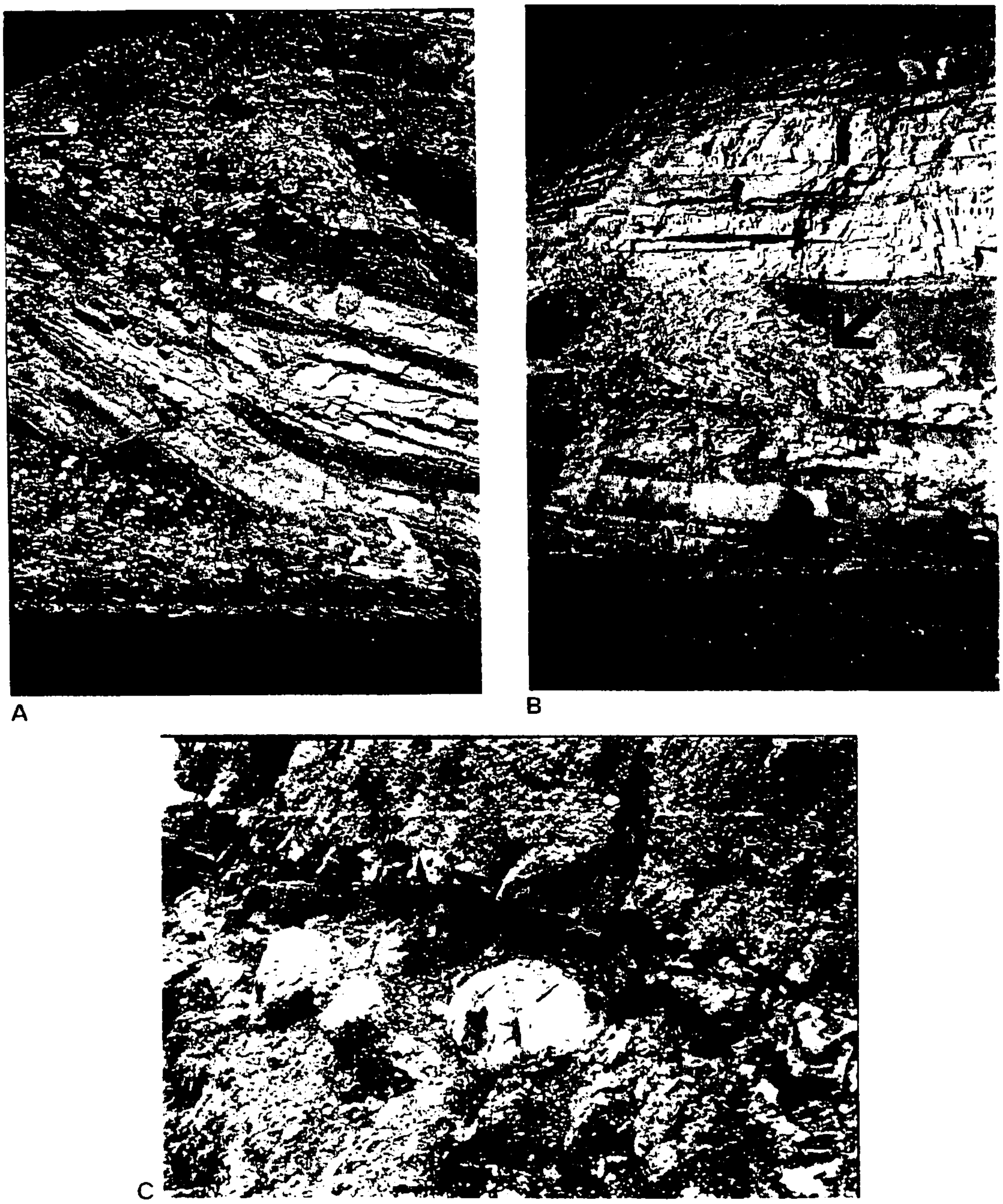


Figure 9.3.

Very fine-to fine-grained sandstones within the Cuesta Creek Member commonly contain beds consisting entirely of asymmetrical low angle, climbing ripple lamination and wavy bedding. Climbing ripples are found with both in-phase and in-drift laminae; ripples are sinuous to linguoid. Ripple laminae commonly grade into wavy laminae. Ripple laminated sandstone beds range in thickness from laterally extensive beds up to 50 cm thick to isolated, lenticular beds encased with argillaceous siltstone. Ripple laminated sandstones commonly form vertically stacked small scale (20-60 cm thick) fining-upward successions in the upper parts of second order channel fills. Individual successions display a gradational change from flaser bedded sandstone to lenticular bedded sandstone and siltstones (Figures 9.2 and 10).

Conglomerate is common in the basal one-third of second order channel fills and ranges from massively bedded (up to 10 m thick) to thin discontinuous lenses interbedded with sandstones. Conglomerates range from matrix to clast supported. Although most conglomerates are disorganized, some conglomerates display inverse and normal grading. Most conglomerate beds thicker than 1 m are bounded by third order surfaces. These massive beds, consisting of amalgamated discontinuous conglomerate lenses, completely fill some third order channels. Amalgamated beds contain multiple internal scour surfaces commonly with several cm of relief at the base of individual conglomerate lenses. Individual conglomerate lenses within an amalgamated bed rarely exceed 60 cm in thickness or extend laterally more than 10 m. Amalgamated beds may reach a maximum thickness of 10 m and have a lateral extent of greater than 50 m. Present, but rare, are massive (1-3 m thick), individual (non-amalgamated) beds of ungraded, crudely imbricated, very poorly sorted, disorganized conglomerate containing granule to small boulder sized clasts (Figure 9.3).

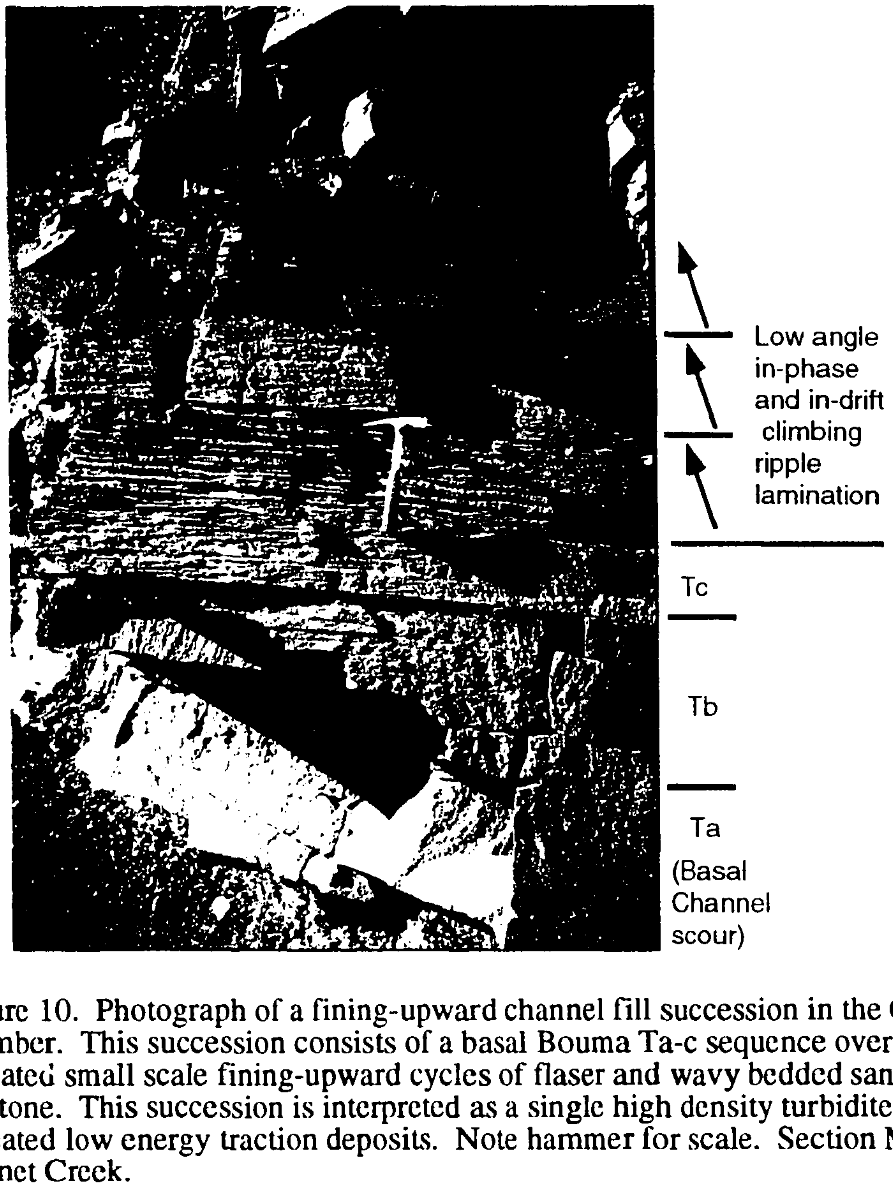


Figure 10. Photograph of a fining-upward channel fill succession in the Cuesta Creek Member. This succession consists of a basal Bouma Ta-c sequence overlain by repeated small scale fining-upward cycles of flaser and wavy bedded sandstone and siltstone. This succession is interpreted as a single high density turbidite overlain by repeated low energy traction deposits. Note hammer for scale. Section MD69, Hornet Creek.

Within the Cuesta Creek Member, beds and lenses of crudely stratified to nonstratified pebbly sandstone are commonly interbedded with thin to medium beds of conglomerate. Sandstone beds generally pinch out over distances of a few tens of meters or less. Sandstone beds range from 5 to 30 cm in thickness and are not graded. Beds of pebbly sandstone normally contain either elongate mud rip-ups or rounded pebbles similar in composition to these in underlying conglomerates. Pebbles comprise less than 15 percent of the composition of the sandstone beds. Sandstone beds are interbedded with both disorganized and organized conglomerates. Organized conglomerates commonly display inversely graded bedding. Sharp basal contacts of overlying conglomerates commonly are defined by scours cut into the underlying sandstone beds. Similarly, the basal contact of overlying sandstone beds are commonly defined by scours cut into the underlying conglomerates and contains some clasts that appear to have been ripped-up from the underlying beds. Both sandstone and conglomerate beds have lateral continuities of only a few tens of m. Lateral continuity of the overlying bed may be different than the underlying bed (Figure 9.1B).

Basal fill of second order channel fills commonly consists of beds of syndepositionally deformed pebbly mudstone. Chaotically bedded mixtures of sandstone, conglomerate, shale and claystone/shale clasts are also present at or near the base of second order channels. Rounded claystone clasts (up to 50 cm in diameter) and angular shale rip-up clasts and shale clasts typically comprise 50-80 percent of these beds. Beds consisting entirely of angular clay rips-ups and/or large rotated blocks of interbedded sandstone, siltstone and mudstone are developed in the lower one-third of second order channel fills (Figure 11). Rotated blocks are up to 4 m in width and 3 m in height. Blocks have a sharp basal contact with the underlying bed and contain bedding rotated by as much as 45 degrees. Bedding in some blocks is largely undeformed, while others contain

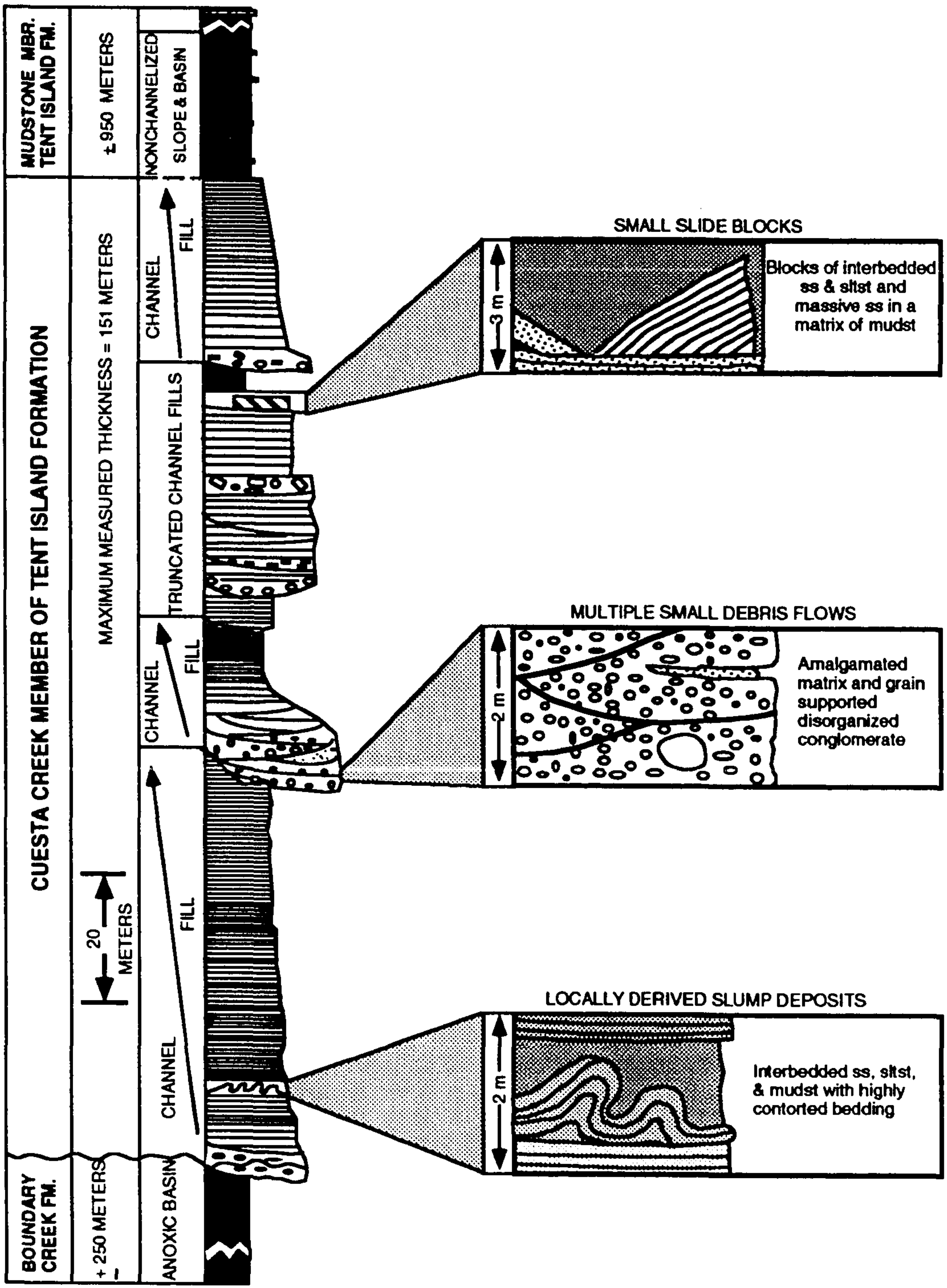


Figure 11. Composite stratigraphic section for submarine canyon deposits of the Cuesta Creek Member illustrating the presence of gravity slides, slumps and debris flows within stacked fining-and thinning-upward second order channel fills.

syndepositional gravity-induced features including deformed beds, internal slump folds and highly fragmented bedding. Small syndepositional normal faults are also present within the Cuesta Creek Member (Figure 9.3)

Sandstones and conglomerates of the Cuesta Creek Member are interpreted to have been deposited by sediment gravity flows and "less episodic" current related traction deposits. Several types of sediment gravity flows are interpreted to have occurred within the Cuesta Creek. Disorganized conglomerates, pebbly mudstones and chaotically bedded mixtures of sandstone, conglomerate and shale, commonly containing large angular clay rip-ups, are interpreted as debris flows. These deposits display the characteristic lack of internal structure, very poor sorting and lack of preferred clast orientation found in debris flows (Reading, 1978). Inversely graded organized conglomerates within the Cuesta Creek are interpreted as traction carpet deposits (R2 division of Lowe, 1982). Most of the conglomerate consist of composite beds and bedsets. Individual beds within conglomerates have highly variable lateral extent, erosional bases and truncated tops. These characteristics indicate that composite conglomerate beds are an amalgamation of multiple small debris flow (Figure 11) or high density turbidite and traction carpet deposits (Figure 12) rather than single event deposits. Rounded clasts within most of the debris flow deposits indicate a complicated transport history prior to initiation of the flows (Clifton, 1984).

Sandstones containing Bouma Ta, Ta-b and Ta-c sequences (Figure 12) are interpreted to be deposits of high density (S3 and S3Tt divisions of Lowe, 1982) or truncated turbidity flows (Lowe, 1982; Reading, 1978; Stanley and others, 1978). Amalgamated beds of fine-grained sandstone and siltstone consisting of stacked Bouma Tc-d sequences (Figure

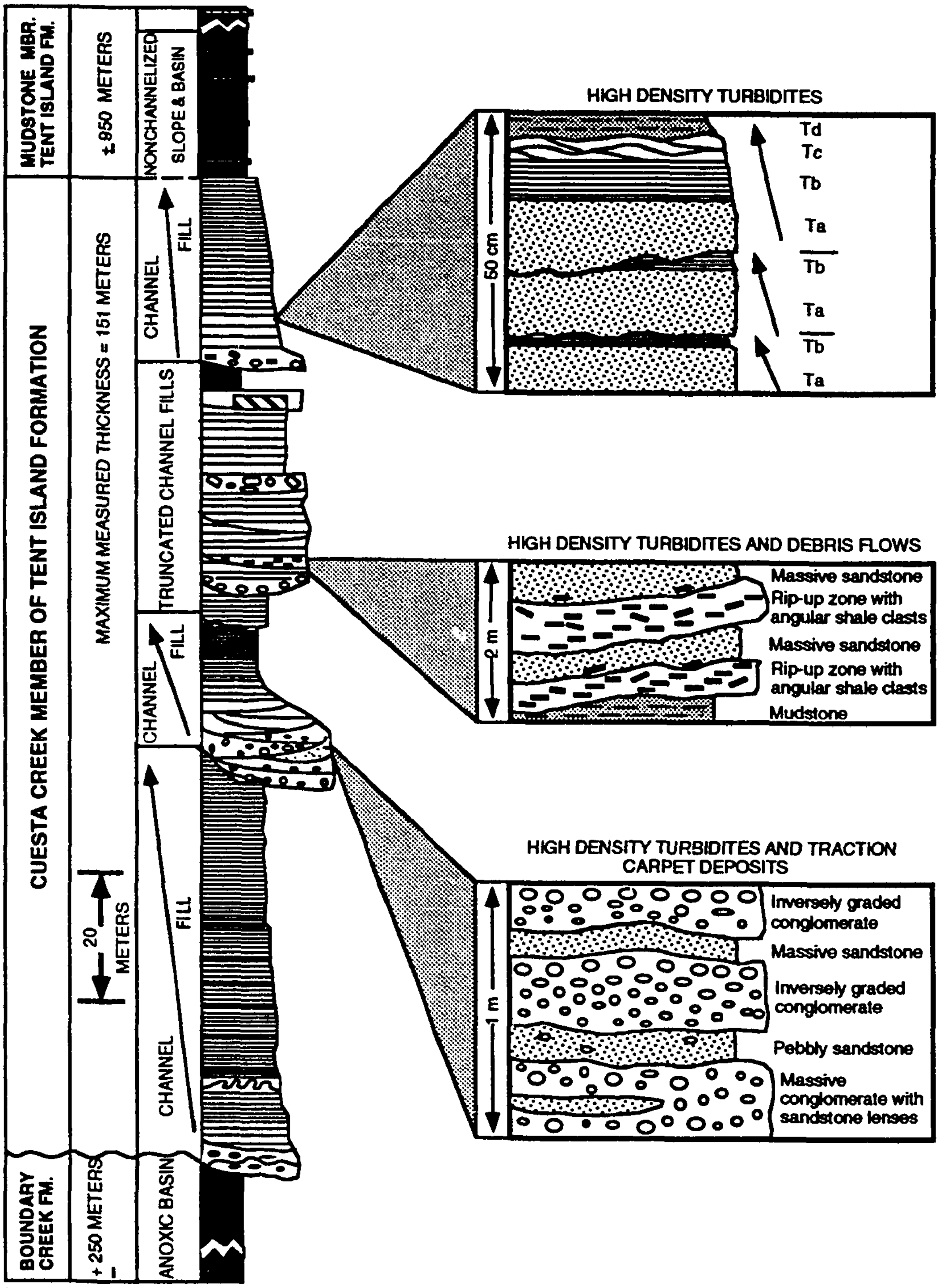


Figure 12. Composite stratigraphic section for submarine canyon deposits of the Cuesta Creek Member illustrating the sedimentology of high density deposits within stacked fining-and thinning-upward second order channel fills.

13) are interpreted as low density turbidites in which traction and suspension are followed by suspension (Lowe, 1982; Reineck and Singh, 1980; Ricci Lucchi, 1985).

Interbedded sandstone and conglomerate couplets (Figure 12) are composite sedimentary units interpreted to consist of multiple small high density turbidites. This interpretation is based on the variance in continuity and the erosional nature of the basal contact of both sandstone and conglomerate beds. An alternative mechanism for the deposition of conglomerate and sandstone couplets in submarine canyon fill does exist, but is not pertinent for the couplets found in the Cuesta Creek Member. Clifton (1984) interpreted that each couplet in Paleocene submarine canyon fill at Point Lobos California represents a single depositional event. However, in the Point Lobos example, a sharp basal contact is present between the conglomerate and underlying sandstone, whereas an ill-defined or gradational contact exits between the conglomerate bed and the overlying sandstone. Clifton proposed a mechanism of emplacement for a couplet consisting of a grain flow for the inversely graded conglomerate, followed by turbidity or fluidized flow for the overlying normally graded sandstone. This mechanism is not applicable for couplets found in the Cuesta Creek Member.

Blocks of interbedded sandstone and mudstone in channel fills (Figure 11) are interpreted as slide blocks. This interpretation is based on the sharp basal contact of blocks with the underlying beds, the limited lateral and vertical extent of blocks and an internal bedding within the blocks that is rotated by as much as 45 degrees to overlying, underlying and laterally equivalent beds. Zones consisting of deformed, folded and highly fragmented beds are present within channel fills (Figure 11). These zones are interpreted in this study as slumps. The deformed beds occur as a zone sandwiched between undisturbed beds, a defining characteristic of slumps (Reading, 1978). Slumps and slides within the Cuesta

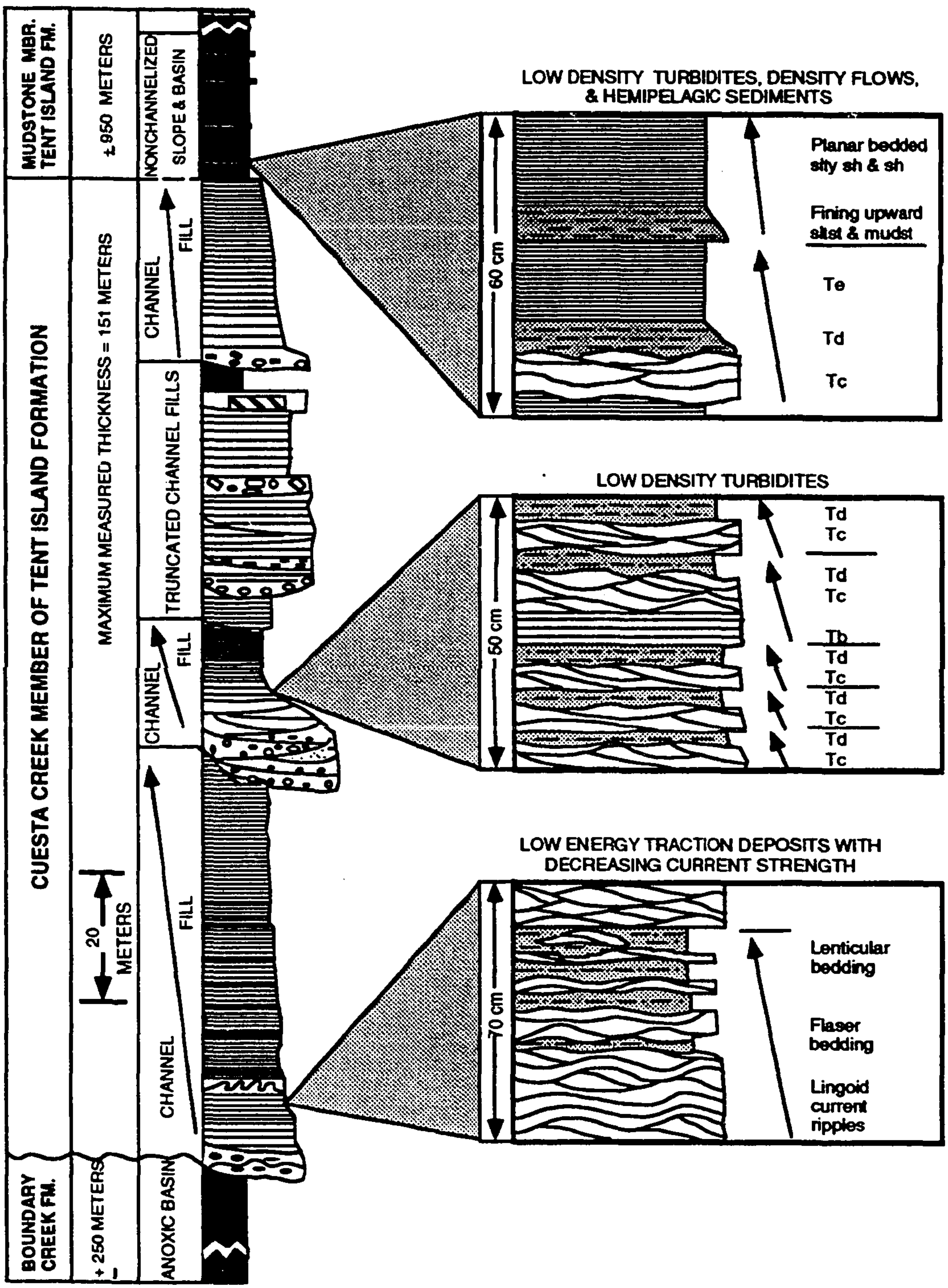


Figure 13. Composite stratigraphic section for submarine canyon deposits of the Cuesta Creek Member illustrating the sedimentology of low energy deposits within stacked fining-and thinning-upward second order channel fills.

Creek are generally small and interpreted to be localized mass movements sourced from the collapse of channel margins or up-dip channel fill.

Asymmetric low-angle climbing ripple laminae (Figure 13) are abundant and commonly do not constitute part of Bouma sequences. Climbing ripple laminae are found both with laminae in-phase and in-drift and are interpreted to be the result of simultaneous traction and suspension with varying ratios of suspended to bed load (Reineck and Singh, 1980; Harms, Southard, and Walker, 1982). The abundance of ripple-laminated sandstone indicates that low energy traction currents played a role throughout the deposition of the finer-grained sediment of the channel fill. The thickness and relative abundance of ripple laminated beds not included in Bouma sequences suggests that low velocity, "fairly long" duration traction currents were responsible for the deposition of these beds within channel fills. The lack of pure suspension sedimentation within these intervals indicates that these low velocity currents were not rare episodic events. Low velocity traction currents can be produced at deep water depths by other mechanisms than turbidites. For example, bottom currents can be produced within submarine canyons by tides, winds, storm relaxation flows, and density underflow from thermo-haline differences (Galloway and Hobday, 1983; Shepard and Marshal, 1978). Tidal and internal wave currents have been reported to produce the downcurrent migration of sand ripples at depths greater than 700 meters in Hydrographer Canyon on the U.S. eastern coast (Keller and Shepard, 1978).

The Cuesta Creek Member is interpreted to have been deposited in a submarine canyon at outer shelf and slope water depths. As discussed below, this interpretation is based on the internal stratigraphy and sedimentology of the member, as well as its relationship with the underlying and overlying units. The Cuesta Creek Member was previously interpreted as a fluvial/deltaic complex (Young, 1975; Holmes and Oliver, 1973). Dixon (1988) interpreted the unit as sediment gravity flow deposits of a submarine fan.

Contact relationships support a submarine canyon interpretation for this unit. The Cuesta Creek Member incises into deep water shales of the Boundary Creek Formation and is conformably overlain by deep water marine shales of the mudstone member of the Tent Island Formation. I interpret the characteristic assemblage of traction carpet deposits (R3), multiple small debris flows, low and high density turbidites, traction current deposits, slumps and slide blocks, and syndepositional normal faults as evidence for deposition on an unstable, steeply dipping depositional paleoslope. The stratigraphic position of the Cuesta Creek (surrounded by deep water marine shales) indicates water depths that were at a minimum below storm wave base. The totally channelized internal architecture and the absence of levee deposits argue for a canyon rather than an inner or middle submarine fan interpretation.

The depositional history of the Cuesta Creek Member involved at least two stages: the cutting of the canyon into the underlying Boundary Creek Formation, and the subsequent deposition of the canyon fill. Initial canyon incision into the Boundary Creek Formation is interpreted to have occurred during a lowering of relative sea level. A gradual rise in relative sea level may be the mechanism responsible for subsequent creation and backfilling of the large intraformational channels within the unit. The transition from the channelized Cuesta Creek into the overlying unchannelized fine-grained mudstone member can be attributed to a rise in relative sea level and the initiation of deposition within a transgressive systems tract. For a more complete discussion see the following section on sequence stratigraphy. The Cuesta Creek forms the base of a depositional sequence which ultimately culminates in the construction and progradation of a deltaic platform. A more complete discussion of the upper contact with the mudstone member and the sequence stratigraphic framework is presented in subsequent sections of this dissertation.

Complete third order channel successions within the Cuesta Creek record a history of event sedimentation indicative of decreasing energy within the depositional system. The following depositional process model is proposed for third order successions: (1) the channel is carved into underlying sediment with little deposition occurring within the active channel. The channel acts as only as a sediment conduit; (2) deposition of debris flows, slumps and slides from up-slope and lateral channel margins; (3) deposition of traction carpets and coarse grained high density turbidites; 4) deposition of finer grained high density turbidites; 5) deposition of low density turbidites and fine-grained traction current deposits; and 6) erosion of upper part of succession to form overlying channel (Figures 11, 12, and 13).

Mudstone Member

The contact between the Cuesta Creek Member and the overlying mudstone member of the Tent Island Formation is gradational both in outcrop and subsurface. The transition occurs as a gradual fining-upward from interbedded sandstone and siltstone into mud-shale and mudstone containing thin siltstone and occasional very fine-grained sandstone beds. In contrast to the channelized nature of bedding in the Cuesta Creek Member, the bedding of the overlying Mudstone member is much more laterally continuous.

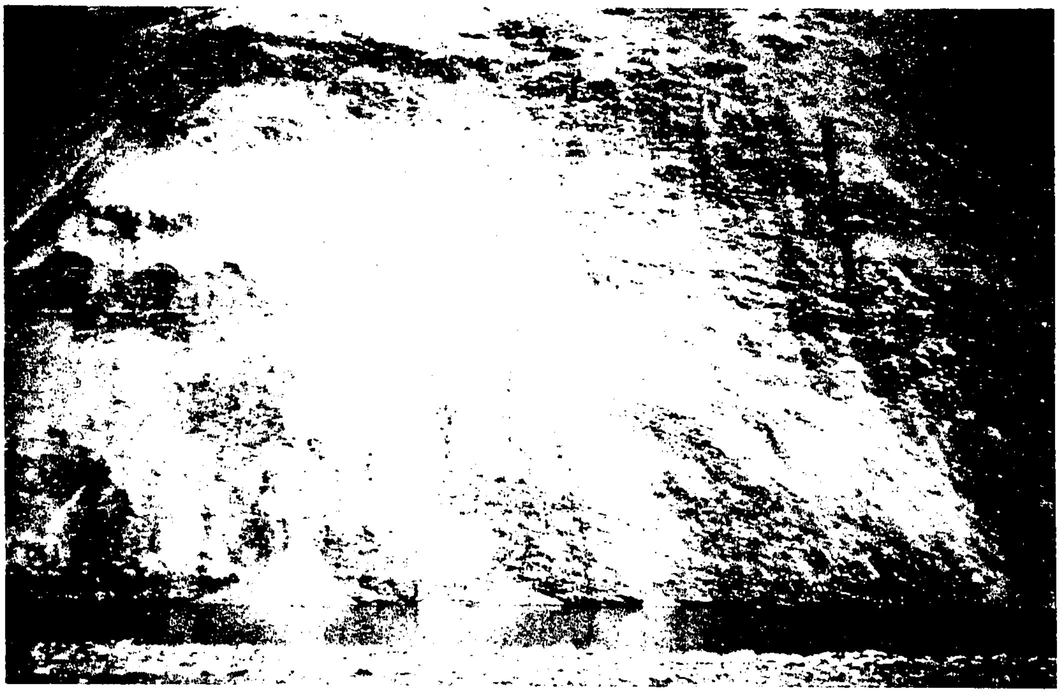
Although composed dominantly of mudstone, the mudstone member contains several other lithologies including siltstone, very fine-to fine-grained sandstone and minor conglomerate. Sandstone within the mudstone member is submature to immature chert litharenite. Grain types include quartz, cherty argillite, chert, volcanic rock fragments, variable amounts of feldspar and minor amounts of metamorphic rock fragments. The percentage of siltstone and sandstone generally increases toward the top of the formation where these lithotypes comprise up to 30 percent of the member. Near its base, siltstone and sandstone typically comprise less than 15 percent of the member. Estimated thickness of the member along the Big Fish River and Cache Creek is 850 m (Young, 1975). In the Chevron Pex et al Fish River B-60 well, 7 km to the north of the outcrop belt, the mudstone member is 735 m thick.

Based on variations in lithology and sedimentary and biogenic structures, the mudstone member is subdivided in this study into four ascending units (A-D). These units were delineated from detailed stratigraphic sections measured along the Big Fish River and Cache Creek. The sedimentology, relationship with overlying and underlying members, and ichnology of the mudstone member suggest that it was deposited in progressively shallowing water depths and represents the distal to proximal progradation of a major deltaic system. Interpreted depositional environments range from slope, outer shelf, and distal prodelta near the base of the member to inner shelf and subaqueous delta plain near the top of the member.

Unit A

Unit A consists of mud-shale and mudstone interbedded with siltstone and minor thin beds of very fine-grained sandstone. Sandstone and siltstone make up approximately five percent of the unit. Sedimentary successions present include thin beds which grade from argillaceous siltstone to mud-shale, laminated mudstone interbedded with siderite cemented siltstone lenses, and thin beds of ripple laminated very fine-grained sandstone and siltstone

Figure 14. Photographs of unit A of the mudstone member of the Tent Island Formation. (A) Large clinoforms in mudstone. These clinoforms are mark the base of the highstand sytems tract of the Fish River sequence. Photo is taken immediately to the north and stratigrahically above section MD50. (B) The rock hammer is resting on a thin bed of very fine-grained sandstone and siltstone which is overlain by mudstone. This succession is interpreted as a low density turbidite. In contrast to the underlying Cuesta Creek Member, the basal mudstone member contains non-channelized low density turbidites and hemipelagic sediments with indivdual beds having very high lateral continuity. This outcrop is interpreted to have been deposited within the transgressive systems tract of the Fish River sequence. Photo is from section MD50, located on the Big Fish River.



A

B

Figure 14.

overlain by medium to thick beds of mudstone (Section MD 50; Figure 14). Sandstone and siltstone beds within unit A are laterally continuous on an outcrop scale. No trace fossils or invertebrate macrofossils were found in unit A. Unit A also contains large mudstone clinoforms. Exposed along the Big Fish River just north of MD50, these clinoforms reach up to 20 m in height and, dip predominantly to the northeast (Figure 14).

The sedimentary structures in unit A are interpreted to have been formed by suspension sedimentation and low density turbidity currents. The repeated successions of thin beds of ripple laminated very fine-grained sandstone, siltstone and thick beds of mudstone and shale are interpreted as the Bouma Tc-e beds of low density turbidites. The thick Te beds at the top of each turbidite indicate that turbidity currents were infrequent events and that suspension deposition of very fine-grained material was the dominant mechanism of sedimentation. The lack of amalgamation of beds indicates that individual turbidites were not reworked or scoured by subsequent turbidity or other bottom currents. In contrast to the Bouma sequences in the Cuesta Creek Member these Bouma sequences are not amalgamated.

The low sand to mudstone ratio, abundance of very fine-grained suspension sediments, and proximity to submarine canyon deposits of the Cuesta Creek Member suggests that unit A of the mudstone member was deposited in a slope to outer shelf environment at low sedimentation rates. Large clinoforms similar to those found in unit A have been described in slope environments in the Delaware Basin in New Mexico (Sarg, 1991, Pers. Comm.). Unit A lacks sedimentary structures such as hummocky cross stratification (HCS) or swaly cross stratification (SCS) that are commonly found in very fine-to fine-grained sandstones affected by wave action. The absence of these stratification types is consistent with the interpretation of deposition at water depths that were below storm wave base.

Unit B

Immediately overlying unit A, unit B is dominated by mudstone but contains more abundant and thicker sandstone beds. Sandstone to mudstone ratios are less than 1/10 in this unit. Sandstone beds in unit B are 2-15 cm thick and are predominantly planar bedded and ripple laminated and commonly overlain by mudstone beds up to several m thick. Some of these sandstone beds contain clay rip-ups and small load casts. Thin beds of hummocky cross-stratified sandstone (HCS) are also present, but less abundant than ripple laminated beds. No trace fossils or invertebrate macrofossils were found in unit B.

Unit B contains sedimentary structures indicative of density flows, suspension, and storm deposition. Thick mudstone that separates sandstone beds demonstrate that suspension deposition was the dominant mechanism of sedimentation. Successions of parallel laminated sandstones, ripple laminated sandstones and mudstone are interpreted as the Tb-Te beds of high density turbidites. Hummocky cross stratified sandstone beds is indicative of deposition in water depths above storm wave base. Dominance of preserved density flow and suspension sedimentation indicates that although storm events could on rare occasions rework bottom sediment, this happened infrequently. This suggests water of sufficient depths that only storms of large magnitude could affect the bottom. Some storm currents can disturb the outer shelf to water depths in excess of 200 m (Komar and others, 1972).

The presence of HCS and the abundance of suspension sediments suggests that unit B of the mudstone member was deposited in an outer to middle shelf environment. The low density turbidites found in unit B, along with the subaqueous delta plain interpretation for parts of the overlying units (discussed in later sections), implies a distal prodelta environment of deposition.

Unit C

Unit C crops out along Cache Creek. Sandstone to mudstone ratios range from 15 percent to 30 percent. Sandstone is present in thin laterally continuous sheets, small slumps, and as the fill in small channels or chutes (Figure 15). Sandstone sheets are laterally continuous on an outcrop scale (greater than 100 m) and are typically thin to medium bedded, burrowed to bioturbated and wavy bedded. These sandstones are interbedded with thin to thick beds of burrowed siltstone and mudstone. The small channels have erosional bases scoured into underlying siltstone and mudstone. Erosional relief along the bases of these channels is a maximum of 1 m, while the channel fill reaches a maximum of 4 meters. The channel fill consists of sandstone and minor amounts of chert pebble conglomerate and mudstone. Individual sandstone beds within these channels range from thin to very thick (up to 2.5 m thick). Sedimentary structures in channelized sandstone beds include convolute bedding and both high and low angle trough cross stratification. The upper few centimeters of both channel fill sandstones and slumps are commonly burrowed. Large load casts occur at the base of channels. Both clast and matrix supported conglomerates are present within channels. Clay matrix supported conglomerates are very poorly sorted and lack internal bedding. Clast supported conglomerates are inversely graded with a matrix of very fine-grained sandstone (R3 division of Lowe, 1983). Also present are laterally discontinuous bodies of sandstone up to 2 m thick and contain internal convolute bedding and burrowing in the upper few cm.

The sedimentary structures in unit C indicate that sandstone and conglomerate were deposited and reworked by several different processes, including debris flows, density

Figure 15. Photographs of unit C of the mudstone member of the Tent Island Formation. (A) Interbedded siltstone and mudstone with lesser very fine-grained sandstone. Sandstone is present in laterally continuous, burrowed to bioturbated, thin to medium beds which are interpreted as distal bars and shelf storm deposits. Outcrop is 22 m in height. (B) Small channel or chute filled with low angle trough cross stratified and convolute bedded sandstone. Sandstone fill is 2 m in thickness. (C) Small channel filled with beds of inversely graded and disorganized conglomerate and low angle trough cross bedded sandstone. Sandstone fill is 3 m in thickness. Small channels are common at the base of laterally continuous marine sandstones within unit A. Photograph A and B are from section MD56, photograph C is from section MD55.

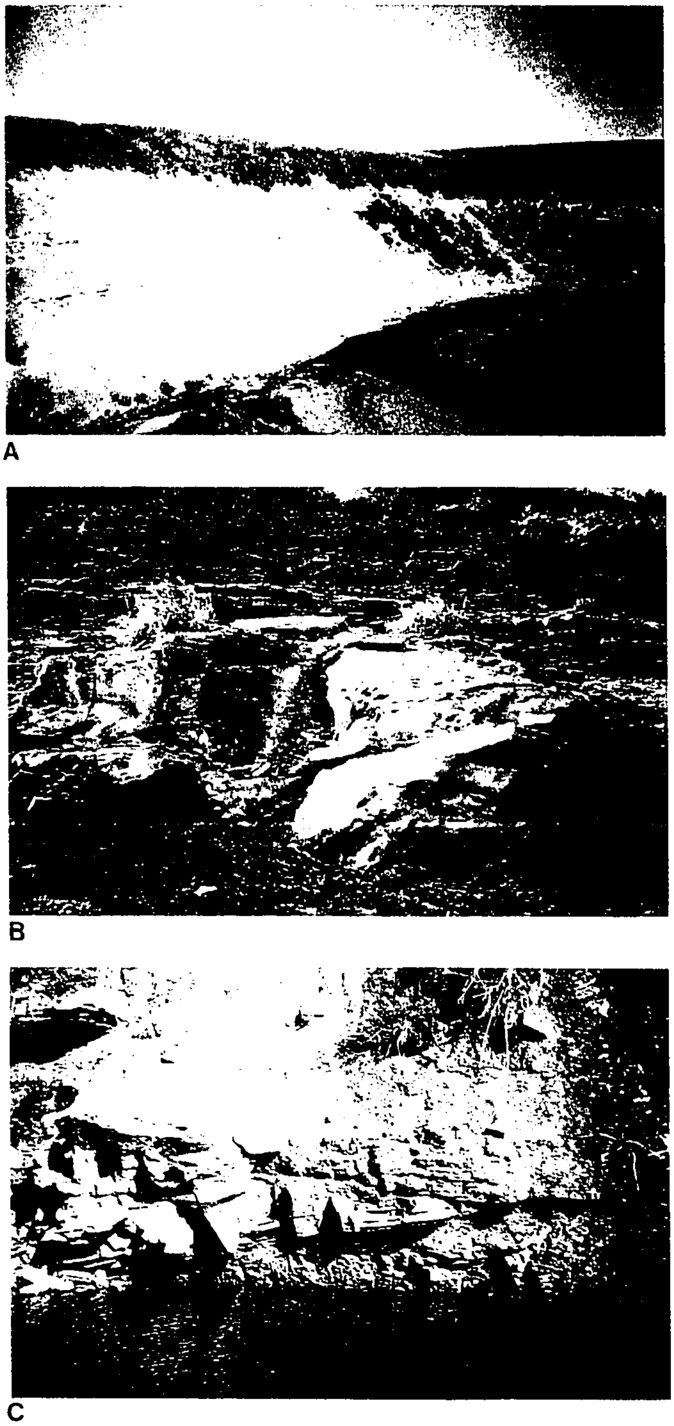


Figure 15.

flows, high density turbidity currents, slumping, migration of dunes and ripples by unidirectional currents, and bioturbation. Interbedded wavy bedded, burrowed sheet sandstone, and burrowed mudstone are common elements of shallow marine deposits (Reading, 1978). Episodic bedload sedimentation is recorded by the laterally persistent sheet sandstone, whereas the thicker mudstone were deposited by suspension sedimentation. The complete burrowing of sheet sands and interbedded siltstone and mudstone indicates rates of sedimentation were sufficiently low for burrowing and grazing organisms to rework sediment. This type of deposition, involving periodic bedload sedimentation followed by long periods of suspension sedimentation, is typical of deposition that occurs in water depths below fair weather wave base, but within storm wave base. Stratification found in the small channels or chutes of unit C indicate that sandstone and conglomerate channel-fill was transported into this environment by several different mechanisms. These mechanisms, including traction by unidirectional current (trough cross-bedded sandstones), high-density turbidites (traction carpets of inversely graded conglomerates), debris flows (disorganized conglomerate) and slumps (chaotically bedded sandstone). The upper section of channel fills is commonly burrowed and overlain by a laterally continuous bed of sandstone, indicating later reworking by current and biogenic activity.

Unit C is interpreted to have been deposited on the inner shelf in prodelta and distal delta front environments. Similar lithofacies have been observed both in modem and ancient delta systems. Vertical stratigraphic transitions from shallow water delta into prodelta or upper-slope sequences containing channeled sands and gravels, slump and mass flow deposits, and well bedded turbidite units displaying partial Bouma sequences have been documented in many basins Minimum bathymetric relief for development of contemporaneous slope and deltaic systems need only be several hundred feet (Galloway and Hobday, 1983). Subaqueous gravity induced mass movements are an integral component of sediment transport on modern deltas. Furthermore, gravity mass movements may occur on low angle slopes (less than 2 degrees) and the transport of sediment from shallow to deep water commonly takes place along well defined mud flow gullies and in a variety of translational slumps (Figures 14 & 15; Coleman and Prior, 1982).

Unit D

Unit D is composed of mudstone, interbedded siltstone and thin to very thick bedded, very fine-to fine-grained sandstone. The upper contact of Unit D is transitional with the base of the sandstone member of the Moose Channel Formation. Although generally less than 20 percent, sandstone can make up to 25 percent of this unit near the contact with the Moose Channel. Sandstone beds within this unit commonly form the upper part of coarsening-and thickening-upward successions (Figure 16). Unit D is present in the uppermost section of the mudstone member and is described from outcrops on the Big Fish River and Cache Creek.

Mudstone at the base of this unit contain thin interbeds of symmetric and asymmetric ripple laminated siltstone and thin beds of rounded chert pebble conglomerate. Sedimentary structures within sandstone beds include small scale hummocky cross stratification, small scale, low angle trough cross bedding, wavy and planar lamination, symmetric and asymmetric ripples, convolute bedding, burrowing, and small mud diapirs. Carbonized organic material is common and ranges from fine-grained, macerated material concentrated along bedding plains to logs.

Figure 16. Photographs of unit D of the mudstone member of the Tent Island Formation. These photographs display a single, 38 m thick, mudstone dominanted coarsening-upward succession which is interpreted as a fine-grained distributary mouth bar. (A) Amalgamated sandstone bed containing a small shale diapir caps the succession. (B) The upper 8 m of the section consists of interbedded hummocky cross stratified, ripple laminated, trough cross stratified and parallel laminated sandstone and ripple laminated siltstone. (C) The basal 30 m of the section consists of mudstone with a few thin beds of pebble conglomerate and ripple laminated siltstone. Photographs are from section MD02.

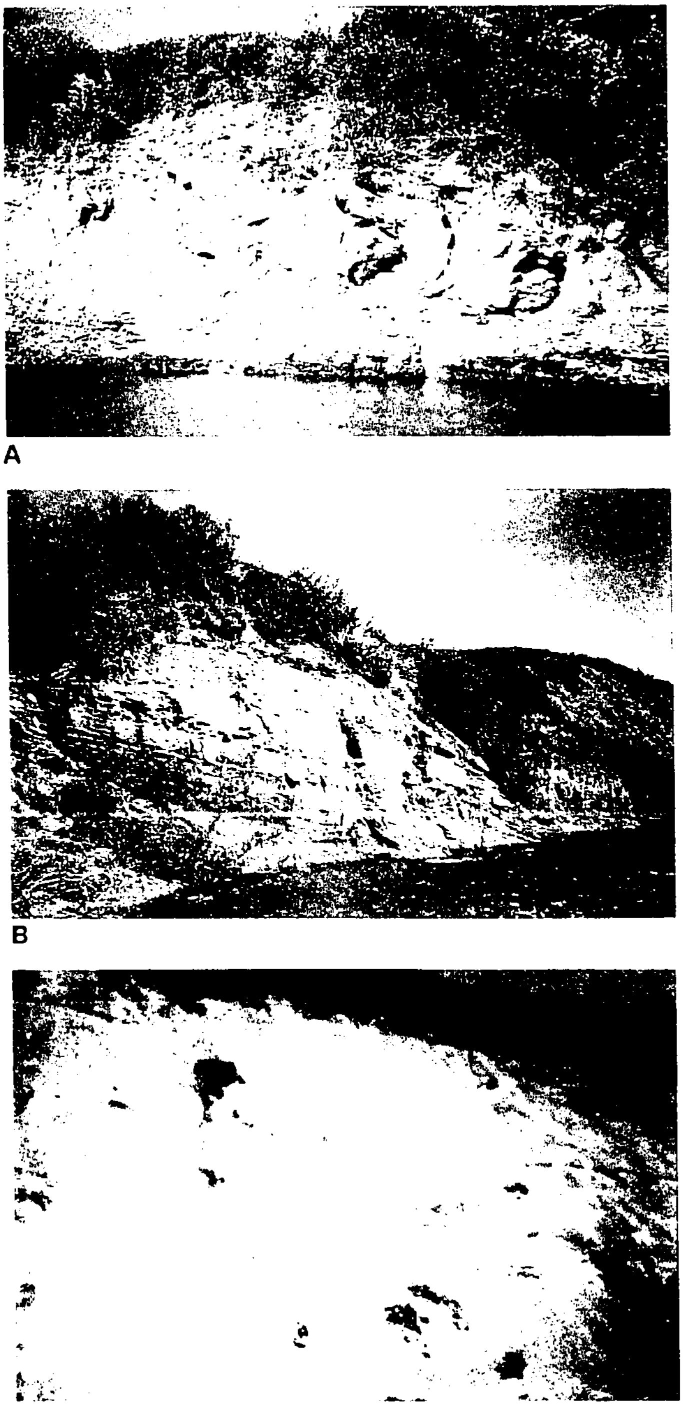


Figure 16.

Unit D is characterized by an assemblage of trace fossils common to the *Cruziana* and *Skolithos* ichnofacies. Trace fossils in Unit D include: *Asteriacites* (starfish resting traces (Hantzschel, 1975)), *Phycodes* (bundled horizontal tunnels in a broom like pattern probably produced by a sediment-feeding worm like animal (Hantzschel, 1975)), *Rhizocorallium* (burrows of deposit feeding animals or as dwelling burrows of plankton-feeding animals (Hantzschel, 1975)), *Skolithos* up to one cm in diameter, *Planolites* (cylindrical, nonbranching horizontal infilled burrows (Hantzschel 1975)), *Crossopodia*, (segmented crawling trails with a median furrow), and possible pelecypod valve impressions and crab walking and feeding trails (Ossian, pers. comm.).

Coarsening-and thickening-upward successions in unit D contain sedimentary structures indicative of decreasing water depths and increased sediment reworking. Depositional processes include suspension, density currents, unidirectional and oscillatory currents generated by storm and fair weather waves and slumping. Mudstone at the base of this unit is the product of suspension sedimentation with ripple laminated interbeds the result of both wave generated oscillatory and unidirectional currents. Thin conglomerate beds were probably deposited by infrequent density flows. Overlying hummocky cross stratified sandstone beds are interpreted as products of either purely oscillatory flow (Dott and Bourgeois, 1982; Southard and others, 1990; Walker and Plint, 1992) or combined flow conditions (Brenchley, 1985; Nottvedt and Kreisa, 1987; Swift and Nummedal, 1987) during storm events. The increase in sandstone percent and bed thickness, and corresponding decrease in mudstone toward the top of individual successions suggest a generally shallower, more agitated environment (Walker and Plint, 1992).

Unit D records deposition within nearshore environments. Coarsening-upward successions containing the succession of sedimentary structures found in unit D are typical of distributary mouth bar deposits found in proximal delta front environments. Individual coarsening-and thickening-upward successions overlie distal bar, bar front and proximal mouth bar crest deposits. Distal bar deposits consist of thin frontal splays of pebbly sandstone, siltstone and hemipelagic shales. The overlying sandstone beds containing HCS and trough cross-stratification are indicative of decreasing water depth and increased reworking by a variety of mechanisms including river currents and normal marine processes. These deposits are interpreted to be middle and proximal bar mouth deposits. The parallel laminated tops of coarsening-upward successions are interpreted as the deposits of bar crests. Small mud diapirs found at the top of coarsening-upward successions (Figure 16) resulted from rapid sedimentation near the mouth of distributary channels. In modern delta systems, rapid deposition of sand at the mouth of major distributaries loads the underlying muds, creating a density inversion. Sediment loading results in differential compaction and flowage of muds which creates diapiric mud spines or mud lumps (Galloway and Hobday, 1983). Abundant woody material found in unit D is typical of modern distributary mouth bar sequences. In modern deltas large accumulations of river-transported organic debris are discharged into the nearshore zone. Wave action grinds down the coarser wood particles into large concentrations of organic debris (Coleman and Prior, 1982).

The *Cruziana* and *Skolithos* ichnofacies in unit D are indicative of water depths associated with shoreface or delta front environments (Pemberton and others, 1992a). Similar assemblages of trace fossils have been well documented in Cretaceous shoreface successions of the Western interior seaway of North America (MacEacheon and Pemberton, 1992). This trace fossil assemblage supports the proximal delta front paleo-environmental interpretation inferred by the physical sedimentology.

Moose Channel Formation

The Moose Channel Formation was defined by Mountjoy (1967). It consists of a lower sandstone member which consists dominantly of fine-to coarse-grained sandstone and an upper member (the Ministicoog Member) which consists of interbedded mudstone, siltstone and very fine-to fine-grained sandstone (Young, 1975). Approximately 900 m of the Moose Channel Formation are exposed at the type section on the Big Fish River (Young, 1975) and in the subsurface to the north (in the Chevron Pex et al Fish River B-60 well) it is 1043 m thick.

The contact between the Tent Island Formation and the overlying Moose Channel Formation is gradational and is marked by a gradual increase in the percentage of sandstone. Sandstone makes up less than 15 percent of the mudstone member of the Tent Island Formation, whereas the basal sandstone member of the Moose Channel Formation has a sand to shale ratio greater than 1:3. For example, in the Chevron Pex et al Fish River B-60 well, which is located immediately north of the type section, more than 50 percent of the Moose Channel Formation is sandstone.

The Moose Channel Formation has been dated as Paleocene (McIntyre, 1985). No sedimentological evidence of an unconformity separating the Tent Island and the Moose Channel Formations was observed. The formation boundary occurs within a succession of rocks interpreted to have been deposited in a proximal delta front environment.

Sandstone within the Moose Channel Formation ranges from fine-to coarse-grained, and is subangular to subrounded. Sandstone are submature to immature chert litharenite and feldspathic litharenite. Grain types include quartz, cherty argillite, chert, volcanic rock fragments, variable amounts of feldspar and minor amounts of metamorphic rock fragments.

Conglomerate within the Moose Channel Formation ranges from matrix to grain supported, and are typically interbedded with pebbly sandstone. Clast types include chert, quartz, volcanic and sandstone rock fragments. Conglomerates commonly occur as thin lags at the base of channels; although, conglomerate beds up to 70 cm in thickness are sometimes present.

Sandstone Member

The sandstone member of the Moose Channel Formation consists of conglomerate, sandstone, siltstone, mudstone, and coal. Dominant lithology is fine-to very fine-grained sandstone. In the type section area, sandstone comprises 85 percent of the 595 meter thickness of the member (Young, 1975). To the north, the Fish River B-60 well penetrated a 877 m thick section of the sandstone member.

The sandstone member is here subdivided into three ascending units (A-C) based on variations in lithology and sedimentary and biogenic structures. These units were delineated from detailed stratigraphic sections measured along the Big Fish River, Cache Creek, and Eagle Creek. The sedimentologic organization, relationship with overlying and underlying members, and ichnofossil assemblage suggest that the sandstone member was deposited during progradation and aggradation of a major deltaic system. Interpreted depositional environments range from inner shelf and subaqueous delta plain to subaerial delta plain.

Unit A

Unit A, exposed along the Big Fish River and Eagle Creek, includes thin to very thick bedded, very fine-to fine-grained sandstone, mudstone, and siltstone. The dominant lithology is very fine-to fine-grained sandstone. The unit contains sedimentary structures that are similar to those in unit D of the mudstone member of the Tent Island Formation, but unit A contains a higher percentage of sandstone, typically 30 to 50 percent.

Unit A contains multiple stacked coarsening-and thickening-upward successions of mudstone, siltstone and very fine-to fine-grained sandstone (Figure 17.1). Individual coarsening and thickening upward cycles range from 18 to 66 m in thickness. The base of these successions comprises of multiple, 10-25 cm thick, fining upward packages consisting of, 1) thin beds of medium-grained sandstones which contain rounded black chert pebbles, overlain by 2) very thin to thin wavy beds and ripple laminated very fine-grained sandstones and siltstones and capped by 3) thin to medium-beds of mudstone. The dominant lithology in the middle and upper parts of the successions is very fine-to fine-grained sandstone which are thin to medium bedded and contain hummocky cross stratification, wavy bedding, ripple lamination, and burrowing. Successions are commonly capped with amalgamated beds up to 1 m thick of parallel laminated, current and oscillation rippled, and low angle trough cross stratified sandstone. Fine-grained woody material is disseminated throughout the sandstones and siltstones. Also common within these successions are the feeding traces of *Chondrites* and the feeding-dwelling burrows of *Trichichnus*.. Sets of coarsening and thickening upward successions are vertically stacked within unit A. The top of an individual succession is abruptly overlain by the basal fine-grained part of the next succession.

Figure 17. Photographs of unit A of the sandstone member of the Moose Channel Formation.

17.1. These photographs display the internal sedimentology of a coarsening-and thickening-upward parasequence of mudstone, siltstone and very fine-to fine-grained sandstone. (A) Overall view of the 48 m thick succession. Up is to the right. (B & C) Basal shale containing rounded chert pebbles. Thin interbeds of shale, siltstone and very fine-grained sandstone dominate the lower 1/3 of the parasequence. (E) Amalgamated fine-grained sandstone beds containing hummocky cross stratification are common in the upper 2/3 of the parasequence. (F) Top of the parasequence consists of a 3 m thick interval of parallel laminated, symmetricaly and assymetrically rippled, and low angle trough cross stratified sandstone. This parasequence is interpreted as a distributary mouth bar succession, which vertically stacks distal bar, bar-front and proximal mouth bar crest deposits. Photographs are from section MD79.

17.2. Large two-dimensional megaripples with amplitudes of up to 30 cm and wavelengths of up to 2 m. The ripples are constructed of matrix supported granule to pebble conglomerate and are interbedded with trough cross bedded and ripple laminated sandstone. Overlying sandstone beds contain abundant *Arenicolites*. (A) Photograph displays a bedding plane surface with two seperate megaripple sets. Photographs B-C are cross sectional views of the ripples. (B) Observe the lack of internal lamination within the ripples. Smaller scale sinuous current ripples are superimposed on some megaripples. The tape measure is 25 cm in length. (C) The megaripples are slightly asymmetrical and flat crested and may be overlain by clay drapes. Hammer for scale. (D) Coarser-grained pebble lags are commonly found in the troughs between ripples. The megaripples are interpreted to be erosional features formed from delta front splays that have been reworked by storm waves. Scale in trough is 15 cm in length. Photographs are from section MD08.

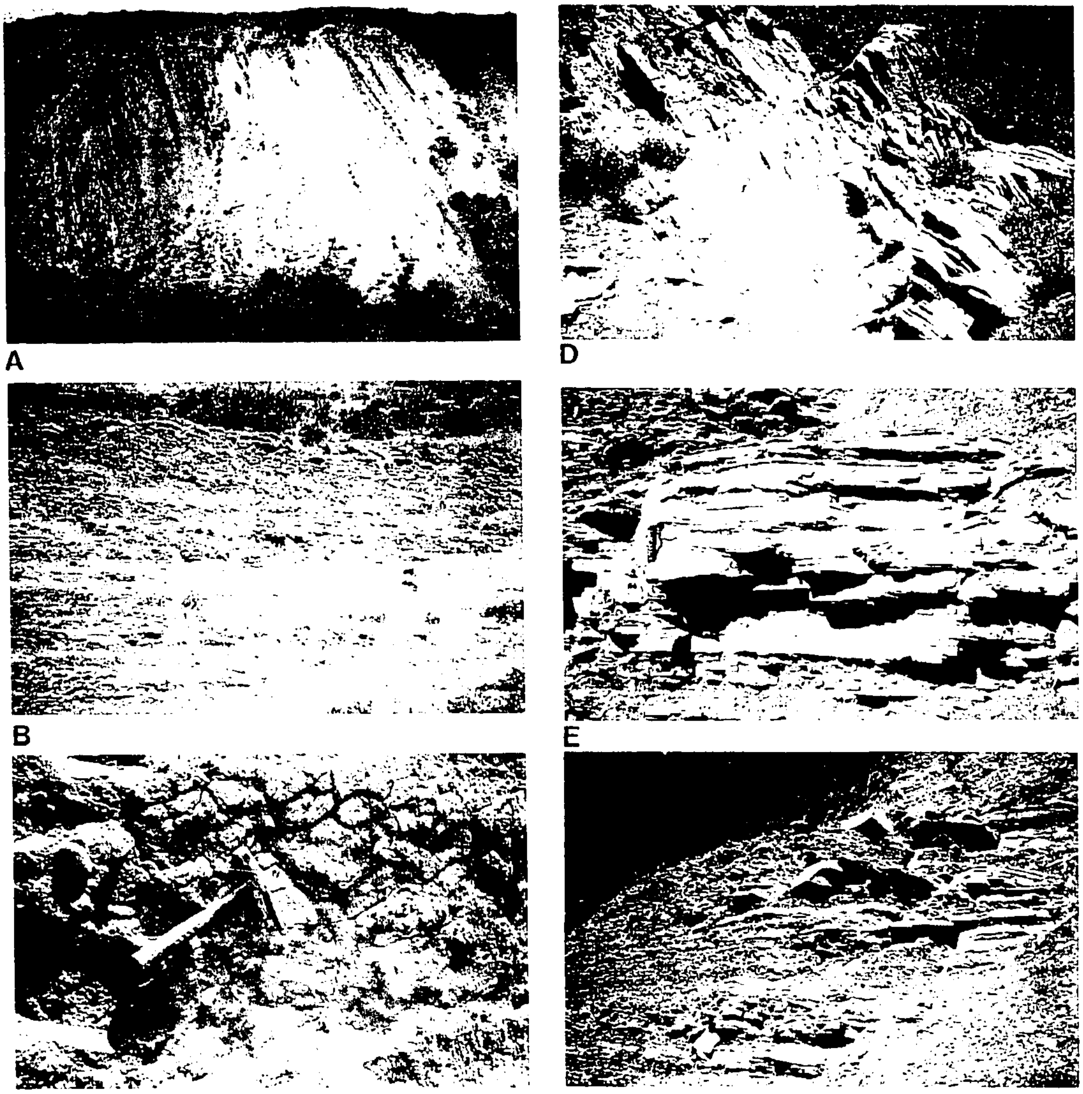


Figure 17.1.

Figure 17.2. A.

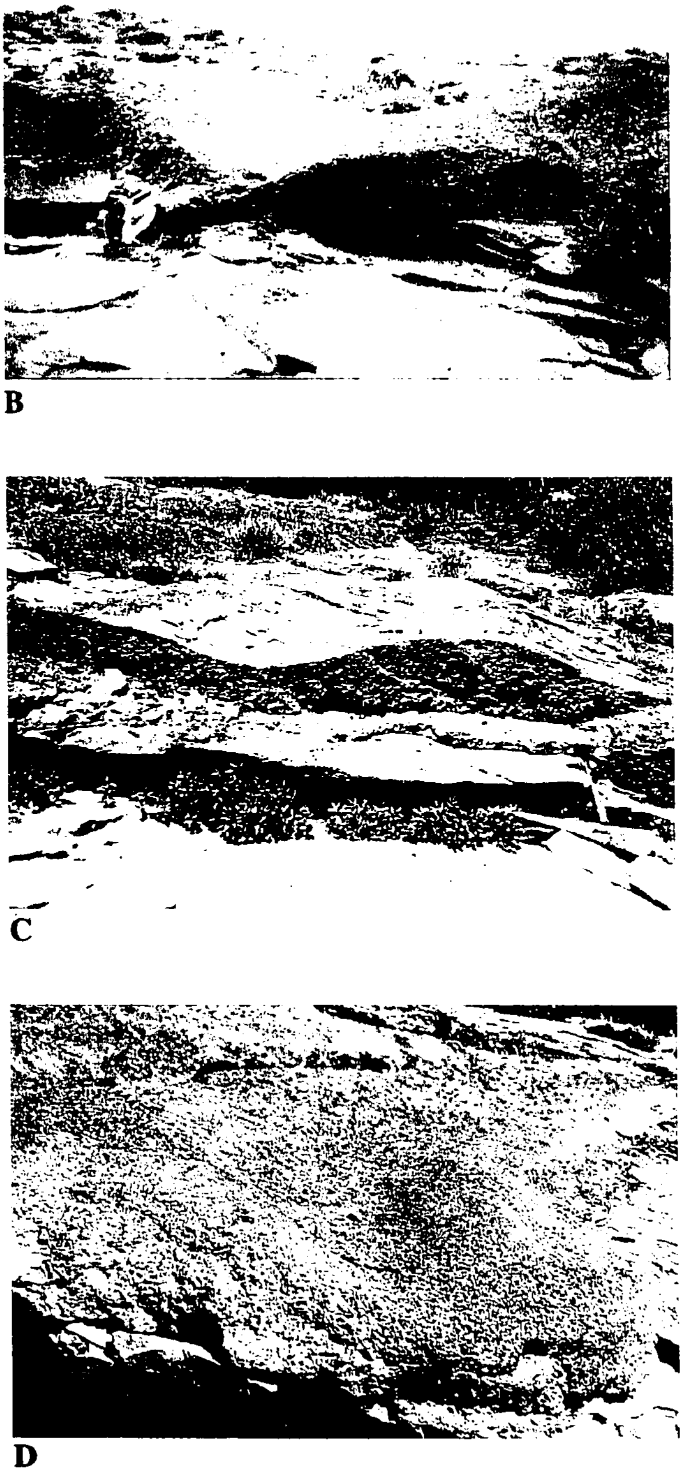


Figure 17.2. B-D.

Unit A contains large megaripple sets. Megaripples are constructed of matrix supported granule to cobble conglomerate. Individual megaripple sets are interbedded with trough cross bedded, symmetrical and asymmetrical ripple laminated sandstone beds that contain abundant *Arenicolites* burrows (Figure 17.2). Megaripples are two-dimensional and have amplitudes up to 30 cm and wavelengths up to 2 m, but lack internal laminae. They are flat crested, slightly asymmetrical and may be overlain by thin claystone drapes. Coarser-grained pebble to cobble lags are occur in megaripple troughs. Smaller scale sinuous asymmetrical ripples are superimposed on some of the megaripples. Within a megaripple set, the orientation of the ripple crests are parallel. However, there is a difference in orientation of ripple crests between stacked sets of megaripples of as much as 70 degrees, indicating significant variation in the direction of wave approach.

The coarsening-and thickening-upward successions in unit A record deposition in conditions of decreasing water depths and increased sediment reworking. Depositional processes include suspension, density currents, unidirectional and oscillatory currents generated by storm and fair weather waves. The 10-25 cm thick, fining-upward packages at the base of coarsening-and thickening-upward successions are interpreted as turbidites. Overlying hummocky cross stratified sandstone beds are interpreted as products of either purely oscillatory flow (Dott and Bourgeois, 1982; Southard and others, 1990; Walker and Plint, 1992) or combined flow conditions (Brenchley, 1985; Nottvedt and Kreisa, 1987; Swift and Nummedal, 1987) during storm events. The increase in sandstone percent and bed thickness, and corresponding decrease in shale toward the top of individual successions, suggest a generally shallower, more agitated environment (Walker and Plint, 1992).

Based on the presence of abundant *Arenicolites* , the conglomeratic megaripple sets were deposited in a shallow marine environment. *Arenicolites* is interpreted as the dwelling burrow of an annelid and is an indicator fossil for the *Skolithos* ichnofacies. It is generally associated with shoreface or tidal flat environments (Pemberton and others, 1992b). The lack of internal lamination in megaripples indicates that they were an oscillatory rather than a migrating bedform. A two-stage process is proposed for their deposition. The first stage involves the transportation of conglomerate into a shallow marine environment. Associated delta front splays and river mouth slumps are able to transport coarse-grained material into the marine environment. In the second stage an individual conglomerate bed is reworked by high energy current. The presence of clay drapes and smaller superimposed ripples indicates that these high energy currents were episodic and followed by periods of low energy deposition. The variation in orientation between megaripple sets indicate that the dominant direction of wave approach was highly variable. This type of variation is common in bedforms that result from currents created by storm wave action. Large, internally symmetrical ripples or sand waves with spacing up to 120 cm and heights of 20-30 cm have been reported in the Lower Cretaceous Grayson Formation in northeast Texas (Hobday and Morton, 1984). These megaripples were associated with nearshore and shoreface deposits and were estimated to have been deposited in water depths of less than 30 m. Large oscillation ripples with wavelengths up to 150 cm and heights of 15-30 have also been reported on the modern northeast Pacific continental shelf at water depths of 80-105 m (Yorath and others, 1979).

Unit A is interpreted to have been deposited in shallow water in a delta front environment. Characteristic coarsening-and thickening-upward successions are interpreted to be stacked distributary mouth bars. Individual coarsening-and thickening-upward successions overlie distal bar, bar front and proximal mouth bar crest deposits. Distal bar deposits consist of thin frontal splays of pebbly sandstone and siltstone and hemipelagic shales. The overlying sandstone beds contain sedimentary structures indicative of decreasing water depth and increased reworking by a variety of mechanisms including river currents and marine processes. These deposits are interpreted to be middle and proximal bar mouth deposits. The top of the successions containing the thick beds of parallel laminated, current and oscillation rippled, and low angle trough cross stratified sandstone is interpreted as the bar crest.

An abrupt change from thick amalgamated sandstone beds to thin mudstone dominated turbidites occurs at the top of each coarsening and thickening upward succession. This change is interpreted as a marine flooding surface which has resulted in an abrupt rise in relative sea level. These successions are by definition parasequences (Van Wagoner and others, 1990). Parasequence boundaries seen in outcrop may be localized and related to autocyclic mechanisms such as delta lobe shifting (autocyclic parasequences) or controlled by regional relative sea level changes (allocyclic parasequences)(Brown, 1992). The vertical stacking of these successions or parasequence sets is indicative of an aggradational depositional system in which sediment supply and accommodation space are approximately balanced.

Unit B

Unit B consists of fine-to medium-grained sandstone (greater than 60 percent), shale, carbonaceous mudstone, siltstone, coal and minor thin conglomerate beds. Sandstone was primarily deposited in broad vertically stacked channels. The lower bounding surfaces on channels are erosional with the overlying channel incising into the underlying. Individual channels can reach observed widths of greater than 100 m and reach a maximum observed depth of 13 m. Channel fill consists of vertically stacked 30 cm to 3 m thick assemblages containing some or all of the following sedimentary structures and lithologies in ascending order: basal scour surface; thin basal conglomerate lags; parallel laminated, wavy bedded, tabular cross bedded or trough cross bedded sandstones; and asymmetrical rippled laminated sandstones. The upper surface of some sandstone beds contain abundant small trails and tracks. The assemblages may be capped by thin beds of mudstone. Sand to log sized carbonized organic material is present throughout the channel fills.

Non-channelized intervals consisting of coarsening-upward successions of subbituminous coal, carbonaceous mudstone, siltstone and sandstone are also present within unit B. Basal coals reach a maximum thickness of 1 m and are overlain by black carbonaceous mudstone beds. Mudstones become progressively siltier toward the top of the successions where they are interbedded with thin beds of parallel and ripple laminated siltstones and parallel laminated, ripple laminated and trough cross bedded sandstones. Root casts are present in some sandstone beds. Complete successions are capped by up to 4 m of parallel laminated and trough cross bedded sandstone. Maximum observed thickness for an individual non-channelized interval is 25 m. Figure 18.1 displays a well-exposed coarsening-upward succession in unit B.

Based on the presence of interbedded coals and roots zones, unit B is interpreted to be nonmarine in origin. Within unit B most channels were filled with sandstone containing sedimentary structures formed by traction deposition. This is indicative of high bedload deposition within an active channel. Preserved sedimentary structures within channel fills are interpreted as channel lags, single and compound longitudinal, lateral and transverse bars. Figure 18.2 displays the upper surface of a sandstone bed interpreted as a lateral bar. The top surface of this bed contains sinuous in-and out-of-phase asymmetric ripples with

Figure 18. Photographs of unit B of the sandstone member of the Moose Channel Formation.

18.1. (A) Scour-and-fill structure. Scale is 15 cm. These structures are found in broad sandstone filled channels which are interpreted as high bed load, distributary channels. Section MD27. (B) A coarsening-upward succession consisting of a basal coal overlain by black carbonaceous mudstone which becomes progressively siltier toward the top where it is interbedded with thin beds of parallel and ripple laminated sandstone. The succession is capped by 4 m of parallel laminated and trough cross bedded sandstone. The succession is interpreted as interdistributary bay fill in which bay and marsh deposits are overlain by crevasse splays and finally capped by a crevasse channel. Up is to the left. Section MD08.

18.2. These photographs display a 1.5 m thick succession of interbedded sandstone, pebbly sandstone and conglomerate. (A) Low angle trough cross bedded sandstone is overlain by tabular cross bed sets and poorly stratified pebbly sandstone and matrix supported conglomerate. The succession is capped by a thin layer of ripple laminated sandstone. (B and D) Bedding plane exposures of the upper surface of the sucession displays both in-phase and out-of-phase sinuous asymmetric ripples, small linear bedforms that are perpendicular to ripples, and abundant tracks and trails. This succession is interpreted as a lateral bar on the margin of a high bed load distributary channel. The bar is interpreted to have been exposed during low water levels. Scale is 15 cm long. (C) A suggested modern analog for the small linear bedforms that are perpendicular to the ripples. This feature was formed by the waterline on a channel margin during a drop in water level. Photographs are from locality MD62.

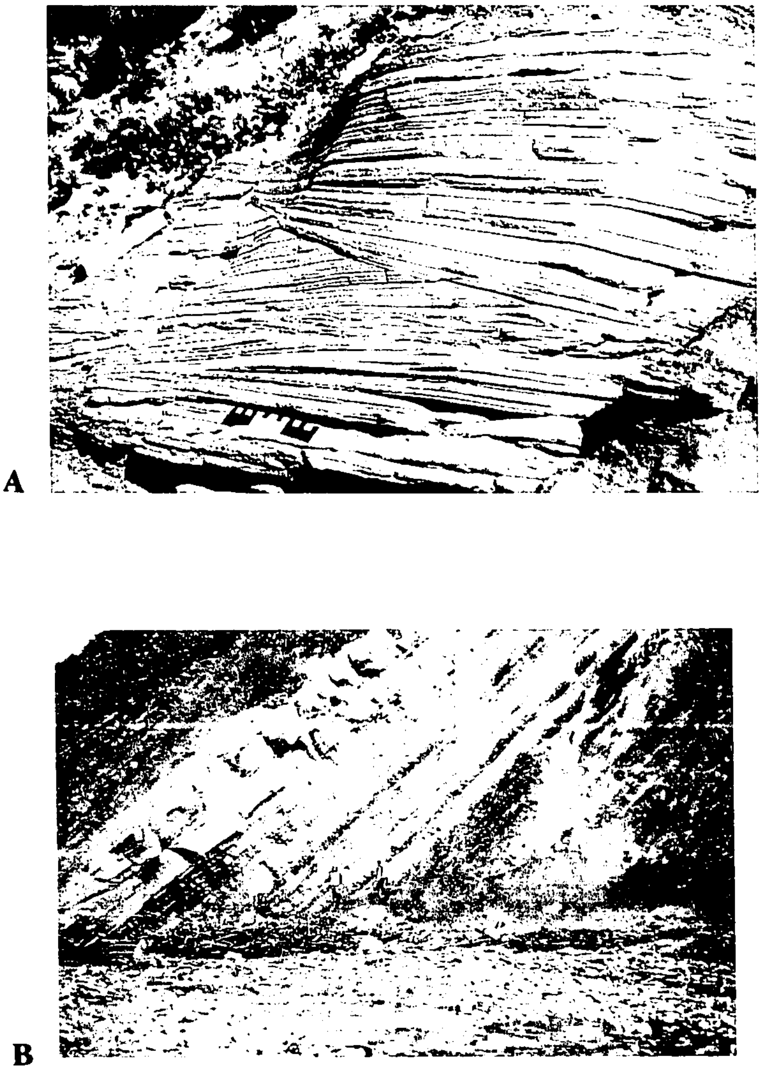


Figure 18.1.

Figure 18.2. A-C.

Figure 18.2. D.

abundant trails and tracks, as well as the small parallel linear features perpendicular to the direction of current movement. These small linear features are interpreted to represent the water mark of successive decreases in water depth along the margin of a channel. Lateral bars form along the margins of low sinuosity channel segments, and are exposed during low flow and submerged during flood (Galloway and Hobday, 1983).

It has been observed in this study that channels in unit B lack features associated with meandering or highly sinuous channels, such as well developed fining-upward successions, point bar, chute bars or large scale lateral accretion surfaces (epsilon cross-bedding).

Unit B is interpreted to have been deposited in a lower delta plain environment. Distributary channel fill, crevasse splays, crevasse deltas, interdistributary bay and marsh deposits have all been recognized within this unit. Coarse-grained distributary channel deposits make up the skeletal framework and are the dominant preserved element of this unit. The channel complex consists of vertically stacked distributary channels whose sandstone fill resulted from active bedload sedimentation. Stacked channel fill complexes form by vertical aggradation within relatively stable channel under conditions of rapid subsidence (Miall, 1985a). In unit B, the base of distributary channels typically scour into underlying sediments. Fine-grained interdistributary and marsh deposits, while present, make up a disproportionately small part of the preserved rock record. Either these environments were rare in this delta system or they were rarely preserved due to erosion by channels. Only one example of a channel plug or abandoned distributary channel was observed (Section MD 66). The mudstone filled channel is interpreted as having been filled by suspension after abandonment. The channel is overlain by a series of sand-rich channel fills.

Non-channelized intervals within unit B are interpreted as interdistributary bay sediment. Carbonaceous mudstone and siltstone are interpreted as bay and pond sediment. Swamp and marsh sedimentation is represented by a few thin to thick beds of subbituminous coal. Bay and pond sediments consist of carbonaceous mudstone and siltstone. Crevasse splays and crevasse splay channels consist of very fine-to coarse-grained rippled, parallel laminated and trough cross bedded sandstone which overly, or are interbedded with, mudstones and siltstones. Coarsening upward successions of non-channelized intervals are produced by levee deposits, the progradation of splay deposits, and finally crevasse channels over embayment muds and silts. In the lower delta plain of modern deltas, crevasse deposits build into shallow bays between, or adjacent to, major distributaries and extend themselves bayward through a system of bifurcating channels similar in plan to the veins of a leaf (Coleman and Prior, 1982).

Unit C

Unit C consists of interbedded conglomerate, pebbly sandstone and sandstone, with minor thin interbeds of mudstone and siltstone. Unit C is distinguished from unit B by an increase in thickness and percentage of conglomerate and pebbly medium-and coarse-grained sandstone, and a decrease in amount of siltstone and mudstone. Sandstone and conglomerate comprise greater than 90 percent of this unit. Granule to cobble conglomerate consists of thin to thick bedded lenses reaching a maximum thickness of 70 cm. Clasts are dominantly subrounded to rounded chert, quartz, volcanic and sandstone rock fragments, but angular mudstone clasts are also present. Conglomerate beds are poorly stratified and matrix supported in fine-to coarse-grained sandstone. Sandstone beds range from thin to very thick bedded and commonly contain rounded pebbles and carbonized woody material up to log sized.

Sandstone and conglomerate within this unit were deposited in broad complex, vertically stacked channels. Individual channel fills reach a maximum observed thickness of 5 m. Typical sedimentary assemblages within these channels consist of a basal scour surface overlain by alternating bedsets of crudely stratified, ungraded to normally graded conglomerate and/or pebbly sandstone, medium-to coarse-grained, crude high angle trough or tabular cross bedded sandstone, and fine-to medium-grained, parallel laminated and low angle trough cross bedded sandstones. Unit C forms the upper steep vertical canyon walls along the junction of Cache Creek and the Big Fish River (Figure 19) and is also exposed along Eagle Creek (Section MD08).

Sandstone and conglomerate within unit C were deposited by traction deposition within broad complex channels. Interpreted bedforms are channel lags, single and compound longitudinal, lateral and transverse bars. Such bedforms are indicative of high bedload deposition which occurs within active braided stream channels. Rare interbedded mudstone intervals were deposited by suspension sedimentation.

Unit C is interpreted as a sandy, braided stream system that occurred within an upper delta plain environment. The thin mudstone and siltstone beds present are interpreted as flood plain and overbank material. Such stacked channel complexes are formed by vertical aggradation under conditions of rapid subsidence (Miall, 1985a). Low sinuosity, high bedload fluvial deposits having similar sedimentary assemblages have been described on the Platte and Saskatchewan Rivers (Miall, 1985b). Lithologic and sedimentologic

Figure 19. Photographs of unit C of the sandstone member of the Moose Channel Formation. (A) This vertical face consists of amalgamated lenticular interbeds of sandstone, pebbly sandstone and conglomerate, typical of unit C. (B) These beds of parallel laminated and tabular cross stratified coarse-grained sandstone are contained within broad complex vertically stacked channel fills. Unit C is interpreted as a sandy, braided, fluvial complex. Locality MD57.

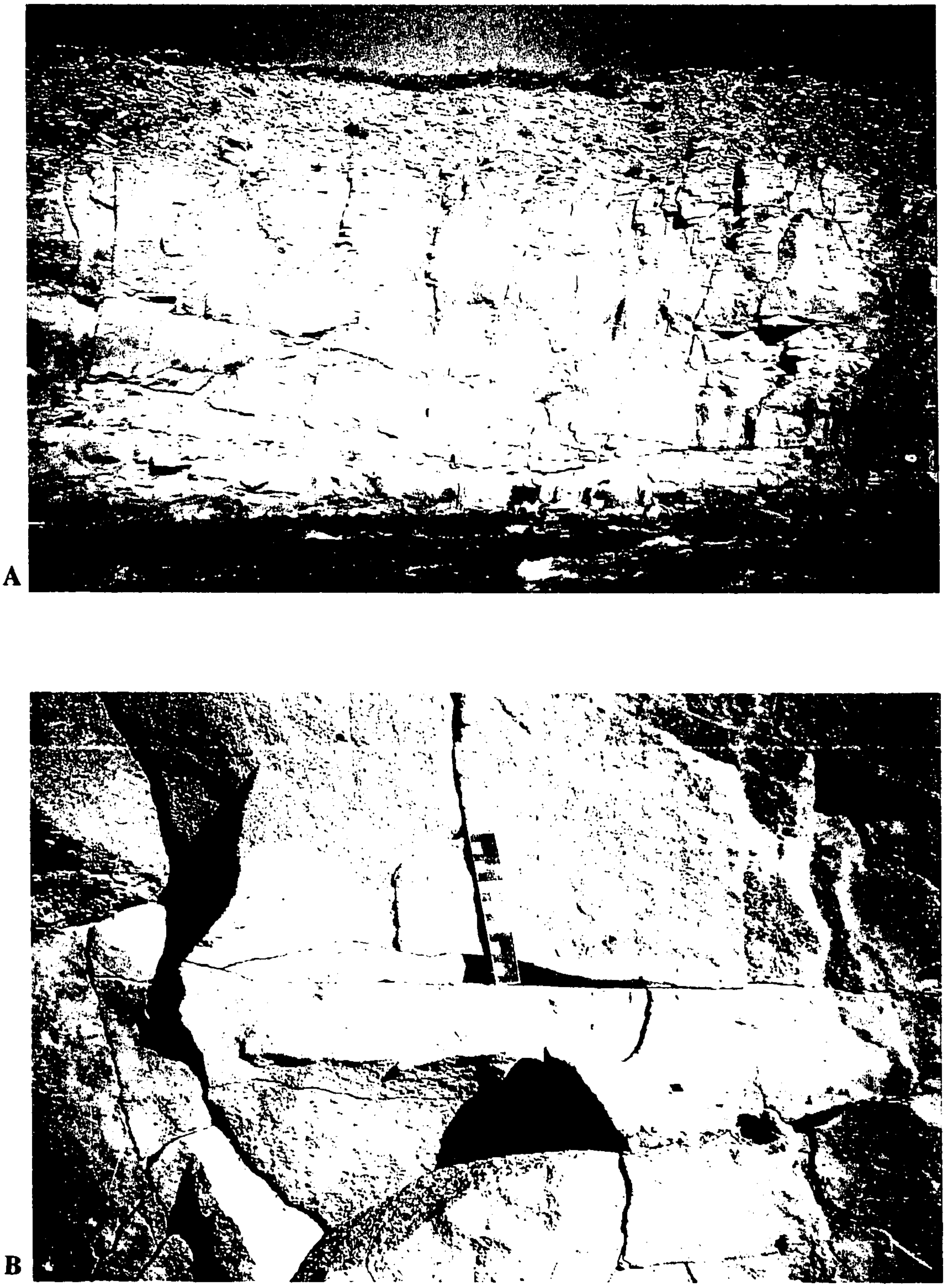


Figure 19.

differences between units B and C reflect a transition from lower to upper delta plain deposition.

In summary, the sandstone member of the Moose Channel Formation consists of conglomerate, sandstone, siltstone, mudstone and coal. The dominant lithology is sandstone, which comprises up to 85 percent of the member at the type section. Based on lithology, sedimentary structures, and biogenic structures, the sandstone member can be subdivided into three ascending units (A-C). The sandstone member is interpreted to have been deposited during the progradation and aggradation of a major deltaic system. Depositional environments range from inner shelf and subaqueous delta plain to subaerial delta plain. Proximal delta front deposits consist dominantly of aggradational coarsening upward parasequence sets (interpreted as distributary mouth bars). Subaerial delta plain deposits are dominated by sand rich, high bed load, distributary channel fill and overlying vertically stacked braided channel complexes. The presence of straight high bed load distributary channels overlain by sandy braided stream deposits suggests a fairly steep gradient and proximal sediment source area.

Ministicoog Member

The Ministicoog Member of the Moose Channel Formation consists of mudstone and siltstone with lesser fine-to very fine-grained sandstone and rare conglomerate. The member is typically recessive and generally poorly exposed. Where it crops out on the west side of the Mackenzie delta, it is up to 366 m thick (Young, 1975). Basal contact with the sandstone member is gradational with the contact placed at the top of the well-bedded or massive sandstone (Young, 1975). At the type section, the Ministicoog Member immediately above the basal contact displays an overall fining upward succession from interbedded sandstone and siltstone to mudstone. Locally, the Ministicoog Member contains significant amount of fine-to very fine-grained sandstone.

Typical sedimentary successions within the sandy sections of the Ministicoog consist of: 1) amalgamated burrowed and trough cross stratified sandstone beds up to 1m in thickness which contain a few thin conglomerate lenses and are interbedded with burrowed siltstone and mudstone (Figure 20), 2) sandstones containing small-scale hummocky cross stratification and asymmetrical ripple lamination which are interbedded with mudstone and ripple laminated siltstones and 3) coarsening-and thickening-upward sequences of interbedded, burrowed and ripple laminated siltstone and trough cross bedded sandstone capped by parallel and ripple laminated sandstone which commonly contain soft sediment deformational structures. Ripple lamination types observed include linguoid asymmetrical, symmetrical and interference ripples. A channelized disorganized cobble to boulder conglomerate is associated with interbedded amalgamated, trough cross bedded sandstone, siltstone and mudstone along Eagle Creek (MD8). Conglomerate consists of deformed and rounded blocks of sandstone in a matrix of argillaceous very fine-grained sandstone. The conglomerate fill reaches a maximum thickness of 8 m (Figure 20).

The abundance of shale in the Ministicoog Member indicates that suspension was the dominant mechanism of deposition. The sedimentary structures present within sandstones indicate deposition primarily by traction processes associated with oscillation (waves) and unidirectional flow (currents). Amalgamated burrowed and cross-bedded sandstone records episodic bedload sedimentation typical of storm deposition found in inner shelfal environments. Intervals containing interbedded shale and hummocky cross stratified sandstone were deposited at water depths below fair weather wave base, but above storm wave base. The presence of disorganized conglomerate containing abundant soft sediment

Figure 20. Photographs of the Ministicoog Member of the Moose Channel Formation. (A) Amalgamated sandstone bed containing thin conglomerate lenses. The upper 2 cm of bed is burrowed. Bed is capped by burrowed mudstone which is scoured by overlying sandstone bed. These internally complex, thickly-bedded sandstones are interpreted as amalgamated shelf storm deposits. See hammer for scale. (B) Disorganized conglomerate consisting of soft sediment deformed balls and blocks of sandstone in a matrix of argillaceous very fine-grained sandstone. The conglomerate reaches a maximum thickness of 7.5 m, is channelized and pinches out laterally in 70 m. Conglomerate channel is interbedded with amalgamated sandstone similar to that in upper photo. It is interpreted as having been deposited as a debris flow in a small channel or gully in a proximal delta front environment. See hammer for scale. Both photographs are from section MD08.

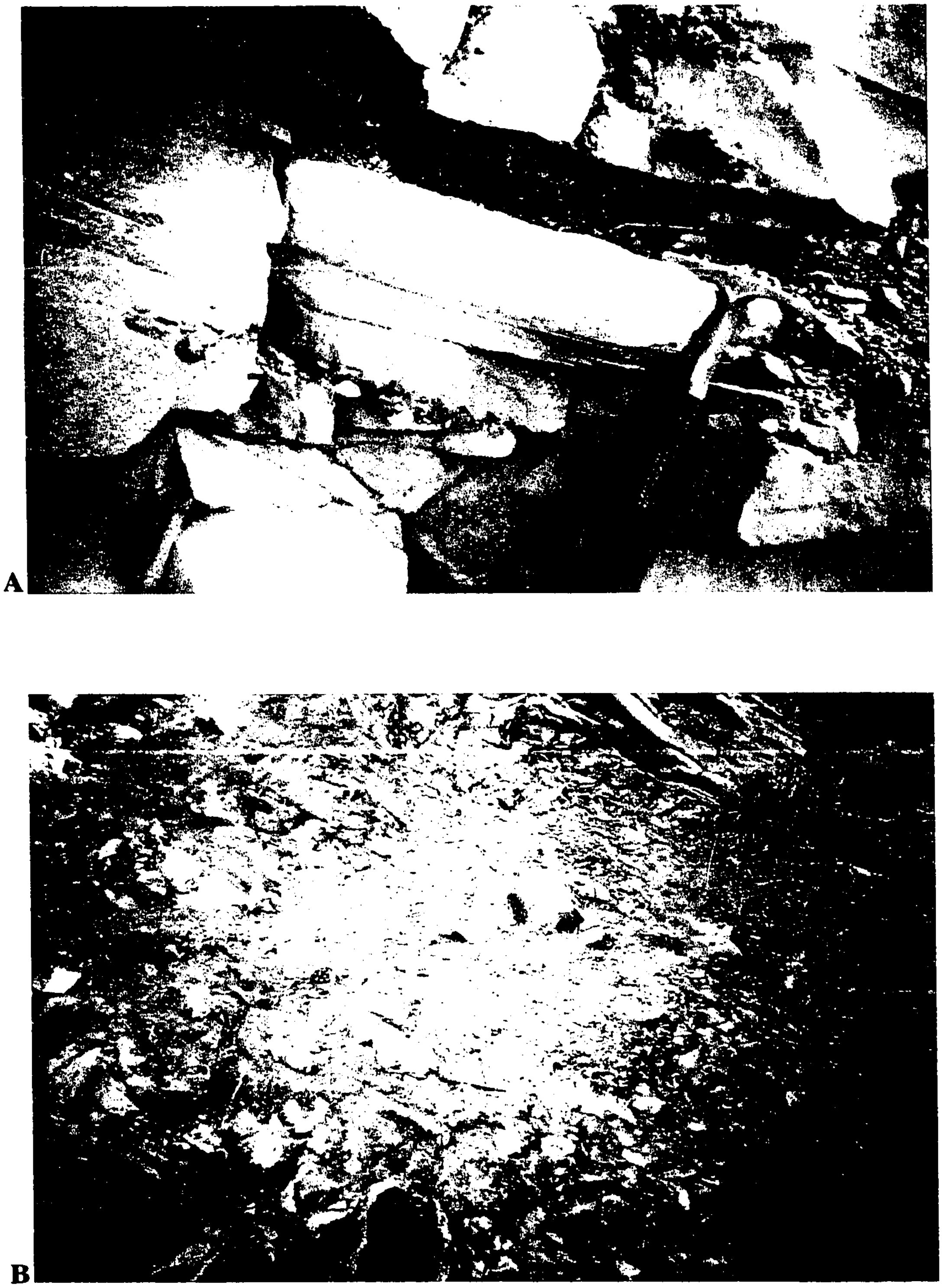


Figure 20.

deformed cobbles and boulders of rounded sandstones is indicative of deposition by debris flow.

Coarsening-and thickening-upward successions in the Ministicoog Member contain sedimentary structures indicative of decreasing water depths and increased sediment reworking. Completely burrowed siltstone beds at the base of coarsening-upward successions indicate relatively low rates of sedimentation. The increase in sandstone percent and bed thickness, and corresponding decrease in mudstone toward the top of individual successions also suggests a generally shallower, more agitated environment (Walker and Plint, 1992). The presence of parallel laminae at the top of coarsening upward successions is characteristic of upper flow regime conditions typical but not restricted to swash zone deposits.

The Ministicoog Member is interpreted to have been deposited in inner shelf and delta front environments. The base of the Ministicoog records the flooding of the underlying subaerial delta plain of the sandstone member. Coarsening-and thickening-upward successions within the Ministicoog Member were deposited as distributary mouth bars. Individual coarsening-and thickening-upward successions overlay distal bar, bar front and proximal mouth bar crest deposits. The channelized debris flow at Eagle Creek may be similar to the delta front mudflow gully deposits described by Coleman from the modem Mississippi delta front (Coleman and Prior, 1982). The abundance of interbedded mudstone, hummocky and trough cross stratified sandstones suggests that episodic storm deposition followed by significant amounts of suspension sedimentation is the dominant mechanism of deposition within the Ministicoog Member. Much of the Ministicoog Member appears to be aggradational. Following the initial transgression, deltaic sources continued to supply sediment with the rate of subsidence approximately equal to the rate of sedimentation.

DEPOSITION OF THE AKLAK MEMBER OF THE REINDEER FORMATION

The Reindeer Formation was defined by Mountjoy (1967) from outcrops in the Caribou Hills on the eastern edge of the Mackenzie Delta. The formation was subdivided by Young (1975) into the Aklak Member and an unnamed upper member. Type section for the Aklak Member is located on Aklak Creek on the western margin of the Mackenzie Delta. The upper member was subsequently named the Taglu Member by Shawa (1978) for a sequence of rocks which conformably overlie the Aklak Member and are present in the Taglu G-33 borehole at depths between 2483 - 2750 m. Both palynomorphs and foraminifers indicate that the Aklak Member is Late Paleocene to Early Eocene in age.(Dixon, Dietrich and McNeil, 1992; Price, McNeil, and Ioannides, 1980; Young, 1978).

This study examined the Aklak Member in exposures along the type section at Aklak Creek, as well as along the Caribou Hills, Eagle Creek and an unnamed creek at 138° 0' and 68° 45' North (Measured Section 34). Due to a lack of outcrop exposure, this study did not examine the Taglu Member.

The Aklak Member consists of include conglomerate, sandstone, pebbly sandstone, siltstone, mudstone, shale and coal. Coals rank from subbituminous A to high volatile C bituminous and typically contain 30 percent mudstone and shale interbeds (Young, 1975). Along Aklak Creek at least ten coal seams are exposed with a total thickness of 27.5 m. This coal was mined until 1956 as a source of fuel for the village of Aklavik (Young, 1978). Mudstone ranges from black to red in color and commonly contains plant material. At locality MD 1 on the northern-most exposures along Aklak Creek the coal has undergone combustion and the associated mudstones are now an oxidized brick-like clinker.

Sandstones within the Aklak Member range from fine-to very coarse-grained, and are subangular to subrounded, submature to immature chert litharenites. Grain types include quartz, cherty argillite, chert, volcanic rock fragments, variable amounts of feldspar and minor amounts of metamorphic rock fragments. Sandstone beds are thin to thick bedded and commonly occur as channel fill.

Conglomerates within the Aklak Member range from matrix to grain supported and range in thickness from 4 m to thin beds (less than 10 cm thick) that are typically interbedded with pebbly sandstone. Clast types include chert, quartz, volcanic and sandstone rock fragments. The Aklak Member contains more abundant and thicker conglomerate than the Moose Channel Formation.

Young (1975) estimated a thickness of 580 m at the type locality on Aklak Creek, but much of the type section is covered. However, the presence of a wide range of dips from vertical to near horizontal suggests significant localized faulting and folding within covered intervals; therefore, it is very difficult to estimate the true thickness of the Aklak Member at its type section. Subsurface studies of the Reindeer Formation (Nentwich, 1980; Nentwich and Yole, 1982) estimate a total thickness of between 1058 m and 1515 m in wells with a maximum thickness of up to 2000 m or more based on seismic sections. Based on well logs, the thickness of the Aklak Member ranges from 320 m to 1399.

The basal contact with the Ministicoog Member of the Moose Channel Formation is exposed both on Aklak Creek and Eagle Creek. The upper contact, of the Aklak Member with the overlying Taglu Member is not exposed due to large covered intervals in the Caribou Hills. On the western side of the Mackenzie Delta northward regional dip places the Aklak/Taglu contact under the Beaufort Sea. Based on subsurface studies the Aklak/Taglu appears to be gradational (Nentwich, 1980; Nentwich and Yole, 1982; Shawa, 1978). Young (1975) defined the contact as the highest significant occurrence of coal beds.

On Aklak and Eagle Creeks the contact between the Ministicoog and Aklak Members is interpreted as a subaerial unconformity (disconformity). Interbedded marine mudstone, siltstone and sandstone of the Ministicoog is abruptly overlain by coal and nonmarine sandstone and conglomerate indicating a significant downward shift in coastal onlap. The unconformity at the base of the Aklak Member has been recognized in the subsurface as far west as the Natsek E-56 well (Dietrich and others, 1989b). There, a maturation discontinuity occurs at the Moose Channel/Aklak contact (average vitrinite reflectance values increase from .6% to .7-.75 Ro). In the Natsek well, the Aklak Member contains a lower percentage of mudstone, more conglomeratic beds and thicker coals than the Moose Channel Formation. On seismic data tied to the Natsek well, the unconformity between the Aklak and the Moose Channel appears as a surface of onlap, separating divergent Aklak sequence reflections from more parallel underlying reflections. In the northeastern Beaufort-Mackenzie basin, Young (1975) reported that an angular unconformity is present between the Ministicoog and Aklak Members in southeastern Richards Island.

Fission track analysis of samples from the Cuesta Creek Member at the type locality on the Big Fish River, south of Aklak Creek, records an uplift event at 53 million years (O'Sullivan, 1993). This Early Eocene date suggests that uplift was occurring to the south during the deposition of the Aklak Member. It also suggests that tectonics rather than a global eustatic sea level change may be responsible for the unconformity at the base of the Aklak Member.

Where it is well exposed, the Aklak Member displays a vertical coarsening-upward sequence on the scale of a few meters to up to 80 m. The complete vertical succession within these sequences consists of a basal coal or interbedded mudstone and coal, overlain by siltstone, sandstone and capped by conglomerate (Figure 21). However, truncated successions in which the coal is directly overlain by sandstone beds are present.

Typical sedimentary structures present within sandstones include trough and tabular cross beds and current ripple laminations. Convolute bedding, root casts, abundant carbonaceous plant material, pebble lags and a few small horizontal and vertical burrows are also present. Both tabular and trough cross stratification are developed within conglomerate beds.

The abundance of coal and root zones throughout the Aklak Member demonstrate a nonmarine origin. The Aklak Member is interpreted to have been deposited in upper delta plain and fluvial environments. Coarsening-upward vertical successions were deposited within ponds, lakes, marshes and swamps (floodplains), crevasse splays and channels, and braided streams. The vertical sequences record the infilling of floodplains by suspended and traction deposited sediment during flood events, through the progradation of crevasse splays and channels. Crevasse channels are overlain by coarser-grained braided stream deposits. Vertical stacking of these sequences is indicative of conditions in which rates of subsidence equal rates of sedimentation. Individual sequences are the result

Figure 21. Photographs of the Aklak Member of the Reindeer Formation. These photographs display a coarsening-upward succession consisting of a basal coal and interbedded mudstone, overlain by mudstone, siltstone, sandstone (B) and capped by conglomerate (A). This vertical succession records the infilling of floodplain marsh and swamp by suspension and traction during flood events through the progradation of crevasse splays and channels. The crevasse channels are overlain by coarse-grained braided stream deposits. These upper delta plain and fluvial sediments are typical of the Aklak Member throughout the study area. Both photographs are from section MD15.

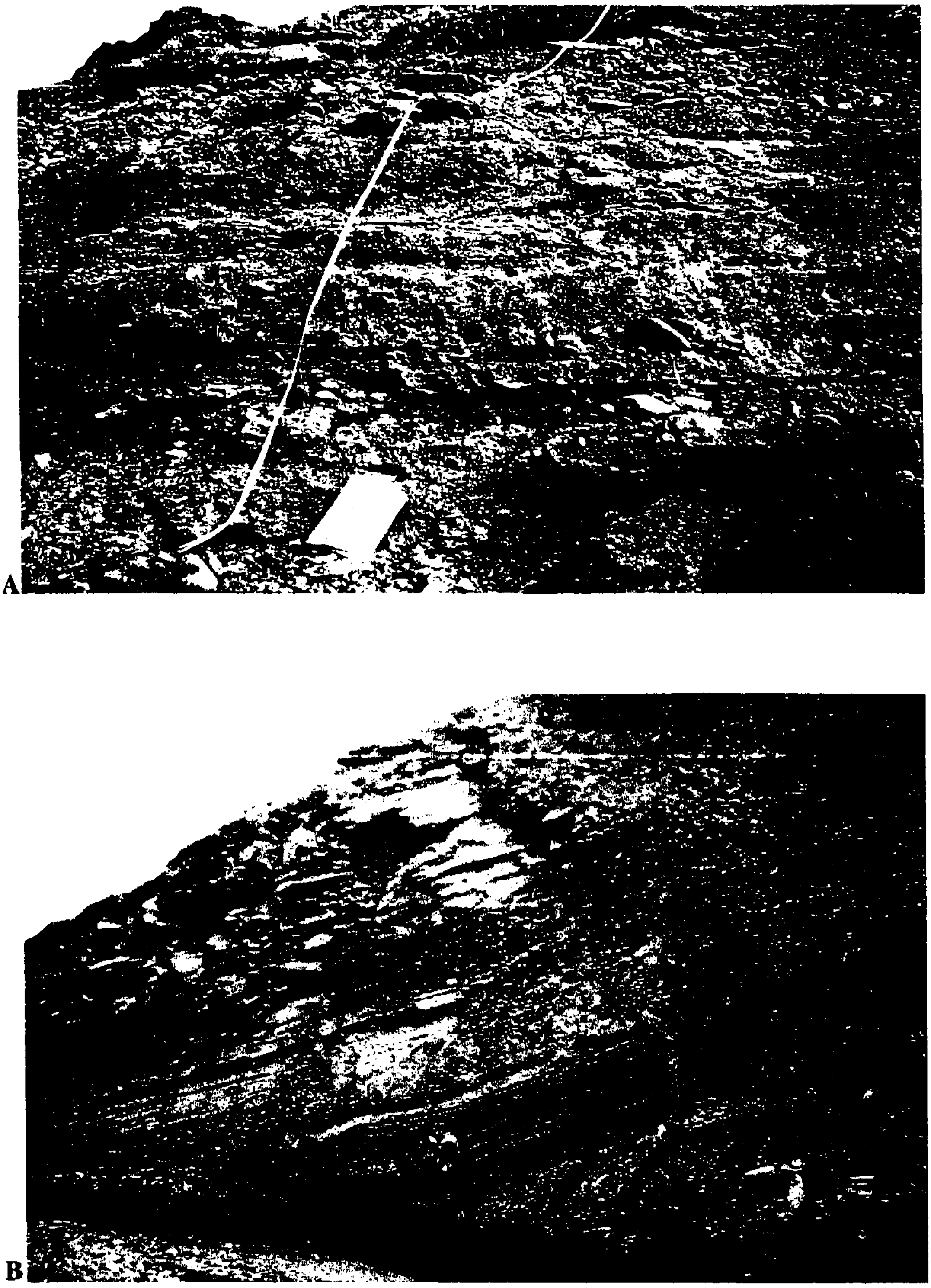


Figure 21.

of the lateral migration of contemporaneous depositional environments, not a fundamental change in sedimentation within the basin.

SEQUENCE STRATIGRAPHIC FRAMEWORK

The internal lithostratigraphy, sedimentary structures and depositional environments of Upper Cretaceous and Lower Tertiary rocks of the Beaufort-Mackenzie basin have been described above. The following discussion places these rocks in a sequence stratigraphic framework. The physical chronostratigraphic units (sequences and systems tracts) defined in this section provide a foundation for better understanding both the depositional history and petroleum potential of the Beaufort-Mackenzie basin and perhaps other similar basins.

Sequence stratigraphy has been defined as the study of genetically related facies within a framework of chronostratigraphically significant surfaces (Van Wagoner and others, 1990). The fundamental unit is the depositional sequence, defined as a stratigraphic unit composed of a relatively conformable succession of genetically related strata, bounded by unconformities or their correlative conformities (Mitchum and others, 1977). Depositional sequences can be divided into smaller stratal units defined as systems tracts. A systems tract is a linkage of contemporaneous depositional systems (Brown and Fisher, 1977). A depositional system has been defined as a three-dimensional assemblage of process-related lithofacies (Fisher and McGowen, 1967).

Sequences and their boundaries are interpreted to form in response to cycles of relative fall and rise of sea level (Van Wagoner and others, 1990). Changes in relative sea level are the result of the interaction of tectonic, eustatic and sedimentation processes. Sequences are physical chronostratigraphic units which can be classified from first to sixth order based on the duration of the cycle (Vail and others, 1977). First order cycles have a duration of 50+ million years. Second order cycles have a duration ranging from 3-50 million years. Third order cycles have a duration of 0.5-3 million years. Fourth order cycles have a duration of 0.08-0.5 million years whereas fifth order cycles have a duration of 0.03-0.08 million years. Fourth and fifth order sequences are also referred to as parasequences or simple sequences (Vail and others, 1991).

Second order cycles consist of multiple, shorter third order cycles. Second order cyclic sequences record major regional transgressive-regressive facies cycles. They result from changes in: 1) the rate of tectonic subsidence in the basin, 2) the rate of uplift in sediment source terrain, and 3) eustatic sea level caused by changes in ocean basin volume. Third order cyclic sequences result from changes in eustatic sea level due to changes in climate and water volume. Local tectonic events may subdue or enhance third order sequence boundaries (Vail and others, 1991).

Sequences are classified as type-1 or type-2 based on the lower sequence boundary. A type-1 sequence has a basal bounding surface characterized by subaerial exposure and concurrent erosion associated with stream rejuvenation, a basinward shift of facies, a downward shift in coastal onlap, and onlap by overlying strata (Figure 22). A type-1 sequence boundary is interpreted to form when the rate of sea level fall exceeds the rate of basin subsidence. Type-1 sequences are divided into lowstand, transgressive and highstand systems tracts (Figures 22 & 23). A lowstand systems tracts is interpreted to be deposited at the base of the sequence during a period of rapid fall of sea level up to the early stages of sea level rise. Lowstand deposits can be subdivided into a basin floor fan, a slope fan and a lowstand wedge. The basin floor fan is characterized by the deposition of submarine fans and associated up-dip submarine canyons and incised fluvial valleys. The slope fan is characterized by turbidite and debris flow deposition on the middle or the base of the slope. The lowstand wedge is characterized by incised valley fill on the shelf, and progradational fill with a wedge geometry on the slope. A transgressive systems tract

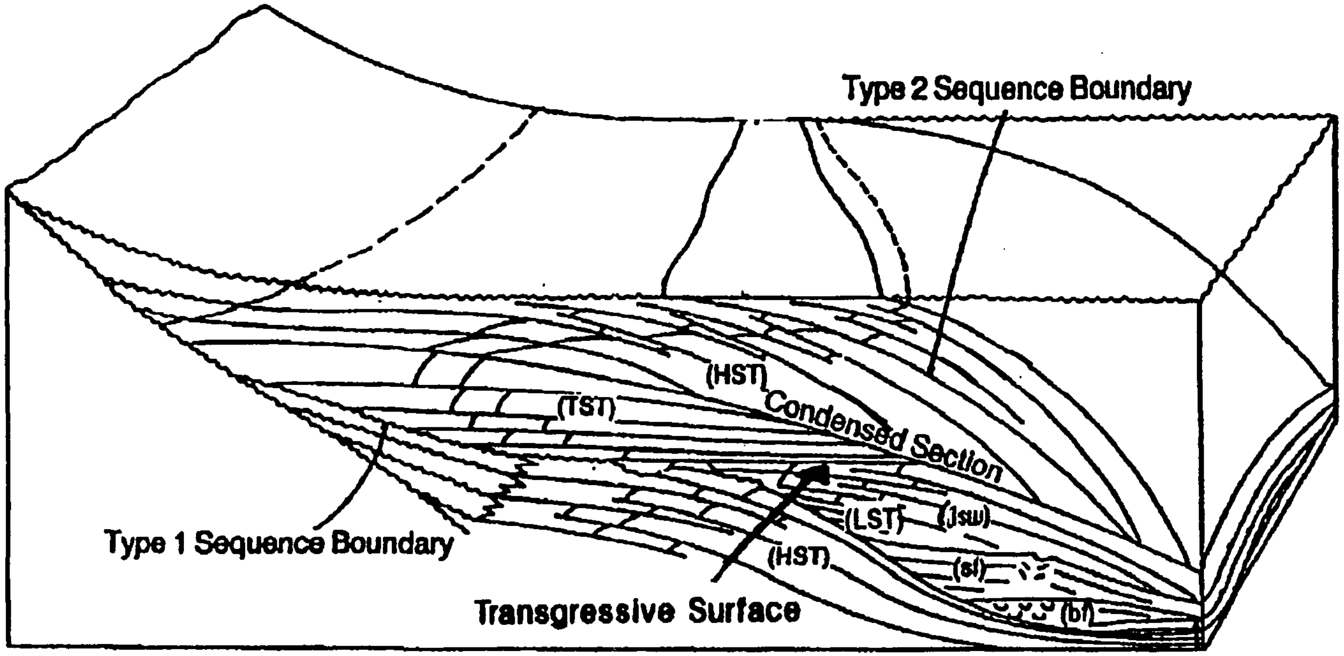


Figure 22. Diagram displaying idealized sequences and systems tracts. HST=highstand systems tract, TST=transgressive systems tract, LST=lowstand systems tract, bf=basin floor fan, sf=slope fan, lsw=lowstand wedge. Modified from Sarg (1990).

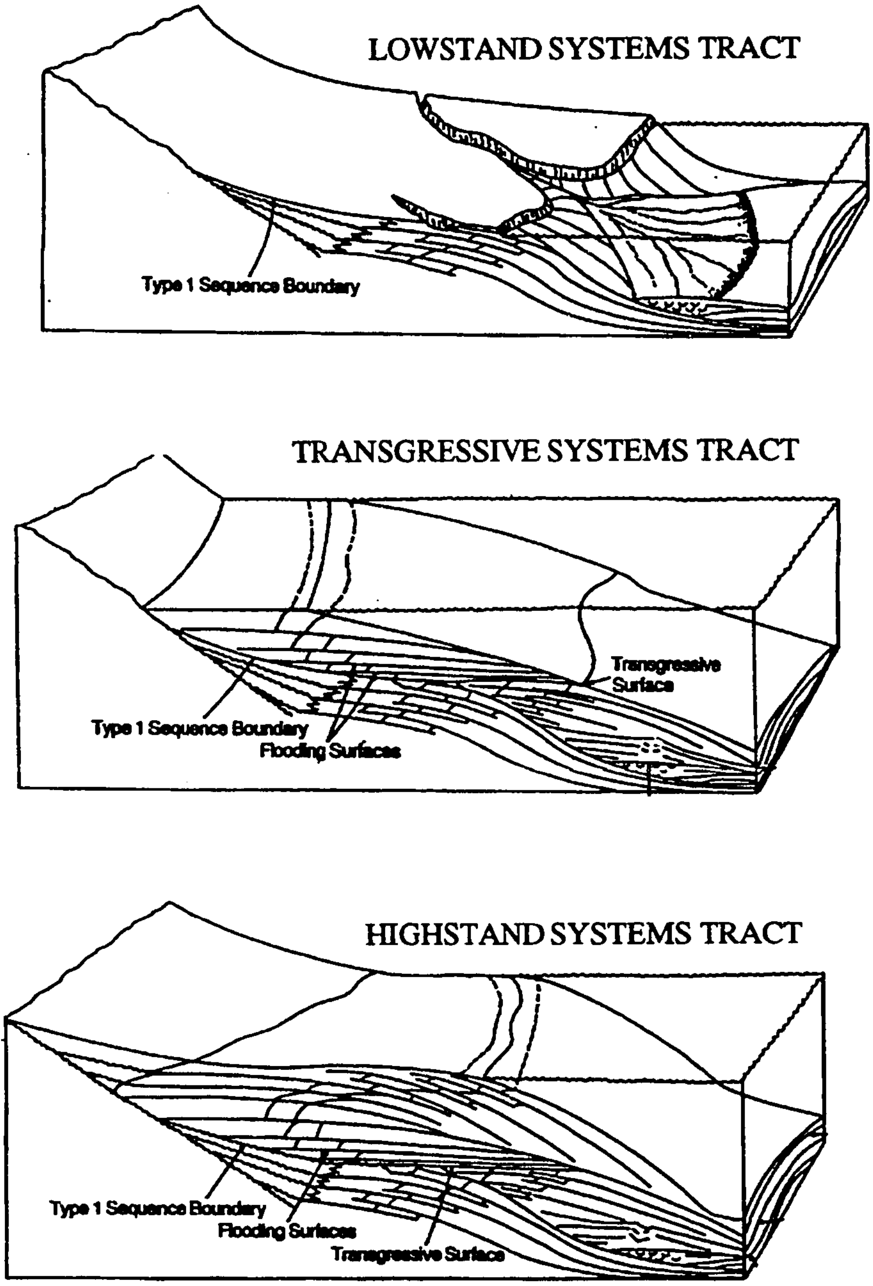


Figure 23. Diagram displaying the development of idealized systems tracts for a type-1 sequence. Modified from Sarg (1990).

overlies the lowstand system tract and is interpreted to be deposited during rapid sea level rise. The transgressive systems tract is characterized by retrogradational sediments, which include a condensed section of hemipelagic and pelagic sediments deposited at slow rates. A highstand systems tract forms the top of a sequence and is interpreted to be deposited in a stillstand of sea level and during the initiation of a new cycle of sea level fall. The highstand systems is characterized by aggradational sedimentation, followed by progradational sedimentation with prograding clinoform geometry (Van Wagoner and others, 1988).

A type-2 sequence boundary is interpreted to form when the rate of eustatic sea level fall is less than the rate of basin subsidence at the depositional-shoreline break so that no relative fall in sea level occurs at the shoreline position (Figure 22). The basal boundary of a type-2 sequence lacks both subaerial erosion associated with stream rejuvenation and a basinward shift in sedimentation. A type-2 sequence has a basal shelf-margin systems tract (characterized by aggradational to weakly progradational sedimentation), transgressive systems tract and a highstand systems tract (Van Wagoner and others, 1988).

Beaufort-Mackenzie Sequences

Based on reflection seismic data and approximately 200 exploration boreholes, Dixon and Dietrich (1988) divided the Upper Cretaceous and Tertiary strata of the Beaufort-Mackenzie basin into ten sequences (Figure 4). The basal four of these sequences, in ascending order are: (1) Boundary Creek, (2) Smoking Hills, (3) Fish River and (4) Lower Reindeer or Aklak. Formations included in the Boundary Creek, Fish River and Aklak sequences are exposed in outcrops on the coastal plain north of the Richardson Mountains and west of the Mackenzie delta, and have been described in earlier sections of this report. The Smoking

Hills sequence includes the entire Smoking Hills Formation, which crops out only on the east side of the Mackenzie delta in the Caribou Hills (Locality MD16).

Within the field area of this study, only the Fish River sequence is exposed sufficiently to interpret systems tracts or parasequences. Outcrops of the Boundary Creek and Smoking Hills sequences are limited to basinal shales which provide insufficient data for interpreting systems tracts or parasequence boundaries. Only the basal nonmarine portion of the Aklak sequence crops out in the field area. While these outcrops are useful in interpreting the boundary between the Aklak and Fish River sequences, they represent only a small part of the sequence. Furthermore, no attempt was made in this study to identify system tracts or parasequences within a totally nonmarine succession. Due to the above concerns, this study singles out the Fish River sequence for further discussion.

Fish River Sequence

As defined in this study, the Fish River sequence encompasses the Tent Island and Moose Channel Formations of the Fish River Group. The Fish River sequence is a relatively conformable succession of genetically related strata bounded at its top and base by unconformities. The Fish River sequence encompasses upper Maastrichtian through Lower Paleocene rocks, spanning an age range of approximately 11 million years. The Fish River sequence is a second order sequence. The basal sequence boundary is placed at the unconformity which underlies the Fish River Group in the southern Beaufort-Mackenzie Basin (Dietrich and others, 1985). The Fish River sequence is interpreted to be a type-1 sequence (Myers, 1992). This interpretation is supported by: 1) presence of a significant Turonian to Maastrichtian unconformity at the base of the sequence, 2) rock units overlying the basal unconformity record a major basinward shift in sedimentation and

3) presence of submarine canyon deposits immediately above the basal sequence boundary in the Fish River area (Myers, 1990).

Upper Sequence Boundary of the Fish River Sequence

The upper sequence boundary of the Fish River sequence is interpreted in this study to be the boundary developed between the Ministicoog Member of the Moose Channel Formation and the base of the Aklak Member of the Reindeer Formation. Placement of the upper sequence boundary at this stratal surface is supported by both outcrop and regional subsurface data. The unconformity at the base of the Aklak Member marks the base of an abrupt regional basinward shift in sedimentation (Figure 24; Dixon and others, 1992a; Nentwich and Yole, 1982). In the Fish River outcrop belt, this unconformity is subaerial. There, shelf and delta front deposits of the Ministicoog Member are abruptly overlain by upper delta plain coal and braided stream deposits of the Aklak Member. The unconformity at the base of the Aklak Member has been recognized in the subsurface as far west as the Natsek E-56 well (Dietrich and others, 1989b). Additionally, in the western Beaufort-Mackenzie basin in the vicinity of the Natsek well, the sequence boundary can be identified by its geometry in seismic reflection data. There, the Aklak Member onlaps the top of the Moose Channel Formation. The abrupt regional basinward shift in sedimentation at the base of the Aklak Member is evidence for a type-1 sequence boundary (Van Wagoner and others, 1990).

An alternative upper sequence boundary for the Fish River sequence has been proposed by other workers (Dietrich and others, 1985; Dixon and others, 1992 a and b) based upon their interpretation of outcrops in the Caribou Hills in the eastern Beaufort-Mackenzie basin. In poorly exposed outcrops in the Caribou Hills, Price and others (1980) identified

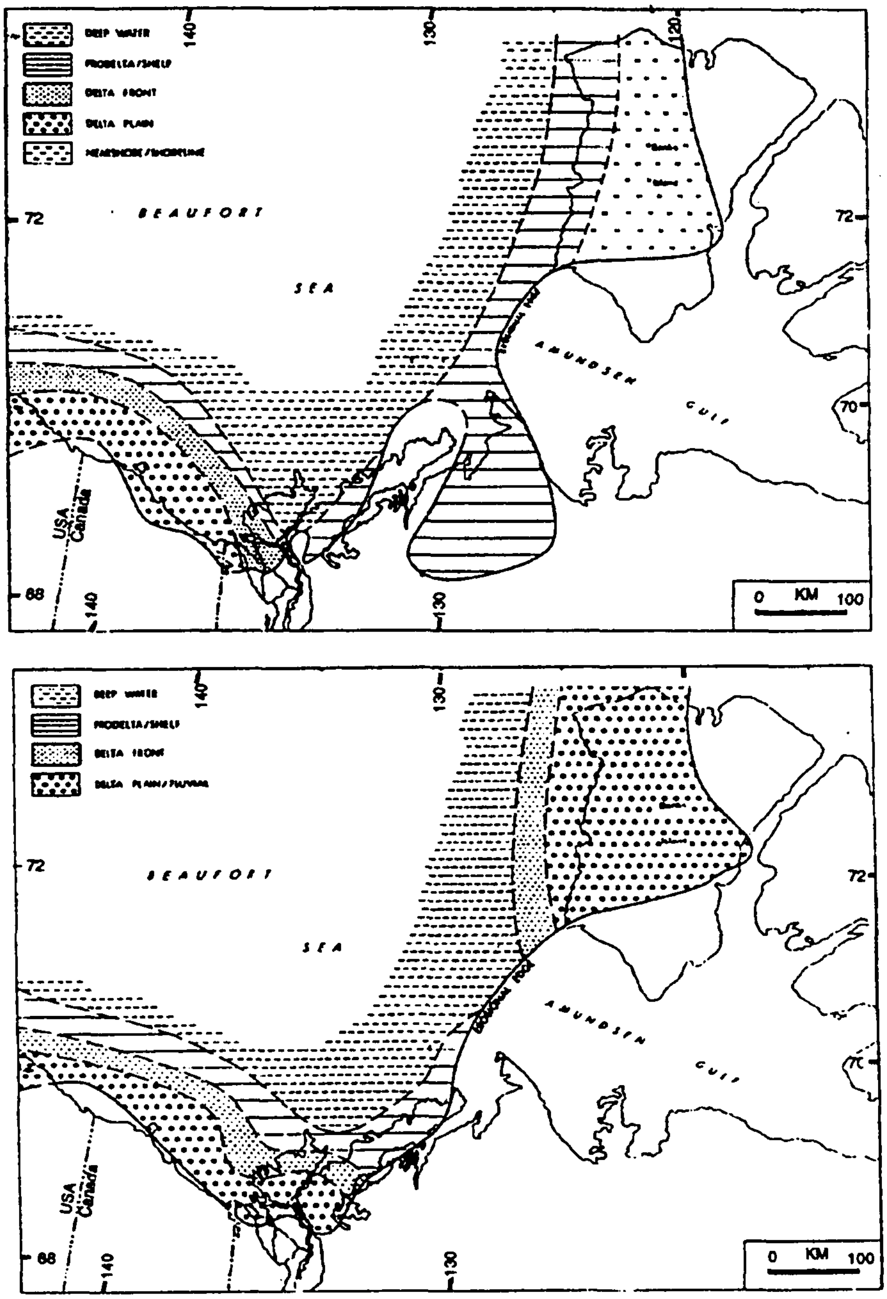


Figure 24. Interpreted depositional environments at time of maximum progradation for the Fish River and Aklak sequences. Fish River sequence (upper diagram), Aklak sequence (lower diagram). From Dixon and others (1992a).

64 m of Moose Channel Formation consisting of sandstone and pebbly sandstone with minor dark clay interbeds. Based on palynology, the entire Moose Channel Formation in the Caribou Hills is Paleocene in age (Ioannides and McIntyre, 1980). In the Caribou Hills, the Moose Channel Formation overlies organic rich marine shale of the Campanian Smoking Hills Formation, with Maastrichtian strata apparently missing at an unconformity. Although the contact is not exposed in outcrop, reflection seismic data support the age control in arguing for an erosional unconformity above the Smoking Hills Formation (Dixon and others, 1992a). The Aklak Member of the Reindeer Formation overlies the Moose Channel Formation in the Caribou Hills and consists of nonmarine carbonaceous claystone and mudstone, lignite, and lesser amounts of sandstone, pebbly sandstone and conglomerate. Based on palynomorphs, the Reindeer Formation in the Caribou Hills is Paleocene to Eocene in age (Price and others, 1980).

Price and others (1980) argue that most of the Moose Channel present is comparable lithologically to the basal sandstone member of the Moose Channel Formation. They suggest that shaly beds in the upper part of the formation may be the feather edge of the Ministicoog Member, based on the presence of the foram *Cyclammina coksuvorovae* in both the type Ministicoog and these uppermost shaly beds. In contrast, Dixon and others (1992a) contend that the presence of *Cyclammina coksuvorovae* in the upper-most shaly beds of the Moose Channel indicates that the entire 64 m Moose Channel section in the Caribou Hills is a part of the Ministicoog Member and that the sandstone member is absent.

Dixon and others (1992a & b) interpretation of the Caribou Hills stratigraphy places Paleocene Ministicoog Member unconformably over Campanian Smoking Hills Formation. They interpret this unconformity as the base of the Aklak sequence. In order to do this they have placed the top of the Fish River sequence at the boundary between the sandstone and

Ministicoog Members of the Moose Channel Formation. This interpretation implies that the Fish River sequence is not present in the Caribou Hills area.

In contrast, the Caribou Hills Moose Channel section is divided in this study into sandstone and Ministicoog Members, as Price and others (1980) did, and the entire formation placed in the Fish River sequence. Under this interpretation, the Fish River sequence in the Caribou Hills is represented by the thin Moose Channel section. The unconformity at the base of the Moose Channel in the Caribou Hills is interpreted as the lower sequence boundary of the Fish River sequence. The upper sequence boundary is placed at the unconformity between marine Ministicoog Member and nonmarine Aklak Member. Placing this sequence boundary above the Ministicoog Member is consistent both with the outcrop data in the Caribou Hills and the regional geology. The contact between the Ministicoog and Aklak Members has been previously documented in this and other studies as a regional unconformity which marks a significant basinward shift in sedimentation. The change in depositional environments between the Ministicoog and Aklak Members in the Caribou Hills is consistent with this interpretation. Furthermore, if the sandstone member is present in the Caribou Hills, as interpreted by Price and others (1980), the unconformity underlying the Moose Channel Formation could not form the base of the Aklak sequence as proposed by Dixon and others (1992a). With the exception of the upper shaly beds, the Moose Channel section in the Caribou Hills is dominantly pebbly sandstone and sandstone (Price and others, 1980). These lithologies are much more common in the sandstone member than in the Ministicoog Member. Figures 25 and 26 are regional stratigraphic cross sections which contrast the interpreted sequence boundaries of Dixon and others (1992a & b) with the boundaries proposed in this study.

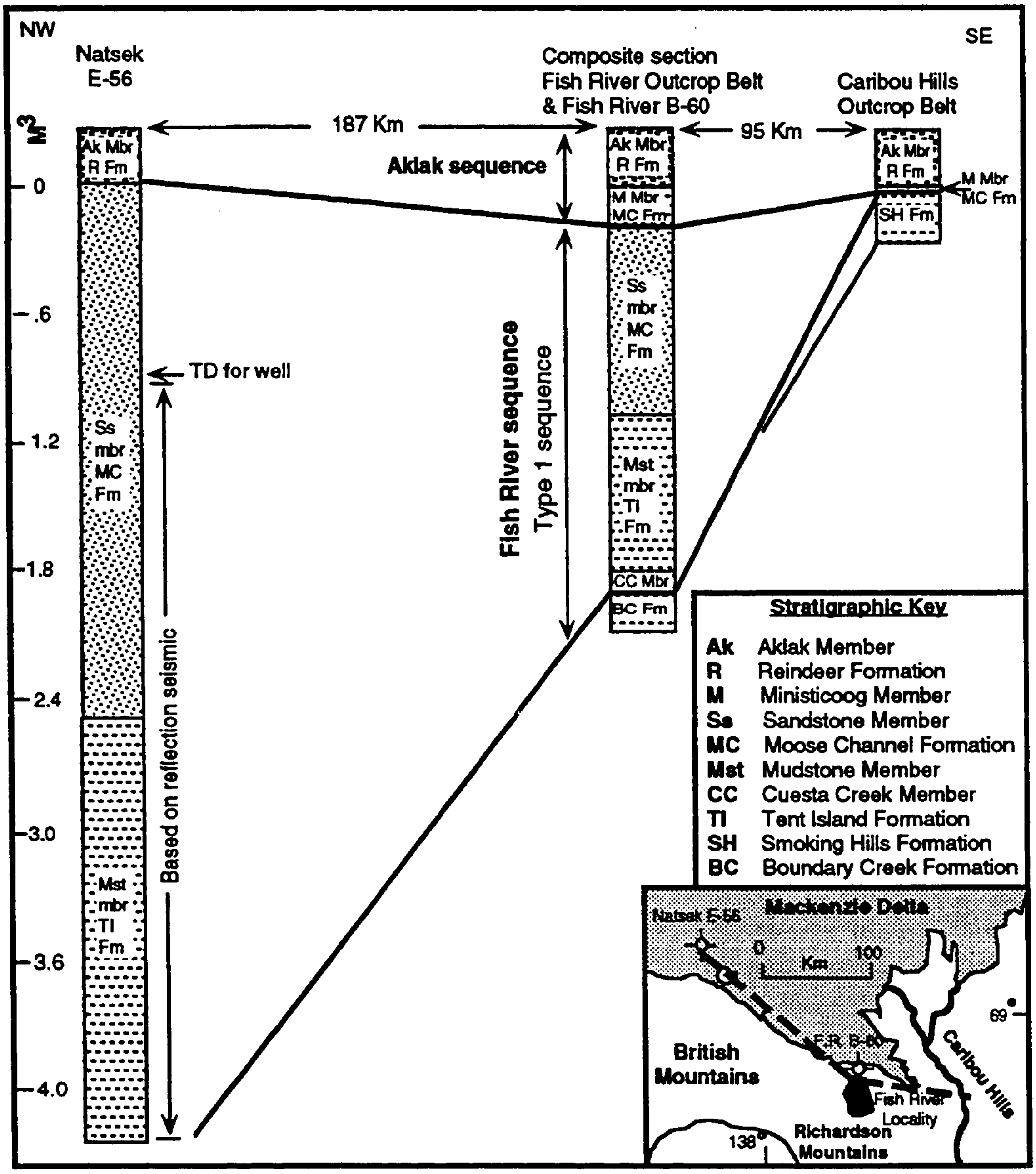


Figure 25. Regional stratigraphic cross section displaying the sequence boundaries for the Fish River sequence as defined by Dixon and others (1992a).

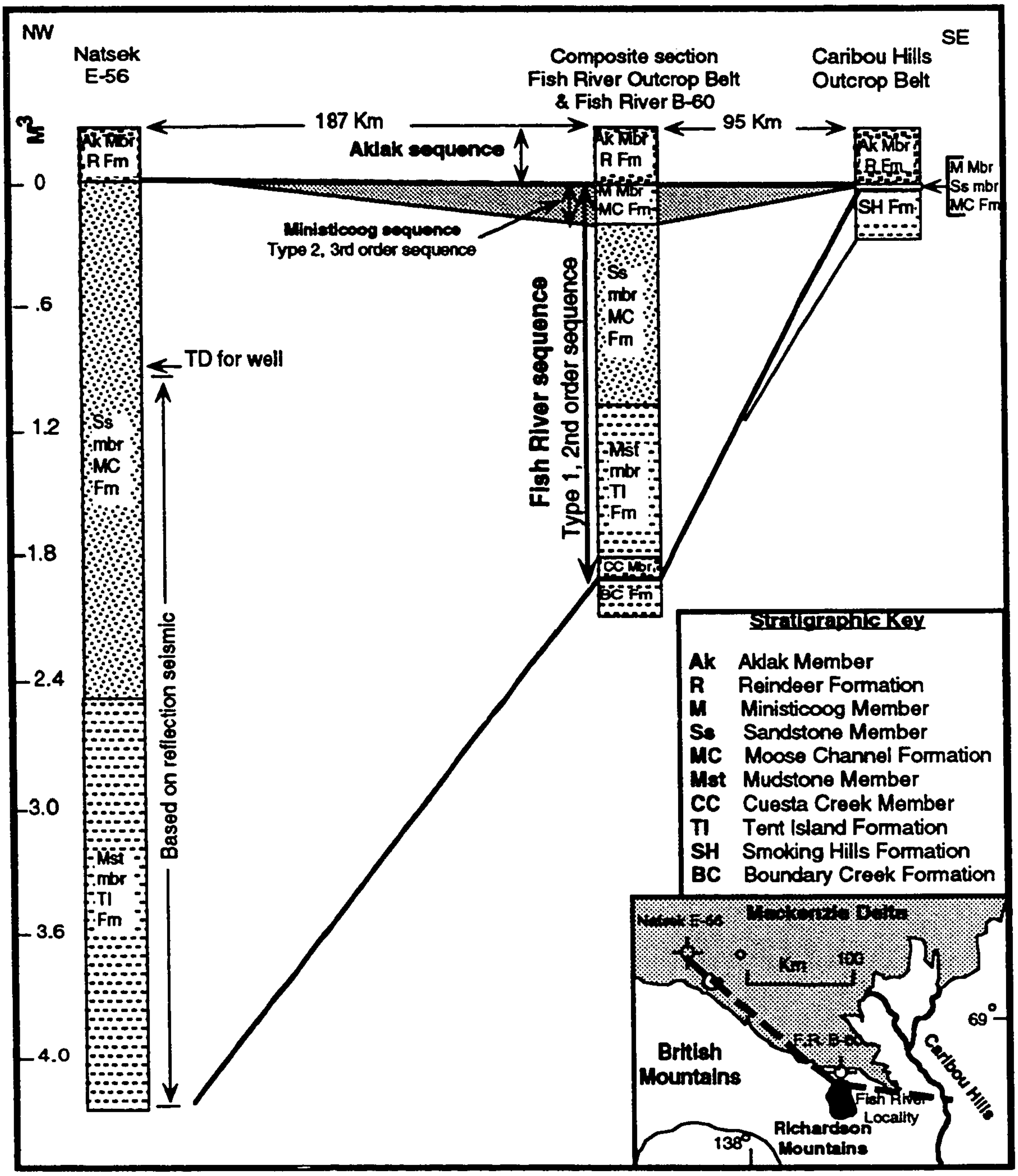


Figure 26. Regional stratigraphic cross section displaying the sequence boundaries for the Fish River sequence as proposed in this study.

Ministicoog Sequence

The Ministicoog sequence is defined herein to be a type-2, third order sequence which is contained within the type-1 second order Fish River sequence. Strata comprising the Ministicoog sequence are the same as those contained within the Ministicoog Member. As has been discussed in previous sections, the Ministicoog Member is interpreted to have been deposited as a consequence of a rise in relative sea level. In the Fish River area, this resulted in a flooding of the subaerial delta plain of the sandstone member. This resulted in the deposition of marine mudstone, siltstone and sandstone over the thick to massive nonmarine sandstone of the sandstone member. This change in lithology and depositional environment can be seen in outcrop on Eagle Creek and the Big Fish River, and in the subsurface in the area immediately east and north of the outcrop belt. In outcrop, the contact between the sandstone and Ministicoog members lacks any significant erosional truncation or any indication of a basinward shift in facies. This type of boundary is typical of a type-2 sequence boundary (Van Wagoner and others, 1990).

The Ministicoog sequence is interpreted to be a third order sequence, based on estimated duration of sedimentation, thickness of the sequence and its lateral extent. Based on the lateral distribution of the Ministicoog Member, the transgression responsible for deposition of the Ministicoog sequence is of a larger scale than can be accounted for by simple autocyclic mechanisms such as delta lobe switching. Age control indicates that the Ministicoog Member was probably deposited over a period of several million years. Additionally, the unit reaches a maximum estimated thickness of over 300 m. This thickness is normally associated with third order sequences (Van Wagoner and others, 1990). The Ministicoog sequence shares a common upper boundary with the Fish River sequence.

Systems Tracts within the Fish River Sequence

Based on outcrop observations made during this study, lowstand, transgressive and highstand systems tracts are interpreted within the Fish River sequence. The lowstand systems tract includes most of the Cuesta Creek Member. Transgressive systems tract deposits include the uppermost hemipelagic canyon fill of the Cuesta Creek Member and the basal part of unit A of the mudstone member of the Tent Island Formation. Highstand systems tract deposits include most of the mudstone member of the Tent Island and the entire Moose Channel Formation. Figures 27, 28 and 29 summarize the lithostratigraphy, depositional environments, depositional history and sequence stratigraphy of the Fish River sequence.

Lowstand Systems Tract

Most of the Cuesta Creek Member is interpreted to have been deposited during a lowstand at the base of the Fish River sequence. Evidence that the Cuesta Creek Member is a lowstand deposit include the major unconformity underlying the member, its environment of deposition, the regional basinward shift in sedimentation which occurs at the base of the Fish River Group (Dixon and others, 1992a and b) and the depositional relationship between the Cuesta Creek Member and the overlying mudstone member (presence of stratal geometries, lithologies and depositional environments indicative of overlying transgressive and highstand systems tracts). The relationship between the formation of submarine canyons the presence of a lowstand systems tract is well documented (Kolla and Macurda, 1988; Van Wagoner and others, 1988).

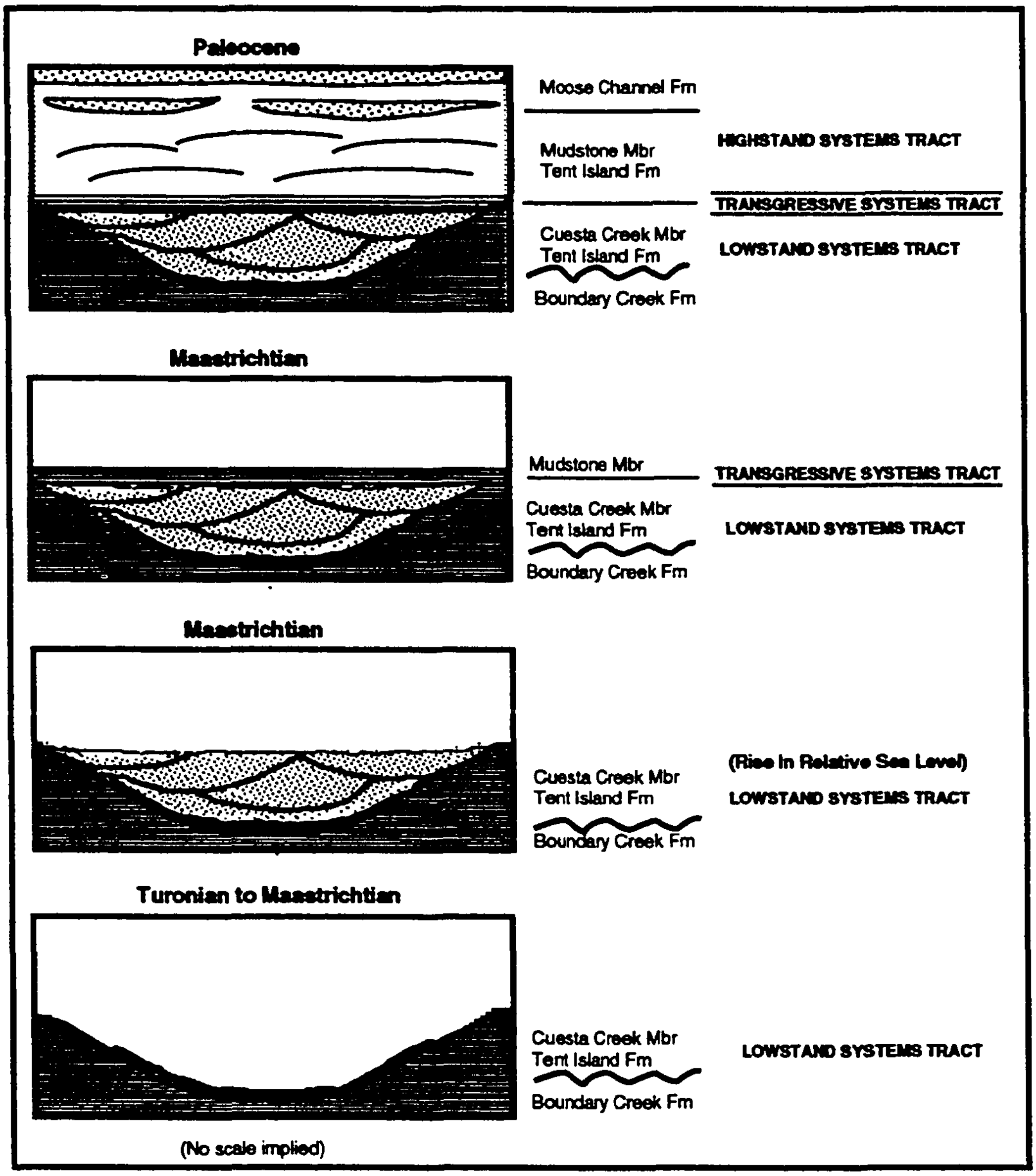


Figure 27. Summary diagram illustrating the development of systems tracts in the Fish River sequence.

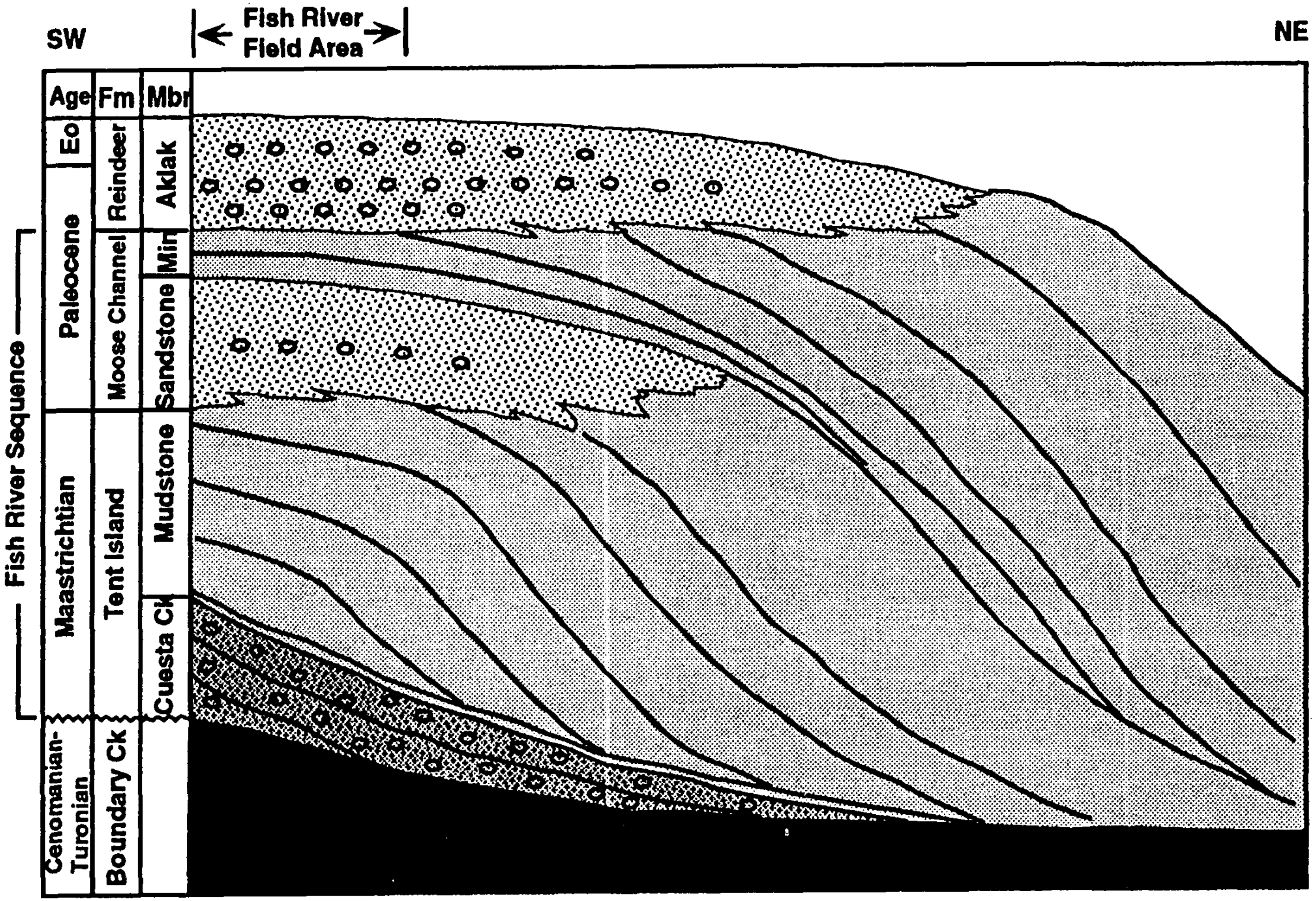


Figure 28. Diagrammatic stratigraphic cross section displaying the interpreted depositional relationships of Upper Cretaceous-Lower Eocene strata in the Fish River area, based on outcrop and well log data. Min = Ministicoog Member.

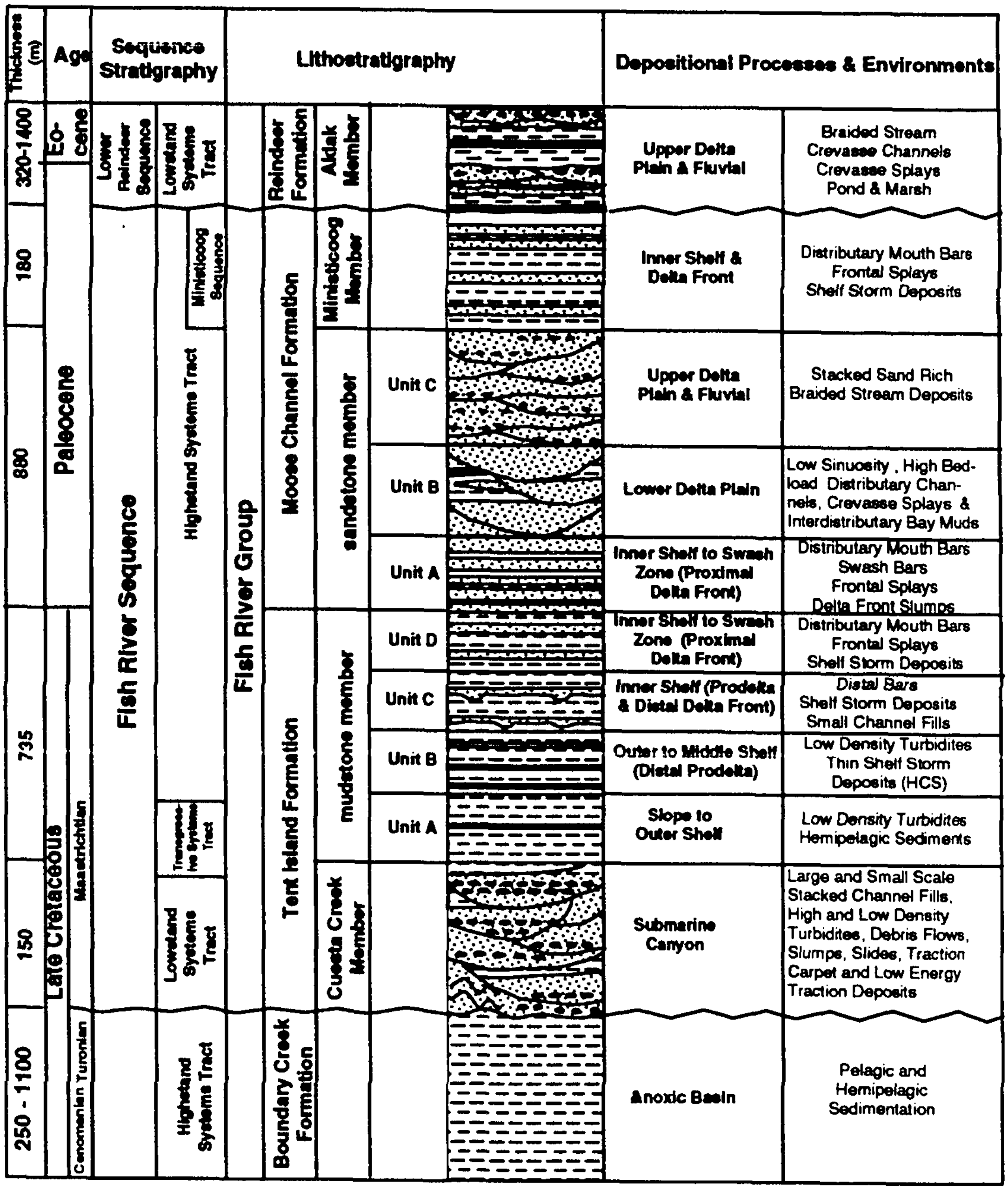


Figure 29. Summary of the lithostratigraphy and sequence stratigraphy of the Fish River Group.

As has been previously discussed, the Cuesta Creek Member is interpreted to have been deposited in a submarine canyon system incised into the slope. The depositional history of the Cuesta Creek Member involved at least three significant stages: the cutting of the canyon into the underlying Boundary Creek Formation, the subsequent deposition of the canyon fill, and finally abandonment of the canyon system (recorded by the upper-most fine-grained canyon fill). This three stage deposition history suggests that the canyon was incised during maximum lowstand and suggests that a yet to be discovered basin floor fan was deposited farther out in the basin. As relative sea level began to rise, the Cuesta Creek canyon system was backfilled with internally complex stacked channel fills and finally abandoned during the initiation of sedimentation during the transgressive systems tract. This backfilling is probably time equivalent to the formation of a slope fan and lowstand wedge in an idealized sequence. A corresponding three stage depositional history has been observed in submarine fan deposits (Mutti, 1985 & 1992; Kolla and Macurda, 1988).

Transgressive Systems Tract

In the Fish River sequence, transgressive systems tract deposits are interpreted to include the uppermost fine-grained channel fill of the Cuesta Creek Member and the basal part of unit A of the mudstone member of the Tent Island Formation. These hemipelagic mudstones and a few interbedded low density turbidites record the end of both submarine canyon incision and active deposition within channels. The mudstone which caps the uppermost channels of the Cuesta Creek Member records post-abandonment suspension sedimentation. Subsequent non-channelized deposits that blanket the passive channel fill (basal part of unit A) are also included in the transgressive systems tract. A rapid rise in relative sea level is postulated as the mechanism responsible for this major change in deposition.

Evidence for the transgressive systems tract includes the presence of laterally continuous hemipelagic mudstones that cap and overlie the Cuesta Creek Member and the presence of large clinoforms in the immediately overlying highstand systems tract deposits. Both of these are defining characteristics for a transgressive systems tract (Van Wagoner and others, 1988).

The transgressive systems tract of the Fish River sequence lacks the classic condensed section associated with transgressive systems tracts described in passive margin or intracratonic settings. Condensed sections contain thin marine beds of hemiplegic or pelagic sediments deposited at very slow rates and commonly contain concentrations of authigenic minerals such as phosphate, glauconite, siderite, pyrite and dolomite as well as high organic content and airborne particles such as volcanic ash and iridium (Loutit and others, 1988; Vail and others, 1991). Because of their composition, condensed sections are commonly associated with a higher background radiation than surrounding sediment rocks. The increased radioactivity commonly makes condensed sections easily discernible on gamma ray well logs (Loutit and others, 1988). None of these distinguishing characteristics were found either in outcrop or on well logs from the Tent Island Formation in the Fish River B-60 well immediately to the north of the outcrop belt. The lack of a condensed section may be indicative of a depositional setting with a higher rate of sedimentation than those found in passive margin settings. The lack of a condensed section is consistent with deposition on an active margin or associated with a fold and thrust belt.

Highstand Systems Tract

The highstand systems tract of the Fish River sequence is interpreted to consist of most of the mudstone member of the Tent Island Formation and all of the Moose Channel Formation. Evidence for the highstand systems tract includes the presence of large clinoforms in the mudstone member, stacked aggradational and progradation parasequence sets in the Tent Island and Moose Channel Formations and the presence of an overlying type-1 unconformity at the base of the Aklak Member.

In the Eagle Creek, Cache Creek and Big Fish River areas, the highstand systems tract consists of a lithologic succession that records the progradation of a major deltaic system. Depositional environments interpreted from outcrop observations range from slope (upper part of unit A of the mudstone member containing large clinoforms) to upper delta plain (unit C of the sandstone member of the Moose Channel). The shallowing-upward sequence represented by slope to proximal delta front deposits of the mudstone member records the construction of a subaqueous delta platform which culminated in the deposition of the overlying proximal delta front and delta plain deposits of the Moose Channel Formation.

On a large scale, the highstand systems tract of the Moose Channel Formation is progradational. On a small scale it contains both aggradational and retrogradational parasequence sets. For example, on Eagle Creek (section MD 79), unit A of the sandstone member of the Moose Channel Formation contains stacked coarsening-upward parasequences. The stacking of these parasequences is indicative of highstand deposits during an aggradational period in which sediment supply and accommodation were balanced. Within the sandstone member, the presence of bedload dominated straight distributaries (unit B) and sandy braided stream deposits (unit C) are indicative of deposition on a high-gradient subaerial delta plain. The presence of interdistributary bay deposits including thin coals in unit B indicates that this system was not a fan delta, but contained a significant lower delta plain. The vertical stacking and total thickness of both upper and lower delta plain channel complexes indicate that both sedimentation and rise in relative sea level were rapid.

The Ministicoog Member is interpreted as the culmination of the highstand systems tract which began with the prodelta facies of the Tent Island Formation. The Ministicoog Member was deposited during a rise in relative sea level and represents the final stages of deposition associated with the Moose Channel delta system. This resulted in the deposition of marine mudstones, siltstones and sandstones over the thick to very thick nonmarine sandstones of the sandstone member. As has been previously discussed, it is appropriate to include this retrogradational to aggradational unit within the highstand systems tract of the type-1 second order Fish River sequence, recognizing it as a smaller scale and shorter duration type-2 third order sequence. Figure 30 is a reconstruction of the highstand systems tract of the Fish River sequence.

Tectonic Influences on Deposition

Compressional deformation can exert primary control on both accommodation and the type and amount of sediment deposited and preserved within a basin (Vail and others, 1991). In this study, the depositional history of the Fish River sequence is interpreted to have been strongly influenced by the tectonics of an evolving fold and thrust belt. This tectonism, combined with subsidence due to post rift thermal cooling of the Canada basin, is

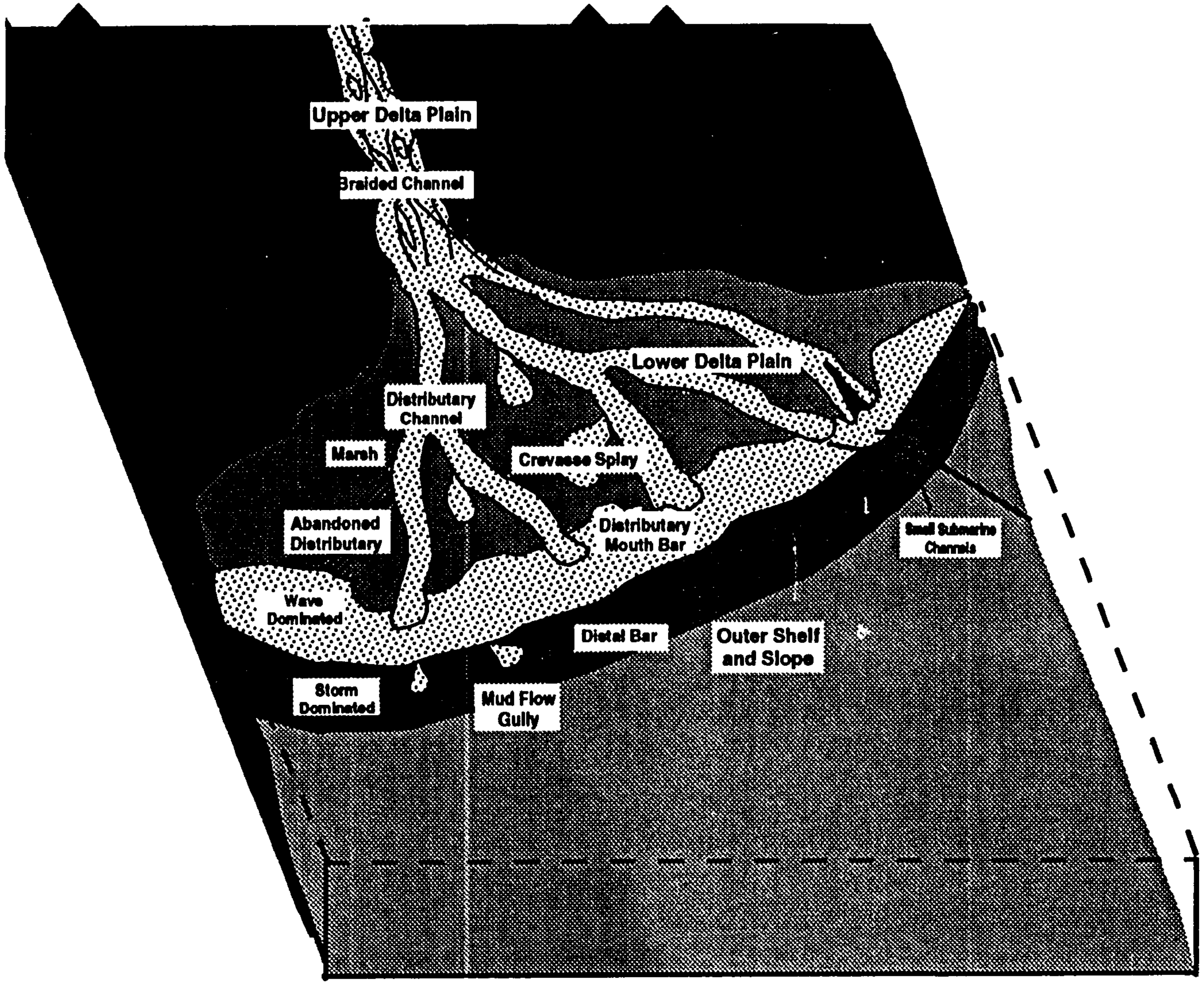


Figure 30. Depositional environments of the highstand systems tract of the Fish River sequence.

interpreted as the dominant control on the internal organization of the sequence. Although eustatic sea level change may have affected the evolution of the Fish River sequence, the striking correlation between tectonic and depositional events indicates contractional deformation exerted a primary control on the depositional history of the Fish River sequence.

Three major lines of evidence support invoking a tectonic model to explain the evolution of the Fish River sequence. These are the regional structural history of the northern Yukon, the nature of the sequence bounding unconformities, and a sedimentary signature indicating deposition during rapid uplift and erosion.

The Fish River sequence was deposited during a time of active compressional tectonics in the northern Yukon. The entire field area of this study lies within a 450 km wide Tertiary fold belt (Dietrich and Lane, 1992). Late Cretaceous to Early Tertiary thrust faults have been documented in the British Mountains to the south and west of the Beaufort-Mackenzie basin (Figure 1.1; Dixon, 1986). Additionally, the Rapid Array fold and thrust belt, located approximately 40 km west of the field area, has been established to be a part of an extensive arcuate zone of deformation that developed in Paleocene-Eocene time (Figure 2; Lane, 1988). Seismic reflection data from the southern margin of the Beaufort-Mackenzie basin also provide evidence of multiple pulses of compressional deformation during the Late Cretaceous and Tertiary (Dietrich and Lane, 1992; Dietrich and others, 1989a & b).

It is difficult to determine the amount of structural deformation that occurred immediately prior to and contemporaneous with deposition of the Fish River sequence. On seismic lines in the Beaufort-Mackenzie basin, the Fish River sequence can be identified with certainty only on the basin margins, where the sequence occurs within the first few thousands of meters below the surface. Throughout most of the central part of the basin, reflection character is lost at depth and identification is difficult (Dietrich and others, 1985). Furthermore, post-Early Eocene deformation commonly overprints evidence of earlier deformation (Dietrich and others, 1989a & b). Outside the Fish River area, much of the Upper Cretaceous section has been removed from the basin margin leaving an incomplete rock record. Majorowicz and Dietrich (1989) estimate that Middle Eocene uplift and erosion has removed as much as 7 km of pre-Middle Eocene strata in the northern Yukon.

However, some data indicate an episode of Late Cretaceous contractional deformation prior to deposition of the Tent Island Formation. Beneath the Demarcation subbasin (Figure 3), seismic data show the truncation of folded Lower Cretaceous and older rocks below an Upper Cretaceous unconformity (Dietrich and Lane, 1992). This unconformity may be the sub-Tent Island Formation unconformity at the base of the Fish River sequence. If so, it provides evidence of active contractional deformation immediately prior to deposition of the Fish River sequence. However, since the unconformity cannot be directly tied to well or outcrop control, an alternative interpretation is that this unconformity separates the Boundary Creek Formation from Albian rocks.

Seismic data from the Natsek area indicate that a major structural detachment occurs at the base of the Fish River sequence (Dietrich and others, 1989b). In the Big Fish River area, shale of the Boundary Creek Formation is incompetently deformed with large recumbent folds (Dixon and others, 1985 and 1992a; Dixon, 1992b). However, since the Boundary Creek Formation is underlain by the more structurally competent Albian rocks (Dixon and others, 1985) and overlain by compacted sandstones and conglomerates of the Cuesta Creek Member, it is difficult to determine if this deformation occurred prior to or after deposition of the Tent Island Formation. The Boundary Creek Formation in the Fish River area may have acted as a local detachment zone for post-Fish River contractional deformation. Where the Boundary Creek and Tent Island Formations crop out, the contact is poorly exposed or covered. The contact relationship is characterized by sandstone, conglomerate or soft sediment deformed chaotically bedded mudstone of Cuesta Creek Member deposited in channels incised into structurally deformed shale of Boundary Creek Formation. Based on regional map relationships, Young (1978) interpreted the Boundary Creek/Cuesta Creek contact as a regional angular unconformity.

The internal lithologic and sedimentologic character of the Fish River sequence is indicative of deposition which occurred during rapid uplift and erosion of a proximal source area. The Fish River and Aklak sequences contain coarse grained deposits indicating proximal source areas and a relatively steep depositional paleoslope. Submarine canyon deposits of the Cuesta Creek Member of the Tent Island Formation, which form the base of the Fish River sequence, contain abundant pebble to cobble conglomerate with clasts up to 2 m in size, debris flow deposits, slide blocks and slumps. These deposits record a proximal coarse-grained source and a steep and unstable submarine slope. These conditions are characteristic of basins with margins experiencing synsedimentary uplift (Mutti, 1992).

Further evidence for tectonic activity is found in the mudstone member. The depositional sequences of passive margin or intracratonic basins typically contain a condensed section of thin marine beds of pelagic or hemipelagic beds deposited at low sedimentation rates (Loutit and others, 1988). In contrast to these sequences, the transgressive systems tract of the Fish River sequence (basal mudstone member) does not contain a true condensed section. Rather than clay shale, the transgressive systems tract contains mudstone with minor siltstone turbidites, indicating a relatively continuous input of terrestrial material. The absence of a condensed section with true pelagic sediment is consistent with deposition on an active margin or a fold and thrust belt.

Upper delta plain deposits of the highstand systems tract (sandstone member of the Moose Channel Formation) consist primarily of a thick vertically stacked succession of coarse-grained braided stream deposits. Braided rivers form in regions where rapid uplift and erosion of the source area creates large volumes of coarse-grained sediments and forms steeper regional gradients. Conversely, meandering or anastomosing rivers form in tectonically inactive areas where there is a lower gradient, and the presence of abundant clay sediments (Cant, 1982). Simple eustatic sea level change does not provide an adequate mechanism for the deposition and preservation of the several hundred meters of coarse-grained braided fluvial channel fill found within the Moose Channel Formation. The deposition and preservation of these coarse-grained deposits requires the uplift of a proximal source area, a steep gradient, and increased accommodation for preservation of nonmarine sediments. These conditions are found in tectonically active areas associated with fold and thrust belts or active margins.

Apatite fission track data suggest that deposition of the Aklak Member occurred during a period of active tectonics. Significantly, fission track analysis of samples from the Cuesta Creek Member type section record rapid cooling at 53 million years, presumably reflecting uplift and erosion (O'Sullivan, 1993). This Early Eocene date indicates that uplift was occurring during deposition of the Aklak Member and that this uplift can be documented as close as 18 kilometers to the south of outcrops of the Aklak Member on Aklak Creek.

The Aklak Member consists largely of conglomerate and sandstone deposited in a braided stream environment. The deposition and preservation of these coarse-grained deposits requires the uplift of a proximal source area, a steep gradient, and increased accommodation for preservation of nonmarine sediments. As has been previously stated, these conditions are found in tectonically active areas associated with fold and thrust belts or active margins.

Model for Tectonically Driven Deposition

Large scale tectonic cyclothems can form along the active margin of foreland basins in response to alternating periods of active thrusting and flexural rebound. Following an episode of thrusting and consequent subsidence in the foreland, removal of the thrust load by erosion and other processes results in flexural rebound of the thrust belt and foreland basin (Blair and Bilodeau, 1988; Heller and others, 1988). During displacement of thrust faults, sedimentation in the foreland basin is typically coarse grained immediately adjacent to the thrust front and grades abruptly into fine-grained deposits that cover most of the basin . During the subsequent period of erosion, a regional unconformity develops in the proximal part of the basin and coarser-grained clastic deposits are distributed much farther into the basin (Heller and others, 1988).

The internal stratigraphic organization of the Fish River sequence records alternating periods of relative sea level fall and rise, interpreted to reflect uplift and subsidence in the Beaufort-Mackenzie basin. The scale and timing of these episodes, combined with the environments of deposition and lithologic character of the rocks, suggest that the driving mechanism was alternating episodes of thrusting followed by flexural rebound. Figure 31 is a tectonic and depositional reconstruction relating specific systems tracts to the tectonic evolution of the basin. Five stages are proposed for the Late Cretaceous to Early Eocene

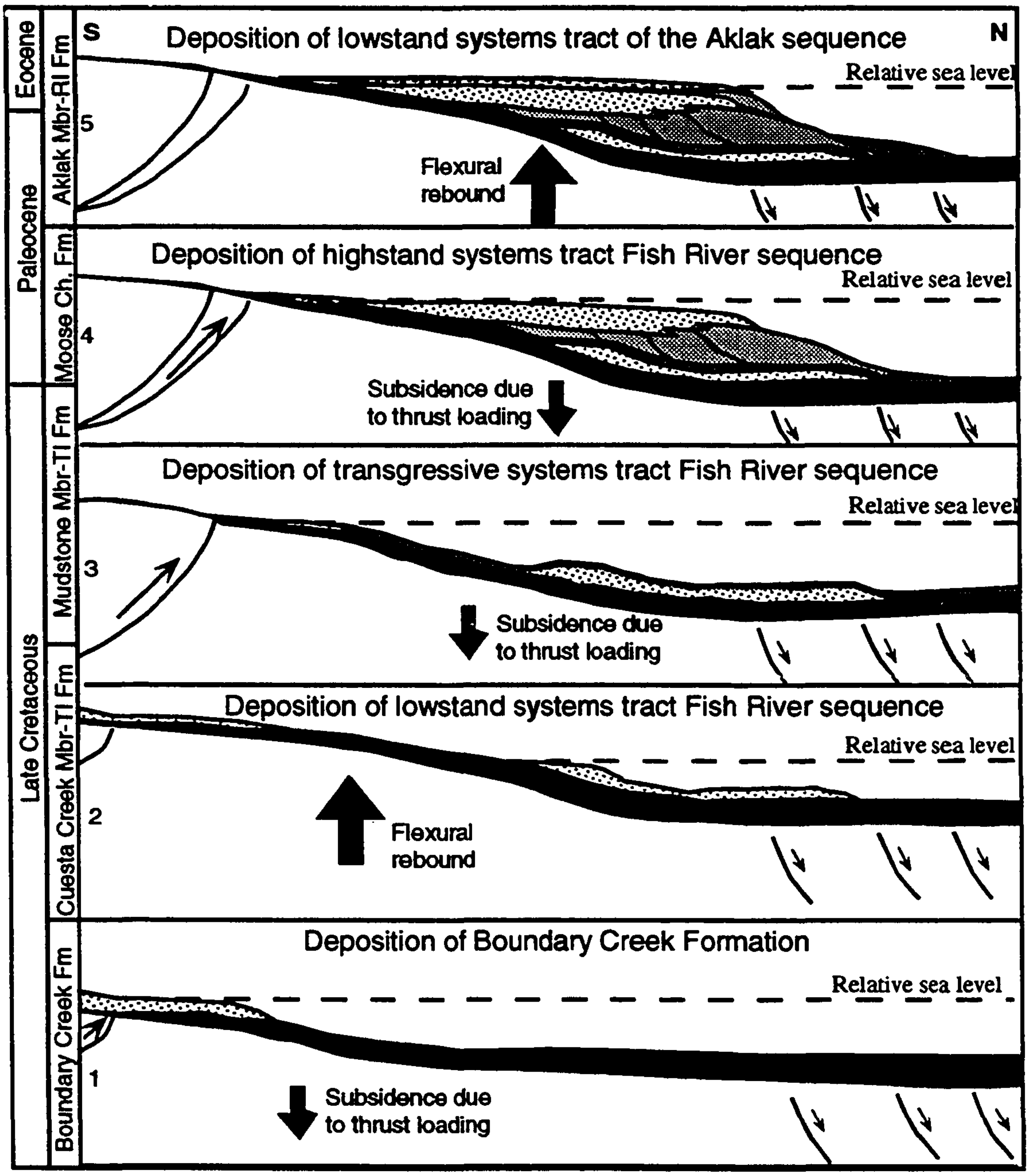


Figure 31. Diagrammatic tectonic/depositional reconstruction of the Fish River sequence. TI = Tent Island Formation, Moose Ch. = Moose Channel Formation and RI = Reindeer Formation.

development of the Beaufort-Mackenzie basin and deposition of the Boundary Creek Formation, Moose Channel Formation and Aklak Member of the Reindeer Formation:

1) Subsidence due to active thrusting (primarily to the south and west of the Fish River area) which combined with subsidence due to post-rift cooling of the southern margin of the Canada basin resulted in wide spread deposition of marine shales of the Cenomanian-Turonian Boundary Creek Formation.

2) This thrusting was followed by a subsequent period of flexural rebound, resulting in the development of the regional sub-Cuesta Creek unconformity and culminating in the deposition of the lowstand systems tract in the Maastrichtian.

3) Renewed thrusting and northward migration of the deformation front in the Maastrichtian resulting in subsidence and relative sea level rise. Deposition of the transgressive systems tract.

4) Continued northward migration of the deformation front in the Paleocene. Rapid subsidence continued north of the deformation front, creating accommodation for deltaic and braided fluvial deposits of the highstand systems tract.

5) Deformation ends in the Late? Paleocene. A second period of post-orogenic flexural rebound results in the development of the regional sub-Aklak unconformity, a major basinward shift in sedimentation and deposition of coarse grained lowstand deposits of the Paleocene Aklak Member.

Implications for Petroleum Exploration

Lowstand Systems Tract

The Cuesta Creek Member has significant potential as a stratigraphic hydrocarbon trap and reservoir. Sandstones and conglomerates within the member are overlain and underlain by shale and laterally confined by the canyon walls. However, despite the abundance of coarse grained clastic sediments, the internal heterogeneity of the member significantly downgrades its potential reservoir quality. This extreme heterogeneity has been illustrated by the previously described channel hierarchy. Reservoir geometry is further complicated by the truncation of channel fills by overlying channels, the presence of small syndepositional normal faults, large variations in percentage of conglomerate and sandstone in channel fills, and variations in channel orientation.

The lack of continuity within outcrops of the Cuesta Creek Member has important implications for examining the unit or similar units in the subsurface. Given closely spaced well control, one would be tempted to use well logs to correlate similar appearing fining upward sequences. However, outcrop data illustrates that even if well spacing is on the typical 40-160 acre spacing within oil fields, such correlation would be incorrect. Furthermore, most third-order channel-fill sequences are small enough that they could not be easily delineated by seismic data. Therefore, subsurface interpretation of rock units like the Cuesta Creek Member must be done with a understanding of their complex internal sedimentology.

The Cuesta Creek Member examined in this study has been interpreted as a submarine canyon system. Assuming this interpretation to be correct, it is reasonable to predict that this canyon system provided the conduit for sediment that could have constructed a large submarine fan system. Although wells have not penetrated such a fan, it represents an interesting play concept for the eastern Beaufort-Mackenzie basin.

Transgressive Systems Tract and Highstand Systems Tract

The transgressive systems tract contains hemipelagic mudstones and minor interbedded low density turbidites. These shales may have some potential as petroleum source rocks. Additionally, they provide a seal for potential lowstand systems tract reservoirs. Very proximal delta front sandstones of the highstand systems tract have excellent potential as reservoir rocks, as do the overlying delta plain facies of the sand rich delta. However, due to the extremely high percentage of sandstone, and the lateral and vertical extent of these sandstones, stratigraphic traps are unlikely.

COMPARISON WITH THE ALASKAN NORTH SLOPE

Upper Cretaceous to Paleocene rocks from many localities throughout the central and eastern North Slope of Alaska record a similar depositional history to that of the Boundary Creek, Tent Island and Moose Channel Formations of the Beaufort-Mackenzie basin (Figure 32; Hubbard and others, 1987; Buckingham, 1987; Bird and Bader, 1987; McMillen and O'Sullivan, 1992). In both the North Slope and Beaufort-Mackenzie basin, these rocks record major episodes of deltaic progradation. Associated with these deltaic successions is a transition from anoxic bentonitic deep marine shale to shelf and delta front sandstone. A similar geologic history and a strikingly similar stratigraphy suggest that coarse-grained submarine canyon deposits, similar to those found in the Cuesta Creek Member, should be present in the central and eastern North Slope of Alaska. To date, however, such deposits have not been identified in outcrop.

Eastern North Slope

On the eastern North Slope, the Upper Cretaceous to Tertiary stratigraphic succession consists of the Hue Shale, Canning Formation, Jago River Formation and the Sagavanirktok Formation (Figure 6). In the eastern Arctic National Wildlife Refuge (ANWR), the organic rich, bentonitic Aptian (?) to Campanian or Maastrichtian Hue Shale is conformably overlain by turbidites of the Canning Formation (Molenaar and others, 1987; Vandergon, 1987). However just west of ANWR, seismic reflection data indicate the presence of a latest Cretaceous regional unconformity (McMillen and O'Sullivan, 1992). Turbidites of the Canning Formation are coeval with fluvial-deltaic rocks of the Jago River Formation exposed at Sabbath Creek (Figure 32; Decker and others, 1987; Buckingham, 1987). The Santonian to Eocene Canning Formation has been divided into a

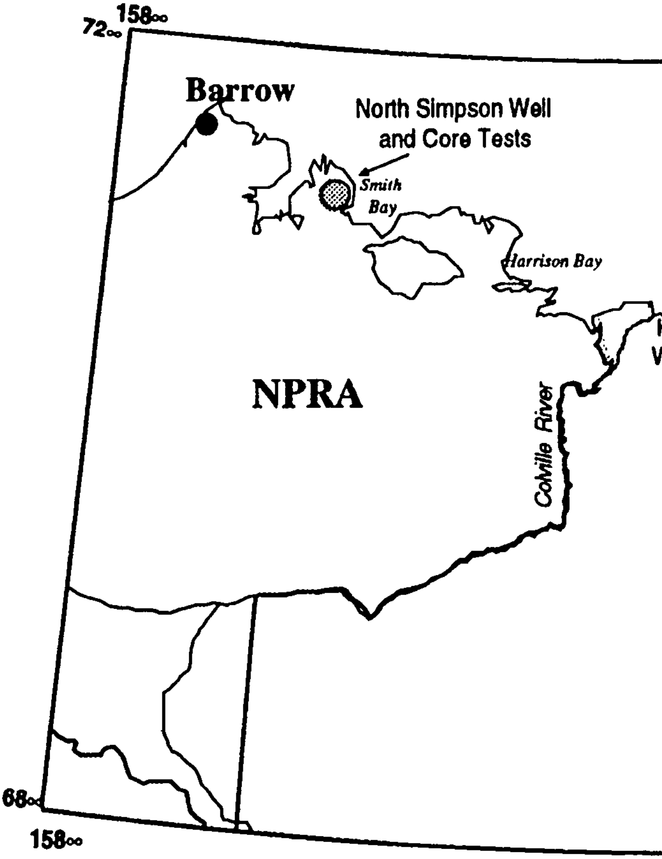
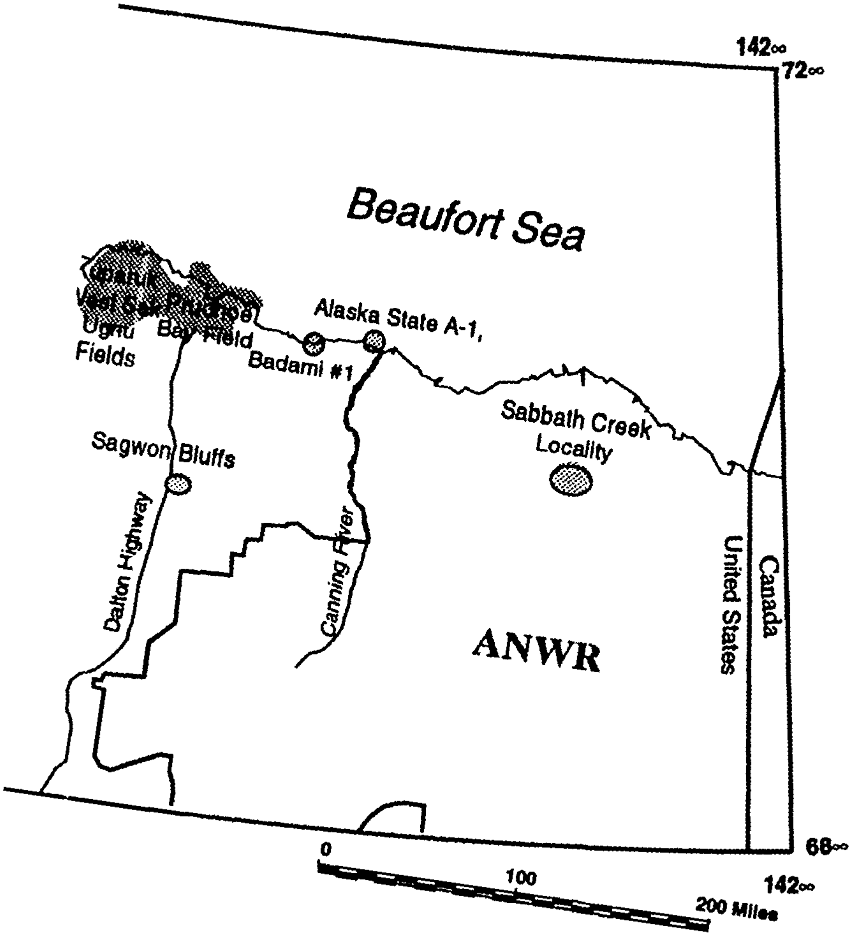


Figure 32. Alaska North Slope location map.


142∞
72∞
Beaufort Sea
Kuparuk
West Sak
Prudhoe Bay Field
Ugnu Fields
Alaska State A-1,
Badami #1
Sabbath Creek Locality
Sagwon Bluffs
Dalton Highway
Canning River
ANWR
United States
Canada
68∞
142∞
0
100
200 Miles

lower turbidite facies and an upper slope and shelf facies (Molenaar and others, 1987). Vandergon (1987) recognized five lithofacies in the lower turbidite facies encompassing middle to inner fan channel, channel-levee, interchannel and possibly slope environments. Slope and shelf facies are only sparsely exposed and consist of bentonitic mudstone and silt-shale with minor thin beds of very fine-or fine-grained sandstone. Sandstone beds of the slope and shelf facies have been interpreted as turbidites in the lower part of the unit and shelf sandstone in the upper part where a gradational contact is present with the overlying Sagavanirktok Formation. In wells a short distance to the west of ANWR, the turbidite facies ranges from 300 to 900 meters thick and the slope and outer shelf facies up to 1220 meters (Molenaar and others, 1987). Oil bearing sandstone near the base of prodelta shale of the Canning Formation was penetrated by the Exxon Alaska State A-1 well on Flaxman Island (Figure 32; Craig and others, 1985; Hubbard and others, 1987). These small toe of slope sands are part of small submarine fan systems and not canyon fill (Molenaar and others, 1986). Similar oil bearing sandstones were also encountered to the west of the A-1 well in the Badami #1 well (Figure 32; Petroleum Information Corporation, 1993). Although significant submarine scour is associated with these toe of slope fans (Molenaar and others, 1986), based on publicly available well data, no coarse grained canyon fill has yet been encountered.

There are several possible reasons for the lack of identified coarse-grained submarine canyon deposits in outcrop or the subsurface on the eastern North Slope. It may be simply that given the limited outcrop exposures and well control, canyon deposits have not been encountered, but are, in fact, present. A second possibility is that a significant canyon system never developed in the Brookian sequence in the eastern north slope. A third possibility is that canyons are present but have not been identified in outcrop because they are filled with fine-grained material. In highly efficient turbidite systems most of the sand can bypass the canyon (Mutti, 1985; Mutti and Ricci Lucchi, 1978).

Central North Slope

On the central North Slope, the stratigraphic succession consists of the Upper Cretaceous Colville Group and the Tertiary Sagavanirktok Formation. The Colville Group comprises a prograding clastic wedge recording basinal, prograding slope, shelf-topset and deltaic depositional environments (Hubbard and others, 1987). The Colville Group has been divided into the Seabee (Shale Wall and Ayiyak members), Prince Creek and the Schrader Bluff Formations (Figure 6; Gyrc and others, 1956; Brosge and Whittington, 1966; Molenaar, 1983). The Colville Group is time equivalent to the Boundary Creek and Tent Island Formations of the Beaufort-Mackenzie basin. In fact, the palynological assemblages of the Upper Cretaceous rocks of the Colville Group of Alaska and the Boundary Creek and Tent Island Formations of the Beaufort-Mackenzie are so similar that they can be correlated at the substage level (Bujak and others, 1987). Like the Boundary Creek and the Hue Shale, the Shale Wall Member consists primarily of bentonitic, organic rich shale. The overlying Ayiyak Member consists of mudstone, siltstone, and minor sandstone.

A major submarine canyon system has been identified in the Colville Group northwest of the Colville River, near Smith Bay (Figure 32). The Simpson canyon is a large north-south trending submarine canyon that is contained within the Seabee Formation (Robinson, 1959 and 1964; Claypool and Magoon, 1988). The canyon fill was penetrated by the North Simpson well and by several Simpson core test holes. The basal unconformity of the Simpson canyon cuts into underlying Cretaceous sandstones and shales of the Nanushuk Group and Torok Formation. The thickness of canyon fill is highly variable and dependent on the relief of the submarine unconformity at the base of the canyon. Simpson Core test #18 penetrated the middle of the canyon and encountered over 396 meters of canyon fill (Robinson, 1959 & 1964). The canyon fill consists primarily of claystone with a few zones of interbedded shale and argillaceous siltstone or sandstone. The bases of core tests #25 and #29 contain 6-12 m or more of breccia containing angular clay shale fragments up to 5 cm in diameter, small coal chips and rare small rounded black chert pebbles in a matrix of argillaceous sandstone or claystone. On the sides of the canyon, large slump blocks of Seabee and Nanushuk Group are present. Dips up to 25 degrees near the base of the formation may represent deposition on the walls of the canyon (Robinson, 1959 & 1964; Claypool and Magoon, 1988).

To the southeast of Cape Simpson and the east of the Colville River, the Colville Group and Sagavanirktok Formations subcrop in the Kuparuk River and Prudhoe Bay oil fields (Figure 32), where the interval has been penetrated by hundreds of wells. Here, the upper Colville Group has been informally divided to include two oil bearing zones (Werner, 1987). The West Sak interval is Maastrichtian in age and is interpreted to have been deposited in inner shelf to delta front environments. The overlying Maastrichtian to Paleocene Ugnu sands have been interpreted to be the overlying delta plain and fluvial deposits (Werner, 1987). Beneath the West Sak, prodelta, slope and basinal mudstone and shales of the Seabee Formation contain numerous small oil bearing discontinuous toe-of-slope sands.

The relationship between the overlying deltaic and shallow marine sandstones of the West Sak and Ugnu and underlying Colville mudstones is similar to that of the Tent Island and Moose Channel marine to nonmarine transition in the Fish River area of the Beaufort-Mackenzie basin. Several marine to nonmarine transitions have been documented in

Upper Cretaceous rocks of the Colville Group to the southwest of the Kuparuk and Prudhoe Bay field areas (Gryc and others, 1956). These transitions may indicate a relative lowstand of sea level in the laterally equivalent outer shelf to slope deposits to the northeast. A lowstand of sea level creates the possibility that submarine canyon deposits may be present in the area between the Colville River and the Prudhoe Bay oil field.

SANDSTONE PETROGRAPHY AND DIAGENETIC HISTORY OF THE FISH RIVER GROUP AND AKLAK MEMBER OF THE MOOSE CHANNEL FORMATION

Introduction and Methodology

An understanding of the composition and diagenetic history of sandstones is critical in estimating their reservoir potential in the subsurface. In this study 120 thin sections were examined from outcrops within the field area. All thin sections were impregnated with blue epoxy and stained for K-feldspar with a sodium colbaltinitrate solution. Twenty-four of these thin sections were selected for quantitative point count analysis. Each thin section was divided into 4 cells of equal area and 100 detrital grains were counted per cell. The use of separate cells allows for a comparison to be made between predicted and calculated analytical error and helps to average out operator error during the point counting process (Decker, 1985). Four hundred detrital sand grains were counted on each of the first 10 thin sections examined. Three hundred grains per thin section were counted on the remaining 14. Cements, matrix, porosity, and authigenic minerals were also counted. A scanning electron microscope (SEM) was used to aid in identification of cements, authigenic minerals, porosity types and diagenetic history.

Classification and Texture of Sandstones

Representative thin sections from sandstones within the Cuesta Creek and mudstone members of the Tent Island Formation, sandstone and Ministicoog members of the Moose Channel Formation and Aklak Member of the Reindeer Formation were point counted. With the exception of 3 samples from the sandstone member of the Moose Channel

Formation, all the sandstones examined are classified under the Folk (1974) classification as submature to immature chert litharenites (Figures 33, 34, 35 and Table 1). Three Moose Channel samples contain enough plagioclase feldspar that they are classified as feldspathic litharenites. Previous workers have classified the Fish River Group and Reindeer Formations as immature chert litharenites (Young, 1975) and subfeldspathic lithic wackes (Holmes, 1972; Holmes and Oliver, 1973).

Grain sizes examined range from very fine-to lower coarse-grained sandstone. Sandstones range from poorly to well sorted. In order to minimize grain size bias, an attempt was made to point count thin sections of relatively uniform grain sizes. However, due to the fine-grained nature and poor sorting of parts of the Tent Island, Moose Channel, and Reindeer formations, the average grain size of individual point counted thin sections vary from lower fine-to upper medium-grained sandstone. Whenever possible, medium-grained sandstones were point counted.

Detrital Composition of Sandstones

Quartz

The quartz content of the thin sections studied range from a high of 65 percent to a low of 30 percent and averages 39 percent. Quartz is present both as monocrystalline (straight and undulatory) and polycrystalline (individual crystals greater than .02 mm). Monocrystalline quartz is slightly more common than polycrystalline quartz at 21 and 18 percent respectively. Plutonic, metamorphic and vein quartz are all common but volcanic quartz was not observed. Within the monocrystalline quartz category, undulatory quartz (>5

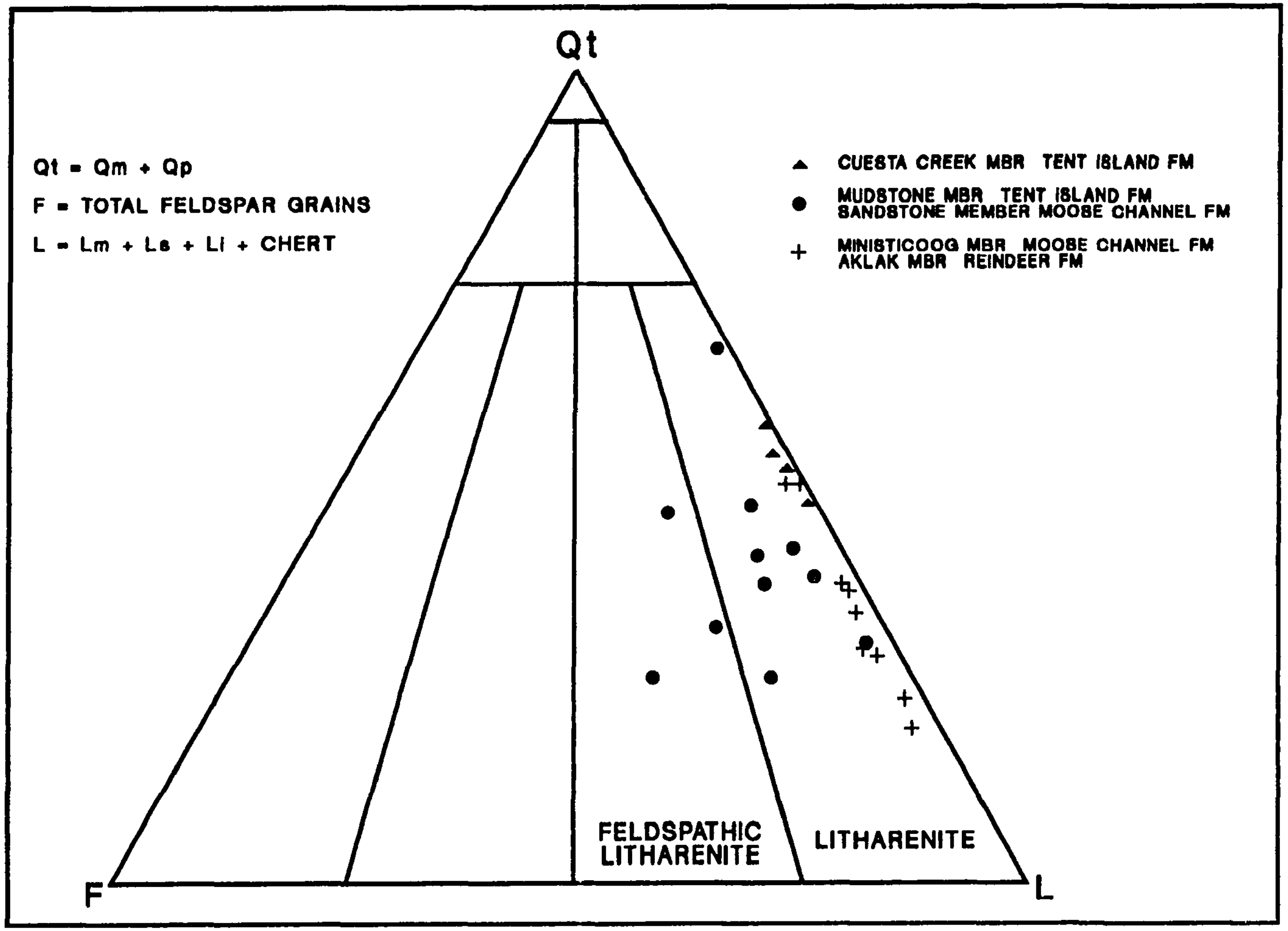


Figure 33. QFL plot for sandstone of the Fish River Group and Aklak Member of the Reindeer Formation.

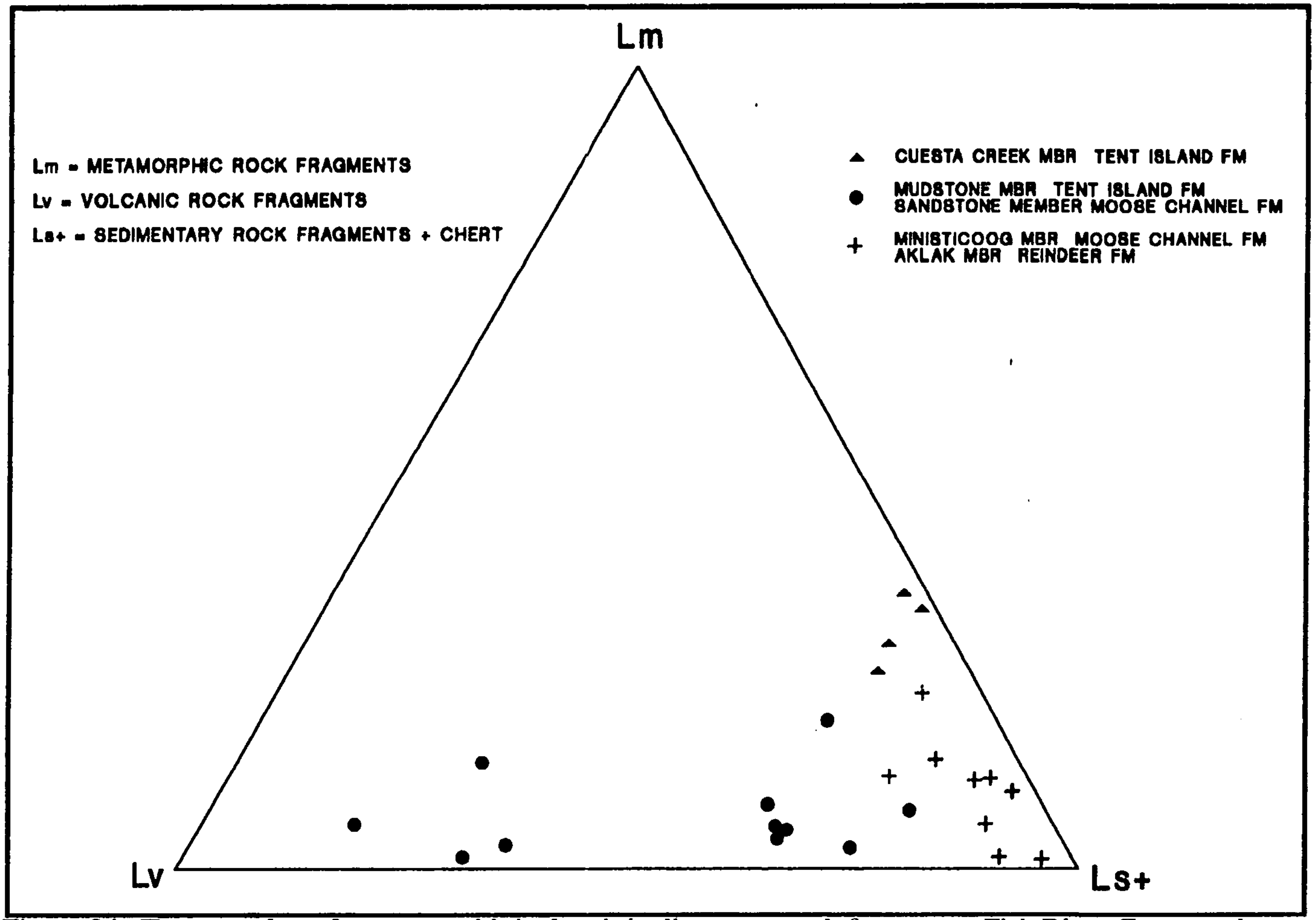


Figure 34. Ternary plot of metamorphic/volcanic/sedimentary rock fragments, Fish River Group and Aklak Member of the Reindeer Formation.

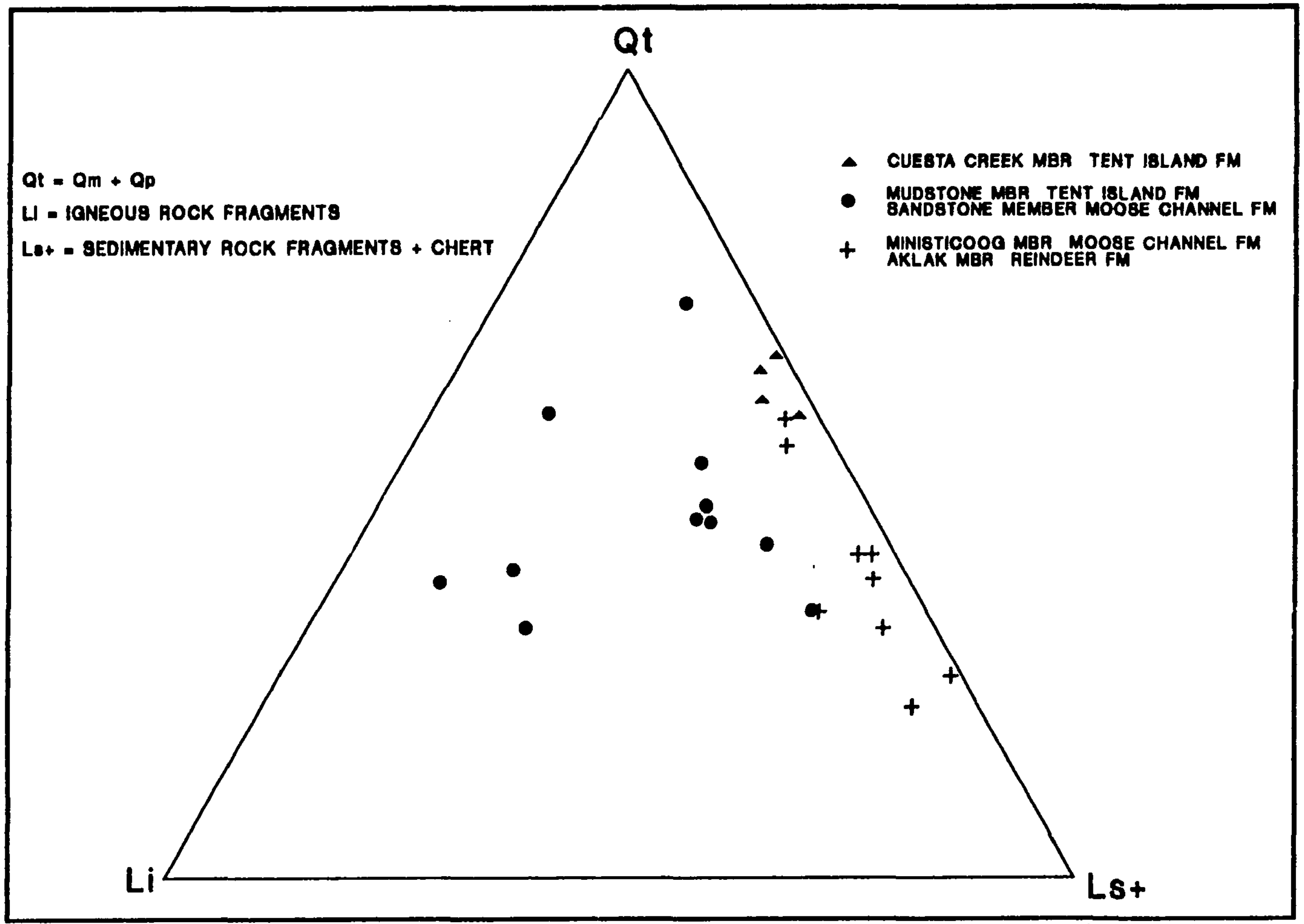


Figure 35. Ternary plot of quartz/igneous rock fragments/sedimentary rock fragments, Fish River Group and Aklak Member of the Reindeer Formation.

Table 1. Average modal compositions (relative percent) for members of the Tent Island, Moose Channel and Reindeer Formations. TI = Tent Island Formation, MC = Moose Channel Formation, RDR = Reindeer Formation, mst = mudstone member, ss = sandstone member, MI = Ministicoog Member and AK = Aklak Member.

	Cuesta Ck Mbr TI	mst mbr TI	ss mbr MC	MI Mbr MC	AK Mbr RDR
Number of Samples	4	2	9	2	7
Qp (Polycrystalline quartz)	33.2%	9.8%	16.3%	14.6%	15.0%
Qm (Monocrystalline quartz)	17.1%	20.0%	25.9%	23.4%	17.2%
Q (Qp+Qm)	50.3%	29.9%	42.2%	38.0%	32.2%
K (Potassium Feldspar)	0.2%	1.1%	2.3%	1.6%	1.2%
P (Plagioclase Feldspar)	0.5%	8.7%	7.6%	0.6%	0.3%
Ls+ (Total sed. rock fragments +chert)	29.3%	32.9%	24.6%	45.9%	54.3%
Lv (total volcanic rock fragments)	1.9%	21.0%	17.5%	3.7%	3.9%
Lp (total plutonic rock fragments)	0.1%	1.8%	0.9%	0.2%	0.5%
Lm (total metamorphic rock fragments)	13.8%	3.0%	3.5%	7.5%	5.7%

percent undulosity) is twice as common as quartz with straight extinction. For the purposes of this study chert was classified with rock fragments.

Feldspar

Feldspar is a relatively minor constituent, making up only 5.5 percent of the detrital grains. The percentage of K-feldspar was fairly constant throughout the interval examined and averaged 1.5 percent. The K-feldspar is typically weathered, subrounded and partially altered to clay. In contrast, much of the plagioclase present is angular, unweathered and associated with an increased amount of unaltered intermediate volcanics. Although the amount of plagioclase averages 4 percent, the upper Tent Island (mudstone member) and lower Moose Channel (Sandstone Member) contains an average of almost 10 percent with some thin sections containing in excess of 15 percent.

Chert and Cherty Argillite

For the purposes of this study, chert is rigidly defined as polycrystalline quartz with crystals less than .02 mm in diameter and with 0-5 percent argillaceous material. Rock fragments with between 5-70 percent argillaceous and/or carbonaceous material are classified as cherty argillite. Because of the gradations that exist between chert, cherty argillite, silicified volcanics, and metaquartzite, chert and chert-like grains are commonly very difficult to categorize (Wolf, 1971). The chert and cherty argillite are a mixed assemblage of devitrified (silicified) volcanics, sedimentary chert and to a much lesser extent metachert and metaquartzite. In some thin sections, chert and cherty argillite grains exhibit gradational textural and compositional transitions which made determining the origin of the grain possible. However, it was not possible to distinguish the origin of many chert and cherty argillite grains. Whenever remnants or ghosts of phenocrysts or a felty texture are present the rock fragment was classified as a volcanic rock fragment. Chert plus cherty argillite makes up 23 percent of the composition of the rocks studied with cherty argillite being the more abundant. Young (1975) reported that an inverse relationship existed between the amount of chert and the amount of plagioclase and volcanic rock fragments. This study agrees with his observations. It is a reasonable hypothesis that some of the increase in chert and cherty argillite in the Ministicoog and Aklak Members is due, at least in part, to the alteration of volcanic rock fragments and, therefore, not totally controlled by increase in sedimentary chert.

Sedimentary Rock Fragments

All gradations from argillite to shale/slate are present, with argillite being the most common. Coal and organic detritus, sandstone, and siltstone fragments are a minor constituent in all but two thin sections.

Igneous Rock Fragments

Volcanic rock fragments make up about 10 percent of the composition of the point counted samples. The volcanic fragments consisted of roughly equal amounts of felsic and intermediate volcanic rock fragments. Only trace amounts (less than 1 percent) of plutonic rock fragments are present.

Metamorphic Rock Fragments

Metamorphic rock fragments make up only 6 percent of the total detrital composition. The quartz mica phyllite fragments are the most common with lesser amounts of schist/gneiss and unfoliated metaclastic fragments present. For a more complete discussion of the composition of these sandstones see Myers (1989).

Rounding and Packing

The detrital sand grains of all formations are dominantly subangular but range from angular to subrounded. The sandstones examined have extremely close packing of grains. All thin sections contain grains with irregular to straight line contacts, rather than the point to point contacts found in undeformed sediments (Scholle, 1979). Penetration of softer grains by quartz and feldspar grains and fractured grains are common. Deformation, slippage, and rotation of ductile grains are typical. Deformation is commonly illustrated by argillite, shale, phyllite and micas which are bent around more resistant grains. Although grain contacts can generally be determined, these liable grains grade into pseudomatrix. Some penetration of quartz, feldspar, volcanic, and chert grains by angular to subangular grains of equal or greater hardness is also present. Good examples of pressure solution between quartz grains were observed. As would be expected, the compaction has significantly reduced primary porosity.

Differentiation of Units Based on Detrital Composition

Detailed modal analysis indicates that some differentiation of the units studied can be made based on composition. It is not surprising that the differentiation of units does not occur at formation boundaries. The compositional variations do, however, occur at the member level and may correspond to significant changes in the depositional history which were discussed in previous sections of this study. The following three divisions can be made based on subtle but significant compositional differences in sandstones: 1. Cuesta Creek Member, Tent Island Formation, 2. mudstone member, Tent Island Formation / sandstone member of the Moose Channel Formation and 3. Ministicoog Member of the Moose Channel Formation/Aklak Member of the Reindeer Formation (Figure 36).

The Cuesta Creek Member of the Tent Island Formation

The Cuesta Creek Member contains both the highest percent of total quartz (50 percent) and polycrystalline quartz (33 percent). The Cuesta Creek contains abundant polycrystalline quartz grains with greater than 3 crystals. The polycrystalline grains display straight contacts between equant interlocking crystals. In addition, the Cuesta Creek samples have the highest ratio of undulatory to nonudulatory quartz. Both characteristics are typical of quartz derived from low grade metamorphic rocks (Basu and others, 1975). The Cuesta Creek also contained the highest percentage of metamorphic rock fragments of any member studied.

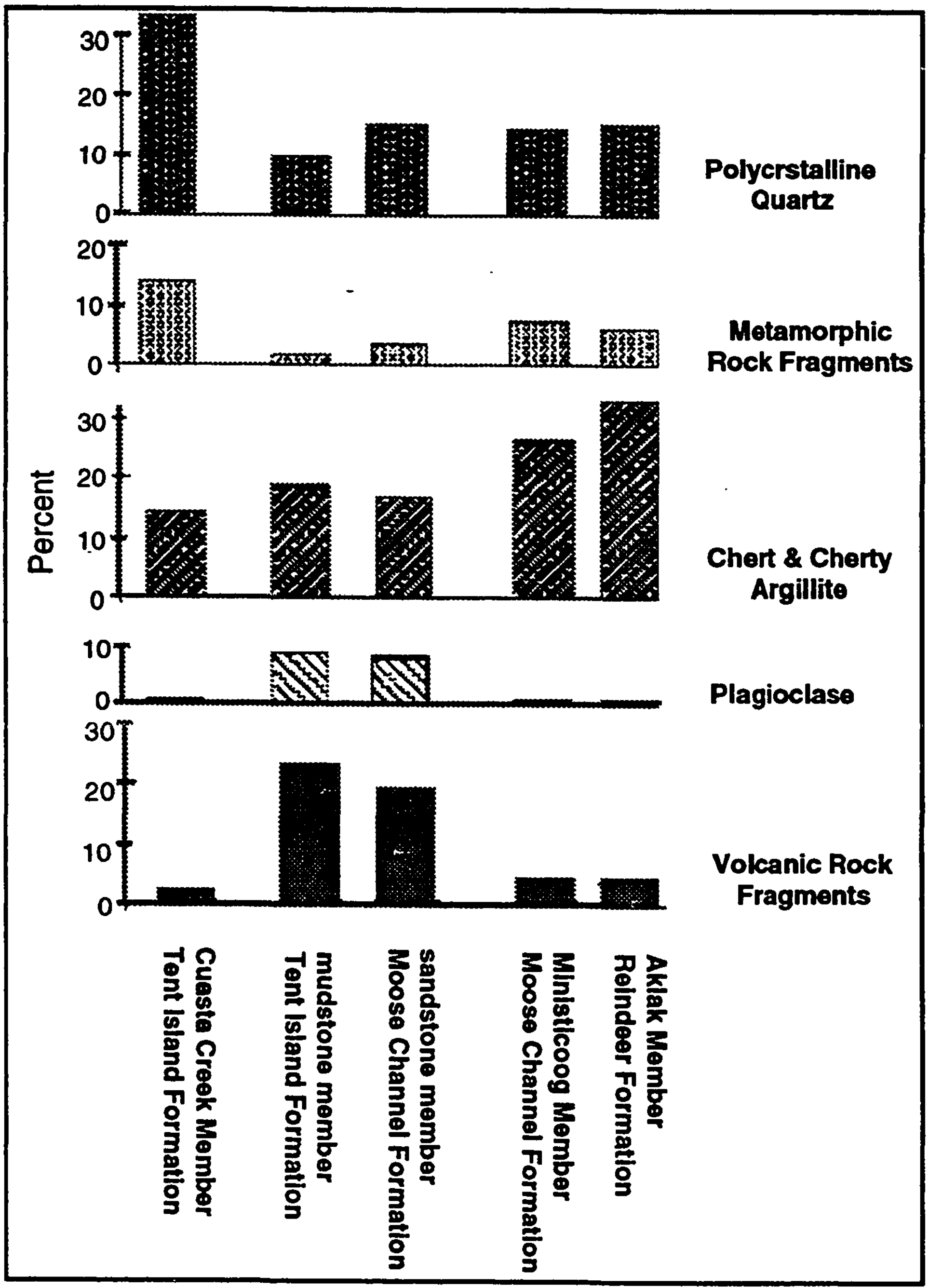


Figure 36. Compositional variation by member of the Tent Island, Moose Channel and Reindeer Formations.

The Mudstone Member of the Tent Island Formation and the Sandstone Member of the Moose Channel Formation

These members can be differentiated from the underlying Cuesta Creek and overlying Ministicoog and Aklak Members by both the amount plagioclase and volcanic rock fragments. Although plagioclase is only a relatively minor constituent, averaging 4 percent of the detrital grains, the amount in the upper Tent Island (mudstone member) and lower Moose Channel (sandstone member) is consistently greater than in either the underlying Cuesta Creek or the overlying Ministicoog and Aklak Members (8 percent versus less than 1 percent). The amount of K-Feldspar is relatively constant and makes up less than 3 percent of any sample. The upper Tent Island and lower Moose Channel also contained a much higher percentage of volcanic rock fragments (19 percent) than either the Cuesta Creek (2 percent) or the Ministicoog and Aklak Members (4 percent).

The Aklak and Ministicoog Members

The Aklak and Ministicoog Members contained a much higher percentage of chert and cherty argillite (32 percent) than the underlying mudstone and sandstone members (18 percent) and Cuesta Creek Member (14 percent). The increase in chert and cherty argillite is probably at least partially related to the decrease in volcanic rock fragments from the underlying Mudstone and Sandstone members. Silicification of volcanic rock fragments and their subsequent transformation into chert and cherty argillite may explain this relationship.

Non-Detrital Constituents

Cements comprise only 5 percent of the bulk composition of the studied thin sections. Cements consist of calcite, siderite, kaolinite, hematite, silica, chlorite, illite/smectite (identified by scanning electron microscope) and undifferentiated clay. Carbonate cement is the most abundant and occurred in several stages.

Cements - Early Diagenesis (Precompaction and Syncompaction)

Minor amounts of early carbonate cement present appear as a precompaction rim cement and porefilling. In addition, minor amounts of discontinuous siderite rim cement are present. The siderite crystals are generally less than .02 mm in diameter. In several of the thin sections a chlorite rim cement is present along flat grain contacts indicating that the cement was present prior to compaction. Both early and late stage chlorite cements are present. The early chlorite cement has a highly weathered appearance. This weathered appearance contrasts to the relatively unaltered appearance of the late stage chlorite cement. Chlorite cement is normally found in association with altered volcanic grains. The chlorite cement was not found in conjunction with precompaction carbonate cement and therefore the time relationship between these cements was not determined. A few examples of a highly altered precompaction clay cement were also present. Thin quartz overgrowths and rare examples of porefilling silica cements were present in almost all the thin sections studied. Based on petrographic analysis, silica cement is only a minor contributor when volumetrically compared to carbonate cement The silica cement was found in areas where pressure solution among quartz grains and quartz and chert grains was present. The minor amounts of silica cement and its juxtaposition to pressure solution features suggests that localized mobilization of silica from quartz and chert grains could account for all the silica cement. The juxtaposition of pressure solution and silica cementation (quartz overgrowths) also suggests that the silica cement was precipitated as a syncompaction cement.

Cements - Replacement and Late Stage

Most of the authigenic carbonate is present as replacement cement. The cement replaces both grains and matrix (Figure 37). Calcite replacement cement can be either poikilotopic or an aggregate of smaller crystals. A continuum ranging between minor partial replacement and complete replacement exists. Calcite commonly replaces feldspar, chert, cherty argillite, argillite, volcanic and some quartz grains. When total or near total grain replacement occurs the postcompaction shape of the grain or matrix material is normally preserved. Although it is common to see this replacement cement partially dissolved, it is normally not fractured or sheared, providing additional evidence that the cement replacement occurred after the majority of the compaction had taken place. Small crystals of siderite are also present within quartz grains. However, it is not possible to determine if the siderite present within these grains is a precompaction or a postcompaction cement. Some thin sections show that replacement siderite is present even after partial to complete dissolution of the grain which it is replacing has occurred. A late stage chlorite cement occurs as a rim cement, a fibrous pore filler and rarely as a direct replacement of volcanic grains. The rim cement commonly lines but seldom fills secondary pores. In some samples, chlorite rims are fractured and broken off from the grain rim, occupying space within the pore space. This indicates that a minor second stage of mechanical compaction occurred after the development of secondary porosity. Fibrous pore filling chlorite cement typically reduces but does not eliminate porosity within the secondary pore space. In some secondary pores there is a late stage microporous kaolinite cement which acts as a partial pore filling. In a few thin sections the kaolinite has completely filled a pore, eliminating all

Figure 37. Photomicrographs illustrating the development of secondary porosity in litharenites of the Moose Channel Formation. (A) Observe presence of secondary porosity criteria: a) corroded grains, b) inhomogenity of packing, c) partial disolution of grains and d) fractured grains. The presence of straight line and inbedded grain contacts and pressure solution features indicate substantial loss of primary porosity prior to the development of secondary pore space. Sample MD819. Plane light. Field of view is 5 mm. (B) Partial dissolution of chert grains and matrix. Observe: e) the preserved early stage authigenic chlorite rim cement. Sample MD2712. Plane light. Field of view is 1.7 mm. (C) Selective replacement of matrix and chert grains by carbonate cement. Dissolution of carbonate replacement cement is interpreted as a major mechanism for the formation of secondary porosity in the Moose Channel Formation. Sample MD7901. Crossed nicols. Field of view is 1.7 mm.

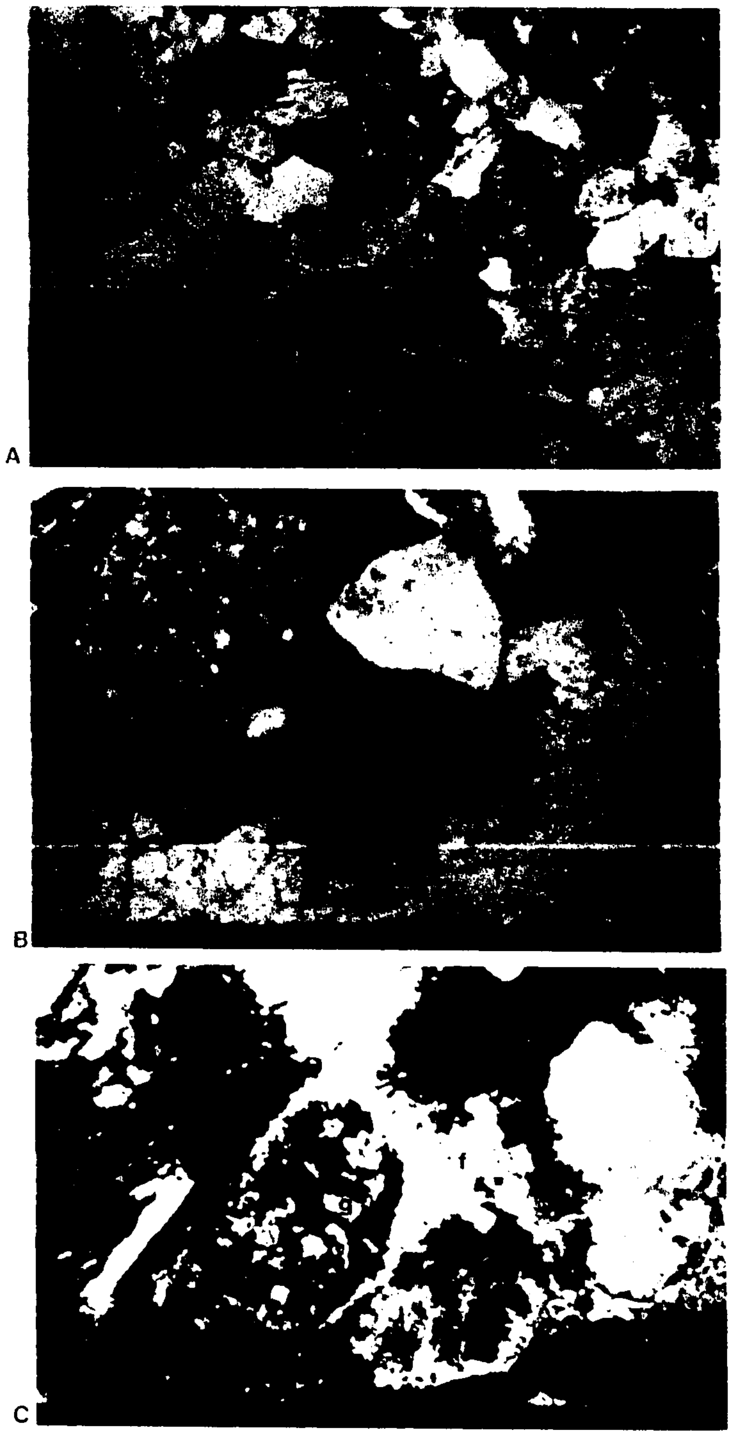


Figure 37.

effective porosity. However in most samples, the kaolinite has only reduced the effective porosity. SEM photos demonstrate well formed undesolved books of kaolinite partially filling secondary pores (Figure 38). This indicates that the microporous nature of the kaolinite cement is not a product of dissolution but is due to the cement being in the relatively early stage of formation. Although they both occupy secondary pore space and are commonly found on the same thin section, the kaolinite and chlorite cement are not found in association with each other. Finally, both hematite and late stage illite/smectite cements are present. These cements appear to be a late stage grain coating and are probably due to surface weathering of outcrop samples.

Porosity

Thin section porosity averages only 3 percent with a maximum of 8 percent. The porosity is low due primarily to the extreme amount of mechanical compaction. Additional porosity loss is due to post compaction cementation. The majority of the porosity present appeared to be secondary rather than primary. Most of the criteria used by Schmidt and McDonald (1979a, b & c) for identifying secondary porosity could be used (Figure 39). Criteria include partial dissolution, molds of grains, inhomogeneity of packing and floating grains, oversized pores, corroded grain margins, elongated pores and fractured grains (Figure 37). Other evidence for concluding that almost all the porosity is secondary is the selective nature of the porosity on both outcrop and subregional scale. Since the amount of porosity is highly variable it is possible to compare thin sections with almost zero effective porosity with those with greater than five percent. In fact, it is possible to find thin sections of similar composition, sorting, grain size and packing from the same outcrop with highly variable amounts of porosity. Because of this and since all the thin sections exhibit good examples of overly close packing, it is possible to eliminate primary porosity as the

Figure 38. Scanning electron microscope photomicrographs of cements in litharenites of the Moose Channel Formation. (A and B) Late stage pore filling kaolinite cement, Sample MD828. Bar scale is 50 um in A and 20 um in B. (C and D) Authigenic chlorite cement in a secondary pore, Sample MD825. Bar scale is 100 um in C and 10 um in D.

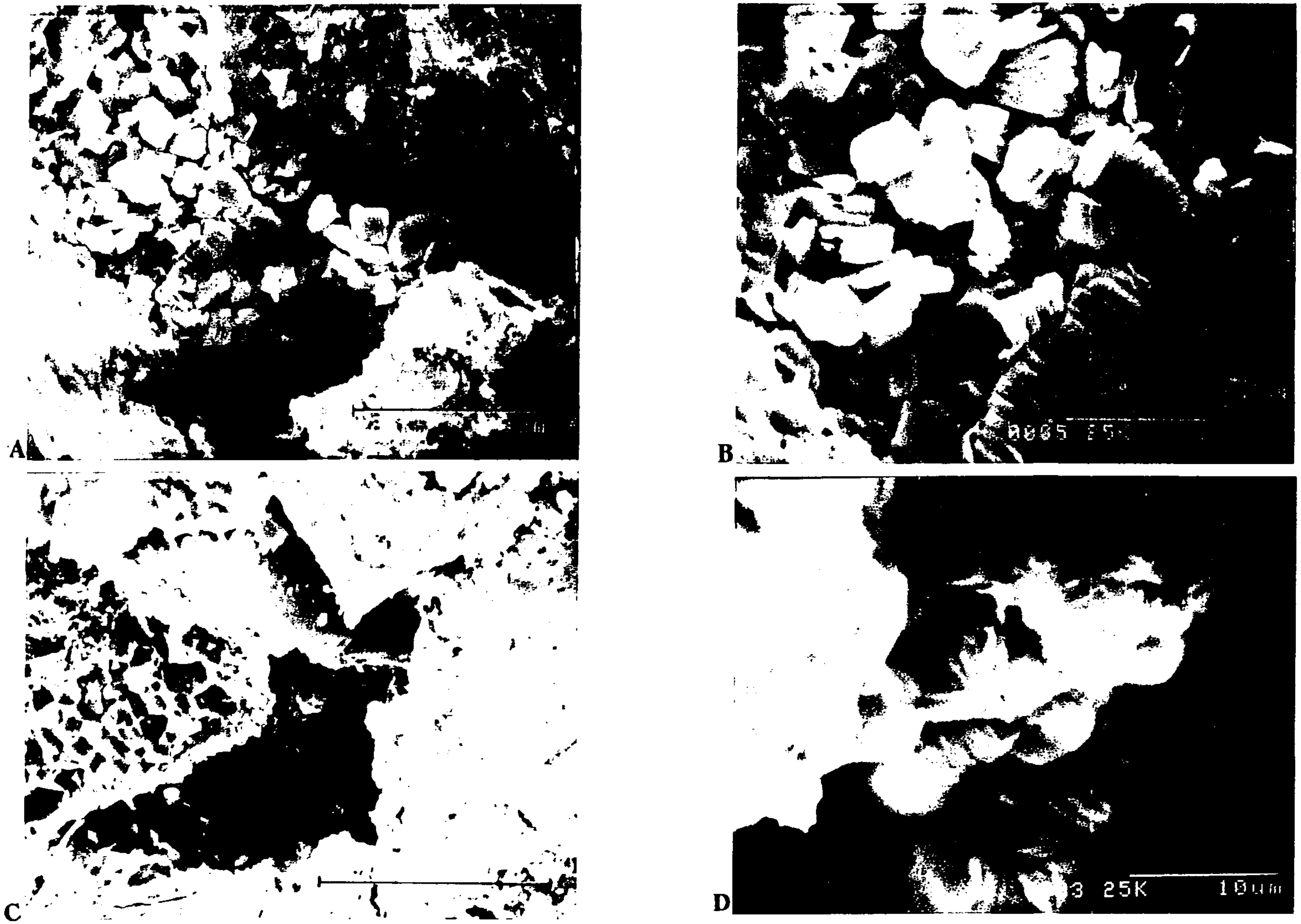


Figure 38.

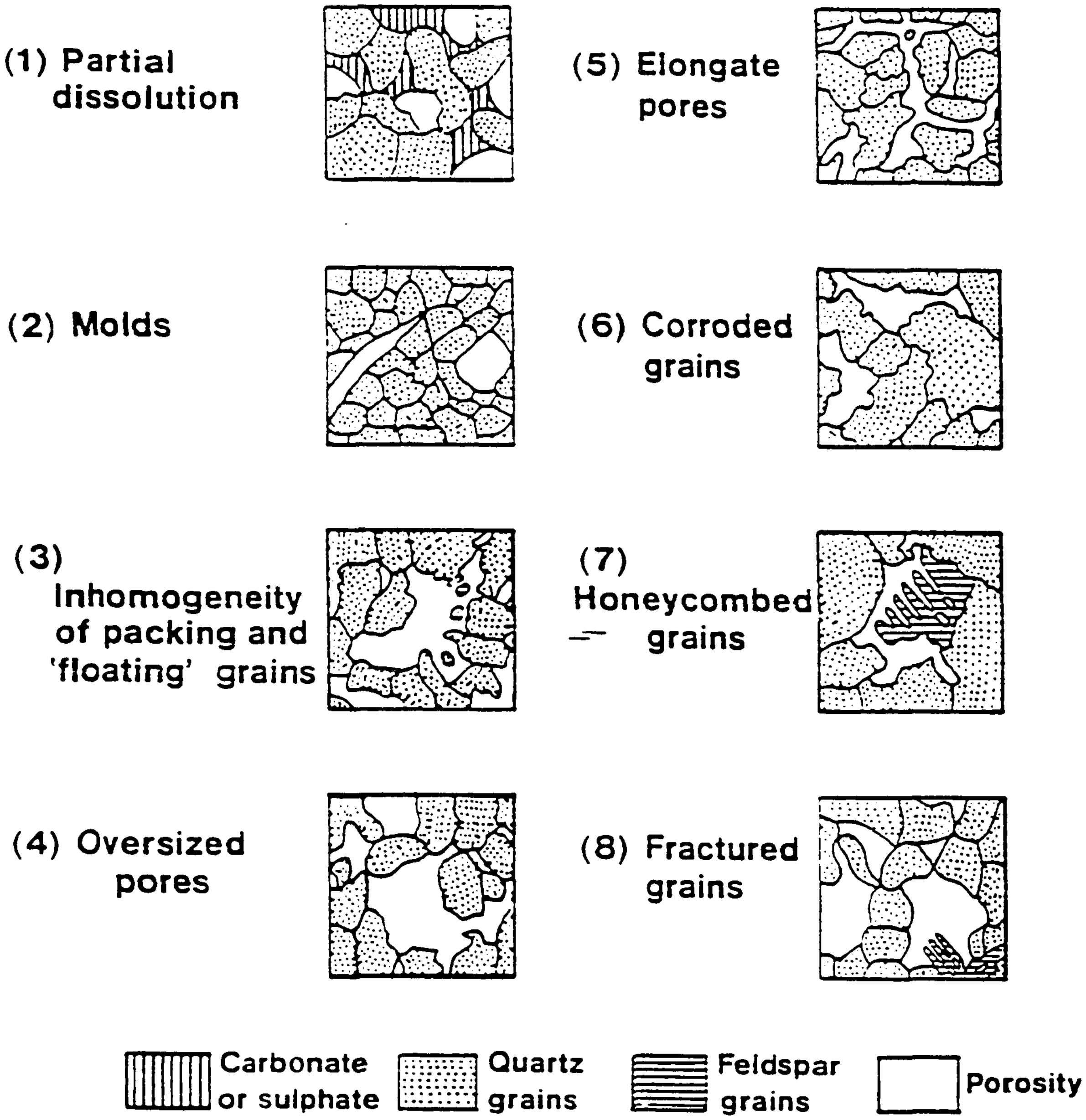


Figure 39. Petrographic criteria for the recognition of secondary sandstone porosity. From Schmidt and MacDonald (1979c).

mechanism for the variability in the amount of porosity present. Therefore, it is concluded that all the thin sections examined have undergone sufficient compaction to eliminate almost all effective primary porosity. Inhomogeneity of packing is especially striking in thin sections with well developed secondary porosity. It is common for an oversized pore to be surrounded by deformed ductile grains and rigid grains with straight line contacts.

Most of the secondary porosity was created by two processes. One is the direct dissolution of framework grains and matrix. The second process involves two steps. In the two step process matrix and grains are initially replaced by carbonate cement, followed by dissolution of the cement. Due to the difficulty of leaching silicate minerals the latter process is thought to be more common (Schmidt and McDonald 1979a, Schmidt, 1987). Examples of both mechanisms are in the thin sections examined. Regardless of the mechanism, much of the secondary porosity occurred as a result of the complete and partial dissolution of less stable grains (primarily volcanics, cherty argillites and feldspars). In addition, dissolution of carbonate cements, matrix, and more stable grains, including chert and quartz is common. Although it is not a major component, a minor amount of fracture porosity is present.

Since only minor cementation occurred prior to the majority of mechanical compaction and the majority of the dissolution occurred to framework grains rather than primary pore filling cement. Secondary porosity in these formations is different then that present in other North Slope reservoirs, such as the Ivishak Formation at Prudhoe Bay. In the Ivishak, much of the secondary porosity is the result of dissolution of a lithofacies dependent early (precompaction) carbonate cement (Melvin and Knight, 1984).

Several possible mechanisms have been described for creating the acidic waters necessary for postburial dissolution. These include the formation of carbonic acid through the release of carbon dioxide from organic matter undergoing thermomaturation (Schmidt and McDonald, 1979 a & c), the presence of highly soluble organic acids (Surdam, Boese, and Crossey, 1984; Siebert, Moncure and Lahann, 1984; Surdam and others 1989), deep penetration of meteoric waters (Galloway, 1984), and the post-uplift penetration of meteoric surface waters (Bjorlykke, 1984).

Diagenetic Sequence

The complex diagenetic sequence of the Tent Island, Moose Channel, and Reindeer formations is summarized in Figure 40. Since primary porosity is at irreducible levels, and secondary porosity is reduced, the sandstones examined would be classified as being in the mature "B" stage of mesodiagenesis (Schmidt and McDonald 1979a; Figure 41) Given age constraints, regional geothermal gradient, and composition of the sandstones studied, this would imply burial to depths probably in excess of 3000 m.

The development of secondary porosity is not uniform on either an outcrop or regional scale. This is demonstrated by the Moose Channel Formation in which sandstones with similar composition, grain size and sorting have a wide range of secondary porosity. For example, even though the two localities are only twenty kilometers apart, secondary porosity was much better developed in samples from Eagle Creek than from the Fish River area. The variation present between areas such as Eagle Creek and the Fish River may be related to differences in the post-compaction burial and uplift history. Variations in secondary porosity on the outcrop scale are probably related to selective fluid pathways.

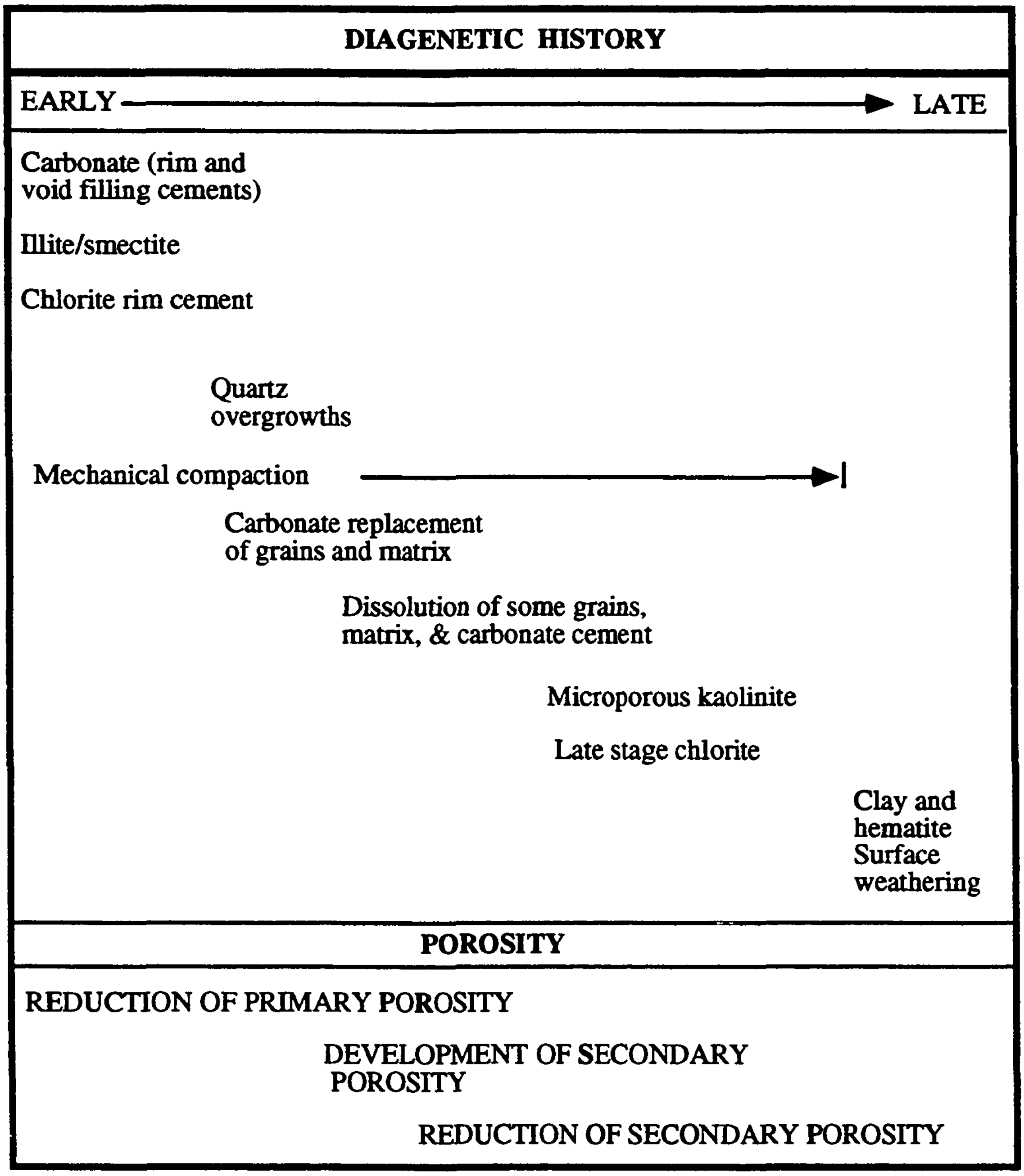


Figure 40. Diagenetic history of the Tent Island, Moose Channel and Reindeer Formations in the Fish River area. Interpreted from thin sections and SEM analysis of outcrop samples.

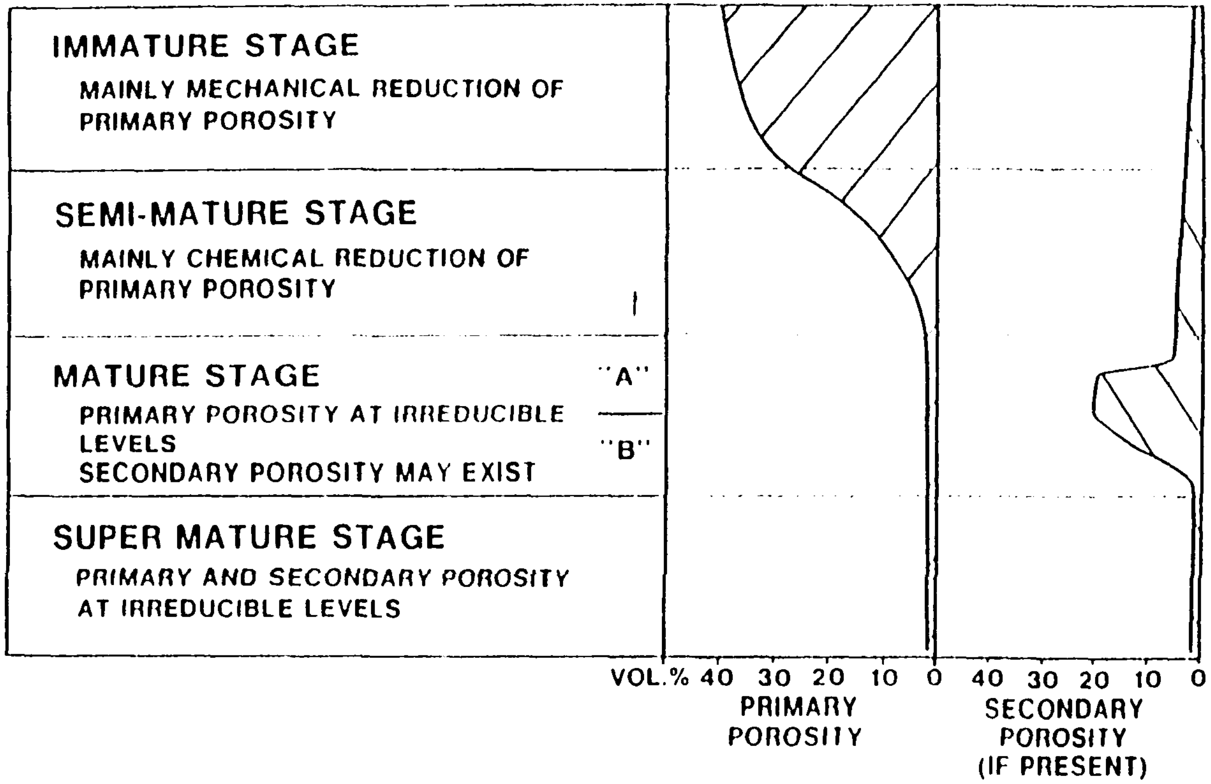


Figure 41. Textural stages of mesodiagenesis of sandstone porosity. From Schmidt and MacDonald (1979c).

Secondary porosity occurred in both the Moose Channel and Reindeer formations, and good examples were found in shelf, delta front, delta plain and fluvial sandstones.

Secondary Porosity in the Subsurface

Dickinson (1985) demonstrated that lithic sandstones suffer a much more rapid lose of primary porosity with depth than do either feldspathic or quartzose sandstones. He plotted a graph of porosity versus depth illustrating three distinctive rates of porosity loss with depth based on sandstone composition. Based on Dickinson's observations, the Moose Channel and Reindeer formations should have porosities of less than 10 percent in the subsurface at depths below 3 kilometers. However, based on data from 7 wells, plots of porosity versus current depth for the Reindeer Formation (Nentwich and Yole, 1982) demonstrated porosities where generally much higher than those predicted by Dickinson's model (in excess of 15 percent). The higher values are probably indicative of development of secondary porosity within the Reindeer Formation. A petrographic study of Upper Cretaceous to Lower Miocene core and cutting samples from the Mackenzie Delta by Schmidt (1987) determined that about 85 percent of the total macroporosity in all units was due to secondary porosity. A subsurface study by Nentwich (1980) also noted abundant secondary porosity.

In summary, secondary porosity is the dominant form of porosity preserved in the studied outcrop samples and in the subsurface. Secondary porosity provides the mechanism to create petroleum reservoirs out of sandstones which: 1) have been buried to depths deep enough to destroy most primary porosity and 2) are compositionally immature. The development of secondary porosity in sandstones of the Beaufort-Mackenzie Basin suggests that the development of secondary porosity is possible in sandstones of similar compositions found in the ANWR Coastal Plain.

Comparison With Deltaic Sandstones of Similar Age on the North Slope of Alaska

Litharenites of the late Cretaceous to Paleocene age were deposited in a series of deltas that existed to the north of the Brooks range on the North Slope of Alaska. These delta systems are generally poorly exposed along river cuts on the coastal plain of the North Slope. Sandstones of these delta systems are a major hydrocarbon exploration target.

One of these delta systems is represented by the Jago River Formation which crops out in the Arctic National Wildlife Refuge of Alaska. Compositionally the Jago River Formation contains more chert and less quartz than either the Moose Channel or Reindeer Formations (Figure 42; Buckingham, 1987). This compositional variation is not surprising. Both units were probably deposited in relative close proximity to their source terrane. Local variations in composition are to be expected. Examination of thin sections from the Jago River Formation at the Sabbath Creek locality illustrates a diagenetic history that is very similar to the Moose Channel and Reindeer Formations in the Beaufort-Mackenzie basin. The Jago River Formation samples display a nearly complete loss of primary porosity (Figure 43). Thin sections examined contain grains with irregular to straight line contacts, rather than the point to point contacts found in undeformed sediments (Scholle, 1979). Penetration of softer grains by quartz, feldspar, and fractured grains are common. Deformation, slippage, and rotation of ductile grains are typical. This is commonly illustrated by argillite, shale, phyllite and micas which are bent around more resistant grains. Based on the almost total loss of primary porosity, the Jago River Formation at

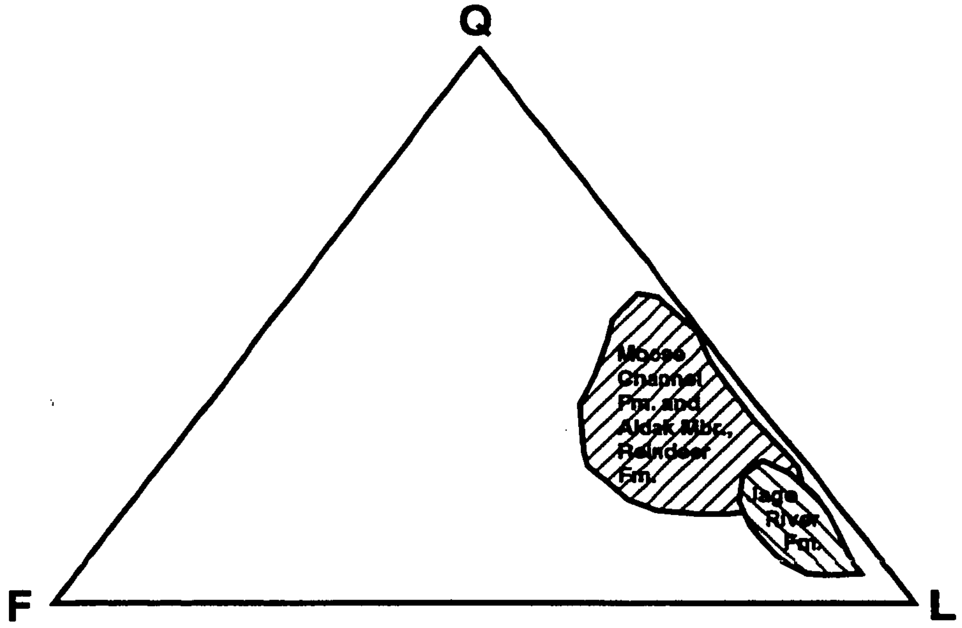


Figure 42. QFL diagram displaying the sandstone composition of the Jago River, Moose Channel and Reindeer Formations. Jago River data from Buckingham (1987).

Figure 43. Photomicrographs of Maastrichtian to Paleocene deltaic litharenites of the Alaska North Slope. These sandstones contain varying amounts of preserved primary and secondary porosity. (A) Complex mix of primary and secondary porosity. Observe: a) Partial dissolution of potassium feldspar grain. Sample NS2001, Kogosukruk Tongue, Prince Creek Formation, Colville River area. Plane light. Field of view is 1.7 mm. (B) Primary porosity at irreducible levels. Observe irregular to straight grain contacts and deformation of softer grains. Sample NS3601, Jago River Formation, Sabbath Creek locality. Crossed nicols. Field of view is 5 mm. (C) Well preserved primary porosity. Observe the point to point grain contacts. Sample NS1001, Sagwon Member, Sagavanirtok Formation, Sagwon Bluffs. Plane light. Field of view is 5 mm.

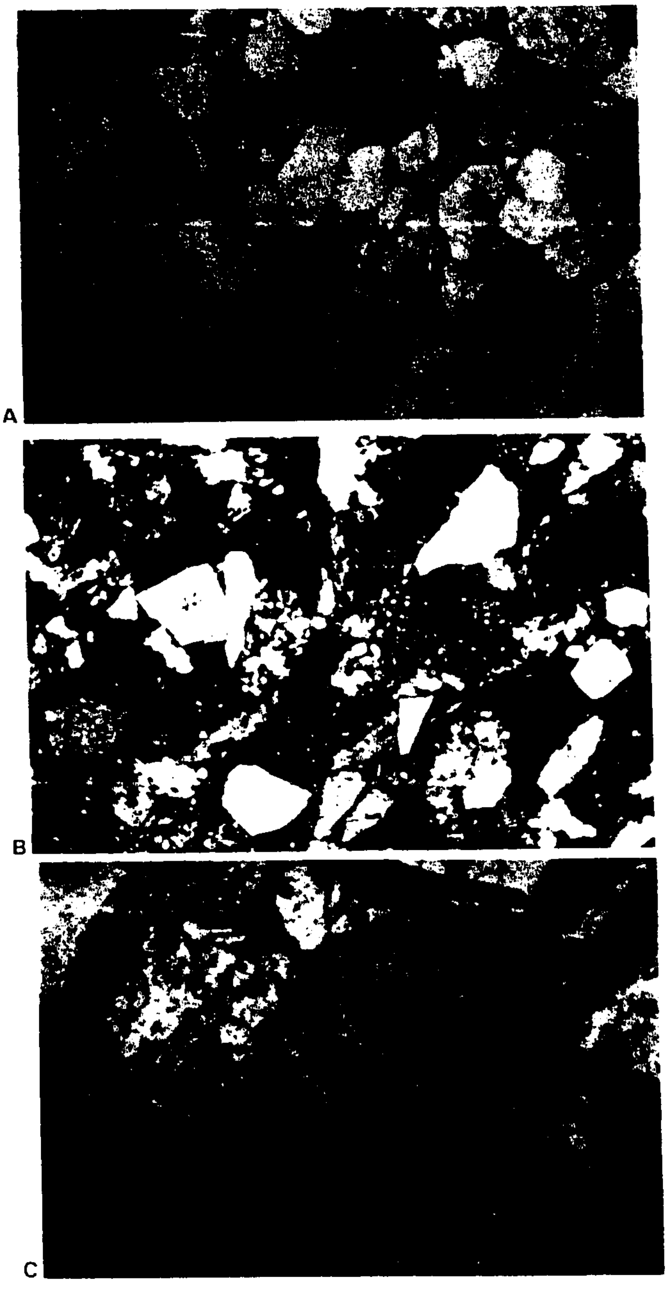


Figure 43.

Sabbath Creek has been buried to depths of greater than 3000 m. Preserved porosity appears to be almost entirely secondary. Preserved porosity is less well developed than that in the Moose Channel and Reindeer but appears to be the result of similar processes. Dissolution of grains and matrix has occurred and appears to have occurred both as a product of the dissolution of carbonate replacement cement and by direct dissolution of grains by pore fluids. Reliance on increased secondary porosity will be necessary if the Jago River Formation is to be considered a reservoir rock in the subsurface.

This contrasts with Upper Cretaceous and Paleocene sandstones which crop out to the west of the Arctic National Wildlife Refuge. Sandstones of the Upper Cretaceous Prince Creek Formation of the Colville Group and Paleocene Sagwon Bluffs Member of the Sagavanirktok Formation were deposited by prograding deltaic systems into the Colville trough (Molenaar, Bird and Kirk, 1987).

Thin sections from outcrops at Sagwon Bluffs (Sagwon Member) and along the banks of the Colville River north of Umiat (Kogosukruk Tongue of the Prince Creek Formation) illustrate the preservation of primary porosity in these litharenites (Figure 43). In contrast to the straight line and inbedded grain contacts present in the Jago River, Tent Island, Moose Channel and Reindeer Formations, most grain contacts are point to point. Although some deformation of the more ductile grains has occurred, this limited deformation contrasts sharply with the extreme deformation seen in thin sections from the Jago River Formation. Samples of the Prince Creek Formation contain minor selective secondary porosity by the partial dissolution of K-feldspar grains (Figure 43). The presence of well preserved primary porosity indicates that these litharenites have never been buried past the immature stage of mesodiagenesis of Schmidt and MacDonald (1979c).

Smosna (1988; 1989) examined thin sections from the Prince Creek Formation in the Square Lake and Umiat No. 11 wells in the National Petroleum Reserve in Alaska and similarly concluded that the maximum depth of burial for these litharenites was 1000 m. Primary porosity is also preserved within equivalent heavy oil bearing sandstones of the Colville Group within the supergiant heavy oil West Sak Oil Field. These reservoir sands are currently buried to depths of 600-1200 m (Werner, 1987).

SUMMARY

The 1900 m thick Maastrichtian to Paleocene Fish River Group consists of a large scale shallowing-upward succession and records depositional environments ranging from submarine canyon to upper delta plain. The Fish River Group consists of the Cuesta Creek and mudstone members of the Tent Island Formation and the sandstone and Ministicoog members of the Moose Channel Formation.

The Maastrichtian Cuesta Creek Member was deposited in a submarine canyon system incised into deep marine shales of the Cenomanian to Turonian Boundary Creek Formation. The Cuesta Creek Member reaches a maximum thickness of 151 m and consists of stacked fining-upward channel fills containing discontinuous beds of conglomerate, sandstone and siltstone. Sandstones and conglomerate beds are interpreted to have been deposited as high and low density turbidites, traction deposits, debris flows, slumps, and slides. The Cuesta Creek Member records the complex depositional history involved in the creation and back filling of a lowstand submarine canyon system. The Cuesta Creek Member is blanketed by non-channelized hemipelagic mudstone at the base of the mudstone member of the Tent Island Formation which records the abandonment of the canyon system.

The 850 m thick Maastrichtian mudstone member is composed dominantly of mudstone with lesser amounts of siltstone, very fine-to fine-grained sandstone and minor conglomerate. The percentage of siltstone and sandstone generally increases from less than 15 percent near the base of the member to up to 30 percent at the top. Based on lithology, sedimentary structures and biogenic structures, the mudstone member can be subdivided into four units. The sedimentology, ichnology, and relationship with overlying and

underlying rock units suggest that the mudstone member was deposited in progressively decreasing water depths associated with the distal to proximal progradation of a major deltaic system. Interpreted depositional environments range from slope, outer shelf, and distal prodelta near the base of the member to inner shelf and subaqueous delta plain near the top of the member.

The Tent Island Formation is conformably overlain by the 880 m thick Paleocene sandstone member of the Moose Channel Formation. Lithologies of the sandstone member include conglomerate, sandstone, siltstone, mudstone and coal. The dominant lithology is sandstone, which comprises up to 85 percent of the member at the type section. Based on lithology, sedimentary structures and biogenic structures, the sandstone member can be subdivided into three units. The sandstone member is interpreted to have been deposited during the progradation and aggradation of a major deltaic system. Depositional environments range from inner shelf and subaqueous delta plain to subaerial delta plain. Proximal delta front deposits consist dominantly of aggradational coarsening-upward parasequence sets (interpreted as distributary mouth bars). Delta plain deposits are dominated by sand rich, high bed load, distributary channel fill and overlying vertically stacked braided channel complexes. The presence of straight high bed load distributary channels overlain by sandy braided stream deposits suggests a fairly steep gradient and proximal sediment source area.

The sandstone member is overlain by the 180 m thick Paleocene Ministicoog Member. The Ministicoog Member consists of mudstone and siltstone with lesser fine-to very fine-grained sandstone and rare conglomerate. Based on sedimentary and biogenic structures, the Ministicoog Member is interpreted to have been deposited in inner shelf and delta front environments. The Ministicoog Member was deposited during a rise in relative sea level and represents the final stages of deposition associated with the Moose Channel delta system.

An estimated 580 m of the 1400 m thick Paleocene to Lower Eocene Aklak Member of the Reindeer Formation is exposed in the study area. This basal part of the member consists of nonmarine conglomerate, sandstone, siltstone, mudstone and coal that are interpreted to have been deposited in an upper delta plain environment. These upper delta plain deposits differ from those of the underlying Fish River Group in that they contain significantly thicker and more extensive coal deposits and a higher percentage of conglomerate within braided stream channel fills. The unconformity between the Ministicoog and the Aklak Member in the study area records a significant unconformity, formed by the subaerial exposure of the platform constructed during deposition of the Fish River Group.

The Fish River sequence encompasses sedimentary rocks of the Tent Island and Moose Channel formations. This sequence meets the criteria of a depositional sequence as defined by Mitchum and others (1977); namely, a stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities. The Fish River sequence is a type-1 sequence. This interpretation is based on the presence of a submarine canyon system immediately overlying the unconformity marking the basal sequence boundary and a major basinward shift in sedimentation. The longevity of the sequence indicates it's a second order sequence. The sequence includes lowstand, transgressive, and highstand systems tracts based on interpretation of outcrop observations. The highstand systems tract of the Fish River sequence includes the smaller scale, type-2, third order Ministicoog sequence. The Fish River sequence is unconformably overlain by the lowstand systems tract of the Aklak sequence.

Sandstones of the Tent Island, Moose Channel, and the Reindeer (Aklak Member) Formations are subangular, highly immature litharenites. Based on differences in the amounts of polycrystalline quartz, metamorphic rock fragments, chert, cherty argillite, plagioclase and volcanic rock fragments, these formations can be separated into three groups at the member level. These three groups are: 1) the Cuesta Creek Member; 2) the mudstone of the Tent Island Formation and the sandstone member of the Moose Channel Formation; and 3) the Ministicoog Member of the Moose Channel Formation and Aklak Member of the Reindeer Formation. These compositional variations relate to major changes in the depositional system but do not correspond to formation boundaries.

All sandstones have lost reducible primary porosity but contain up to 8 percent secondary porosity. Based on composition, age, amount of compaction and current geothermal gradient, these sandstones have been buried to depths of at least 3000 m. Secondary porosity resulted from dissolution of grains and matrix, both directly and indirectly through initial replacement and subsequent dissolution of the cement.

A six stage diagenetic history has been interpreted for these sandstones. It includes: 1) minor carbonate rim, illite/smectite and chlorite cementation; 2) mechanical compaction, pressure solution, and the formation of some quartz overgrowths; 3) carbonate replacement of some grains and matrix along with the loss of most primary porosity; 4) formation of secondary porosity through dissolution; 5) decrease in the amount of secondary porosity through minor mechanical compaction and formation of microporous kaolinite and chlorite pore filling cements; and 6) surface weathering and formation of hematite and clay cements.

CONCLUSIONS

The Fish River and Aklak sequences were deposited during the northward migration of a fold and thrust belt across a north-facing passive continental margin. There are no published detailed sequence stratigraphic studies or models for this tectonic setting. The well constrained systems tracts delineated by this study provide a detailed framework for analyzing the depositional history, reservoir continuity and reservoir distribution in this and other similar tectonic settings.

The internal stratigraphic organization of the Fish River sequence records alternating periods of uplift and subsidence in the Beaufort-Mackenzie basin. The scale and timing of these episodes, combined with the environments of deposition and lithologic character of the rocks, suggests that the driving mechanism was alternating episodes of thrusting and subsidence in the adjacent foreland, followed by flexural rebound.

The Cuesta Creek Member is identified as the channel fill deposits of a submarine canyon system. The complex internal stratigraphy and sedimentary structures described and interpreted in this study provide insight into the depositional processes and history of ancient submarine canyons.

The Cuesta Creek Member is the first major coarse-grained submarine canyon system identified and systematically described in outcrop on the North Slope of Alaska, northern Yukon and northwestern Northwest Territories. The distinguishing characteristics of the Cuesta Creek Member provide a guide for identifying ancient submarine canyons in outcrop.

The depositional history of the Cuesta Creek Member involved at least three significant stages: the cutting of the submarine canyon into the underlying Boundary Creek Formation, the subsequent deposition of the canyon fill and finally abandonment of the canyon system (recorded by the upper-most fine-grained canyon fill). This three stage deposition history suggests that the canyon was incised during maximum lowstand and indicates that a yet to be discovered basin floor fan was deposited more distally in the basin.

Reconstruction of the highstand systems tract indicates a large scale delta system which combines characteristics of a fan or braid delta (an upper delta plain dominated by a sand rich braided stream complex) and river and wave dominated deltas (stacked distributary mouth bars and an established lower delta plain containing distributary and crevasse channels and interdistributary bays and marshes). These characteristics indicate that this delta system does not fit within any current classification system and has no published analog.

Despite a complex post-depositional history including deep burial, loss of effective primary porosity and many stages of cementation, sandstones of the Fish River Group and Aklak Member still contain significant secondary porosity.

Finally, this study refines the regional lithostratigraphy and sequence stratigraphy of the Upper Cretaceous through Lower Eocene of the Beaufort-Mackenzie basin. It also provides good analogs for understanding the depositional history of similar aged rocks on the Alaska North Slope.

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APPENDIX 1: MEASURED SECTIONS

Note: measured section number is on the top right corner of each page of a section.

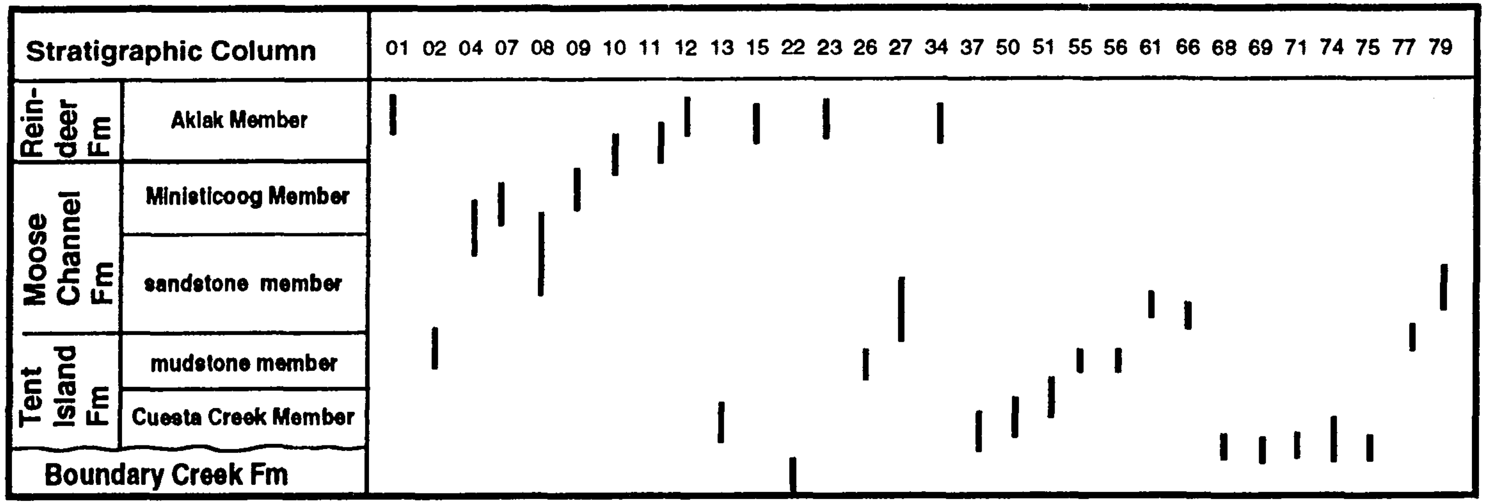


Figure 44. Relative stratigraphic position of measured sections.

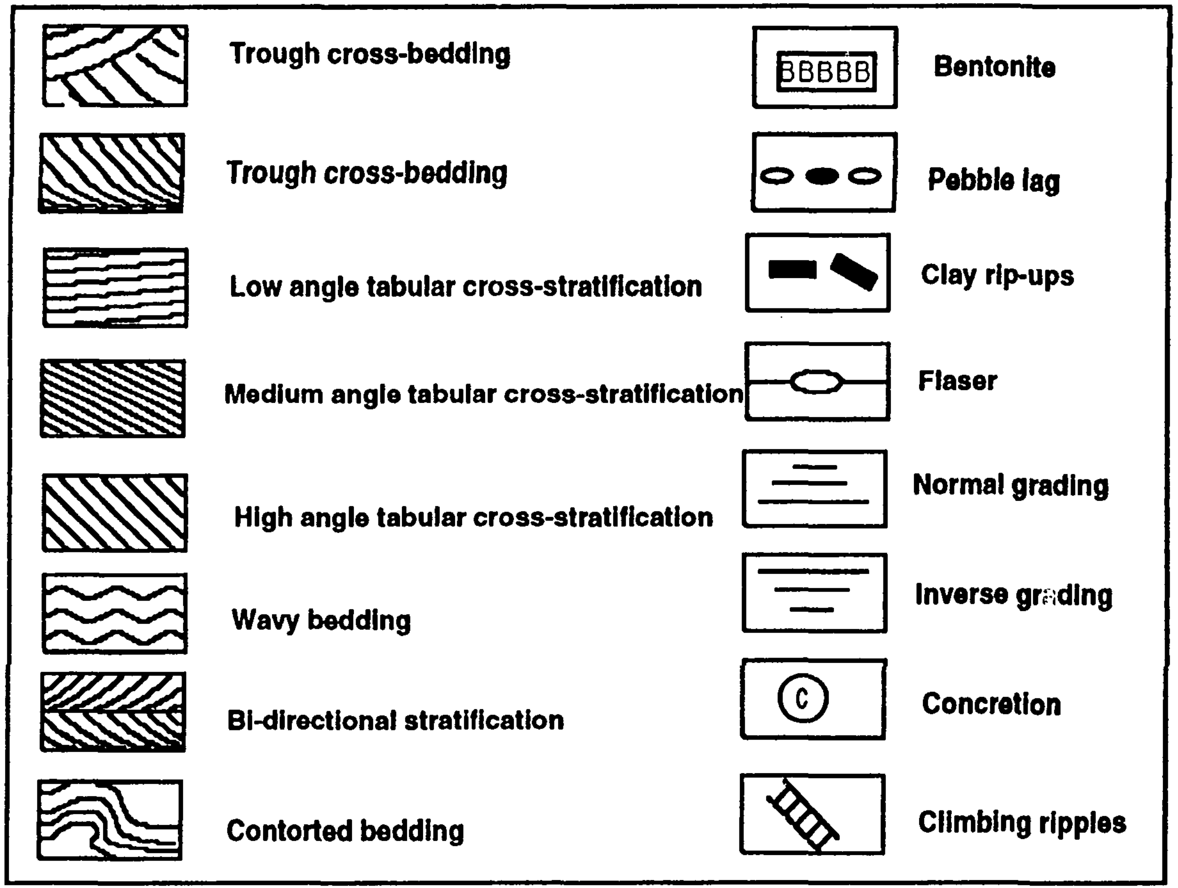


Figure 45. Key for sedimentary structures.
45.1. Page 1 key for sedimentary structures.

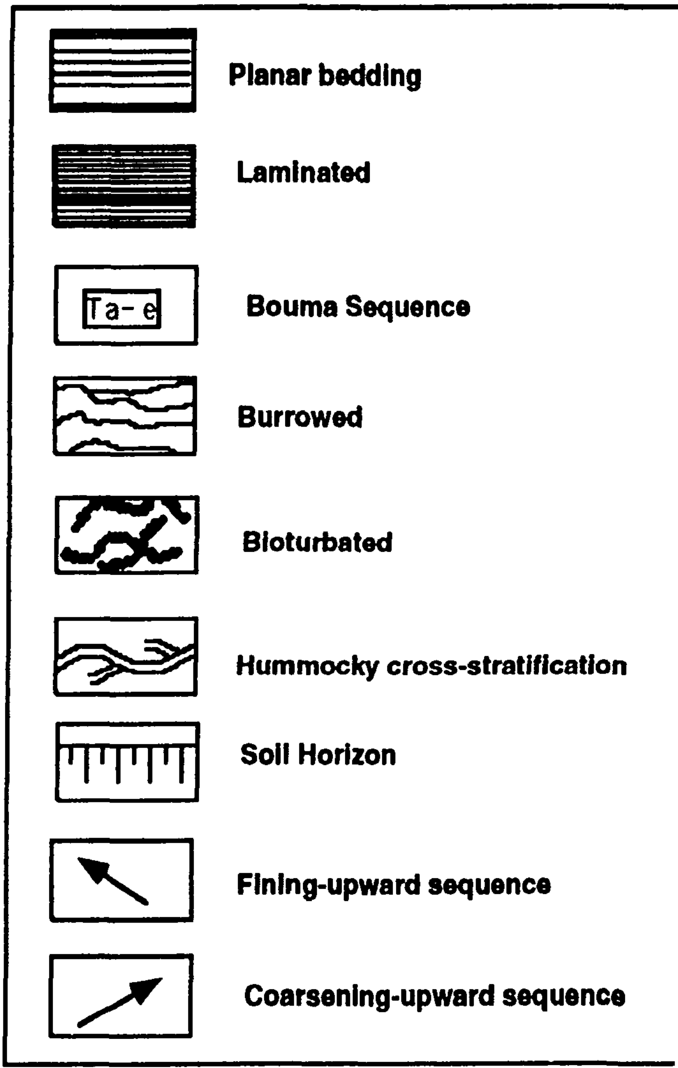
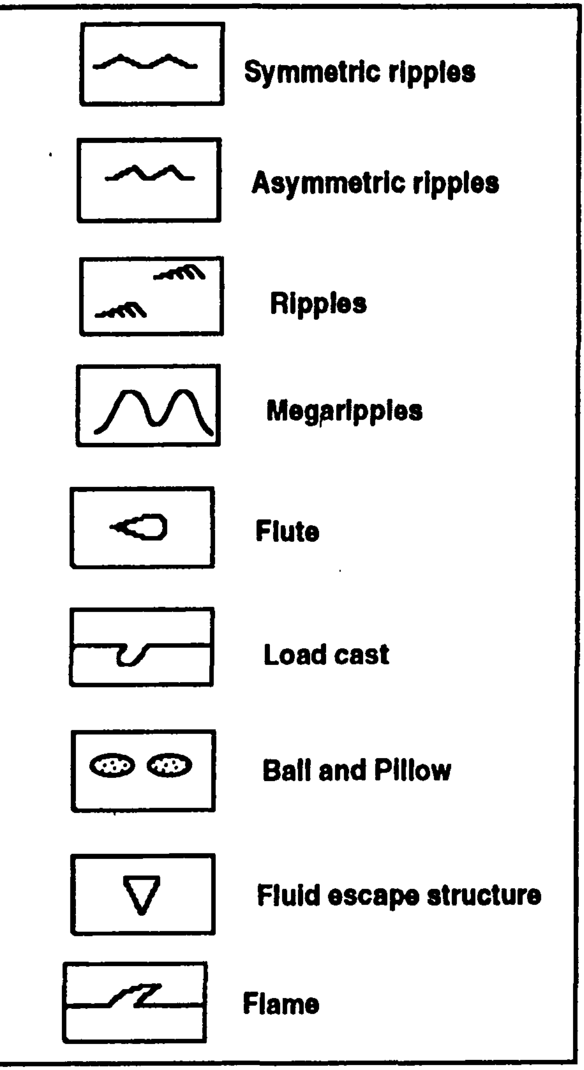


Figure 45.2. Page 2 key for sedimentary structures.


Symmetric ripples
Asymmetric ripples
Ripples
Megaripples
Flute
Load cast
Ball and Pillow
Fluid escape structure
Flame

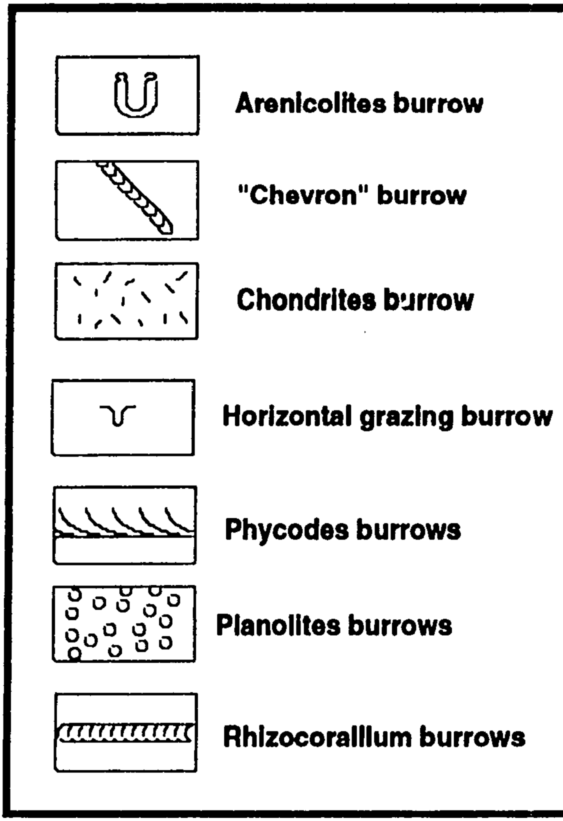
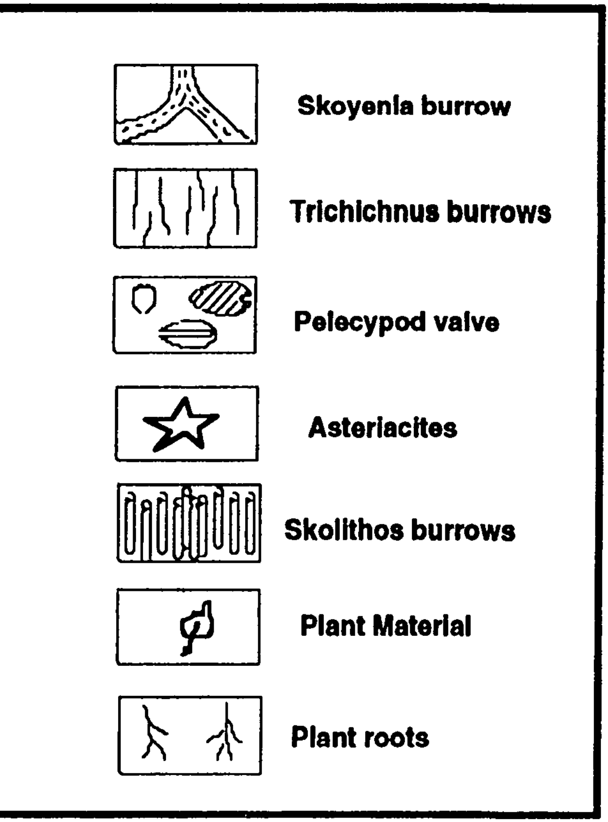
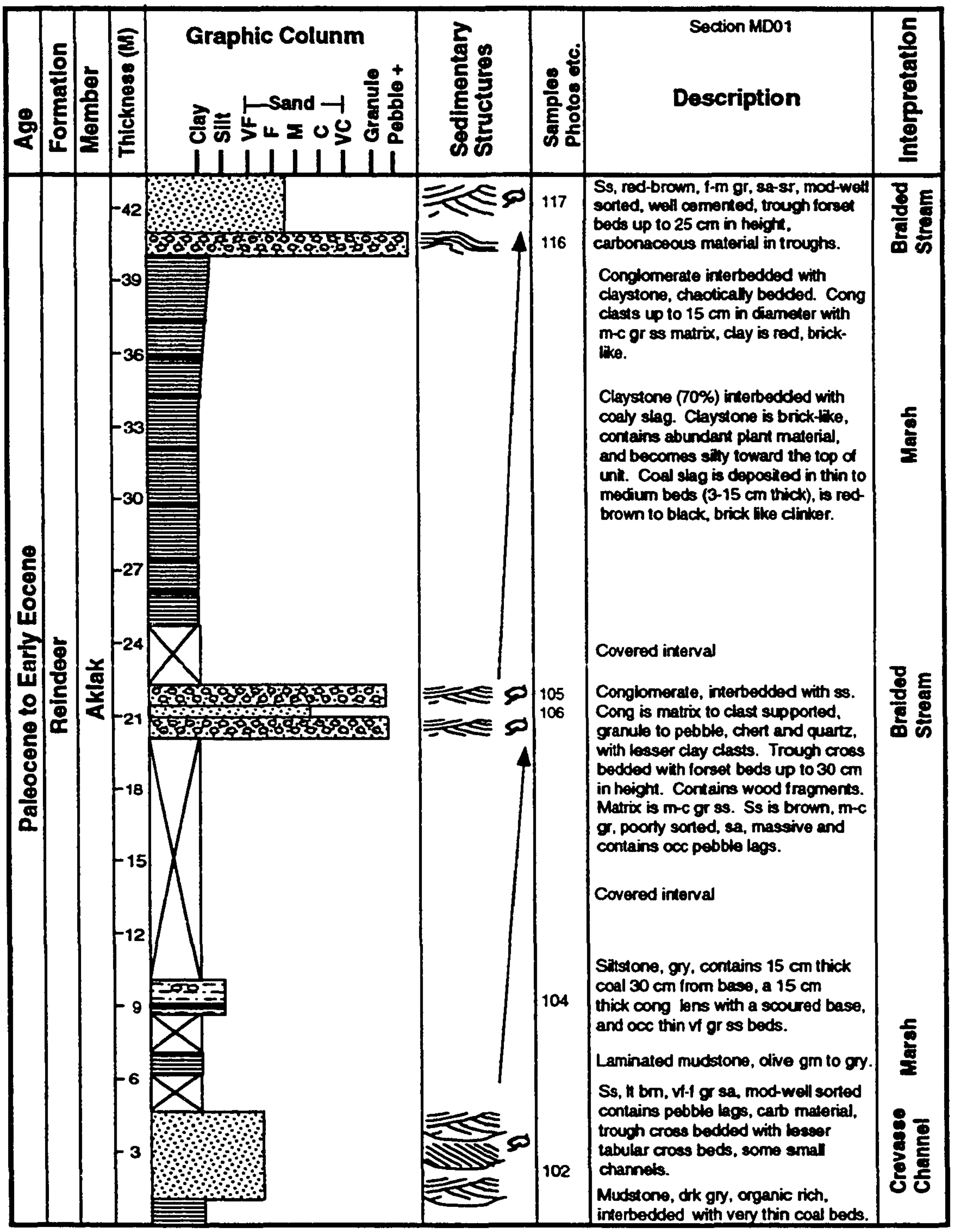


Figure 46. Key for fossils.


Skoyenia burrow
Trichichnus burrows
Pelecypod valve
Asteriacites
Skolithos burrows
Plant Material
Plant roots



Ss, red-brown, f-m gr, sa-sr, mod-well sorted, well cemented, trough forset beds up to 25 cm in height, carbonaceous material in troughs.

Conglomerate interbedded with claystone, chaotically bedded. Cong clasts up to 15 cm in diameter with m-c gr ss matrix, clay is red, brick-like.

Claystone (70%) interbedded with coaly slag. Claystone is brick-like, contains abundant plant material, and becomes silty toward the top of unit. Coal slag is deposited in thin to medium beds (3-15 cm thick), is red-brown to black, brick like clinker.

Covered interval

Conglomerate, interbedded with ss. Cong is matrix to clast supported, granule to pebble, chert and quartz, with lesser clay clasts. Trough cross bedded with forset beds up to 30 cm in height. Contains wood fragments. Matrix is m-c gr ss. Ss is brown, m-c gr, poorly sorted, sa, massive and contains occ pebble lags.

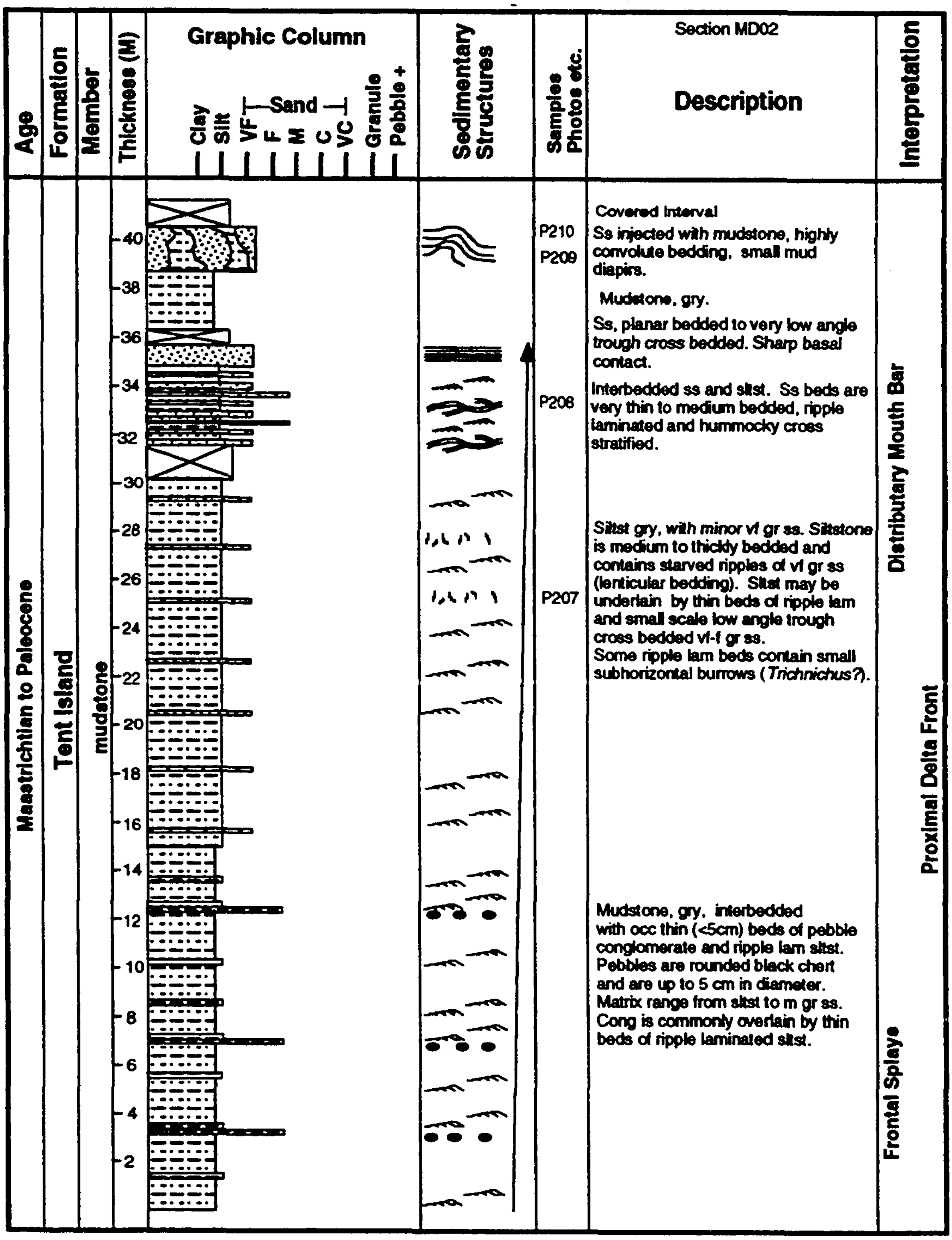
Covered interval

Siltstone, gry, contains 15 cm thick coal 30 cm from base, a 15 cm thick cong lens with a scoured base, and occ thin vf gr ss beds.

Laminated mudstone, olive grn to gry.

Ss, lt brn, vf-f gr sa, mod-well sorted contains pebble lags, carb material, trough cross bedded with lesser tabular cross beds, some small channels.

Mudstone, drk gry, organic rich, interbedded with very thin coal beds.



Section MD02

Description

Covered Interval

Ss *injected* with *mudstone*, highly convolute bedding, small mud diapirs.

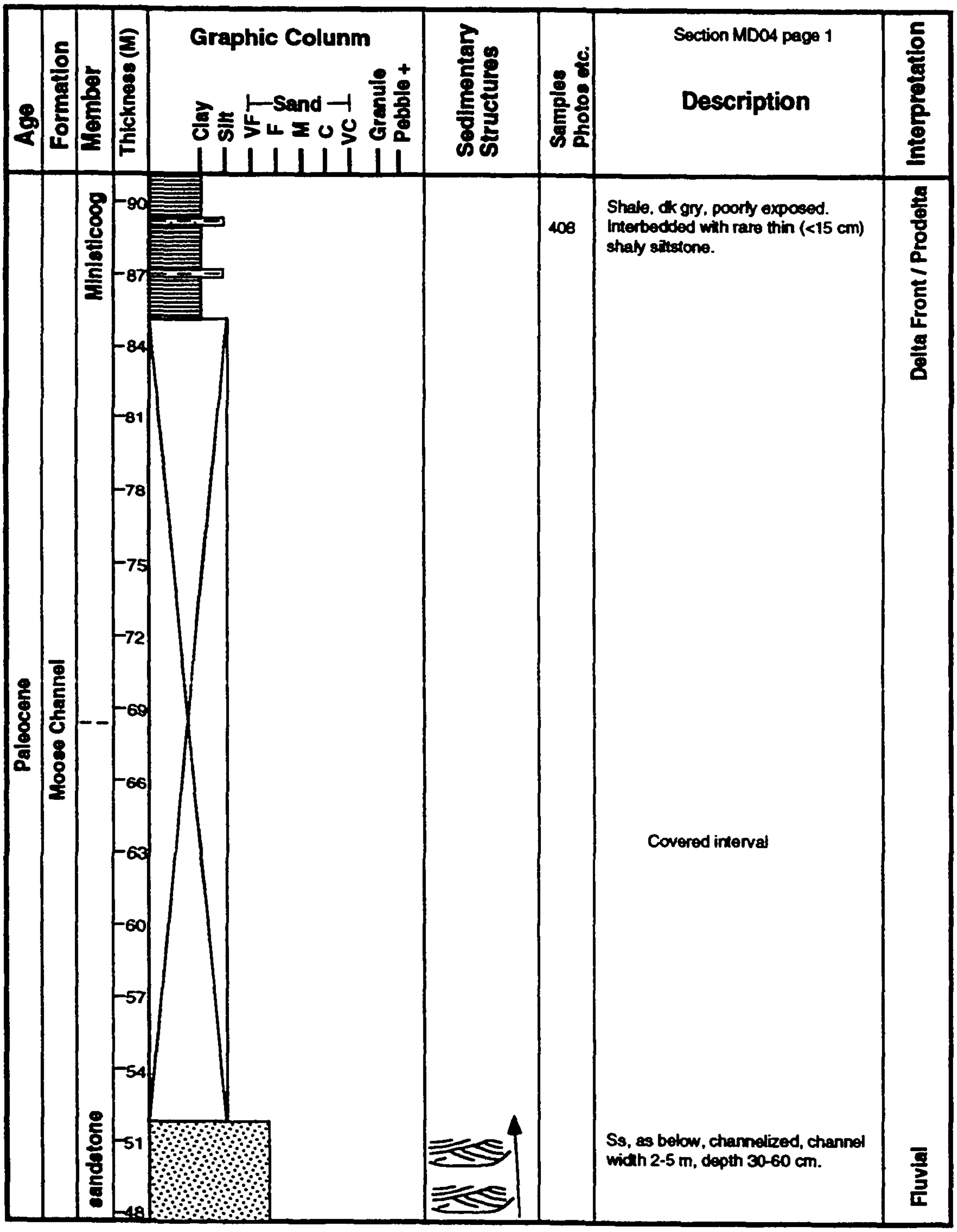
Mudstone, gry.

Ss, planar bedded to very low angle *trough cross bedded. Sharp basal* contact.

Interbedded ss and sltst. Ss beds are very thin to medium bedded, ripple laminated and hummocky cross stratified.

Siltst gry, *with minor vf gr ss. Siltstone* is medium to thickly bedded and contains starved ripples of vf gr ss (lenticular bedding). Sltst may be underlain by thin beds of ripple lam and small scale low angle trough cross bedded vf-f gr ss.
Some ripple lam beds contain small subhorizontal burrows (*Trichnichus?*).

Mudstone, gry, interbedded with occ thin (<5cm) beds of pebble conglomerate and ripple lam sltst. Pebbles are rounded black chert and are up to 5 cm in diameter. Matrix range from sltst to m gr ss. Cong is commonly overlain by thin beds of ripple laminated sltst.

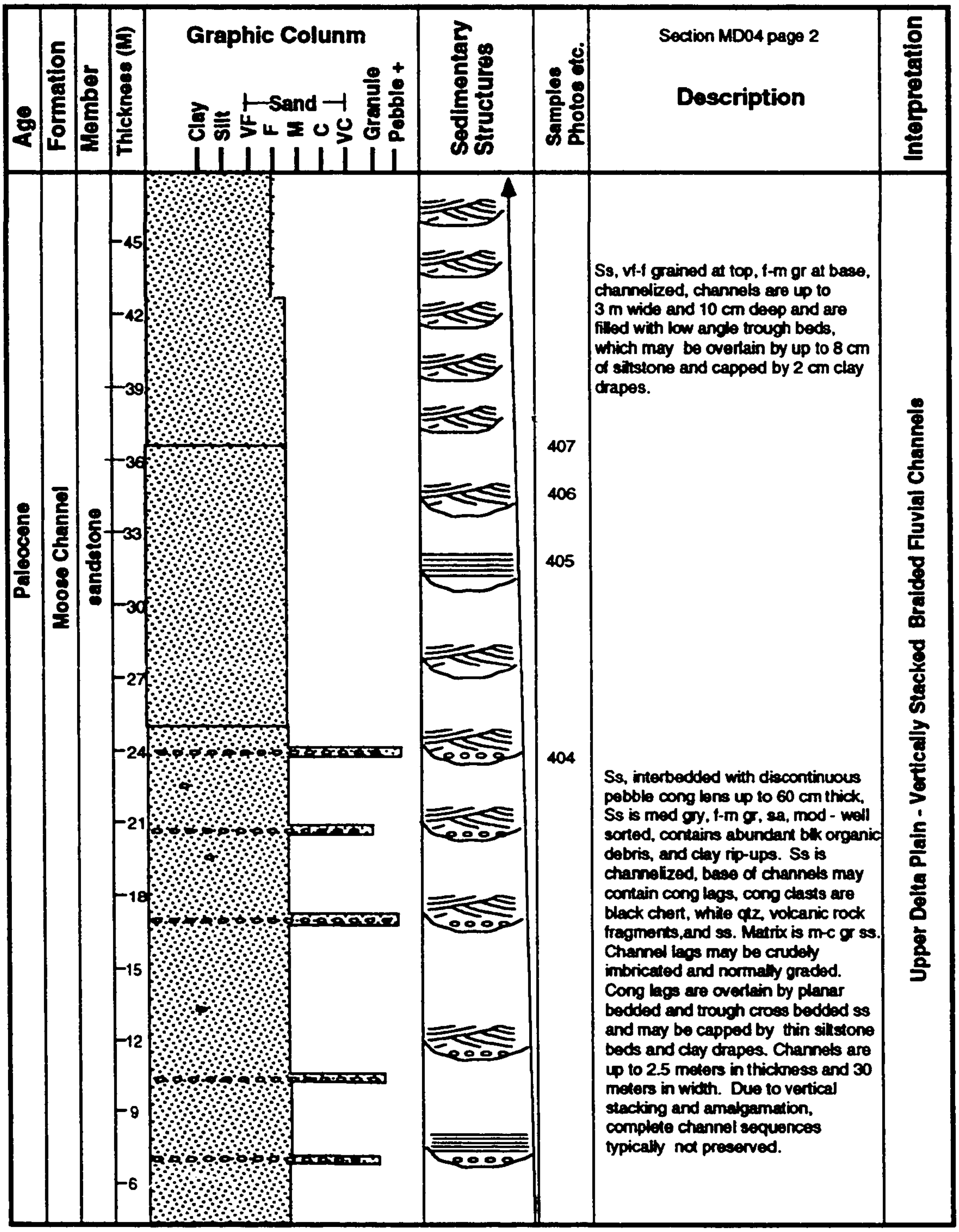


Section MD04 page 1

Shale, dk gry, poorly exposed. Interbedded with rare thin (<15 cm) shaly siltstone.

Covered interval

Ss, as below, channelized, channel width 2-5 m, depth 30-60 cm.

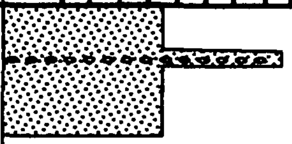
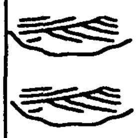


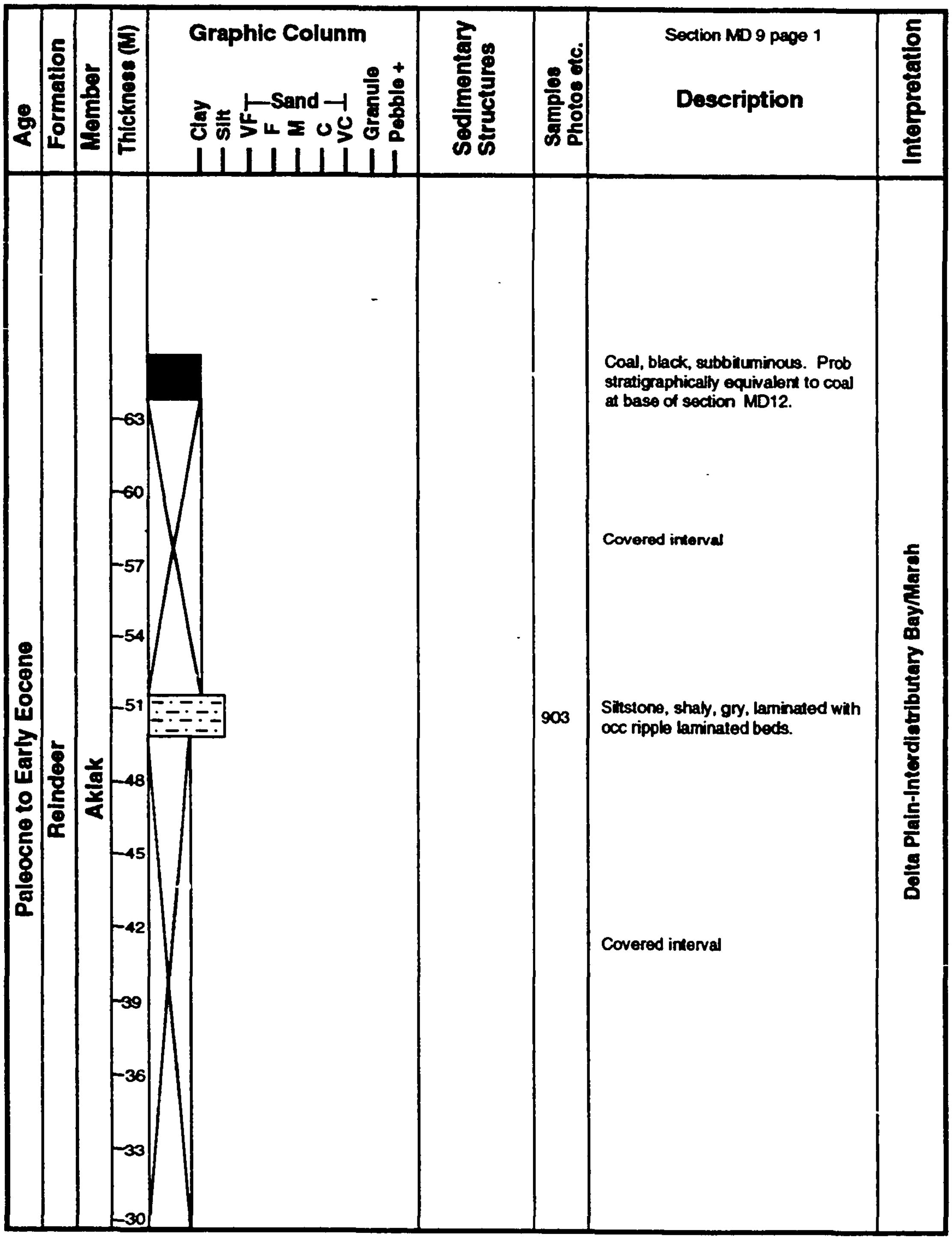
Section MD04 page 2

Description

Ss, vf-f grained at top, f-m gr at base, channelized, channels are up to 3 m wide and 10 cm deep and are filled with low angle trough beds, which may be overlain by up to 8 cm of siltstone and capped by 2 cm clay drapes.

Ss, interbedded with discontinuous pebble cong lens up to 60 cm thick, Ss is med gry, f-m gr, sa, mod - well sorted, contains abundant blk organic debris, and clay rip-ups. Ss is channelized, base of channels may contain cong lags, cong clasts are black chert, white qtz, volcanic rock fragments,and ss. Matrix is m-c gr ss. Channel lags may be crudely imbricated and normally graded. Cong lags are overlain by planar bedded and trough cross bedded ss and may be capped by thin siltstone beds and clay drapes. Channels are up to 2.5 meters in thickness and 30 meters in width. Due to vertical stacking and amalgamation, complete channel sequences typically not preserved.

Age	Formation	Member	Thickness (M)	Graphic Colunm Clay Silt VF F M C VC Sand Granule Pebble +	Sedimentary Structures	Samples Photos etc.	Section MD04 page 3 Description	Interpretation
Paleocene	Moose Channel	sandstone	3			403 402 401	As above	



Section MD 9 page 1

Description

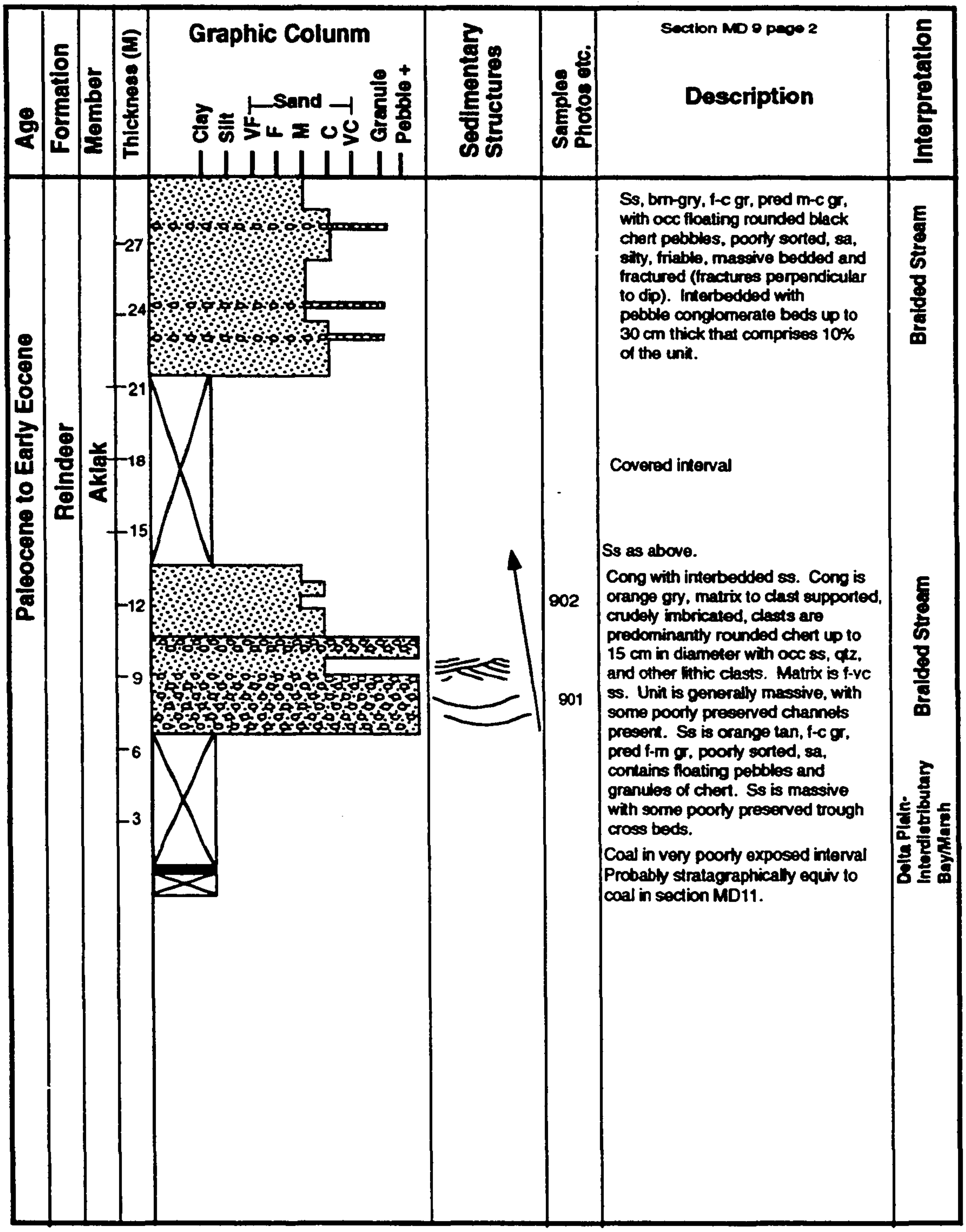
Coal, black, subbituminous. Prob stratigraphically equivalent to coal at base of section MD12.

Covered interval

Siltstone, shaly, gry, laminated with occ ripple laminated beds.

Covered interval

]



Section MD 9 page 2

Description

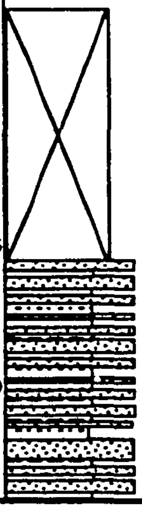
Ss, brn-gry, f-c gr, pred m-c gr, with occ floating rounded black chert pebbles, poorly sorted, sa, silty, friable, massive bedded and fractured (fractures perpendicular to dip). Interbedded with pebble conglomerate beds up to 30 cm thick that comprises 10% of the unit.

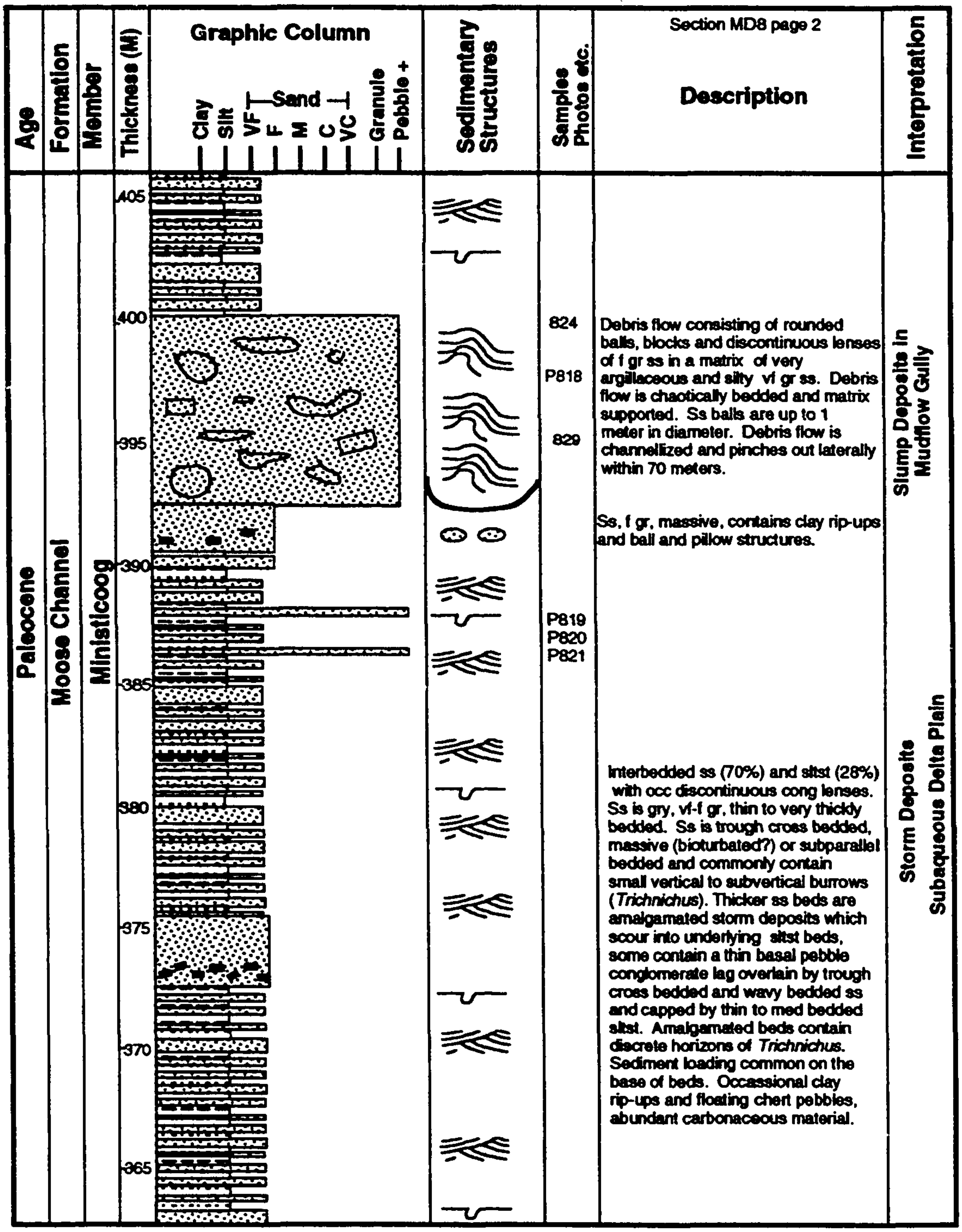
Covered interval

Ss as above.

Cong with interbedded ss. Cong is orange gry, matrix to clast supported, crudely imbricated, clasts are predominantly rounded chert up to 15 cm in diameter with occ ss, qtz, and other lithic clasts. Matrix is f-vc ss. Unit is generally massive, with some poorly preserved channels present. Ss is orange tan, f-c gr, pred f-m gr, poorly sorted, sa, contains floating pebbles and granules of chert. Ss is massive with some poorly preserved trough cross beds.

Coal in very poorly exposed interval Probably stratagraphically equiv to coal in section MD11.

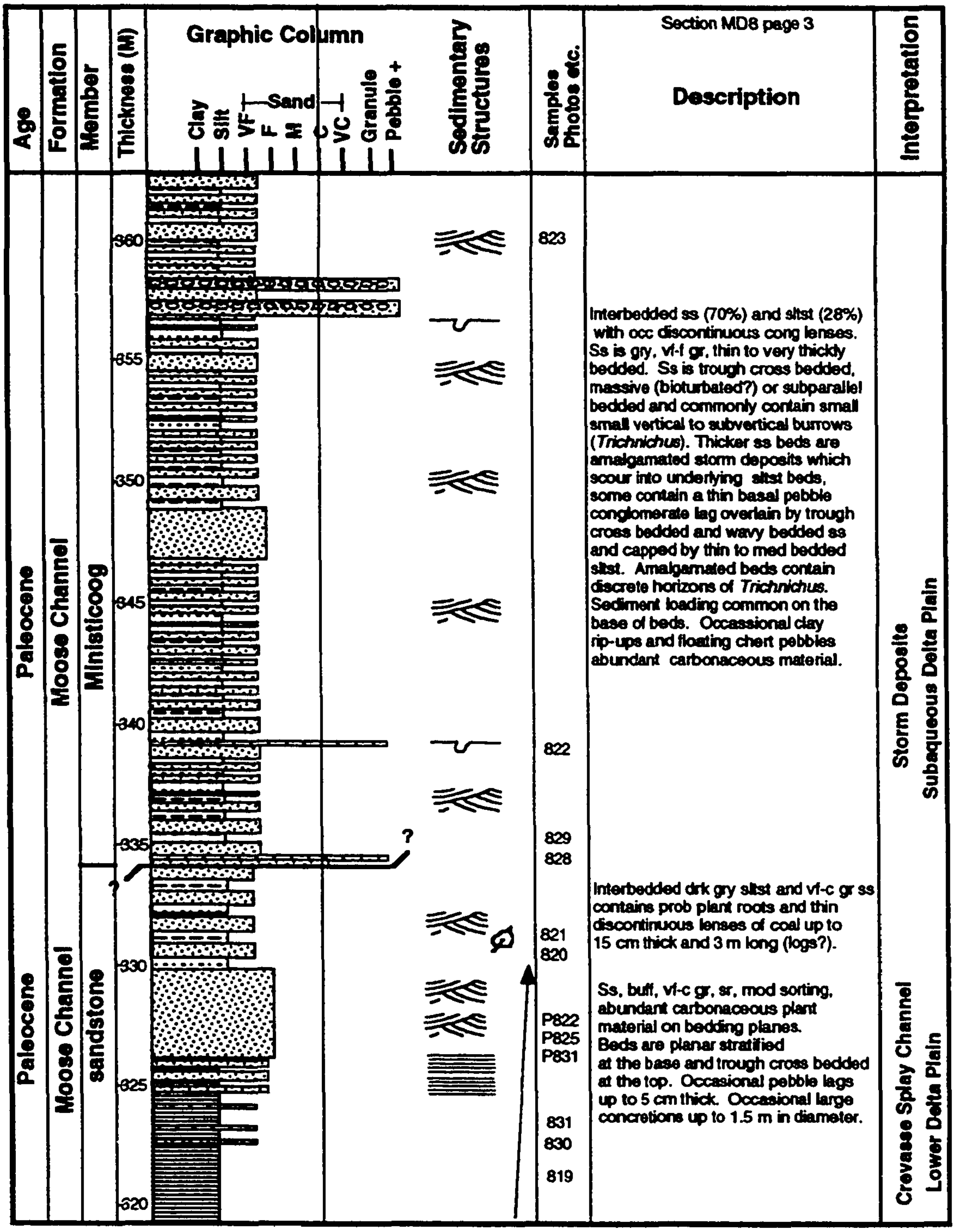
Age	Formation	Member	Thickness (M)	Graphic Column Clay, Silt, VF, F, M, C, VC (Sand), Granule, Pebble +	Sedimentary Structures	Samples Photos etc.	Section MD8 page 1 Description	Interpretation
Paleocene	Moose Channel	Ministicoog	415 410				Covered interval Poorly exposed interbedded ss (70%) and sltst (30%) with occ discontinuous cong lenses. Ss is gry, vf-f gr, thin to very thickly bedded. Ss contains low angle trough cross and subparallel laminations.	Shelf Storm Deposits Subaqueous Delta Plain



Debris flow consisting of rounded balls, blocks and discontinuous lenses of f gr ss in a matrix of very argillaceous and silty vf gr ss. Debris flow is chaotically bedded and matrix supported. Ss balls are up to 1 meter in diameter. Debris flow is channelized and pinches out laterally within 70 meters.

Ss, f gr, massive, contains clay rip-ups and ball and pillow structures.

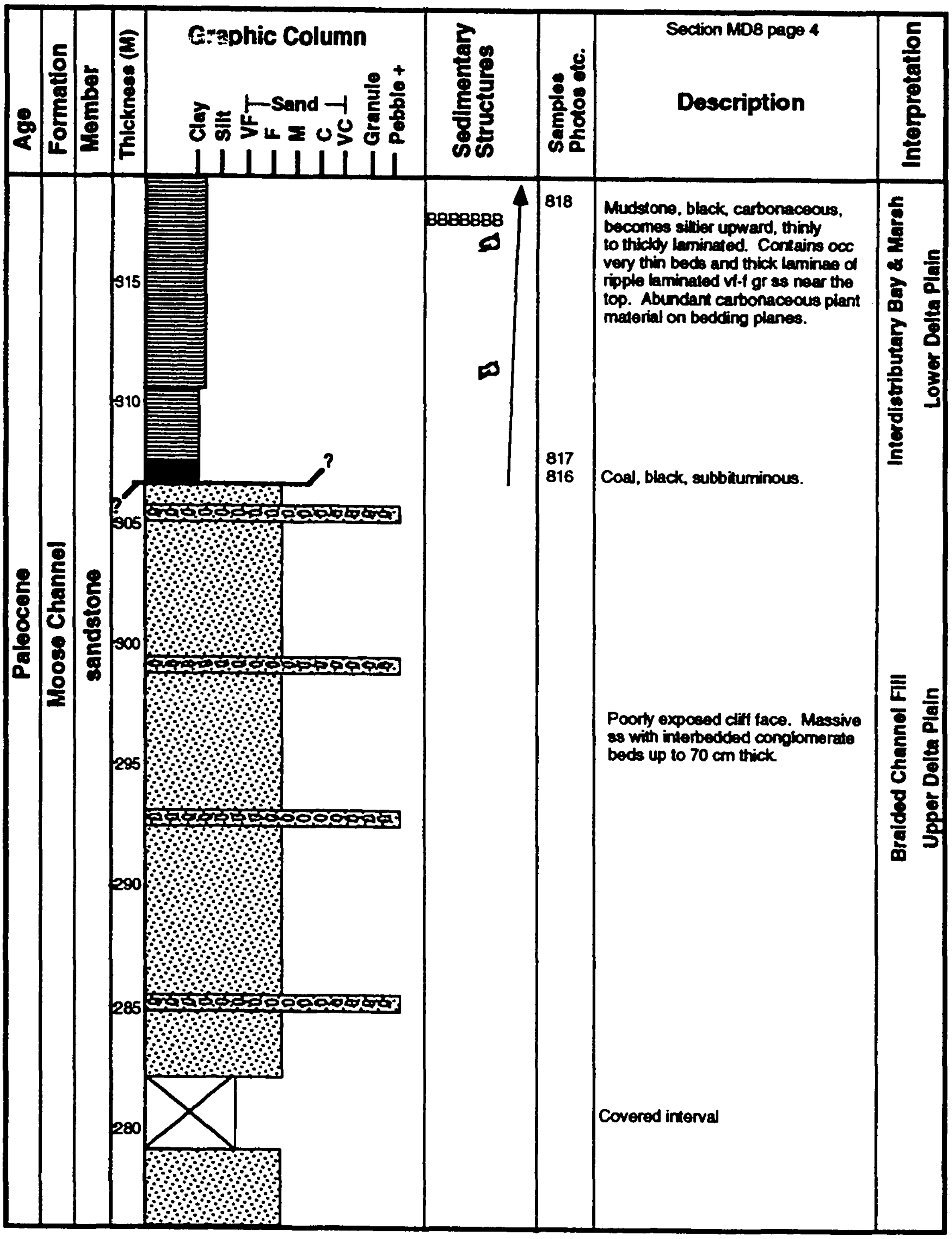
Interbedded ss (70%) and sltst (28%) with occ discontinuous cong lenses. Ss is gry, vf-f gr, thin to very thickly bedded. Ss is trough cross bedded, massive (bioturbated?) or subparallel bedded and commonly contain small vertical to subvertical burrows (*Trichnichus*). Thicker ss beds are amalgamated storm deposits which scour into underlying sltst beds, some contain a thin basal pebble conglomerate lag overlain by trough cross bedded and wavy bedded ss and capped by thin to med bedded sltst. Amalgamated beds contain discrete horizons of *Trichnichus*. Sediment loading common on the base of beds. Occassional clay rip-ups and floating chert pebbles, abundant carbonaceous material.



Interbedded ss (70%) and sltst (28%) with occ discontinuous cong lenses. Ss is gry, vf-f gr, thin to very thickly bedded. Ss is trough cross bedded, massive (bioturbated?) or subparallel bedded and commonly contain small small vertical to subvertical burrows (*Trichnichus*). Thicker ss beds are amalgamated storm deposits which scour into underlying sltst beds, some contain a thin basal pebble conglomerate lag overlain by trough cross bedded and wavy bedded ss and capped by thin to med bedded sltst. Amalgamated beds contain discrete horizons of *Trichnichus*. Sediment loading common on the base of beds. Occassional clay rip-ups and floating chert pebbles abundant carbonaceous material.

Interbedded drk gry sltst and vf-c gr ss contains prob plant roots and thin discontinuous lenses of coal up to 15 cm thick and 3 m long (logs?).

Ss, buff, vf-c gr, sr, mod sorting, abundant carbonaceous plant material on bedding planes. Beds are planar stratified at the base and trough cross bedded at the top. Occasional pebble lags up to 5 cm thick. Occasional large concretions up to 1.5 m in diameter.

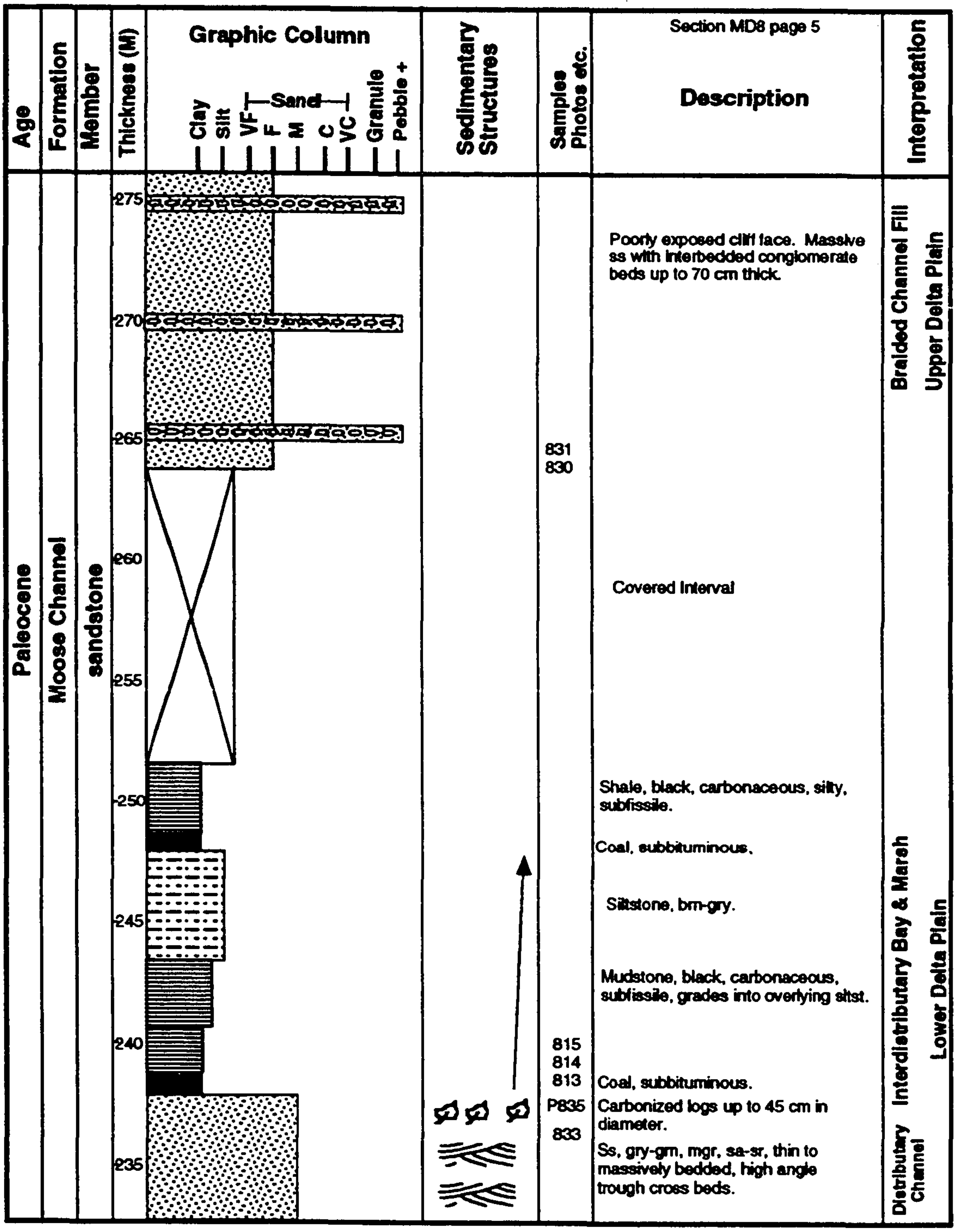


Mudstone, black, carbonaceous, becomes siltier upward, thinly to thickly laminated. Contains occ very thin beds and thick laminae of ripple laminated vf-f gr ss near the top. Abundant carbonaceous plant material on bedding planes.

Coal, black, subbituminous.

Poorly exposed cliff face. Massive ss with interbedded conglomerate beds up to 70 cm thick.

Covered interval



Section MD8 page 5

Description

Poorly exposed cliff face. Massive ss with interbedded conglomerate beds up to 70 cm thick.

Covered Interval

Shale, black, carbonaceous, silty, subfissile.

Coal, subbituminous.

Siltstone, brn-gry.

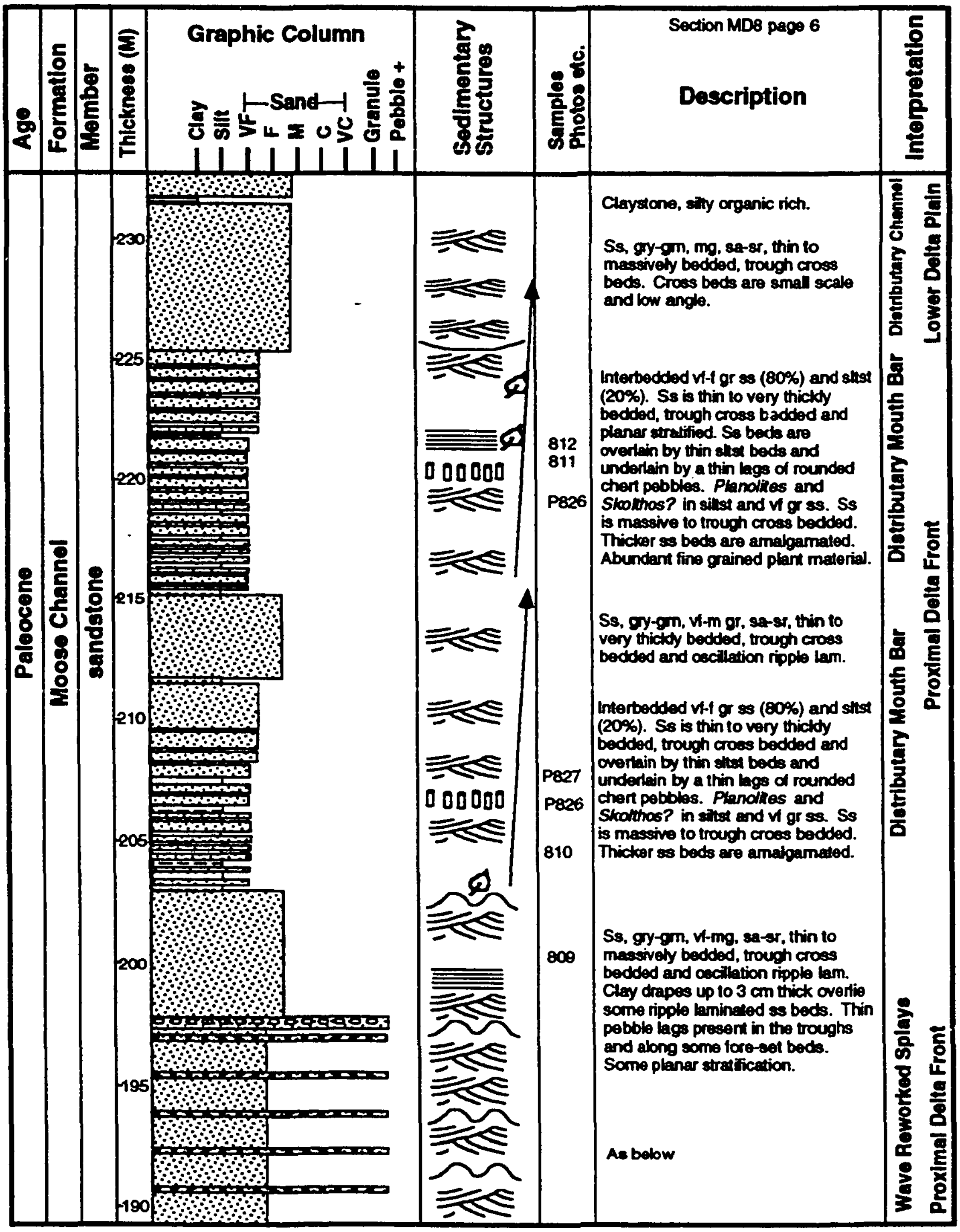
Mudstone, black, carbonaceous, subfissile, grades into overlying sltst.

Coal, subbituminous.

Carbonized logs up to 45 cm in diameter.

Ss, gry-grn, mgr, sa-sr, thin to massively bedded, high angle trough cross beds.

Section MD8 page 6



Claystone, silty organic rich.

Ss, gry-grn, mg, sa-sr, thin to massively bedded, trough cross beds. Cross beds are small scale and low angle.

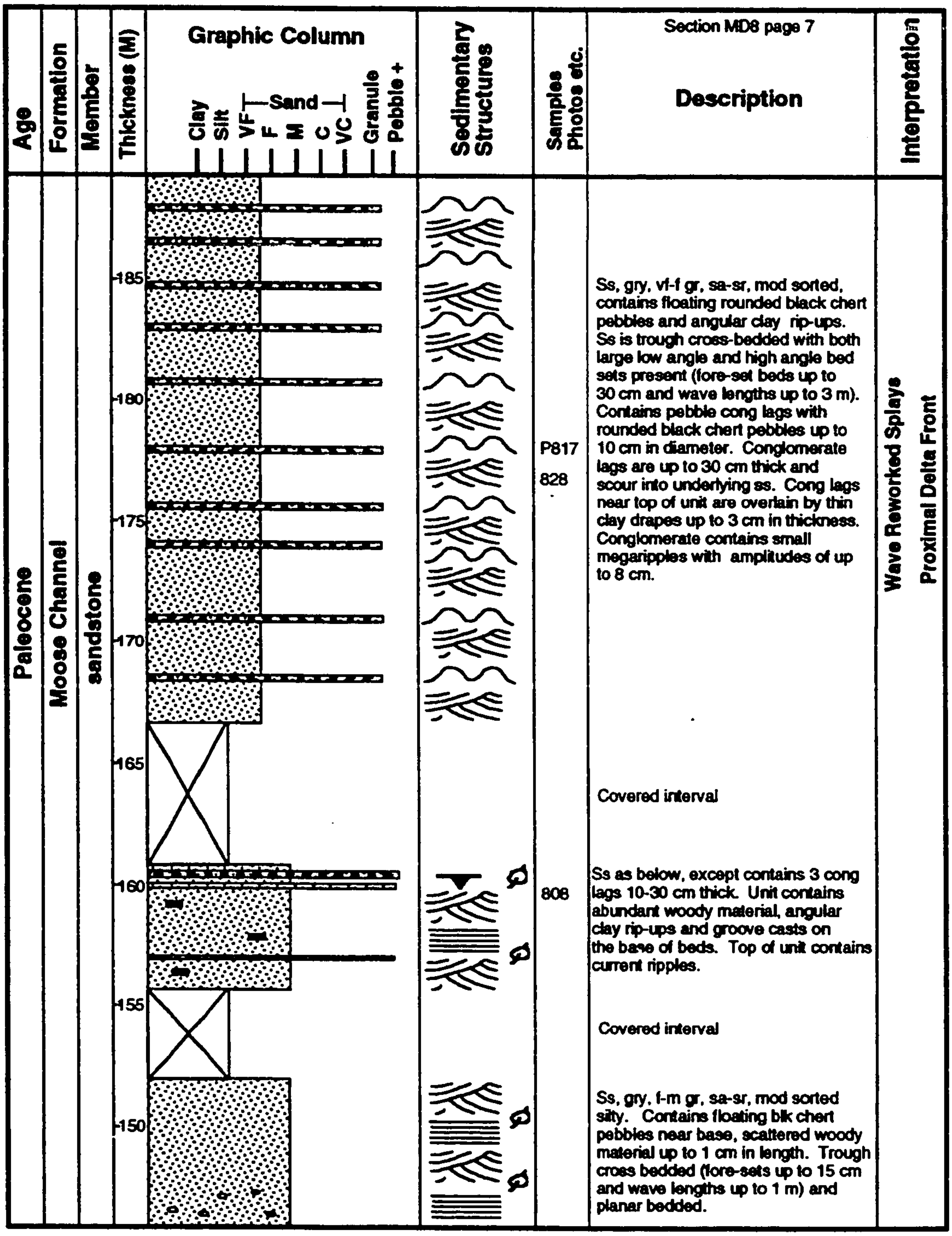
Interbedded vf-f gr ss (80%) and sltst (20%). Ss is thin to very thickly bedded, trough cross badded and planar stratified. Ss beds are overlain by thin sltst beds and underlain by a thin lags of rounded chert pebbles. *Planolites* and *Skolthos?* in siltst and vf gr ss. Ss is massive to trough cross bedded. Thicker ss beds are amalgamated. Abundant fine grained plant material.

Ss, gry-grn, vf-m gr, sa-sr, thin to very thickly bedded, trough cross bedded and oscillation ripple lam.

Interbedded vf-f gr ss (80%) and sltst (20%). Ss is thin to very thickly bedded, trough cross bedded and overlain by thin sltst beds and underlain by a thin lags of rounded chert pebbles. *Planolites* and *Skolthos?* in siltst and vf gr ss. Ss is massive to trough cross bedded. Thicker ss beds are amalgamated.

Ss, gry-grn, vf-mg, sa-sr, thin to massively bedded, trough cross bedded and oscillation ripple lam. Clay drapes up to 3 cm thick overlie some ripple laminated ss beds. Thin pebble lags present in the troughs and along some fore-set beds. Some planar stratification.

As below



Section MD8 page 7

Description

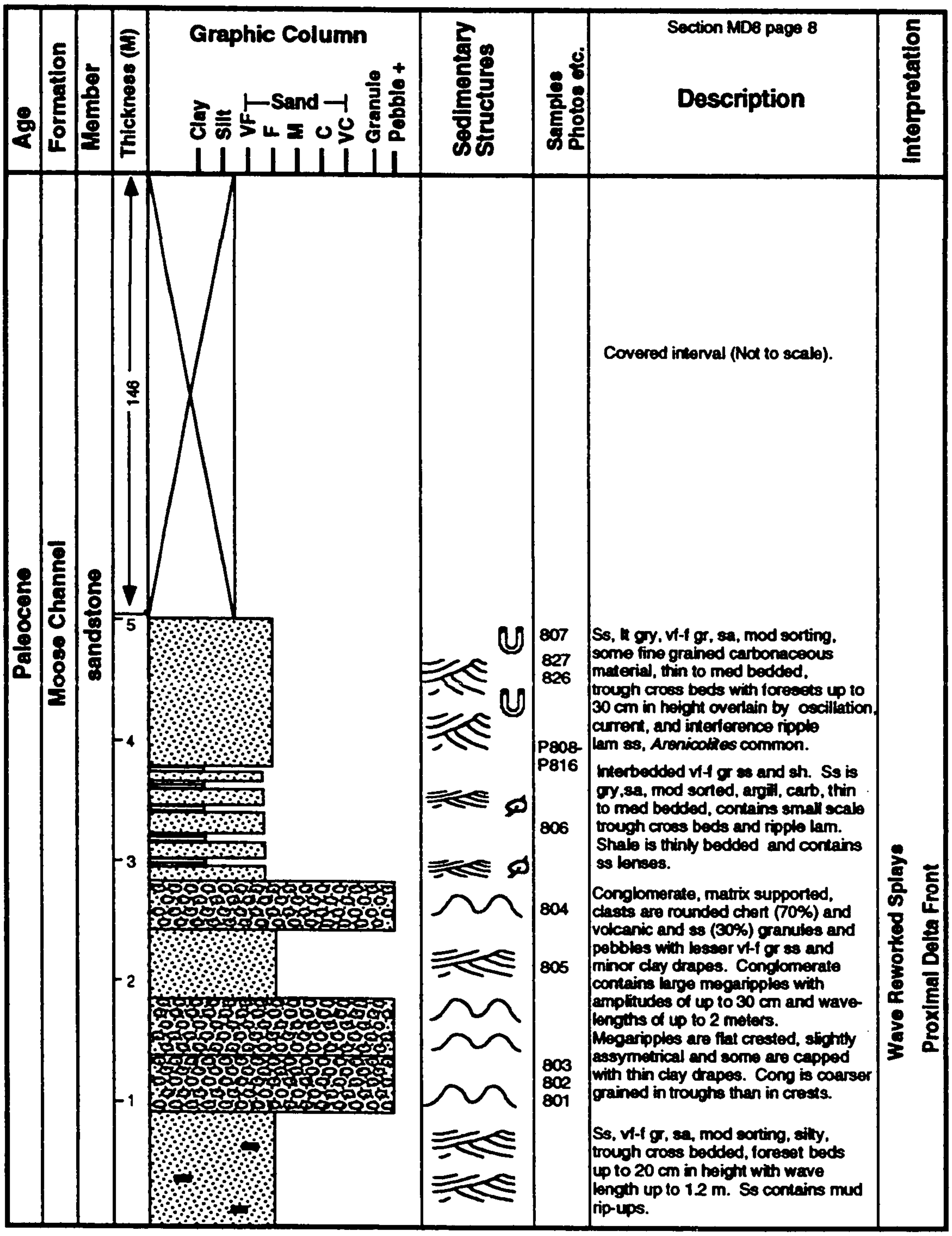
Ss, gry, vf-f gr, sa-sr, mod sorted, contains floating rounded black chert pebbles and angular clay rip-ups. Ss is trough cross-bedded with both large low angle and high angle bed sets present (fore-set beds up to 30 cm and wave lengths up to 3 m). Contains pebble cong lags with rounded black chert pebbles up to 10 cm in diameter. Conglomerate lags are up to 30 cm thick and scour into underlying ss. Cong lags near top of unit are overlain by thin clay drapes up to 3 cm in thickness. Conglomerate contains small megaripples with amplitudes of up to 8 cm.

Covered interval

Ss as below, except contains 3 cong lags 10-30 cm thick. Unit contains abundant woody material, angular clay rip-ups and groove casts on the base of beds. Top of unit contains current ripples.

Covered interval

Ss, gry, f-m gr, sa-sr, mod sorted silty. Contains floating blk chert pebbles near base, scattered woody material up to 1 cm in length. Trough cross bedded (fore-sets up to 15 cm and wave lengths up to 1 m) and planar bedded.



Section MD8 page 8

Description

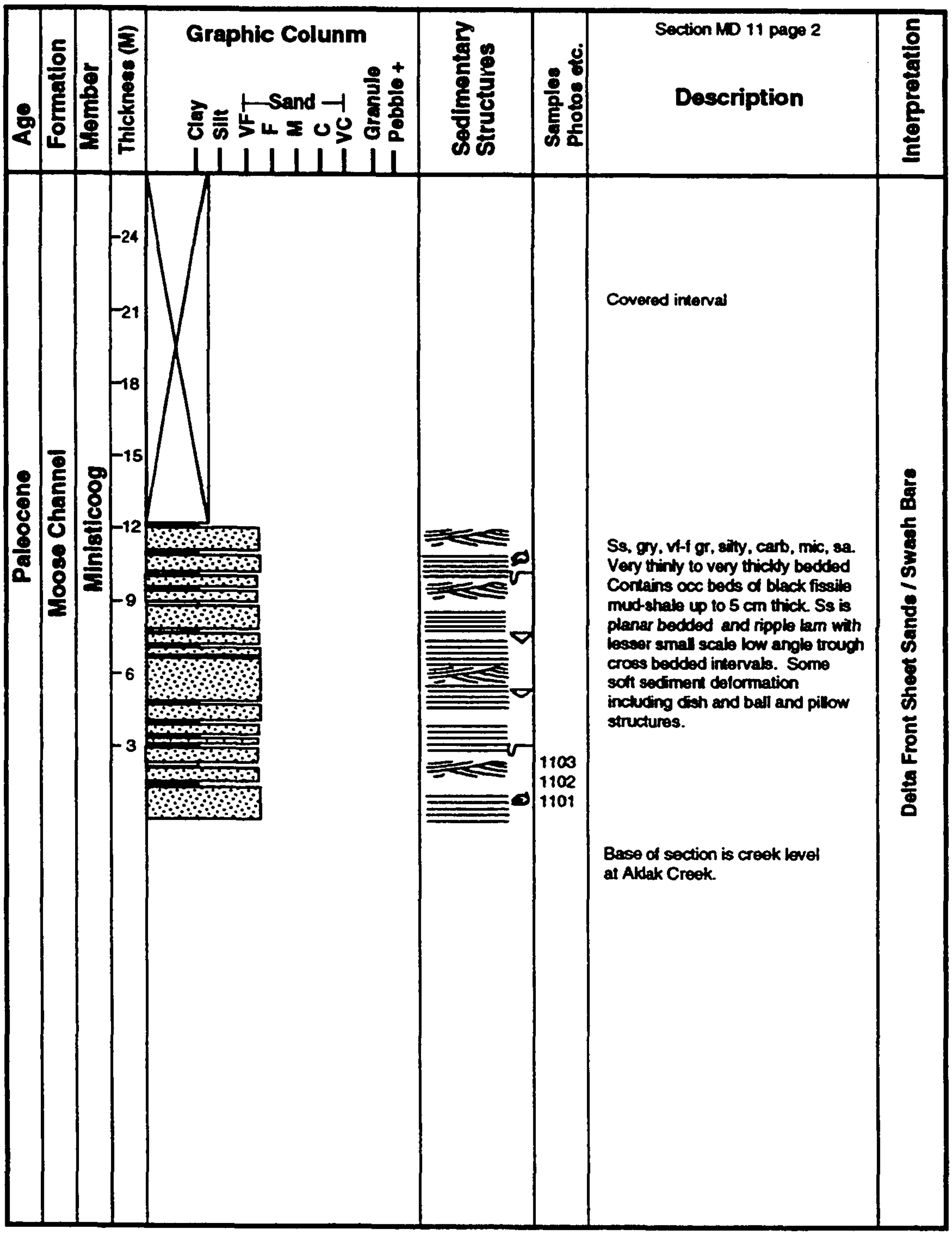
Covered interval (Not to scale).

Ss, lt gry, vf-f gr, sa, mod sorting, some fine grained carbonaceous material, thin to med bedded, trough cross beds with foresets up to 30 cm in height overlain by oscillation, current, and interference ripple lam ss, *Arenicolites* common.

Interbedded vf-f gr ss and sh. Ss is gry,sa, mod sorted, argill, carb, thin to med bedded, contains small scale trough cross beds and ripple lam. Shale is thinly bedded and contains ss lenses.

Conglomerate, matrix supported, clasts are rounded chert (70%) and volcanic and ss (30%) granules and pebbles with lesser vf-f gr ss and minor clay drapes. Conglomerate contains large megaripples with amplitudes of up to 30 cm and wavelengths of up to 2 meters. Megaripples are flat crested, slightly assymetrical and some are capped with thin clay drapes. Cong is coarser grained in troughs than in crests.

Ss, vf-f gr, sa, mod sorting, silty, trough cross bedded, foreset beds up to 20 cm in height with wave length up to 1.2 m. Ss contains mud rip-ups.



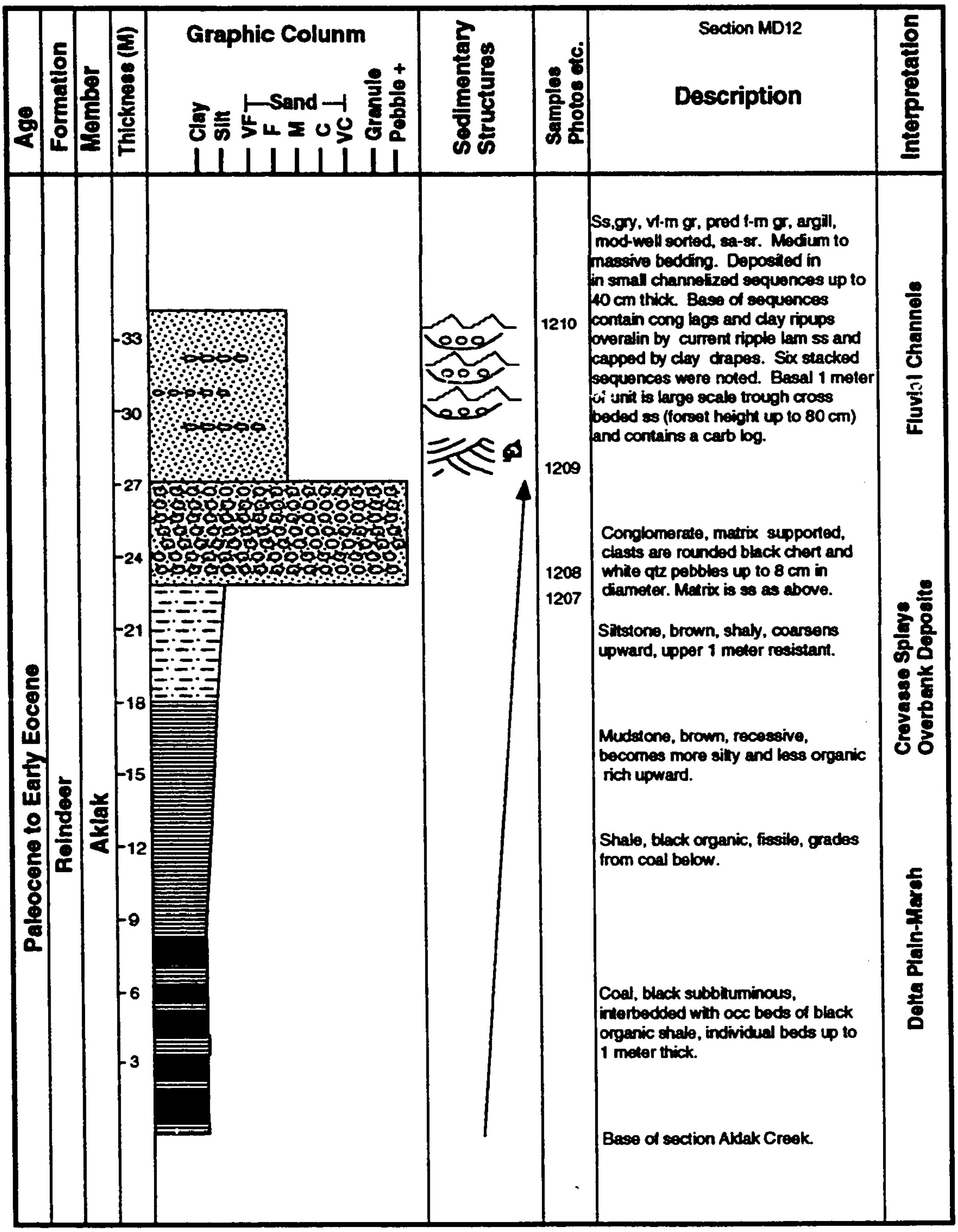
Section MD 11 page 2

Description

Covered interval

Ss, gry, vf-f gr, silty, carb, mic, sa. Very thinly to very thickly bedded Contains occ beds of black fissile mud-shale up to 5 cm thick. Ss is *planar bedded and ripple lam* with lesser small scale low angle trough cross bedded intervals. Some soft sediment deformation including dish and ball and pillow structures.

Base of section is creek level at Aklak Creek.



Ss,gry, vf-m gr, pred f-m gr, argill, mod-well sorted, sa-sr. Medium to massive bedding. Deposited in in small channelized sequences up to 40 cm thick. Base of sequences contain cong lags and clay ripups overalin by current ripple lam ss and capped by clay drapes. Six stacked sequences were noted. Basal 1 meter of unit is large scale trough cross beded ss (forset height up to 80 cm) and contains a carb log.

Conglomerate, matrix supported, clasts are rounded black chert and white qtz pebbles up to 8 cm in diameter. Matrix is ss as above.

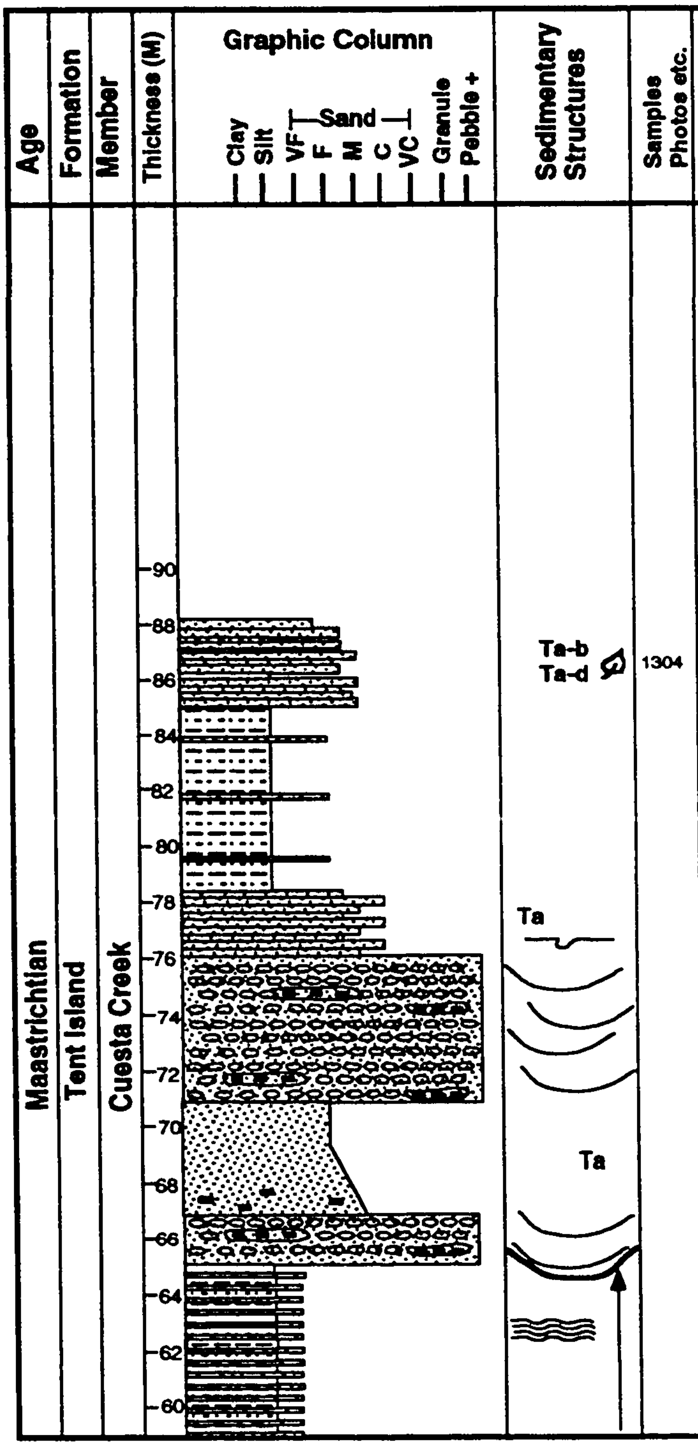
Siltstone, brown, shaly, coarsens upward, upper 1 meter resistant.

Mudstone, brown, recessive, becomes more silty and less organic rich upward.

Shale, black organic, fissile, grades from coal below.

Coal, black subbituminous, interbedded with occ beds of black organic shale, individual beds up to 1 meter thick.

Base of section Aklak Creek.



Section MD13 page 1

Description

Ss, f-m gr with minor sltst, thin to med bedded, Bouma Ta-b with lesser Ta-d. Turbidites range from 7-30 cm thick (average 20 cm). Some have mud rip-ups and normal grading in Ta beds. Abundant fine grained organic material.

Sltst with lesser mudstone and minor f gr ss lenses. Ss lenses are less than 15 cm thick. Unit is very poorly exposed.

Ss, f-c gr with rare (<5%) lenses of matrix supported conglomerate. Ss beds average 30 cm in thickness and are commonly graded (c-f gr or m-f gr) Base of beds display soft sediment deformation and contain clay rip-ups. Bouma Ta.

Conglomerate (85%) interbedded with discontinuous lenses of ss up to 45 cm thick. (15%). Cong is matrix supported (matrix is m gr ss),ungraded with rare normal graded beds, and deposited in small channels up to 4.5 m deep. Clasts are rounded chert, metamorphic and ss pebbles and granules with occasional clasts up to 45 cm in diameter.

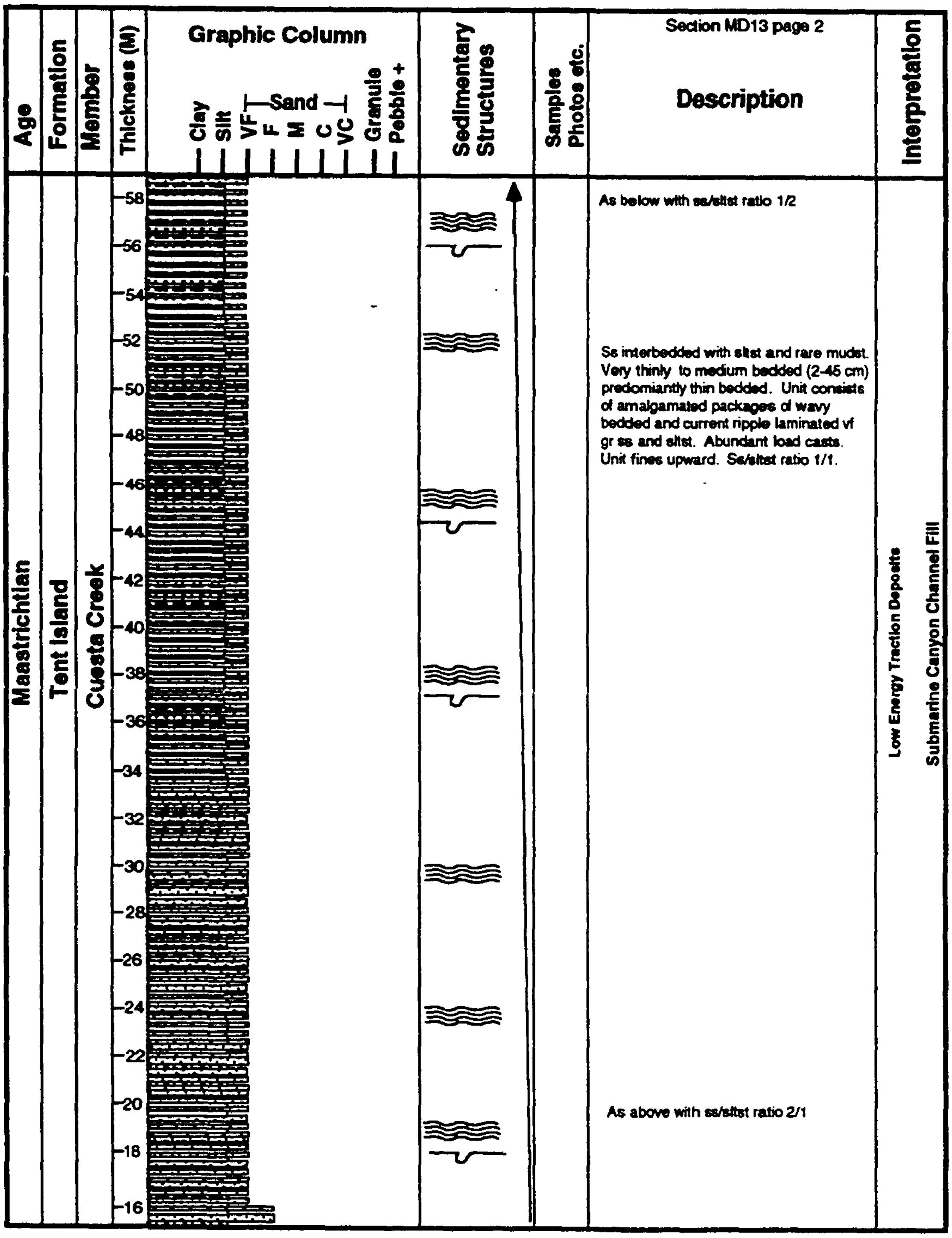
Ss, f-m gr, massively bedded, contains angular mud rip-ups, fines upward from upper medium to f gr in lower 2m.

Conglomerate interbedded with discontinuous lenses of m-c gr ss 8- 30 cm thick. Cong is matrix supported (matrix is f-c gr ss), inversely graded, and deposited in small channels . Clasts are rounded, chert, metamorphic rock fragments and vein qtz granule to pebble sized and angular to rounded clay rip-ups up to 8 cm in length.

Interpretation

Traction Carpet Deposits, High Density Turbidites and Debris Flows

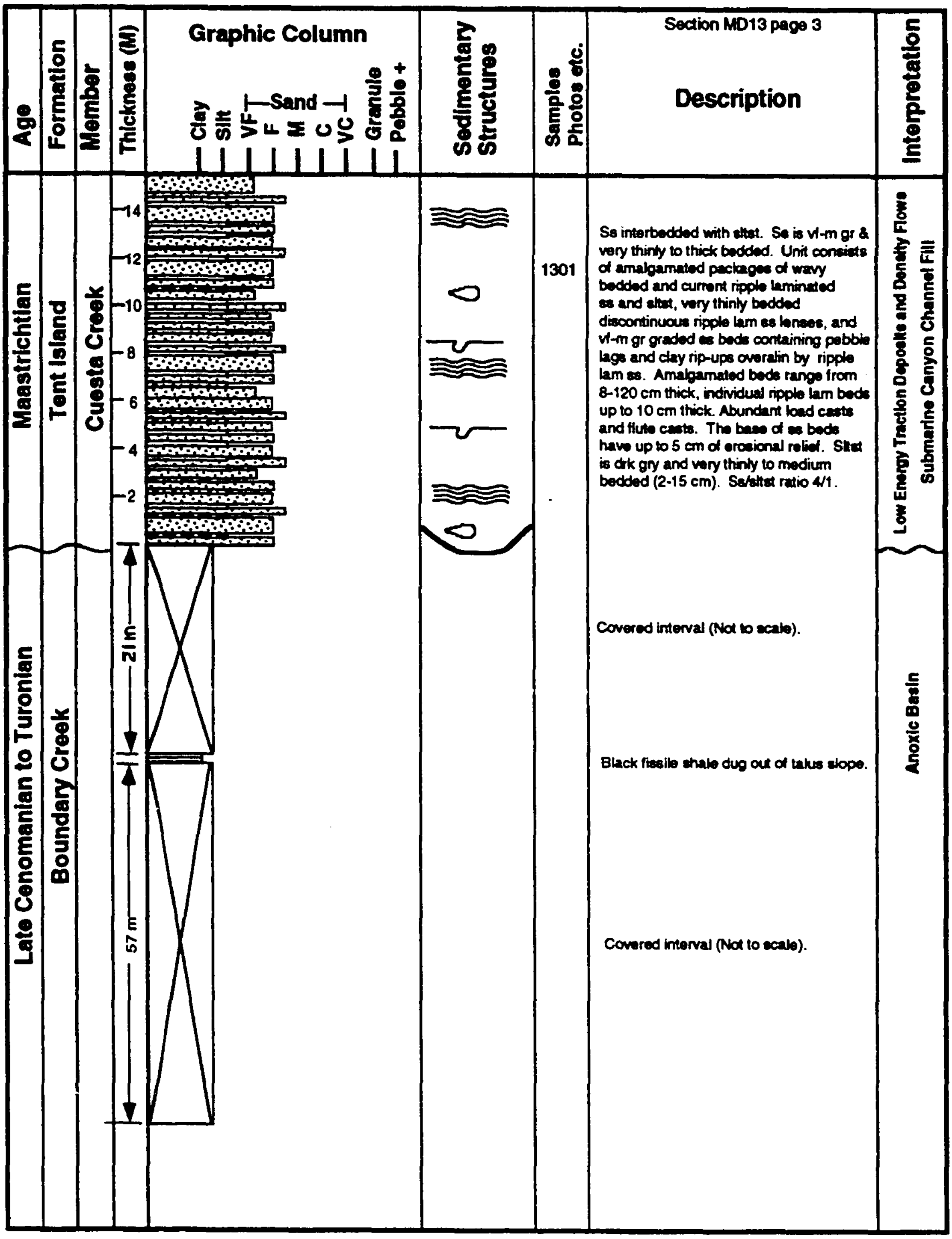
Submarine Canyon Channel Fill



As below with ss/sltst ratio 1/2

Ss interbedded with sltst and rare mudst. Very thinly to medium bedded (2-45 cm) predomiantly thin bedded. Unit consists of amalgamated packages of wavy bedded and current ripple laminated vf gr ss and sltst. Abundant load casts. Unit fines upward. Ss/sltst ratio 1/1.

As above with ss/sltst ratio 2/1



Section MD13 page 3

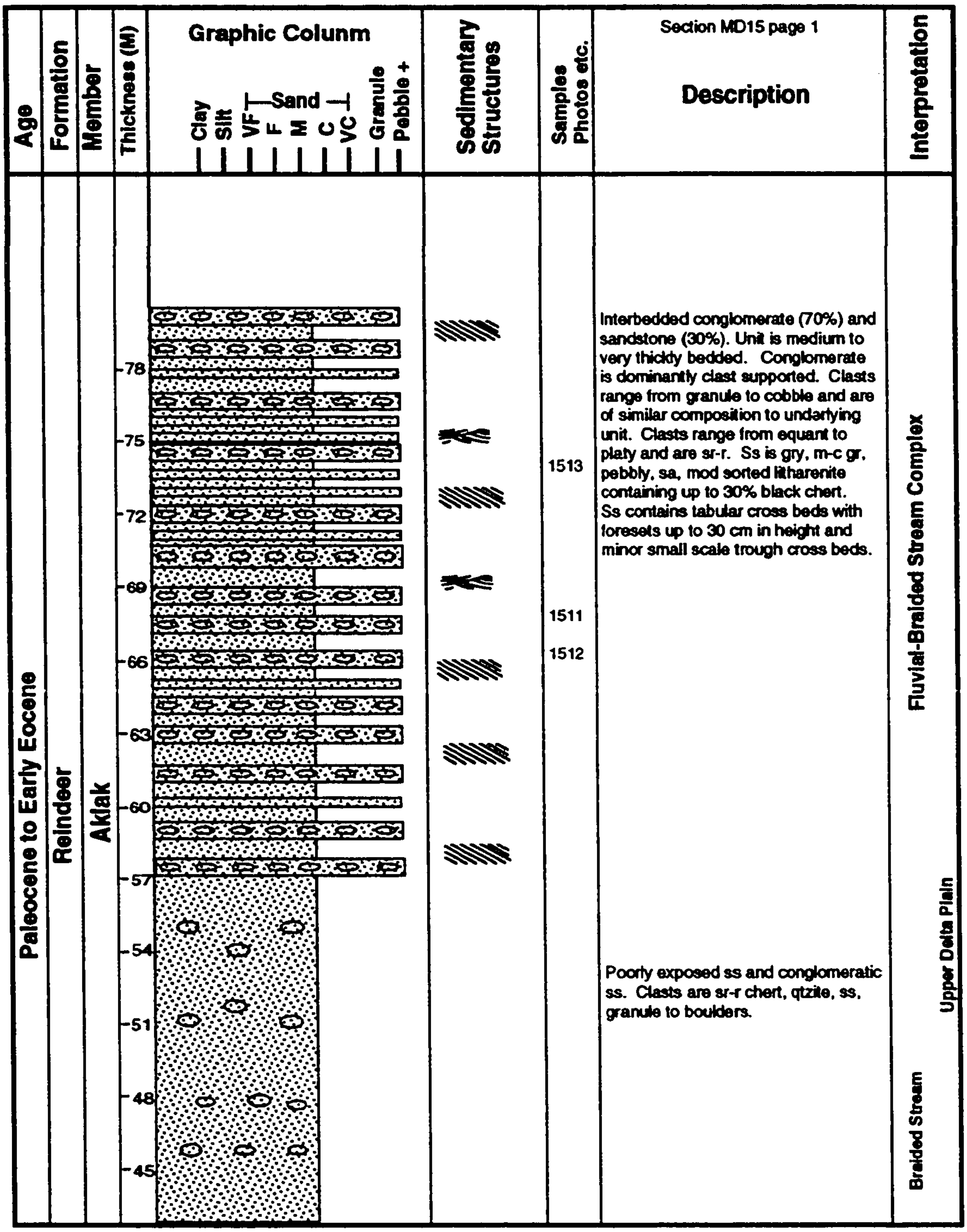
Description

Ss interbedded with sltst. Ss is vf-m gr & very thinly to thick bedded. Unit consists of amalgamated packages of wavy bedded and current ripple laminated ss and sltst, very thinly bedded discontinuous ripple lam ss lenses, and vf-m gr graded ss beds containing pebble lags and clay rip-ups overalin by ripple lam ss. Amalgamated beds range from 8-120 cm thick, individual ripple lam beds up to 10 cm thick. Abundant load casts and flute casts. The base of ss beds have up to 5 cm of erosional relief. Sltst is drk gry and very thinly to medium bedded (2-15 cm). Ss/sltst ratio 4/1.

Covered interval (Not to scale).

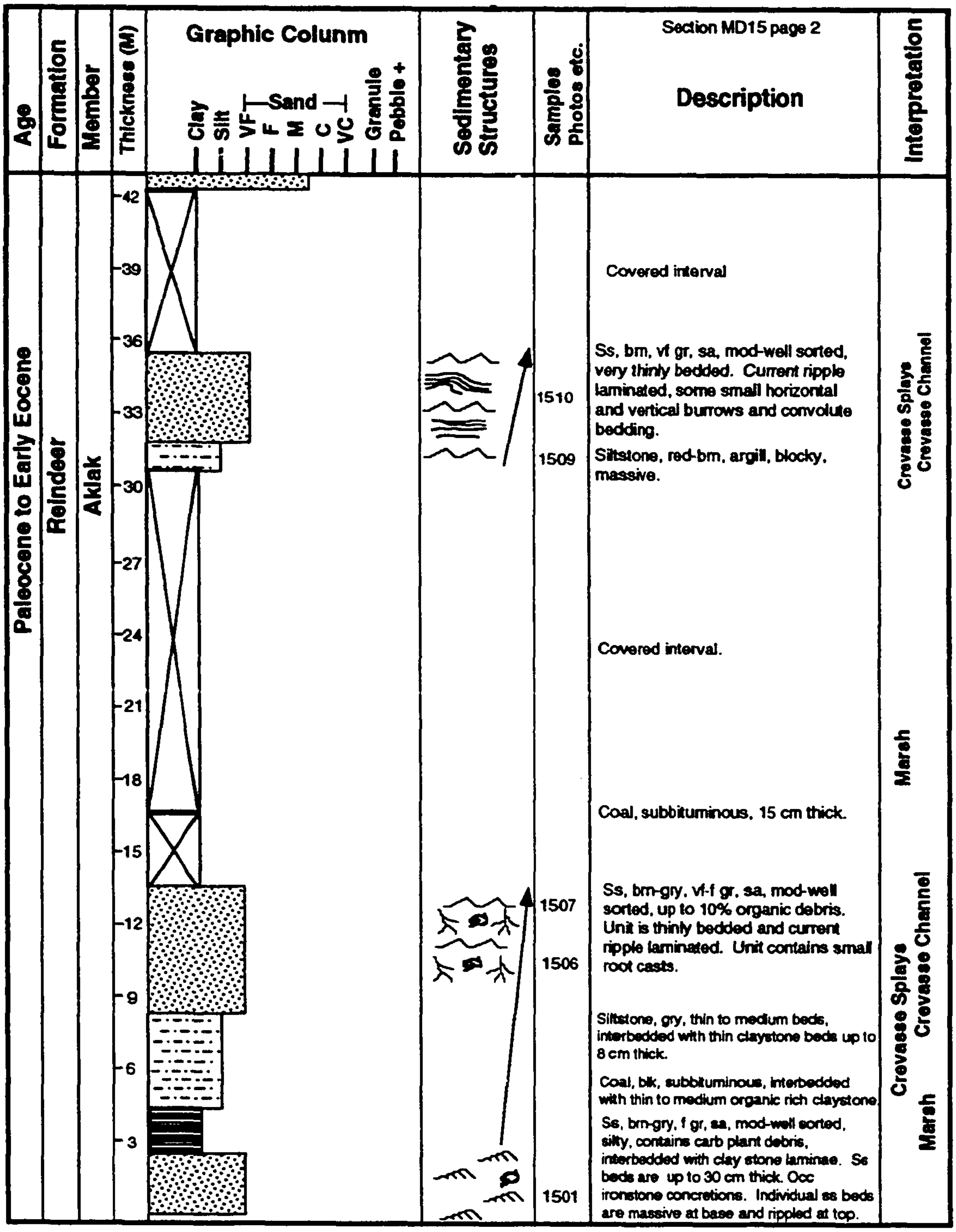
Black fissile shale dug out of talus slope.

Covered interval (Not to scale).



Interbedded conglomerate (70%) and sandstone (30%). Unit is medium to very thickly bedded. Conglomerate is dominantly clast supported. Clasts range from granule to cobble and are of similar composition to underlying unit. Clasts range from equant to platy and are sr-r. Ss is gry, m-c gr, pebbly, sa, mod sorted litharenite containing up to 30% black chert. Ss contains tabular cross beds with foresets up to 30 cm in height and minor small scale trough cross beds.

Poorly exposed ss and conglomeratic ss. Clasts are sr-r chert, qtzite, ss, granule to boulders.



Section MD15 page 2

Description

Covered interval

Ss, brn, vf gr, sa, mod-well sorted, very thinly bedded. Current ripple laminated, some small horizontal and vertical burrows and convolute bedding.

Siltstone, red-brn, argil, blocky, massive.

Covered interval.

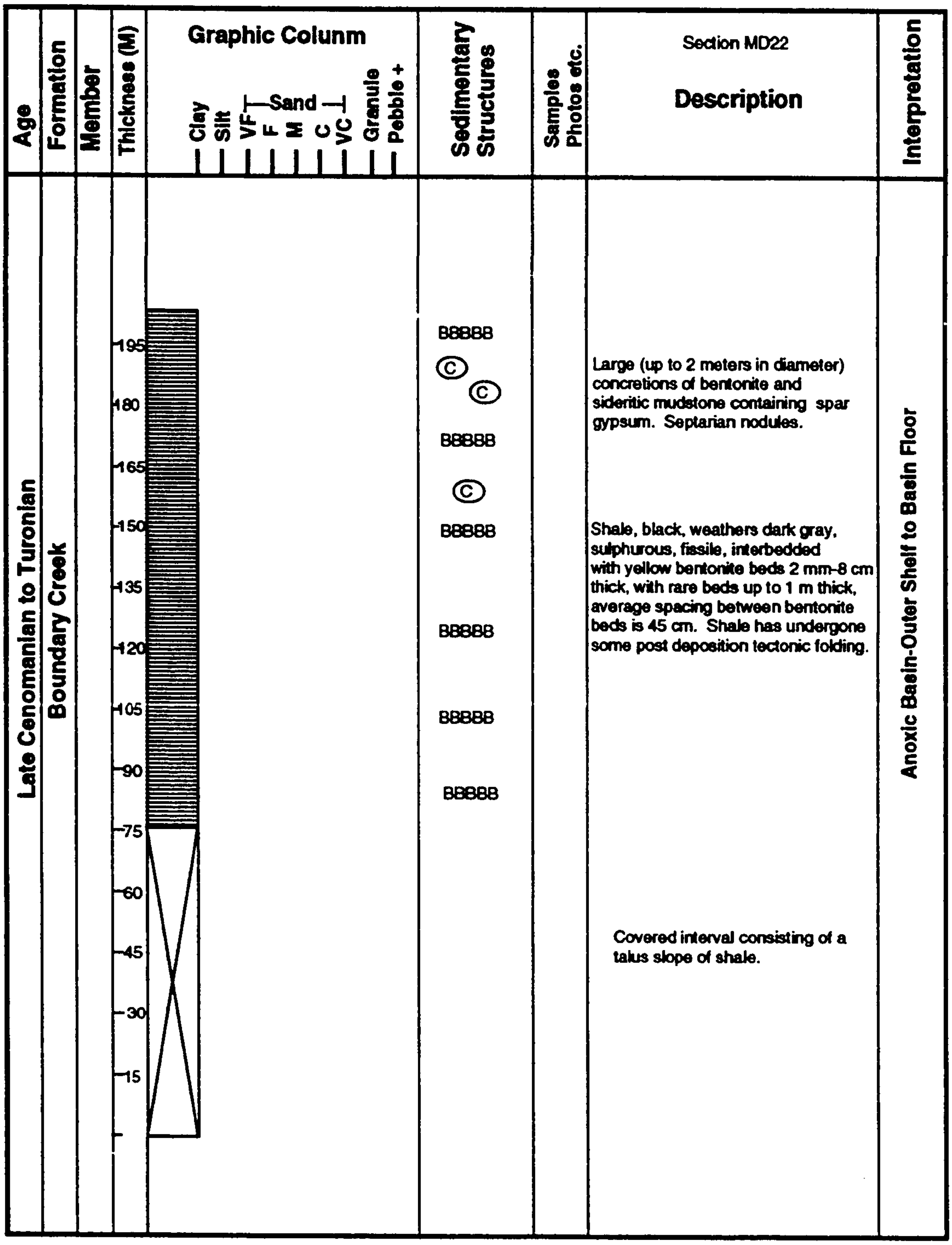
Coal, subbituminous, 15 cm thick.

Ss, brn-gry, vf-f gr, sa, mod-well sorted, up to 10% organic debris. Unit is thinly bedded and current ripple laminated. Unit contains small root casts.

Siltstone, gry, thin to medium beds, interbedded with thin claystone beds up to 8 cm thick.

Coal, blk, subbituminous, interbedded with thin to medium organic rich claystone.

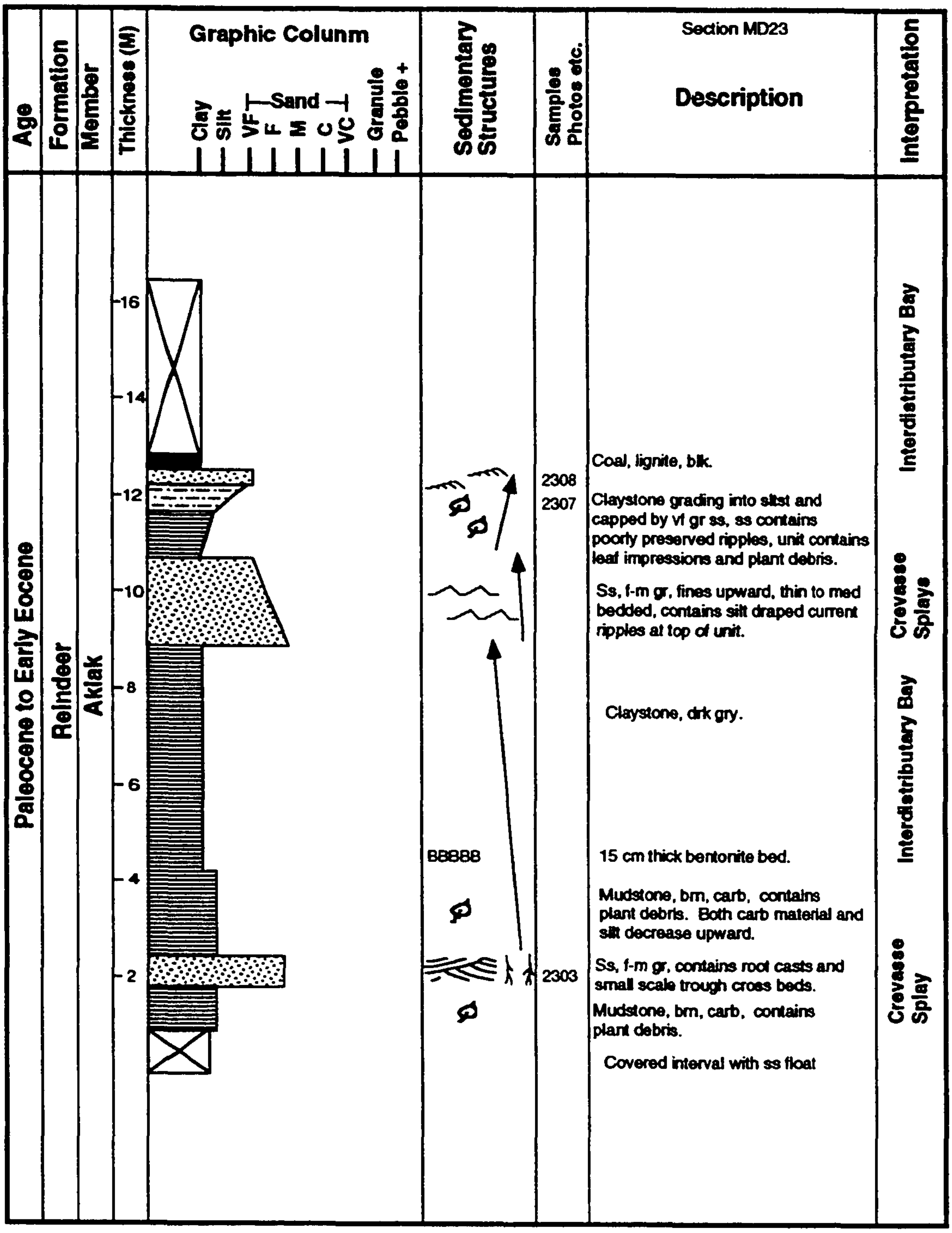
Ss, brn-gry, f gr, sa, mod-well sorted, silty, contains carb plant debris, interbedded with clay stone laminae. Ss beds are up to 30 cm thick. Occ ironstone concretions. Individual ss beds are massive at base and rippled at top.



Large (up to 2 meters in diameter) concretions of bentonite and sideritic mudstone containing spar gypsum. Septarian nodules.

Shale, black, weathers dark gray, sulphurous, fissile, interbedded with yellow bentonite beds 2 mm-8 cm thick, with rare beds up to 1 m thick, average spacing between bentonite beds is 45 cm. Shale has undergone some post deposition tectonic folding.

Covered interval consisting of a talus slope of shale.



Coal, lignite, blk.

Claystone grading into sltst and capped by vf gr ss, ss contains poorly preserved ripples, unit contains leaf impressions and plant debris.

Ss, f-m gr, fines upward, thin to med bedded, contains silt draped current ripples at top of unit.

Claystone, drk gry.

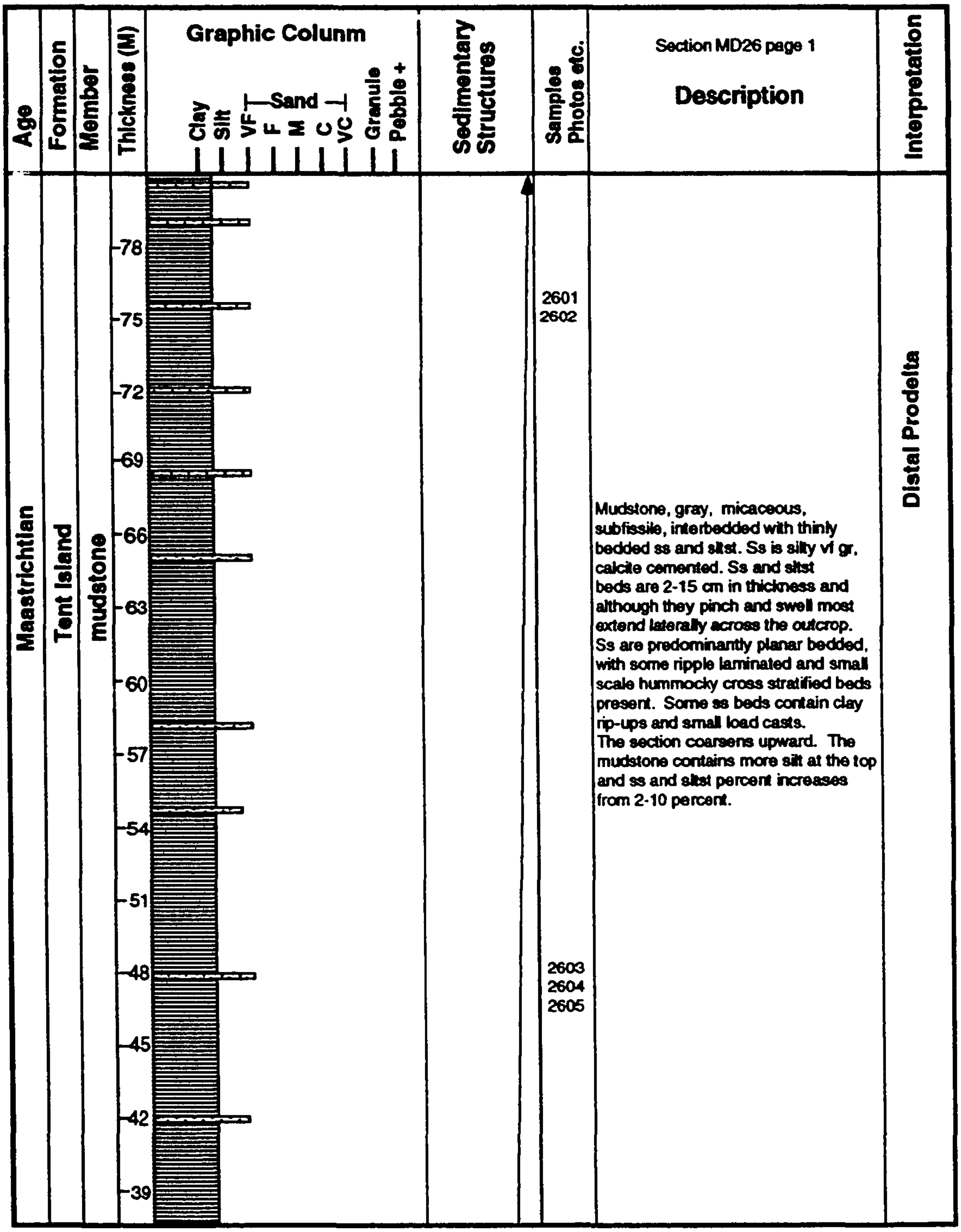
15 cm thick bentonite bed.

Mudstone, brn, carb, contains plant debris. Both carb material and silt decrease upward.

Ss, f-m gr, contains root casts and small scale trough cross beds.

Mudstone, brn, carb, contains plant debris.

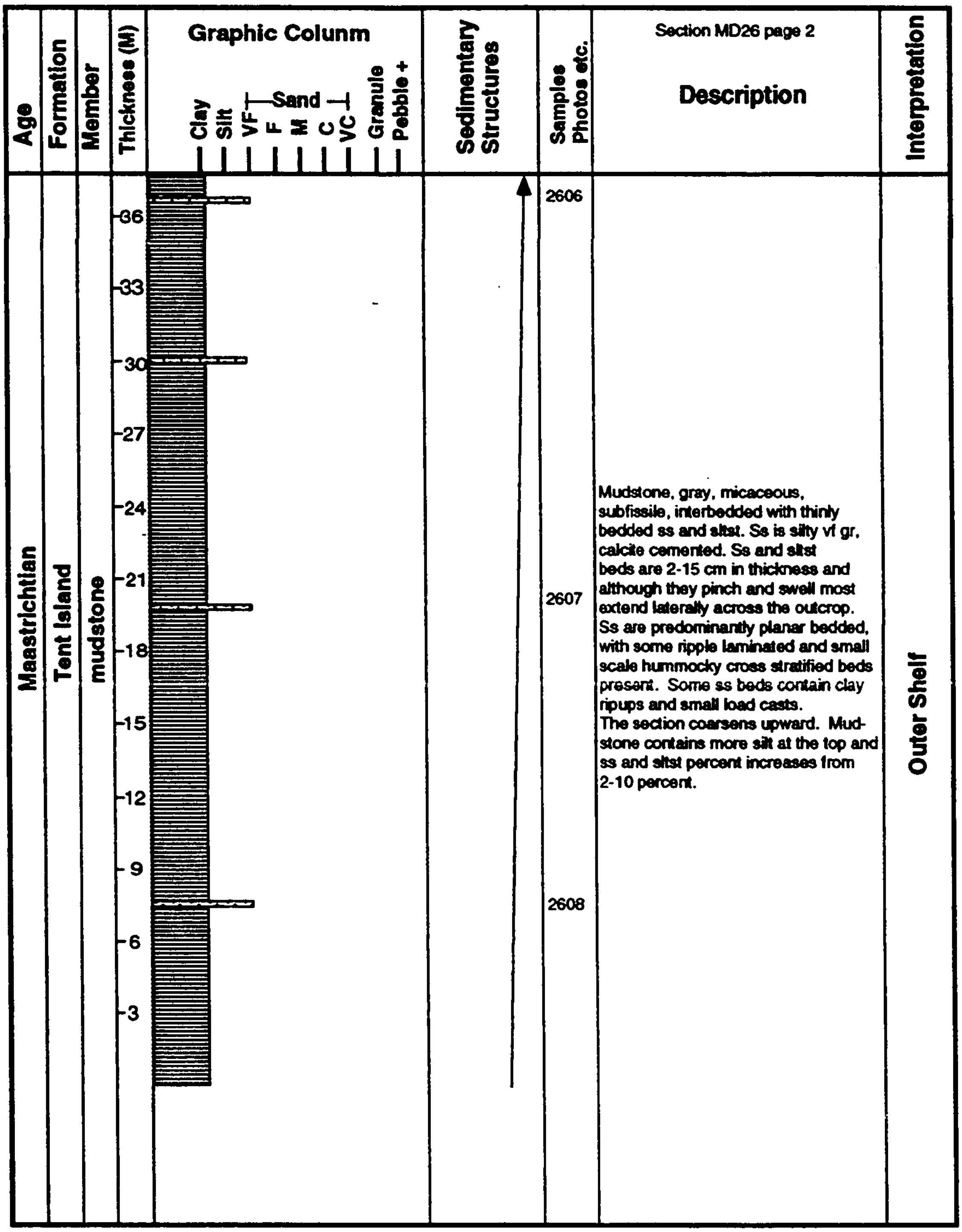
Covered interval with ss float



Section MD26 page 1

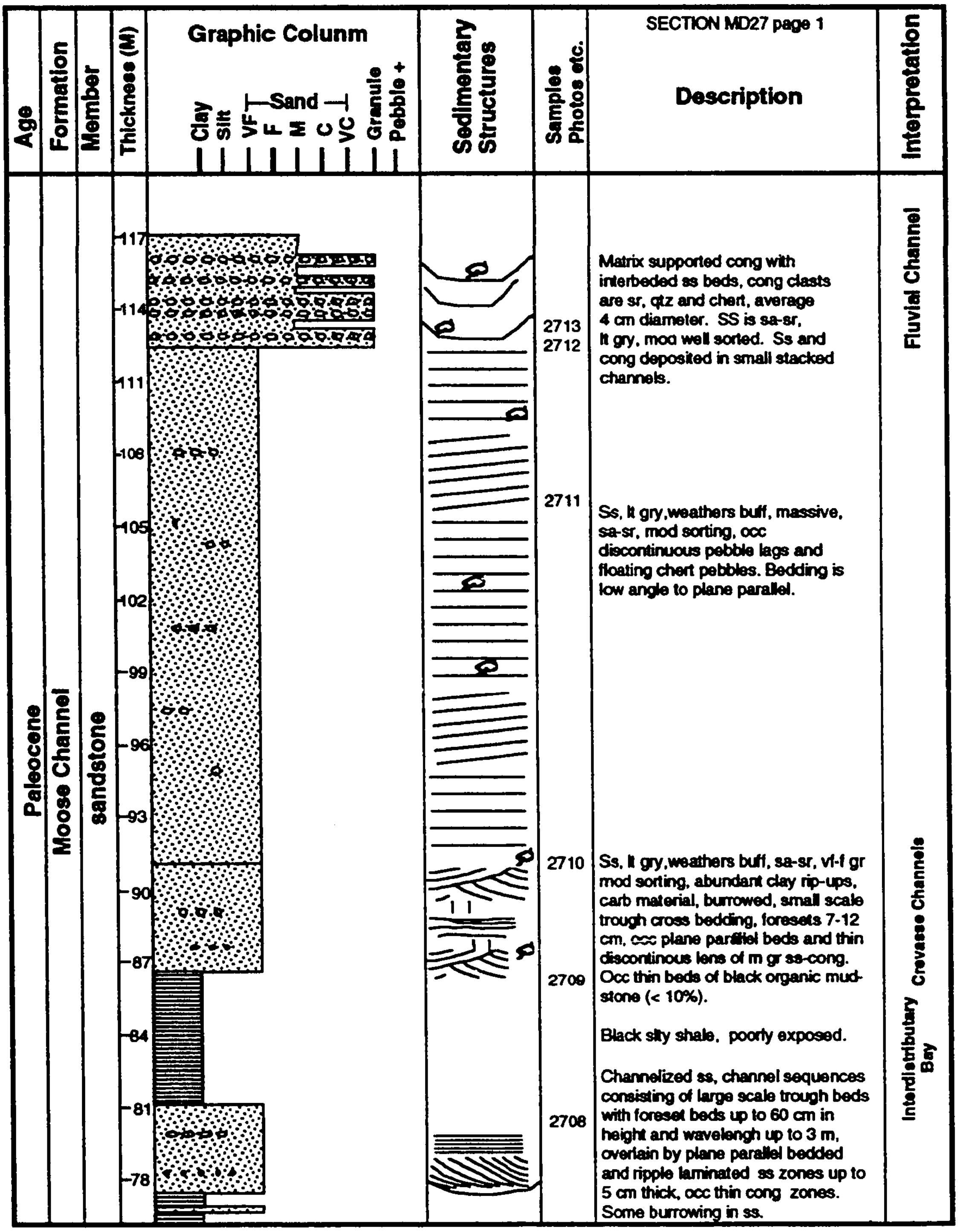
Description

Mudstone, gray, micaceous, subfissile, interbedded with thinly bedded ss and sltst. Ss is silty vf gr, calcite cemented. Ss and sltst beds are 2-15 cm in thickness and although they pinch and swell most extend laterally across the outcrop. Ss are predominantly planar bedded, with some ripple laminated and small scale hummocky cross stratified beds present. Some ss beds contain clay rip-ups and small load casts.
The section coarsens upward. The mudstone contains more silt at the top and ss and sltst percent increases from 2-10 percent.



Mudstone, gray, micaceous, subfissile, interbedded with thinly bedded ss and sltst. Ss is silty vf gr, calcite cemented. Ss and sltst beds are 2-15 cm in thickness and although they pinch and swell most extend laterally across the outcrop. Ss are predominantly planar bedded, with some ripple laminated and small scale hummocky cross stratified beds present. Some ss beds contain clay ripups and small load casts.

The section coarsens upward. Mudstone contains more silt at the top and ss and sltst percent increases from 2-10 percent.



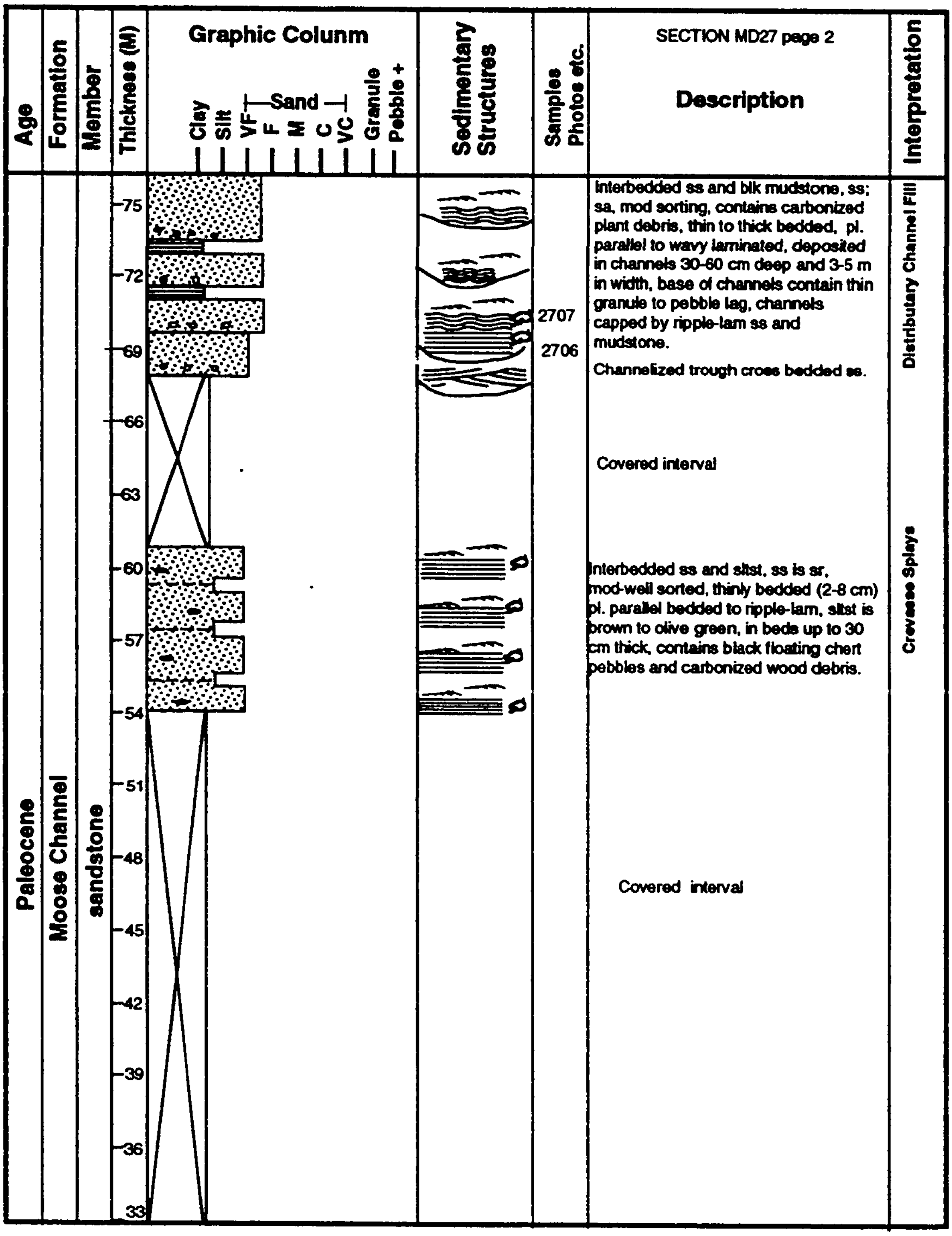
Matrix supported cong with interbeded ss beds, cong clasts are sr, qtz and chert, average 4 cm diameter. SS is sa-sr, lt gry, mod well sorted. Ss and cong deposited in small stacked channels.

Ss, lt gry,weathers buff, massive, sa-sr, mod sorting, occ discontinuous pebble lags and floating chert pebbles. Bedding is low angle to plane parallel.

Ss, lt gry,weathers buff, sa-sr, vf-f gr mod sorting, abundant clay rip-ups, carb material, burrowed, small scale trough cross bedding, foresets 7-12 cm, occ plane parallel beds and thin discontinous lens of m gr ss-cong. Occ thin beds of black organic mudstone (< 10%).

Black sity shale, poorly exposed.

Channelized ss, channel sequences consisting of large scale trough beds with foreset beds up to 60 cm in height and wavelengh up to 3 m, overlain by plane parallel bedded and ripple laminated ss zones up to 5 cm thick, occ thin cong zones. Some burrowing in ss.



SECTION MD27 page 2

Description

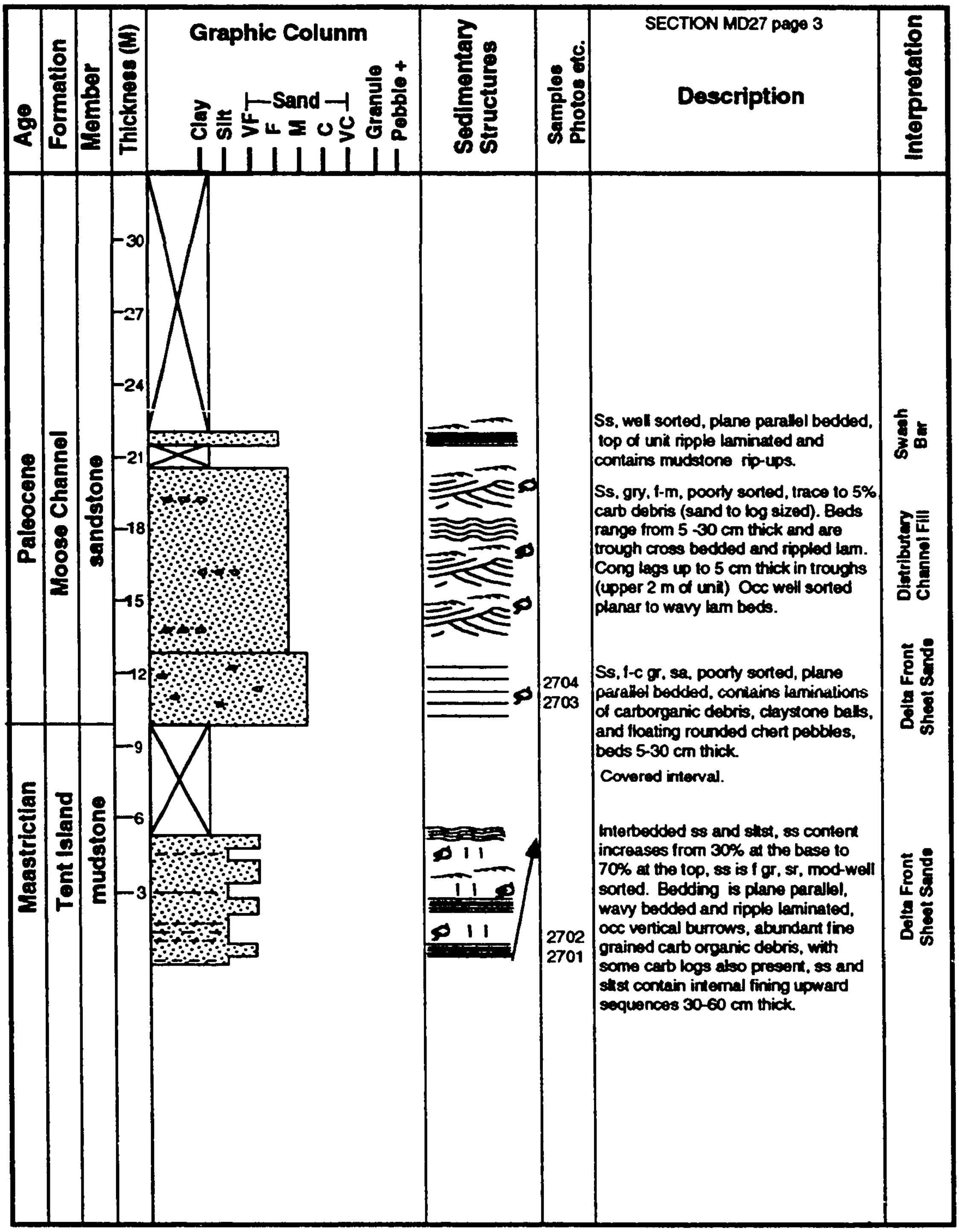
Interbedded ss and blk mudstone, ss; sa, mod sorting, contains carbonized plant debris, thin to thick bedded, pl. parallel to wavy laminated, deposited in channels 30-60 cm deep and 3-5 m in width, base of channels contain thin granule to pebble lag, channels capped by ripple-lam ss and mudstone.

Channelized trough cross bedded ss.

Covered interval

Interbedded ss and sltst, ss is sr, mod-well sorted, thinly bedded (2-8 cm) pl. parallel bedded to ripple-lam, sltst is brown to olive green, in beds up to 30 cm thick, contains black floating chert pebbles and carbonized wood debris.

Covered interval



SECTION MD27 page 3

Description

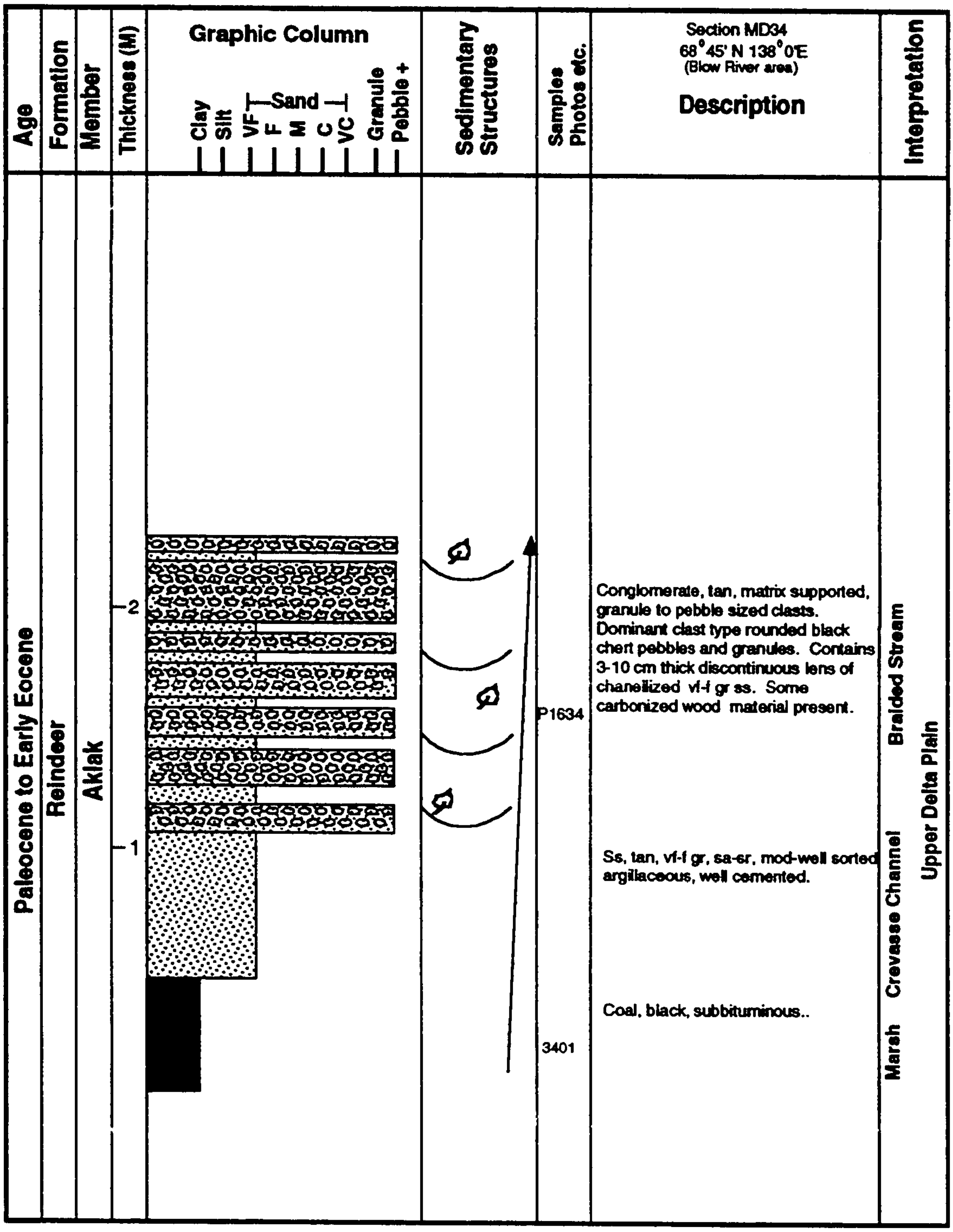
Ss, well sorted, plane parallel bedded, top of unit ripple laminated and contains mudstone rip-ups.

Ss, gry, f-m, poorly sorted, trace to 5% carb debris (sand to log sized). Beds range from 5 -30 cm thick and are trough cross bedded and rippled lam. Cong lags up to 5 cm thick in troughs (upper 2 m of unit) Occ well sorted planar to wavy lam beds.

Ss, f-c gr, sa, poorly sorted, plane parallel bedded, contains laminations of carborganic debris, claystone balls, and floating rounded chert pebbles, beds 5-30 cm thick.

Covered interval.

Interbedded ss and sltst, ss content increases from 30% at the base to 70% at the top, ss is f gr, sr, mod-well sorted. Bedding is plane parallel, wavy bedded and ripple laminated, occ vertical burrows, abundant fine grained carb organic debris, with some carb logs also present, ss and sltst contain internal fining upward sequences 30-60 cm thick.



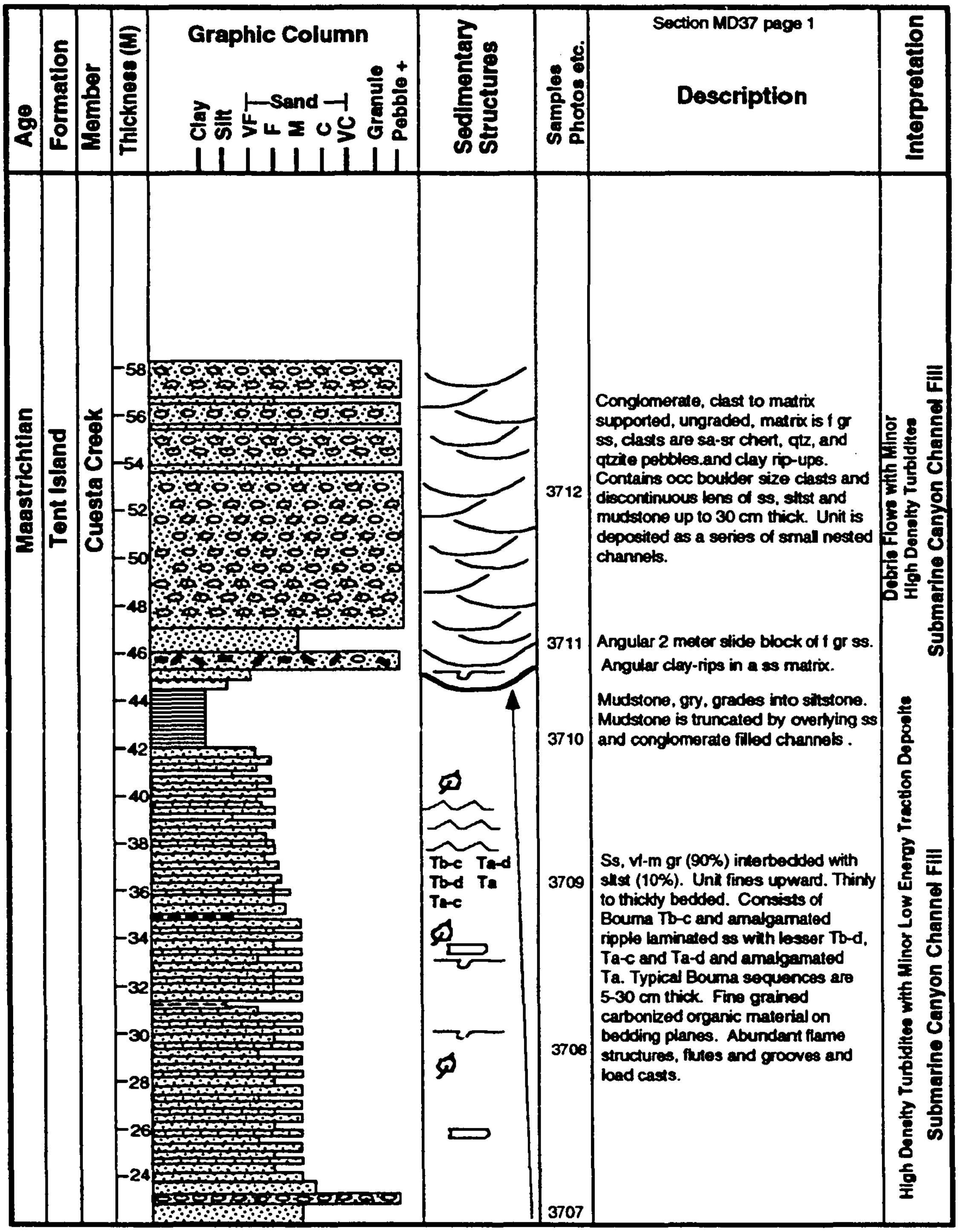
Section MD34
68°45' N 138°0'E
(Blow River area)

Description

Conglomerate, tan, matrix supported, granule to pebble sized clasts. Dominant clast type rounded black chert pebbles and granules. Contains 3-10 cm thick discontinuous lens of chanelized vf-f gr ss. Some carbonized wood material present.

Ss, tan, vf-f gr, sa-sr, mod-well sorted argillaceous, well cemented.

Coal, black, subbituminous..



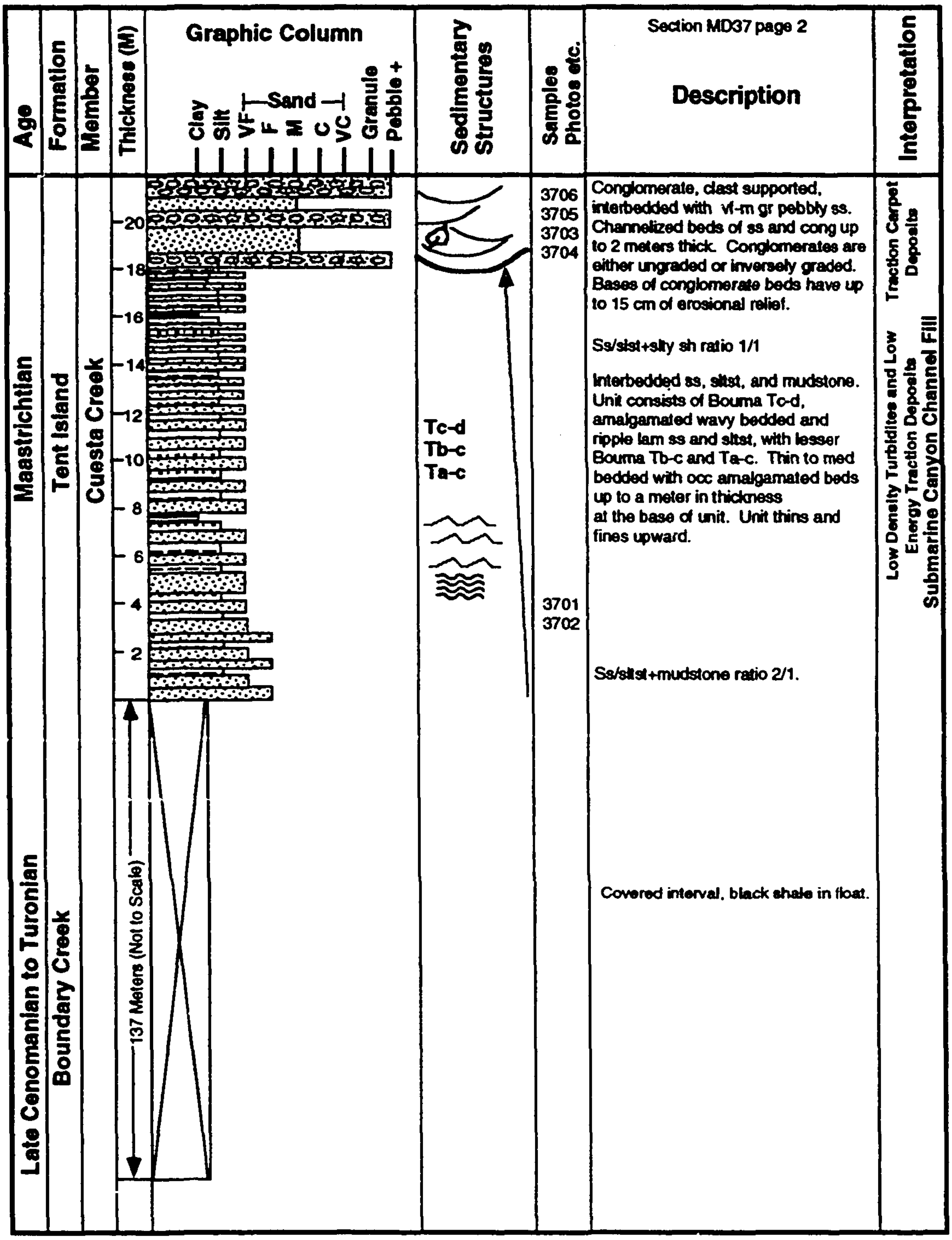
Conglomerate, clast to matrix supported, ungraded, matrix is f gr ss, clasts are sa-sr chert, qtz, and qtzite pebbles.and clay rip-ups. Contains occ boulder size clasts and discontinuous lens of ss, sltst and mudstone up to 30 cm thick. Unit is deposited as a series of small nested channels.

Angular 2 meter slide block of f gr ss.

Angular clay-rips in a ss matrix.

Mudstone, gry, grades into siltstone. Mudstone is truncated by overlying ss and conglomerate filled channels .

Ss, vf-m gr (90%) interbedded with sltst (10%). Unit fines upward. Thinly to thickly bedded. Consists of Bouma Tb-c and amalgamated ripple laminated ss with lesser Tb-d, Ta-c and Ta-d and amalgamated Ta. Typical Bouma sequences are 5-30 cm thick. Fine grained carbonized organic material on bedding planes. Abundant flame structures, flutes and grooves and load casts.



Section MD37 page 2

Description

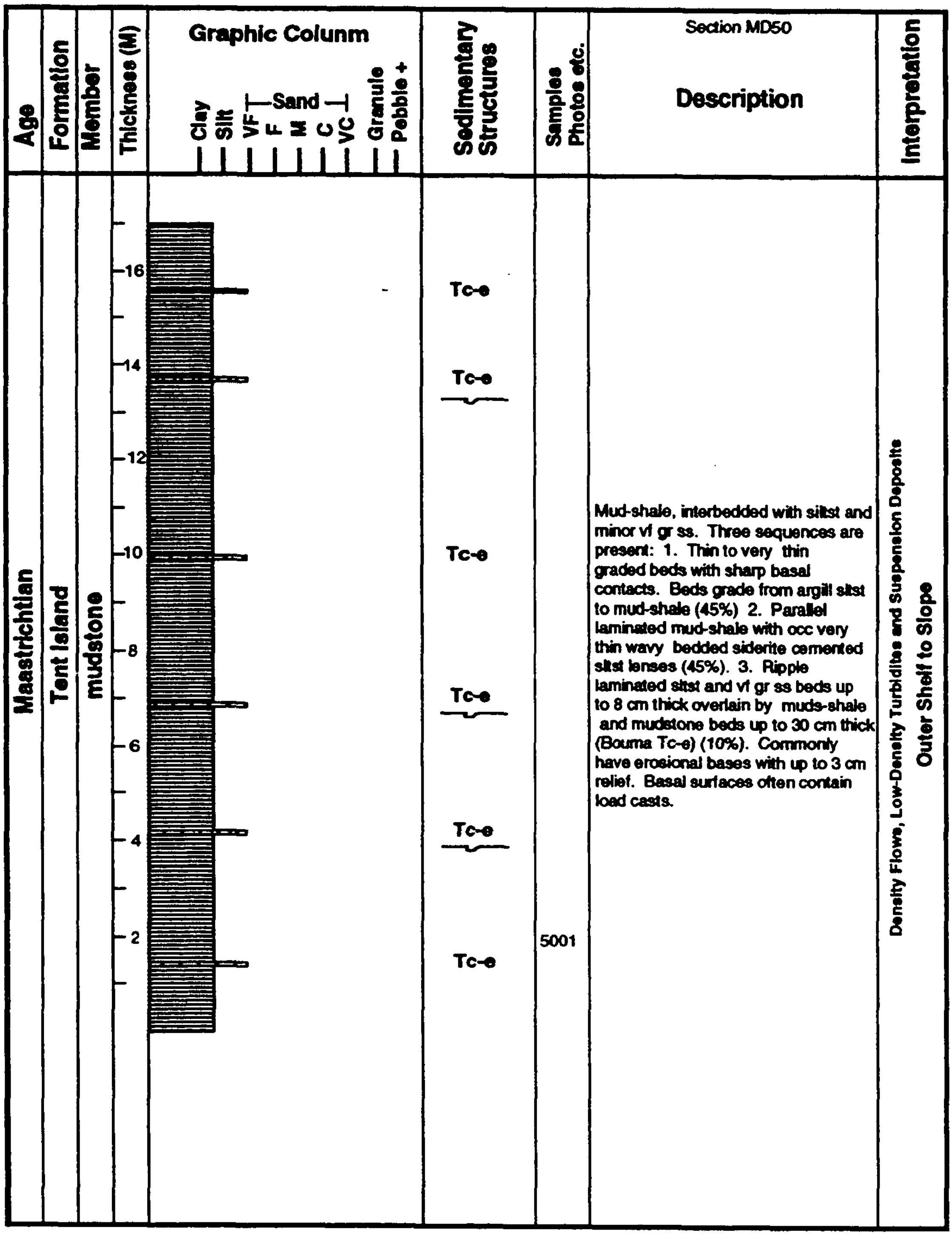
Conglomerate, clast supported, interbedded with vf-m gr pebbly ss. Channelized beds of ss and cong up to 2 meters thick. Conglomerates are either ungraded or inversely graded. Bases of conglomerate beds have up to 15 cm of erosional relief.

Ss/slst+silty sh ratio 1/1

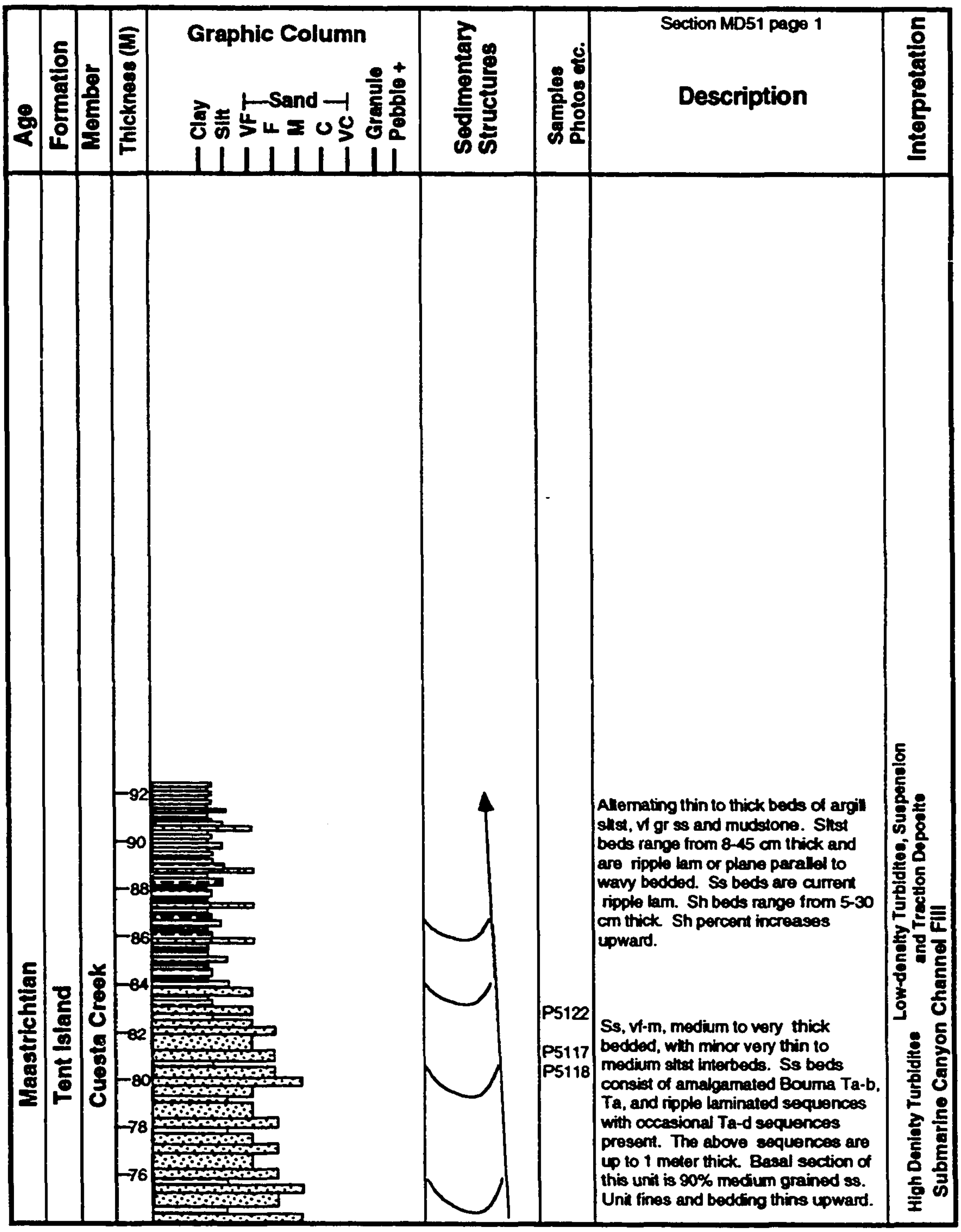
Interbedded ss, sltst, and mudstone. Unit consists of Bouma Tc-d, amalgamated wavy bedded and ripple lam ss and sltst, with lesser Bouma Tb-c and Ta-c. Thin to med bedded with occ amalgamated beds up to a meter in thickness at the base of unit. Unit thins and fines upward.

Ss/sltst+mudstone ratio 2/1.

Covered interval, black shale in float.

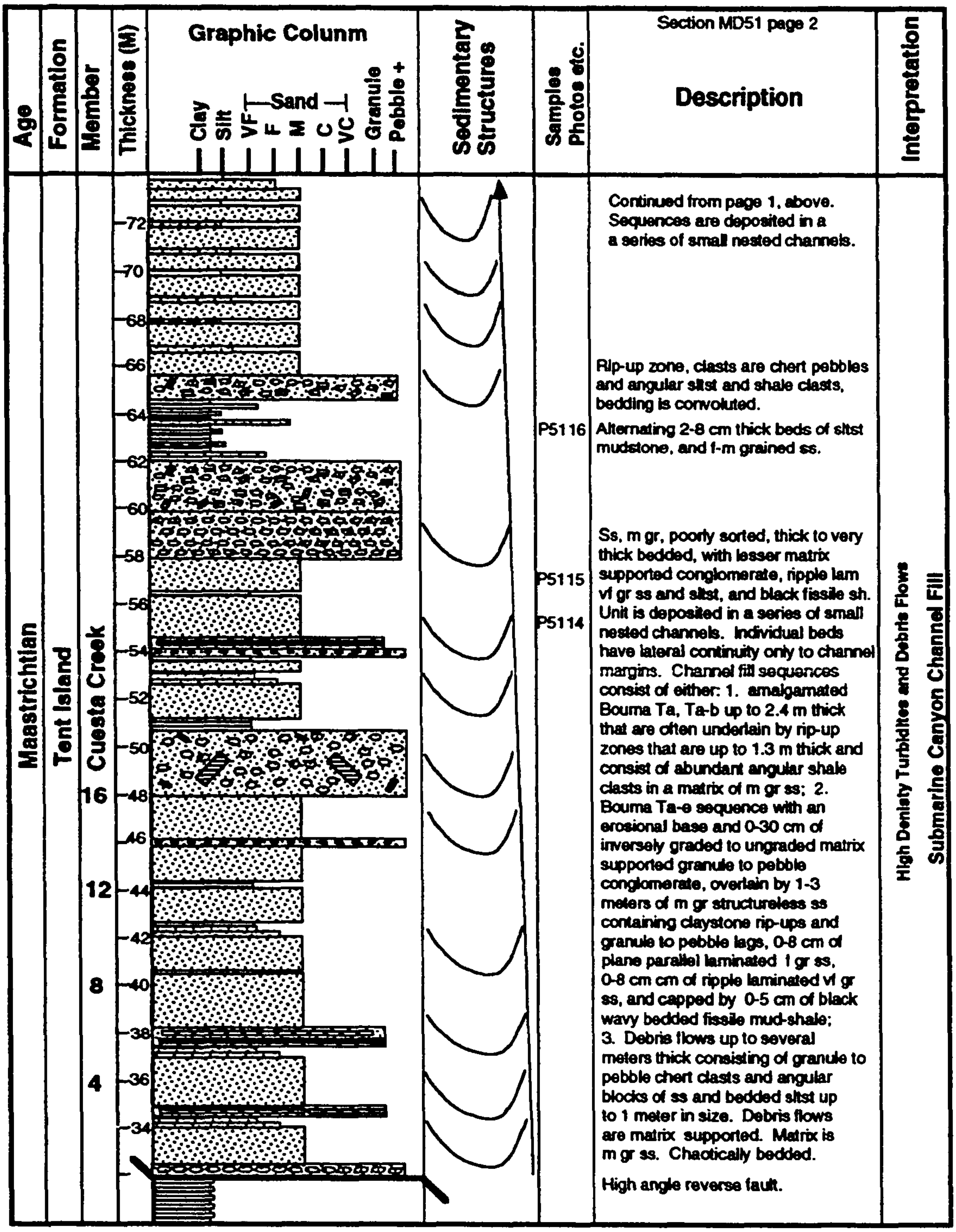


Mud-shale, interbedded with siltst and minor vf gr ss. Three sequences are present: 1. Thin to very thin graded beds with sharp basal contacts. Beds grade from argill sltst to mud-shale (45%) 2. Parallel laminated mud-shale with occ very thin wavy bedded siderite cemented sltst lenses (45%). 3. Ripple laminated sltst and vf gr ss beds up to 8 cm thick overlain by muds-shale and mudstone beds up to 30 cm thick (Bouma Tc-e) (10%). Commonly have erosional bases with up to 3 cm relief. Basal surfaces often contain load casts.



Alternating thin to thick beds of argill sltst, vf gr ss and mudstone. Sltst beds range from 8-45 cm thick and are ripple lam or plane parallel to wavy bedded. Ss beds are current ripple lam. Sh beds range from 5-30 cm thick. Sh percent increases upward.

Ss, vf-m, medium to very thick bedded, with minor very thin to medium sltst interbeds. Ss beds consist of amalgamated Bouma Ta-b, Ta, and ripple laminated sequences with occasional Ta-d sequences present. The above sequences are up to 1 meter thick. Basal section of this unit is 90% medium grained ss. Unit fines and bedding thins upward.



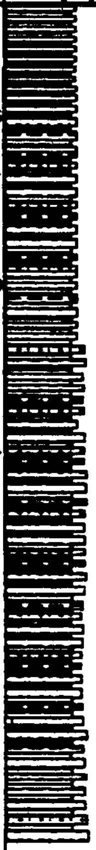
Continued from page 1, above.
Sequences are deposited in a
a series of small nested channels.

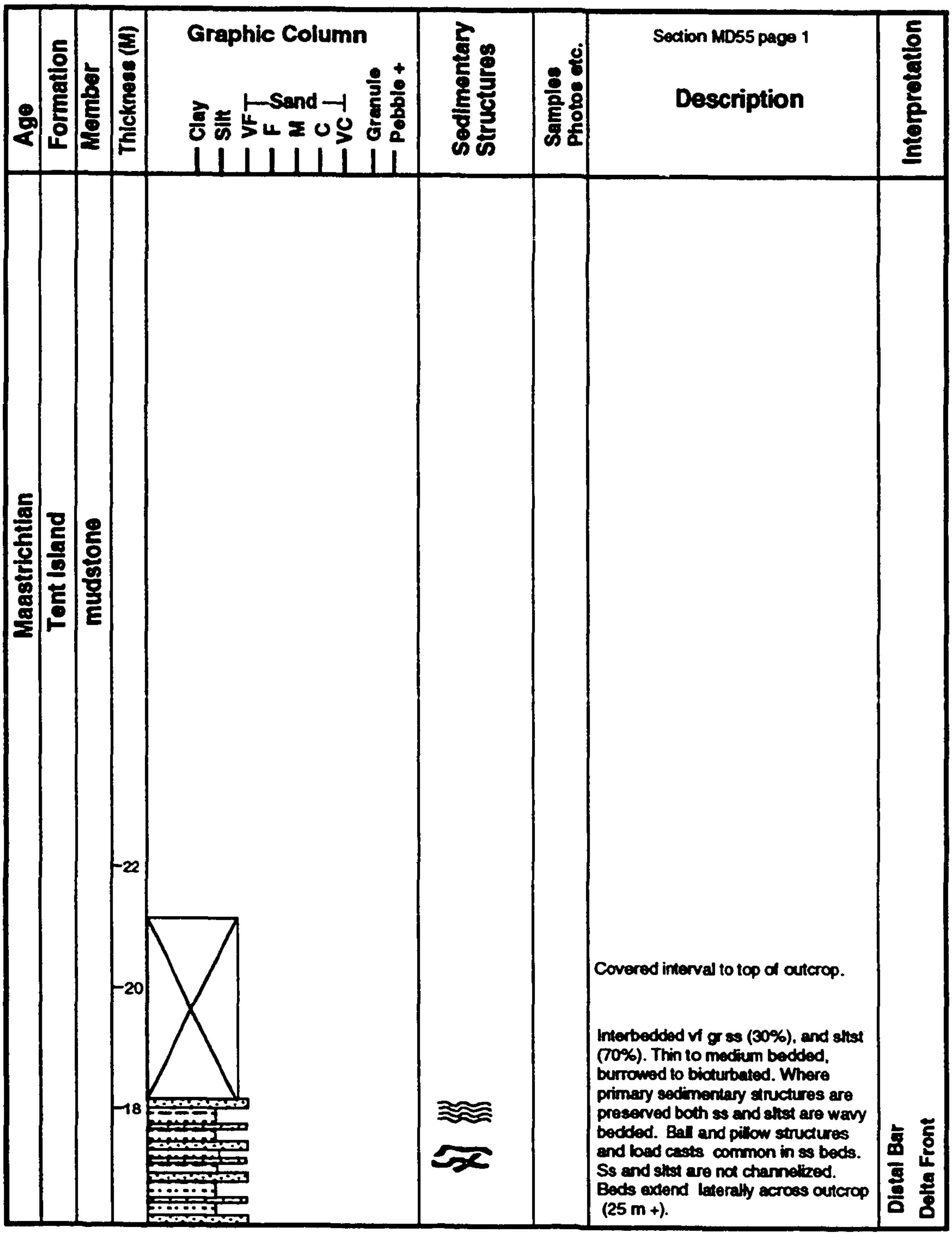
Rip-up zone, clasts are chert pebbles and angular sltst and shale clasts, bedding is convoluted.

Alternating 2-8 cm thick beds of sltst mudstone, and f-m grained ss.

Ss, m gr, poorly sorted, thick to very thick bedded, with lesser matrix supported conglomerate, ripple lam vf gr ss and sltst, and black fissile sh. Unit is deposited in a series of small nested channels. Individual beds have lateral continuity only to channel margins. Channel fill sequences consist of either: 1. amalgamated Bouma Ta, Ta-b up to 2.4 m thick that are often underlain by rip-up zones that are up to 1.3 m thick and consist of abundant angular shale clasts in a matrix of m gr ss; 2. Bouma Ta-e sequence with an erosional base and 0-30 cm of inversely graded to ungraded matrix supported granule to pebble conglomerate, overlain by 1-3 meters of m gr structureless ss containing claystone rip-ups and granule to pebble lags, 0-8 cm of plane parallel laminated f gr ss, 0-8 cm cm of ripple laminated vf gr ss, and capped by 0-5 cm of black wavy bedded fissile mud-shale; 3. Debris flows up to several meters thick consisting of granule to pebble chert clasts and angular blocks of ss and bedded sltst up to 1 meter in size. Debris flows are matrix supported. Matrix is m gr ss. Chaotically bedded.

High angle reverse fault.

Age	Formation	Member	Thickness (M)	Graphic Colunm Clay Silt VF F M C VC Sand Granule Pebble +	Sedimentary Structures	Samples Photos etc.	Section MD51 page 3 Description	Interpretation
Maastrichtian	Tent Island	Cuesta Creek	28 26 24 22 20 18 16 14 12 10 8 6 4 2				Alternating thin to thick beds of argill siltstone and mudstone. Siltstone beds range from 8-45 cm thick and are plane parallel to wavy bedded. Base of sltst beds have up to 8 cm of erosional relief. Siltst beds are abruptly overlain by laminated mudstone beds ranging from 5-30 cm thick. Mudstone percent increases upward to greater than 50%. Siltstone beds thin upwards to so that maximum thickness at top of this unit is 10 cm. Sltst and mudstone beds have good lateral continuity across the outcrop (30 m).	Density Flows and Suspension Deposits

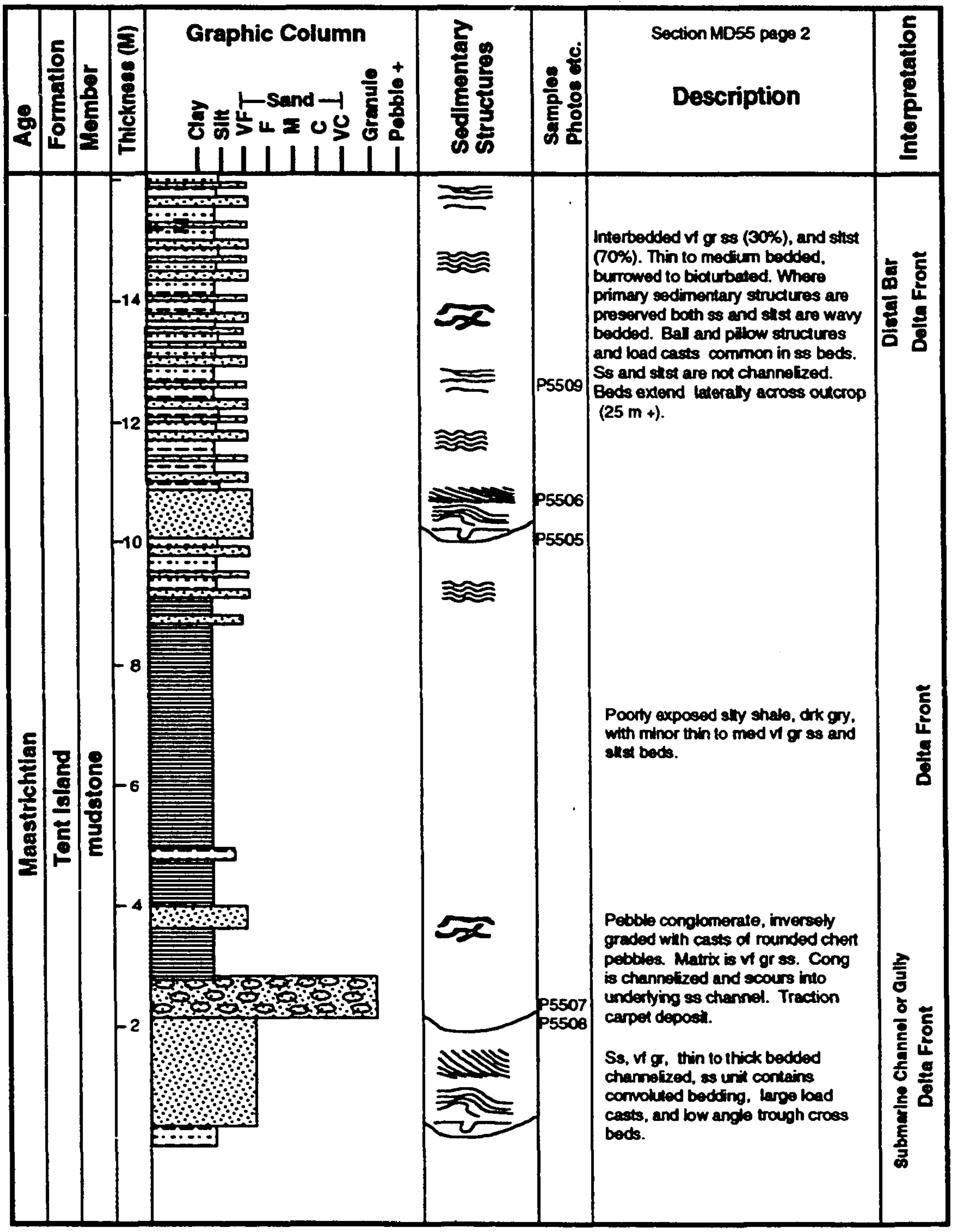


Section MD55 page 1

Description

Covered interval to top of outcrop.

Interbedded vf gr ss (30%), and sltst (70%). Thin to medium bedded, burrowed to bioturbated. Where primary sedimentary structures are preserved both ss and sltst are wavy bedded. Ball and pillow structures and load casts common in ss beds. Ss and sltst are not channelized. Beds extend laterally across outcrop (25 m +).

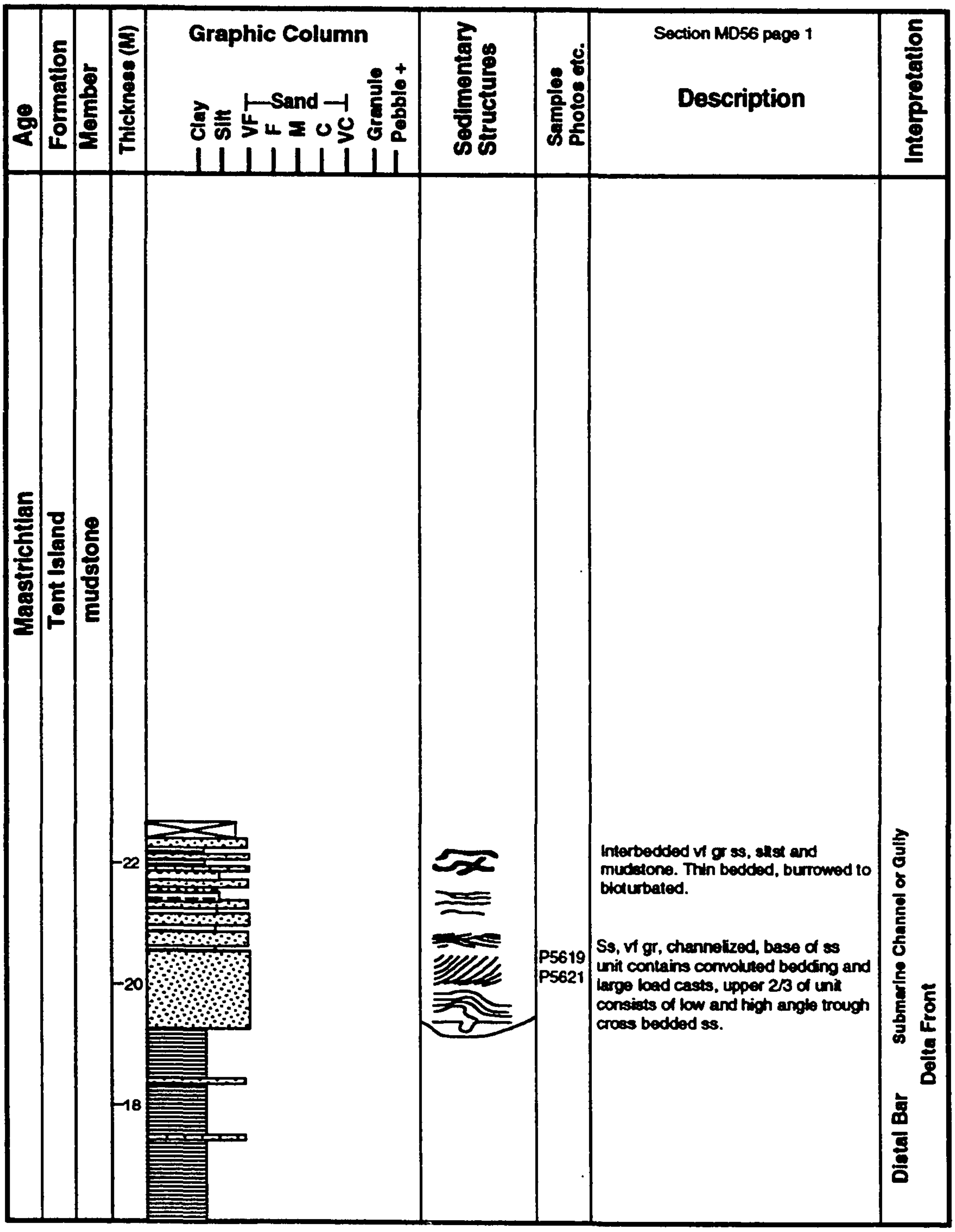


Interbedded vf gr ss (30%), and sltst (70%). Thin to medium bedded, burrowed to bioturbated. Where primary sedimentary structures are preserved both ss and sltst are wavy bedded. Ball and pillow structures and load casts common in ss beds. Ss and sltst are not channelized. Beds extend laterally across outcrop (25 m +).

Poorly exposed silty shale, drk gry, with minor thin to med vf gr ss and sltst beds.

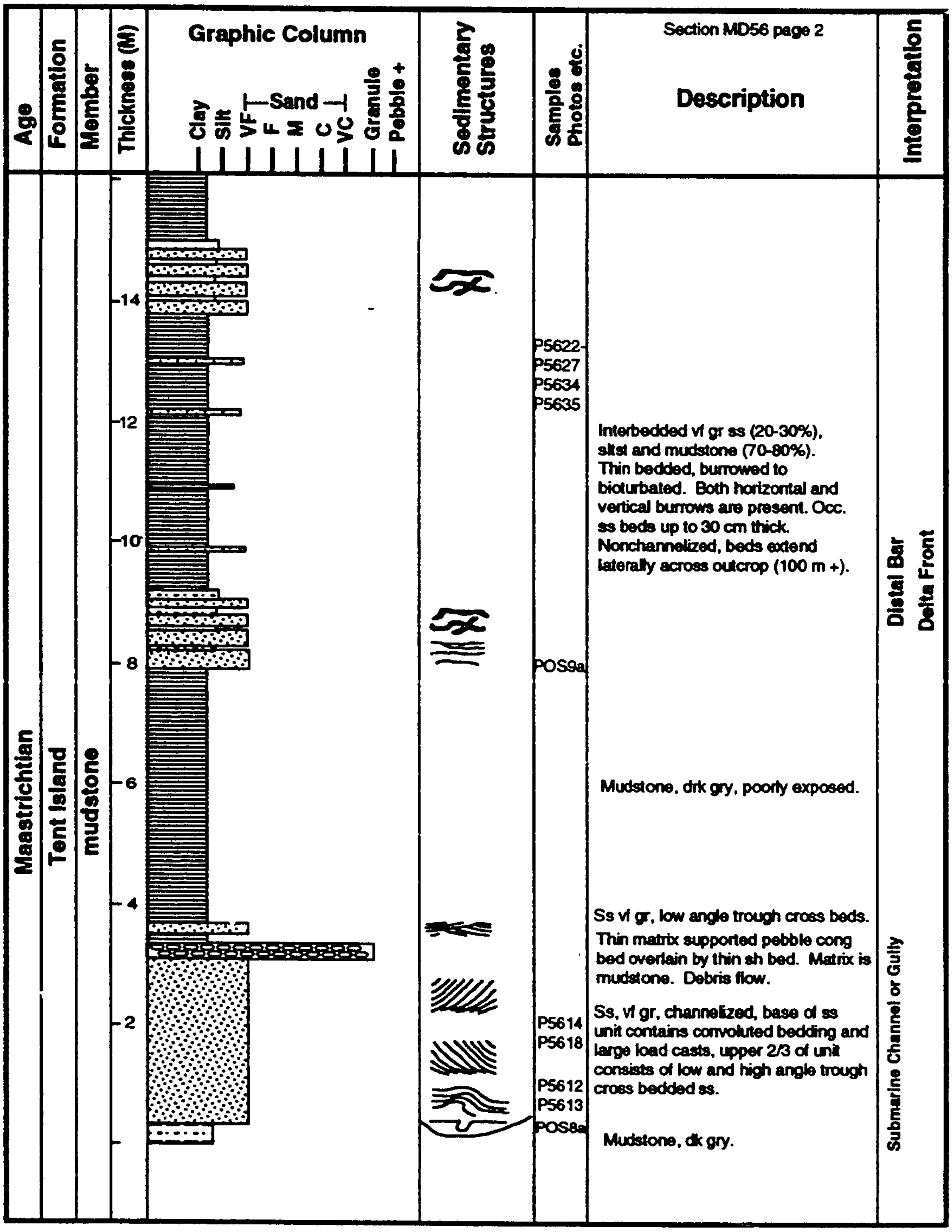
Pebble conglomerate, inversely graded with casts of rounded chert pebbles. Matrix is vf gr ss. Cong is channelized and scours into underlying ss channel. Traction carpet deposit.

Ss, vf gr, thin to thick bedded channelized, ss unit contains convoluted bedding, large load casts, and low angle trough cross beds.



Interbedded vf gr ss, sltst and mudstone. Thin bedded, burrowed to bioturbated.

Ss, vf gr, channelized, base of ss unit contains convoluted bedding and large load casts, upper 2/3 of unit consists of low and high angle trough cross bedded ss.



Section MD56 page 2

Description

Interbedded vf gr ss (20-30%), sltst and mudstone (70-80%). Thin bedded, burrowed to bioturbated. Both horizontal and vertical burrows are present. Occ. ss beds up to 30 cm thick. Nonchannelized, beds extend laterally across outcrop (100 m +).

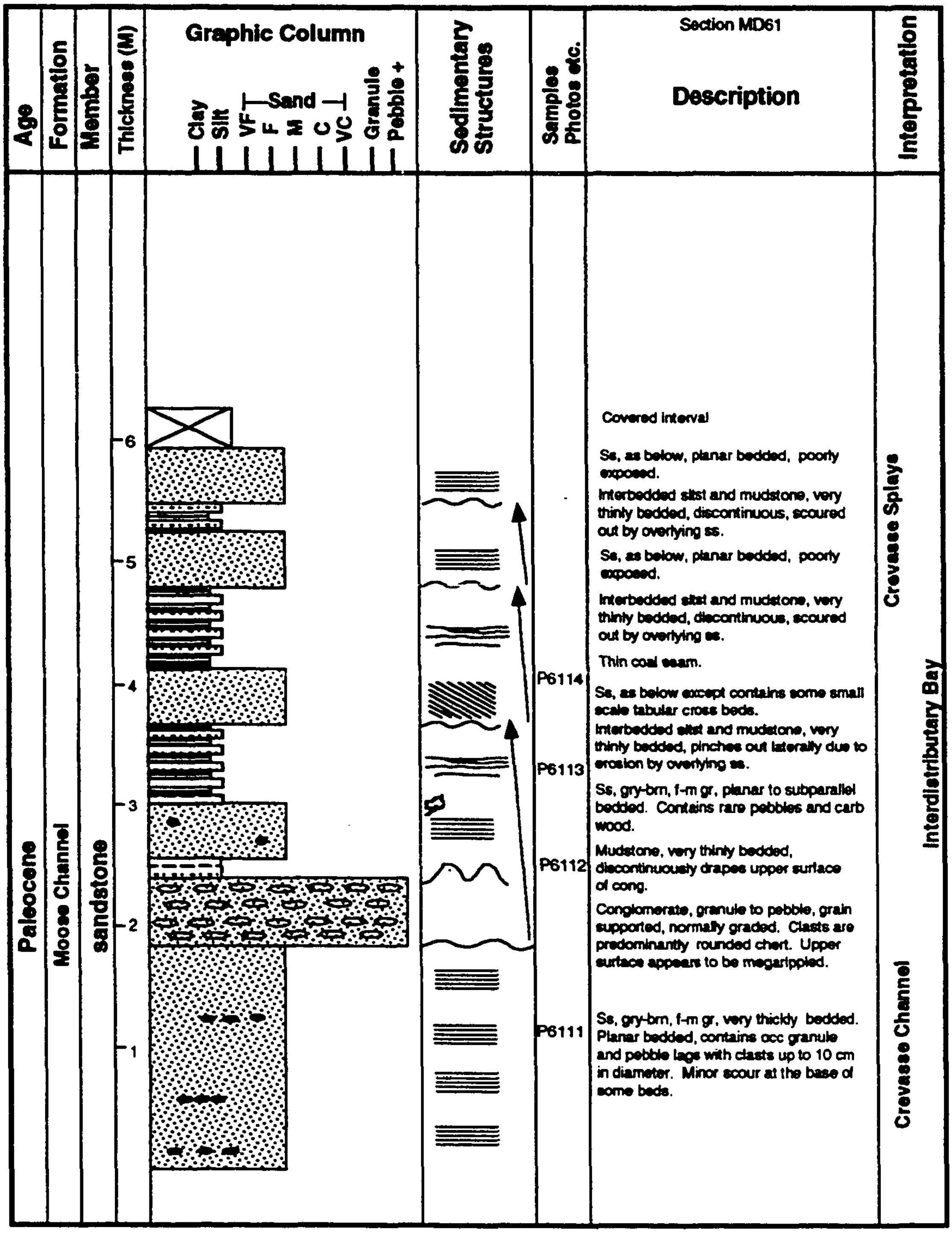
Mudstone, drk gry, poorly exposed.

Ss vf gr, low angle trough cross beds.

Thin matrix supported pebble cong bed overlain by thin sh bed. Matrix is mudstone. Debris flow.

Ss, vf gr, channelized, base of ss unit contains convoluted bedding and large load casts, upper 2/3 of unit consists of low and high angle trough cross bedded ss.

Mudstone, dk gry.



Covered interval

Ss, as below, planar bedded, poorly exposed.

Interbedded sltst and mudstone, very thinly bedded, discontinuous, scoured out by overlying ss.

Ss, as below, planar bedded, poorly exposed.

Interbedded sltst and mudstone, very thinly bedded, discontinuous, scoured out by overlying ss.

Thin coal seam.

Ss, as below except contains some small scale tabular cross beds.

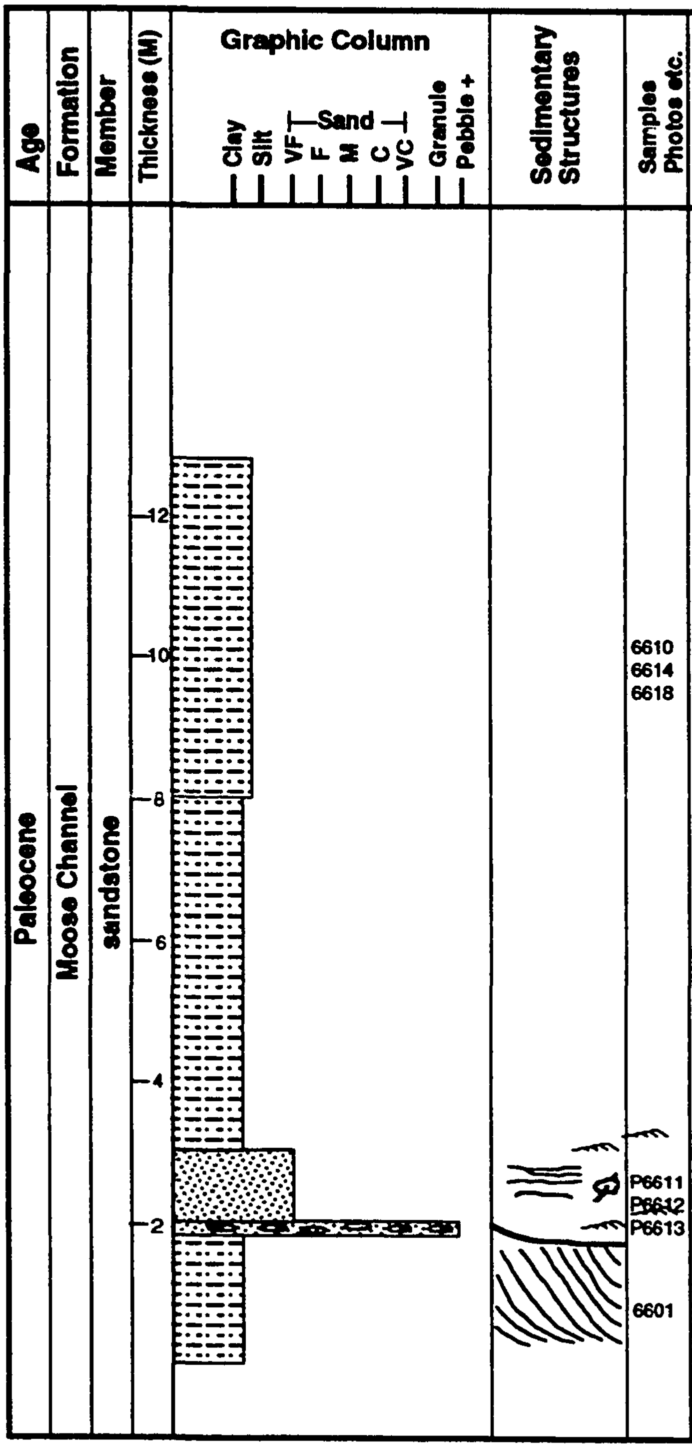
Interbedded sltst and mudstone, very thinly bedded, pinches out laterally due to erosion by overlying ss.

Ss, gry-brn, f-m gr, planar to subparallel bedded. Contains rare pebbles and carb wood.

Mudstone, very thinly bedded, discontinuously drapes upper surface of cong.

Conglomerate, granule to pebble, grain supported, normally graded. Clasts are predominantly rounded chert. Upper surface appears to be megarippled.

Ss, gry-brn, f-m gr, very thickly bedded. Planar bedded, contains occ granule and pebble lags with clasts up to 10 cm in diameter. Minor scour at the base of some beds.



Section MD66

Description

Sltst, gry, slightly coarser grained and thicker bedded (thin to thick) than underlying unit. Channelized, beds and total thickness of unit thin toward channel margins.

Sltst and mudstone, gry, thin to med bedded. Channelized, beds and total thickness of unit thin toward channel margins.

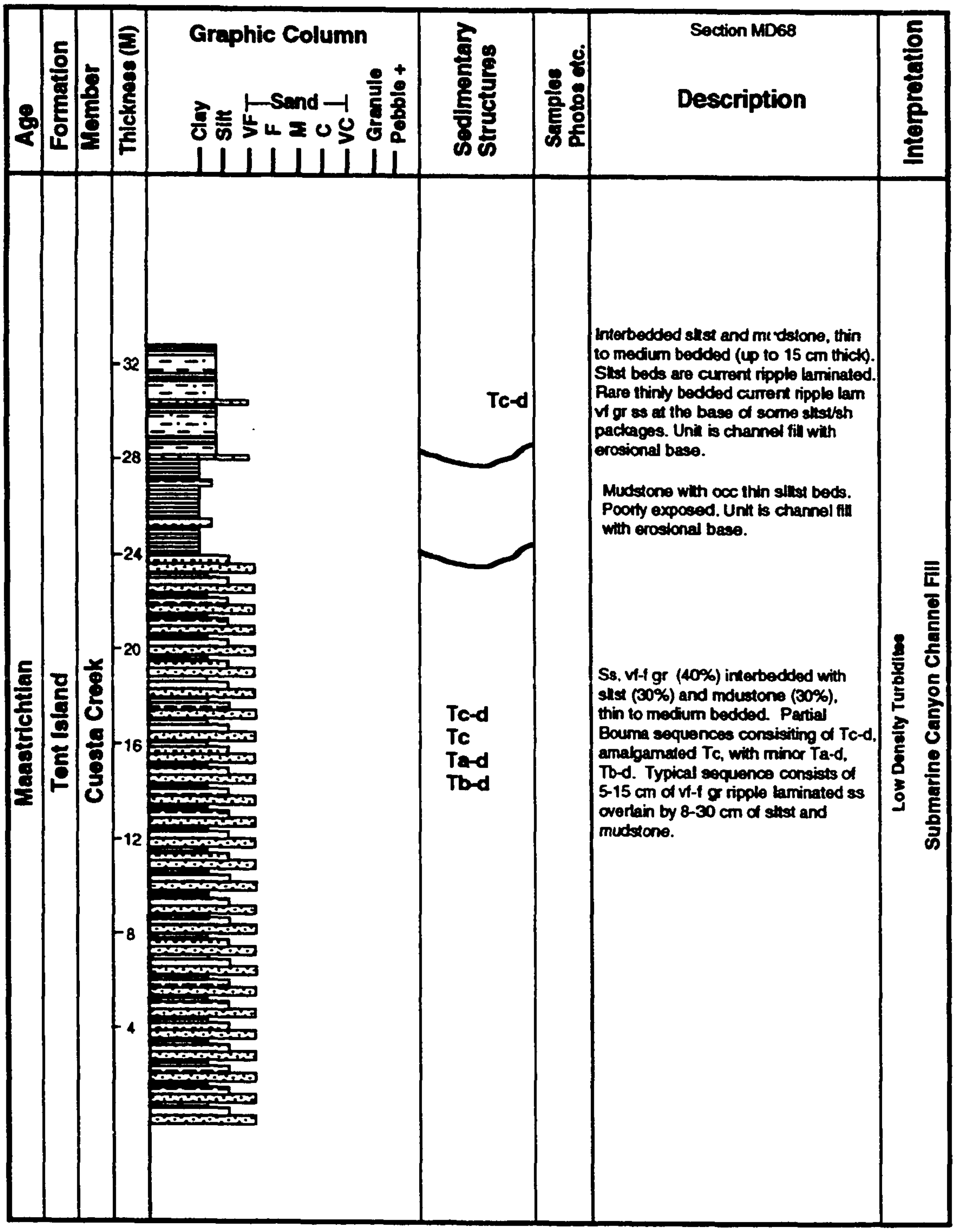
Ss, lt gry, medium to thickly bedded, burrowed, ripple laminated, contains abundant fine grained organic material. Both cong and ss on lap on to top epsilon cross bed of underlying sltst.

Cong, chert pebble, matrix supported.

Shaly siltstone, gry, medium to thickly bedded, epsilon cross bedded (lateral accretion surfaces) with up to 2 m of vertical relief. Possible pelecapod mold.

Interpretation

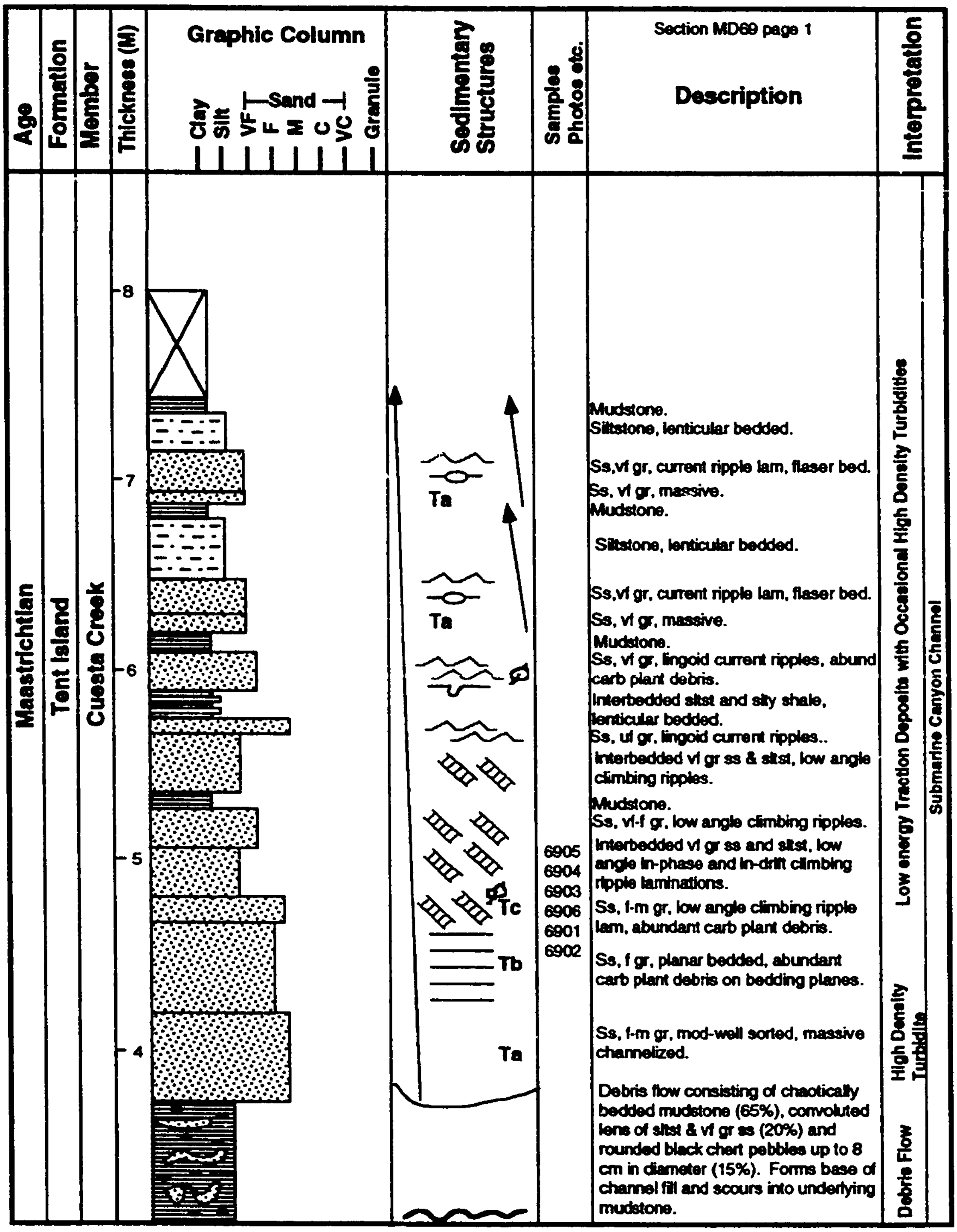
Abandoned Distributary Channel
Lower Delta Plain



Interbedded sltst and mudstone, thin to medium bedded (up to 15 cm thick). Sltst beds are current ripple laminated. Rare thinly bedded current ripple lam vf gr ss at the base of some sltst/sh packages. Unit is channel fill with erosional base.

Mudstone with occ thin sltst beds. Poorly exposed. Unit is channel fill with erosional base.

Ss, vf-f gr (40%) interbedded with sltst (30%) and mdustone (30%), thin to medium bedded. Partial Bouma sequences consisiting of Tc-d, amalgamated Tc, with minor Ta-d, Tb-d. Typical sequence consists of 5-15 cm of vf-f gr ripple laminated ss overlain by 8-30 cm of sltst and mudstone.



Section MD69 page 1

Description

Mudstone.

Siltstone, lenticular bedded.

Ss,vf gr, current ripple lam, flaser bed.

Ss, vf gr, massive.

Mudstone.

Siltstone, lenticular bedded.

Ss,vf gr, current ripple lam, flaser bed.

Ss, vf gr, massive.

Mudstone.

Ss, vf gr, lingoid current ripples, abund carb plant debris.

Interbedded sltst and slty shale, lenticular bedded.

Ss, uf gr, lingoid current ripples..

Interbedded vf gr ss & sltst, low angle climbing ripples.

Mudstone.

Ss, vf-f gr, low angle climbing ripples.

Interbedded vf gr ss and sltst, low angle in-phase and in-drift climbing ripple laminations.

Ss, f-m gr, low angle climbing ripple lam, abundant carb plant debris.

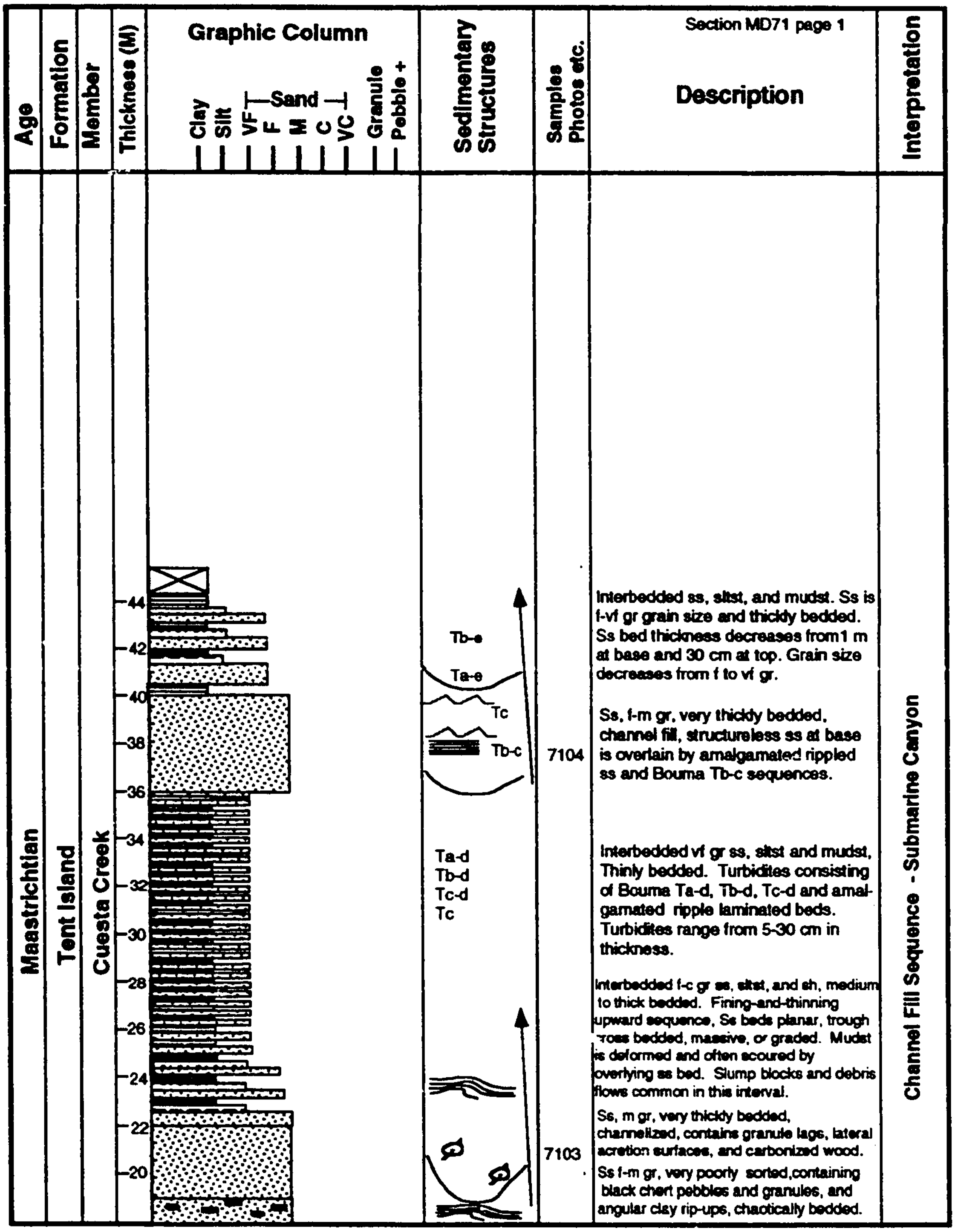
Ss, f gr, planar bedded, abundant carb plant debris on bedding planes.

Ss, f-m gr, mod-well sorted, massive channelized.

Debris flow consisting of chaotically bedded mudstone (65%), convoluted lens of sltst & vf gr ss (20%) and rounded black chert pebbles up to 8 cm in diameter (15%). Forms base of channel fill and scours into underlying mudstone.

6905
6904
6903
6906
6901
6902

Age	Formation	Member	Thickness (M)	Graphic Column Clay, Silt, VF, F, M, C, VC (Sand), Granule, Pebble +	Sedimentary Structures	Samples Photos etc.	Section MD69 page 2 Description	Interpretation
Late Cenomanian to Turonian	Boundary Creek		3 2 1				Unconformity Mudstone, blk, weathers gry, contains minor disseminated silt. Unit is poorly exposed.	Anoxic Basin



Interbedded ss, sltst, and mudst. Ss is f-vf gr grain size and thickly bedded. Ss bed thickness decreases from 1 m at base and 30 cm at top. Grain size decreases from f to vf gr.

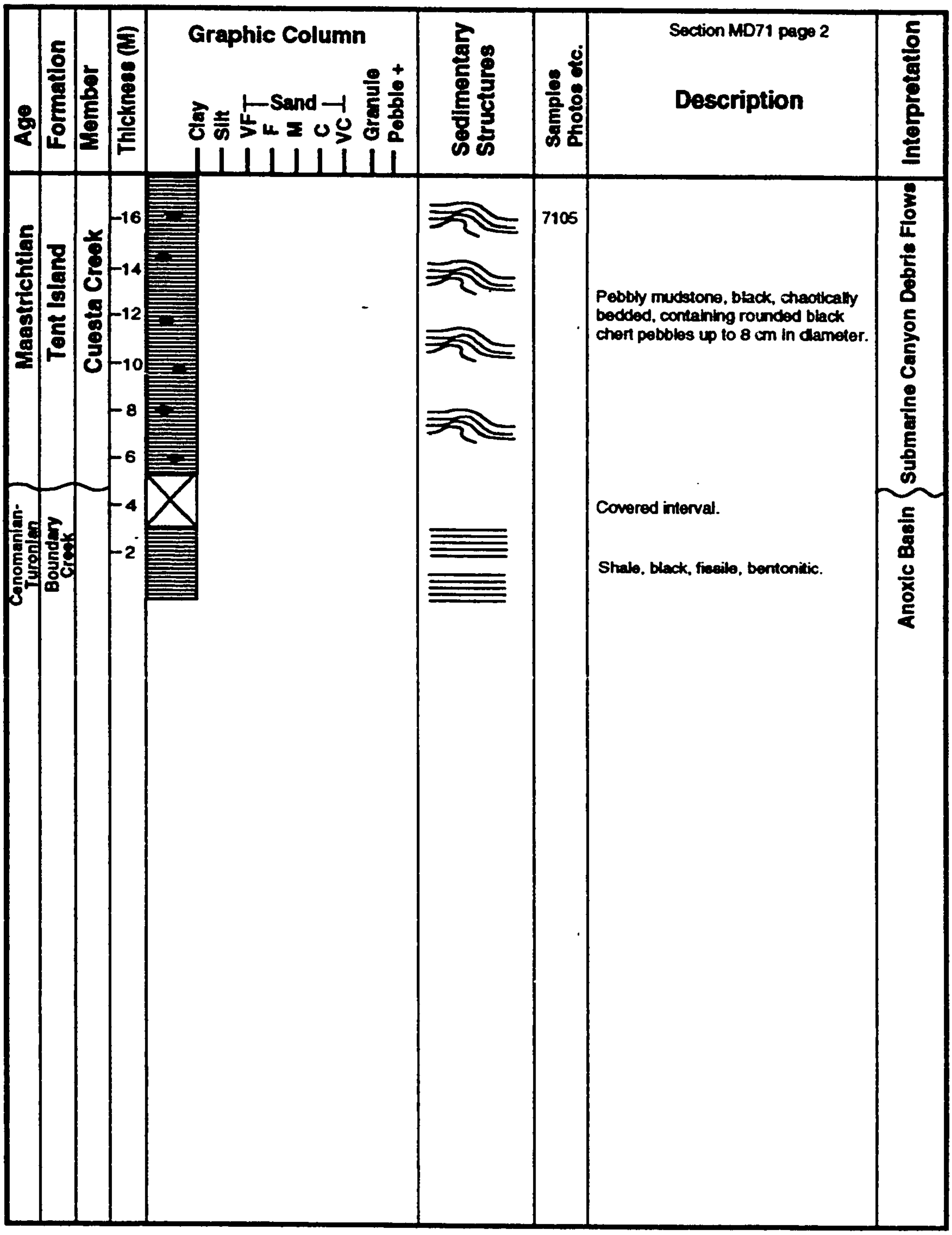
Ss, f-m gr, very thickly bedded, channel fill, structureless ss at base is overlain by amalgamated rippled ss and Bouma Tb-c sequences.

Interbedded vf gr ss, sltst and mudst, Thinly bedded. Turbidites consisting of Bouma Ta-d, Tb-d, Tc-d and amalgamated ripple laminated beds. Turbidites range from 5-30 cm in thickness.

Interbedded f-c gr ss, sltst, and sh, medium to thick bedded. Fining-and-thinning upward sequence, Ss beds planar, trough cross bedded, massive, or graded. Mudst is deformed and often scoured by overlying ss bed. Slump blocks and debris flows common in this interval.

Ss, m gr, very thickly bedded, channelized, contains granule lags, lateral acretion surfaces, and carbonized wood.

Ss f-m gr, very poorly sorted, containing black chert pebbles and granules, and angular clay rip-ups, chaotically bedded.



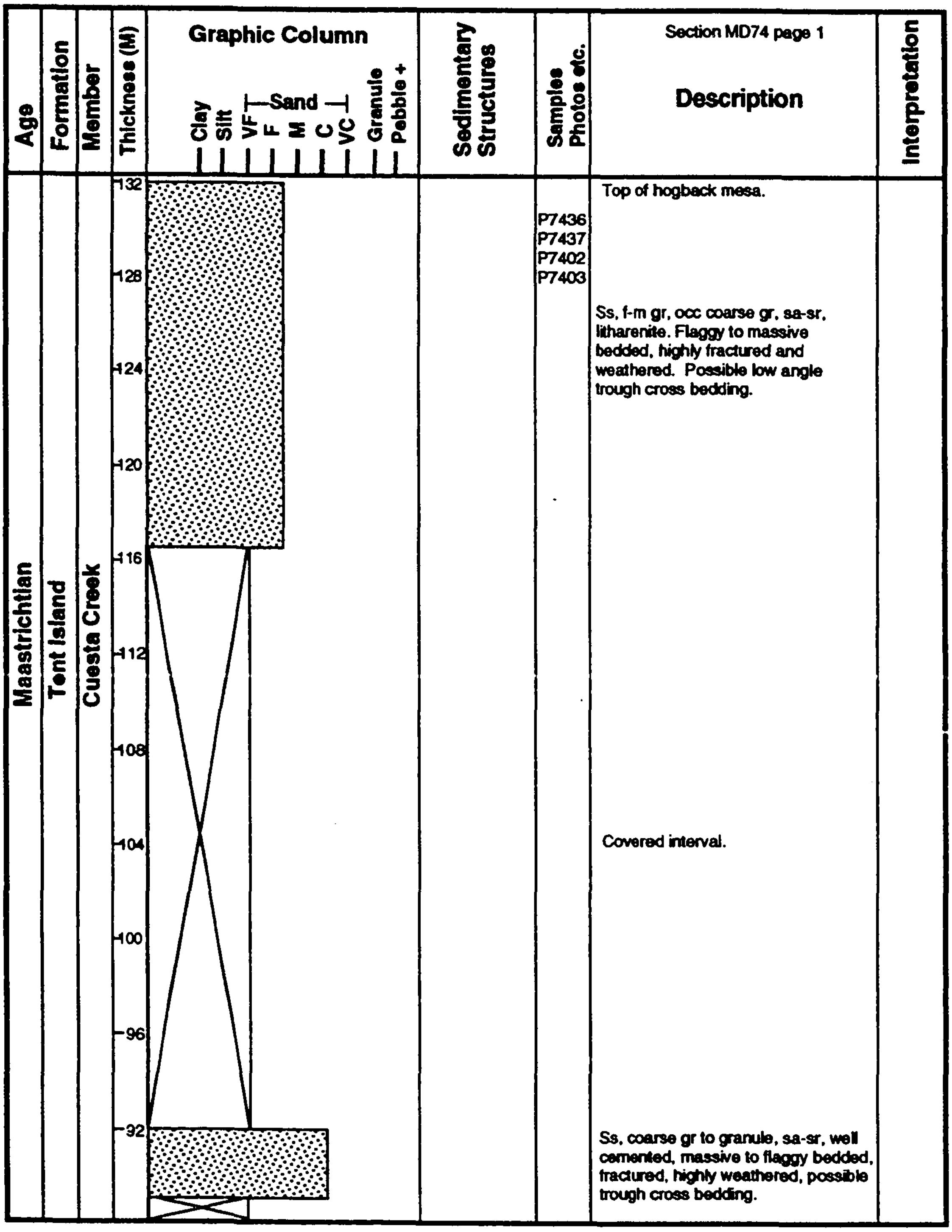
Section MD71 page 2

Description

Pebbly mudstone, black, chaotically bedded, containing rounded black chert pebbles up to 8 cm in diameter.

Covered interval.

Shale, black, fissile, bentonitic.



Section MD74 page 1

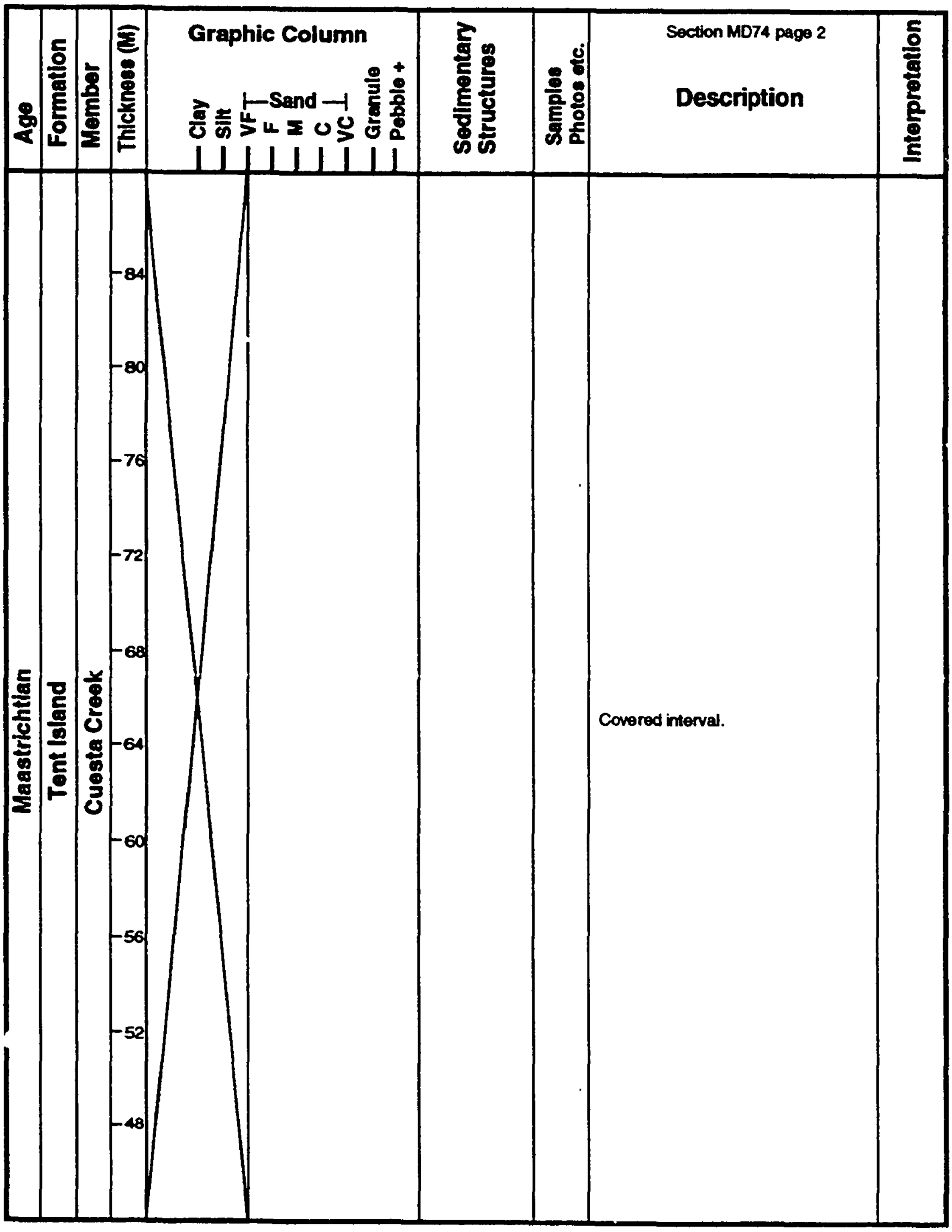
Description

Top of hogback mesa.

Ss, f-m gr, occ coarse gr, sa-sr, litharenite. Flaggy to massive bedded, highly fractured and weathered. Possible low angle trough cross bedding.

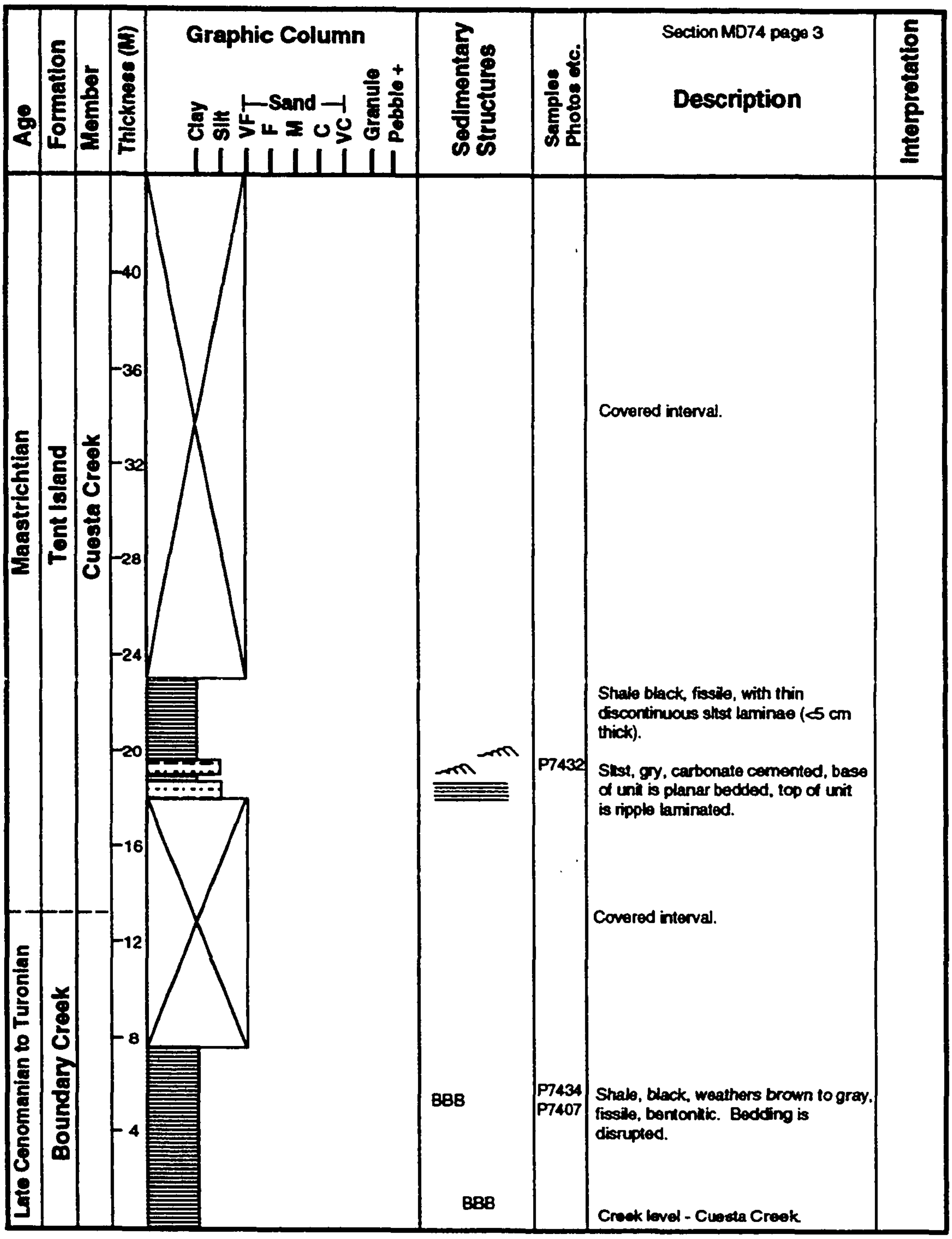
Covered interval.

Ss, coarse gr to granule, sa-sr, well cemented, massive to flaggy bedded, fractured, highly weathered, possible trough cross bedding.



Section MD74 page 2

Covered interval.



Section MD74 page 3

Covered interval.

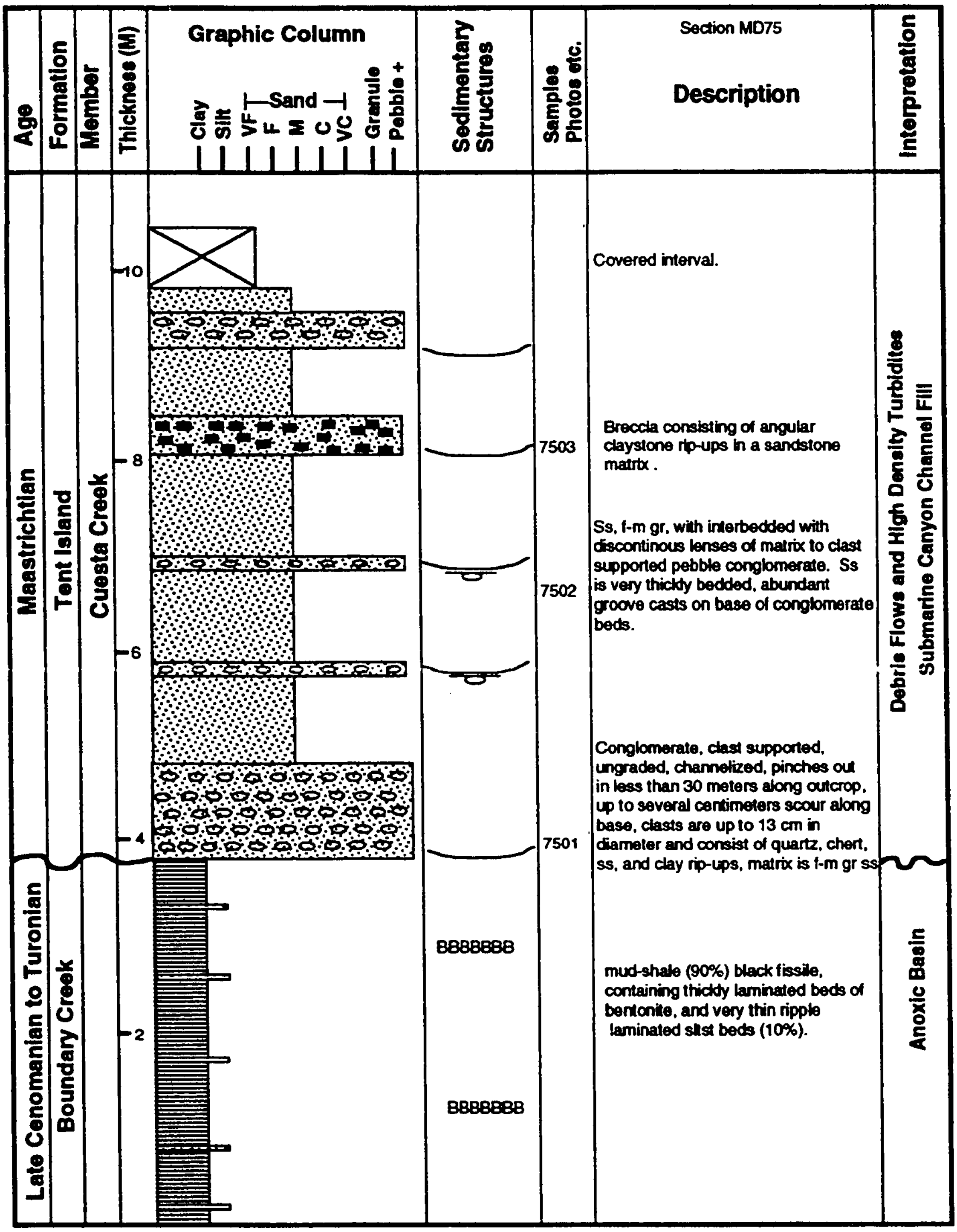
Shale black, fissile, with thin discontinuous sltst laminae (<5 cm thick).

Sltst, gry, carbonate cemented, base of unit is planar bedded, top of unit is ripple laminated.

Covered interval.

Shale, black, weathers brown to gray, fissile, bentonitic. Bedding is disrupted.

Creek level - Cuesta Creek.



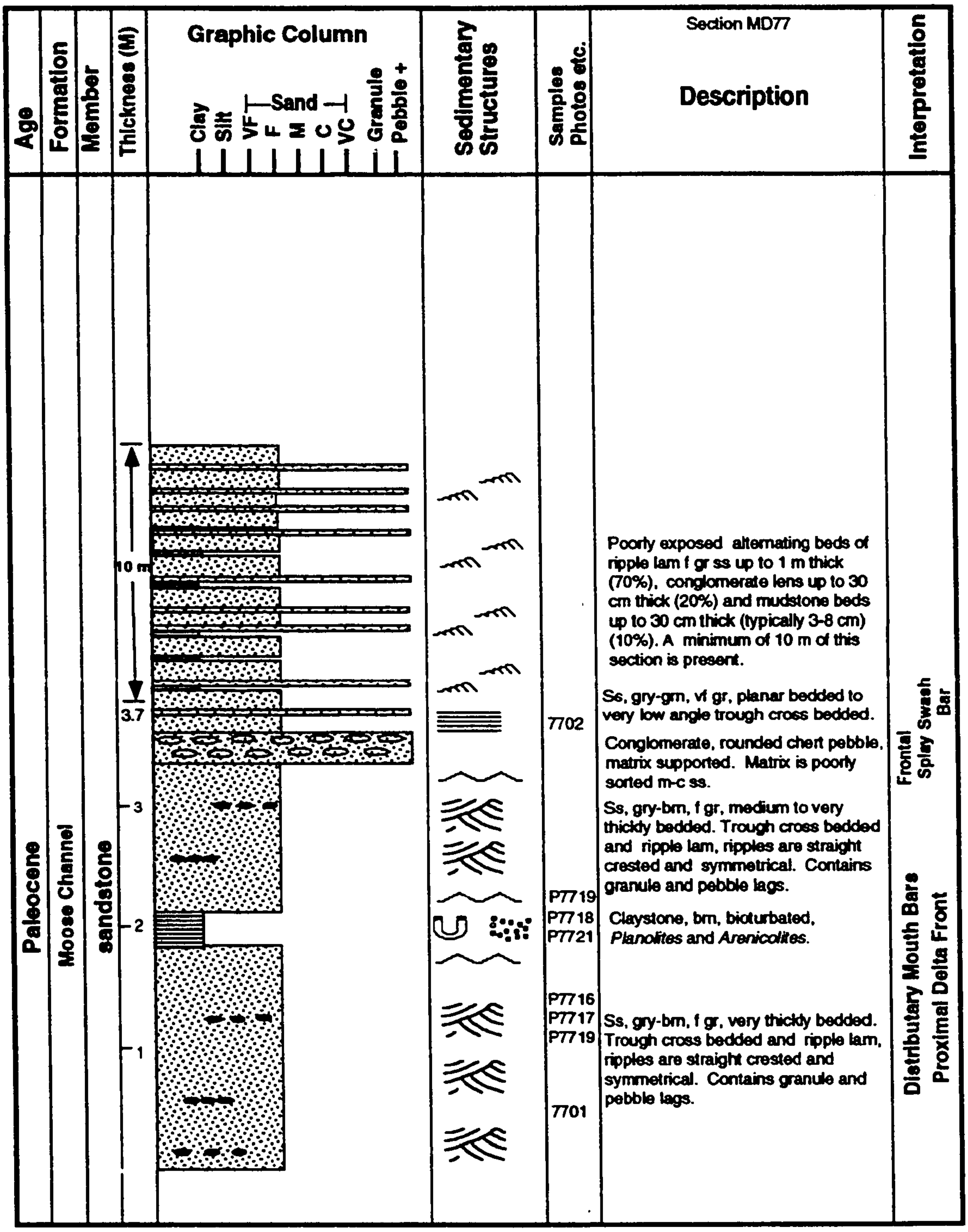
Covered interval.

Breccia consisting of angular claystone rip-ups in a sandstone matrix.

Ss, f-m gr, with interbedded with discontinous lenses of matrix to clast supported pebble conglomerate. Ss is very thickly bedded, abundant groove casts on base of conglomerate beds.

Conglomerate, clast supported, ungraded, channelized, pinches out in less than 30 meters along outcrop, up to several centimeters scour along base, clasts are up to 13 cm in diameter and consist of quartz, chert, ss, and clay rip-ups, matrix is f-m gr ss

mud-shale (90%) black fissile, containing thickly laminated beds of bentonite, and very thin ripple laminated sltst beds (10%).



Poorly exposed alternating beds of ripple lam f gr ss up to 1 m thick (70%), conglomerate lens up to 30 cm thick (20%) and mudstone beds up to 30 cm thick (typically 3-8 cm) (10%). A minimum of 10 m of this section is present.

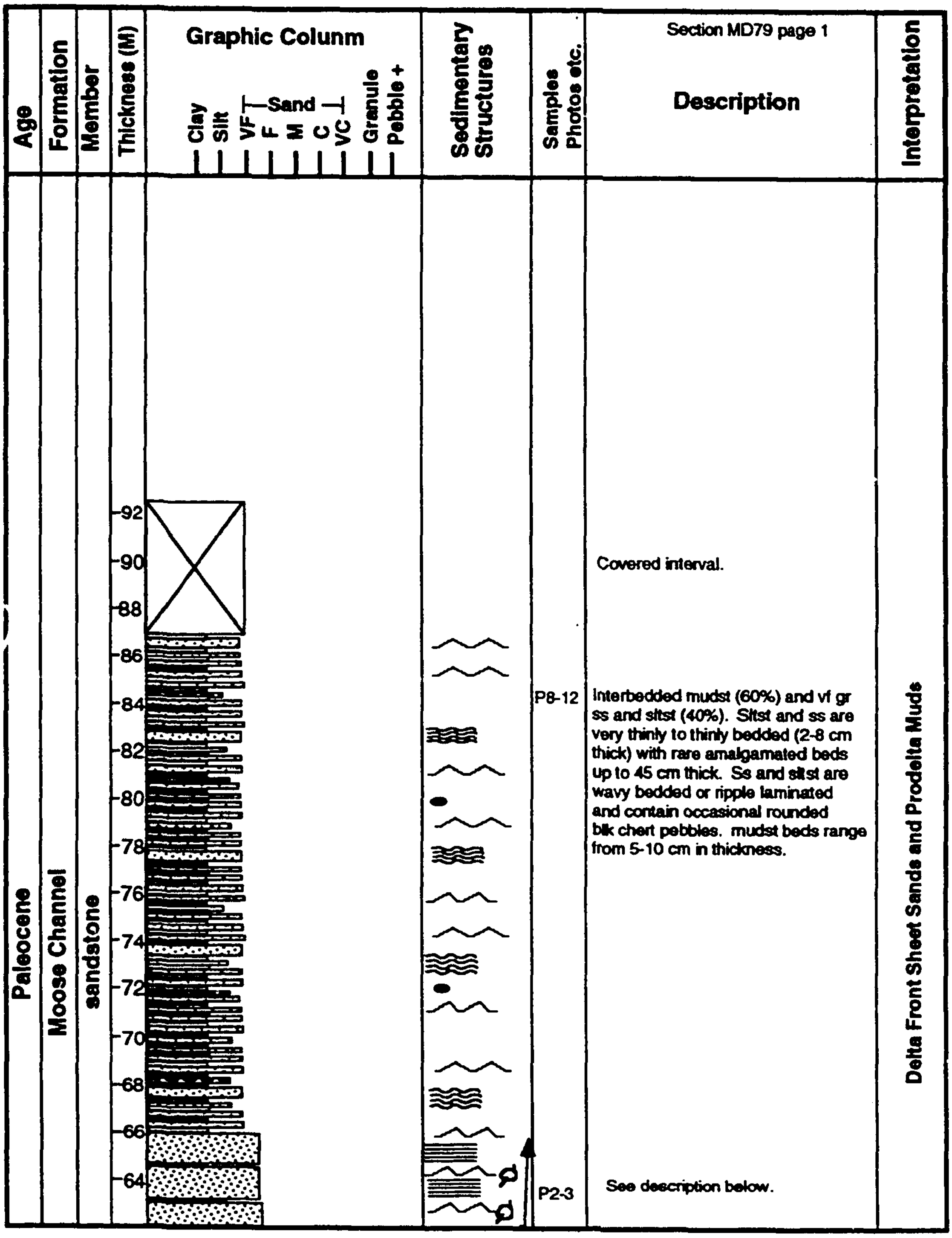
Ss, gry-grn, vf gr, planar bedded to very low angle trough cross bedded.

Conglomerate, rounded chert pebble, matrix supported. Matrix is poorly sorted m-c ss.

Ss, gry-brn, f gr, medium to very thickly bedded. Trough cross bedded and ripple lam, ripples are straight crested and symmetrical. Contains granule and pebble lags.

Claystone, brn, bioturbated, *Planolites* and *Arenicolites*.

Ss, gry-brn, f gr, very thickly bedded. Trough cross bedded and ripple lam, ripples are straight crested and symmetrical. Contains granule and pebble lags.



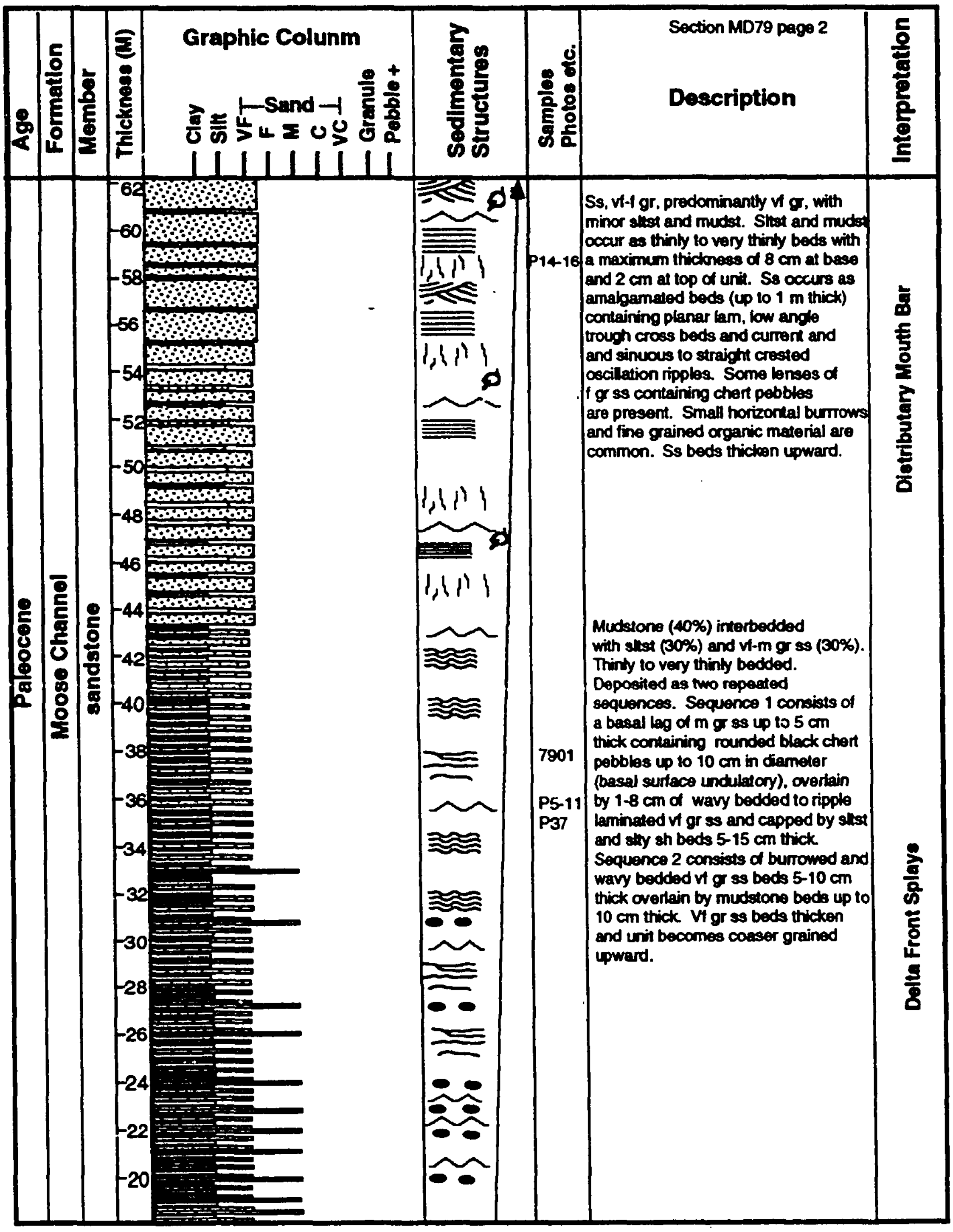
Section MD79 page 1

Description

Covered interval.

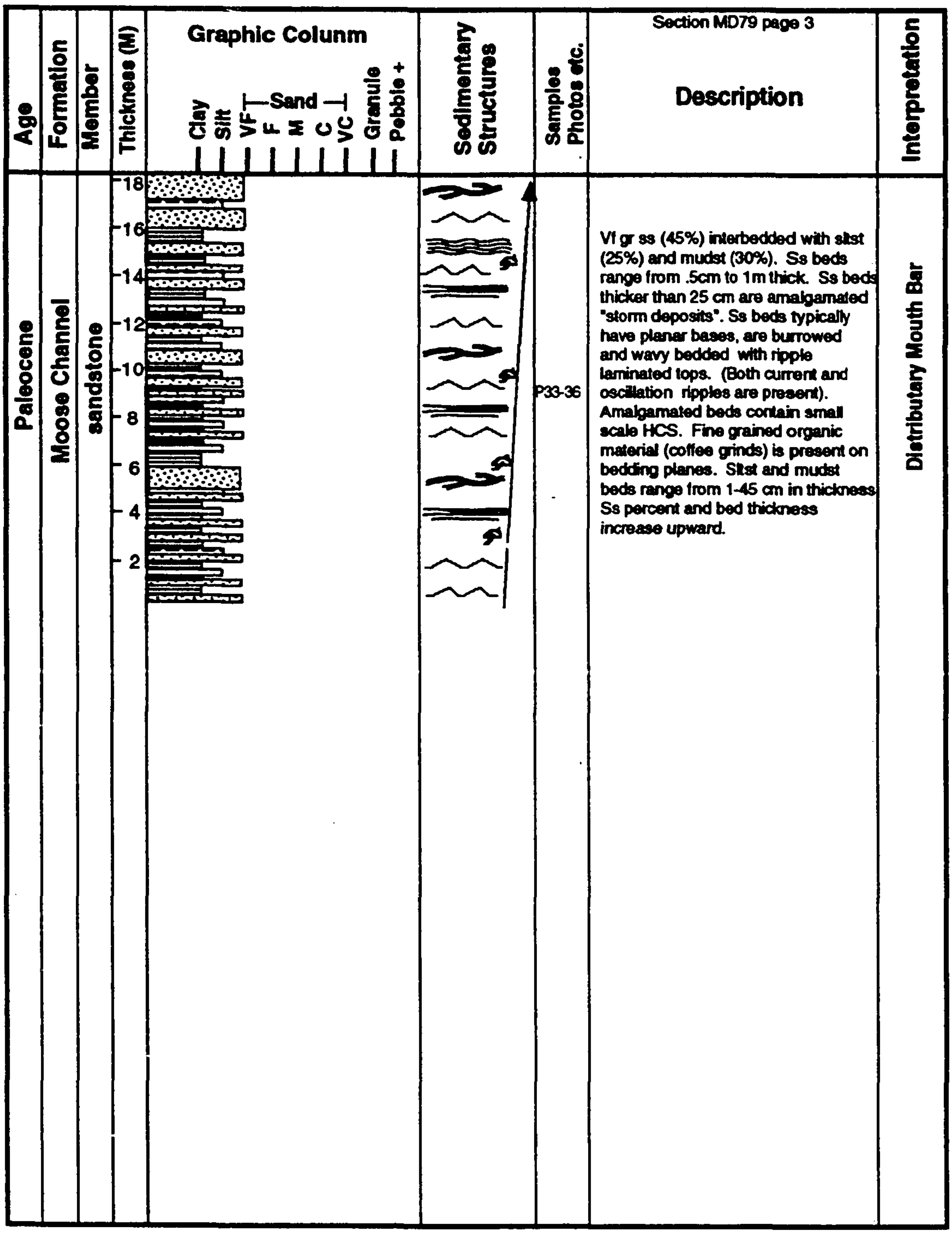
Interbedded mudst (60%) and vf gr ss and sltst (40%). Sltst and ss are very thinly to thinly bedded (2-8 cm thick) with rare amalgamated beds up to 45 cm thick. Ss and sltst are wavy bedded or ripple laminated and contain occasional rounded blk chert pebbles. mudst beds range from 5-10 cm in thickness.

See description below.



Ss, vf-f gr, predominantly vf gr, with minor sltst and mudst. Sltst and mudst occur as thinly to very thinly beds with a maximum thickness of 8 cm at base and 2 cm at top of unit. Ss occurs as amalgamated beds (up to 1 m thick) containing planar lam, low angle trough cross beds and current and and sinuous to straight crested oscillation ripples. Some lenses of f gr ss containing chert pebbles are present. Small horizontal burrows and fine grained organic material are common. Ss beds thicken upward.

Mudstone (40%) interbedded with sltst (30%) and vf-m gr ss (30%). Thinly to very thinly bedded. Deposited as two repeated sequences. Sequence 1 consists of a basal lag of m gr ss up to 5 cm thick containing rounded black chert pebbles up to 10 cm in diameter (basal surface undulatory), overlain by 1-8 cm of wavy bedded to ripple laminated vf gr ss and capped by sltst and silty sh beds 5-15 cm thick. Sequence 2 consists of burrowed and wavy bedded vf gr ss beds 5-10 cm thick overlain by mudstone beds up to 10 cm thick. Vf gr ss beds thicken and unit becomes coaser grained upward.



Vf gr ss (45%) interbedded with sltst (25%) and mudst (30%). Ss beds range from .5cm to 1m thick. Ss beds thicker than 25 cm are amalgamated "storm deposits". Ss beds typically have planar bases, are burrowed and wavy bedded with ripple laminated tops. (Both current and oscillation ripples are present). Amalgamated beds contain small scale HCS. Fine grained organic material (coffee grinds) is present on bedding planes. Sltst and mudst beds range from 1-45 cm in thickness. Ss percent and bed thickness increase upward.

PLATE 1: SPREAD SHEET OF PETROGRAPHIC POINT COUNT DATA
Myers, Mark D.
Evolution of Late Cretaceous-Early Tertiary Depositional Sequences in the Beaufort-Mackenzie Basin; Canada

Mackenzie Delta Petro. Data

	A	B	C	D	E	F	G	H	J	K	L
1	PETROGRAPHIC MODAL ANALYSIS										
2	MARK MYERS OCTOBER 1989										
3	SAMPLE NUMBER	88MD203	85MD2704	85MD404	85MD2708B	85MD2711B	85MD2712A	85MD2714B	85MD809	85MD812	85MD8
4	LOCALITY	FISH RIVER	FISH RIVER	FISH RIVER	FISH RIVER	FISH RIVER	FISH RIVER	FISH RIVER	EAGLE CREEK	EAGLE CREEK	EAGLE C
5	LATITUDE	68 33' N	68 33' N	68 36' N	68 33' N	68 33' N	68 33' N	68 33' N	68 43' N	68 43' N	68 43' N
6	LONGITUDE	138 18' W	135 15' W	136 10' W	135 15' W	135 15' W	135 15' W	135 15' W	138 33' W	136 33' W	136 33'
7	COLLECTED BY	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM
8	POINT COUNTED BY	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM
9	ROCK UNIT	UPPER TI	UPPER TI	LOWER MC	BASE MC	MC	MC	MC	MC	MC	MC
10	DEPOSITIONAL ENVIRONMENT	DELTA FRONT	DELTA FRONT	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DP/FLUVIAL	SHELF	DELTA FRONT	DELTA
11	GRAIN SIZE	UM-LC	VF-F	M	VF-F	F	F-M	M	M	UM	M
12	ROUNDING	SUBANGULAR	A-SA	SUBANGULAR	A-SA	A-SA	SA-SR	SA	SA-SR	SA-SR	SUBANG
13	SORTING	WELL	MODERATE	MODERATE	POORLY	MODERATE	WELL	MODERATE	MOD-WELL	MOD-WELL	MODERA
14											
15	*QUARTZ*										
16	QUARTZ, polycrystalline, coarse	27	7	58	37	15	53	31	25	32	
17	QUARTZ, monocrystalline, undulose	33	35	83	53	43	33	40	58	55	
18	QUARTZ, monocrystalline, straight	19	56	35	59	25	38	14	20	13	
19	QUARTZ, polycrystalline, equigranular	7	20	8	22	14	20	14	17	14	
20	QUARTZ, polycrystalline, foliated	4	1	10	3	1	4	2	2	3	
21	QUARTZ, undifferentiated										
22	*FELDSPAR*										
23	PLAGIOCLASE, twinned	7	24	1	29	24	6	21	5	6	
24	PLAGIOCLASE, untwinned		38	1	32	80	27	32	4	4	
25	POTASSIUM FELDSPAR		9	5	5	7	7	5	6	17	
26	FELDSPAR, undifferentiated										
27	FELDSPAR, altered										
28	*SEDIMENTARY ROCK FRAGMENTS*										
29	CHERT (microcrystalline quartz)	56	10	13	17	10	49	34	29	23	
30	CHERT, radiolarian	5		3				2		1	
31	CHERT, foliated	3	1	2	1	1	2	1	1	3	
32	CHERT, fibrous						1		1		
33	PROBABLE CHERTY GRAIN										
34	CHERTY ARGILLITE	53	4	10	6	7	56	33	55	36	
35	ARGILLITE	4	14	8	6	8	6	4	6	16	
36	SILTSTONE	7		3		1	2	2	2	4	
37	SANDSTONE	12		3			2		2	4	
38	SLATE/SHALE	5	2	3	4	3	9	2	3	5	
39	CARBONATE, extrabasinal	5		4				-	1	1	
40	COAL/ORGANIC DETRITUS	1	31	1	5	6	1	2		1	
41	PROBABLE SEDIMENTARY ROCK FRAG.										
42	UNDIFFERENTIATED SRF										
43	*VOLCANIC ROCK FRAGMENTS*										
44	VITRIC/CRYPTOCRYSTALLINE VRF		16		1	4	1	2			
45	MICROCRYSTALLINE FELSIC VRF	6	14	1	21	26	11	24	4	19	
46	MICROGRANULAR FELSIC VRF	2	6	4	15	6	16	18	5	8	
47	MICROLITIC VRF	10	78		36	81	24	79	12	2	
48	LATHWORK VRF	11	13	10	13	21	8	21	25	15	
49	MAFIC VRF										
50	TUFFACEOUS VRF			2					1		
51	ALTERED VRF										
52	PROBABLE VRF										
53	UNDIFFERENTIATED VRF										
54	*METAMORPHIC ROCK FRAGMENTS*										
55	UNFOLIATED METACLASTIC			5	1	2	4			3	
56	QUARTZ MICA PHYLLITE	10	2	4	18	7	11	6		2	
57	QUARTZ-MICA SCHIST/GNEISS	6	1	9			2	1	7	4	
58	GREENSTONE										
59	GREEN PHYLLITE					1					
60	GREENSCHIST/AMPHIBOLITE										
61	HORNFELS										
62	PROBABLE MRF										
63	UNDIFFERENTIATED MRF										
64	*PLUTONIC ROCK FRAGMENTS*										
65	FELSIC PRF	2	1	2	4	1	1	6	3	4	
66	MAFIC PRF										
67	INTERMEDIATE PRF	4	5	1		1			1		
68	PROBABLE PRF										
69	UNDIFFERENTIATED PRF										
70	*DETRITAL MINERALS*										
71	BIOTITE		2								
72	WHITE MICA		4		7	1		1	3	1	
73	CHLORITE		1	1	5	2		2	1		
74	CLINOPYROXENE										
75	AMPHIBOLE										
76	GARNET										
77	ZIRCON										
78	TOURMALINE										
79	RUTILE										
80	OTHER MINERALS						2				
81	UNDIFFERENTIATED HEAVY MINERAL										
82	INDETERMINANT GRAIN	1	5	1		2		1	1	4	
83	*MATRIX*										
84	SILTY	4		37	1	1					
85	ARGILLACEOUS	10		2					1	2	
86	PSUEDOMATRTIX	5									
87	MATRIX, other or undifferentiated		3		5		2	3			
88	*CEMENT*										
89	SILICA	2		1						2	
90	CARBONATE, undifferentiated	30	70		40	2			4	18	
91	CARBONATE, calcite										
92	CARBONATE, dolomite										
93	CARBONATE, ankerite										
94	CARBONATE, siderite										
95	HEMATITE	7		4						8	

Mackenzie Delta Petro. Data

J	K	L		M	N	O	P	Q	R	S	T	U	V	W	X
			1												
			2												
5MD809	85MD812	85MD819	3	85MD7901	85MD823	85MD1105B	85MD1106	85MD1109A	85MD1201	85MD1208A	85MD1501	85MD1511	85MD104	85MD3706	85MD3711
AGLE CREEK	EAGLE CREEK	EAGLE CREEK	4	EAGLE CREEK	EAGLE CREEK	AKLAK CREEK	AKLAK CREEK	AKLAK CREEK	AKLAK CREEK	AKLAK CREEK	AKLAK CREEK	AKLAK	AKLAK CREEK	BIG FISH RIV.	BIG FISH RIV.
8 43' N	68 43' N	68 43' N	5	68 44' N	68 43' N	68 40' N	68 40' N	68 40' N	68 41' N	68 41' N	68 41' N	68 41' N	68 41' N	68 29' N	68 29' N
36 33' W	136 33' W	136 33' W	6	136 35' W	136 33' W	136 21' W	136 21' W	136 21' W	136 20' W	136 20' W	136 20' W	136 20' W	136 19' W	136 26' W	136 26' W
DM	MDM	MDM	7	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM
DM	MDM	MDM	8	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM	MDM
C	MC	MC	9.	LOWER MC	MINISTICOOG	MINISTICOOG	AKLAK	AKLAK	AKLAK	AKLAK	AKLAK	AKLAK	AKLAK	CUESTA CREE	CUESTA CREE
HELF	DELTA FRONT	DELTA PLAIN	10	DELTA FRONT	DF-SHELF	DF-SHELF	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	DELTA PLAIN	SUB. CANYON	SUB. CANYON
	UM	M	11	UM	UM-LC	VF-F	VF-F	F-M	FINE	VF-F	UF-LM	UM-LC	VF-LM	UM	UM
A-SR	SA-SR	SUBANGULAR	12	SA-SR	SUBANGULAR	SA-SR	SA-SR	SA-SR	SA	SA-SR	SA-SR	SA-SR	SA-SR	SA-A	SA
OD-WELL	MOD-WELL	MODERATE	13	MODERATE	POORLY	WELL	MODERATE	MODERATE	WELL	WELL	WELL	MOD	WELL	POORLY	POORLY
			14												
			15												
25	32	24	16	25	25	18	34	35	28	31	29	26	8	61	62
58	55	69	17	37	37	82	74	40	38	56	33	21	24	40	42
20	13	29	18	32	9	44	36	17	21	25	35	10	11	24	8
17	14	10	19	17	7	45	47	21	18	31	30	12	19	20	39
2	3	4	20	2	7	2	1	1	4	3	2		1	10	7
			21												
			22												
5	6	10	23	4		1	1	2		2	2			3	1
4	4	3	24		2	1	1				1				
6	17	9	25	8	6	5	1	8	5	5	3	3	5	2	
			26												
			27										1		
			28												
29	23	15	29	34	56	16	28	67	29	31	38	69	55	8	19
	1		30		3		5	1				5	2		
1	3		31	1	1	1	1	1		3	1	5	2		1
1		1	32							1	2			2	
			33												
55	36	43	34	63	70	40	53	73	51	89	81	85	69	24	43
6	18	12	35	11	17	30	29	24	36	47	42	32	22	16	9
2	4	2	36	4	4	1		6	10	1		4	10	1	
2	4	2	37	2	3	1	2	5	3	2		5	4	2	
3	5	3	38	6	16	15	8	10	14	11	20	8	17	26	14
1	1	11	39	1					3						
	1		40	2	4	31	23	9	9	17	22	5	21	4	2
			41												
			42												
			43												
			44	2			1	1			1				
4	19	1	45	10	8	6	5	9	2	5	2	4	5	2	5
5	8	1	46	4	1	5	7	3		4	4		9	3	5
12	2	14	47	17	3		4	22	1	4	1			2	2
25	15	23	48	5	2			4			1		2		1
			49												
1			50												
			51												
			52												
			53												
			54												
	3		55	1	5	9	9	7	6	10	5	1		8	11
	2	4	56	2	3	32	16	23	4	18	23		5	14	10
7	4	3	57	2	5	2	4	3	8	1	2	4	1	15	13
			58												
			59												
			60												
			61												
			62												
			63												
			64												
3	4	2	65	2	1		1	4	2		4		2	1	
			66												
1			67												
			68												
			69												
			70												
			71			1					1		1	3	
3	1	4	72		3	11	6	0	5	2	6	1		8	13
1			73	2		1	2	2	3		5		2		
			74												
			75												
			76												
			77												
			78												
			79												
		1	80												
			81	1											
1	4		82	3	2		1	2		1	4		2	1	2
			83												
		1	84	4	2				4			1	1	2	
1	2	2	85	10	9				11			3	11	4	3
			86	3	1	2			5				1	3	5
			87			5	2	5		1	3				
			88												
	2		89	2					1	4				2	
4	18	5	90	67						1				1	
			91												
			92												
			93												
			94												

U	V	W	X	Y		Z	AA	AB	AC	AD	AE	AF	AG	AH
					1									
					2		AVE CC	AVE UTI	AVE L. MC	AVE UTI+LMC	AVE MI	AVE AK	AVE MI & AK	AVE TOTAL
5MD1511	85MD104	85MD3708	85MD3711	88MD7101	3	88MD7104	N=4	N=2	N=9	N=11	N=2	N=7	N=11	N=24
KLAK	AKLAK CREEK	BIG FISH RIV	BIG FISH RIV.	HORNET CREE	4	HORNET CREEK								
8 41' N	68 41' N	68 29' N	68 29' N	68 41' N	5	68 41' N								
36 20' W	136 19' W	136 26' W	136 26' W	136 42' W	6	136 42' W								
DM	MDM	MDM	MDM	MDM	7	MDM								
DM	MDM	MDM	MDM	MDM	8	MDM								
KLAK	AKLAK	CUESTA CREE	CUESTA CREE	CUESTA CREE	9	CUESTA CREEK								
ELTA PLAIN	DELTA PLAIN	SUB. CANYON	SUB. CANYON	SUB. CANYON	10	SUB. CANYON								
M-LC	VF-LM	LM	LM	LM	11	M								
A-SR	SA-SR	SA-A	SA	SA-SR	12	SA								
OD	WEL.	POORLY	POORLY	MODERATE	13	MODERATE								
					14									
					15									
26	8	61	62	81	16	88								
21	24	40	42	38	17	24								
10	11	24	8	20	18	9								
12	19	20	30	16	19	11								
	1	10	7	6	20	6								
					21									
					22									
		3	1	1	23	1								
					24									
3	5	2			25									
					26									
	1				27									
					28									
69	55	8	19	8	29	4								
5	2				30									
5	2		1	1	31									
		2			32									
					33									
85	69	24	43	21	34	37								
32	22	16	9	12	35	17								
4	10	1			36	9								
5	4	2		1	37	3								
8	17	26	14	32	38	19								
				5	39	5								
5	21	4	2	4	40	2								
					41									
					42									
					43									
					44									
4	5	2	5		45	2								
	9	3	5		46									
		2	2		47	1								
	2		1		48									
					49									
					50									
					51									
					52									
					53									
					54									
1		8	11	10	55	11								
	5	14	10	15	56	20								
4	1	15	13	17	57	22								
					58									
					59									
					60									
					61									
					62									
					63									
					64									
	2	1			65									
					66									
					67									
					68									
					69									
					70									
	1	3		1	71	2								
1		8	13	10	72	7								
	2				73									
					74									
					75									
					76									
					77									
					78									
					79									
					80									
					81									
	2	1	2	1	82									
					83									
1	1	2		6	84	4								
3	11	4	3	21	85	17								
	1	3	5	8	86	12								
					87									
					88									
		2		9	89	2								
		1		6	90	6								
					91									
					92									
					93									
					94									
7		16	14	5	95	9								

84	SILTY	4		37	1	1				
85	ARGILLACEOUS	10		2					1	2
86	PSUEDOMATRTIX	5								
87	MATRIX, other or undifferentiated		3		5		2	3		
88	*CEMENT*									
89	SILICA	2		1						2
90	CARBONATE, undifferentiated	30	70		40	2			4	18
91	CARBONATE, calcite									
92	CARBONATE, dolomite									
93	CARBONATE, ankerite									
94	CARBONATE, siderite									
95	HEMATITE	7		4						6

	A	B	C	D	E	F	G	H	J	K
96	CLAY MINERALS, undifferentiated	2		3	3	2	29	3	2	5
97	KAOLINITE	2		2					1	9
98	SULFATES									
99	GLAUCONY									
100	PHOSPHATES									
101	CEMENT, other or undifferentiated									
102	*METAMORPHIC MINERALS*									
103	CHLORITE	3		3	5	4				1
104	ZEOLITE									
105	ALBITE									
106	EPIDOTE									
107	CLINOZOISITE									
108	ZOISITE									
109	PREHNITE									
110	PUMPELLYITE									
111	ACTINOLITE									
112	GLAUCOPHANE									
113	LAWSONITE									
114	JADITE									
115	OTHER METAMORPHIC MINERALS					2				
116	*OVERSIZE & INTRABASINAL GR.*									
117	OVERSIZE, clastic rip-up									
118	OVERSIZE, invertebrate fossil									
119	OVERSIZE, intrabasinal carbonate									
120	DETRITAL PEBBLE									
121	OTHER OVERSIZE GRAIN									
122	*MISCELLANEOUS*									
123	POROSITY	1	1	15		6	4	4	29	8
124	OIL									
125	BITUMIN									
126										
127	*TOTALS*-------------------									
128	TOTAL DETRITAL SAND GRAINS	300	400	300	400	400	400	400	300	300
129	TOTAL MATRIX	19	3	39	6	1	2	3	1	2
130	TOTAL CEMENT	43	70	10	43	4	29	3	7	40
131	TOTAL METAMORPHIC MINERALS	3	0	3	5	6	0	0	0	1
132	TOTAL OVERSIZE GRAINS	0	0	0	0	0	0	0	0	0
133	TOTAL POINTS COUNTED	366	474	367	454	417	435	410	337	351
134										
135	*PERCENTAGES*-------------									
136	DETRITAL GRAINS	82.0%	84.4%	81.7%	88.1%	95.9%	92.0%	97.6%	89.0%	85.5%
137	MATRIX	5.2%	0.6%	10.6%	1.3%	0.2%	0.5%	0.7%	0.3%	0.6%
138	CEMENT	11.7%	14.8%	2.7%	9.5%	1.0%	6.7%	0.7%	2.1%	11.4%
139	METAMORPHIC MINERALS	0.8%	0.0%	0.8%	1.1%	1.4%	0.0%	0.0%	0.0%	0.3%
140	OVERSIZE GRAINS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
141	POROSITY	0.3%	0.2%	4.1%	0.0%	1.4%	0.9%	1.0%	8.6%	2.3%
142	PETROLEUM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
143	POROSITY + PETROLEUM	0.3%	0.2%	4.1%	0.0%	1.4%	0.9%	1.0%	8.6%	2.3%
144	Qm	17.3%	22.8%	39.3%	28.0%	17.0%	17.8%	13.5%	26.0%	22.7%
145	Qms (straight extinction)	6.3%	14.0%	11.7%	14.8%	6.3%	9.5%	3.5%	6.7%	4.3%
146	Qmu (undulose extinction)	11.0%	8.8%	27.7%	13.3%	10.8%	8.3%	10.0%	19.3%	18.3%
147	Qp	12.7%	7.0%	25.3%	15.5%	7.5%	19.3%	11.8%	14.7%	16.3%
148	C (chert)	21.3%	2.8%	6.0%	4.5%	2.8%	13.0%	9.3%	10.3%	9.0%
149	C* (C+ CHERTY ARGILLITE)	39.0%	3.8%	12.3%	6.0%	4.5%	27.0%	17.5%	28.7%	21.0%
150	Qp* (Qp+C)	34.0%	9.8%	31.3%	20.0%	10.3%	32.3%	21.0%	25.0%	25.3%
151	Q (TOTAL QUARTZ)	30.0%	29.6%	64.7%	43.5%	24.5%	37.0%	25.3%	40.7%	39.0%
152	Q* (TOTAL QUARTZ + CHERT	51.3%	32.5%	70.7%	48.0%	27.3%	50.0%	34.5%	51.0%	48.0%
153	K (POTASSIUM FELDSPAR)	0.0%	2.3%	1.7%	1.3%	1.8%	1.8%	1.3%	2.0%	5.7%
154	P (PLAGIOCLASE FELDSPAR)	2.3%	15.0%	0.7%	15.3%	26.0%	8.3%	13.3%	3.0%	3.3%
155	F (TOTAL FELDSPAR)	2.3%	17.3%	2.3%	16.5%	27.8%	10.0%	14.5%	5.0%	9.0%
156	Ls- (SRF-C)	29.0%	12.8%	13.7%	5.3%	5.8%	19.5%	10.8%	23.0%	22.3%
157	Ls+ (SRF+C)	50.3%	15.5%	19.7%	9.8%	8.5%	32.5%	20.0%	33.3%	31.3%
158	Lvf (felsic VRF)	2.7%	9.5%	1.7%	9.3%	9.5%	7.5%	11.0%	3.0%	9.0%
159	Lvm (mafic +intermediate VRF)	7.0%	22.8%	4.0%	12.3%	25.5%	8.0%	25.0%	12.7%	5.7%
160	Lv (total volcanic rock fragments)	9.7%	32.3%	5.7%	21.5%	35.0%	15.5%	36.0%	15.7%	14.7%
161	Lm (total metamorphic rock fragment	5.3%	0.8%	6.0%	4.8%	2.5%	4.3%	1.8%	2.3%	3.0%
162	Lpf (felsic prf)	0.7%	0.3%	0.7%	1.0%	0.3%	0.3%	1.5%	1.0%	1.3%
163	Lpm (mafic PRF)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
164	Lpi (intermediate PRF)	1.3%	1.3%	0.3%	0.0%	0.3%	0.0%	0.0%	0.3%	0.0%
165	Lp (total plutonic rock fragments)	2.0%	1.5%	1.0%	1.0%	0.5%	0.3%	1.5%	1.3%	1.3%
166	Li (Lv+Lp)	11.7%	33.8%	6.7%	22.5%	35.5%	15.8%	37.5%	17.0%	16.0%
167	L (Ls+ + Lv +Lm +Lp)	67.3%	50.0%	32.3%	37.0%	46.5%	52.5%	59.3%	52.7%	50.3%
168	L- (Ls- + Lv + Lm + Lp)	46.0%	47.3%	26.3%	32.5%	43.8%	39.5%	50.0%	42.3%	41.3%
169	Lt (Qp* + Ls - + Lv + Lm + Lp)	80.0%	57.0%	57.7%	52.5%	54.0%	71.6%	71.0%	67.3%	66.7%
170										
171	*RATIOS*-----------------									
172	Q:F:L (quartz)	30.1%	30.7%	65.1%	44.8%	24.8%	37.2%	25.5%	41.4%	39.7%
173	Q:F:L (feldspar)	2.3%	17.6%	2.3%	17.0%	28.1%	10.1%	14.6%	5.1%	9.2%
174	Q:F:L (lithics)	67.6%	51.5%	32.6%	38.1%	47.1%	52.8%	59.8%	53.6%	61.2%
175	Q*:F:L- (quartz+chert)	51.5%	33.5%	71.1%	49.5%	27.6%	50.3%	34.8%	51.9%	48.8%
176	Q*:F:L- (feldspar)	2.3%	17.8%	2.3%	17.0%	28.1%	10.1%	14.6%	5.1%	9.2%
177	Q*:F:L- (lithics)	46.2%	48.7%	26.5%	33.5%	44.3%	39.7%	50.5%	43.1%	42.0%
178	Q:Ls+:Li (quartz)	32.6%	37.7%	71.1%	57.4%	35.8%	43.4%	30.5%	44.7%	45.2%
179	Q:Ls+:Li (SRF+chert)	54.7%	19.8%	21.6%	12.9%	12.4%	38.1%	24.2%	36.6%	36.3%
180	Q:Ls+:Li (lithic igneous)	12.7%	42.7%	7.3%	29.7%	51.8%	18.5%	45.3%	18.7%	18.5%
181	Q:Ls+:Lv (	33.3%	38.4%	71.9%	58.2%	36.0%	43.5%	31.1%	45.4%	45.9%
182	Q:Ls+:Lv	55.9%	20.0%	21.9%	13.0%	12.5%	38.2%	24.6%	37.2%	36.9%
183	Q:Ls+:Lv	10.7%	41.6%	6.3%	28.8%	51.5%	18.2%	44.3%	17.5%	17.3%
184	Q:Ls+:(Li+F)	31.8%	30.9%	69.3%	47.2%	25.5%	38.8%	26.0%	42.4%	40.9%
185	Q:Ls+:(Li+F)	53.4%	16.1%	21.1%	10.6%	8.8%	34.1%	20.6%	34.7%	32.9%
186	Q:Ls+:(Li+F)	14.8%	53.0%	9.6%	42.3%	65.7%	27.0%	53.5%	22.9%	26.2%
187	Qms:Qmu:Qp	21.1%	47.1%	18.0%	33.9%	25.5%	25.7%	13.9%	16.4%	11.1%
188	Qms:Qmu:Qp	36.7%	29.4%	42.8%	30.5%	43.9%	22.3%	39.6%	47.5%	47.0%
189	Qms:Qmu:Qp	42.2%	23.5%	39.2%	35.6%	30.6%	52.0%	46.5%	36.1%	41.9%
190	Lv:Ls+:Lm	14.8%	66.5%	18.1%	59.7%	76.1%	29.7%	62.3%	30.5%	29.9%

	A	B	C	D	E	F	G	H	J	K
191	Lv:Ls+:Lm	77.0%	32.0%	62.8%	27.1%	16.5%	62.2%	34.6%	64.9%	63.9%
192	Lv:Ls+:Lm	8.2%	1.5%	19.1%	13.2%	5.4%	8.1%	3.0%	4.6%	6.1%
193	Framework:Matrix:Cement	82.9%	84.6%	86.0%	89.1%	98.8%	92.8%	98.5%	97.4%	87.7%
194	Framework:Matrix:Cement	5.2%	0.6%	11.2%	1.3%	0.2%	0.5%	0.7%	0.3%	0.6%

		1	84	4	2				4			1	1	2	
1	2	2	85	10	9				11			3	11	4	
			86	3	1	2			5				1	3	
			87			5	2	5		1	3				
			88												
	2		89	2					1	4				2	
4	16	5	90	67						1				1	
			91												
			92												
			93												
			94												
	6	4	95	4	5				8		1	7		16	

J	K	L		M	N	O	P	Q	R	S	T	U	V	W	X
2	5		96		2	1			3					4	
1	9	7	97		17				12			7		11	
			98												
			99												
			100												
			101				1	5							
			102												
	1		103			2	10	5	1	1	5	4		1	
			104												
			105												
			106												
			107												
			108												
			109												
			110												
			111												
			112												
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			117												
			118												
			119												
			120												
			121												
			122												
29	8	13	123		17	16	26		16	16	10	27	19	12	
			124												
			125												
			126												
			127												
300	300	300	128	300	300	400	400	400	300	400	400	300	300	300	3
1	2	3	129	17	12	7	2	5	20	1	3	4	13	9	
7	40	16	130	73	24	1	1	5	24	5	1	14	0	34	
0	1	0	131	0	0	2	10	5	1	1	5	4	0	1	
0	0	0	132	0	0	0	0	0	0	0	0	0	0	0	
337	351	332	133	390	353	426	439	415	363	423	419	349	332	356	3
			134												
			135												
89.0%	85.5%	90.4%	136	76.9%	85.0%	93.9%	91.1%	96.4%	82.6%	94.6%	95.5%	86.0%	90.4%	84.3%	88.0
0.3%	0.6%	0.9%	137	4.4%	3.4%	1.6%	0.5%	1.2%	5.5%	0.2%	0.7%	1.1%	3.9%	2.5%	2.3
2.1%	11.4%	4.8%	138	18.7%	6.8%	0.2%	0.2%	1.2%	6.8%	1.2%	0.2%	4.0%	0.0%	9.6%	6.2
0.0%	0.3%	0.0%	139	0.0%	0.0%	0.5%	2.3%	1.2%	0.3%	0.2%	1.2%	1.1%	0.0%	0.3%	0.0
0.0%	0.0%	0.0%	140	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
8.6%	2.3%	3.9%	141	0.0%	4.8%	3.8%	5.9%	0.0%	5.0%	3.8%	2.4%	7.7%	5.7%	3.4%	3.5
0.0%	0.0%	0.0%	142	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
8.6%	2.3%	3.9%	143	0.0%	4.8%	3.8%	5.9%	0.0%	5.0%	3.8%	2.4%	7.7%	5.7%	3.4%	3.5
26.0%	22.7%	32.7%	144	23.0%	15.3%	31.5%	27.5%	14.3%	19.7%	20.3%	17.0%	10.3%	11.7%	21.3%	16.7
6.7%	4.3%	9.7%	145	10.7%	3.0%	11.0%	9.0%	4.3%	7.0%	6.3%	6.8%	3.3%	3.7%	8.0%	2.7
19.3%	18.3%	23.0%	146	12.3%	12.3%	20.5%	18.5%	10.0%	12.7%	14.0%	8.3%	7.0%	8.0%	13.3%	14.0
14.7%	16.3%	12.7%	147	14.7%	13.0%	16.3%	20.5%	14.3%	18.7%	16.3%	15.3%	12.7%	9.3%	30.3%	33.0
10.3%	9.0%	5.3%	148	11.7%	20.0%	4.3%	8.5%	17.3%	9.7%	8.8%	10.3%	26.3%	19.7%	3.3%	6.7
28.7%	21.0%	19.7%	149	32.7%	43.3%	14.3%	21.8%	35.5%	26.7%	31.0%	30.5%	54.7%	42.7%	11.3%	21.0
25.0%	25.3%	18.0%	150	26.3%	33.0%	20.5%	29.0%	31.5%	26.3%	25.0%	25.5%	39.0%	29.0%	33.7%	39.7
40.7%	39.0%	45.3%	151	37.7%	28.3%	47.8%	48.0%	28.5%	36.3%	36.5%	32.3%	23.0%	21.0%	51.7%	49.7
51.0%	48.0%	50.7%	152	49.3%	48.3%	52.0%	56.5%	45.8%	46.0%	45.3%	42.5%	49.3%	40.7%	55.0%	56.3
2.0%	5.7%	3.0%	153	2.7%	2.0%	1.3%	0.3%	2.0%	1.7%	1.3%	0.8%	1.0%	1.7%	0.7%	0.0
3.0%	3.3%	4.3%	154	1.3%	0.7%	0.5%	0.5%	0.5%	0.0%	0.5%	0.8%	0.0%	0.0%	1.0%	0.3
5.0%	9.0%	7.3%	155	4.0%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.5%	1.0%	2.0%	1.7%	0.3
23.0%	22.3%	24.3%	156	29.7%	38.0%	29.5%	28.8%	31.8%	42.0%	41.8%	41.3%	46.3%	47.7%	24.3%	22.7
33.3%	31.3%	29.7%	157	41.3%	58.0%	33.8%	37.3%	49.0%	51.7%	50.5%	51.5%	72.7%	67.3%	27.7%	29.3
3.0%	9.0%	0.7%	158	5.3%	3.0%	2.8%	3.3%	3.3%	0.7%	2.3%	1.8%	1.3%	4.7%	1.7%	3.3
12.7%	5.7%	12.3%	159	7.3%	1.7%	0.0%	1.0%	6.5%	0.3%	1.0%	0.5%	0.0%	0.7%	0.7%	1.0
15.7%	14.7%	13.0%	160	12.7%	4.7%	2.8%	4.3%	9.8%	1.0%	3.3%	2.3%	1.3%	5.3%	2.3%	4.3
2.3%	3.0%	2.3%	161	1.7%	4.3%	10.8%	7.3%	8.3%	6.0%	7.3%	7.5%	1.7%	2.0%	12.3%	11.3
1.0%	1.3%	0.7%	162	0.7%	0.3%	0.0%	0.3%	1.0%	0.7%	0.0%	1.0%	0.0%	0.7%	0.3%	0.0
0.0%	0.0%	0.0%	163	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
0.3%	0.0%	0.0%	164	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
1.3%	1.3%	0.7%	165	0.7%	0.3%	0.0%	0.3%	1.0%	0.7%	0.0%	1.0%	0.0%	0.7%	0.3%	0.0
17.0%	16.0%	13.7%	166	13.3%	5.0%	2.8%	4.5%	10.8%	1.7%	3.3%	3.3%	1.3%	6.0%	2.7%	4.3
52.7%	50.3%	45.7%	167	56.3%	67.3%	47.3%	49.0%	68.0%	59.3%	61.0%	62.3%	75.7%	75.3%	42.7%	45.0
42.3%	41.3%	40.3%	168	44.7%	47.3%	43.0%	40.5%	50.8%	40.7%	52.3%	52.0%	49.3%	55.7%	39.3%	38.3
67.3%	66.7%	58.3%	169	71.0%	80.3%	63.5%	69.5%	82.3%	76.0%	77.3%	77.5%	88.3%	84.7%	73.0%	78.0
			170												
			171												
41.4%	39.7%	46.1%	172	38.4%	28.9%	49.4%	49.1%	28.8%	37.3%	36.8%	33.6%	23.1%	21.4%	53.8%	52.
5.1%	9.2%	7.5%	173	4.1%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.6%	1.0%	2.0%	1.7%	0
53.8%	51.2%	46.4%	174	57.5%	68.5%	48.8%	50.1%	68.7%	61.0%	61.5%	64.8%	75.9%	76.6%	44.4%	47.
51.9%	48.8%	51.5%	175	50.3%	49.2%	53.7%	57.8%	46.2%	47.3%	45.6%	44.3%	49.5%	41.4%	57.3%	59
5.1%	9.2%	7.5%	176	4.1%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.6%	1.0%	2.0%	1.7%	0
43.1%	42.0%	41.0%	177	45.6%	48.1%	44.4%	41.4%	51.3%	51.0%	52.6%	54.2%	49.5%	56.6%	41.0%	40.
44.7%	45.2%	51.1%	178	40.8%	31.0%	56.7%	53.5%	32.3%	40.5%	40.4%	37.1%	23.7%	22.3%	63.0%	59.
36.6%	36.3%	33.5%	179	44.8%	63.5%	40.1%	41.5%	55.5%	57.6%	56.0%	59.2%	74.9%	71.4%	33.7%	35.2
18.7%	18.5%	15.4%	180	14.4%	5.5%	3.3%	5.0%	12.2%	1.9%	3.6%	3.7%	1.4%	6.4%	3.3%	5.2
45.4%	45.9%	51.5%	181	41.1%	31.1%	56.7%	53.6%	32.7%	40.8%	40.4%	37.5%	23.7%	22.4%	63.3%	59.
37.2%	36.9%	33.7%	182	45.1%	63.7%	40.1%	41.8%	56.2%	58.1%	56.0%	59.0%	74.9%	71.9%	33.9%	35.2
17.5%	17.3%	14.8%	183	13.8%	5.1%	3.3%	4.7%	11.2%	1.1%	3.6%	2.6%	1.4%	5.7%	2.9%	5.2
42.4%	40.9%	47.2%	184	39.1%	30.1%	55.5%	53.0%	31.4%	39.8%	39.7%	36.4%	23.5%	21.8%	61.8%	59
34.7%	32.9%	30.9%	185	42.9%	61.7%	39.2%	41.2%	54.0%	56.6%	54.9%	58.2%	74.1%	69.9%	33.1%	35.
22.9%	26.2%	21.9%	186	18.0%	8.2%	5.2%	5.8%	14.6%	3.6%	5.4%	5.4%	2.4%	8.3%	5.2%	5
16.4%	11.1%	21.3%	187	28.3%	10.6%	23.0%	18.8%	14.9%	19.3%	17.1%	27.1%	14.5%	17.5%	15.5%	5
47.5%	47.0%	50.7%	188	32.7%	43.5%	42.9%	38.5%	35.1%	34.9%	38.4%	25.6%	30.4%	38.1%	25.8%	28
36.1%	41.9%	27.9%	189	38.9%	45.9%	34.0%	42.7%	50.0%	45.9%	44.5%	47.3%	55.1%	44.4%	58.7%	66
30.5%	29.9%	28.9%	190	22.6%	7.0%	5.8%	8.7%	14.6%	1.7%	5.3%	3.7%	1.8%	7.1%	5.5%	9

J	K	L		M	N	O	P	Q	R	S	T	U	V	W	X
64.9%	63.9%	65.9%	191	74.3%	86.6%	71.4%	76.4%	73.1%	88.1%	82.8%	84.1%	96.0%	90.2%	65.4%	65.
4.5%	6.1%	6.2%	192	3.0%	6.5%	22.8%	14.9%	12.3%	10.2%	11.9%	12.2%	2.2%	2.7%	29.1%	25.
97.4%	87.7%	94.0%	193	76.9%	69.3%	98.0%	99.3%	97.6%	87.2%	98.5%	99.0%	94.3%	95.8%	87.5%	91.
0.3%	0.6%	0.9%	194	4.4%	3.6%	1.7%	0.5%	1.2%	5.8%	0.2%	0.7%	1.3%	4.2%	2.6%	2.

3	11	4	3	21	85	17								
	1	3	5	8	86	12								
					87									
					88									
		2		9	89	2								
		1		6	90	6								
					91									
					92									
					93									
					94									
7		16	14	6	95	9								

U	V	W	X	Y		Z	AA	AB	AC	AD	AE	AF	AG	AH
		4			96									
7		11	7	1	97	2								
					98									
					99									
					100									
					101									
					102									
4		1			103	1								
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					122									
27	10	12	12	1	123	2								
					124									
					125									
					126									
					127									
300	300	300	300	300	128	300								
4	13	0	8	35	129	33								
14	0	34	21	21	130	19								
4	0	1	0	0	131	1								
0	0	0	0	0	132	0								
346	332	356	341	357	133	355								
					134									
					135									
86.0%	90.4%	84.3%	88.0%	84.0%	136	84.5%	85.2%	83.3%	88.1%	67.3%	89.9%	91.2%	90.9%	68.3%
1.1%	3.9%	2.5%	2.3%	9.8%	137	9.3%	6.0%	2.6%	2.9%	2.9%	2.4%	1.8%	1.9%	3.0%
4.0%	0.0%	9.6%	6.2%	5.9%	138	5.4%	6.7%	13.5%	6.1%	7.4%	3.2%	1.8%	2.1%	5.4%
1.1%	0.0%	0.3%	0.0%	0.0%	139	0.3%	0.1%	0.4%	0.4%	0.4%	0.3%	0.9%	0.6%	0.5%
0.0%	0.0%	0.0%	0.0%	0.0%	140	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.7%	5.7%	3.4%	3.5%	0.3%	141	0.6%	1.9%	0.2%	2.4%	2.0%	4.2%	4.2%	4.2%	2.8%
0.0%	0.0%	0.0%	0.0%	0.0%	142	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7.7%	5.7%	3.4%	3.5%	0.3%	143	0.6%	1.9%	0.2%	2.4%	2.0%	4.2%	4.2%	4.2%	2.8%
10.3%	11.7%	21.3%	16.7%	19.3%	144	11.0%	17.1%	20.4%	25.1%	[illegible]	24.6%	17.6%	19.2%	21.4%
3.3%	3.7%	8.0%	2.7%	6.7%	145	3.0%	5.1%	10.7%	8.8%	9.1%	7.6%	6.2%	6.5%	7.6%
7.0%	8.0%	13.3%	14.0%	12.7%	146	8.0%	12.0%	9.7%	16.3%	15.2%	17.0%	11.4%	12.7%	13.8%
12.7%	9.3%	30.3%	33.0%	34.3%	147	35.0%	33.2%	9.4%	16.0%	14.9%	14.9%	15.2%	15.2%	17.6%
26.3%	19.7%	3.3%	6.7%	3.0%	148	1.3%	3.6%	10.7%	7.7%	8.2%	11.0%	13.8%	13.2%	9.5%
54.7%	42.7%	11.3%	21.0%	10.0%	149	13.7%	14.0%	18.9%	17.6%	17.9%	28.7%	33.9%	32.3%	22.8%
39.0%	29.0%	33.7%	39.7%	37.3%	150	36.3%	36.8%	20.1%	23.7%	23.1%	25.9%	29.1%	28.4%	27.0%
23.0%	21.0%	51.7%	40.7%	53.7%	151	46.0%	50.3%	29.9%	41.1%	39.2%	39.4%	32.9%	34.3%	38.9%
49.3%	40.7%	55.0%	56.3%	56.7%	152	47.3%	53.8%	40.6%	48.8%	47.4%	60.4%	46.7%	47.5%	48.4%
1.0%	1.7%	0.7%	0.0%	0.0%	153	0.0%	0.2%	1.3%	2.2%	2.0%	1.6%	1.2%	1.3%	1.5%
0.0%	0.0%	1.0%	0.3%	0.3%	154	0.3%	0.5%	9.6%	0.6%	8.7%	0.6%	0.4%	0.4%	4.4%
1.0%	2.0%	1.7%	0.3%	0.3%	155	0.3%	0.7%	10.9%	10.7%	10.8%	2.1%	1.6%	1.7%	5.9%
46.3%	47.7%	24.3%	22.7%	25.0%	156	30.7%	25.7%	19.7%	16.0%	16.7%	33.1%	38.3%	37.9%	25.9%
72.7%	67.3%	27.7%	29.3%	28.0%	157	32.0%	29.3%	30.4%	23.8%	24.9%	44.1%	53.1%	51.2%	35.4%
1.3%	4.7%	1.7%	3.3%	0.0%	158	0.7%	1.4%	6.6%	6.3%	6.3%	2.9%	2.5%	2.6%	4.2%
0.0%	0.7%	0.7%	1.0%	0.0%	159	0.3%	0.5%	16.0%	12.4%	13.0%	0.7%	1.6%	1.4%	6.9%
1.3%	5.3%	2.3%	4.3%	0.0%	160	1.0%	1.9%	22.6%	18.6%	19.3%	3.6%	4.0%	3.9%	11.1%
1.7%	2.0%	12.3%	11.3%	14.0%	161	17.7%	13.8%	2.7%	3.4%	3.3%	8.0%	6.0%	6.4%	6.0%
0.0%	0.7%	0.3%	0.0%	0.0%	162	0.0%	0.1%	9.4%	0.8%	0.7%	0.1%	0.5%	0.4%	0.5%
0.0%	0.0%	0.0%	0.0%	0.0%	163	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.0%	0.0%	0.0%	0.0%	0.0%	164	0.0%	0.0%	1.3%	0.1%	0.3%	6.0%	0.0%	0.0%	0.2%
0.0%	0.7%	0.3%	0.0%	0.0%	165	0.0%	0.1%	1.7%	0.9%	1.0%	0.1%	0.5%	0.4%	0.7%
1.3%	6.0%	2.7%	4.3%	0.0%	166	1.0%	2.0%	24.3%	19.5%	20.3%	3.7%	4.6%	4.4%	11.7%
75.7%	75.3%	42.7%	45.0%	42.0%	167	50.7%	45.1%	57.4%	46.7%	48.6%	55.9%	63.7%	62.0%	53.1%
49.3%	55.7%	39.3%	38.3%	39.0%	168	49.3%	41.5%	46.7%	39.0%	40.3%	44.9%	49.8%	48.0%	43.7%
88.3%	84.7%	73.0%	78.0%	76.3%	169	85.7%	78.3%	66.9%	62.7%	63.4%	70.7%	78.9%	77.1%	70.7%
					170									
					171									
23.1%	21.4%	53.8%	52.3%	55.9%	172	47.4%	52.3%	30.4%	41.7%	39.8%	40.5%	33.5%	35.0%	39.7%
1.0%	2.0%	1.7%	0.4%	0.3%	173	0.3%	0.7%	11.1%	10.9%	10.9%	2.2%	1.6%	1.8%	6.1%
75.9%	76.6%	44.4%	47.4%	43.8%	174	52.2%	47.0%	58.5%	47.4%	49.3%	57.3%	64.9%	63.2%	54.2%
49.5%	41.4%	57.3%	59.3%	59.0%	175	48.8%	56.1%	41.3%	49.5%	48.1%	51.8%	47.6%	48.5%	49.4%
1.0%	2.0%	1.7%	0.4%	0.3%	176	0.3%	0.7%	11.1%	10.9%	10.9%	2.2%	1.6%	1.8%	6.1%
49.5%	56.6%	41.0%	40.4%	40.6%	177	50.9%	43.2%	47.6%	39.6%	40.9%	46.0%	50.8%	49.7%	44.6%
23.7%	22.3%	63.0%	59.6%	65.7%	178	58.2%	61.7%	35.3%	48.7%	46.4%	45.2%	36.3%	38.2%	45.2%
74.9%	71.4%	33.7%	35.2%	34.3%	179	40.5%	35.9%	36.0%	28.2%	29.5%	50.6%	58.7%	56.9%	41.1%
1.4%	6.4%	3.3%	5.2%	0.0%	180	1.3%	2.5%	28.7%	23.1%	24.1%	4.3%	5.0%	4.9%	13.6%
23.7%	22.4%	63.3%	59.6%	65.7%	181	58.2%	61.7%	36.0%	49.2%	47.0%	45.2%	36.5%	38.4%	45.6%
74.9%	71.9%	33.9%	35.2%	34.3%	182	40.5%	35.9%	36.7%	28.5%	29.9%	50.7%	59.0%	57.2%	41.5%
1.4%	5.7%	2.9%	5.2%	0.0%	183	1.3%	2.4%	27.2%	22.3%	23.2%	4.1%	4.5%	4.4%	13.0%
23.5%	21.8%	61.8%	59.4%	65.4%	184	58.0%	61.2%	31.3%	43.2%	41.2%	44.1%	35.7%	37.5%	42.3%
74.1%	69.9%	33.1%	35.1%	34.1%	185	40.3%	35.6%	31.9%	25.0%	26.2%	49.4%	57.6%	55.9%	38.5%
2.4%	8.3%	5.2%	5.8%	0.4%	186	1.7%	3.2%	36.8%	31.8%	32.7%	6.5%	6.7%	6.7%	19.2%
14.5%	17.5%	15.5%	5.4%	12.4%	187	6.5%	10.1%	35.9%	21.5%	23.3%	19.2%	18.9%	18.9%	19.5%
30.4%	38.1%	25.8%	28.2%	23.6%	188	17.4%	23.9%	32.5%	39.7%	38.7%	43.1%	34.6%	36.9%	35.4%
55.1%	44.4%	58.7%	66.4%	64.0%	169	76.1%	66.0%	31.6%	38.9%	37.9%	27.7%	46.4%	44.2%	45.1%
1.8%	7.1%	5.5%	9.6%	0.0%	190	2.0%	4.3%	40.5%	40.7%	40.6%	6.4%	6.4%	6.4%	21.1%

U	V	W	X	Y		Z	AA	AB	AC	AD	AE	AF	AG	AH
96.0%	90.2%	65.4%	65.2%	66.7%	191	63.2%	65.0%	54.6%	51.8%	62.4%	79.2%	84.1%	83.1%	67.5%
2.2%	2.7%	29.1%	25.2%	33.3%	192	34.9%	30.7%	4.9%	7.5%	7.0%	14.4%	8.5%	10.5%	11.4%
94.3%	95.8%	87.5%	91.2%	84.3%	193	85.2%	67.0%	83.8%	90.7%	68.4%	94.1%	98.2%	95.8%	91.3%
1.3%	4.2%	2.6%	2.4%	9.8%	194	9.4%	6.1%	2.6%	3.0%	2.9%	2.6%	1.8%	2.0%	3.1%
										7.6%	3.4%	1.9%	2.2%	5.6%

101	CEMENT, other or undifferentiated										
102	*METAMORPHIC MINERALS*										
103	CHLORITE	3		3	5	4				1	
104	ZEOLITE										
105	ALBITE										
106	EPIDOTE										
107	CLINOZOISITE										
108	ZOISITE										
109	PREHNITE										
110	PUMPELLYITE										
111	ACTINOLITE										
112	GLAUCOPHANE										
113	LAWSONITE										
114	JADITE										
115	OTHER METAMORPHIC MINERALS					2					
116	*OVERSIZE & INTRABASINAL GR.*										
117	OVERSIZE, clastic rip-up										
118	OVERSIZE, invertebrate fossil										
119	OVERSIZE, intrabasinal carbonate										
120	DETRITAL PEBBLE										
121	OTHER OVERSIZE GRAIN										
122	*MISCELLANEOUS*										
123	POROSITY	1	1	15		6	4	4	29	8	13
124	OIL										
125	BITUMIN										
126											
127	*TOTALS*-------------------										
128	TOTAL DETRITAL SAND GRAINS	300	400	300	400	400	400	400	300	300	30
129	TOTAL MATRIX	19	3	39	6	1	2	3	1	2	3
130	TOTAL CEMENT	43	70	10	43	4	29	3	7	40	1
131	TOTAL METAMORPHIC MINERALS	3	0	3	5	8	0	0	0	1	
132	TOTAL OVERSIZE GRAINS	0	0	0	0	0	0	0	0	0	
133	TOTAL POINTS COUNTED	366	474	367	464	417	435	410	337	351	33
134											
135	*PERCENTAGES*-------------										
136	DETRITAL GRAINS	82.0%	84.4%	81.7%	88.1%	95.9%	92.0%	97.6%	89.0%	85.5%	90.4
137	MATRIX	5.2%	0.6%	10.6%	1.3%	0.2%	0.5%	0.7%	0.3%	0.6%	0.9
138	CEMENT	11.7%	14.8%	2.7%	9.5%	1.0%	6.7%	0.7%	2.1%	11.4%	4.8
139	METAMORPHIC MINERALS	0.8%	0.0%	0.8%	1.1%	1.4%	0.0%	0.0%	0.0%	0.3%	0.0
140	OVERSIZE GRAINS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
141	POROSITY	0.3%	0.2%	4.1%	0.0%	1.4%	0.9%	1.0%	6.6%	2.3%	3.9
142	PETROLEUM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
143	POROSITY + PETROLEUM	0.3%	0.2%	4.1%	0.0%	1.4%	0.9%	1.0%	8.6%	2.3%	3.9
144	Qm	17.3%	22.8%	39.3%	28.0%	17.0%	17.8%	13.5%	26.0%	22.7%	32.7
145	Qms (straight extinction)	6.3%	14.0%	11.7%	14.8%	6.3%	9.5%	3.5%	6.7%	4.3%	9.7
146	Qmu (undulose extinction)	11.0%	8.8%	27.7%	13.3%	10.8%	8.3%	10.0%	19.3%	16.3%	23.0
147	Qp	12.7%	7.0%	25.3%	15.5%	7.5%	19.3%	11.8%	14.7%	16.3%	12.7
148	C (chert)	21.3%	2.8%	6.0%	4.5%	2.8%	13.0%	9.3%	10.3%	9.0%	5.3
149	C* (C+ CHERTY ARGILLITE)	39.0%	3.8%	12.3%	6.0%	4.5%	27.0%	17.5%	28.7%	21.0%	19.7
150	Qp* (Qp+C)	34.0%	9.8%	31.3%	20.0%	10.3%	32.3%	21.0%	25.0%	25.3%	16.0
151	Q (TOTAL QUARTZ)	30.0%	29.8%	64.7%	43.5%	24.5%	37.0%	25.3%	40.7%	39.0%	45.3
152	Q* (TOTAL QUARTZ + CHERT	51.3%	32.5%	70.7%	48.0%	27.3%	50.0%	34.5%	51.0%	48.0%	50.7
153	K (POTASSIUM FELDSPAR)	0.0%	2.3%	1.7%	1.3%	1.8%	1.8%	1.3%	2.0%	5.7%	3.0
154	P (PLAGIOCLASE FELDSPAR)	2.3%	15.0%	0.7%	15.3%	26.0%	8.3%	13.3%	3.0%	3.3%	4.3
155	F (TOTAL FELDSPAR)	2.3%	17.3%	2.3%	16.5%	27.8%	10.0%	14.5%	5.0%	9.0%	7.3
156	Ls- (SRF-C)	29.0%	12.8%	13.7%	5.3%	5.8%	19.5%	10.8%	23.0%	22.3%	24.3
157	Ls+ (SRF+C)	50.3%	15.5%	19.7%	9.8%	8.5%	32.5%	20.0%	33.3%	31.3%	29.7
158	Lvf (felsic VRF)	2.7%	9.5%	1.7%	9.3%	9.5%	7.5%	11.0%	3.0%	9.0%	0.7
159	Lvm (mafic +intermediate VRF)	7.0%	22.8%	4.0%	12.3%	25.5%	8.0%	25.0%	12.7%	5.7%	12.3
160	Lv (total volcanic rock fragments)	9.7%	32.3%	5.7%	21.5%	35.0%	15.5%	36.0%	15.7%	14.7%	13.0
161	Lm (total metamorphic rock fragment	5.3%	0.8%	6.0%	4.8%	2.5%	4.3%	1.8%	2.3%	3.0%	2.3
162	Lpf (felsic prf)	0.7%	0.3%	0.7%	1.0%	0.3%	0.3%	1.5%	1.0%	1.3%	0.7
163	Lpm (mafic PRF)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0
164	Lpl (intermediate PRF)	1.3%	1.3%	0.3%	0.0%	0.3%	0.0%	0.0%	0.3%	0.0%	0.0
165	Lp (total plutonic rock fragments)	2.0%	1.5%	1.0%	1.0%	0.5%	0.3%	1.5%	1.3%	1.3%	0.7
166	Li (Lv+Lp)	11.7%	33.8%	6.7%	22.5%	35.5%	15.8%	37.5%	17.0%	16.0%	13.7
167	L (Ls+ + Lv +Lm +Lp)	67.3%	50.0%	32.3%	37.0%	46.5%	52.5%	59.3%	52.7%	50.3%	45.7
168	L- (Ls- + Lv + Lm + Lp)	46.0%	47.3%	26.3%	32.5%	43.8%	39.5%	50.0%	42.3%	41.3%	40.3
169	Lt (Qp* + Ls - + Lv + Lm + Lp)	80.0%	57.0%	57.7%	52.5%	54.0%	71.8%	71.0%	67.3%	66.7%	58.3
170											
171	*RATIOS*------------------										
172	Q:F:L (quartz)	30.1%	30.7%	65.1%	44.8%	24.8%	37.2%	25.5%	41.4%	39.7%	46.1
173	Q:F:L (feldspar)	2.3%	17.8%	2.3%	17.0%	28.1%	10.1%	14.6%	5.1%	9.2%	7.5
174	Q:F:L (lithics)	67.6%	51.5%	32.6%	38.1%	47.1%	52.8%	59.8%	53.6%	61.2%	46.4
175	Q*:F:L- (quartz+chert)	51.5%	33.5%	71.1%	49.5%	27.6%	50.3%	34.8%	51.9%	48.6%	51.5
176	Q*:F:L- (feldspar)	2.3%	17.8%	2.3%	17.0%	28.1%	10.1%	14.6%	5.1%	9.2%	7.5
177	Q*:F:L- (lithics)	46.2%	48.7%	26.5%	33.5%	44.3%	39.7%	50.5%	43.1%	42.0%	41.0
178	Q:Ls+:Li (quartz)	32.6%	37.7%	71.1%	57.4%	35.8%	43.4%	30.5%	44.7%	45.2%	51.1
179	Q:Ls+:Li (SRF+chert)	54.7%	19.6%	21.6%	12.9%	12.4%	38.1%	24.2%	36.6%	36.3%	33.5
180	Q:Ls+:Li (lithic igneous)	12.7%	42.7%	7.3%	29.7%	51.8%	18.5%	45.3%	16.7%	18.5%	15.4
181	Q:Ls+:Lv (	33.3%	38.4%	71.9%	58.2%	36.0%	43.5%	31.1%	45.4%	45.9%	51.5
182	Q:Ls+:Lv	55.9%	20.0%	21.9%	13.0%	12.5%	38.2%	24.6%	37.2%	36.9%	33.7
183	Q:Ls+:Lv	10.7%	41.6%	6.3%	28.8%	51.5%	18.2%	44.3%	17.5%	17.3%	14.8
184	Q:Ls+:(Li+F)	31.8%	30.9%	69.3%	47.2%	25.5%	38.8%	26.0%	42.4%	40.9%	47.2
185	Q:Ls+:(Li+F)	53.4%	16.1%	21.1%	10.6%	6.8%	34.1%	20.6%	34.7%	32.9%	30.9
186	Q:Ls+:(Li+F)	14.8%	53.0%	9.6%	42.3%	65.7%	27.0%	53.5%	22.9%	26.2%	21.9
187	Qms:Qmu:Qp	21.1%	47.1%	16.0%	33.9%	25.5%	25.7%	13.9%	16.4%	11.1%	21.3
188	Qms:Qmu:Qp	36.7%	29.4%	42.8%	30.5%	43.9%	22.3%	39.6%	47.5%	47.0%	50.7
189	Qms:Qm :Qp	42.2%	23.5%	39.2%	35.6%	30.6%	52.0%	46.5%	36.1%	41.9%	27.9
190	Lv:Ls+:Lm	14.8%	66.5%	16.1%	59.7%	76.1%	29.7%	62.3%	30.5%	29.9%	26.9

	A	B	C	D	E	F	G	H	J	K	L
191	Lv:Ls+:Lm	77.0%	32.0%	62.8%	27.1%	18.5%	62.2%	34.6%	64.9%	63.9%	85.9
192	Lv:Ls+:Lm	8.2%	1.5%	19.1%	13.2%	5.4%	8.1%	3.0%	4.5%	6.1%	5.2
193	Framework:Matrix:Cement	82.9%	84.6%	86.0%	89.1%	98.8%	92.8%	98.5%	97.4%	87.7%	94.0
194	*Framework:Matrix:Cement*	5.2%	0.6%	11.2%	1.3%	0.2%	0.5%	0.7%	0.3%	0.6%	0.9
195	Framework:Matrix:Cement	11.9%	14.8%	2.9%	9.6%	1.0%	6.7%	0.7%	2.3%	11.7%	6.0
196	P/F	100.0%	87.0%	28.6%	92.4%	93.7%	82.5%	91.4%	60.0%	37.0%	59.1
197											
198	*SUMMARY*----------------										
199	QUARTZ (Q)	30.0%	29.8%	64.7%	43.5%	24.5%	37.0%	25.3%	40.7%	39.0%	45.3
200	FELDSPAR (F)	2.3%	17.3%	2.3%	16.5%	27.8%	10.0%	14.5%	5.0%	9.0%	7.3
201	SEDIMENTARY ROCK FRAGMENTS (Ls+	50.3%	15.5%	19.7%	9.8%	8.5%	32.5%	20.0%	33.3%	31.3%	29.7
202	VOLCANIC ROCK FRAGMENTS (Lv)	9.7%	32.3%	5.7%	21.5%	35.0%	15.5%	36.0%	15.7%	14.7%	13.0
203	METAMORPHIC ROCK FRAGMENTS (Lm)	5.3%	0.8%	6.0%	4.8%	2.5%	4.3%	1.8%	2.3%	3.0%	2.3
204	PLUTONIC ROCK FRAGMENTS	2.0%	1.5%	1.0%	1.0%	0.5%	0.3%	1.5%	1.3%	1.3%	0.
205	OTHER DETRITAL MINERALS	0.3%	3.0%	0.7%	3.0%	1.3%	0.5%	1.0%	1.7%	1.7%	1.
206	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.

	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
102														
103		1				2	10	5	1	1	5	4		1
104														
105														
106														
107														
108														
109														
110														
111														
112														
113														
114														
115														
116														
117														
118														
119														
120														
121														
122														
123	29	8	13		17	16	26		18	16	10	27	19	12
124														
125														
126														
127														
128	300	300	300	300	300	400	400	400	300	400	400	300	300	300
129	1	2	3	17	12	7	2	5	20	1	3	4	13	9
130	7	40	16	73	24	1	1	5	24	5	1	14	0	34
131	0	1	0	0	0	2	10	5	1	1	5	4	0	1
132	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	337	351	332	390	353	428	439	415	363	423	419	349	332	356
134														
135														
136	69.0%	85.5%	90.4%	78.9%	85.0%	93.9%	91.1%	96.4%	82.6%	94.6%	95.5%	86.0%	90.4%	84.3%
137	0.3%	0.6%	0.9%	4.4%	3.4%	1.6%	0.5%	1.2%	5.5%	0.2%	0.7%	1.1%	3.9%	2.5%
138	2.1%	11.4%	4.8%	18.7%	6.8%	0.2%	0.2%	1.2%	6.6%	1.2%	0.2%	4.0%	0.0%	9.6%
139	0.0%	0.3%	0.0%	0.0%	0.0%	0.5%	2.3%	1.2%	0.3%	0.2%	1.2%	1.1%	0.0%	0.3%
140	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
141	8.6%	2.3%	3.9%	0.0%	4.8%	3.8%	5.9%	0.0%	5.0%	3.8%	2.4%	7.7%	5.7%	3.4%
142	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
143	8.6%	2.3%	3.9%	0.0%	4.8%	3.8%	5.9%	0.0%	5.0%	3.8%	2.4%	7.7%	5.7%	3.4%
144	26.0%	22.7%	32.7%	23.0%	15.3%	31.5%	27.5%	14.3%	19.7%	20.3%	17.0%	10.3%	11.7%	21.3%
145	6.7%	4.3%	9.7%	10.7%	3.0%	11.0%	9.0%	4.3%	7.0%	6.3%	8.8%	3.3%	3.7%	8.0%
146	19.3%	18.3%	23.0%	12.3%	12.3%	20.5%	18.5%	10.0%	12.7%	14.0%	8.3%	7.0%	8.0%	13.3%
147	14.7%	16.3%	12.7%	14.7%	13.0%	16.3%	20.5%	14.3%	16.7%	16.3%	15.3%	12.7%	9.3%	30.3%
148	10.3%	9.0%	5.3%	11.7%	20.0%	4.3%	8.5%	17.3%	9.7%	8.8%	10.3%	26.3%	19.7%	3.3%
149	28.7%	21.0%	19.7%	32.7%	43.3%	14.3%	21.8%	35.5%	26.7%	31.0%	30.5%	54.7%	42.7%	11.3%
150	25.0%	25.3%	18.0%	26.3%	33.0%	20.5%	29.0%	31.5%	26.3%	25.0%	25.5%	39.0%	29.0%	33.7%
151	40.7%	39.0%	45.3%	37.7%	28.3%	47.8%	48.0%	28.5%	36.3%	36.5%	32.3%	23.0%	21.0%	51.7%
152	51.0%	48.0%	50.7%	49.3%	48.3%	52.0%	56.5%	45.8%	46.0%	45.3%	42.5%	49.3%	40.7%	56.0%
153	2.0%	5.7%	3.0%	2.7%	2.0%	1.3%	0.3%	2.0%	1.7%	1.3%	0.8%	1.0%	1.7%	0.7%
154	3.0%	3.3%	4.3%	1.3%	0.7%	0.5%	0.5%	0.5%	0.0%	0.5%	0.8%	0.0%	0.0%	1.0%
155	6.0%	9.0%	7.3%	4.0%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.5%	1.0%	2.0%	1.7%
156	23.0%	22.3%	24.3%	29.7%	38.0%	29.5%	28.8%	31.8%	42.0%	41.8%	41.3%	46.3%	47.7%	24.3%
157	33.3%	31.3%	29.7%	41.3%	58.0%	33.8%	37.3%	49.0%	51.7%	50.5%	51.5%	72.7%	67.3%	27.7%
158	3.0%	9.0%	0.7%	5.3%	3.0%	2.8%	3.3%	3.3%	0.7%	2.3%	1.8%	1.3%	4.7%	1.7%
159	12.7%	5.7%	12.3%	7.3%	1.7%	0.0%	1.0%	6.5%	0.3%	1.0%	0.5%	0.0%	0.7%	0.7%
160	15.7%	14.7%	13.0%	12.7%	4.7%	2.8%	4.3%	9.8%	1.0%	3.3%	2.3%	1.3%	5.3%	2.3%
161	2.3%	3.0%	2.3%	1.7%	4.3%	10.8%	7.3%	8.3%	8.0%	7.3%	7.5%	1.7%	2.0%	12.3%
162	1.0%	1.3%	0.7%	0.7%	0.3%	0.0%	0.3%	1.0%	0.7%	0.0%	1.0%	0.0%	0.7%	0.3%
163	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
164	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
165	1.3%	1.3%	0.7%	0.7%	0.3%	0.0%	0.3%	1.0%	0.7%	0.0%	1.0%	0.0%	0.7%	0.3%
166	17.0%	16.0%	13.7%	13.3%	5.0%	2.8%	4.5%	10.8%	1.7%	3.3%	3.3%	1.3%	6.0%	2.7%
167	52.7%	50.3%	45.7%	56.3%	67.3%	47.3%	49.0%	68.0%	59.3%	61.0%	62.3%	75.7%	75.3%	42.7%
168	42.3%	41.3%	40.3%	44.7%	47.3%	43.0%	40.5%	50.8%	49.7%	52.3%	52.0%	49.3%	55.7%	39.3%
169	67.3%	66.7%	58.3%	71.0%	80.3%	63.5%	69.5%	82.3%	76.0%	77.3%	77.5%	88.3%	84.7%	73.0%
170														
171														
172	41.4%	39.7%	46.1%	38.4%	28.3%	49.4%	49.1%	28.8%	37.3%	36.8%	33.6%	23.1%	21.4%	53.8%
173	5.1%	9.2%	7.5%	4.1%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.6%	1.0%	2.0%	1.7%
174	53.6%	51.2%	46.4%	57.5%	68.5%	48.8%	50.1%	68.7%	61.0%	61.5%	64.8%	75.9%	76.6%	44.4%
175	61.8%	48.6%	51.5%	50.3%	49.2%	53.7%	57.8%	46.2%	47.3%	45.6%	44.3%	49.5%	41.4%	57.3%
176	5.1%	9.2%	7.5%	4.1%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.6%	1.0%	2.0%	1.7%
177	43.1%	42.0%	41.0%	45.6%	48.1%	44.4%	41.4%	51.3%	51.0%	52.6%	54.2%	49.5%	56.6%	41.0%
178	44.7%	45.2%	51.1%	40.8%	31.0%	56.7%	53.5%	32.3%	40.5%	40.4%	37.1%	23.7%	22.3%	63.0%
179	36.6%	36.3%	33.5%	44.8%	63.5%	40.1%	41.5%	55.5%	57.6%	56.0%	59.2%	74.9%	71.4%	33.7%
180	18.7%	18.5%	15.4%	14.4%	5.5%	3.3%	5.0%	12.2%	1.9%	3.6%	3.7%	1.4%	6.4%	3.3%
181	45.4%	45.9%	51.5%	41.1%	31.1%	56.7%	53.6%	32.7%	40.8%	40.4%	37.5%	23.7%	22.4%	63.3%
182	37.2%	36.9%	33.7%	45.1%	63.7%	40.1%	41.6%	56.2%	58.1%	56.0%	59.9%	74.9%	71.9%	33.9%
183	17.5%	17.3%	14.8%	13.8%	5.1%	3.3%	4.7%	11.2%	1.1%	3.6%	2.6%	1.4%	5.7%	2.9%
184	42.4%	40.9%	47.2%	39.1%	30.1%	55.5%	53.0%	31.4%	39.8%	39.7%	36.4%	23.5%	21.8%	61.8%
185	34.7%	32.9%	30.9%	42.9%	61.7%	39.2%	41.2%	54.0%	56.6%	54.9%	58.2%	74.1%	69.9%	33.1%
186	22.9%	26.2%	21.9%	16.0%	8.2%	5.2%	5.8%	14.6%	3.6%	5.4%	5.4%	2.4%	8.3%	5.2%
187	16.4%	11.1%	21.3%	28.3%	10.6%	23.0%	18.8%	14.9%	19.3%	17.1%	27.1%	14.5%	17.5%	15.5%
188	47.5%	47.0%	50.7%	32.7%	43.5%	42.9%	38.5%	35.1%	34.9%	38.4%	25.6%	30.4%	38.1%	25.8%
189	36.1%	41.9%	27.9%	38.9%	45.9%	34.0%	42.7%	50.0%	45.9%	44.5%	47.3%	55.1%	44.4%	58.7%
190	30.5%	29.9%	28.9%	22.8%	7.0%	5.8%	8.7%	14.6%	1.7%	6.3%	3.7%	1.8%	7.1%	5.5%
	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
191	64.9%	63.9%	65.9%	74.3%	86.6%	71.4%	78.4%	73.1%	88.1%	82.8%	84.1%	96.0%	90.2%	65.4%
192	4.5%	6.1%	5.2%	3.0%	6.5%	22.8%	14.9%	12.3%	10.2%	11.9%	12.2%	2.2%	2.7%	29.1%
193	97.4%	87.7%	94.0%	76.9%	89.3%	98.0%	99.3%	97.6%	87.2%	98.5%	99.0%	94.3%	95.8%	87.5%
194	0.3%	0.6%	0.9%	4.4%	3.6%	1.7%	0.5%	1.2%	5.8%	0.2%	0.7%	1.3%	4.2%	2.6%
195	2.3%	11.7%	6.0%	18.7%	7.1%	0.2%	0.2%	1.2%	7.0%	1.2%	0.2%	4.4%	0.0%	9.9%
196	60.0%	37.0%	59.1%	33.3%	25.0%	28.6%	66.7%	20.0%	0.0%	26.6%	50.0%	0.0%	0.0%	60.0%
197														
198														
199	40.7%	39.0%	45.3%	37.7%	28.3%	47.8%	48.0%	28.5%	36.3%	36.5%	32.3%	23.0%	21.0%	51.7%
200	5.0%	9.0%	7.3%	4.0%	2.7%	1.8%	0.8%	2.5%	1.7%	1.8%	1.5%	1.0%	2.0%	1.7%
201	33.3%	31.3%	29.7%	41.3%	58.0%	33.8%	37.3%	49.0%	51.7%	50.5%	51.5%	72.7%	67.3%	27.7%
202	15.7%	14.7%	13.0%	12.7%	4.7%	2.8%	4.3%	9.8%	1.0%	3.3%	2.3%	1.3%	5.3%	2.3%
203	2.3%	3.0%	2.3%	1.7%	4.3%	10.8%	7.3%	8.3%	6.0%	7.3%	7.5%	1.7%	2.0%	12.3%
204	1.3%	1.3%	0.7%	0.7%	0.3%	0.0%	0.3%	1.0%	0.7%	0.0%	1.0%	0.0%	0.7%	0.3%
205	1.7%	1.7%	1.7%	2.0%	1.7%	3.3%	2.3%	1.0%	2.7%	0.8%	4.0%	0.3%	1.7%	4.0%
206	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

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3	4	13	9	8	35	129	33								
1	14	0	34	21	21	130	19								
5	4	0	1	0	0	131	1								
0	0	0	0	0	0	132	0								
19	349	332	356	341	357	133	355								
						134									
						135									
5%	86.0%	90.4%	84.3%	88.0%	84.0%	136	84.5%	85.2%	63.3%	88.1%	87.3%	89.9%	91.2%	90.9%	88.3%
7%	1.1%	3.9%	2.5%	2.3%	9.8%	137	9.3%	6.0%	2.6%	2.9%	2.9%	2.4%	1.8%	1.9%	3.0%
2%	4.0%	0.0%	9.6%	6.2%	5.9%	138	5.4%	6.7%	13.5%	6.1%	7.4%	3.2%	1.8%	2.1%	5.4%
2%	1.1%	0.0%	0.3%	0.0%	0.0%	139	0.3%	0.1%	0.4%	0.4%	0.4%	0.3%	0.9%	0.8%	0.5%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	140	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4%	7.7%	5.7%	3.4%	3.5%	0.3%	141	0.6%	1.9%	0.2%	2.4%	2.0%	4.2%	4.2%	4.2%	2.8%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	142	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4%	7.7%	5.7%	3.4%	3.5%	0.3%	143	0.6%	1.9%	0.2%	2.4%	2.0%	4.2%	4.2%	4.2%	2.8%
0%	10.3%	11.7%	21.3%	16.7%	19.3%	144	11.0%	17.1%	20.4%	25.1%	24.3%	24.6%	17.6%	19.2%	21.4%
8%	3.3%	3.7%	8.0%	2.7%	6.7%	145	3.0%	5.1%	10.7%	8.8%	9.1%	7.6%	6.2%	6.5%	7.6%
3%	7.0%	8.0%	13.3%	14.0%	12.7%	146	8.0%	12.0%	9.7%	16.3%	15.2%	17.0%	11.4%	12.7%	13.8%
3%	12.7%	9.3%	30.3%	33.0%	34.3%	147	35.0%	33.2%	8.4%	16.0%	14.9%	14.9%	15.2%	15.2%	17.6%
3%	26.3%	19.7%	3.3%	6.7%	3.0%	148	1.3%	3.6%	10.7%	7.7%	8.2%	11.0%	13.9%	13.2%	9.5%
5%	54.7%	42.7%	11.3%	21.0%	10.0%	149	13.7%	14.0%	18.9%	17.6%	17.8%	26.7%	33.9%	32.3%	22.6%
5%	39.0%	29.0%	33.7%	39.7%	37.3%	150	36.3%	36.8%	20.1%	23.7%	23.1%	25.9%	29.1%	29.4%	27.0%
%	23.0%	21.0%	51.7%	49.7%	53.7%	151	46.0%	50.3%	29.9%	41.1%	39.2%	39.4%	32.9%	34.3%	38.9%
5%	49.3%	40.7%	55.0%	56.3%	56.7%	152	47.3%	53.8%	40.6%	48.8%	47.4%	50.4%	46.7%	47.5%	48.4%
%	1.0%	1.7%	0.7%	0.0%	0.0%	153	0.0%	0.2%	1.3%	2.2%	2.0%	1.6%	1.2%	1.3%	1.5%
%	0.0%	0.0%	1.0%	0.3%	0.3%	154	0.3%	,0.5%	9.6%	8.6%	8.7%	0.6%	0.4%	0.4%	4.4%
%	1.0%	2.0%	1.7%	0.3%	0.3%	155	0.3%	0.7%	10.9%	10.7%	10.8%	2.1%	1.6%	1.7%	5.9%
%	46.3%	47.7%	24.3%	22.7%	25.0%	156	30.7%	25.7%	19.7%	16.0%	16.7%	33.1%	39.3%	37.9%	25.9%
%	72.7%	67.3%	27.7%	29.3%	28.0%	157	32.0%	29.3%	30.4%	23.8%	24.9%	44.1%	53.1%	51.2%	35.4%
%	1.3%	4.7%	1.7%	3.3%	0.0%	158	0.7%	1.4%	6.6%	6.3%	6.3%	2.9%	2.5%	2.8%	4.2%
%	0.0%	0.7%	0.7%	1.0%	0.0%	159	0.3%	0.5%	16.0%	12.4%	13.0%	0.7%	1.6%	1.4%	6.9%
%	1.3%	5.3%	2.3%	4.3%	0.0%	160	1.0%	1.9%	22.6%	18.6%	19.3%	3.6%	4.0%	3.9%	11.1%
%	1.7%	2.0%	12.3%	11.3%	14.0%	161	17.7%	13.8%	2.7%	3.4%	3.3%	8.0%	6.0%	6.4%	6.0%
%	0.0%	0.7%	0.3%	0.0%	0.0%	162	0.0%	0.1%	0.4%	0.8%	0.7%	0.1%	0.5%	0.4%	0.5%
%	0.0%	0.0%	0.0%	0.0%	0.0%	163	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
%	0.0%	0.0%	0.0%	0.0%	0.0%	164	0.0%	0.0%	1.3%	0.1%	0.3%	0.0%	0.0%	0.0%	0.2%
%	0.0%	0.7%	0.3%	0.0%	0.0%	165	0.0%	0.1%	1.7%	0.9%	1.0%	0.1%	0.5%	0.4%	0.7%
%	1.3%	6.0%	2.7%	4.3%	0.0%	166	1.0%	2.0%	24.3%	19.5%	20.3%	3.7%	4.6%	4.4%	11.7%
%	75.7%	75.3%	42.7%	45.0%	42.0%	167	50.7%	45.1%	57.4%	46.7%	48.6%	55.9%	63.7%	62.0%	53.1%
%	49.3%	55.7%	39.3%	38.3%	39.0%	168	49.3%	41.5%	46.7%	39.0%	40.3%	44.9%	49.8%	48.8%	43.7%
5%	88.3%	84.7%	73.0%	78.0%	76.3%	169	85.7%	78.3%	66.9%	62.7%	63.4%	70.7%	78.9%	77.1%	70.7%
						170									
						171									
6%	23.1%	21.4%	53.8%	52.3%	55.9%	172	47.4%	52.3%	30.4%	41.7%	39.8%	40.5%	33.5%	35.0%	39.7%
5%	1.0%	2.0%	1.7%	0.4%	0.3%	173	0.3%	0.7%	11.1%	10.9%	10.9%	2.2%	1.6%	1.8%	6.1%
%	75.0%	76.6%	44.4%	47.4%	43.8%	174	52.2%	47.0%	58.5%	47.4%	49.3%	57.3%	64.9%	63.2%	54.2%
%	49.5%	41.4%	57.3%	59.3%	59.0%	175	48.8%	56.1%	41.3%	49.5%	48.1%	51.8%	47.6%	48.5%	49.4%
5%	1.0%	2.0%	1.7%	0.4%	0.3%	176	0.3%	0.7%	11.1%	10.8%	10.8%	2.2%	1.6%	1.8%	6.1%
2%	49.5%	56.6%	41.0%	40.4%	40.6%	177	50.9%	43.2%	47.6%	39.6%	40.9%	46.0%	50.8%	49.7%	44.6%
1%	23.7%	22.3%	63.0%	59.6%	65.7%	178	58.2%	61.7%	35.3%	48.7%	46.4%	45.2%	36.3%	38.2%	45.2%
.2%	74.9%	71.4%	33.7%	35.2%	34.3%	179	40.5%	35.9%	36.0%	28.2%	29.5%	50.6%	58.7%	56.9%	41.1%
.7%	1.4%	6.4%	3.3%	5.2%	0.0%	180	1.3%	2.5%	28.7%	23.1%	24.1%	4.3%	5.0%	4.9%	13.6%
.5%	23.7%	22.4%	63.3%	59.6%	65.7%	181	58.2%	61.7%	36.0%	49.2%	47.0%	45.2%	35.5%	38.4%	45.6%
.9%	74.9%	71.9%	33.9%	35.2%	34.3%	182	40.5%	35.9%	36.7%	28.5%	29.9%	50.7%	59.0%	57.2%	41.5%
.6%	1.4%	5.7%	2.9%	5.2%	0.0%	183	1.3%	2.4%	27.2%	22.3%	23.2%	4.1%	4.5%	4.4%	13.0%
.4%	23.5%	21.8%	61.8%	59.4%	65.4%	184	58.0%	61.2%	31.3%	43.2%	41.2%	44.1%	35.7%	37.5%	42.3%
.2%	74.1%	69.9%	33.1%	35.1%	34.1%	185	40.3%	35.6%	31.9%	25.0%	26.2%	49.4%	57.6%	55.9%	38.5%
.4%	2.4%	8.3%	5.2%	5.6%	0.4%	186	1.7%	3.2%	36.8%	31.8%	32.7%	6.5%	6.7%	6.7%	19.2%
.1%	14.5%	17.5%	15.5%	5.4%	12.4%	187	6.5%	10.1%	35.9%	21.5%	23.3%	19.2%	18.9%	18.9%	19.5%
.6%	30.4%	38.1%	25.8%	28.2%	23.6%	188	17.4%	23.9%	32.5%	39.7%	38.7%	43.1%	34.8%	36.9%	35.4%
.3%	55.1%	44.4%	58.7%	66.4%	64.0%	189	76.1%	66.0%	31.6%	38.9%	37.9%	37.7%	46.4%	44.2%	45.1%
.7%	1.8%	7.1%	5.5%	9.6%	0.0%	190	2.0%	4.3%	40.5%	40.7%	40.6%	6.4%	6.4%	6.4%	21.1%
	U	V	W	X	Y		Z	AA	AB	AC	AD	AE	AF	AG	AH
.1%	96.0%	90.2%	65.4%	65.2%	66.7%	191	63.2%	65.0%	54.6%	51.8%	52.4%	79.2%	84.1%	83.1%	67.5%
.2%	2.2%	2.7%	29.1%	25.2%	33.3%	192	34.9%	30.7%	4.9%	7.5%	7.0%	14.4%	9.5%	10.5%	11.4%
.0%	94.3%	95.8%	87.5%	91.2%	84.3%	193	85.2%	87.0%	83.8%	90.7%	89.4%	94.1%	98.2%	95.8%	91.3%
.7%	1.3%	4.2%	2.6%	2.4%	9.8%	194	9.4%	6.1%	2.6%	3.0%	2.9%	2.6%	1.8%	2.0%	3.1%
.2%	4.4%	0.0%	9.9%	6.4%	5.9%	195	6.4%	6.9%	13.5%	6.3%	7.6%	3.4%	1.9%	2.2%	5.6%
.0%	0.0%	0.0%	60.0%	100.0%	100.0%	196	100.0%	75.0%	88.2%	79.7%	81.2%	26.7%	22.5%	23.6%	74.8%
						197									
						198									
.3%	23.0%	21.0%	51.7%	49.7%	53.7%	199	46.0%	50.3%	29.9%	41.1%	39.2%	39.4%	32.9%	34.3%	38.9%
5%	1.0%	2.0%	1.7%	0.3%	0.3%	200	0.3%	0.7%	10.9%	10.7%	10.8%	2.1%	1.6%	1.7%	5.9%
5%	72.7%	67.3%	27.7%	29.3%	28.0%	201	32.0%	29.3%	30.4%	23.8%	24.9%	44.1%	53.1%	51.2%	35.4%
3%	1.3%	5.3%	2.3%	4.3%	0.0%	202	1.0%	1.9%	22.6%	18.6%	19.3%	3.6%	4.0%	3.9%	11.1%
5%	1.7%	2.0%	12.3%	11.3%	14.0%	203	17.7%	13.8%	2.7%	3.4%	3.3%	8.0%	6.0%	6.4%	6.0%
%	0.0%	0.7%	0.3%	0.0%	0.0%	204	0.0%	0.1%	1.7%	0.9%	1.0%	0.1%	0.5%	0.4%	0.7%
%	0.3%	1.7%	4.0%	5.0%	4.0%	205	3.0%	4.0%	1.9%	1.4%	1.5%	2.6%	1.8%	2.0%	2.0%
%	100.0%	100.0%	100.0%	100.0%	100.0%	206	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%