THE SEDIMENTOLOGY AND PETROLOGY OF THE OKSE BAY GROUP (MIDDLE AND UPPER DEVONIAN) ON S.W. ELLESMERE ISLAND AND NORTH KENT ISLAND IN THE CANADIAN ARCTIC ARCHIPELAGO

BY

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DEDICATION

To Claudia Elizabeth Bovard (Rice), my mother, and Leon Herbert Rice, my father.

The quotes on this page, all from Francis J. Pettijohn, summarize some of my deeper feelings about the science I have chosen to pursue.

"Mapping is indeed the essence of geology, and those who think otherwise are grossly in error. An occasional field excursion will not do. Understanding comes only from prolonged daily field contact."

- taken from page 136 of: Pettijohn, F.J.; 1984, Memoirs Of An Unrepentant Field Geologist, The University Of Chicago Press, 260 p.

"The decline of the field course and field studies is a symptom - a symptom of a fundamental misconception concerning the nature of geology. It leads to the conferring of Ph.D.'s in geology on persons who are fundamentally not geologists..."

"Nothing, my friends, is so sobering as an outcrop."

- the above two quotes are part of F.J. Pettijohn's presidential address delivered to the 30th annual meeting of the Society of Economic Paleontologists and Mineralogists on April 24, 1956 which was published in the Bulletin of the American Association of Petroleum Geologists, 1956, volume 40, no. 7, pg. 1455-1461.

Abstract.

The Strathcona Fiord Formation varies from a paralic environment at Stenkul Fiord to a small, highly sinuous, meandering fluvial environment at Muskox Fiord. The remaining formations in the Okse Bay Group are consistent with respect to their depositional setting. The Nordstrand Point Formation constitutes a small, sinuous, meandering fluvial environment. The Fram and Hell Gate Formations represent progressively larger, less sinuous, meandering fluvial systems. The Hecla Bay Formation is the only braided fluvial formation in the Okse Bay Group.

The Okse Bay Group is extremely compositionally homogeneous, both stratigraphically and areally. As a result of burial metamorphism, most of the originally sub-arkosic sandstones are now quartz arenites. Sandstone in the Okse Bay Group is well sorted and very fine grained. The sand size detritus in most of the Okse Bay Group was well lithified during early diagenesis. The sand of the Hecla Bay Formation was not lithified until late diagenetic conditions were attained. Late diagenetic textures suggest that maximum burial depth varied between 3 - 5.5 km depending on the geothermal gradient.

Cathodoluminescence microscopy revealed mainly rounded detrital textures, minor pressure solution of framework grains, confirmed the cement paragenesis and contributed to the source terrane interpretation.

Variations in the volume of sandstone, characteristic grain size, fluvial architecture, and paleochannel scale in the Okse Bay Group are complimentary in suggesting that continuous but variable rates of epeirogenesis of a source terrane occurred throughout Okse Bay Group time.

Regional paleocurrent trends, areal detrital composition trends and spore-based younging trends all indicate an eastern source terrane.

Source terrane constraints imposed by the interpretation of bedrock composition and tectonic behavior, and the directional constraints, are satisfied by the Ellesmere Island - Greenland craton with its Proterozoic intra-cratonic Thule Basin. Most of the detritus was recycled from the Thule Basin.

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As is often the case when a large project is finally completed a considerable number of individuals need to be thanked for their assistance at various stages of its development. The patient supervisor of this research was Dr. G.V. Middleton. He is thanked for his insight as to the proper direction to follow at a number of critical points in the research. In particular, he is thanked for the petrographic tutoring he provided on a number of occasions. This project was suggested to the author by Dr. U. Mayr of the Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, Calgary, Alberta. It constitutes part of project 810016 conducted by the ISPG on southern Ellesmere Island. The field work was effectively completely financed by the ISPG. I consider myself privileged to have worked with their officers in the Canadian high Arctic. Special thanks go to Drs. Ulrich Mayr, Andy Okulitch, Ray Thorsteinsson and Ashton Embry, all of the ISPG, for their friendship and advice. George Hobson and the Polar Continental Shelf Project in Ottawa is thanked for the generous number of Twin Otter and helicopter hours they provided. Without their logistical support scientific research in the Canadian Arctic Archipelago would be extremely difficult to impossible. Dr. D.C. McGregor of the Geological Survey of Canada in Ottawa is thanked for his spore identifications which proved so valuable in refining the sedimentologic interpretations. Dr. Andrew Miall of the Department of Geology at the University of Toronto is thanked for several very stimulating discussions on the Okse Bay Group. It was he who initially suggested the possibility that the Thule Basin might be a candidate for the source terrane of the Okse Bay Group. He is also thanked for the use of his microscope and camera equipment which made the taking of photomicrographs much more efficient than it would have been at McMaster. The Ontario Geological Survey is thanked for the unlimited use of their drafting equipment and their encouragement in the final stages of this project. Mr. Len Zwicker, John Cekr and Jack Whorwood, all of the Department of Geology at McMaster University, are thanked for their help in the preparation of thin sections, use of the luminoscope, and for various types of photographic advice, respectively. I was fortunate enough to have several very good field assistants during this project. The best was Mr. Eric Zaunscherb, an experienced field geologist whose maturity and sense of responsibility in prolonged isolated situations is exemplary. The aerial photographs in this report, copyright

1959, Her Majesty the Queen in Right of Canada, are reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada.

Ann Kathleen Hurt somehow managed to put up with me over the last two years of this degree and in so doing contributed immensely to its successful completion.

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1.0 Introduction

1.1 Introductory Statement

This study is concerned with the sedimentology of the Okse Bay Group (Embry and Klovan, 1976) on North Kent and southwestern Ellesmere Islands in the eastern Canadian Arctic Archipelago. This group of predominantly fluviatile siliciclastics is 3078 m (10,100 ft) thick (McLaren, 1963a), consists of five formations (Embry and Klovan, 1976) and represents the final phase of sedimentation in this area of the Franklinian Basin. The Okse Bay Group constitutes the non-marine portion of the Devonian clastic wedge (Tozer and Thorsteinsson, 1964) in the eastern Arctic Archipelago which is the uppermost sedimentary package of the Franklinian miogeocline which includes strata of Late Proterozoic to Middle Paleozoic age. In a global context, the Middle and Upper Devonian age of the Okse Bay Group makes it broadly correlative with the Upper Old Red Sandstone of the Anglo-Welsh Province (Allen, 1962).

The stratigraphic framework of the Okse Bay Group has been established by McLaren (1963a) during the Geological Survey of Canada's Operation Franklin and by Embry and Klovan (1976).

1.2 Study Area Description and Logistics

This investigation was conducted on southwestern Ellesmere Island and North Kent Island in the eastern Canadian Arctic Archipelago. The latter is a small island separating Grinnell Peninsula (northwestern Devon Island) from the southwestern extremity of Ellesmere Island. The field area is roughly bounded between 83°45'- 90°20' west longitude and 76°40'- 77°25' north latitude. The area is periglacial and permanent ice caps partially cover both southwestern Ellesmere and North Kent Islands. Elevations over the ice caps reach approximately 1500 m and 600 m, respectively. While land surface elevations gradually increase towards the ice caps most of the region investigated lies under 700 m in elevation. As the region is technically classified as a cold desert all rivers in the area are fed by glacial meltwater and are therefore subject to extreme diurnal variations in discharge during the high arctic summer. Many of the rivers exhibit a braided channel pattern, especially where they are debouching into bays or fiord heads. Fiords are commonly incised many kilometers inland and give southwestern Ellesmere an extremely irregular coastline.

The weather during three field seasons was extremely variable, as is characteristic of high arctic regions.

Temperatures varied roughly between $-5^{0}C$ and $+20^{0}C$ and sudden July snowstorms were not uncommon. The wind was a nearly constant companion and severe wind chill factors frequently occurred late in the field season. The high arctic summer was very short and consisted of an approximately seven day stretch of clear and relatively warm weather. The most common weather conditions consisted of low cloud ceilings, temperatures around 5-$10^{0}C$ and light to moderate winds.

Congelifraction is a very prominent process in the field area. While carbonate lithologies stand up well to this process and can form many spectacular exposures along fiord walls, as a general rule the more porous nature of the sandstones has resulted in their mechanical disintegration. Many exposures consist of felsenmeer rather than intact rock. Nevertheless, a number of good exposures were located within the field area.

The logistical base for this study was Resolute Bay located on Cornwallis Island approximately 350 km to the southwest. The dirt airstrip at Resolute Bay is sufficiently well maintained by the Ministry of Transport to allow regular servicing by Boeing 737 jets out of Calgary and Montreal. Transportation to and from the field area was by Twin Otter bush plane out of Resolute Bay.

Transportation between work locations in the field area was by helicopter either out of Resolute Bay or from a base camp located within or sufficiently close to the field area.

1.3 Regional Geological Setting

1.3.1 Structural Setting

The field area is contained within the Central Ellesmere Fold Belt (Fortier et al., 1963, Figure 1). The fold belt is bounded to the south by the northward dipping Southern Ellesmere Homocline and to the north, it is unconformably bounded by the southeastern extremity of the Sverdrup Basin. The field area within the fold belt is structurally simple and there were no complex stratigraphies to be unravelled prior to or during the measurement of sections. The main structural feature in the area is the Schei Syncline. The axis of this syncline trends northeast-southwest down the length of the field area. The syncline is a very open flexure with dips on the north limb (roughly 15^0-30^0 range) exceeding those on the south limb (most less than 20^0) except where local faulting has occurred. Numerous northwest-southeast and northeast-southwest trending thrust faults occur throughout the area. Their lateral component of slip has resulted in local offsets of the synclinal axis and in minor local stratigraphic displacement (Kerr and Thorsteinsson, 1972). Regional strike parallels the synclinal axis. Throughout much of the central portion of the field area, all five formations are exposed (most exposures of poor quality) on both the north and south limbs of the syncline. In the western portion, the lowest and highest formations are commonly missing due either to lack of exposure or recent erosion. In the Vendom Fiord region, immediately east of the eastern extremity of the field area, the fold belt changes direction and trends northward due to the buttressing effect of the Precambrian cratonic area on eastern Ellesmere. In the Vendom Fiord region and in the Strathcona Fiord-Canon Fiord region to the north, fold closures increase and much of the Okse Bay Group has been erosionally bevelled off. Only the Strathcona Fiord, Hecla Bay and Fram Formations are present in the Vendom Fiord area and only the former two in the Strathcona Fiord-Canon Fiord region (Roblesky, 1979 and Trettin, 1978, respectively).

1.3.2 Tectonic History

As was the case for the structural setting, the tectonic history of the Okse Bay Group on southwestern Ellesmere and North Kent Islands is uncomplicated. Only one diastrophic event has had a significant effect on the region, the Ellesmerian Orogeny, which at the close of the Late Devonian exerted a north-south compressive force on the sediments of the Franklinian Miogeocline producing the Schei Syncline. The main east-west compressive phase of the later Eurekan Orogeny occurred during the post Middle Eocene to pre Early Miocene period (Riediger, Bustin and Rouse, 1984). The only effect this diastropic event has had on the field area was to produce the broadly north-south trending thrust faults mentioned above.

1.3.3 Stratigraphic and Depositional Framework

The Okse Bay Group consists of five formations: the Strathcona Fiord, Hecla Bay, Fram, Hell Gate and Nordstrand Point Formations, in ascending stratigraphic order (Embry and Klovan, 1976). Within the group, all formation contacts are conformable. Within the field area, the group constitutes the youngest stratigraphic unit and forms the current erosion surface. The basal formation, the Strathcona Fiord, conformably overlies the Bird Fiord Formation (Mid Devonian), a marine shelf to deltaic clastic unit, in the western part of the field area and the Blue Fiord Formation (late Lower Devonian), a shelf carbonate unit, in the eastern part of the field area. The Strathcona Fiord Formation is a partial facies equivalent to the Bird

Fiord Formation.

The depositional framework for the Okse Bay Group on southwestern Ellesmere Island has been established principally through investigations by H.P. Trettin (1969a, 1969b, 1971, 1978, 1979). Although only the Strathcona Fiord and Hecla Bay Formations are exposed in central Ellesmere Island, his work in this region and in northern Ellesmere has allowed the delineation of broad depositional realms which serve to place the Okse Bay Group in context. Three principal depositional realms have been defined. From north to south on Ellesmere Island they are as follows:

1. Pearya

This region is exposed along the northern coast of Ellesmere Island. It is currently interpreted as a composite terrane with Caledonian affinities in fault contact with the Clements Markham Fold Belt (Trettin, 1987). Embry and Klovan (1976) and Trettin (1978) have suggested that Pearya was a significant source of siliciclastic detritus to the prograding fluvial clastic wedge now known as the Okse Bay Group. Others (Roblesky, 1979) think that its influence in this respect was minimal to non-existent.

2. Hazen Trough

The Hazen Trough is a major depositional realm extending northeast-southwest across Axel Heiberg Island, north central and northern Ellesmere Island and along the northern coast of Greenland. It is interpreted by Trettin (1971, 1979) and Trettin and Balkwill (1979) as a starved deep water basin constituting the northern portion of the Franklinian Basin which separated Pearya to the northwest from an unstable miogeoclinal carbonate shelf to the southeast. The trough is ensialic and is thought to have formed by subsidence of the crust possibly in sympathy with known Devonian granitic plutonism in the region of Pearya.

3. Southeastern Shelf

The southeastern shelf broadly follows the trend of the Central Ellesmere Fold Belt from the Canon Fiord region of central Ellesmere Island to the southwestern portion of the field area. It is interpreted as the miogeoclinal portion of the Franklinian Basin (Embry and Klovan, 1976). During the late Lower Devonian, it was a carbonate shelf as recorded by the Blue Fiord Formation (Smith and Stearn, 1982). A change over most of the Blue Fiord carbonate shelf to a siliciclastic shelf to deltaic environment is indicated by the early Middle Devonian Bird Fiord Formation (Embry and

Klovan, 1976). It is onto this siliciclastic to carbonate shelf that the sediments of the Okse Bay Group prograded, overlying siliciclastics (Bird Fiord) west of Vendom Fiord and carbonates (Blue Fiord) east and north of Vendom Fiord.

1.4 Previous Geological Investigations

Previous geological literature relevant to this study can be broadly divided into two groups. The first group contains only those studies done on the Okse Bay Group within the field area of the current investigation. The second group contains papers which either deals with the Okse Bay Group in adjacent areas or in some way contributes to the general understanding of these sediments. Many of these papers reflect on the provenance of the sediments. The previous literature will be discussed briefly, in chronological sequence, from oldest to youngest. Four papers, Schei (1903, 1904), McLaren (1963a), and Embry and Klovan (1976), belong to the first group. The remainder of the papers discussed below belong in the second group.

Although several earlier Arctic explorers (Nares, 1875-76 and Greely, 1881-84) had travelled the waters bordering the eastern and northern coasts of Ellesmere Island, none had investigated the coasts of southwestern Ellesmere or gone on inland sledge journeys in that region

(Christie, 1982). The first expedition to do so was the Second Norwegian Polar Expedition in the Fram, 1898-1902, led by Captain Otto Sverdrup. One of Sverdrup's scientific team, Per Schei, was a geologist. Schei participated in many coastal and overland sledge journeys on southwestern Ellesmere during the spring snow season. Sverdrup chose inner Goose Fiord as the winter harbour for 1900-1901 and because the ice did not go out of the fiord the following summer, had to winter there again, 1901-1902. It was during this time that Schei collected data on the sedimentary strata of the region. What is now known as the Okse Bay Group comprises series E of Schei (1903, 1904) plus two additional overlying formations, the Hell Gate and Nordstrand Point Formations (McLaren, 1963a; the nomenclature of Embry and Klovan, 1976, is used here). Schei apparently did not examine the two upper formations, as we now know them, lying in the region of the fiord head and north of it (Holtedahl, 1917, in McLaren, 1963a). The collection of fish and plant fossils made by Schei and other crew members from shale horizons in what we now know must have been the Fram Formation, is still the best available from this area.

Schei died soon after returning to Europe and as a result no final report on the stratigraphy was published

(Christie, 1981). Several analyses of specific aspects of his data were published by other scientists. The first of these was by Nathorst in 1904 who provided detailed descriptions of the plant fossils (McLaren, 1963a). Kiaer (1915) published descriptions of the fish fossils brought back by Schei. Holtedahl (1917) also published a review of Schei's work.

The interval from 1920-1950 was barren with respect to Arctic exploration of any relevance to the Okse Bay Group. However, in 1950 the Geological Survey of Canada started a systematic study of the Arctic Islands and in 1955 launched the first major geological reconnaissance program of this region, dubbed "Operation Franklin" the memoir for which was published in 1963 (Christie, 1981). One result of this program was the recognition of a sequence (up to 5000 m thick, Embry and Klovan, 1976) of Devonian clastic strata extending across the width of the Arctic Archipelago from Ellesmere to Banks Island. As a consequence of work done during Operation Franklin, Thorsteinsson and Tozer (1960), postulated that the source of the clastics was a tectonic upland that had lain along the northwest coast of the archipelago (Trettin, 1978). Martin (1961) shared this view and extended it to suggest that similar clastics in the Yukon and Alaska were also derived from this upland

(Trettin, 1978). In 1963, the results of Operation Franklin were published as Memoir 320. As part of this program D.J. McLaren mapped what is now known as the Okse Bay Group along the inner eastern side of Goose Fiord as well as in the area of Okse Bay and Bird Fiord. He introduced the term Okse Bay Formation for the sediments and defined four informal members. In ascending stratigraphic order they were: 1) lower sandstone member 2) lower sandstone and shale member 3) upper sandstone member 4) upper sandstone and shale member (McLaren, 1963a). His lowest two members were equivalent to what Schei had termed series E. As a consequence of work in the western arctic islands, Tozer and Thorsteinsson (1964) continued to suggest a northwestern source for the Devonian clastics (Trettin, 1978). Temple (1965) noted the highly siliceous nature of the Devonian clastics on Bathurst Island and was the first to question their derivation from a plutono-volcanic source. Grant and Pendergast (1971) presented a different view on the derivation of the sediments. They used gravity anomaly maps and suggested that the principal sources lay to the east and south (Roblesky, 1979). McGill (1974) headed an industry field party which mapped the Vendom Fiord region lying just to the northeast of the field area of this investigation. What is now known to be the Strathcona Fiord, Hecla Bay and

Fram Formations are exposed in this region. MGill's study was oriented toward petroleum exploration and he provided only cursory environmental interpretations which subsequent work has shown to be, in large, correct. The non-marine Devonian clastics in the Arctic Islands have also been related to the much studied Old Red Sandstone of the British Isles. Dineley (1975) attempted to reconstruct Devonian paleogeography and suggested that the tectonic uplands of the Okse Bay sediments could have been the East Greenland Caledonides.

The most recent and thorough study of the Okse Bay Group on southwestern Ellesmere Island was that of Embry and Klovan (1976). They investigated the Okse Bay sediments in this area as part of an Arctic-wide stratigraphic and sedimentologic study of the Devonian clastic deposits. As a result of their work on southwest Ellesmere Island the Okse Bay Formation was elevated to group status with the five constituent formations which have been mentioned previously. The upper three formations, the Fram, Hell Gate and Nordstrand Point Formations, were defined in their study. The correlation between the four informal members of McLaren (1963a) and the five formations of Embry and Klovan (1976) is given below (from Embry and Klovan, 1976).

McLaren (1963a)	Embry and Klovan (1976)
Lower sandstone mbr.	Strathcona Fd. and Hecla Bay Fms.
Lower sst. and sh. mbr.	Fram Fm.
Upper sandstone mbr.	Hell Gate Fm.
Upper sst. and sh. mbr.	Nordstrand Point Fm.

The environmental interpretation proposed by Embry and Klovan (1976) for these formations on southwestern Ellesmere Island, is as follows:

Formation	Depositional Environment
Strathcona Fiord	tidal flat and delta-plain
Hecla Bay	sandy braided fluvial
Fram	meandering fluvial
Hell Gate	sandy braided fluvial
Nordstrand Point	meandering fluvial

Embry and Klovan (1976) also addressed the question of the provenance of the sediments. They cautiously concluded that the Precambrian shield of Ellesmere Island and Greenland and the East Greenland Caledonides were the main source regions with Pearya being a less important supplier of detritus.

Trettin (1978) investigated the Strathcona Fiord and

Hecla Bay Formations in the Strathcona Fiord and Canon Fiord region of west-central Ellesmere Island. As mentioned previously, these two formations are the only parts of the Okse Bay Group that are present in this region due to post Devonian erosion. The depositional environment of the Strathcona Fiord Formation was interpreted to range from sub-tidal through delta plain to meandering river, alluvial plain settings. The interpretation offered for the Hecla Bay Formation on southwestern Ellesmere Island (sandy braided fluvial) by Embry and Klovan (1976) was extrapolated to this area. Trettin's investigations into the provenance of these sediments produced some data which was ambiguous as to a northwestern (Pearya) or eastern (Ellesmere-Greenland shield and East Greenland Caledonides) derivation. He concluded that the provenance is uncertain and recommended more extensive work.

Roblesky (1979) investigated the Strathcona Fiord and Hecla Bay Formations in the Vendom Fiord region located just northeast of this study's field area. The interpretation of the depositional environments were the same as Trettin (1978) suggested for the Strathcona Fiord-Canon Fiord region of west-central Ellesmere Island. Roblesky's paleocurrents (although few) and investigations into the provenance of these sediments strongly favoured derivation from high grade metamorphic terrains. He suggested that the adjacent shield areas of eastern Ellesmere Island and Greenland were the most likely source regions.

The most recent contribution is that of Smith and Stearn (1982) and is with regard to the depositional framework on the miogeoclinal shelf immediately preceding Okse Bay Group time. Their Figure 6, based on regional correlations, presents trends of early Late Emsian facies belts through the field area of this study. They determined that these facies belts were migrating northwestwards and suggested that the platform facies would be in the area east of Blue Fiord by early Eifelian time (this implies a shoreline in the Bird Fiord region in the west and Stenkul Fiord region in the east at the start of Okse Bay Group time). As such, a shoreline trend at the start of Okse Bay Group sedimentation (Late Emsian or Early Eifelian, Trettin, 1978; tentatively Early Eifelian, this study, see age for section S1) is suggested which carries with it important implications as to the direction of inclination of the regional paleoslope (i.e., inclined to the northwest).

1.5 Present Investigation

The present investigation constitutes part of a regional mapping project (810016) initiated by the Institute of Sedimentary and Petroleum Geology (GSC, Calgary) on southern Ellesmere Island in the summer of 1981 (see Okulitch and Mayr, 1982).

The coordinates of the field area of this investigation have been given previously (see 1.2). The period from mid June to mid August during the summers of 1981, 1982 and 1983 constitutes the amount of time spent in the field. Approximately two weeks were lost each season due to logistical difficulties and/or bad weather. In total, approximately eighteen weeks (4.5 months) of field work was completed. The initial and last field seasons were spent fly camping out of a Geological Survey of Canada base camp located either within (1981 season) or adjacent to (1983 season) the field area. The 1982 season was worked as an independent two man crew with logistical support from Resolute Bay on Cornwallis Island.

The field work for this project consisted of measuring section. The location of exposures of the Okse Bay Group was not a problem within the field area. However, the location of well preserved exposures suitable for detailed sedimentologic study was difficult. It was quickly discovered that aerial photographs were not reliable for this purpose. While they readily indicated where exposures were located, the altitude at which they were taken precluded the reliable determination of exposure quality. As a consequence, critical helicopter reconnaissance flights were completed during the 1981 season which served to locate good quality exposures for that and subsequent field seasons. A total of thirteen sections were measured. It was hoped to have them reasonably evenly spaced throughout the field area but in actuality good quality exposures were sufficiently scarce that a section was measured wherever it was located. Sections varied between approximately 130 m to 700 m in length and frequently incorporated portions of two formations. While all of the five constituent formations of the Okse Bay Group were investigated, the lowest and highest formations (Strathcona Fiord and Nordstrand Point, respectively) were included in, or constituted, sections only twice and once, respectively. The formations most thoroughly investigated in this study are the Hecla Bay, Fram and Hell Gate Formations (see below). In some sections, significant portions consisted of either felsenmeer or tundra. The rate of section measuring varied between 50 and 100 m a day. The magnetic compass was usable in this area but became somewhat erratic in the extreme western portions. In these regions it was frequently checked against topographic maps or aerial photographs. Lithologic and palynologic samples were taken whenever

whenever appropriate and/or available up through each section. The palynology samples were processed, identified and dated by Dr. D.C. McGregor of the Geological Survey of Canada, Ottawa. The results of his work can be found in McGregor (1982, 1984a,b). All directional structure measurements had the local or unit attitude removed by rotation about the formation strike on a Schmidt net prior to calculation of any vector means. Even low (less than 10^0) formation dips can significantly affect the dip direction recovered from the Schmidt net.

The thirteen sections measured for this project add up to a total of 5471 m. The amount of section accumulated for each formation is as follows (14 m of the Bird Fiord Formation were also measured at one locality): Strathcona Fiord - 539 m, Hecla Bay - 1501 m, Fram - 2354 m, Hell Gate - 955 m, Nordstrand Point - 108 m.

1.6 Justification and Objectives of the Study

The principle contribution of Embry and Klovan (1976), with respect to the Okse Bay Group on southwestern Ellesmere Island, was the provision of a stratigraphic and depositional framework for future research. The scope of their project precluded a more detailed sedimentologic study of the Okse Bay Group and they could only provide a general and brief overview of the sedimentology of each of the constituent formations. Their closing remark (Embry and Klovan, 1976, p. 617) stressed that the Devonian clastic wedge was worthy of a great deal more sedimentologic research. Trettin (1978, p. 87) also stated the need for more extensive work on the Okse Bay Group as a result of his investigations on west-central Ellesmere Island. The necessity of having a more thorough understanding of the sedimentology of these sediments is also accentuated by the fact that the clastic wedge has played a key role in numerous plate tectonic models for the Arctic Islands (Embry and Klovan, 1976) and has been incorporated into attempts to reconstruct the paleogeography of the Old Red Sandstone continent (Dineley, 1975).

In the context of a justifiable need for a more detailed investigation into the sedimentology of the Okse Bay Group, the objectives of this project are:

1. To refine the existing environmental interpretations of Embry and Klovan (1976) by looking at more sections of the Okse Bay Group in greater detail.
2. To attempt to gain some insight into basin architecture during Okse Bay Group time, which represents

the final phase of sedimentation in this area of the Franklinian Basin, through correlation with as much biostratigraphic (palynologic) control as could be acquired.

3. To investigate the provenance of the Okse Bay Group by a more thorough petrologic characterization of the sediments and by the acquisition of more paleocurrent data.

2.0 FORMATION ANALYSIS

The purpose of this chapter is to describe the lithologic and paleontologic data acquired for each formation at each section locality at which it was investigated and to suggest an environmental interpretation.

The breakdown of each section into facies constitutes the major and fundamental part of the environmental analysis. The degree to which one subdivides a section into facies is determined by the objective(s) of the study. The degree of subdivision attained varied both between and within the sections examined during this study. It was determined by the time available for the study of any one section, the weather during the data acquisition and the quality of the exposures being examined. Overall time constraints sometimes precluded the rigorous measurement of the vertical sequence of primary sedimentary structures. In such instances a qualitative assessment of the sequence and the relative proportions was noted.

2.1 Strathcona Fiord Formation

2.1.1 Introduction

The Strathcona Fiord Formation is the basal formation of the Okse Bay Group. The formation is only present east of the Cornwallis Fold Belt which is centrally located in the Arctic Islands. Its distribution and thickness variation in the eastern Arctic Islands was determined by Embry and Klovan (1976, figure 25). This formation was encountered at three of the thirteen section locations chosen for this study: section S1 - at the outer, eastern side of Stenkul Fiord; section HB1 - along a river located southwest of Sor Fiord; section S2 - located northeast of the head of Muskox Fiord. These localities are indicated on Figure 2.1.1-1.

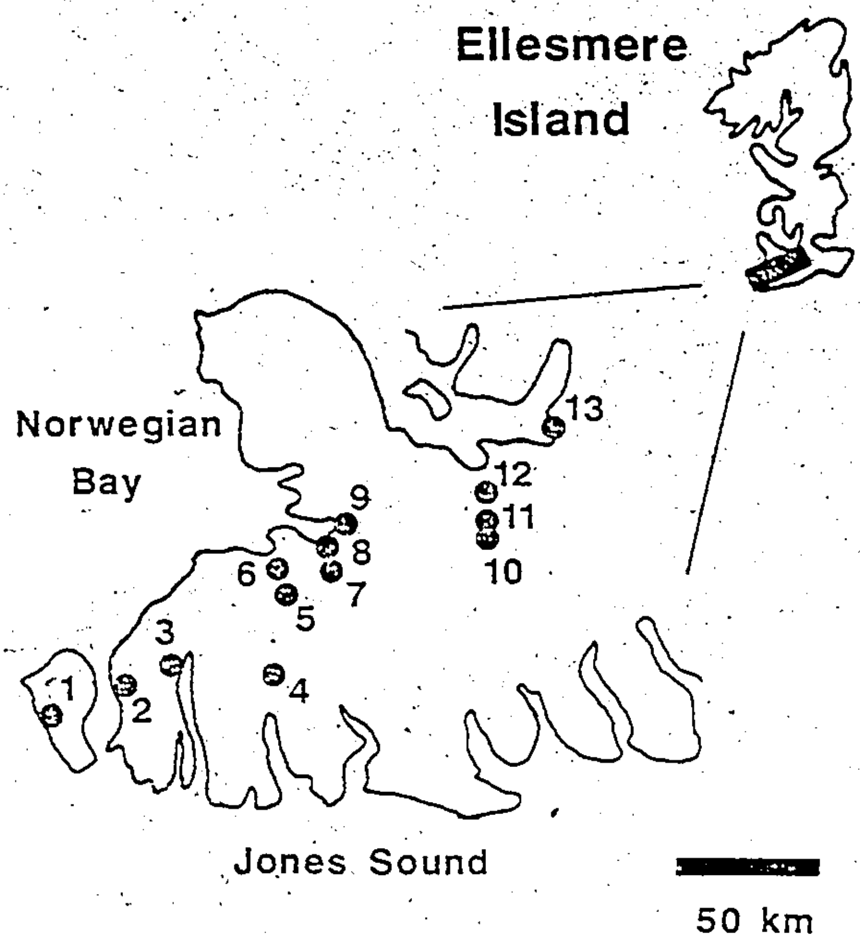
2.1.2 Summary of Lithological Descriptions and Age Determinations from Previous Studies

2.1.2.1 Lithological Descriptions

Although not exposed at Goose Fiord, the formation belongs to the lowest part of Schei's series E (1903, 1904). McLaren (1963a) examined 213 m (700 ft) of the formation approximately 10 km (6 miles) east of the head of Bird Fiord and assigned it to the basal part of his lower sandstone member. While similar beds did not outcrop along the east side of inner Goose Fiord, he suspected their presence in this area by the occurrence of red colored solifluction mud. He describes the beds east of Bird Fiord as "consisting of red and green sandy shales interbedded

Figure 2.1.1 - 1 Location of measured sections on southwestern Ellesmere Island and North Kent Island:

1. Section HB2
2. Section F3
3. Section F4
4. Section S2
5. Section HG1
6. Section HG3
7. Section HG2
8. Section F2
9. Section HB3
10. Section HB1
11. Section F5
12. Section F1
13. Section S1


Ellesmere
Island
Norwegian
Bay
13
12
9
11
8
6
10
7
5
3
1
2
4
Jones Sound
50 km

with varying amounts of thick bedded to massive sandstones". McLaren (1963b) also described his lower sandstone member from along the Tucker River, near Tucker Point, on eastern Grinnell Peninsula, Devon Island. The lower 91 m (300 ft) of this member correspond to the Strathcona Fiord Formation and are described as consisting of "red and green sandy shales and sandstones that rarely outcrop".

McGill (1974) mapped what we now know to be the Strathcona Fiord Formation in the Vendom Fiord area and referred to it as his "shale and evaporite member." It was briefly described as consisting of red and green shales having weathered surfaces frequently littered with fragments of anhydrite. Minor sandstones also occurred in this member which he suggested were deposited in a fluvial environment. He interpreted the shales to have been deposited in a "restricted lagoon under arid conditions."

Embry and Klovan (1976) examined the Strathcona Fiord Formation at a 200 m section located east of Bird Fiord (same location as McLaren, 1963a). They placed the contact with the underlying Bird Fiord Formation at the base of the first red shale unit and briefly described the formation as consisting of "red, green and grey shale with thin interbeds of grey, coarse siltstone and very fine grained sandstone" with the latter dominated by ripple cross-lamination.

The formation was examined, named, and the type section defined by Trettin during Embry and Klovan's study, but his study was not published until 1978. Trettin examined the formation in the Strathcona to Canon Fiords region on west-central Ellesmere Island. He defined a type section approximately 15 km southeast of the southeastern extremity of Canon Fiord (Trettin, 1978). At this location, the formation was broken down into five members, A-E, two of which (C and D) had lithofacies defined (see Trettin, 1978, p. 58-64). Member A consisted of thinly interstratified carbonate and clastic sediments interpreted to represent an environment ranging from shallow sub-tidal to high intertidal. Member B lacked carbonates and consisted mainly of siltstone and fine to medium grained sandstone found in units ranging from 0.3-12 m in thickness. It was suggested to represent a delta front environment. Member C and D consisted of coarse to fine grained clastics, with the former differentiated from the latter by the presence of carbonate units. Member C was interpreted to represent a delta plain environment, and member D was tentatively suggested to represent a more landward, lower alluvial plain type of setting. Member E consisted mainly of interstratified red and green siltstone, and very fine grained silty sandstone with less abundant fine to medium grained sandstone. It was assigned the same environmental interpretation as member D.

Roblesky (1979) also examined the Strathcona Fiord Formation in the Vendom Fiord area. He examined the formation at five locations. From the best of these exposures, he defined four members, A-D. Member A consisted of sandstone, siltstone, mudstone and skeletal grainstones and contained glauconite. Rare sedimentary structures consisted of laminations and rippling. The formation was suggested to represent a shallow sub-tidal marine portion of a marine to non-marine transitional unit. Member B consisted of greenish sandstones with rare red siltstones and also contained glauconite. Ripple cross-lamination, planar tabular and trough cross-beds, siltstone clast conglomerate horizons and scour surfaces characterize the sandstones. It was interpreted to represent the upper portion of the transitional unit mentioned above. Member C consisted of greyish green to red weathering sandstones with less common siltstone and rare conglomerate and limestone. It was organized into alternating resistant and recessive intervals. Ripple cross-lamination in the sandstones and siltstones was the most common sedimentary structure. The sandstones also displayed planar tabular and trough cross-stratification. The carbonate strata in this member occurred in 0.25-1 m beds. This member was interpreted to represent a distal alluvial plain setting with meandering channels and brackish to fresh water lakes and lagoons. Member D consisted of sandstone and siltstone with minor conglomerate arranged in fining upward cycles dominated by siltstone. Sandstone averaged 4-6 m and siltstone 7-10 m in thickness. Planar tabular and trough cross-bedding and ripple cross-lamination were common sedimentary structures. The member was interpreted to represent a meandering, alluvial plain setting. The thickness of members C and D exceeded that of members A and B indicating that the Strathcona Fiord Formation was mainly meandering fluvial in the Vendom Fiord area.

2.1.2.2 Age Determination

McLaren (1963a) examined what we now know to be the Strathcona Fiord Formation (lower part of his lower sandstone member) in the area east of the head of Bird Fiord. He states that poorly preserved plant remains were collected from the lower sandstone member (presumably from the shalier, lower part of the member) but does not report the age assigned to these specimens (if ages were assigned). While McGill (1974) examined the Strathcona Fiord Formation (his shale and evaporite member) in the Vendom Fiord region, he did not make fossil collections of any kind. Embry and Klovan (1976) examined the Strathcona Fiord Formation in the same area examined earlier by McLaren. They rely on spore analyses from immediately underlying and overlying formations to date the Strathcona Fiord Formation as Lower(?)-Middle Givetian. Trettin (1978) gives an age range for the formation on west-central Ellesmere Island as being from near the Dalejan-Eifelian boundary to Late Givetian, based on fossils recovered from the underlying Blue Fiord Formation and overlying Hecla Bay Formation. Roblesky (1979) dates the formation in the Vendom Fiord area using conodonts and spores as Dalejan-Eifelian to middle(?) Givetian. The age of the top of the formation could be somewhat younger however as his highest palynology sample came from approximately 300 m below the top of the formation.

2.1.3 Summary Facies Descriptions

The purpose of this section is to describe the lithological composition of the Strathcona Fiord Formation as a whole, by considering the three sections at which it was examined, cumulatively. The Strathcona Fiord Formation can be broken down into six facies and nineteen sub-facies.

These are indicated on Figure 2.1.3-1, where their relative abundance is indicated by their percentage of the Strathcona Fiord Formation by cumulative thickness. The descriptive attributes of the sub-facies are presented in Table 2.1.3-1.

Facies 2 - Sandstone

As indicated by Figure 2.1.3-1, sandstone is the dominant lithology in the Strathcona Fiord Formation. Eleven sub-facies have been defined, the attributes of which are contained in Table 2.1.3-1. As previously mentioned, it was sometimes necessary to only qualitatively note the relative proportions of primary sedimentary structures in a unit. As a result, the average thickness and range given for the sub-facies in the table must only be considered as a good approximation. Intervals of highly frost-heaved sandstone were simply assigned a number two. Most sandstones in the Strathcona Fiord Formation are ripple cross-laminated (2c), with planar tabular cross-stratified units (2a) and parallel laminated units (2b) being of secondary and tertiary importance, respectively. The average unit thickness of most sub-facies is less than 1.0 m, with planar tabular cross-stratified sandstone (2a) displaying a maximum average unit thickness of 2.5 m. Most

Figure 2.1.3 - 1 Sub-facies in the Strathcona Fiord Formation (all sections considered cumulatively). The ordinate scale is percentage by cumulative thickness.

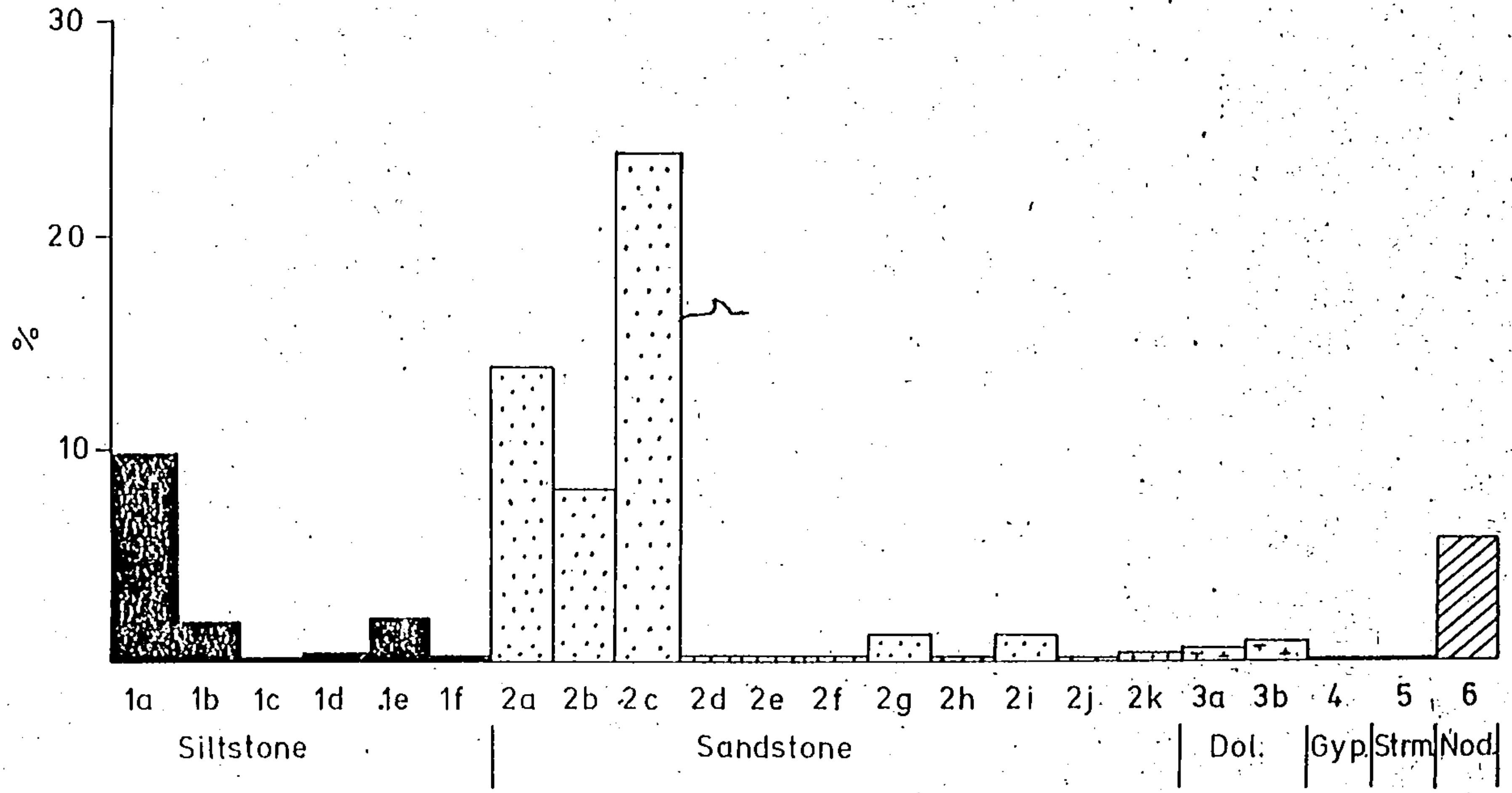

30
20
10
%
1a
1b
1c
1d
1e
1f
2a
2b
2c
2d
2e
2f
2g
2h
2i
2j
2k
3a
3b
4
5
6
Siltstone
Sandstone
Dol.
Gyp.
Strm
Nod

Table 2.1.3.-1 Descriptive Attributes of Sub-Facies Defined in the Strathcona Fiord Formation (All Sections Considered Cumulatively).

Facies 1 - Siltstone (14.5%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	66.9	0.9; cm-3.3	red, grey, green, brown/ red, grey, green	nf
parallel laminated siltstone	1b	12.4	1.1; 0.2-3.5	red, green, grey/ red, green, grey	nf
ripple cross laminated siltstone	1c	0.7	0.2	red, grey/red	nf
wavy laminated siltstone	1d	3.4	1.3; 1.2-1.4	grey, red/grey	nf
rooted siltstone	1e	14.5	1.7; 0.1-7.7	red, grey, brown, green/grey, red, green	comminuted plant debris
siltstone with trace fossils	1f	2.1	0.2; 0.1-0.5	red, green/grey	*Conostichus* and other burrows

Comment: may be ripple cross laminated or non-stratified

Facies 2 - Sandstone (49.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	27.9	2.5; 0.06-17.1	brown, grey, yellow, red, green, orange/ grey, red, white	ostracoderm fragments, gastropod cast, burrows

Comment: loading, siltstone clasts; cross beds mainly large scale with minor small scale occurrences

parallel laminated sandstone	2b	16.1.	0.81; 0.05-4.5	brown, black, green, red, grey, yellow/grey, red, white, green	*Lingula*, gastropod casts, plant fragments, *Conostichus*, other burrows

Comment: may contain siltstone clasts and dewatering structures

ripple cross laminated sandstone	2c	48.4	0.61; cm-3.3	brown, grey, red, green, black, orange, yellow/grey, red, brown, green, white	*Lingula* and other brachiopods, ostracoderm fragments, plant fragments, *Cruziana*, *Conostichus*, and other burrows

Comment: may contain dissolution cavities (fossil dissolution), load structures, mudcracks, dewatering structures, siltstone clasts

structureless sandstone with trace fossils	2d	0.4	1.3	yellow/grey	unidentified burrows

Comment: one occurrence only

sandstone with rooting	2e	0.8	0.52; cm-1.3	brown, grey red/red, grey	ostracoderm fragments, unidentified burrows

Comment: may contain mudcracks

sandstone with climbing ripple drift cross-lamination	2f	0.4	0.4; 0.08-0.6	green/grey	*Lingula*, plant fragments, unidentified burrows

Comment: can contain siltstone clasts

wavy and irregularly laminated sandstone	2g	2.4	1.0; cm-2.0	brown, yellow, grey/grey, green	*Cruziana*, other unidentified burrows

Comment: can contain dissolution cavities; mudcracks, siltstone clasts

sandstone with primary current lineation	2h	0.2	0.50; 0.4-0.7	red, brown/red, grey	nf
non-stratified sandstone	2i	2.6	0.54; 0.24-1.9	brown, red, grey/red, grey	nf

Comment: can contain dissolution cavities, siltstone clasts

sandstone with chert pebbles	2j	0.1	0.2	grey/white	ostracoderm fragments

Comment: can contain siltstone clasts

bedded sandstone with no bedforms	2k	0.8	0.10; cm-0.60	brown, green, red/grey, red	unidentified burrows

Comment: can contain siltstone clasts

Facies 3 - Dolomite (1.4%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
massive dolomite	3a	35.7	1.25; 1.2-1.3	brown/grey	nf

Comment: can be pyritic and contain dissolution cavities

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
irregularly to wavy laminated dolomite	3b	64.3	1.3; 0.8-2.1	brown, grey/grey, green	burrows, bioclastic horizons

Comment: can contain dissolution cavities and intraclasts

Facies 4 - Gypsum/Anhydrite (0.1%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
			0.7	white/white	nf

Comment: one occurrence only

Facies 5 - Stromatolite Horizon (0.1%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
			0.12; 0.02-0.4	brown/grey	ostracodes, bioclastic horizon

Comment: can be pyritic

<u>Facies 6</u> - Nodular Weathering Horizon (5.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
			1.1; 0.2-2.5	grey, white, red	nf

NOTE: 1) % of sub-facies in this table differs from those %'s shown in Figure 2.1.3-1 where the sub-facies %'s represent their proportion of the total thickness of Strathcona Fiord Formation measured i.e., Section S1, plus the Strathcona Fiord portion at Sections S2 and HB1.

2) 28.3% of measured section in the Strathcona Fiord Formation is covered.

3) W/f - weathered colour/fresh colour; dominant colour, if any, underscored in each case

4) Thickness - the first number represents the average thickness, if more than one occurrence; the second hyphenated pair of numbers represents the range in unit thickness

5) Paleo - fossil content; nf - no macroscopic fossils

Strathcona Fiord sandstones weather brown, but yellow, black, orange, green, red and grey hues are also seen. On a fresh surface they most commonly are grey and less frequently green, red or white. All sandstone sub-facies of the Strathcona Fiord are fossiliferous except sandstone with primary current lineation (2h) and non-stratified sandstone (2i). The fossil content of each sub-facies is listed in Table 2.1.3-1.

Facies 1 - Siltstone/Siltstone and Shale

Figure 2.1.3-1 indicates that facies 1 is secondary in importance in the Strathcona Fiord Formation. Six siltstone/siltstone and shale sub-facies have been distinguished and are described in Table 2.1.3-1. Subsequently, this facies will be referred to as the siltstone facies, with the possibility of a shale admixture being implied. In general, this facies is relatively recessive weathering. Highly weathered intervals in which other descriptive attributes could not be determined were simply designated as facies 1. All the siltstone sub-facies are variably argillaceous, micaceous and calcareous. Non-stratified siltstone (1a) is the dominant sub-facies. Parallel laminated (1b) and rooted siltstone (1e) are of secondary and roughly equal importance in the formation.

Unit thickness for the various sub-facies is commonly less than 1.0 m with the maximum average unit thickness (1.7 m) belonging to rooted siltstone (1e). Siltstones in the Strathcona Fiord Formation most commonly weather red, but are also found weathering grey, green, and brown. Fresh surface colors are either red, grey or green with no one color dominant. On the macroscopic scale most siltstone sub-facies are unfossiliferous; only 1e and 1f contain visible fossils (Table 2.1.3-1).

Facies 3 - Dolomite

Figure 2.1.3-1 indicates that dolomite is a minor lithology in the Strathcona Fiord Formation. It occurs only as thin units in section S1, interstratified with sandstone and siltstone. Two sub-facies are present, a massive dolomite (3a) and an irregularly to wavy laminated dolomite (3b). The attributes of both are presented in Table 2.1.3-1. Very highly weathered intervals in which no other features could be discerned were simply designated three. Units of each sub-facies average approximately 1.0 m in thickness. Dolomite units weather either grey or brown and are commonly grey, occasionally green on a fresh surface. Macroscopic fossils are present only in the irregularly to wavy laminated units (3b).

Facies 4 - Gypsum/Gypsum and Anhydrite

This facies occurs only once in section S1 and is therefore a very minor component of the formation as a whole. It is found as a white weathering horizon approximately 0.7 m thick (Table 2.1.3-1).

Facies 5 - Stromatolite Horizon

This facies is also a very minor lithological component of the Strathcona Fiord Formation (Figure 2.1.3-1). It is found only in section S1, and is usually associated with dolomite (facies 3). It occurs as thin, low relief, mat-like horizons usually only tens of centimeters in thickness. These horizons are often fossiliferous (ostracodes). They weather brown with grey fresh surfaces (Table 2.1.3-1).

Facies 6 - Nodular Weathering Horizons

Nodular weathering horizons occur only in section S2 and section HB1. Overall, they are a minor lithology in the Strathcona Fiord Formation (Figure 2.1.3-1). The units are thin, averaging approximately 1.0 m in thickness. They have a nodular appearance and weather a mottled grey, red and white. The host lithology was either a fine to very fine grained sandstone or a siltstone. The units are occasionally slightly calcareous and contain no macroscopic fossils (Table 2.1.3-1).

2.1.4 Section S1

2.1.4.1 Location, Thickness and Contact Relations

This section is located at the outer, eastern side, of Stenkul Fiord on south-central Ellesmere Island. Figure 2.1.4.1-1 is an aerial photograph of the vicinity of this section with the staff measured section indicated. The base of this section is located at 432825 E, 8596750 N, UTM zone 17x, NTS 49D, Vendom Fiord sheet.

The total thickness of the Strathcona Fiord Formation at this location is 1178 m (staff measured). Only the basal 293 m were well exposed along the northern side of a small ravine running into the fiord. They constitute section S1 and represent 25% of the formation thickness at this location.

The Strathcona Fiord Formation at this location rests conformably on the Blue Fiord Formation whose uppermost strata consist of thin biostromal carbonate and grey siltstone. The criterion used to pick the base of the formation was the base of the lowest red unit. The basal 10

Figure 2.1.4.1 - 1 Aerial photograph of section S1 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16676-142.


HB
Fm

m of the formation consisted of highly frost-heaved, thinly interstratified, grey and red siltstone and very fine sandstone. This criterion is the same as that used by Embry and Klovan (1976) at their locality just east of the head of Bird Fiord. The upper contact with the overlying Hecla Bay Formation is not exposed, but the attitude of the strata above and below the contact zone is effectively the same. It is safe to state, therefore, that the contact is conformable, but whether it is erosional or gradational could not be determined.

2.1.4.2 Age

The majority of siltstone/shale in this section is highly weathered and not suitable for palynological sampling. Six samples were collected, and submitted to D.C. McGregor (GSC, Ottawa) for analysis. The size of the samples approximated that of two closed fists held together. Three of the six samples were productive and the remainder barren. The lowest sample (GSC Loc. C-91922) was taken at 27.4 m above the base of the section and tentatively indicated an early Eifelian age. An intermediate sample (GSC Loc. C-91924) collected from 101.9 m above the base gave a probable age of about mid-Eifelian. The highest productive sample (GSC Loc. C-91926) was gathered at 197 m above the base of the section (96 m from the top) and gave a mid-Eifelian age. The list of spores and other palynomorphs found in these samples is contained in McGregor (1982).

In summary, the Strathcona Fiord Formation in this section ranges in age from tentatively early Eifelian to mid-Eifelian. The top of the section is 96 m above the highest productive sample, and the top of the formation is another 885 m above that, so that the formation at this locality is possibly somewhat younger than mid-Eifelian. The age of the base of the formation compares well with the earliest age (near the Dalejan-Eifelian boundary) obtained by Trettin (1978) in west-central Ellesmere Island and Roblesky (1979) at Vendom Fiord. It appears that the Strathcona Fiord Formation in west-central Ellesmere Island and in the Vendom Fiord-Stenkul Fiord region, is somewhat older than the formation immediately east of Bird Fiord where Embry and Klovan (1976) date it as Lower(?)-Middle Givetian.

2.1.4.3 Paleocurrent Analysis

While several primary sedimentary structures of directional significance occur in the Strathcona Fiord Formation at section S1 (see facies content in 2.1.4.4) time restrictions permitted the acquisition of paleocurrent measurements only from cross-bedded units. These units are extremely rare throughout this section of the formation. Only nine measurements were obtained, all of which are from large scale, planar tabular sets. The paucity of cross-bedding is a representative characteristic of the formation at this location. While many intervals in the section are highly weathered, this did not preclude the recognition of this sedimentary structure. Five of the measurements were obtained from what is interpreted as a tidal inlet sequence near the base of the formation, three from two tidal channel sequences in the middle of the formation and one from what is interpreted as a mixed-flat deposit. Figure 4.1-1 shows the rose diagram constructed from the nine measurements. The vector mean is oriented toward the northwest. Considering the few measurements and their stratigraphic separation the significance of the diagram is minimal. The measurements are discussed again, subsequently, in the context of the interpretation offered for their containing stratigraphic unit.

2.1.4.4 Facies Content

Section S1 represents the thickest section measured in this formation and is also the most complex.

The Strathcona Fiord Formation at this location consists of five facies and eighteen sub-facies. Their relative percentage of the section, by cumulative thickness, is indicated on Figure 2.1.4.4-1. The dominant sub-facies are ripple cross-laminated sandstone (2c), planar tabular cross-bedded sandstone (2a) and non-stratified siltstone (1a), in decreasing order of importance.

Three of the five facies (facies 3 - dolomite, facies 4 - gypsum/anhydrite, facies 5 - stromatolite horizons) constituting the lithological makeup of this section only occur in the Strathcona Fiord Formation at this location. Consequently, their summary descriptions previously given in 2.1.3 should be referred to. Their relative abundance, by cumulative thickness, at this location is 2.6%, 0.2% and 0.2%, respectively. Table 2.1.4.4-1 contains the descriptive attributes of the sub-facies at section S1. Those sub-facies only occurring in the Strathcona Fiord Formation at this location have been previously described in Table 2.1.3-1. This includes the two dolomite sub-facies (3a, 3b), two siltstone sub-facies (1d, 1f) and four sandstone sub-facies (2d, 2f, 2g, 2h). The relative abundance of these sub-facies in their respective facies, by cumulative thickness, is as follows:

1d - 8.3%	3a - 34.6%	2d - 10%
1f - 5.6%	3b - 65.4%	2f - 1.0%
		2g - 5.3%
		2h - 0.5%

Summary descriptions of the sandstone and siltstone at section S1 is given below. Figure 2.1.4.4-2 presents the drafted section (in pocket).

Facies 2 - Sandstone

Figure 2.1.4.4-1 indicates that sandstone is the dominant lithology at section S1. It constitutes 39.5% of the formation by cumulative thickness. Most sandstone is ripple cross-laminated (2c). Based on hand lens examination, grain size ranges from coarse silt to very fine sand. Average unit thickness varies from a maximum of 1.9 m in planar tabular cross-bedded sandstone (2a), to a minimum of 0.04 m in rooted sandstone (2e). Most sandstone at this section weathered brown, but also displays red, yellow, and green colors. Fresh surfaces are almost always grey. All sandstone sub-facies are fossiliferous except sandstone with primary current lineation (2h) and non-stratified sandstone (2i). Their fossil content is given in Table 2.1.4.4-1.

Figure 2.1.4.4 - 1 Sub-facies in the Strathcona Fiord Formation at section S1. The ordinate scale is percentage by cumulative thickness.

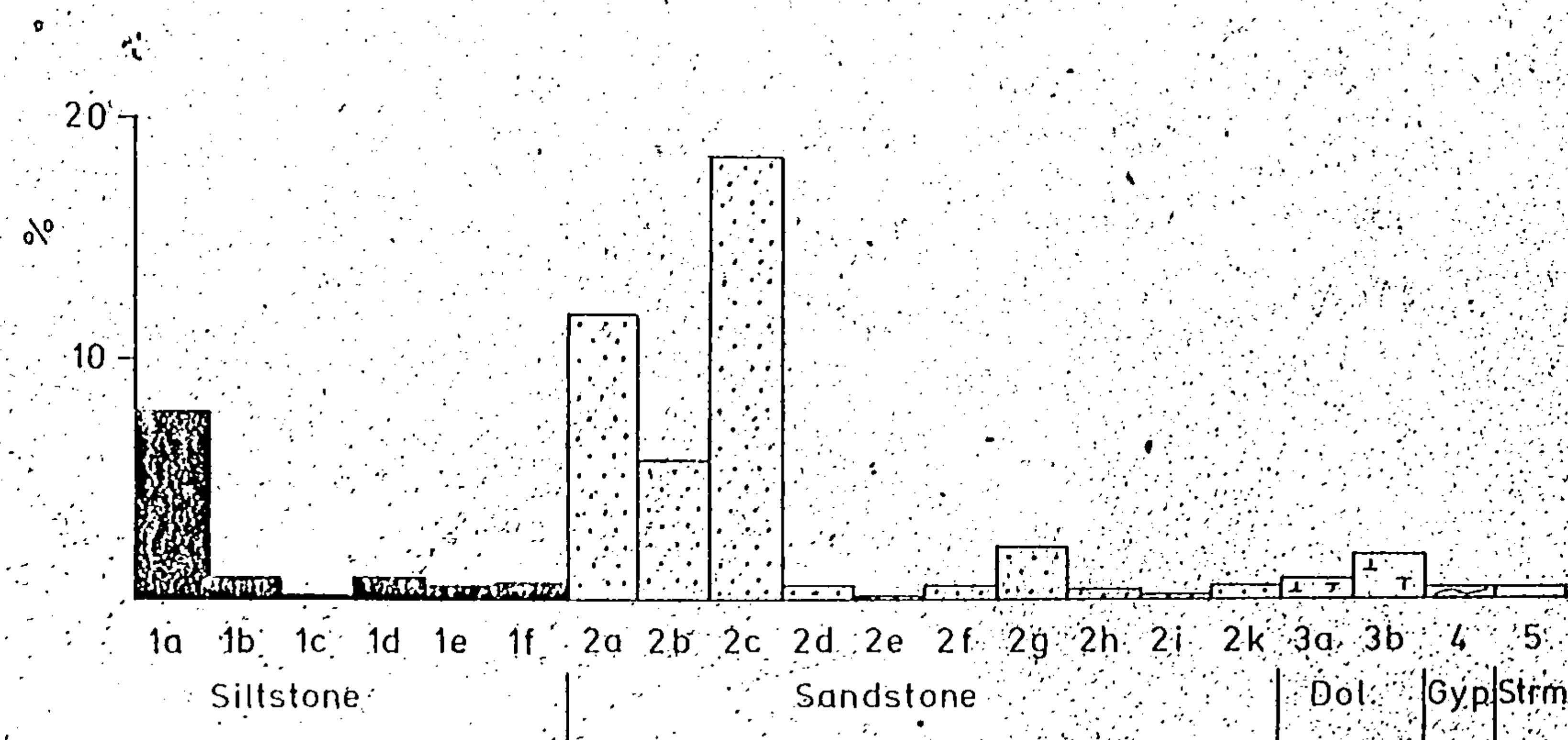

%
20
10
1a
1b
1c
1d
1e
1f
2a
2b
2c
2d
2e
2f
2g
2h
2i
2k
3a
3b
4
5
Siltstone
Sandstone
Dol.
Gyp
Strm

Table 2.1.4.4.-1 Descriptive Attributes of Sub-Facies Defined in the Strathcona Fiord Formation at Section S1.

<u>Facies 1</u> - Siltstone (10.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	73.1	0.5; cm-3.3	<u>red</u>, brown, grey, green/<u>grey</u>, red, green	nf
Comment: can contain mudcracks					
parallel laminated siltstone	1b	8.3	0.5; 0.2-1.0	grey, green, <u>red</u>/<u>grey</u>, red, green	nf
ripple cross laminated siltstone	1c	0.9	0.05	red, grey/red, grey	nf
rooted siltstone	1e	3.7	0.4; 0.05-0.8	<u>red</u>, grey/grey	root traces

<u>Facies 2</u> - Sandstone (39.5%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross bedded sandstone	2a	29.9	1.9; cm-8.0	<u>brown</u>, red, green, orange, yellow/grey	burrows, gastropod casts, ostracoderm fragments
Comment: may contain siltstone clasts					

parallel laminated sandstone	2b	14.7	0.8; cm-3.0	brown, red, green, black, yellow/grey, red, green	*Lingula*, plant debris, unidentified burrows
Comment: may contain siltstone clasts					
ripple cross-laminated sandstone	2c	46.3	0.6; cm-12.3	red, brown, green, grey, black, yellow/grey, red, green	*Lingula*, brachiopod fragments, plant debris, gastropod casts, / *Cruziana*, conostichus, other burrows
Comment: can contain dewatering structures, dissolution cavities, siltstone clasts, pyrite					
rooted sandstone	2e	0.3	0.04; 0.03-0.05	brown/grey	root traces
non-stratified sandstone	2i	0.3	0.2	brown/grey	nf
Comment: can contain dissolution cavities and siltstone clasts					
bedded sandstone without preserved bedforms	2k	0.8	0.1; cm-0.25	brown, green/grey	unidentified burrows
Comment: can contain siltstone clasts					

NOTE: 1) w/f, thickness, and paleo. as per comments 3, 4, and 5 following Table 2.1.3-1
2) 46.7% of section S1 is covered.
3) not all sub-facies present at section S1 are contained in this table; see text for explanation.

Facies 1 - Siltstone

Siltstone is second in importance as a lithology at section S1. It represents 10.8% by cumulative thickness. Most siltstone intervals weather recessively and are non-stratified (1a). Average unit thickness varies from a maximum of 0.5 m for non-stratified (1a) and parallel laminated siltstone (1b), to a minimum of 0.05 m for ripple cross-laminated siltstone (1c). Siltstones weather dominantly red, with common grey and green colors as well. Fresh surfaces are commonly grey. All sub-facies are fossil-free excepting 1f, which contains Cruziana and other unidentified burrows.

2.1.5 Section S2

2.1.5.1 Location, Thickness And Contact Relations

Section S2 is located approximately 15 km north-northeast of Muskox Fiord. The base of the section is located at 489000 E, 8159000 N, UTM zone 16X, NTS 49B, Baad Fiord sheet. Figure 2.1.5.1-1 is an aerial photograph of the area of section S2 showing the line of section and formation contacts.

Section S2 includes 13.5 m of the uppermost Bird Fiord Formation at its base followed by 199 m of Strathcona

Figure 2.1.5.1 - 1 Aerial photograph of section S2 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16756-122.


1 km

Fiord Formation representing the complete formation thickness in this area. Only the Strathcona Fiord Formation is discussed. The contact between the Bird Fiord and Strathcona Fiord Formation was not observed, but is inferred to be conformable on the basis of similar attitudes above and below the contact zone. The age of the uppermost Bird Fiord Formation in this area is late Eifelian-early Givetian based on spore identifications by McGregor (1982, pg. 13-14) from samples collected in the top 13.5 m of the formation (GSC Loc. C-91929, 91930, 91931). The Hecla Bay Formation conformably and gradationally overlies the Strathcona Fiord Formation in this area. This contact was observed near the top of the west wall of the small stream cut in which the section is located.

2.1.5.2 - Age

Unfortunately, no productive palynology samples were obtained from the Strathcona Fiord Formation at this section. The base of the formation must be approximately late Eifelian-early Givetian however, as the highest productive palynology sample collected from the Bird Fiord Formation was only 6.8 m below the contact between the two formations and gave a late Eifelian-early Givetian age (GSC Loc. C-91931; McGregor, 1982). Nothing can be said regarding the age of the top of the formation since no age has been obtained from the overlying Hecla Bay Formation in this area.

2.1.5.3 Paleocurrent Analysis

Twenty-eight paleocurrent measurements, all from large scale, planar tabular cross-strata were obtained from the Strathcona Fiord Formation at this location. Seven of these were obtained from sandstone units representing crevasse splays. The rose diagram of planar tabular cross-strata, exclusive of overbank measurements, shows a vector mean to the northeast (028^0; Figure 4.1-1). A vector mean however, can hide a vertical change in paleoflow. Of possible significance is a shift from a northeasterly to northwesterly paleoflow direction which first occurs in a 0.70 m thick medium grained, grey-white sandstone unit (contrasting with the red-brown, finer grained, Strathcona Fiord sandstone) at 147.6 m above the base of the section. This unit is interpreted as a crevasse splay deposit (J1 in the interpretation). It represents the initial appearance of grey-white colored Hecla Bay (the overlying formation) detritus. While the containing unit is suggested to be an overbank flood deposit, all paleocurrents (9) recorded from the overlying part of the section were contained in channel sandstone units also consisting of grey-white colored Hecla Bay detritus and also giving a northwesterly paleoflow. The implication of the coincidence of the initial appearance of Hecla Bay detritus as an overbank flood deposit with a marked change in paleoflow which is maintained in overlying channel sandstones is as follows. Since the overlying Hecla Bay Formation is interpreted as a sandy braided fluvial deposit (presented in a subsequent section) the change in alluvial regime from a meandering fluvial Strathcona Fiord Formation (see below) may have been initiated by a high energy flood event (avulsion) that re-oriented the river course from a northeasterly to northwesterly direction. Unfortunately, this must only be considered as speculation. The maintenance of an overall northwesterly paleoflow in the overlying Hecla Bay Formation cannot be confirmed since no paleocurrents have been recorded from it due to very poor exposure quality.

2.1.5.4 Facies Content

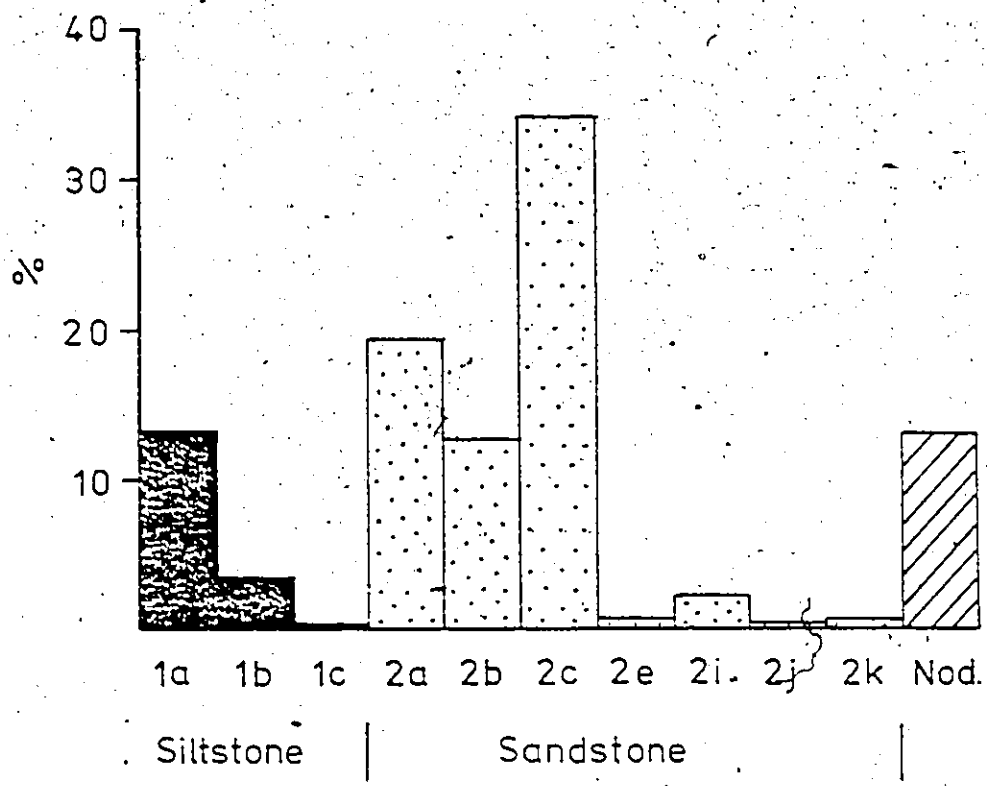
Section S2 consists of three facies and ten sub-facies. In decreasing order of dominance the lithologies are sandstone, siltstone and nodular weathering horizons. The relative abundance, by cumulative thickness, of the various sub-facies is shown on Figure 2.1.5.4-1.

Table 2.1.5.4-1 presents the descriptive attributes of the sub-facies. One sandstone sub-facies (sandstone with chert pebbles-2j) is restricted in occurrence to this section. It has therefore been previously described in Table 2.1.3-1. It only occurs once in this section and represents 0.1% of the sandstone. Covered interval constitutes 20.5% of the Strathcona Fiord Formation at this location. Summary descriptions of the three facies are given below. Figure 2.1.5.4-2 is the drafted section (in pocket).

Facies 2 - Sandstone

Sandstone dominates this section representing 70.2% by cumulative thickness. Figure 2.1.5.4-1 indicates that ripple cross-laminated sandstone (2c) is the dominant sub-facies followed by planar tabular cross-bedded sandstone (2a) and parallel laminated sandstone (2b). Most sandstone is red or brown weathering and dominantly red colored on a fresh surface. Maximum and minimum average unit thickness is 3.5 m for sub-facies 2b and 0.1 m for sub-facies 2e. Sub-facies 2b, 2i, and 2k contain no macroscopic fossils. Other than root traces in sub-facies 2e, the only macroscopic fossils are fragments of ostracoderm in sub-facies 2a, 2c, and 2j.

Figure 2.1.5.4 - 1 Sub-facies in the Strathcona Fiord Formation at section S2. The ordinate scale is percentage of the formation by cumulative thickness.



40
30
20
10
%
1a
1b
1c
2a
2b
2c
2e
2i
2j
2k
Nod.
Siltstone
Sandstone

Table 2.1.5.4.-1 Descriptive Attributes of Sub-Facies Defined in the Strathcona Fiord Formation at Section S2

Facies 1 - Siltstone (16.7%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	78.2	1.1; 0.04-3.0	red, brown, grey, green/red, grey, green	nf
Comment: hematite pellets up to 2.0 cm apparent maximum dimension can be found in a reduced upper portion of some units					
parallel laminated siltstone	1b	20.8	2.8; 2-3.5	red/red	nf
ripple cross-laminated siltstone	1c	1.0	0.2	red/red	nf

Facies 2 - Sandstone (70.2%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	27.5	1.5; 0.4-4.0	grey, brown, orange/white, red, grey	ostracoderm fragments
Comment: can contain siltstone clasts					

parallel laminated sandstone	2b	18.2	3.5; 2.5-4.5	grey, brown/red, grey	nf
Comment: can contain siltstone clasts					
ripple cross laminated sandstone	2c	48.8	0.8; 0.1-3.3	<u>brown</u>, red, grey, green, orange, black/<u>red</u>, brown, grey, green, white	ostracoderm fragments
Comment: can contain siltstone clasts					
rooted sandstone	2e	1.0	0.1; 0.1-0.2	<u>brown</u>, red, grey/red	nf
non-stratified sandstone	2i	3.4	0.63; 0.6-0.7	red, brown/red	nf
bedded sandstone without preserved bed forms	2k	0.8	0.3	red/red	nf
Comment: one occurrence only					

<u>Facies 6</u> - Nodular Weathering Horizons (13.1%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
			1.2; 0.2-2.5	variegated grey, white and red	nf

<u>NOTE:</u> 1) w/f, thickness and paleo. as per comments 3,4, and 5, following Table 2.1.3-1.

Facies 1 - Siltstone

Siltstone is of secondary importance in the Strathcona Fiord Formation representing 16.7% by cumulative thickness. The dominant weathered and fresh surface color is red. Some weathered surfaces may show brown, grey or green hues, while a small number of fresh surfaces may be grey or green. A maximum average unit thickness of 2.8 m is displayed by parallel laminated siltstone (1b). A minimum average unit thickness of 0.2 m is found in ripple cross-laminated siltstone (1c). No macroscopic fossil evidence occurs in any of the siltstone sub-facies.

Facies 6 - Nodular Weathering Horizons

Nodular weathering horizons are the least abundant facies in section S2, representing only 13.1% by cumulative thickness. These horizons have a nodular (1-7 cm) weathering style and weather a variegated grey, white and red. They average 1.2 m in thickness, contain no macroscopic fossils and can be slightly calcareous.

2.1.6 Section HB1 (Strathcona Fiord Formation portion)

2.1.6.1 Location, Thickness and Contact Relations

Section HB1 lies along a river approximately 23 km south-southwest of Sor Fiord. The base of the section is located at 560600E, 8556850N, UTM Zone 16X, NTS 49C, Baumann Fiord sheet. Figure 2.1.6.1-1 is an aerial photograph of the area of section HB1 showing the line of section and formation contacts.

Most of section HB1 consists of the Hecla Bay Formation, only the basal 46.9 m were measured in the uppermost Strathcona Fiord Formation. The formation is underlain by the Bird Fiord Formation and overlain by the Hecla Bay Formation in this area. The contact with the Bird Fiord was not seen and that with the overlying Hecla Bay was conformable and erosional. The basal Hecla Bay Formation at this location is a conglomerate lying erosionally on the finer grained Strathcona Fiord Formation sediments.

2.1.6.2 Age

Only two palynology samples were acquired from this short section in the Strathcona Fiord Formation. Both were unproductive (McGregor, 1984a, pg. 15). The closest productive sample was taken from the Hecla Bay Formation 26.8 m above the contact with the Strathcona Fiord Formation (GSC Loc. C-91990). It gave an age of early mid-Eifelian.

Figure 2.1.6.1 - 1 Aerial photograph of sections HB1, F5 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16778-109.


1 km
Fm.

As the basal contact was not seen, no information regarding its age was collected.

2.1.6.3 Paleocurrent Analysis

Four paleocurrent measurements were obtained from the Strathcona Fiord Formation at this section location. All four are from large scale, planar tabular cross-beds in a 2.3 m channel sandstone, 24.3 m above the base of the section. Figure 4.1-1 contains the rose diagram constructed from these measurements. It shows a vector mean of 044^0. The channel sandstone from which these measurements were taken is the only channel fill sediment in this short section of the formation. It is composed of Hecla Bay style detritus (grey-white colored), as were the upper channel fills at section S2. This is to be expected in light of the proximity to the contact with the overlying Hecla Bay Formation. While the northeasterly vector mean compliments a northeasterly paleocurrent direction obtained from the channel fills containing Strathcona Fiord style detritus at section S2, it differs from those channels that contained Hecla Bay style detritus which, for the most part, showed northwesterly oriented paleocurrents. However, considering the distance separating sections S2 and HB1, and the very small sample size, a great deal of interpretative significance cannot be attached.

2.1.6.4 Facies Content

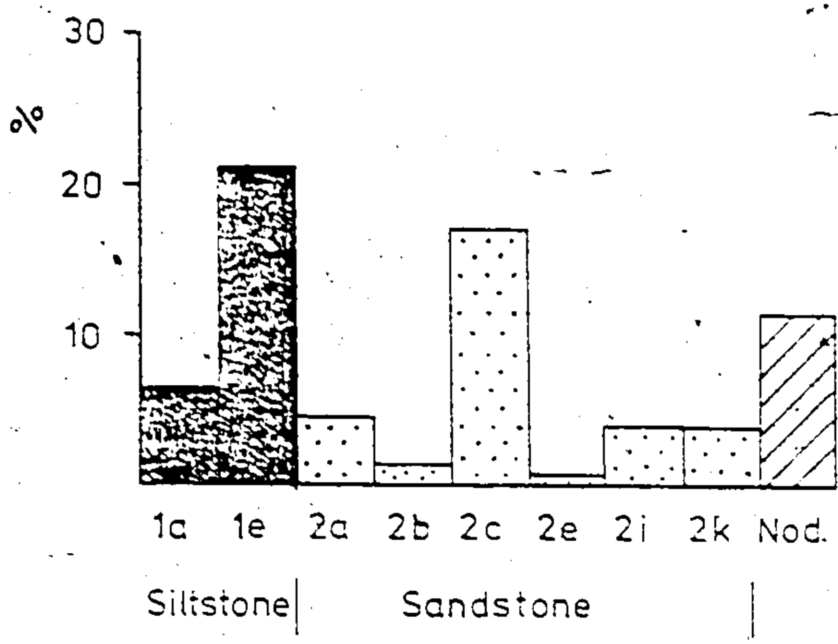
The Strathcona Ford portion of section HB1 consists of sandstone (31.1%), siltstone (29.9%) and nodular weathering horizons (11.3%). Covered interval represents 27.7% of the Strathcona Fiord Formation at this location. Three facies and eight sub-facies have been delineated. Figure 2.1.6.4-1 indicates their relative abundance by cumulative thickness. Their descriptive attributes are given below in Table 2.1.6.4-1. Some poorly exposed siltstone intervals occurred in the section for which only gross lithology could be discerned. These were simply coded as facies 1. They represent 7.9% of the siltstone.

Brief summary descriptions of the sandstone and siltstone lithologies are given below. Facies 6, nodular weathering units, are described in Table 2.1.6.4-1. The drafted section is presented in Figure 2.1.6.4-2 (in pocket).

Facies 2 - Sandstone

The sandstone in the Strathcona Fiord Formation at this location is all very fine grained. The dominant

Figure 2.1.6.4 - 1 Sub-facies in the Strathcona Fiord Formation at section HB1. The ordinate scale is percentage of the formation by cumulative thickness.



30
%
20
10
1a
1e
2a
2b
2c
2e
2i
2k
Nod.
Siltstone
Sandstone

Table 2.1.6.4.-1 Descriptive Attributes of the Sub-Facies Defined in the Strathcona Fiord Formation at section HB1

Facies 1 - Siltstone (29.9%)

SUB FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non stratified siltstone	1a	21.4	0.43; 0.10-0.80	brown, green, red, grey/green, red	nf
rooted siltstone	1e	70.7	2.4; 0.15-6.9	red, green, grey/green, brown	plant fragments

Facies 2 - Sandstone (31.1%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross bedded sandstone	2a	13.7	1.0	grey, brown/red, white	nf
parallel laminated sandstone	2b	4.1	0.6	grey/white	nf

ripple cross-laminated sandstone	2c	54.8	0.53; 0.1-0.9	brown, grey, orange/red, grey, white	ostracoderm fragments
rooted sandstone	2e	2.1	0.3	brown/red	nf
non-stratified sandstone	2i	12.3	0.6; 0.4-1.0	orange, grey/green, grey	nf
bedded sandstone without preserved bedforms	2k	13	1.9	green, red/grey	nf

Facies 6 - Nodular Weathering Horizons (11.3%)

SUB FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
			0.8; 0.4-1.2	variegated grey, white, red	nf

NOTE: 1) w/f, thickness, and paleo. as per comments 3,4, and 5, following Table 2.1.3-1.

weathering colors are grey and brown, with minor orange, green and red hues. Fresh surfaces are dominantly red or grey, with minor green and white colors. Maximum and minimum average unit thickness is 1.9 m for sub-facies 2k, and 0.3 m for 2e. Macroscopic fossil content is limited to ostracoderm fragments in the ripple cross-laminated sandstones (2c).

Facies 1 - Siltstone

Figure 2.1.6.4-1 indicates that siltstone is of approximately equal importance to sandstone in this section. Overall, it is recessive weathering and is dominantly red and grey, with minor brown and green colors. Fresh surfaces are either brown or green in color. A maximum average unit thickness of 2.4 m occurs in the rooted sub-facies (1e). Macroscopic fossils, other than root traces, are limited to plant fragments also occurring in sub-facies 1e.

2.1.7 Interpretation Of Depositional Environments

2.1.7.1. Section S1

Facies sequence is heavily relied upon in the following interpretation. Many of the subfacies are individually non-diagnostic of environment of deposition (such as non-stratified siltstone or ripple cross-laminated sandstone). However, when small groups of these (genetic associations) are examined within the context of the environment suggested by the larger scale evidence, they assume an environmental significance. A formal contingency table analysis of the vertical succession of sub-facies in search of preferred transitions (Markov Chain analysis) was investigated but found unfeasible for this section. The highly variable exposure quality of the finely interstratified sediments, and severe time constraints, precluded the establishment of a sufficiently reliable vertical sequence.

The regional stratigraphic context of the Strathcona Fiord Formation does not change between central and southwestern Ellesmere Island. The formation is everywhere constrained between a fluvial unit above (Hecla Bay Formation) and a siliciclastic marine to deltaic, or shelf carbonate unit, below (Bird Fiord Formation in the west and Blue Fiord Formation in the east, respectively). As mentioned in 2.1.4.1, section S1 is a basal section in the formation. Basal portions of the formation in adjacent areas have been examined and interpreted as tidal flat-delta plain (Embry and Klovan, 1976), shallow sub-tidal marine (Roblesky, 1979) and shallow sub-tidal to high intertidal (Trettin, 1978). The established regional stratigraphy and previous interpretations create reliable constraints on what one should anticipate for the environment of deposition of the basal Strathcona Fiord Formation at section S1 (i.e., a near shore, shallow marine to tidal flat depositional setting). The initial examination of the section provided sufficient evidence to warrant using this environmental setting in an interpretation. This evidence consisted of:

1) the overall finely interstratified nature of the sandstone and siltstone

2) the conformable basal contact with an underlying biostromal shelf carbonate unit in the Blue Fiord Formation

3) the dominance of non-stratified siltstone and very fine grained, ripple cross-laminated sandstone

4) the paucity of large scale cross-bedding

5) the abundance of trace fossils

6) the rare occurrence of thin dolomite, stromatolite and gypsum-anhydrite units.

The Barrier Island-Lagoon-Tidal Flat Modal

The barrier island-lagoon-tidal flat model is considered most appropriate for the interpretation of section S1. Subsequent to a brief review of this model, an interpretation of the constituent facies is presented. The essential components of the above model are:

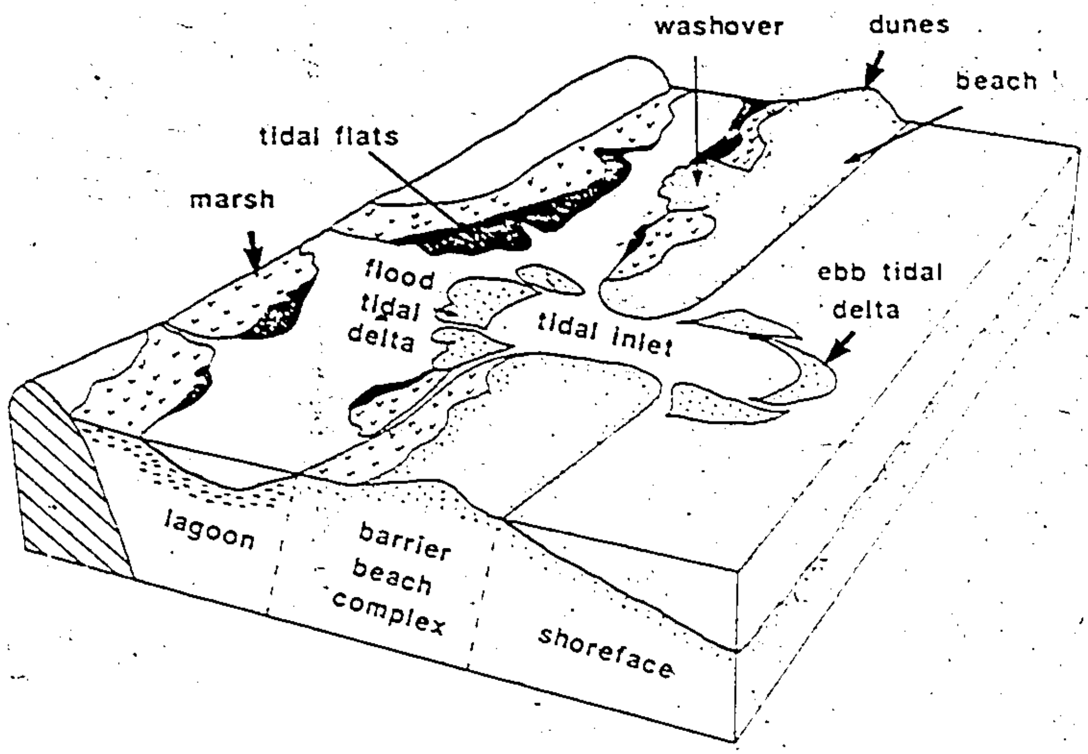
1) a barrier island complex

2) a protected lagoon lying between the barrier island and the mainland

3) tidal flats fringing the mainland and sometimes the lagoonward margin of the barrier island.

Figure 2.1.7.1-1, taken from Reinson (1984), illustrates the components of a tidal flat-lagoon-barrier island system. It is not intended that this figure be considered as an accurate representation of the environmental setting envisaged for the Strathcona Fiord Formation at section S1. Figure 2.1.7.1-2, taken from Reineck (1972), presents the vertical sequence of sediments developed under a progradational regime in a barrier island-lagoon-tidal flat model. While all of these environments are interpreted as being present in section S1 (some environments are represented by an associated sub-environment), those of the intertidal zone (sand flat, mixed flat and mud flat) occur most frequently. Tidal flats have been studied most extensively along the German and Dutch coasts of the Wadden Sea (Reineck, 1972; van Straaten, 1954, 1961). Other principal areas of tidal flat research are the Wash in eastern England (Evans, 1965, 1975), the Bay of Fundy in Nova Scotia, Canada (Klein, 1963, 1967) and the

Figure 2.1.7.1 - 1 Components of a barrier island-lagoon-tidal flat depositional setting. Modified from Reinson, 1984.


washover
dunes
beach
tidal flats
marsh
flood tidal delta
tidal inlet
ebb tidal delta
lagoon
barrier beach complex
shoreface

Gulf of California, U.S.A. (Thompson, 1968, 1975). Major references on this environment would include:

1). Reineck (1972), who provides an excellent bibliography on tidal flat research on the German North Sea coast.

2) Ginsburg (1975), in which case studies of modern and ancient tidal flats are presented.

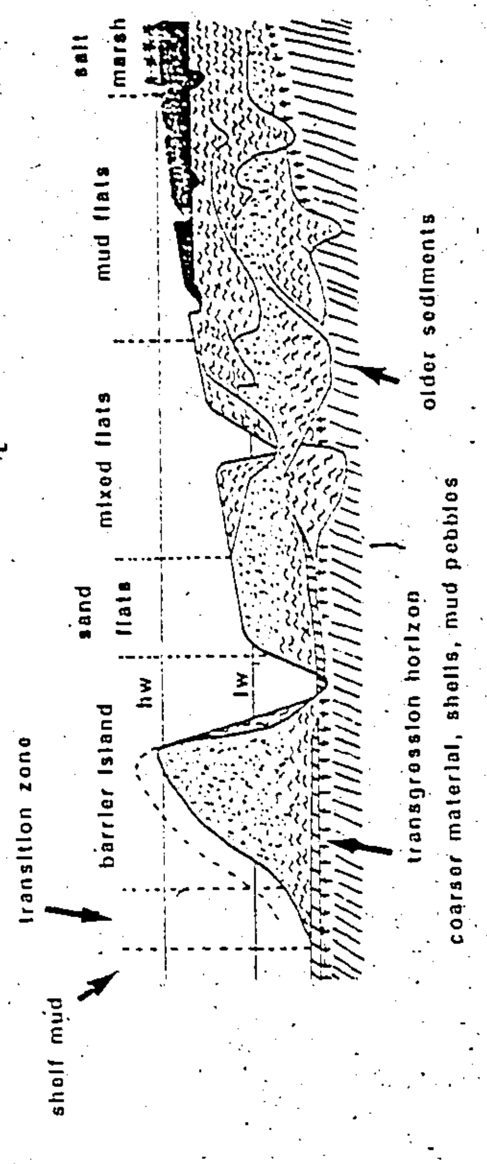
3) Davies (1978).

4) Reineck and Singh (1975).

5) Weimer, Howard and Lindsay (1982).

The upper and lower limits of the intertidal zone is defined by the maximum high tide and the minimum low tide experienced by a region. For many, but not all tidal flats, the intertidal zone can be thought of as consisting of three zones which are ultimately determined by the average energy which is dissipated against them by waves and tides. The sand flats are the lowest zone and experience the highest ambient energy. The sediments of this zone are the first to feel any incoming waves and are the most frequently innundated. As a result, finer sediments are winnowed out leaving a residual sand deposit. The intermediate zone, relative to lowest low tide, is the mixed flats, implying an admixture of silt and clay with sand. Ideally, the percentage of silt and clay increases gradually up through this zone in response to a gradual decrease in the ambient

Figure 2.1.7.1 - 2 Stratigraphic sequence developed under a progradational regime in a barrier island-lagoon-tidal flat depositional setting. Modified from Reineck, 1972.


shelf mud
transition zone
barrier island
hw
lw
sand flats
mixed flats
mud flats
salt marsh
older sediments
transgression horizon
coarser material, shells, mud pebbles

energy level due to a reduced wave energy and innundation frequency. The mud (silt and clay) flats are the highest zone and are subjected to fewer innundations and less wave energy than the sand or mixed flats. The sediments of this zone consist almost wholly of silt and clay with minor additions of finer sand during storms. Often, the upper part of mud flats are partially colonized by marsh-type (halophytes) plants. It is stressed, however, that not all tidal flats exhibit such a simple arrangement. A good example of this is the Wash of eastern England. Evans (1965) determined a considerably more complex vertical zonation for these tidal flats than is summarized above.

In addition to a surficial zonation on the basis of the ambient energy level, tidal flats are internally divisible into two basic types of deposits, these are:

1) tidal channel deposits (including tidal creeks and gullies)

2) interchannel deposits

In general, tidal channel density decreases and size increases as you proceed seaward through the surficial zonation mentioned above. Tidal channels are highly mobile in a fashion analogous to a meandering alluvial channel (Reineck, 1967, Bridges and Leeder, 1976). Their migration is most rapid during late ebb flow when the seaward flowing currents are the strongest and commonly occurs at a rate of 10's of meters/year (Elliot, 1978). Like meandering river channels, they have erosional bases, depositional inner banks (point bars with epsilon surfaces) and erosional outer banks, may fine upwards and may sometimes have their channel form preserved. While tidal channel networks are a prominent feature of most modern tidal flats, the tidal flats associated with the Colorado River delta at the head of the Gulf of California (Thompson, 1975) are a unique modern example of tidal flat development without tidal channels.

The prevalent model regarding the development of tidal flat sequences is based largely on studies of modern tidal flats and portrays tidal flat deposits as consisting dominantly of the geologically more preservable tidal channel fill sequences overlain by a veneer of interchannel finer deposits with a much lower preservation potential (for example see Weimer, Howard and Lindsay, 1982). Tidal channel networks are perceived as completely reworking the deposits of the sand and mixed flats, and partially reworking the mud flat deposits, as a consequence of their rapid lateral migration associated with the tidal cycle. It is around this point, i.e. the nature of the sedimentary sequence anticipated for ancient tidal flat settings, that an apparent discrepancy develops suggesting a lack of understanding of current tidal flat environments. As Weimer, Howard and Lindsay (1982, pg. 192) point out, there are many examples in the geologic record of sedimentary sequences interpreted as tidal flat deposits that do not contain significant tidal channel fill deposits. This discrepancy between the modern and ancient is as yet not explained with our only modern example of such a situation being the somewhat unique setting at the head of the Gulf of California, as mentioned above.

An important final point regarding tidal flat sequences concerns their thickness, i.e., they are very thin. The slope on Figure 2.1.7.1-2 is highly exaggerated. On modern tidal flats the slope of the tidal flat surface is only a few degrees. As a result, although the belt of tidal flat facies may be several kilometers wide, perpendicular to the shoreline trend, the change in elevation between the sand flats and mud flats is only a few meters. Several ancient examples of intertidal deposits are also reported to be very thin. Klein (1971) reports an intertidal thickness of only ca. 1 m, Johnson (1975) reports a thickness of ca. 2 m for combined sub-tidal and intertidal deposits and a thickness of only ca. 1 m for the intertidal deposits alone, and Tankard and Hobday (1977) recorded a thickness of only 1.5 m for what they interpreted as lower and upper intertidal sediments. However, despite the thinness of an individual intertidal sequence in both modern and ancient examples some sections of ancient intertidal sediments are much thicker (for example: Kuijpers (1971) - 270 m, Mackenzie (1972) - 30 m, Tankard and Hobday (1977) - 60 - 70 m). In such cases the authors resort to regional subsidence to explain the accentuated thicknesses.

The stratigraphic thinness of ancient, individual, intertidal sequences highlights the absolute necessity of doing detailed section measuring if the goal is to delineate the various sub-environments of such a setting or of associated environments in a barrier island-lagoon-tidal flat model.

Genetic Associations

The breakdown of section S1 into facies/sub-facies is strictly descriptive, not interpretative. As mentioned above, many of the facies/sub-facies are not diagnostic of a specific depositional setting. They must be interpreted largely on the basis of facies sequence using the barrier island-lagoon-tidal flat model reviewed above. For this reason, a number of genetic associations have been defined. They consist of a package of facies/sub-facies for which an interpretation is suggested using this sedimentary model. The interpretation of section S1 consists of the interpretations suggested for the constituent genetic associations. Table 2.1.7.1-1 summarizes these associations for section S1. Figure 2.1.7.1-3 is a bar graph showing the percentage, by cumulative thickness, of section S1 represented by each genetic association. Figure 2.1.7.1-4 is the block diagram representation of the depositional setting envisaged for the basal Strathcona Fiord Formation at section S1. The position of the genetic associations within this model is indicated. Selected features of the Strathcona Fiord Formation at this section location are presented in Plate 2.1.7.1-1. Each genetic association is discussed below.

A. Shallow Neritic Association

This association occurs only once at the base of the section, immediately overlying a biostromal carbonate unit in the underlying Blue Fiord Formation with a sharp contact. The interpretation results from its being sandwiched between the shelf carbonate unit below and what is interpreted as a tidal inlet sequence above (see genetic association B, below). The association is 13.4 m thick, representing 4.6% of section S1. Lithologically it consists

Figure 2.1.7.1 - 3 Relative abundance of genetic associations in the Strathcona Fiord Formation at section S1 (percentage by cumulative thickness).

A - neritic association
B - tidal inlet association
C - lagoonal association
D - sand flat association
E - mixed flat association
F - tidal channel association
G - mud flat association
H - evaporite association

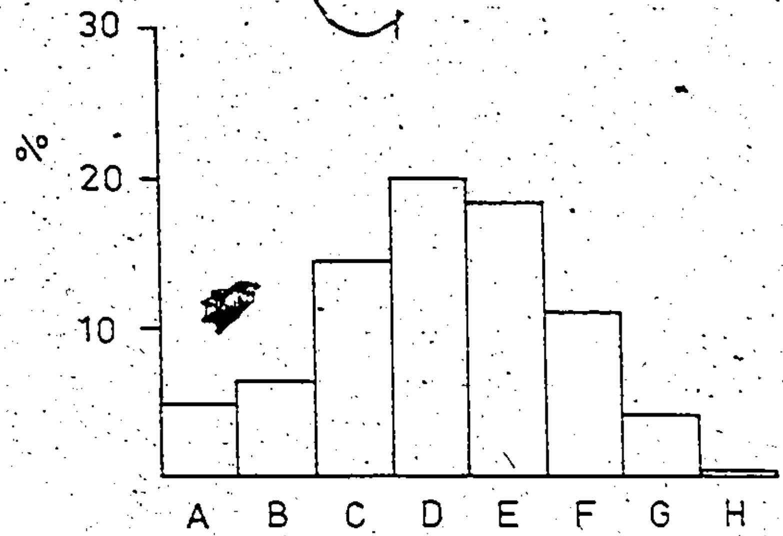

30
%
20
10
A
B
C
D
E
F
G
H

Figure 2.1.7.1 - 4 Block diagram representation of the depositional setting of the Strathcona Fiord Formation at section S1. Letters refer to specific genetic associations, some of which are shown in Figure 2.1.7.1 - 5. Note the extreme vertical exaggeration.

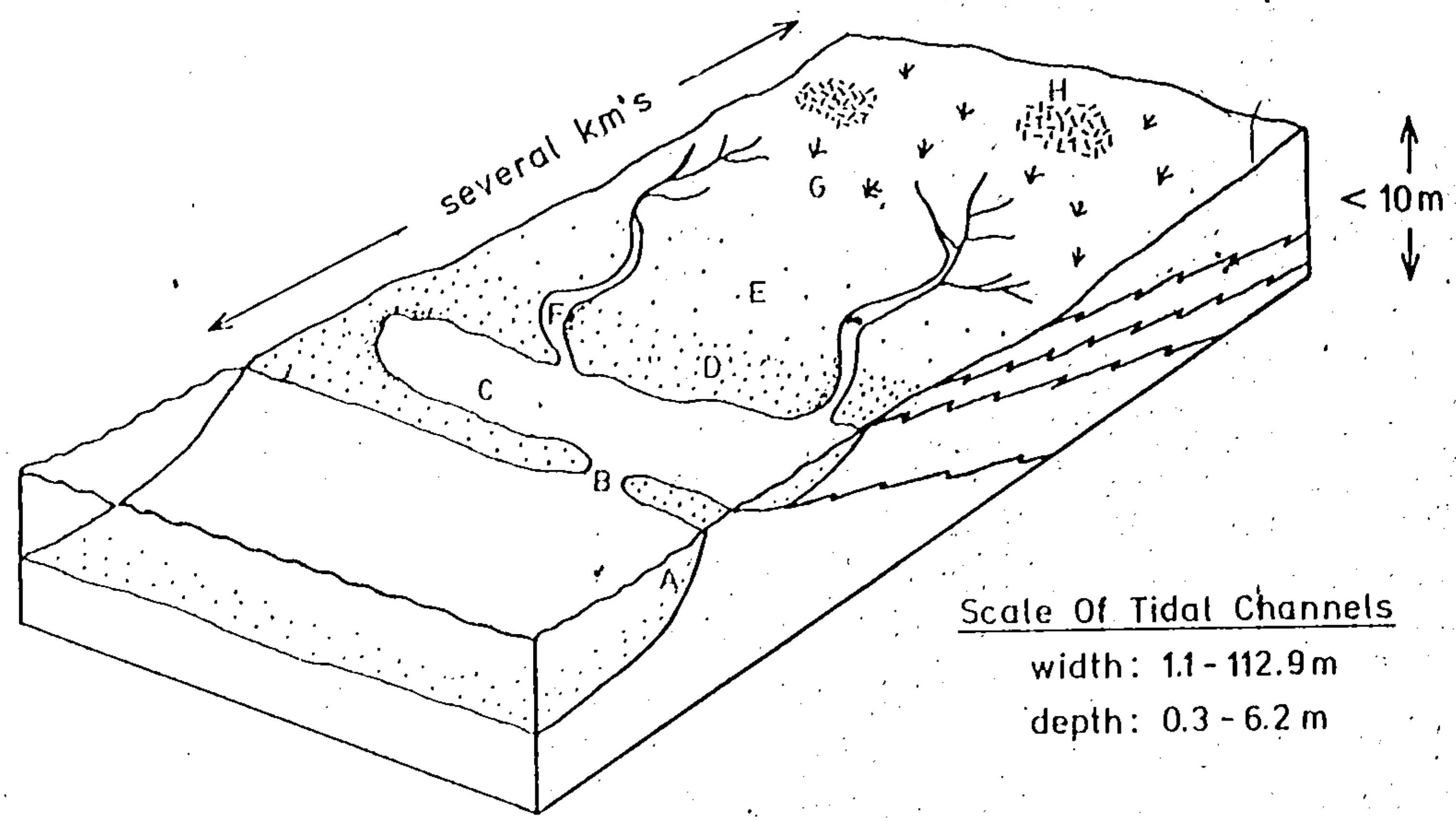

several km's
< 10m
A
B
C
D
E
F
G
H
Scale Of Tidal Channels
width: 1.1 - 112.9 m
depth: 0.3 - 6.2 m

Table 2.1.7.1.-1 Genetic Associations In The Strathcona Fiord Formation At Section S1.

ASSOCIATION	CODE	ZONE	CRITERIA
Neritic (A)			
neritic siltstone	A1	shallow neritic	/
neritic sandstone	A2		/
Tidal Inlet (B)			
deep tidal inlet	B1	shallow neritic	sandstone; must be cross-bedded
shallow tidal inlet	B2		sandstone; parallel laminated or rippled
Lagoonal (C)			
lagoonal siltstone	C1	back barrier subtidal	/
lagoonal silty dolomite	C2		/
lagoonal sandstone	C3		no thickness limitation but must be sandwiched between other C associations
lagoonal stromatolites	C4		/
Sand Flats	D	lower intertidal	≥ 1.0 m thick
Mixed Flat (E)	E1	mid-intertidal	interlaminated, no couplets
	E2		couplets; both sandstone and siltstone < 0.5 m thick
	E3		sandstone only; must be < 1.0 M thick to distinguish from association D; erosive or non-erosive basal contact
	E4		siltstone only; must be < 1.0 m thick to distinguish from association G1
Tidal Channel (F)			
tidal channel basal fill	F1	low or mid-intertidal	sandstone; must contain cross bedding erosive base
tidal channel low flow fill	F2		siltstone only
tidal channel high fill	F3		sandstone; parallel laminated to rippled

Mud Flats (G)	G1	high intertidal	siltstone; must be > 1.0 M to distinguish from association E4
	G2		sandstone; erosive or non-erosive basal contact and < 1.0 m; must be sandwiched by G1 to distinguish it from association E3
Evaporite	H	highest intertidal	gypsum/anhydrite

NOTE: 1) C3 - this sandstone could be associated with a flood tidal delta or a washover deposit
2) C4 - low relief (< 5 cm) stromatolites interpreted as representing a shallow, protected part of the lagoon
3) E3 - this sandstone interpreted to represent a higher energy interchannel deposit, possibly a storm event
4) E4 - this siltstone interpreted to represent a period of normal ambient energy in an interchannel area
5) G2 - this sandstone interpreted to represent a higher energy deposit on the mud flats, possibly a storm event
6) In addition to the criteria stated in the Table, stratigraphic context is relied heavily upon to make the subtle distinctions in depositional environment at this exposure of the Strathcona Fiord Formation.

Plate 2.1.7.1 - 1 The basal 293 m of the Strathcona Fiord Formation at section S1 located on the eastern margin of outer Stenkul Fiord.

A. A tidal inlet sequence near the base of the Strathcona Fiord Formation. The Jacobs Staff is 1.5 m in height.

B. A well preserved outcrop of the mixed intertidal flats (sand and silt/clay) genetic association. The hammer is 30 cm in length.

C. An erosionally based tidal channel sequence. The hammer is 34 cm in length.

D. A well preserved bedding plane exposure showing capped-off ripples in the mixed intertidal flats genetic association. The scale is 15 cm in length.

E. A second example of a tidal channel deposit interstratified amongst mixed intertidal flat sediments. Note the secondary gypsum nodules both in the basal zone as well as in the upper cross-stratified interval. The tidal channel deposit is ca. 1.0 m thick.

F. The underside of a bedding-plane slab of mixed intertidal flat sediments showing a variety of trace fossils. The scale is 15 cm in length.

G. Possible double-crested ripples (bottom left) in a bedding-plane slab of mixed intertidal flat sediments. The scale is 15 cm in length.

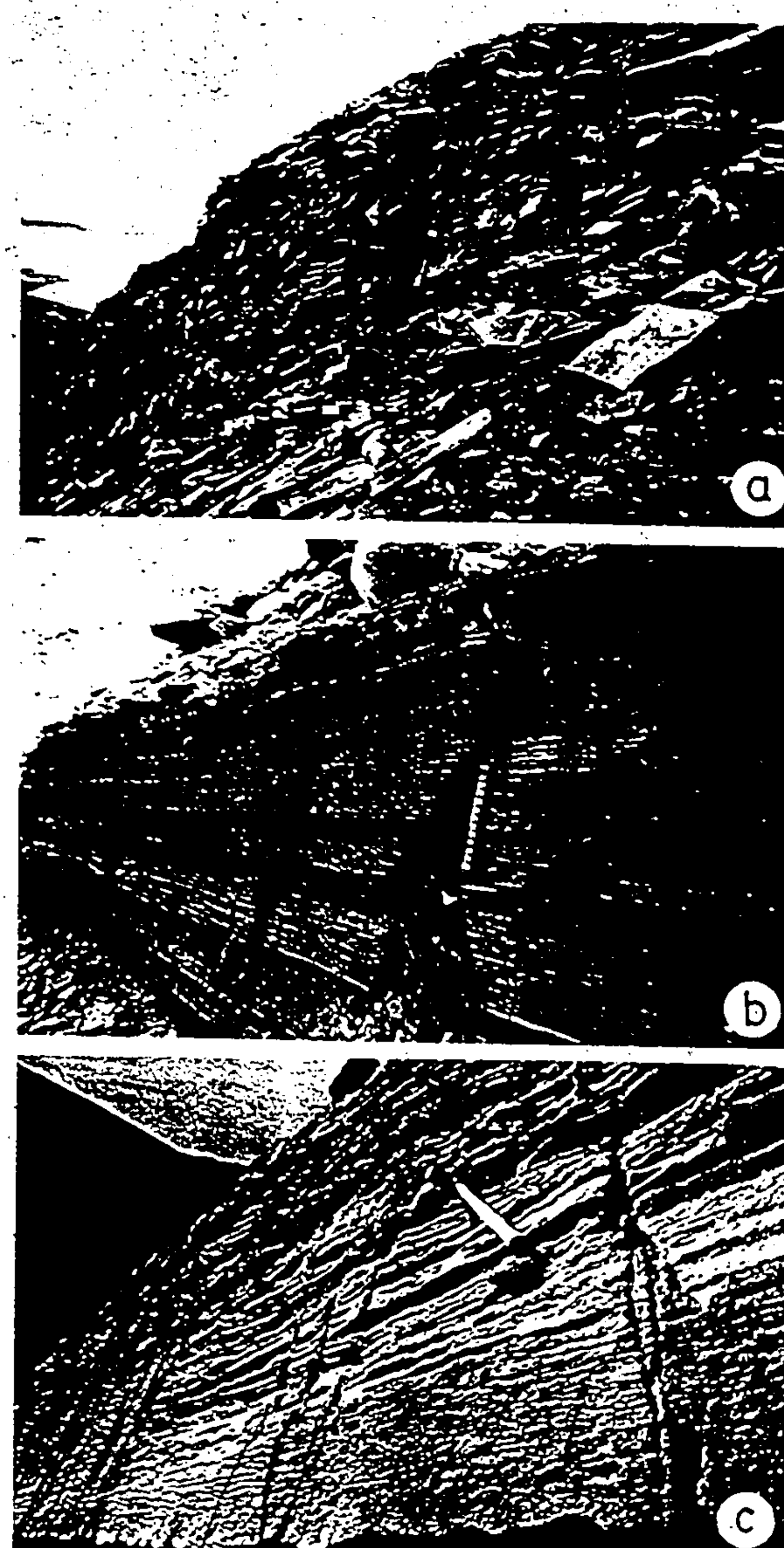
H. Soft sediment loading in mixed intertidal flat deposits. The scale is 15 cm in length.

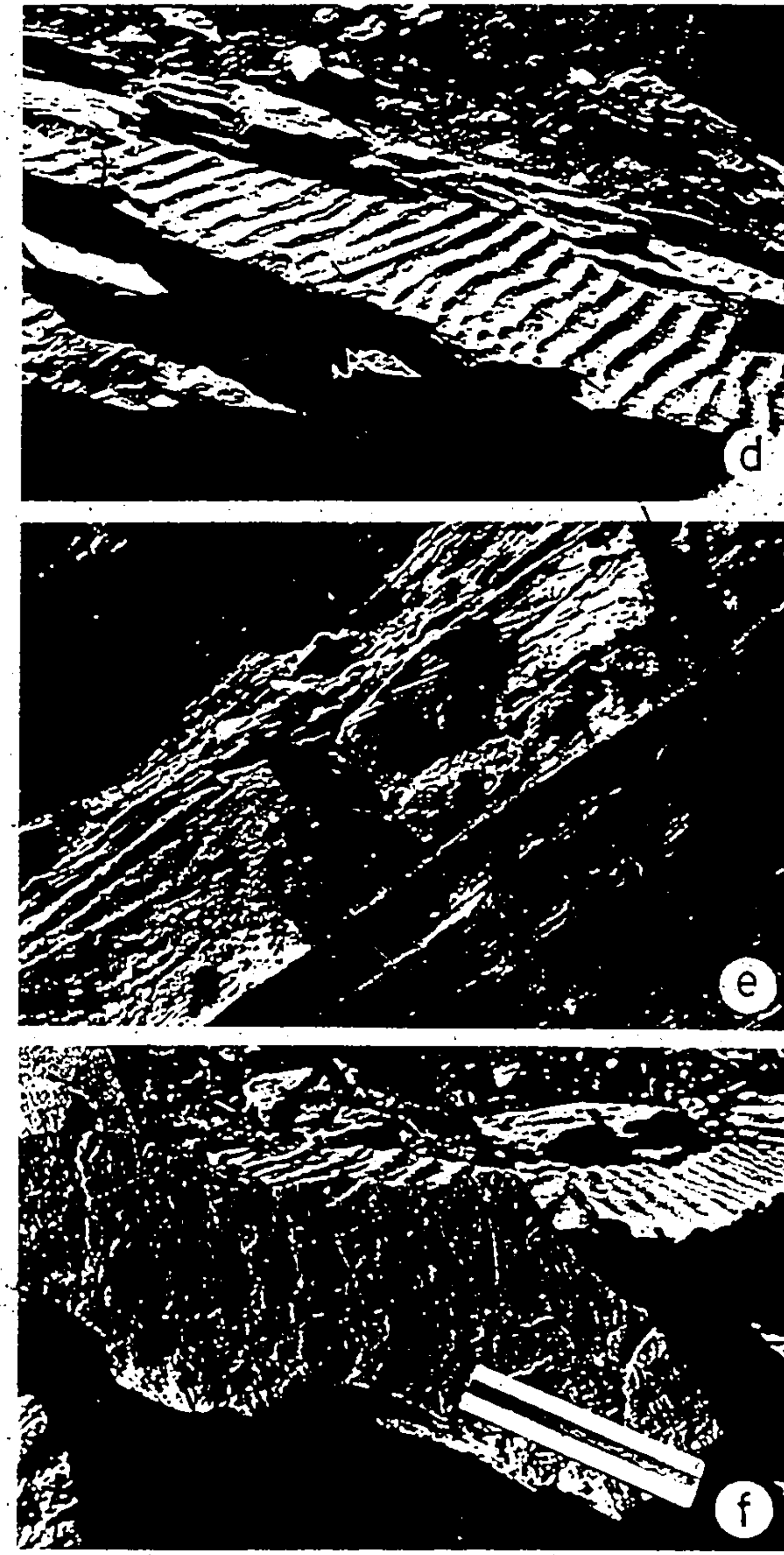
I. Cruziana in sandy intertidal flat deposits. The scale is 15 cm in length.

J. Conostichus and other trace fossils on the underside of a bedding-plane slab of mixed intertidal flat sediments. The scale is 15 cm in length.

K. A partial gastropod cast in a sample of sandy intertidal flat deposits. The scale is 15 cm in length.

L. A low amplitude (<5 cm) stromatolite mat interstratified amongst lagoonal deposits. The scale is 15 cm in length.


a
b
c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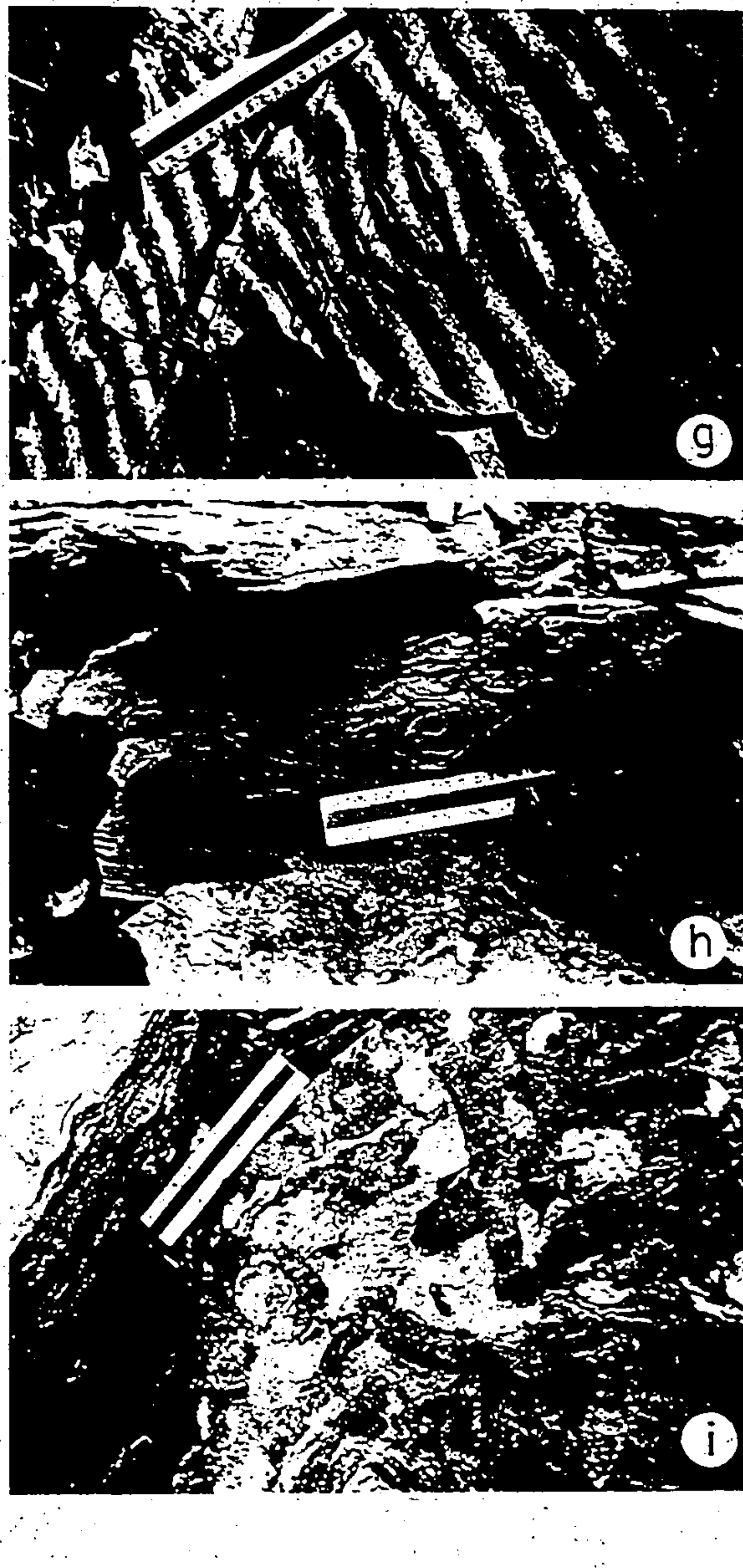
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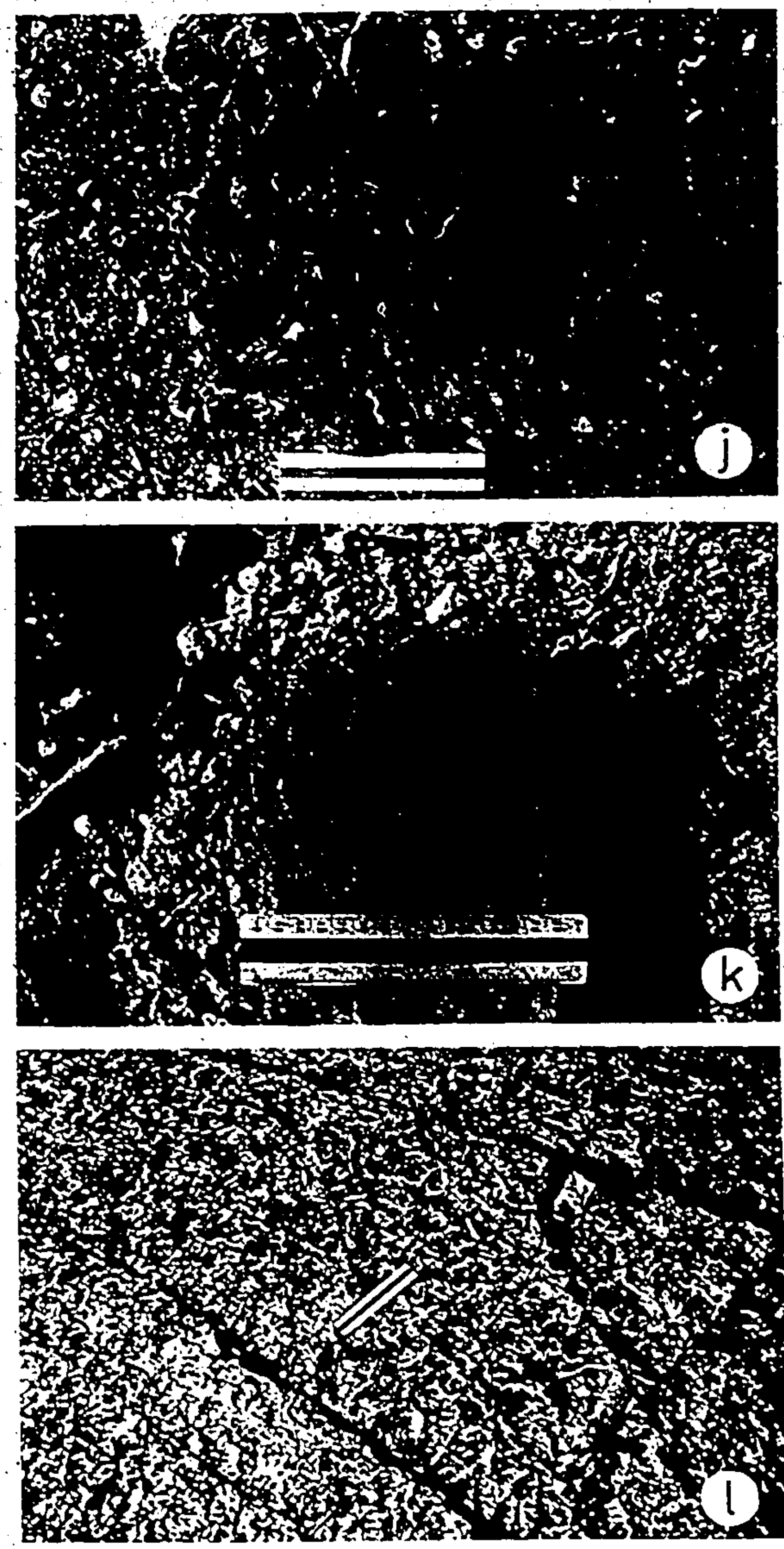
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of siltstone (facies 1) and very fine grained sandstone (facies 2). The siltstone represents 78.3% of the association. The constituent sandstone sub-facies and their respective proportions of the association are: ripple cross-laminated sandstone (2c - 18.5%), sandstone with climbing ripple drift cross-lamination (2f - 2.1%) and large scale, planar tabular cross-bedded sandstone (2a - 1.1%). Internally, all observable basal contacts are gradational, excepting the base of sub-facies 2a, which is erosional. The association is interpreted to represent shallow siliciclastic shelf sediments upon which a barrier island (by inference only) and associated tidal inlet developed.

B. Tidal Inlet Association

This genetic association occurs only once in section S1, erosionally overlying the shallow neritic association discussed above. The upper contact with what is interpreted to be a lagoonal deposit is covered. This association is 18 m thick, representing 6.1% of section S1. The tidal inlet sequence is composed of 17.1 m of large scale, planar tabular cross-bedding (sub-facies 2a - 95% of the inlet sequence, by thickness) considered to be analogous to the deep-channel facies of Kumar and Sanders (1974). It is erosionally overlain by 0.9 m of parallel laminated sandstone with minor ripple cross-lamination (2b and 2c - 5%) considered analogous to Kumar and Sanders' shallow-channel facies. While the overall thickness of the association exceeds that of the Fire Island Inlet documented by Kumar and Sanders, it is within the 20 m maximum depth range given by Elliott (1978) for tidal inlets. Matching of the association in question with Fire Island Inlet indicates a very good comparison, with respect to scale, between the interpreted (0.9 m) and documented (ca. 0.8 m) shallow-channel facies, but a considerably exaggerated thickness (17.1 m versus 5.5 m) for the interpreted deep-channel facies. In fact, however, it is precisely this portion of the inlet sequence that they suggested would be the most variable as it is determined by the depth of the erosion achieved by the inlet throat currents. Elements of Fire Island Inlet missing from this association are a basal shell lag (only siltstone clasts were observed) and the sub-aqueous and sub-aerial spit facies. The absence of shell debris may only be apparent (i.e. there, but not observed) but even if real is not critical enough to void the interpretation. With respect to the spit facies, it would have a very low preservation potential and additionally, Fire Island Inlet is but one case study. It is quite conceivable that a tidal inlet should lack a well developed spit. The tidal inlet interpretation implies the presence of a barrier island somewhere in the region of section S1. That section S1 should only expose a tidal inlet sequence, with no indications of a sub-aerial barrier island, is not considered unusual however, since tidal inlets can reach several kilometers in width (Elliott, 1978). The tidal inlet sequence is shown in Figure 2.1.7.1-5.

Only five planar tabular cross-bed measurements were recorded from the tidal inlet sequence. They are oriented toward the northeast and northwest with a northerly vector mean. Since tidal inlets can reach up to several kilometers in width, these five measurements do not constitute a sufficiently large data base to be of any interpretive use, such as approximating shoreline trend.

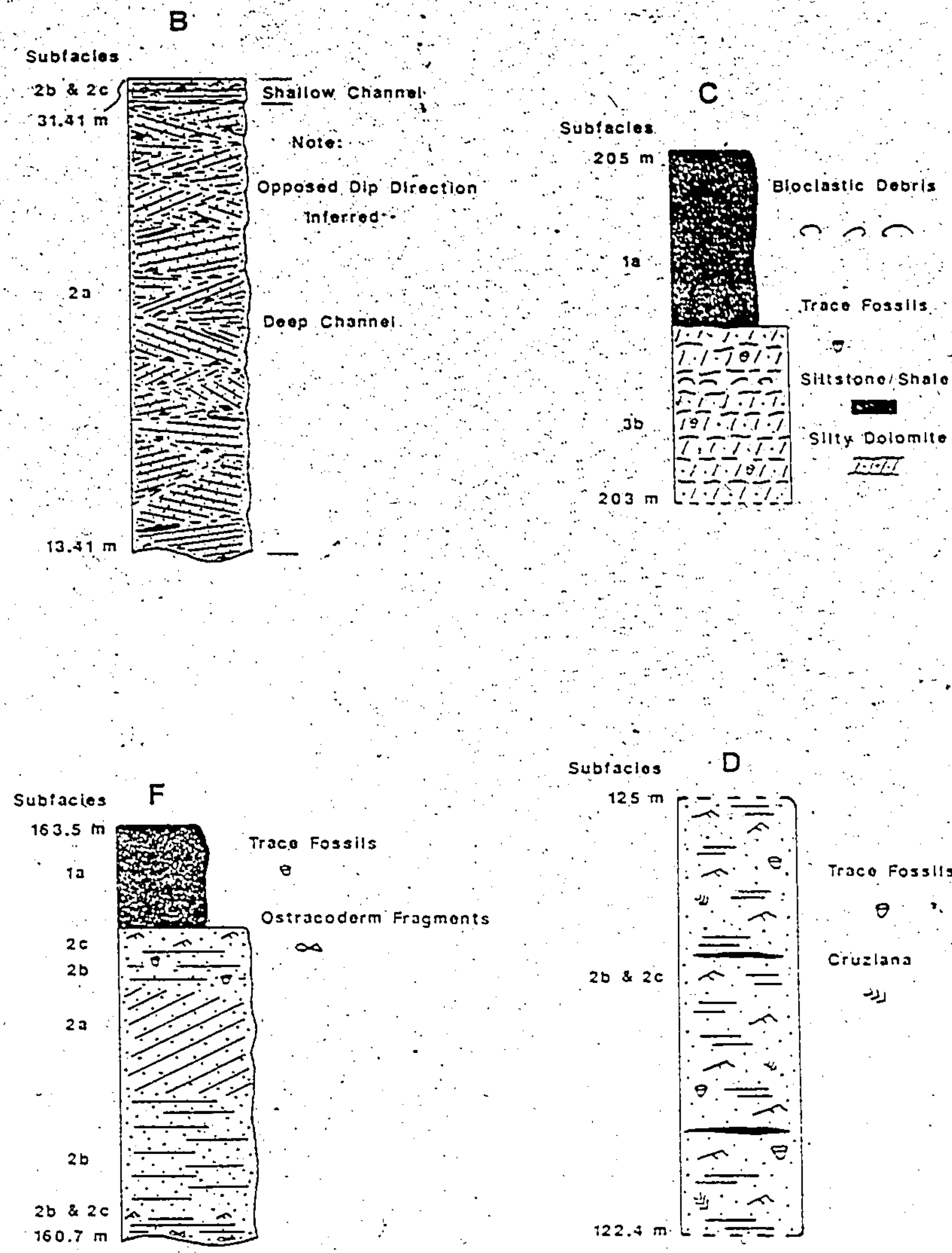
Complimentary evidence for the tidal inlet interpretation is derived from a palynological analysis of a siltstone sample (GSC Loc. C-91922) collected from a minor lens within the deep-channel facies. McGregor (1982, pg. 10) makes the following comment:

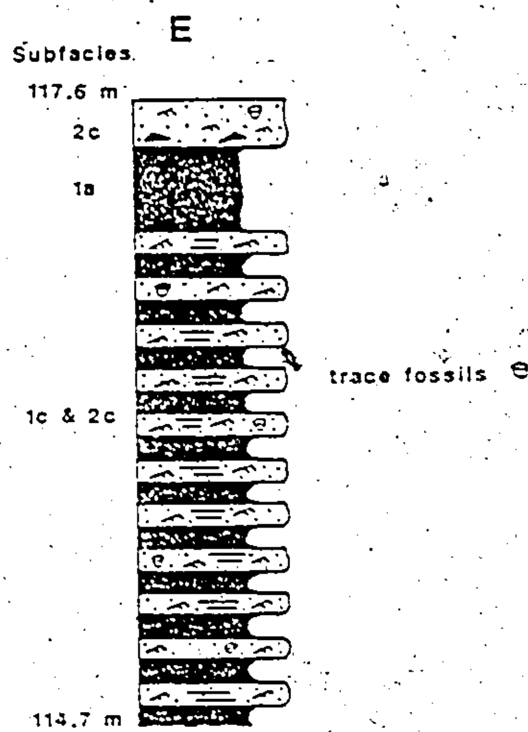
"the assemblage also contains abundant vascular plant debris and rare leiosphaerid acritarchs. The acritarchs suggest a marine environment of deposition, but the abundance of fragments of land plants and the abundance and

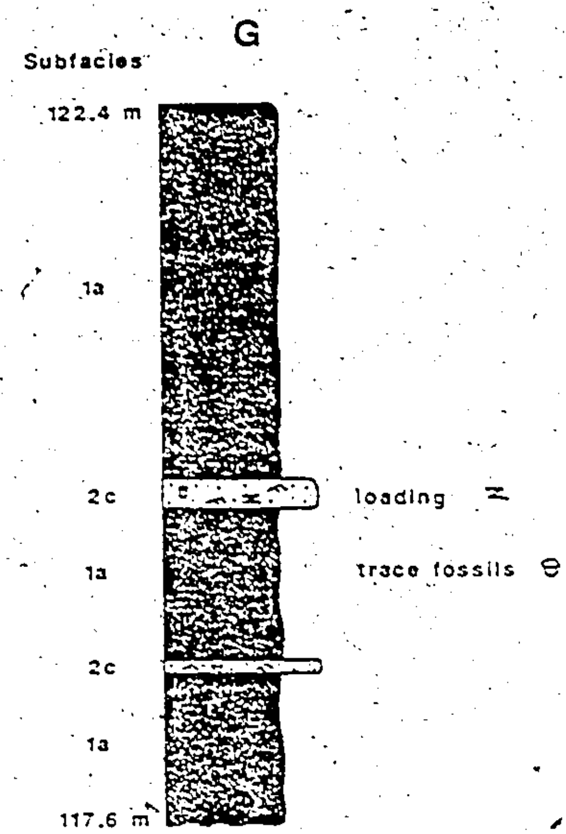
Figure 2.1.7.1 - 5 Selected genetic associations in the Strathcona Fiord Formation at section S1:

B - tidal inlet association
C - lagoonal association
F - tidal channel association
D - sand flats association
E - mixed flats association
G - mud flats association

Note the differences in scale amongst these selected intervals in section S1.


B
Subfacies
2b & 2c
31.41 m
2a
13.41 m
Shallow Channel
Note:
Opposed Dip Direction
Inferred
Deep Channel
C
Subfacies
205 m
1a
3b
203 m
Bioclastic Debris
Trace Fossils
Siltstone/Shale
Silty Dolomite
F
Subfacies
163.5 m
1a
2c
2b
2a
2b
2b & 2c
160.7 m
Trace Fossils
Ostracoderm Fragments
D
Subfacies
125 m
2b & 2c
122.4 m
Trace Fossils
Cruziana


E
Subfacies
117.6 m
2c
1a
trace fossils
1c & 2c
114.7 m


G
Subfacies
122.4 m
1a
2c
loading
1a
trace fossils
2c
1a
117.6 m

relatively large size of the spores suggest that the land vegetation from which they were derived was not far from the depositional site."

C. <u>Lagoonal Association</u> (sub-tidal)

The lagoonal association occurs seven times throughout section S1, ranging in thickness from 0.7 - 19.5 m and composed of only one or several sub-facies. An example of a lagoonal sequence is given in Figure 2.1.7.1-5. Cumulatively, the thickness of these occurrences represents 14.2% of the section. The lagoonal association can overlie sub-facies of the tidal inlet association, lower sand flats (see below), tidal channel (see below), or mixed flats (see below). All observable basal contacts to this association are gradational. The association underlies sub-facies belonging to lower sand flats and mixed flats. All observable upper contacts of the association are also gradational. The mechanism controlling the stratigraphic position of this association is suggested to be subtle landward or seaward shifts of the surficial tidal flat zonation previously discussed. A lateral shifting of these zones could be due to slight variations in the delicate balance between local subsidence and sediment supply to the back-barrier region. A similar mechanism has been suggested by Tankard and Hobday (1977) for the Graafwater Formation of South Africa.

Siltstone, sandstone, dolomite and stromatolite horizons are found in this association, but not all were encountered at every occurrence. The reason for the interpretation of the carbonate and closely associated siliciclastics as a lagoonal association is the stratigraphic position and sub-facies characteristics, in light of the sedimentary model being used as a predictive guide for this section. The siltstone is present in non-stratified (1a), parallel laminated (1b) and wavy laminated (1d) sub-facies. It is considered to represent part of the lagoonal background sedimentation. Sandstone in this association is represented by ripple cross-laminated (2c) and wavy to irregularly laminated sub-facies (2g). The sandstone is suggested to be part of flood-tidal delta or washover deposits in the lagoon. While no thickness limitations are imposed, for a sandstone to be interpreted as part of the lagoonal association it must be sandwiched between other members of this association. Dolomite is usually silty and is present as both massive (3a) and wavy to irregularly laminated sub-facies (3b). It is also considered to be part of the background sedimentation in the lagoon. Stromatolites (facies 5) are found in several occurrences of the lagoonal association and are considered supportive of this interpretation. They are very low amplitude (< 5 cm) forms found in mat-like horizons and are therefore suggestive of a protected environment, such as one would anticipate in a back-barrier lagoonal setting. While stromatolites are relatively rare in modern carbonate sediments due to excessive browsing by algae eating organisms such as gastropods and ostracods, von der Borch (1976) has described their occurrence in carbonate lakes of the Coorong Lagoon in South Australia. He cites Peterson (1962) on the Mississippian carbonate rocks of the Cumberland Plateau in Tennessee as an ancient counterpart.

Most of the basal contacts amongst the sub-facies making up a lagoonal association are covered. Of those that are not, all are gradational, excepting two instances, a stromatolite - siltstone transition which is sharp and a silty dolomite - siltstone transition which is slightly erosive.

Macroscopic fossil evidence in this association, other than the stromatolite units themselves, is limited to bio-clastic horizons and burrows in some occurrences of the wavy to irregularly laminated silty dolomite, and a brachiopod hash found on top of one of the stromatolite horizons. Suspected fossil (brachiopod?) dissolution cavities are common in the silty dolomite, however.

McGregor (1982, pg. 11) makes the following supportive comments on a palynomorph assemblage recovered from a siltstone sub-facies (GSC Loc. C-91926) in one of the lagoonal associations:

" In addition to spores it contains scolecodonts, and large thin leiospaerid acritarchs that indicate a marine environment of deposition. As at Loc. C-91922, vascular plant debris is abundant and one fragment was recovered that may be a piece of a spine-bearing eurypterid cuticle. Taken together, the various fossils comprising this palynomorph assemblage are consistent with deposition in a near-shore neritic environment".

D. Sand Flats Association

There are twelve occurrences of this association throughout section S1 ranging from 1.0 - 24.4 m in thickness. The position of the sand flats within the surficial zonation of the intertidal zone is depicted in Figure 2.1.7.1-2. This association represents 19.8% of the section by cumulative thickness. The association is found lying above members of mixed flat, lagoonal, and mud flat associations, in decreasing order of frequency. It lies below members of mixed flat, lagoonal, mud flat, and tidal channel associations in decreasing order of frequency. The basal and upper contacts are in most instances covered, but when not they are all gradational. The same mechanism of lateral shifting of the surficial zones of tidal flats that is discussed above for the lagoonal association is suggested to account for this variation in stratigraphic position. Discontinuities in the vertical sequence of zones that is anticipated using the barrier island-lagoon-tidal flat model (i.e. stratigraphic jumps from a sand flat to a mudflat, omitting the intermediate mixed flat, for example) are suggested to be due to rapid lateral shifting of the zones that create omissions.

Sandstone is represented by ripple cross-laminated (2c), parallel laminated (2b), climbing-ripple-drift cross-laminated (2f), irregular and wavy laminated (2g), burrowed (2d) and primary current lineation (2h) sub-facies. Of these sub-facies, 2c and 2b most frequently represent the sand flats association, while the rest are only rare occurrences. Contacts amongst the sub-facies in this association are mainly covered, but all that could be seen are gradational. To be interpreted as an intertidal sand flat deposit, sandstone units had to equal or exceed 1.0 m in thickness. This arbitrary criterion distinguishes between sand flat sand deposits and sand deposited on the mixed or mud flats (storm event) which would be extremely unlikely to reach such a thickness. This criterion and the stratigraphic context, in consideration of the sedimentary model being used as the interpretive guide for this section, warrants the identification of an intertidal sand flat association.

Fossil evidence found at isolated occurrences of this association includes Cruziana, molds or casts of planispirally and conispirally coiled gastropods, several unidentified burrow types, Lingula, plant compressions, and pyritic nodules and dissolution cavities thought to be representative of fossil replacement and dissolution, respectively.

An example of a sand flat sequence is presented in Figure 2.1.7.1-5.

E. Mixed Flats

Mixed flats occupy an intermediate position between lower sand flats and higher mud flats on the intertidal profile. Eighteen occurrences of a mixed flat association are defined for section S1. Their cumulative thickness represents 18.3% of the section. Thickness for individual occurrences ranges from 0.3 - 13.2 m, averaging 3.0 m. This association is found overlying the following associations: sand flats, tidal channel, evaporite, lagoonal, and mud flats. It is most commonly found above the sand flat association. Its basal contact is in many instances covered, but where observable, is gradational. The following associations are observed stratigraphically above the mixed flats association: tidal channel, evaporite, sand flats, lagoonal and mud flats. The most common overlying association is the sand flats association. The upper contact is frequently covered with rubble, but where observable is usually gradational into the overlying unit. Exceptions occur where a tidal channel or evaporite unit overlie it, in which case the contact is either erosional or sharp, respectively. The mechanism of lateral shifts of the intertidal zones suggested previously for the lagoonal and sand flat associations is also suggested to account for the variety of stratigraphic positions in which the mixed flat association occurs. Support for this causative mechanism lies in the fact that the sand flat association, ideally underlying the mixed flats in the intertidal profile, is the most frequent genetic association both overlying and underlying it. An example of an interval of mixed flat sediments is given in Figure 2.1.7.1-5.

As the name suggests, the mixed flat association lithologically consists of a mixture of sandstone and siltstone. The most common sub-facies found are non-stratified siltstone (1a) and ripple cross-laminated sandstone (2c). The mixed flat association is broken down into four components, E1-E4, as presented in Table 2.1.7.1-1. Not all of these are present at every occurrence of the association. The sub-facies content of each component of the association is given below, with the most frequently occurring sub-facies underlined in each case:

E1 - siltstone sub-facies <u>1a</u> and 1f
- sandstone sub-facies <u>2b</u>, <u>2c</u> and 2k

E2 - siltstone sub-facies <u>1a</u>, 1c, 1e, 1f
- sandstone sub-facies 2a, 2b, <u>2c</u>, 2e, 2g, 2k

E3 - sandstone sub-facies <u>2b</u>, <u>2c</u>, 2e, 2g, 2k, 2i

E4 - siltstone sub-facies <u>1a</u>, 1b, 1e, 1f

The contacts amongst the sub-facies are commonly covered. When not covered, sandstone to siltstone transitions are gradational while those from siltstone to sandstone are usually slightly erosive.

As given above, the most common sub-facies of component E1 and E2 are non-stratified siltstone (1a) and ripple cross-laminated sandstone (2c). The distinction between these two components of the association is based on the style of the interstratification. Although E1 contains finely intercalated sandstone and siltstone there is no preferred arrangement to the strata (i.e., no couplets). In contrast, E2 consists of repetitive couplets of ripple cross-laminated sandstone (rarely shows small scale cross-bedding) grading into non-stratified siltstone. The couplets are usually several tens of centimeters thick. In order to be designated E2, both members of a sandstone-siltstone pair have to be less than 0.5 m thick. This ensures the maintenance of a couplet scale which is compatible with what is observed in the section and avoided confusion between the siltstone and sandstone sub-facies of E2 and those of component E3 and E4, discussed below. Component E2 is suggested to represent the chance preservation of tidal cycle deposits. It is thus analogous to what Reineck (1967) termed coarse, rhythmically laminated bedding. Only eight instances of this component of the mixed flats association are defined in section S1. The sandstone and siltstone of component E1 are interlaminated. They are interpreted to represent deposition under a tidal current regime which did not differentiate between flood- and ebb-tidal currents as strongly as did the tidal cycles responsible for the E2 couplets. Components E3 and E4 are interpreted to represent periods of unusually high and low ambient energy on the tidal flats, respectively. To be designated E3, a sandstone unit must be less than 1.0 m thick to avoid confusion with the sand flats association. While an E3 sandstone must not be less than 1 cm thick, it can be less than 50 cm thick (see E2 definition above) provided it is not part of a sandstone-siltstone couplet (Table 2.1.7.1-1). E3 sandstone is suggested to represent a storm deposit on the tidal flats. Such an interpretation was suggested by Sellwood (1972) and Johnson (1975) to account for non-erosive (Sellwood) and erosive (Johnson) based sands interstratified with muddier tidal flat sediments. In both of these examples, the sand deposits in question exhibited upper flow regime, parallel lamination and in Sellwood's paper rippled sandstone was also found. This compares well to the sub-facies found in E3. As shown above, the most frequently occurring sub-facies are 2c and 2b (ripple cross-laminated and parallel laminated sandstone, respectively). The siltstone units designated E4 must be less than 1.0 m thick to avoid confusion with the mud flat association (discussed subsequently). Similarly, they can also be less than 50 cm thick as long as they are not part of a sandstone-siltstone couplet (see E2 definition above).

The sub-facies composition of components E1 to E4 described above and the stratigraphic context of the occurrences of this association in section S1 are felt to be sufficient grounds for assigning the association to a mixed flat position in the intertidal zone. The large average thickness of 3.0 m for the occurrences of this association in section S1 compared to the thickness of entire intertidal zones on modern tidal flats (commonly less than 1-2 m) can be attributed to subsidence of the shoreline on which the tidal flats developed.

Fossil evidence is sparse for the components of this genetic association. Conostichus and other unidentified burrows occur in sub-facies belonging to component E1. Some E2 sub-facies contain unidentified burrows, ostracoderm fragments and possible root casts. If the root cast identification is correct, it indicates sparse vegetation by probable marsh-type grasses on the mixed flats. E3 sub-facies contain Conostichus, other unidentified burrows, Cruziana and unidentified brachiopods. Sub-facies of component E4 also contain possible root casts suggesting tidal flat vegetation. E4 sub-facies produced the only productive palynology sample from the mixed flats association (GSC Loc. C-91924). Unfortunately, the spores are not abundant enough, or sufficiently well preserved, to permit any environmental implications to be made (see

McGregor, 1982, pg. 10-11).

F. Tidal Channel Association

Seven occurrences of tidal channel deposits are defined in section S1. Their thickness ranges from 0.4 - 9.5 m, averaging 4.6 m. Their cumulative thickness represents 11% of the section. The tidal channel association is found above sediments interpreted as sand flat, mixed flat and mud flat associations. It is most commonly found above mixed flat sediments. All basal contacts that are not covered are erosional. The association is found below sediments of the lagoonal, mixed flat and mud flat associations, most commonly below the mixed flats. The upper contact of the association is only observable in two instances; both of which are gradational. Tidal channels are best developed in the sand and mixed flats zones of the intertidal profile (Figure 2.1.7.1-2). The fact that the interpreted tidal channel association is found most commonly above and below mixed flat sediments therefore lends credence to the interpretation. The causal mechanism accounting for the varied stratigraphic position is again suggested to be lateral shifting of the intertidal zones.

Three components of this association are distinguished, based on sub-facies content. Component F1, interpreted to be a high flow basal channel fill, consists of the cross-bedded sandstone sub-facies (2a). Component F2, interpreted as a high to waning flow, higher channel fill consists of parallel laminated (2b) and ripple cross-laminated (2c) sandstone sub-facies. Occasionally, parting lineation can be discerned on bedding plane exposures. A low flow channel fill consisting of the non-stratified siltstone sub-facies (1a) is designated as component F3. Sediments of components F2 and F3 have to occur in stratigraphic juxtaposition with the cross-bedded sandstone of component F1 to be distinguishable from other intertidal zone sediments. In every occurrence of this association the contacts amongst the sub-facies are gradational where observed. Figure 2.1.7.1-5 contains an example of a tidal channel fill in section S1.

Fossil evidence from this association consists of ostracoderm fragments and molds/casts of straight coned and coiled gastropods found in sub-facies of component F1 and unidentified burrows found in sub-facies of components F2 and F3.

Three paleocurrent measurements were obtained from the basal channel fills (component F1) throughout this section. One measurement came from ca. 131.5 m above the base of section and two from ca. 162.8 m above base. Although all are oriented toward the northwest, the small sample size and stratigraphic separation minimizes their interpretive use. Tidal channels can display either unimodal or bimodal paleocurrent patterns with ebb oriented currents usually dominating in the latter case. If the number of measurements recorded from any one tidal channel fill had been sufficient to establish the presence of either a unimodal or bimodal pattern, then a rough approximation of shoreline orientation might have been obtained.

Research on modern tidal channels (Bridges and Leeder, 1976) indicates that their behavior, specifically their migration, is highly analogous to that of meandering fluvial channels. In this context, it is reasonable to apply the techniques of paleochannel reconstruction. Table 2.1.7.1-2 presents the results of such a reconstruction for the tidal channels in section S1. This table is intended to provide some idea of the scale of the tidal channels at section S1. It is not meant as an accurate estimate of their dimensions. The table suggests that tidal channel widths varied from 1-113 m while depth ranged from < 1.0 m to > 6.0 m.

Table 2.1.7.1-2 Estimates of Paleochannel Morphology and Flow Characteristics for Tidal Channels in the Strathcona Fiord Formation at Section S1

Ch	Db(m)	Dbc(m)	Wb(m)	F	P	Qm(m^3/s)	L(m)
1	4.2	2.7	31.4	11.6	1.8	7.7	492.5
2	4.6	3.0	36.9	12.3	1.8	10.6	567.8
3	2.8	1.8	16.8	9.3	1.9	2.2	284.5
4	2.6	1.7	15.4	9.1	1.9	1.8	264.9
5	0.4	0.3	1.1	3.7	2.5	0.01	26.6
6	8.0	5.2	86.1	16.6	1.6	59.4	1194.4
7	9.5	6.2	112.9	18.2	1.6	103.5	1511.9

Db - bankfull depth from coarse member thickness

Dbc - corrected bankfull depth (x 0.585/0.9 = 0.65)

Wb - bankfull width, from Dbc and Leeder (1973), equation 1

F - width/depth ratio

P - sinuosity, from Ethridge and Schumm (1978, pg. 706).

Qm - mean annual discharge, from Ethridge and Schumm (pg.706)

L - meander wave length, from Ethridge and Schumm

G. Mud Flat Association

A mud flat association occurs six times in section S1. Its cumulative thickness represents 4.1% of the section. It ranges from 1.0 - 4.8 m thick, averaging 2.0 m. This inflated average thickness, relative to the thicknesses reported for the entire intertidal zone from modern studies, may be attributable to a high rate of shoreline subsidence. The mud flat association is found immediately above sediments of the mixed flat, sand flat and tidal channel associations. It most commonly overlies the mixed flat sediments. All basal contacts observed are gradational. This association is found immediately under the same three associations commonly found underneath it. It most commonly underlies the sand and mixed flats associations. Its upper contact is usually covered, but where not (once only), it is gradational. Again, the variable stratigraphic position is considered to be due to lateral shifts of the zones composing the surficial intertidal profile. The mudflat association is sub-divided into two components, G1 and G2. Component G1 consists of siltstone sub-facies 1a, 1b and 1d, with non-stratified siltstone (1a) being most common. It is interpreted to represent normal fines deposition in an interchannel mud flat area. To be designated G1, a siltstone unit has to equal or exceed 1.0 m in thickness, to avoid confusion with siltstone of other associations. Component G2 consists solely of ripple cross-laminated sandstone (2c) and is a relatively rare occurrence, being defined only twice in this section with an average thickness of 0.15 m. It is interpreted as representing a storm deposit on the mud flats and is thus analogous to component E3 of the mixed flats association. It must be sandwiched between G1 siltstone units and less than 1.0 m thick to be so designated and to distinguish it from sandstone of other genetic associations (Table 2.1.7.1-1). Contacts amongst the sub-facies of component G1 and between components G1 and G2 are all gradational. Fossil evidence from this association consists of Conostichus and other unidentified burrows found in the sandstone of component G2. An example of a sequence of mud flat sediment is contained in Figure 2.1.7.1-5.

H. Evaporite

Only one bed of gypsum-anhydrite is present in section S1. This bed is 0.7 m thick and is sandwiched between E1 and E2 sediments of the mixed flat association. Its basal contact with component E2 is sharp and its upper contact with component E1 is gradational. While only one bed is present, several other instances of lenses and/or nodules are noted in sediments of the sand flat, mixed flat, mud flat and tidal channel associations. These lenses/nodules are found most commonly in the mixed flat association. They indicate an early diagenetic, soft sediment process of saline water percolation and precipitation. In one instance, nodules occur along foresets in a basal tidal channel fill. In this case, the foresets likely served as preferred loci of percolating saline water. Both the single bed of gypsum-anhydrite and the nodules/lenses of early diagenetic gypsum-anhydrite amongst the intertidal sediments suggest a semi-arid, hot climatic setting during the deposition of the basal Strathcona Fiord Formation at section S1. The occasional plant debris and possible root casts found in some of the intertidal sediments suggest that the climate was not thoroughly arid. This climatic inference is supported by paleomagnetic work by Lapointe and Dankers (1982) who show that the Lower Devonian paleo-equator passed through what is now the Arctic Archipelago placing this study area within 5^0 south of the equator. The gypsum-anhydrite bed represents a position high in the intertidal zone which is subject to very infrequent tidal innundations.

Discussion

Having suggested an interpretation for each genetic association defined in section S1, the purpose of this discussion is to stress particular aspects of the interpretation and to point out additional implications that result from it.

1. Paleotidal Range

Considerable research has been done relating tidal range to coastal morphology. At section S1, tidal inlet and tidal flat sediments are identified while a barrier island is only inferred. Work by Hayes and Kana (1976) has indicated that few barrier islands developed in microtidal settings have associated tidal inlets. This suggests that the tidal range classification for the Strathcona Fiord Formation at section S1 is mesotidal (2-4 m).

Klein (1971) has suggested that the paleotidal range of ancient intertidal sediments might be indicated by the thickness of sediments found between the base of the sand flats and the top of the mud flats. For this to work, one needs a gradual, uninterrupted shift of the intertidal zones, either to landward or to seaward, so that the complete intertidal package is represented. At section S1, as mentioned repeatedly above, the thicknesses of many intertidal associations exceed their modern counterparts and are suggested to have been accentuated by subsidence coinciding with lateral shifts of the intertidal zones. Additionally, the lateral shifts of the intertidal zones often did not persist long enough, in either the seaward or landward direction, to cover the entire intertidal profile (i.e. a sand flat may be overlain by a mixed flat and then another sand flat rather than a mud-flat, due to a change in the direction of lateral shift). Only one interval, (mud flat - mixed flat - sand flat) representing a complete seaward shift of the intertidal zones, apparently not over-thickened by subsidence (this might imply a more rapid lateral shift), is isolated in the section. Its thickness is 3.1 m, within the range of a mesotidal classification. Nevertheless, this is but one example and the choice of which sequence has been over-thickened by subsidence is too subjective to suggest that Klein's technique can be applied to this section.

2. Evidence of Emergence

Features reflecting a falling water level in a tidal environment are commonly found on the interchannel flats and mainly involve modified ripple forms. Reineck and Singh (1975, pg. 366-370) review the modification of ripples in a tidal environment. Since they are surface features, high quality bedding plane exposures are necessary to see them in ancient tidal flat deposits. Such exposures are very rare in section S1. Features indicative of a falling water level and inferred emergence occur only once and consist of double-crested and capped-off ripples. The former results from the superimposition of smaller ripples (shallower water) on the flanks of earlier formed larger ripples (deeper water). The latter represents flattening of ripple crests by wind induced small waves on the tidal flat surface during very shallow water depths immediately preceding sub-aerial exposure.

Mudcracks were observed only rarely throughout the section and could be indicative of synaeresis as well as sub-aerial exposure.

3. Paucity of Tidal Channels

Only seven instances of tidal channel fill are encountered in the Strathcona Fiord Formation at section S1. This contrasts with what one would anticipate from modern analogues in which tidal channel deposits are considered to represent the bulk of the intertidal zone as a result of their lateral migration. The paucity of tidal channel deposits at section S1 reinforces Weimer, Howard and

Lindsay's (1982, pg. 192) observation that significant disparities can exist between ancient and modern tidal flat sequences. As indicated in Figure 2.1.7.1-4, the tidal flats of the basal Strathcona Fiord Formation at section S1 are envisaged to be largely featureless with only a few dissecting tidal channels.

4. Excessive Thickness of the Tidal Flat Sequence

Relative to the thickness of intertidal sediments recorded from modern studies (3-10 m, MacKenzie, 1972) the 200+ m (excluding the neritic, tidal inlet and lagoonal associations) of tidal flat sediments preserved in section S1 must be considered unusual. As mentioned previously, Kuijpers (1971) records a comparable thickness (270 m) of tidal flat deposits from the Upper Devonian of County Cork, Ireland. Also, MacKenzie (1972) and Tankard and Hobday (1977) record exaggerated thicknesses (30 m and 70 m, respectively) of sub-tidal and intertidal sediments. In this interpretation, as in the other ancient examples, subsidence is suggested to be the cause. The preservation of this thickness of intertidal sediments implies the following:

1. While lateral shifts of facies belts (zones) occurred within the intertidal environment, major changes in

depositional environment (i.e. due to transgression or regression) did not occur for a prolonged period of geologic time, implying a stable although subsiding shoreline. Van Straaten (1961, pg. 215) suggests that such a situation would be highly uncommon.

2. The rate of sediment supply must have been relatively constant throughout the period of time represented by section S1 (early? to mid-Eifelian) in order for sedimentation to keep pace with subsidence. Van Straaten further suggests that this situation is even more unlikely.

In the context of Van Straaten's view on the likelihood of such a situation developing along a shoreline, it is suggested that proximity to a major point source of sediment could account for the ability of sedimentation to keep pace with subsidence. If a major delta forming river was the sediment source and the tidal flats are deltaic, the subsiding nature of the shoreline could be easily explained as subsidence is commonly associated with the delta fringe environment.

2.1.7.2 <u>Section S2</u>

The facies/sub-facies composition of the

Strathcona Fiord Formation at section S2 has been previously discussed in 2.1.5.4. The interpretation of the depositional environment of the Strathcona Fiord Formation at this location is based on the definition and interpretation of several genetic associations. The sequence of facies/sub-facies is again critical in the definition of the genetic associations since individually they are not diagnostic of environmental setting. The genetic associations defined in the Strathcona Fiord Formation at section S2 are presented and interpreted below subsequent to a review of the model used in the interpretation.

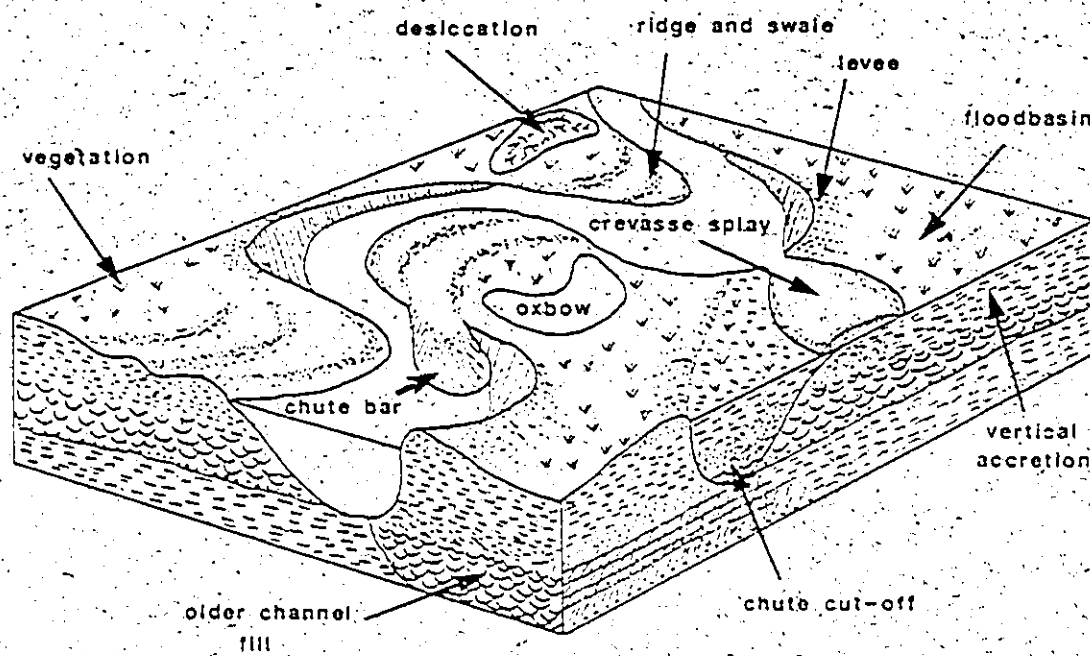
The initial examination of section S2 showed that it is composed of alternating resistant and recessive intervals arranged into fining-upward sequences of varying scale. The resistant intervals consist of erosively based sandstone units frequently displaying cross-bedding near their base and rooting near or at the contact with the overlying recessive interval. The recessive intervals are thicker, consist of siltstone and frequently display nodular weathering horizons suggestive of pedogenesis. Cumulatively, this stratigraphic arrangement resembles the lateral and vertical accretion deposits of a meandering river. The meandering fluvial sedimentary model is therefore used to interpret section S2. The regional stratigraphic context supports this choice of sedimentary model since the Strathcona Fiord Formation is underlain by a marine to deltaic Bird Fiord Formation and overlain by the sandy braided Hecla Bay Formation. A brief review of the meandering river model is presented below.

The Meandering Stream Model

The development of the classical model for lateral and vertical accretion deposits of meandering rivers is mainly due to a series of papers by J.R.L. Allen between 1964 and 1974 (Collinson, 1978, pg. 53). In these papers, developed around exposures of Devonian fluviatile red beds in the Catskill Mountains of New York State and in the Anglo-Welsh Basin of Britain, Allen firmly established the fining-upward sequence for meandering rivers. This sequence consists of a basal, erosively based, often cross-bedded, coarser sandstone member representing lateral accretion (point bar) channel deposits overlain by a finer, largely siltstone/shale vertical accretion member representing overbank sedimentation on the river's flood plain. The meandering river sedimentary model has received a great deal of attention. Excellent recent reviews of this model can be found in Collinson (1978), and Walker and Cant (1984). The former is a thorough review of this environment while the latter is a more efficient but still complete and informative overview. Walker and Cant (1984) present the ideal vertical profile developed for the classical meandering river model. While the fining-upward cycle constitutes the core of this model, numerous sub-environments are also incorporated into it. Figure 2.1.7.2-1 is a block diagram of a hypothetical meandering river depicting the various channel and overbank sub-environments (from Walker and Cant, 1984, Figure 1). Some of these sub-environments have been identified in the Strathcona Fiord Formation at section S2 (see interpretation of genetic associations).

An unfortunate by-product of the acceptance of this model is that it is applied rigorously to all interpreted meandering sequences. While the basic attributes of the model (i.e. a coarse channel member and a fine overbank member) may be universal to meandering stream deposits, the facies composition, the proportions of the two members and the presence of the various sub-environments is not. These aspects of the interpretation must be determined for each suspected meandering sequence. A good example of this is Allen (1965), wherein he presents representative vertical

Figure 2.1.7.2 - 1 Sub-environments in a meandering fluvial depositional setting. Modified from Walker and Cant, 1984.


desiccation
ridge and swale
levee
floodbasin
vegetation
crevasse splay
oxbow
chute bar
vertical
accretion
older channel
fill
chute cut-off

profiles from the Old Red Sandstone of seven different regions to emphasize the variation in facies composition, proportion of the coarse and fine members, and the variation in the overall thickness of the fining-upward sequence. These variations provide vital bits of information on channel characteristics (from facies composition) and meander-belt behavior (from coarse to fine member ratio) at any particular location. It must be remembered that meandering and braided rivers are two end points in the fluvial spectrum and that much variation in the basic fining-upward sequence is to be expected. The classical meandering river model represents a specific region within this spectrum, one that characterizes a relatively small, suspension load river. The classical model is developed around two assumptions:

1) the only formative discharge is bankfull discharge
2) helicoidal flow exists everywhere around a meander bend (Collinson, 1978)

The application of the classical model to an ancient sequence carries the above assumptions with it. While it is unquestionably generally applicable, the model is extremely simplistic and has outlived itself as a tool for increasing our knowledge of the meandering fluvial regime. What is currently needed are detailed sequence oriented studies of different types of modern meandering rivers that would allow the filling of more of the fluvial spectrum. Unfortunately, little has been accomplished in this respect. Leeder and Bridges (1975), and Jackson (1975, 1976) have demonstrated how variations from fully developed helicoidal flow around a meander can affect the sequence of primary sedimentary structures developed on the point bar surface. In particular, Jackson demonstrated that, for the meanders in the Wabash River, fully developed helicoidal flow only formed in the downstream half of the bend, and to varying proportions, depending on the curvature of the meander and the nature of the movement involved in meander shifts. Even in the fully developed helicoidal flow zones the sequence of primary structures only generally resembled that of the classical fining-upward model. The effect of two formative river stages in determining topography and morphological elements of the point bar surface is documented by Harms, MacKenzie and McCubbin, (1963) and McGowen and Garner (1970). In both instances a two tier point bar surface is developed, each level having its characteristic surficial and internal features (Collinson, 1978, pg. 34).

The case studies mentioned above demonstrate that variations in sedimentary sequence do arise when the basic assumptions of the classical model break down. While such variation is anticipated to be the normal rather than the unusual situation in meandering fluvial deposits, the paucity of modern case studies makes it difficult to generalize upon any variations to the extent that they may be used as guides in the interpretation of ancient meandering fluvial sequences. Only the most general aspects of the classical model (i.e. coarse member = lateral accretion channel deposits; fine member = vertical accretion overbank deposits) are applied to the Strathcona Fiord Formation at section S2. A significant difference in the coarse/fine member ratio between the classical model (c/f = 0.77, Walker and Cant, 1984, Figure 2) and the channel fills at section S2 (av. c/f = 0.26) indicate marked variation in fluvial behavior. The characteristics of the meandering river deposits preserved in section S2 are presented in the following interpretation and discussion.

Genetic Associations

Two genetic associations are identified in section S2, a channel association (coarse member) and an overbank association (fine member). These are presented in Table 2.1.7.2-1 along with the criteria used in the designations. A more thorough description of each association follows this

Table 2.1.7.2.-1 Genetic Associations in the Strathcona Fiord Formation at section S2.

Association	Code	Criteria
<u>Channel Association</u>	I	equal to or greater than 1.0 m thick and without rooted sandstone (2e)
basal channel fill	I1	erosional basal contact followed by cross bedded (2a), non-stratified (2i) or parallel laminated (2b) sandstone with lag.
upper channel fill	I2	overlies I1; gradational basal contact; rippled sandstone (2c) with occasional thin non-stratified siltstone (1a) lenses.
<u>Overbank Association</u>	J	
distal crevasse splay	J1	must be less than 1.0 m thick to distinguish from I1; usually erosionally based; mainly rippled (2c), non-stratified (2i) or cross-bedded (2a) sandstone.
floodplain siltstone	J2	stratigraphically associated with other overbank deposits.
nodular weathering horizons	J3	
proximal crevasse splay sandstone	J4	must be equal to or greater than 1.0 m in thickness and contain rooted sandstone (2e) to distinguish it from channel sandstones; usually erosionally based with rippled sandstone (2c) and rarely non-stratified (2i) or cross bedded (2a) sandstone
levee deposit	J5	rippled sandstone (2c) and non-stratified siltstone (1a) arranged in couplets 10 s cm thick

Note: 1) J1 and J4 are overbank flood deposits; while evidence for lensing out of units or for a radial flow pattern was not observed, this may be due to poor outcrop quality and a crevasse splay interpretation remains likely.

table. Selected features of the Strathcona Fiord Formation at this location are presented in Plate 2.1.7.2-1. It is important to stress that not all of the constituent facies/sub-facies of an association, or component of an association, are found at every occurrence of it. Rather, what is found is a smaller sub-set of all possible facies/sub-facies.

I. Channel Association

Seven intervals of channel fill deposits are identified in section S2. Cumulatively, the thickness of these deposits represents 9.3% of the section. The channel fills average 2.7 m in thickness, ranging from 1.3 - 4.5 m. In order for a sandstone interval to be designated as a channel fill it must be erosionally based followed by cross-bedding or parallel lamination. In addition, an arbitrary thickness criterion (equal to or greater than 1.0 m) is applied. This serves to distinguish between main channel deposits and channelled, erosionally based, overbank flood deposits which are occasionally cross-bedded (see J1 below). Collinson (1978, pg. 54) has also suggested an arbitrary thickness criterion (2.0 m) to distinguish between these two types of deposits which might otherwise be confused. While some overbank sandstones do exceed 1.0 m,

Plate 2.1.7.2 - 1 The Strathcona Fiord Formation at section S2 located approximately 15 km NNE of the head of Muskox Fiord.

A. The top of section S2 looking southeast at a part of the Sydkap Icecap. Logan tents for scale in the left foreground.

B. A single-story, main-channel sandstone erosionally overlying the variegated floodplain fines of an underlying fining upward cycle. The Jacobs Staff is 1.5 m in length.

C. Thinner floodplain sandstone and variegated siltstone. The variegated weathering color of the siltstone is an indication of floodplain pedogenesis. The Jacobs Staff is 1.5 m in length.

D. An erosional contact between a channel sandstone and the underlying floodplain siltstone. The hammer is 30 cm in length.

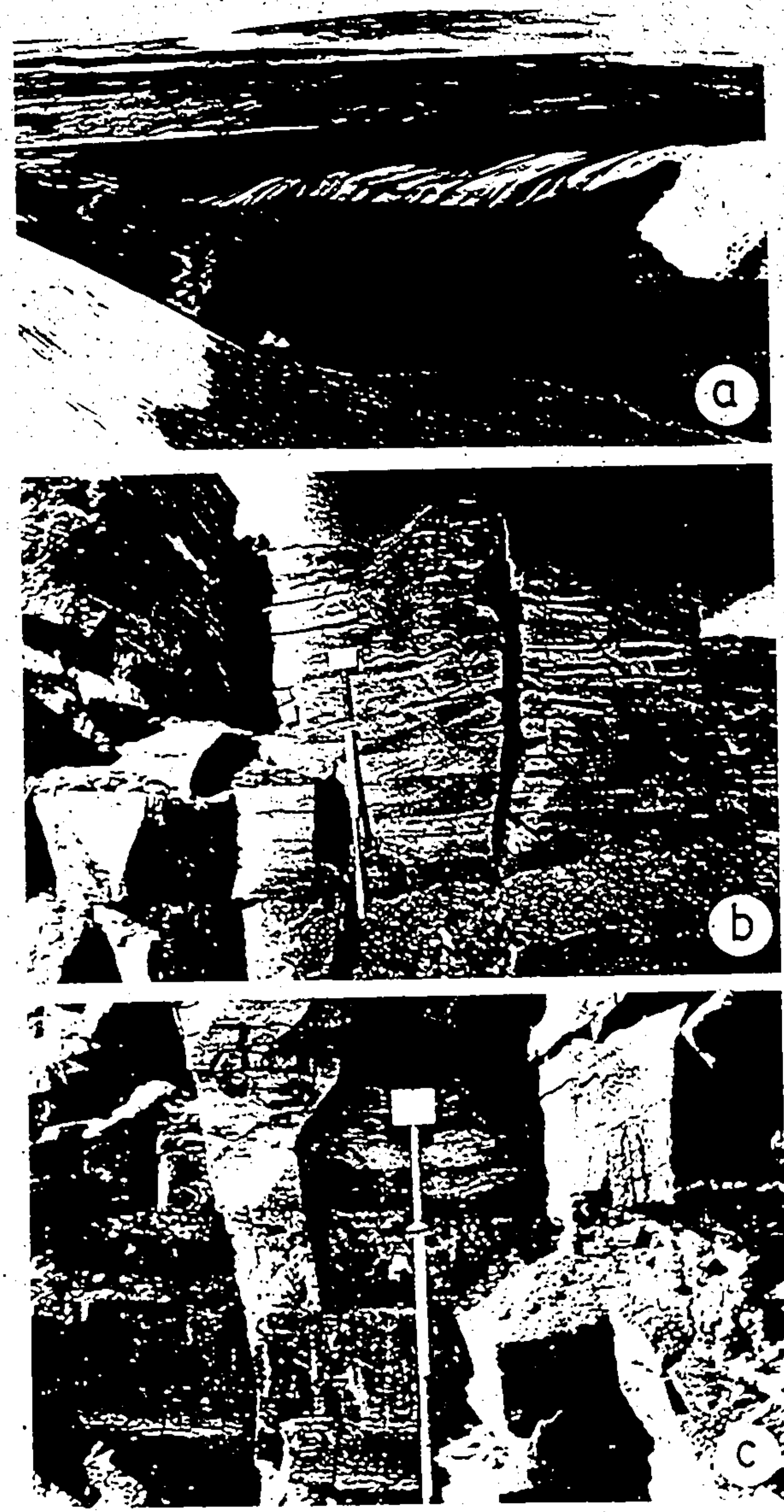
E. Several fining upward cycles in the Strathcona Fiord Formation. The thinness of the sandstone units suggests that they are floodplain deposits. Note the gently inclined surface sloping into the photograph in the closest sandstone. This probably represents a lateral accretion surface in the floodplain sandstone. Backpack for scale.

F. An indication of rooting in the upper portion of a floodplain sandstone. The hammer is 30 cm in length.

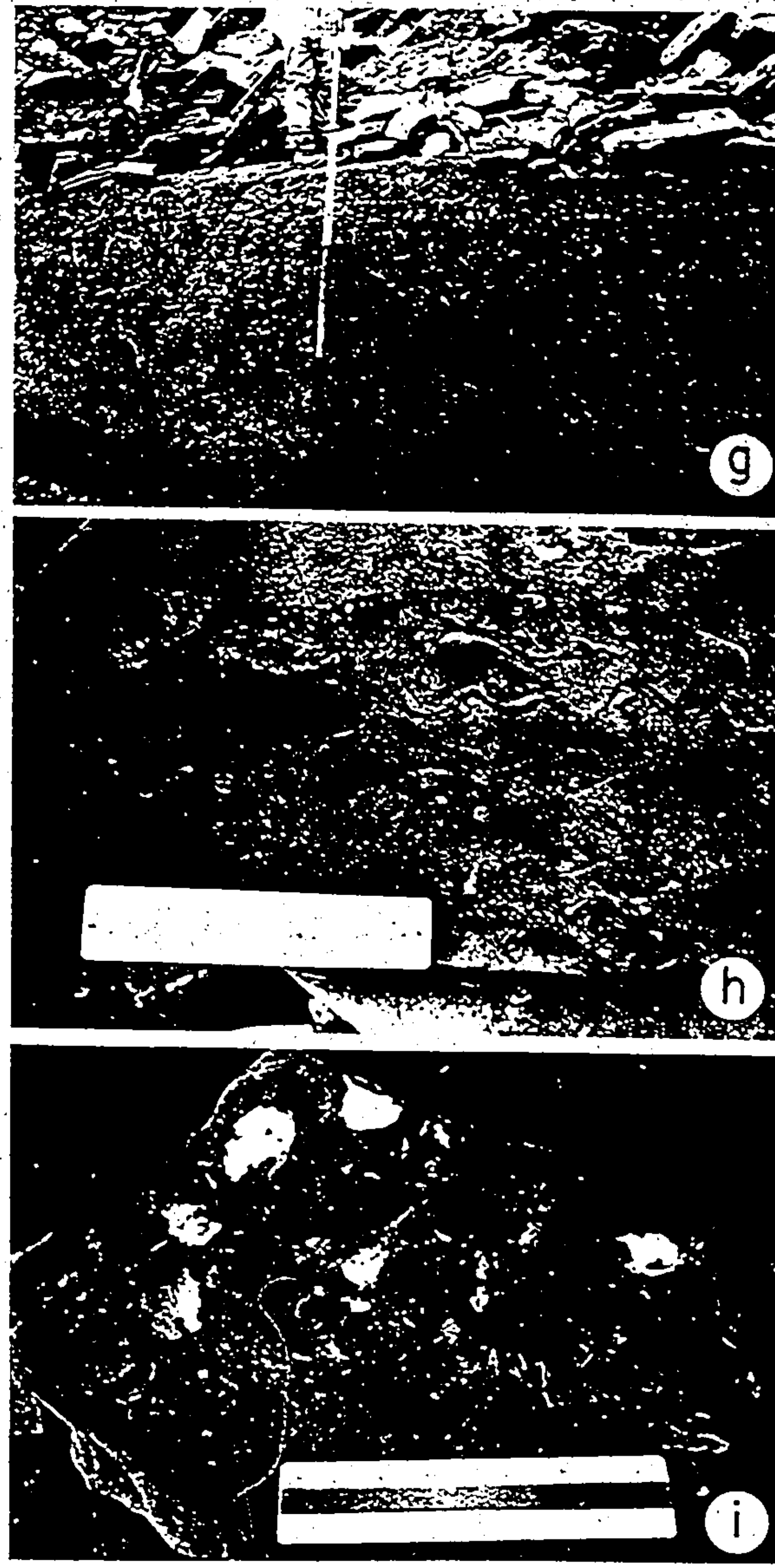
G. An unusually thick nodular weathering horizon developed in floodplain siltstone. Such horizons are indicators of floodplain pedogenesis. The Jacobs Staff is 1.5 m in length.

H. Trace fossils and possible root casts on the underside of a slab of floodplain sandstone. The scale is 15 cm in length.

I. Ostracoderm fragments occurring as a lag in a slab from the basal portion of a main-channel sandstone. The scale is 15 cm in length.


a
b
c


d
e
f


g
h
i

other lithological features preclude their being designated as part of a main channel fill sequence (see J4 below). Many of the contacts between the channel and overbank associations are covered by rubble. Of those that are not, the basal and upper contact of the channel association are always erosional and gradational, respectively.

Two components of the channel association are identified, a basal channel fill (I1) and an upper channel fill to quiet water deposit (I2). The contact between the two is gradational where not covered by rubble. Not every occurrence of the channel association contains a gradation from basal to upper point bar deposits. In many instances only basal deposits are preserved. The basal channel deposits (I1) most commonly consist of cross-bedded sandstone (2a); in one instance chert pebbles occur as part of a basal lag (2j). Lag commonly occurs in either the cross-bedded or parallel laminated sub-facies since both occur immediately overlying the erosional base. The clasts are most commonly composed of siltstone, with occasional quartzite, and in one instance included chert pebbles, as mentioned above. The sub-facies composition of I2 consists most commonly of ripple cross-laminated sandstone (2c), with minor rooted sandstone (2e) and non-stratified siltstone (1a). The siltstone occurs as lenses in the upper channel fill deposits and is interpreted to be indicative of deposition from quiet eddies that are removed from the thalweg. The rooted sandstone represents vegetation of the highest channel fill sediments subsequent to channel abandonment. Fossil evidence at this section of the Strathcona Fiord Formation is limited to fragments of ostracoderms found as lag in cross-bedded or parallel laminated sandstones. Several unidentified trace fossils also occur.

J. Overbank Association

Ten occurrences of an overbank association are identified in section S2. Cumulatively, this association represents 37.4% of the formation by thickness. Its average thickness is 7.4 m, ranging from 0.6 - 19.2 m. Contacts with underlying and overlying channel fill deposits are gradational and erosional, respectively. Five components of this association are distinguished (J1 to J5, Table 2.1.7.2-1).

Component J1 is the second most frequently occurring member of this association representing 14.8% by thickness. This component averages 0.55 m in thickness, ranging from 0.1 - 0.9 m. It is composed of sandstone sub-facies 2l, 2c, 2e, 2i and 2k. The ripple cross-laminated sub-facies

(2c) is dominant. Cross-bedded sandstone (2a) occurs occasionally. This component of the overbank association is interpreted to represent a distal crevasse splay deposit. It is commonly, but not always, erosionally based and occurs in association with other overbank deposits. The thickness must be less than 1.0 m to distinguish these deposits from component I1 of the channel association.

Component J2 is the most frequently occurring component of the overbank association representing 36% by cumulative thickness. It averages 1.3 m thick, ranging from 0.04 - 3.5 m. It is dominated by non-stratified siltstone (1a), with only several occurrences of rippled (1c) and parallel laminated siltstone (1b). It is interpreted to represent vertical accretion of fines (silt and clay) from flood waters in a distal overbank setting. The top of J2 deposits are occasionally reduced to a green-grey color where overlain by a channel or splay sandstone and can contain 2-3 cm (A-axis) hematite pellets. The reduction is suggested to be due to the saturation of previously dry, well aerated, overbank sediment by flood water or ground water otherwise associated with a returning channel.

Component J3 represents 27.9% of the overbank association, by cumulative thickness. It averages 1.2 m thick, ranging from 0.2 - 2.5 m. It is composed of variegated red, white and grey nodular weathering horizons (facies 6) interpreted as indicative of pedogenic processes operating on overbank silts and clays. The occasional rooted surface (sub-facies 2e) of an underlying sandstone supports this interpretation. The nodules of these horizons are slightly calcareous and are 3-4 cm in maximum apparent dimension. Component J4 represents 14% of the overbank association, by cumulative thickness. It averages 2.1 m thick, ranging from 1.2 - 3.3 m. It is composed almost entirely of ripple cross-laminated sandstone (2c), with minor rooted sandstone (2e). Since the thickness of these sandstone deposits exceeds 1.0 m they are suggested to be more proximal crevasse splay deposits possibly representing multiple depositional events. They are distinguished from channel fill deposits by their occurrence amongst other overbank sediment. Small, low angle scours in some J4 deposits suggest successive crevasse splay flood events.

Component J5 represents only 7.3% of the overbank association, by cumulatively thickness. Its average thickness is 2.7 m, ranging from 2.4 - 3.0 m. It consists of couplets of ripple cross-laminated sandstone (2c) and non-stratified siltstone (1a). The couplets are tens of centimeters thick and are always gradationally associated with other overbank deposits. They are interpreted to represent episodic waning flows in a proximal overbank setting, possibly a levee. A levee is preferred over a crevasse splay since the latter is considered to be a more erosive environment where overbank fines are less likely to be preserved.

The only fossil material recovered from the overbank association is ostracoderm fragments found in some J4 sandstones.

Facies Sequence Analysis

The purpose of this section is to objectively analyze the vertical succession of facies/sub-facies delineated in the Strathcona Fiord Formation at section S2 in search of a degree of order (non-randomness) and possibly cyclicity. If such order/cyclicity exists, it may be used to provide an objective check of the subjective evaluation of the facies sequence given in the interpretation. The quantitative technique employed for this purpose is known to geologists as a Markov Chain analysis, named after the nineteenth century mathematician A.A. Markov (Carr, 1982). To statisticians the procedure is known by the more general statistical name of contingency (frequency) table analysis. As stressed by Walker (1984), the facies sequence is the key to an environmental interpretation since individual facies are often not diagnostic of depositional environment. In a Markov Chain analysis the facies/sub-facies are thought of as states. One looks for the presence of a Markov process in the measured section, i.e., that the probability of an upward transition to a particular state is dependant on the nature of the preceding state or states. If the section contains a Markov process then it has a non-random component in it, or in other words, a degree of order. A Markov Chain may be of the first or higher order depending on whether the probability of a given state occurring is dependant on the immediately preceding state only or on several of the preceding states. Only first order Markov chains are searched for in this analysis. The methodology involved in a Markov Chain analysis involves the formulation of a matrix of observed transitions between facies from one's measured section(s) and a matrix of expected (predicted) values using a random model. A statistical comparison of the two tables then allows the determination of which pair(s) of facies transitions are non-random (i.e., exhibit a Markov process) and which are solely random. From the non-random pairs of facies transitions a preferred facies relationship diagram and/or its graphical equivalent, a summary section, can be constructed which can then be used as an interpretive tool. References to the application of Markov processes in geology can be found in Powers and Easterling (1982), Carr (1982), Walker (1979, 1984) and Harper (1984). In 1982 the statistical techniques used in the previous geological applications of Markov Chain analysis are shown to be incorrect in papers by Carr (1982) and Powers and Easterling (1982). In summary, the errors lay in the manner in which the expected frequencies are derived and in how cells (pairs of facies transitions) are chosen as being non-random. The earlier technique used only row totals, ignoring column totals, to generate the expected cell frequencies. In using the difference matrix (Selley, 1970) to determine which cells are non-random it ignored all negative differences (observed minus expected) and failed to test the significance of positive differences, all of which are considered indicative of non-randomness (Carr, 1982). The details of why the earlier technique is wrong can be found in Carr (1982) and Harper (1984). Use of the correct technique does make a considerable difference in determining the final assemblage of facies transitions which are considered non-random and from which an interpretation can be made. This is blatantly seen if one compares Walker (1979, Figure 3) and Harper (1984, Figure 1). Harper's methodology has produced fewer non-random transitions and as a result has also removed the cyclicity from Walker's data.

Interestingly, if the same data (Battery Point data, Cant and Walker, 1976) are analyzed using the technique suggested (not developed) by Carr (1982) a still further reduction in the number of non-random transitions results (three less).

This suggests that the technique used by Carr is more conservative regarding its choice of non-random facies transitions.

A basic assumption which is required to perform a Markov Chain analysis on a measured section(s) is that the data (transition frequencies) exhibits stationarity. Stationarity means that transition probabilities are constant through time (Powers and Easterling, 1982, pg. 919). This ends up meaning that one does not combine data from differing depositional environments (for example, fluvial and marine) since the transition probabilities would be expected to vary with environmental setting and would therefore exhibit non-stationarity.

The method used by Carr (1982) is applied to the Strathcona Fiord Formation data at section S2. It is also used for all other Markov Chain analyses done in this study. To derive the matrix of expected transition frequencies Carr fits a log-linear model of quasi-independence (Goodman, 1968) to the data using a modification of the Deming-Stephan iterative proportional fitting procedure suggested by

Bishop, Fienberg and Holland (1975). A model of quasi-independence is required since an upward transition of a facies into itself is not recognized resulting in a matrix with a diagonal of zeros (structural zeros). The selection of cells (facies transitions) which are contributing the most to a departure from the quasi-independent model occurs when a chi-square test of independence indicates that the data contains a Markovian process. The selection of deviant cells uses a stepwise procedure (the criterion is the maximum absolute standardized deviate = observed - expected/square root of expected) described by Brown (1974) wherein each cell considered non-random is treated as a structural zero and the expected value matrix is refitted to the log-linear model and tested again for independence. The stepwise selection ends when the probability associated with the chi-square statistic in the test of independence exceeds the chosen level of significance (the alpha level was relaxed to 0.2 in this study). This selection procedure is not performed if the initial chi-square statistic exceeded the chosen level of significance (i.e., the data does not contain a Markovian process). Carr (1982) used the statistical software package BMDP-2f for his computations. Throughout this study the current equivalent program BMDP-4f (Brown, 1983) is used wherever a Markov Chain analysis is performed. Brown (1983) incorporates a very readable overview of appropriate aspects of contingency table analysis into the explanations of corresponding aspects of program 4f. The data input necessary to run the program consists simply of a matrix of observed facies transitions. An example of a Markov Chain analysis is provided in appendix A. Covered intervals in the measured section are simply ignored with the immediately preceding facies unit having no upward transition.

Output for the Strathcona Fiord Formation at section S2 is presented in Figure 2.1.7.2-2. It consists of a table of observed cell frequencies, a table of expected cell frequencies derived by fitting the log-linear model, a table of expected cell frequencies derived from fitting the model after deletion of deviant cells, and a list of the deviant (non-random) cells and their corresponding probabilities. These probabilities must only be considered as approximate however, as there are a large number of low (less than unity) expected cell values. Brown (1983, pg. 157) points out that such a situation causes the distribution of the chi-square statistic determined for the expected value matrix to differ significantly from the chi-square distribution and thus jeopardize the validity of the cell selection procedure. Brown (1983, pg. 157) gives criteria

Figure 2.1.7.2 - 2 Markov chain analysis of the Strathcona Fiord Formation at section S2. Calculations were performed using BMDP-4f.

BHDP4F CONTINGENCY TABLE ANALYSIS OF STRATHCONA FIORD PORTION OF SECTION 52

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	1B	1C	2A	2C	2E	2I	2J	6	TOTAL
1A	0	0	0	2	18	0	1	1	1	23
1B	0	0	0	1	0	0	1	0	0	2
1C	0	0	0	0	2	0	0	0	0	2
2A	0	0	0	0	5	0	0	0	2	7
2C	14	0	1	0	0	4	0	0	10	29
2E	1	0	0	0	0	0	0	0	3	4
2I	0	0	0	0	0	0	0	0	2	2
2J	0	0	0	1	0	0	0	0	0	1
6	10	2	0	3	2	0	0	0	0	17
TOTAL	25	2	1	7	27	4	2	1	18	87

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 87
SUMMED OVER 72 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	55	85.74	.0050	113.19	.0000	6

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	1B	1C	2A	2C	2E	2I	2J	6	TOTAL
1A	[illegible]	.6	.3	2.0	12.2	1.1	.6	.3	6.0	23.0
1B	.6	.0	.0	.1	.8	.1	.0	.0	.4	2.0
1C	.6	.0	.0	.1	.9	.1	.0	.0	.4	2.0
2A	2.2	.1	.1	.5	2.8	.3	.1	.1	1.4	7.0
2C	13.5	.5	.4	2.3	17.4	1.6	.8	.4	8.6	29.0
2E	1.2	.1	.0	.3	1.6	.1	.1	.0	.8	4.0
2I	.6	.0	.0	.1	.8	.1	.0	.0	.4	2.0
2J	.3	.0	.0	.1	.4	.0	.0	.0	.2	1.0
6	6.1	.4	.2	1.3	7.9	.7	.4	.2	3.8	17.0
TOTAL	25.0	2.0	1.0	7.0	27.0	4.0	2.0	1.0	18.0	87.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF STRATHCONA FIORD PORTION OF SECTION S2

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	35.74	55	.00501	5.160	1B	2I
1	79.10	54	.01281	3.701	2J	2A
2	74.15	53	.02912	3.387	1B	2A
3	68.21	52	.05509	2.741	5	13
4	61.11	51	.15705	2.659	2I	6
5	54.13	50	.31798			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

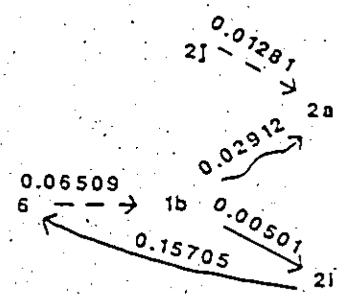
***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

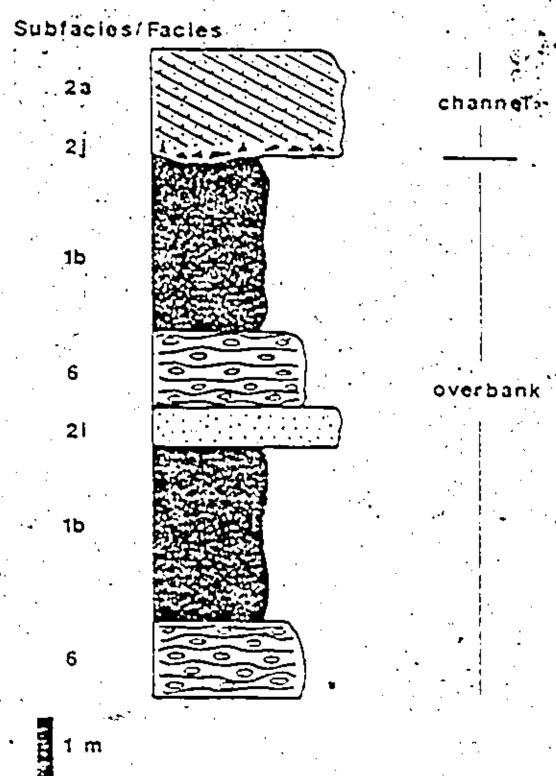
BELOW \ ABOVE	1A	1B	1C	2A	2C	2E	2I	2J	6
1A	.0 *	.0 *	.3	1.6	13.3	1.2	.3	.3	5.5
1B	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *
1C	.5	.0 *	.0 *	.1	.8	.1	.0	.0	.3
2A	2.3	.0 *	.1	.0 *	3.1	.3	.1	.2	1.2
2C	15.3	.0 *	.4	2.3	.0 *	1.8	.4	.4	8.3
2E	1.3	.0 *	.0	.2	1.7	.0 *	.0	.0	.7
2I	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *
2J	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *
6	5.5	.0 *	.2	.8	7.5	.7	.2	.2	.0 *

that permit one to judge when this problem exists. As Beeden (1983) points out, this can create a problem if the probability associated with a selected non-random cell is close to the chosen level of significance (i.e., a more accurate probability, if known, might result in the cell being random). As can be seen in Figure 2.1.7.2-2, if the level of significance is kept at 0.10 only five facies transitions may be considered non-random and no cyclicity is present. If the level is relaxed to 0.20 however, an additional cell is added and a cycle develops (in the context of the problems associated with low expected cell values mentioned above, the selection of this cell might be questioned as its probability (0.15705) is close to the criterion level of 0.20). As mentioned previously in this study, a relaxation of the level of significance up to 0.20 is considered permissable. This can increase the number of non-random cells selected from the data and allow the detection of cyclicity in the measured section. Harper (1984, Figure 1) also permits such a relaxation. The preferred facies relationship diagram constructed from the non-random cells of Figure 2.1.7.2-2 is presented in Figure 2.1.7.2-3. The cycle of 6-1b-2i-6 is apparent in this diagram. The graphical equivalent to this diagram, the summary section, is also presented in Figure 2.1.7.2-3. The

Figure 2.1.7.2 - 3 Preferred facies relationship diagram (top) and summary section (bottom) for the Strathcona Fiord Formation at section S2. Average sub-facies thickness was used in the construction of the summary section. The calculations were performed using BMDP-4F.



NON-RANDOM FACIES TRANSITIONS



SUMMARY SECTION

summary section is constructed using average facies thicknesses given in 2.1.5.4. In the context of the previous interpretation, it provides an objective characterization of the Strathcona Fiord Formation at this location. The summary section indicates the formation to be an overbank dominated meandering fluvial system. Units indicative of both flood events (sub-facies 2i) and soil forming processes (facies 6) are contained within the normal overbank fines (sub-facies 1b).

Discussion

The meandering fluvial environmental setting envisaged for the Strathcona Fiord Formation at this location is depicted in Figure 2.1.7.2-4. An interval of channel and overbank association sediments is presented in Figure 2.1.7.2-5. In addition to the general interpretation given previously several topics warrant special discussion:

1. Paleoclimatic Setting

Due to prolonged sub-aerial exposure, overbank sediments contain the key to paleoclimatic interpretation (Collinson, 1978). At section S2 the overbank sediments (genetic association J) commonly contain nodular weathering horizons (facies 6). These horizons are slightly calcareous

Figure 2.1.7.2 - 4 Block diagram representation of the depositional setting of the Strathcona Fiord Formation at sections S2 and HB1. Five different components of the overbank genetic association (J) are shown in the diagram. See text for a discussion of each.

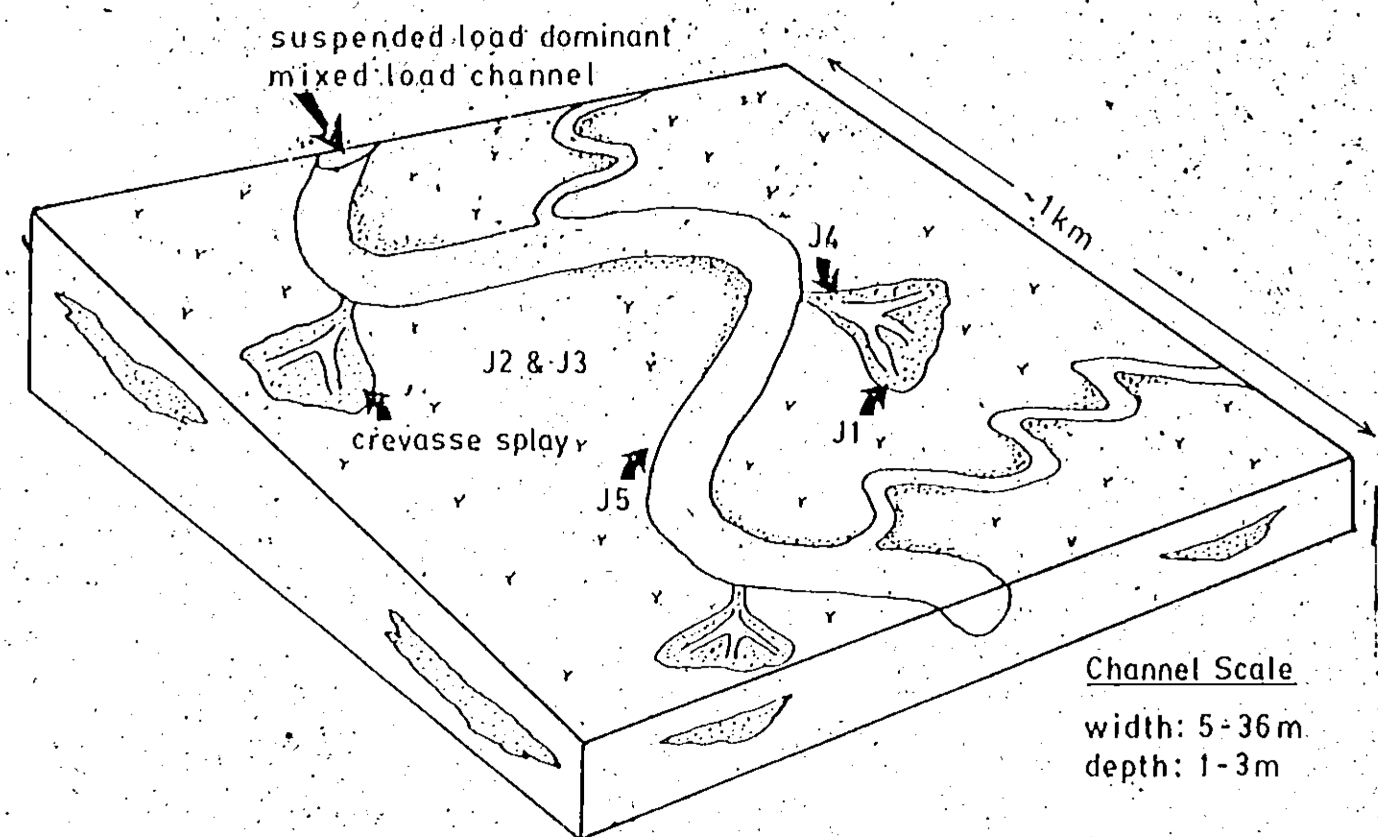
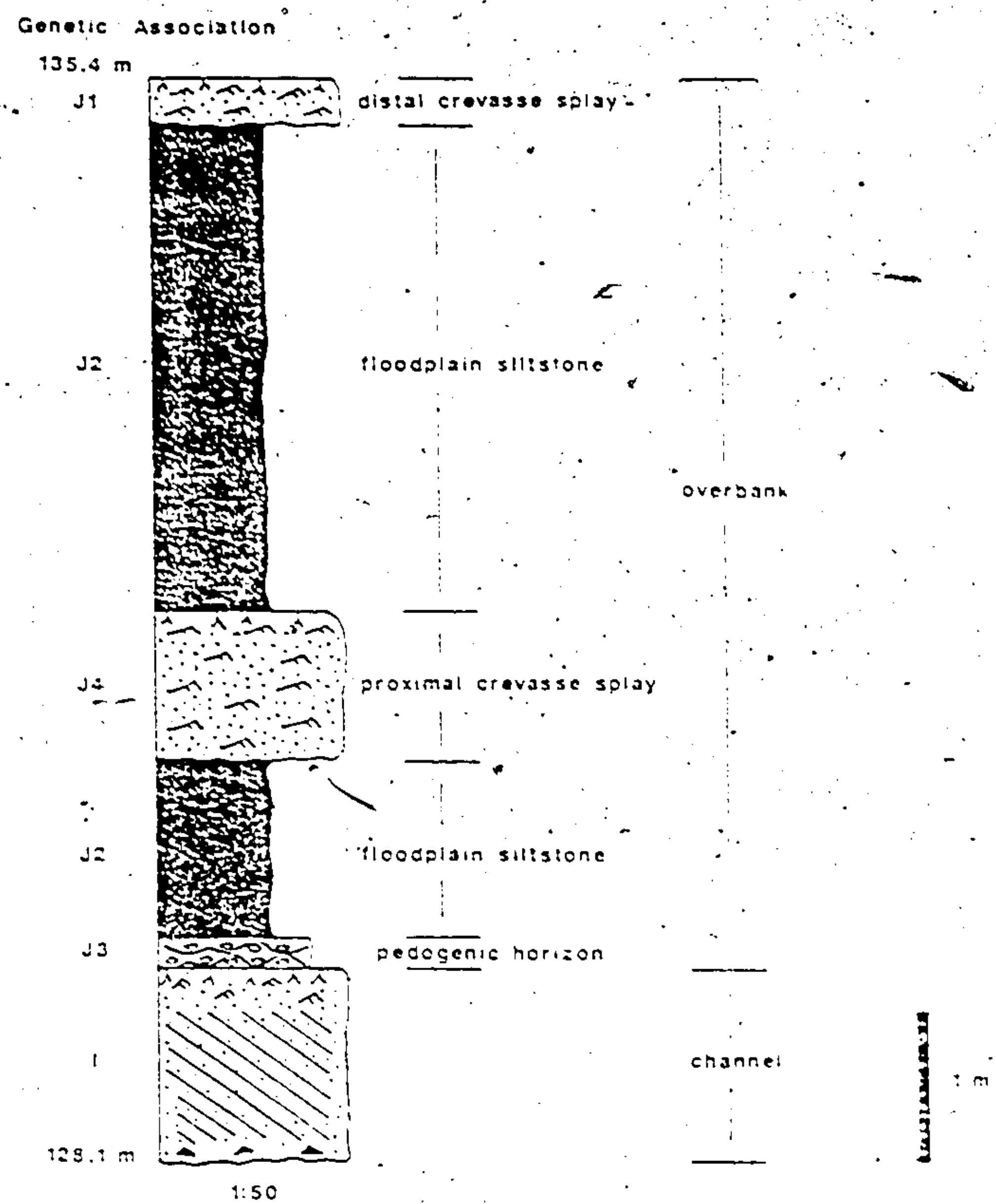

suspended load dominant
mixed load channel
~1km
J4
J1
J2 & J3
crevasse splay
J5
Channel Scale
width: 5-36m
depth: 1-3m

Figure 2.1.7.2 - 5 Genetic associations in the Strathcona Fiord Formation at sections S2 and HB1. A representative interval from the formation at section S2 is shown in this diagram.



Genetic Association
135.4 m
J1
distal crevasse splay
J2
floodplain siltstone
overbank
J4
proximal crevasse splay
J2
floodplain siltstone
J3
pedogenic horizon
I
channel
1 m
128.1 m
1:50

and their overall nodular appearance suggests they are analogous to a calcrete profile of intermediate maturity (Collinson, 1978, Table 3.1, pg. 41). Leeder (1975) discusses the development of calcrete profiles; he indicates that such profiles develop under low water table conditions in a semi-arid environment by downward percolating groundwater which dissolves calcium carbonate high in the soil profile and precipitates it at a lower level, during drier periods. The nodular weathering horizons in section S2 are suggested to be indicative of semi-arid climatic conditions. The absence of coal partings or lenses in the overbank sediments at this locality supports this suggestion. The lithologic features and age of the Strathcona Fiord Formation at section S2 make it highly comparable to the Old Red Sandstone of Britain and the Catskill red beds in New York State. Woodrow, Fletcher and Ahrnsbrak (1973) have suggested a semi-arid climatic setting at the time of deposition of these sediments. This lends furthers credence to the paleoclimatic interpretation suggested for the Strathcona Fiord Formation at section S2. It is noteable that lithologic evidence found in the Strathcona Fiord Formation at section S1 also leads to the suggestion of a semi-arid paleoclimate.

2. Channel Migration Frequency

The coarse member (channel fill sediments)/fine member (overbank sediment) ratio for meandering fluvial deposits can be used as an indication of the frequency of channel migration through a particular area of the flood plain. In general, an inverse relationship exists between the channel migration frequency and the amount of overbank sediment preserved. Highly sinuous, suspension-load channels tend to produce a flood plain architecture in which channel sediments are isolated in more voluminous overbank deposits (for example, the Devonian of Spitzbergen, Moody-Stuart, 1966) while less sinuous bed material-load channels create a fluvial architecture dominated by channel deposits rather than overbank flood deposits (Collinson, 1978). Also, in order for overbank deposits to be preserved (net aggradation) regional subsidence must be sufficient to prevent complete reworking as a result of channel migration. Of the seven occurrences of channel fill deposits in section S2, a coarse/fine member ratio could be determined for four, which averaged 0.26. The size of this ratio relative to that for the classical fining-upward model for meandering rivers (0.77), indicates the dominance of overbank sediments in the Strathcona Fiord Formation at this location. In such a setting, the migration of highly sinuous suspension load channels is commonly restricted to a well defined meander belt by the presence of numerous clay plugs in the flood plain sequence created by channel-abandonment (Collinson, 1978).

3. Vertical Change in Fluvial Style

The coarse/fine member ratio changes upward through the Strathcona Fiord Formation at section S2. Of the four channel sequences for which the ratio could be calculated, the lowest two have a c/f = 0.09 (0.11 and 0.07) while the highest two have a c/f = 0.42 (0.49 and 0.35). This indicates a relative increase in the amount of main channel deposits in the upper portion of section S2. As the overlying Hecla Bay Formation is interpreted to be a sandy braided system, this change to a larger c/f ratio in the upper part of the Strathcona Fiord Formation is reflecting a gradual transition from a meandering to a braided fluvial regime. It is noteworthy that the sandstone of the two channel deposits associated with the higher c/f ratio is drastically different from stratigraphically lower Strathcona Fiord channel fill sandstone. The higher channel sandstones are much cleaner, coarser grained, greyish-white sandstone resembling that of the overlying Hecla Bay Formation and contrasting with the red, finer grained, Strathcona Fiord Formation channel sandstone lower in the section. These channel sandstones obviously represent the initial influx of Hecla Bay detritus to this area. The occurrence of Hecla Bay channel sandstones not only coincides with an increased c/f ratio but, as discussed previously (2.1.5.3), also coincides with a possible change in paleocurrent trend. In addition, the first and only occurrence of chert pebbles as part of a basal channel lag is found in the highest Hecla Bay style channel sandstone.

4. Paleochannel Characteristics

Paleochannel morphologic and flow characteristics can be estimated using empirical relations between morphology and various aspects of the flow that have been developed from data on modern rivers. These paleohydrologic techniques have been summarized and critically assessed by Leeder (1973), and Ethridge and Schumm (1978). In the latter paper, the authors stress that the values derived from the equations can only be considered as rough estimates of the morphologic or flow parameters. The two principle reasons for this are:

1) The data on which the empirical relations are based is quite limited in terms of the variety of physiographic and

climatic settings, and the scale of the rivers that are represented.

2) Difficulties associated with the estimation of paleochannel depth and width, which are required input data if any further reconstruction of paleochannel characteristics is to be accomplished.

The reader is referred to Ethridge and Schumm (1978) for a thorough discussion of the history of paleohydrologic reconstruction and the problems associated with its application. These authors suggest two methodologies when attempting a paleohydrologic reconstruction, one requiring an estimate of the percentage of silt and clay in the channel bottom and banks, plus an estimate of channel width and depth, and the other requiring only an estimate of channel width and depth in order to be able to use their set of equations. The latter methodology (their method 2) is adopted in this study. The set of equations associated with this method is given in their Table 2, pg. 706-707. The estimate of channel width and depth is usually derived from preserved epsilon (point bar) surfaces. However, as Leeder (1973) pointed out, these surfaces are not commonly preserved in the rock record. While bankfull channel depth can be estimated from the thickness of the coarse member of the fining upward sequence, a way to estimate bankfull width is commonly not available. Leeder determined that the two were highly correlated for channels with a high sinuosity (P > 1.7) and developed a regression equation from his data which permits the estimation of bankfull width from bankfull depth (his Figure 3, pg. 269 and equation 1, pg. 268). Table 2.1.7.2-2 gives the estimated morphologic and flow characteristics for the four paleochannels for which reliable estimates of the coarse member thickness could be obtained. The bankfull depths represent the thickness of the coarse member corrected for the difference between channel depth in a meander bend and that in a straight reach (x 0.585, Khan, 1971), and also corrected for sediment compaction (0.9, Ethridge and Schumm, 1978, pg. 709). The bankfull depths given in Table 2.1.7.2-2, are therefore straight reach depths, not meander depths. The bankfull widths in Table 2.1.7.2-2 are determined from bankfull depths using Leeder's (1973) equation 1. This equation is metric so no conversion is required. However, the equations for mean annual discharge (Qm) and meander wave length (L) in Ethridge and Schumm (1978) are in Imperial Units, so a conversion of the final value to metric is required. It is stressed that Table 2.1.7.2-2 is only intended to give an indication of the scale of the fluvial system at section S2

Table 2.1.7.2-2 Estimates of Paleochannel Morphology and Flow Characteristics For The Strathcona Fiord Formation at Section S2.

Ch.	Db(m)	Dbc(m)	Wb(m)	F	P	Qm(m^3/s)	L(m)
Strathcona Fiord Detritus							
1	2.0	1.3	10.2	7.8	2	0.78	183.7
2	1.3	0.8	5.2	6.6	2.1	0.18	105.6
Hecla Bay Detritus							
3	1.8	1.2	8.7	7.2	2.1	0.58	157.7
4	4.5	2.9	35.5	12.2	1.8	9.77	550.2

Db - bankfull depth from coarse member thickness

Dbc - corrected bankfull depth (x 0.585/0.9 = 0.65)

Wb - bankfull width from Dbc and Leeder (1973), equation 1

F - width depth ratio

P - sinuosity from Ethridge and Schumm (1978, pg. 706)

Qm - mean annual discharge from Ethridge and Schumm (pg. 706)

L - meander wave length from Ethridge and Schumm (pg. 707) and not to give accurate estimates of the paleochannel parameters. Paleochannels 1 and 2 contain Strathcona Fiord style detritus while 3 and 4 represent channels from the upper part of the section containing Hecla Bay style detritus. The calculations in Table 2.1.7.2-2 reflect the transition in channel style as the Strathcona Fiord-Hecla Bay contact is approached. The increased width/depth ratio (F) and decreased sinuosity (P) are both reflecting the initial stages in the change from a meandering to a braided fluvial regime (see 2.2.8).

The calculations also create a problem. How can channels of this small a scale produce such an overbank dominant fluvial sequence (see earlier c/f ratio). It is highly unlikely that they could. It is suggested that the paleohydrologic calculations point to larger channels in the fluvial Strathcona Fiord Formation which are currently unexposed. Taylor and Walker (1984) reached a similar conclusion regarding the magnitude of paleochannels in the Blairmore Group of Alberta. In light of this interpretation, the overbank dominant fluvial sequence exposed at section S2 is suggested to represent deposition by smaller channels that are tributary to a larger main channel. The floodplain is envisaged as being part of a broad, low lying, coastal plain. The coastal plain setting is suggested as a result of the shoreline position at the start of Okse Bay Group deposition (in the region of Bird Fiord) which may be inferred from the work of Smith and Stearn (1982; refer to end of 1.4). The present distance between Bird Fiord and the location of section S2 is roughly 50 km. Since this distance is across the Schei Syncline it would have been slightly greater at the time of deposition.

2.1.7.3 Section HB1 (Strathcona Fiord Formation portion)

The Strathcona Fiord Formation at section HB1 is overlain and underlain by a sandy braided Hecla Bay Formation and marine to deltaic Bird Fiord Formation, respectively. The facies sequence and lithologic features of the Strathcona Fiord Formation at this location are similar to those exhibited by the formation at section S2. Especially prevalent are well developed nodular weathering units (facies 6) interpreted as indicative of pedogenesis in a floodplain setting. As a consequence of this similarity with section S2, as well as the stratigraphic context, the meandering fluvial sedimentary model is also chosen to interpret this section in the Strathcona Fiord Formation. An overview of the model was presented in 2.1.7.2.

A contingency table analysis was not conducted at this section due to its size (47 m) and also because of only one occurrence of a channel sandstone.

The interpretations suggested for the genetic associations defined in this section are those given to the same association in section S2. As a result, only a descriptive summary of each association is given below. The reader is referred to Table 2.1.6.4-1 and the interpretations offered for section S2. The drafted section is contained in Figure 2.1.6.4-2 (in pocket).

Genetic Associations

As was the case for section S2, two genetic associations, an overbank and channel association, are defined in the Strathcona Fiord Formation at section HB1. Selected features of the formation at this location are presented in Plate 2.1.7.3-1.

I. Channel Association

Only one occurrence of this association is noted for this section. It is 2.3 m thick, representing 4.9% of the Strathcona Fiord Formation. The channel fill is enclosed in overbank sediments with an erosional basal contact and a gradational upper contact. The basal channel fill sediments

Plate 2.1.7.3 - 1 The uppermost 47 m of the Strathcona Fiord Formation at section HB1 located approximately 23 km SSW of the head of Sor Fiord.

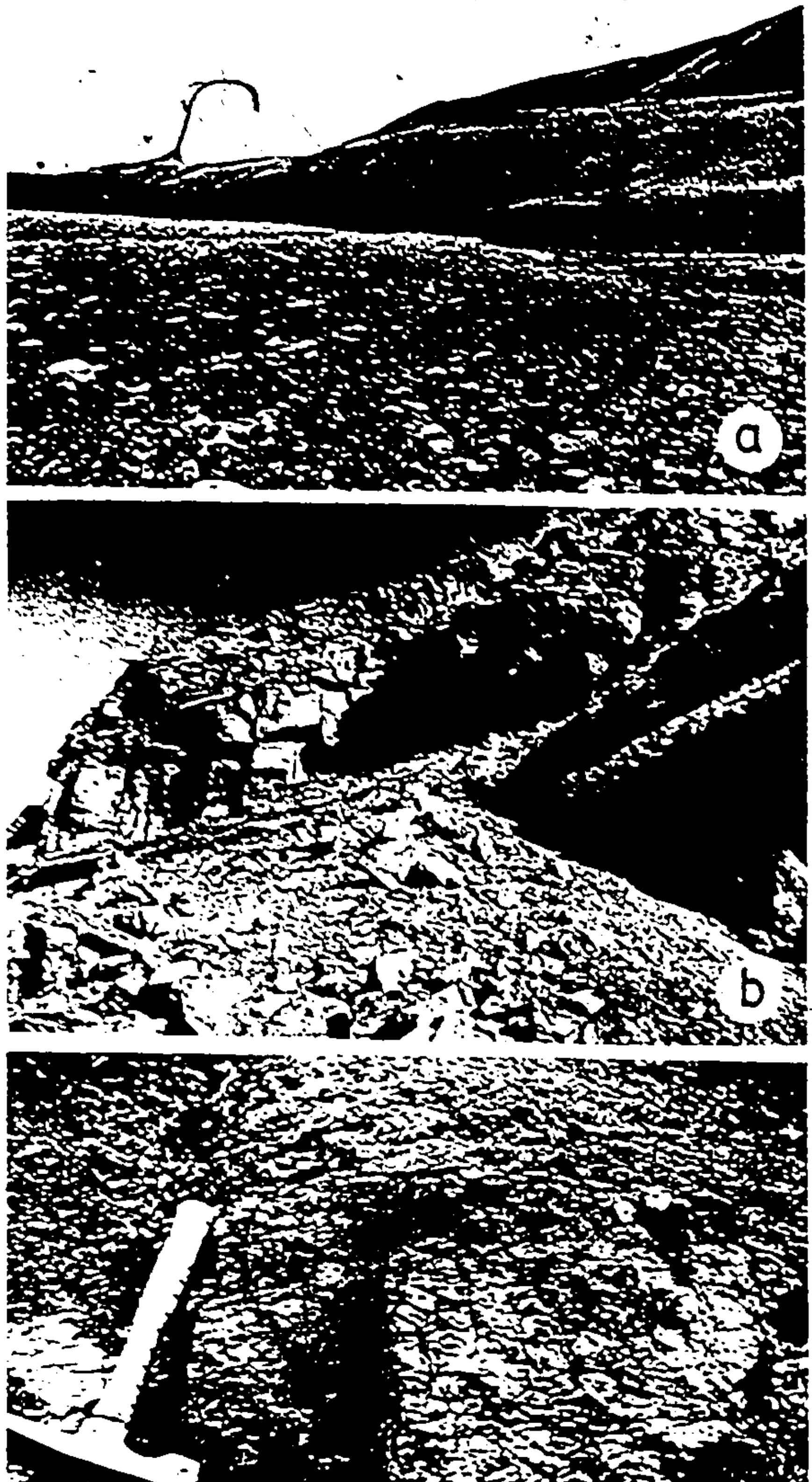
A. The Strathcona Fiord Formation at section HB1.

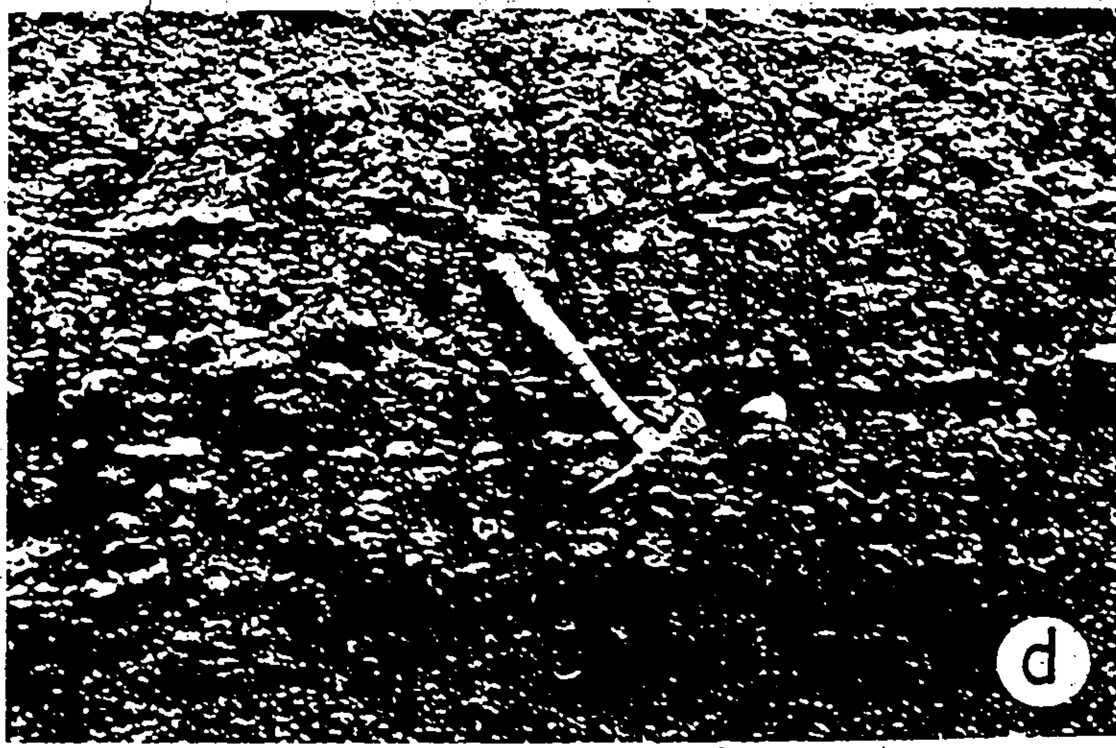
B. The conformable Hecla Bay Formation (resistant sandstone unit above the scree slope) - Strathcona Fiord Formation (recessive sandstone and siltstone interval grading into the scree slope) contact at section HB1.

C. An irregular pattern of reduction in the top of a floodplain sandstone indicative of rooting. The hammer is 30 cm in length.

D. A thick nodular weathering interval in floodplain siltstone indicative of pedogenesis. The hammer is 30 cm in length.

E. Floodplain sandstone and siltstone in the Strathcona Fiord Formation at section HB1. The Jacobs Staff (right center) is 1.5 m in height.


a
b
c



(component I1) at this location consist of large scale, planar tabular cross-stratified (2a) and parallel laminated (2b) sandstone with minor siltstone clasts occurring as lag in the base of sub-facies 2a. The upper channel fill sediments consist only of several lenses of non-stratified siltstone (1a) representing quiet water deposition away from the thalweg.

J. Overbank Association

The overbank association at this section of the Strathcona Fiord Formation average 9.7 m thick and dominates the exposure (67.4%). It is gradational from the upper channel fill sediments and scoured into by the basal channel fill sandstone. All five components (J1-J5) defined in section S2 are present at this location. Contacts amongst the components are gradational where exposed. The percentage, by cumulative thickness, of the overbank association represented by each component, as well as its average thickness and range is as follows:

J1 - 16.2%; Av. = 0.59 m, range = 0.2-1.4 m
J2 - 45.4%; Av. = 1.2 m, range = 0.2-6.7 m
J3 - 17.8%; Av. = 0.60 m, range = 0.2-1.2 m
J4 - 11%; Av. = 1.6 m, range = 1.5-1.7 m
J5 - 15.1%; Av. = 2.2 m, range = 0.2-4.2 m

The facies/sub-facies composition of the overbank components is as follows, with the most frequently occurring sub-facies underlined:

J1 - sandstone: <u>2c</u>, 2i, 2e, 2k

J2 - siltstone: <u>1a</u>, 1e

J3 - nodular weathering unit (facies 6)

J4 - sandstone: <u>2c</u>, 2i, 2a

J5 - sandstone: <u>2c</u>, 2e

- siltstone: 1a, 1e

Fossil remains in the overbank sediments at this section consist of ostracoderm fragments in component J5 and small plant fragments in component J2.

<u>Discussion</u>

A small meandering channel (2-3 m in depth) was responsible for the deposition of the sediment in this short exposure of the Strathcona Fiord Formation. However, it cannot be stated that the entire formation represents a meandering fluvial depositional setting since it is not known how representative this exposure is of the complete formation at this location.

2.2 Hecla Bay Formation

2.2.1 Introduction

The Hecla Bay Formation is the second lowest formation in the Okse Bay Group. Within the study area the contact with the underlying Strathcona Fiord Formation and the overlying Fram Formation is conformable. The formation has the largest areal extent of all the formations in the Okse Bay Group, extending from west-central Ellesmere Island in the east to the west coast of Melville Island in the west. Its areal extent and thickness variation throughout the Arctic Archipelago was presented by Embry and Klovan (1976, Figure 26). In the western Arctic Archipelago the Hecla Bay Formation is transitional into the Weatherall Formation on Melville Island (Embry and Klovan, 1976, Figure 15).

The formation was examined at four of the thirteen section localities established during this study. Arranged from east to west, they are section HB1 located along a river ca. 23 km southwest of the head of Sor Fiord, section HB3 located ca. 3 km east of the head of the eastward directed arm of Bird Fiord, section F4 located along the inner western margin of Goose Fiord, and section HB2 located along the inner northern side of a small river valley approximately one half the way up the western coast of North Kent Island. Refer to Figure 2.1.1-1 for these section locations. These localities are discussed separately in subsequent portions of this report.

2.2.2 Summary Of Lithological Descriptions and Age Determinations from Previous Studies

2.2.2.1 Lithological Descriptions

The Hecla Bay Formation belongs to the lower part of Schei's series E (1903, 1904; McLaren, 1963a; Embry and Klovan, 1976) as defined at Goose Fiord. It is also equivalent to the bulk of McLaren's lower sandstone member (1963a, pg. 328-329). McLaren describes it as a bright orange-yellow weathering, variably ferruginous, massive and thick bedded, medium to coarse grained, quartzose sandstone with subordinate shale bands.

Tozer and Thorsteinsson (1964) defined the type locality of the formation on the south flank of the Robertson Point Anticline, 11 km north-northwest of the head of Beverly Inlet, Melville Island (Christie and Embry, 1981, pg. 58). At this location the formation is 847 m thick and consists of very highly weathered, white to orange, fine grained, quartzose sandstone. Embry and Klovan (1976, pg. 529) describe the sandstone at the type locality as having weathered to a white, unconsolidated sand.

Embry and Klovan (1976) examined the Hecla Bay

Formation in the western and eastern Arctic Archipelago. On southwestern Ellesmere Island the formation was investigated in the Okse Bay-Bird Fiord region. In this area, as elsewhere, the formation consisted of fine to medium grained, well sorted, quartzose sandstone with thin intervals of dark grey to black shale and siltstone. Sedimentary structures consisted mainly of trough and planar tabular cross-beds. Embry and Klovan (1976) suggested a sandy braided fluvial depositional environment for the formation in the eastern and central Arctic Archipelago, and a deltaic to marine depositional setting in the Western Arctic Archipelago where coarsening-upward cycles with pelecypod coquinas were identified.

Trettin (1978) examined the Hecla Bay Formation on west-central Ellesmere Island. In this region he describes the formation as consisting of mainly grey to orange weathering, fine to coarse grained sandstone with minor amounts of interstratified, very fine to fine grained sandstone and siltstone, the latter commonly weathering a reddish color. Chert pebble conglomerate constituted only ca. 1% of the section examined. He suggests that the formation in this region represents deposition in a sandy braided fluvial environment, as was suggested by Embry and Klovan (1976) for the formation on southern Ellesmere.

Roblesky (1979) examined the Hecla Bay Formation at four sections in the Vendom Fiord region of southern Ellesmere Island. He describes the formation in this region as consisting of mineralogically and texturally mature, mainly medium grained quartz arenites with very minor siltstone and conglomerate. Sedimentary structures were hard to discern but included planar tabular cross-beds, ripple cross-lamination and horizontal lamination. He also interpreted the formation to represent a sandy braided fluvial depositional system.

2.2.2.2 Age Determinations

While crew members of the Second Norwegian Polar Expedition took extensive plant and fish collections from the Okse Bay Group (Schei's series E, 1904) at Goose Fiord (McLaren, 1963a, pg. 328-329) they sampled what must have been the Fram Formation overlying the Hecla Bay Formation. Nathorst (1904) examined the plant remains from this collection and assigned them a Late Devonian age, which would then be a minimum age for the underlying Hecla Bay Formation in this region.

Embry and Klovan (1976, pg. 540) used palynological data to date the Hecla Bay Formation at various locations in the Arctic Archipelago. Data from the Bird Fiord locality, lying within the study area of this investigation, indicated a range in age from Early (?) - Middle Givetian to Early Frasnian.

Trettin (1978, pg. 72) reports palynological data from the Hecla Bay Formation on west-central Ellesmere Island. The formation in this region ranged from Middle to Late Givetian.

Roblesky (1979) reports a Middle to Late (?) Givetian age for the basal part of the Hecla Bay Formation in the Vendom Fiord region of southern Ellesmere Island, also derived from palynology.

In summary, previous work on the Hecla Bay Formation in central and southern Ellesmere Island has indicated that its maximum range in age would be Early (?) Givetian to Early Frasnian.

2.2.3 Summary Facies Descriptions

As in 2.1.3, the purpose of this section is to summarize the lithological makeup of the Hecla Bay Formation as a whole, by considering the locations at which it was examined, cumulatively. The facies/sub-facies breakdown of the Hecla Bay Formation at section HB1, HB2 and F4 are combined to this end. While the formation is well exposed at section HB3 (ca. 3 km east of Bird Fiord), the quality of the exposure is very poor consisting largely of effectively in place, but highly frost heaved rock. Stratigraphic unit definition similar to that achieved at the other locations is impossible and the section is used largely for the small number of measurable directional structures it contains and for petrographic data. Of the 890 m the above three exposures represent, 13.6% is covered interval.

The Hecla Bay Formation consists overwhelmingly of sandstone (93%) with minor amounts of siltstone (5.6%) and conglomerate (1.4%). Summary descriptions of each of these facies is given below. Ten sandstone sub-facies, three siltstone and two conglomerate sub-facies are identified. Their relative abundance in the formation, by cumulative thickness, is shown in Figure 2.2.3-1. Their important descriptive attributes are summarized in Table 2.2.3-1.

Facies 2 - Sandstone

Sandstone in the Hecla Bay Formation is predominantly orange to grey-white weathering and grey-white on fresh surface. Only a small percentage shows grey or purple weathering colors. Of the ten sub-facies defined, large

Figure 2.2.3 - 1 Sub-facies in the Hecla Bay Formation (all sections considered cumulatively). Percentage by cumulative thickness is shown on the ordinate scale.

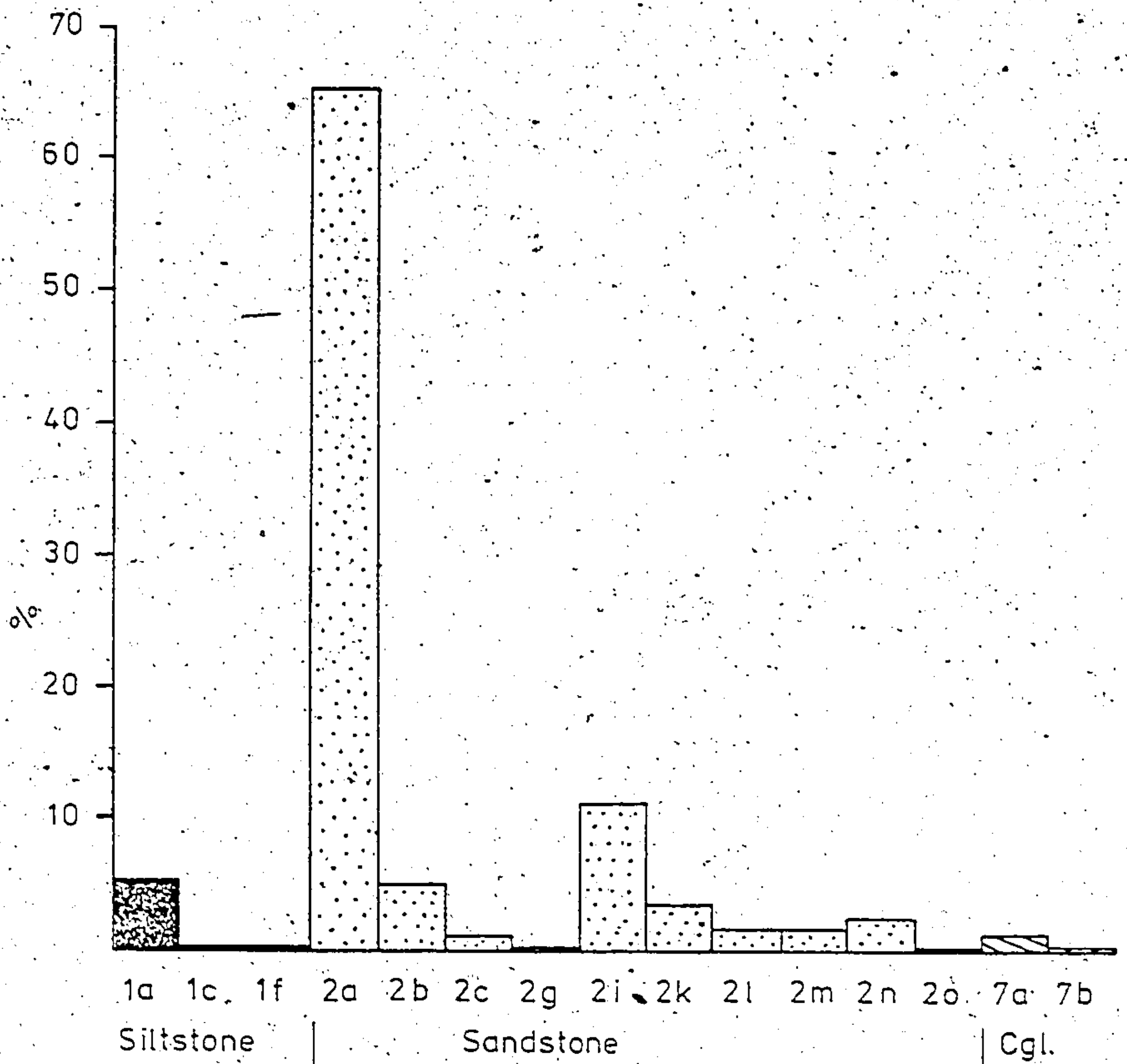

70
60
50
40
30
20
10
%
1a
1c
1f
2a
2b
2c
2g
2i
2k
2l
2m
2n
2o
7a
7b
Siltstone
Sandstone
Cgl.

Table 2.2.3.-1 Descriptive Attributes of Sub-Facies Defined in the Hecla Bay Formation (All Sections Considered Cumulatively)

Facies 1 - Siltstone (5.6%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	96.2	0.8; 0.01-9.9	grey, purple, green/grey, green	comminuted plant debris
ripple cross-laminated siltstone	1c	2.3	1.0	green/green	nf
Comments: one occurrence only					
siltstone with trace fossils	1f	1.5	0.6	grey/green	dwelling burrows
Comments: one occurrence only					

Facies 2 - Sandstone (93%)

SUB FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	71.1	3.6; 0.2-23.8	orange, grey, purple/grey-white	small to large fragments of plant casts; ostracoderm fragments
parallel laminated sandstone	2b	5.3	1.2; 0.1-8.0	orange, grey/grey-white	comminuted plant debris

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
ripple cross-laminated sandstone	2c	1.0	0.4; 0.02-1.2	orange, grey/grey-white, grey	nf
wavy and irregularly laminated sandstone	2g	0.2	0.5; 0.3-0.8	orange/grey-white	nf
non-stratified sandstone	2i	12.6	1.7; 0.02-11	orange, grey, purple/grey-white	comminuted plant debris, ostracoderm fragments
bedded sandstone without bedforms	2k	3.9	1.3; 0.2-4	orange, purple/grey-white	comminuted plant debris
trough cross-bedded sandstone	2l	1.5	1.5; 0.4-4.1	orange/grey-white	comminuted plant debris
highly scoured sandstone	2m	1.7	2.1; 0.6-4.7	orange/grey-white	comminuted plant debris
sandstone with overturned cross-beds	2n	2.5	0.8; 0.3-2	orange, grey, purple/grey-white	nf
sandstone with chevron cross stratification	2o	0.1	0.5; both	orange/grey-white	nf

scale, planar tabular cross-bedded sandstone (2a) is by far the most important, representing 71.1% of the sandstone. Of secondary and tertiary importance are the non-stratified (2i, 12.6%) and parallel laminated (2b, 5.3%) sub-facies often found in contact with the planar tabular cross-bedded sub-facies. The largest average unit thickness occurs in the planar tabular cross-bedded sandstones (3.6 m) and the minimum is found in the rarely occurring ripple cross-laminated sandstones (0.4 m).

Macroscopic fossil evidence is limited to plant debris and ostracoderm fragments. Comminuted plant debris can be found along depositional surfaces in most of the sandstone sub-facies. Larger fragments of plant casts and/or ostracoderm fragments are only present in the non-stratified or planar tabular cross-bedded sandstones.

Facies 1 - Siltstone

As mentioned above, siltstone is volumetrically very minor in the Hecla Bay Formation. Most siltstones are grey to dark green on both weathered and fresh surfaces with occasional purple hues also found. Non-stratified siltstone (1a) is the dominant sub-facies representing 96.2% of the occurrences. Its unit thickness averages 0.8 m, reaching a maximum of 9.9 m. As indicated in Table 2.2.3-1, the other two sub-facies, ripple cross-laminated siltstone (2c) and siltstone with trace fossils (2e), only occur once.

Macroscopic fossil evidence is limited to unidentified dwelling burrows and comminuted plant debris. Palynomorphs, predominantly spores, are described and identified by McGregor (1984a).

Facies 7 - Conglomerate

Conglomerate is even rarer in the Hecla Bay Formation than siltstone. It represents only 1.4% of the formation by cumulative thickness. Conglomerate units are restricted to the basal part of the formation. They occur almost entirely as non-stratified units (sub-facies 7a, 82.6%) with only one instance of a large scale, planar tabular cross-bedded unit (sub-facies 7b). Weathered and fresh surfaces are brown or grey in color. Non-stratified units are the thickest, reaching a maximum of 2.2 m, averaging 1.2 m. Clasts in the conglomerates include chert, sandstone and siltstone rip-up clasts.

Macroscopic fossil evidence consists of fragments of plant casts and ostracoderm fragments found as additional biogenic clasts in the conglomerate.

2.2.4 Section HB1 (Hecla Bay Formation portion)

2.2.4.1 Location, Thickness and Contact Relations

As mentioned previously in 2.1.6.1, this section includes the exposed portions of the Strathcona Fiord Formation and Hecla Bay Formation in this area. The Strathcona Fiord Formation portion is discussed in 2.1.6 and 2.1.7.3. The Hecla Bay Formation portion of the section, 504.4 m, representing the complete formation in this area, is described herein. The top of section HB1 is continuous into section F5 which is discussed in another portion of this report (2.3.4). As stated in 2.1.6.1, the base of the section is located at 560600E, 8556850N, UTM Zone 16X, NTS 49C, Baumann Fiord Sheet. The reader is referred to Figure 2.1.6.1-1 for an aerial photograph of the section.

The lower contact with the Strathcona Fiord Formation is well exposed. The Hecla Bay Formation overlies the Strathcona Fiord Formation erosionally, but conformably, with conglomerate units found within the basal 23 m. The upper contact with the overlying Fram Formation is not exposed, but is presumed conformable since the strata attitudes above and below the contact zone are comparable.

2.2.4.2 Age

Nine of ten palynology samples collected from the siltstone in this section of the Hecla Bay Formation are productive. The base of the formation in this area is dated as early Mid-Eifelian from a sample at 26.8 m above the Strathcona Fiord-Hecla Bay contact (GSC Loc. C-91990; McGregor, 1984a, pg. 15). The highest dated sample is positioned 142.9 m below the Hecla Bay-Fram contact; it gives an age of early, but not earliest, Givetian (GSC Loc. C-91997). The top of the formation could be somewhat younger given the distance between the highest dated sample and the Hecla Bay-~~Fram~~ contact zone.

The drafted section of this exposure of the Hecla Bay Formation is presented in Figure 2.1.6.4-2 (in pocket).

2.2.4.3 Paleocurrent Analysis

The well preserved, horizontal exposures along the river at this location are very conducive to paleocurrent measurements. The largest number of measurements obtained from any one location were recorded at this exposure of the Hecla Bay Formation. The directional data consists of 191 large scale, planar tabular cross-bed measurements, 7 trough cross-bed orientation measurements, 6 parting lineation measurements, 2 sets of chevron strata, and 1 channel axis orientation measurement. Figure 4.1-1 contains the rose diagram for the planar tabular cross-bed measurements. As indicated in this figure, the vector mean for the planar tabular cross-beds is 323^0 with the data displaying a considerable range of values (standard deviation about the vector mean = 88^0, variance = .7744). This flow direction contrasts with that obtained from the trough axes (vector mean = 236^0), parting lineation (054^0-234^0) and channel scour axis (northeast-southwest). The flow direction obtained from the planar tabular cross-beds is considered more reliable due to the much larger data base for this structure; this is especially important in the context of the sandy braided fluvial interpretation presented subsequently in 2.2.8. This depositional setting is characterized by the large directional variability displayed by its primary sedimentary structures, including the higher order structures such as channel scours. Many more measurements of trough axes, parting lineation and channel scours would be required before the associated vector means could be considered as reliable indicators of overall flow direction for the fluvial system.

2.2.4.4 Facies Content

This section of the Hecla Bay Formation is well exposed and preserved. It contains only 15.3% covered interval. It consists of sandstone (92%), siltstone (5.8%) and conglomerate (2.2%). The sandstone at this location is represented by nine sub-facies, four of which are new. The new sub-facies are trough cross-bedded sandstone (2l), highly scoured sandstone (2m), sandstone with overturned planar tabular cross-beds (2n), and sandstone with chevron cross- bedding (2o). Both siltstone and conglomerate are represented by two sub-facies. Each conglomerate sub-facies is new. The descriptive attributes of the sub-facies are presented in Table 2.2.4.4-1. Sandstone sub-facies 2m and 2o, and siltstone and conglomerate sub-facies 1f and 7b, respectively, only occur at this exposure of the formation. They have therefore been previously described in Table 2.2.3-1. The sandstone sub-facies are both minor representing only 3.1% and 0.3%, respectively, of the sandstone, by cumulative thickness. The siltstone and conglomerate sub-facies (1f and 7b), similarly represent only 2.4% and 20% of their respective facies. The proportion of the formation represented by the various sub-facies is presented in Figure 2.2.4.4-1. As indicated by this figure, large scale, planar tabular cross-bedded

Figure 2.2.4.4 - 1 Sub-facies in the Hecla Bay Formation at section HB1. Percent of the formation by cumulative thickness on the ordinate scale.

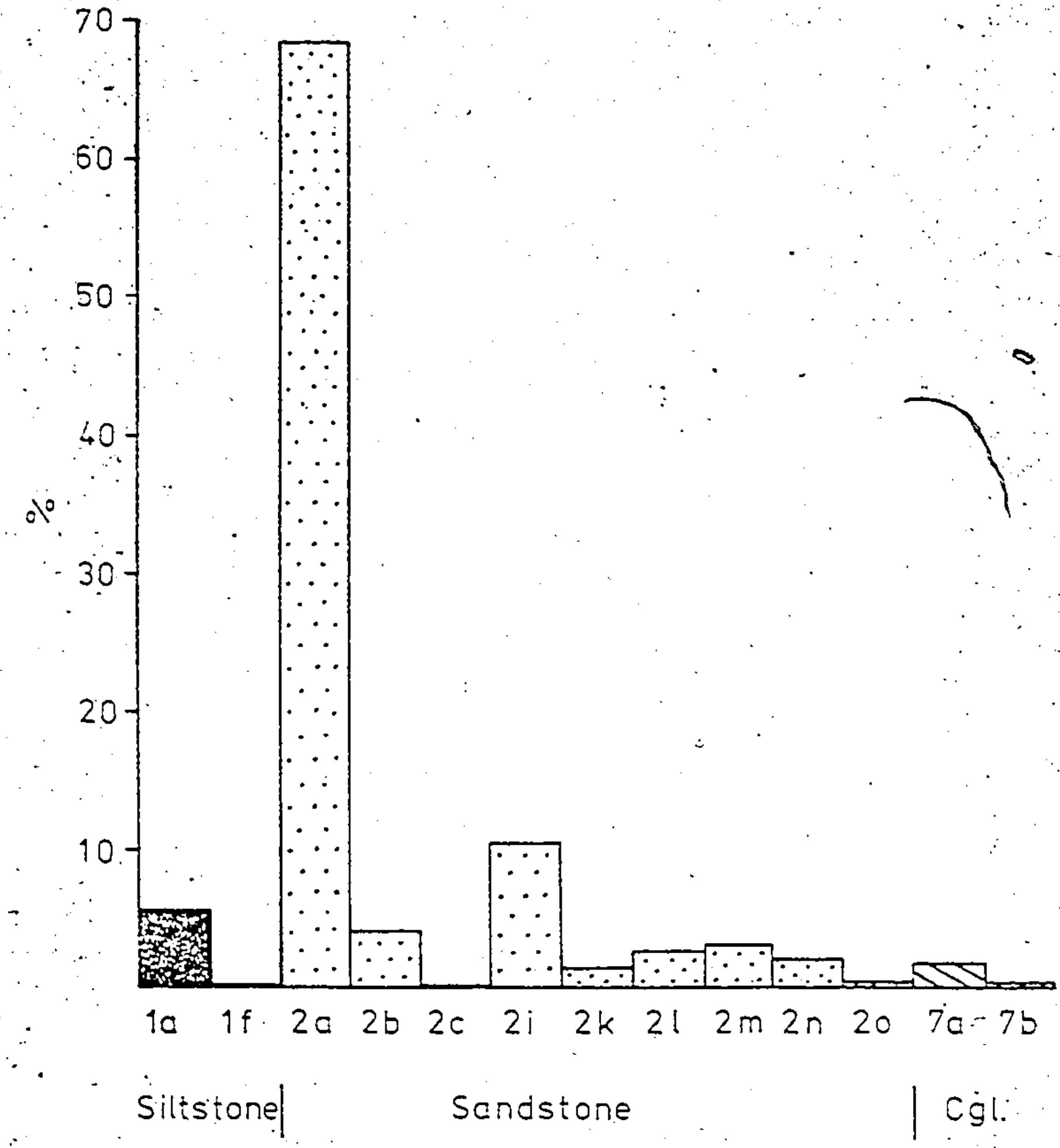

70
60
50
40
30
20
10
%
1a
1f
2a
2b
2c
2i
2k
2l
2m
2n
2o
7a
7b
Siltstone
Sandstone
Cgl.

Table 2.2.4.4.-1 Descriptive Attributes of Sub-Facies Defined in the Meola Bay Formation at section HB1

<u>Facies 1</u> - Siltstone (5.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	97.6	0.93; 0.06-9.9	<u>grey</u>, <u>green</u>/green, grey	comminuted plant debris

<u>Facies 2</u> - Sandstone (92%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	74.4	5.2; 0.4-23.8	<u>orange</u>, grey/<u>white</u>, grey	fine plant debris, ostracoderm fragments
parallel laminated sandstone	2b	4.2	1.8; 0.5-8.0	<u>orange</u>, grey/<u>white</u>, grey	nf
ripple cross-laminated sandstone	2e	0.1	0.25; 0.2-0.3	orange/white	nf
non-stratified sandstone	2i	11.4	2; 0.4-11	<u>orange</u>, grey/<u>white</u>, grey, green	fine plant debris, ostracoderm fragments
bedded sandstone without bedforms	2k	1.8	1.4; 0.8-2.1	orange/white	nf

trough cross-bedded sandstone	21	2.5	2.5; 0.6-4.1	orange, grey/white	fine plant debris
sandstone with overturned cross-beds	2n	2.2	0.9; 0.5-2.0	orange/white	nf.

Facies 7 - Conglomerate (2.2%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified conglomerate	7a	80	1.0; 0.4-2.2	brown, grey/ brown, grey	fine plant debris, ostracoderm fragments

Comments: clasts are siltstone, sandstone and chert

NOTE: See comments 3,4, and 5, folllowing Table 2.1.3-1.

sandstone dominates (68.4%) this exposure of the Hecla Bay Formation.

Summary descriptions of each facies is given below. Selected features in the Hecla Bay Formation at this location are presented in Plate 2.2.4.4-1.

Facies 1 - Siltstone

Siltstone is a minor facies at this location. It represents only 5.8% of the formation and displays green or grey hues on both the weathered and fresh surface. Siltstone is almost entirely non-stratified (1a) with an average non-stratified unit thickness of 0.93 m. Other than a single occurrence of a burrowed siltstone interval (1f), this facies contains no macroscopic fossil evidence. Microscopic fossil evidence, in the form of spores, was recovered from the siltstone however (McGregor, 1984a).

Facies 2 - Sandstone

Most (92%) of the Hecla Bay Formation at this location consists of orange to tan weathering, quartz-rich sandstones that are white to grey on a fresh surface. Nine sub-facies are defined, the most prominent of which is large scale, planar tabular cross-bedded sandstone (2a - 74.4%). Average unit thickness varies from a minimum of 0.25 m for

Plate 2.2.4.4 - 1 The Hecla Bay Formation at section HB1 located approximately 23 km SSW of the head of Sor Fiord.

A. Interstratified conglomerate (Cgl.) and sandstone in the basal 23 m of the Hecla Bay Formation. The hammer is 30 cm in length.

B. Typical river outcrop of the Hecla Bay Formation. Assistant (arrow) for scale.

C. A major amalgamation (erosion) surface in the Hecla Bay Formation delineated by the Jacobs Staff and the three arrows. The staff is 1.5 m in length.

D. Doubly overturned cross-strata near the top of a channel sandstone unit. Hammer (arrow) is 30 cm in length.

E. A thicker, dark weathering siltstone cap representing overbank fines deposition. Its lower contact is sharp and the upper is erosional. The hammer is 30 cm in length.

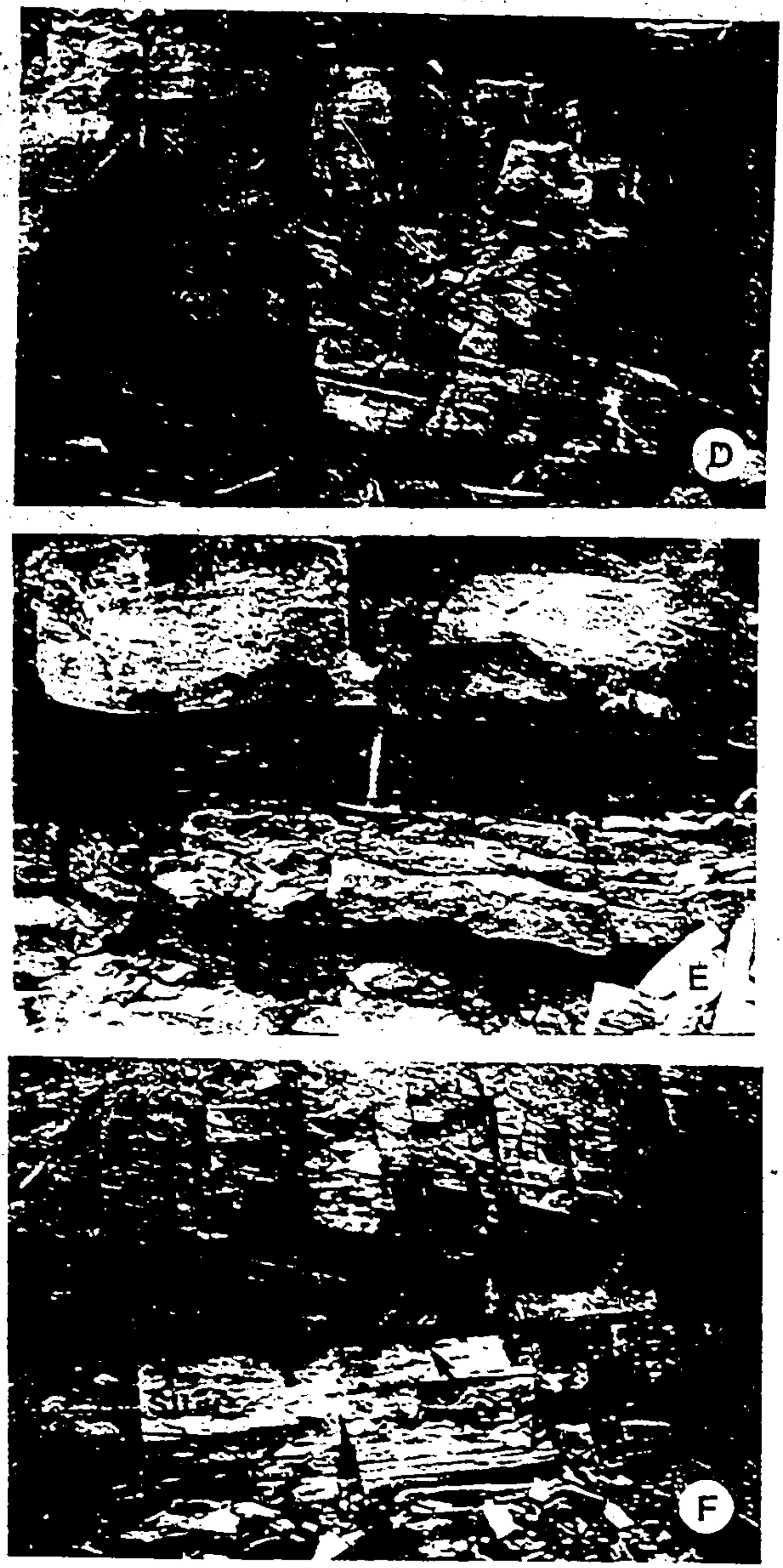
F. A thin lens of dark weathering overbank/sand-flat-top siltstone (left arrow) capping an underlying channel sandstone and erosionally overlain by another sandstone unit. The hammer (right arrow) is 30 cm in length.

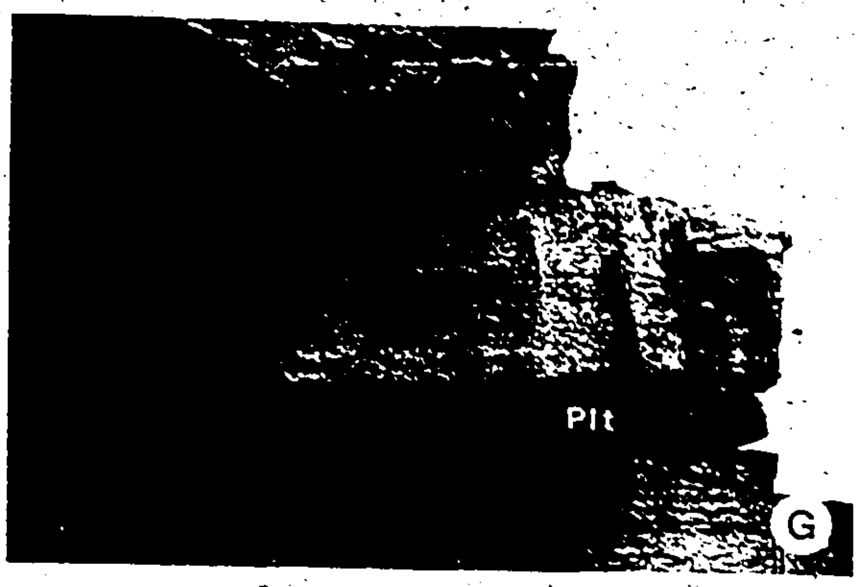
G. Two horizons of concentrated fine organic (plant) debris (plt) near the top of a channel sandstone unit representing very low flow to standing water conditions. The exposed portion of the hammer handle is 6 cm in length.

H. A highly contorted sandstone unit representing a high energy flood event. The hammer is 30 cm in length.

I. A lens of quartz and chert pebble conglomerate (cgl.) near the top of the Hecla Bay Formation. The hammer is 30 cm in length.


A
B
C


D
E
F


Plt
G


H


I

ripple cross-laminated sandstone (2c) to a maximum of 5.2 m for cross-bedded sandstone.

Macroscopic fossil evidence consists of fine plant debris and/or ostracoderm fragments in some of the sub-facies; the latter often occurs as part of a lag.

Facies 7 - Conglomerate

Conglomerate, like siltstone, is a minor facies representing only 2.2% by cumulative thickness. Conglomerate units are grey or brown, both on weathered and fresh surfaces. They are largely non-stratified (7a - 80%) with only one planar tabular cross-bedded unit noted (7b - 20%). Average unit thickness for the non-stratified conglomerate is 1.0 m. Clast composition usually consists of a mixture of siltstone, sandstone and chert.

Macroscopic fossil evidence consists of plant fragments and/or ostracoderm fragments.

2.2.5. Section F4 (Hecla Bay Formation portion)

2.2.5.1 Location, Thickness and Contact Relations

Section F4 is located ca. 35 km headward of the entrance to Goose Fiord, along its western margin. The base of the section is positioned at 456500E, 8534000N, UTM zone 16X, NTS 59A, Cardigan Straight Sheet. The upper 210.3 m of the Hecla Bay Formation constitute the lower part of this exposure.

The Hecla Bay Formation is conformably overlain by the Fram Formation, the contact being well exposed. The Hecla Bay Formation is presumed underlain by the unexposed Strathcona Fiord Formation, based on McLaren (1963a, pg. 329), who suggests the formations presence due to "red-stained mud and shale fragments in solifluction gravels south of Middagskollen on the east side of the inner part of the Fiord". On the western margin of the fiord, a low lying tundra covered area separating the Hecla Bay Formation from outcrops of the Bird Fiord Formation farther down the fiord could be representing the Strathcona Fiord Formation. Figure 2.2.5.1-1 is the aerial photograph of section F4 and vicinity showing formation contacts and the line of section.

Figure 2.2.5.1-2 is the drafted section for this exposure (in pocket).

2.2.5.2 Age

All ten palynology samples collected from siltstone in the Hecla Bay Formation contained identifiable spores (McGregor, 1984a, pg. 4-7). The lowest sample collected came from 12.3 m above the base of the section and

Figure 2.2.5.1 - 1 Aerial photograph of section F4 and vicinity showing the line of section -- and relevant formation contacts. EM&R/NAPL A-16752-109.

gave an age of Late Eifelian or Earliest Givetian (GSC Loc. C-91950). Since this sample is located above the base of the formation (possibly in the area of 100 m), the lowest Hecla Bay in this area could be older.

The highest sample was collected 1.8 m below the exposed contact with the overlying Fram Formation. Its age is the upper third of the Givetian to lowermost Frasnian (GSC Loc. C-91957).

2.2.5.3 Paleocurrent Analysis

The Hecla Bay Formation is not as well preserved in the fiord cliffs at this location as it was in the low lying river exposures at section HB1. Consequently, fewer directional structures could be measured. Forty two measurements of large scale, planar tabular cross-strata, three of which represent overturned cross-beds, constitute the paleocurrent data obtained from the Hecla Bay Formation at this location. Figure 4.1-1 contains the rose diagram for this data (n=39). It shows a vector mean oriented toward the northeast (046^0). The measurements are reasonably well spread out over the exposed formation thickness and display no significant vertical variation in mean flow direction. All measurements are from channel sandstone in a sandy braided fluvial depositional setting

(2.2.8).

2.2.5.4 Facies Content

Although this exposure of the Hecla Bay Formation is highly weathered, there are sufficiently numerous intervals of intact rock in the fiord wall to permit the piecing together of a section with no covered interval. This exposure of the formation is dominated by sandstone (95.2% - facies 2) with only minor siltstone (4.8% - facies 1). One siltstone sub-facies and seven sandstone sub-facies are defined at this exposure; none of these are new. Their relative proportion of the formation, by cumulative thickness, is indicated in Figure 2.2.5.4-1. As is the case at section HB1, planar tabular cross-bedded sandstone (2a) and non-stratified sandstone (2i) dominate the exposure. Table 2.2.5.4-1 presents the descriptive attributes of the sub-facies composing the formation at this location. Since wavy and irregularly laminated sandstone (2g) is restricted in its occurrence to this exposure, it has been previously described in Table 2.2.3-1. This is a very minor sub-facies constituting only 0.8% of the formation, by cumulative thickness.

Figure 2.2.5.4 - 1 Sub-facies in the Hecla Bay Formation at section F4. Percent of the formation by cumulative thickness on the ordinate scale.

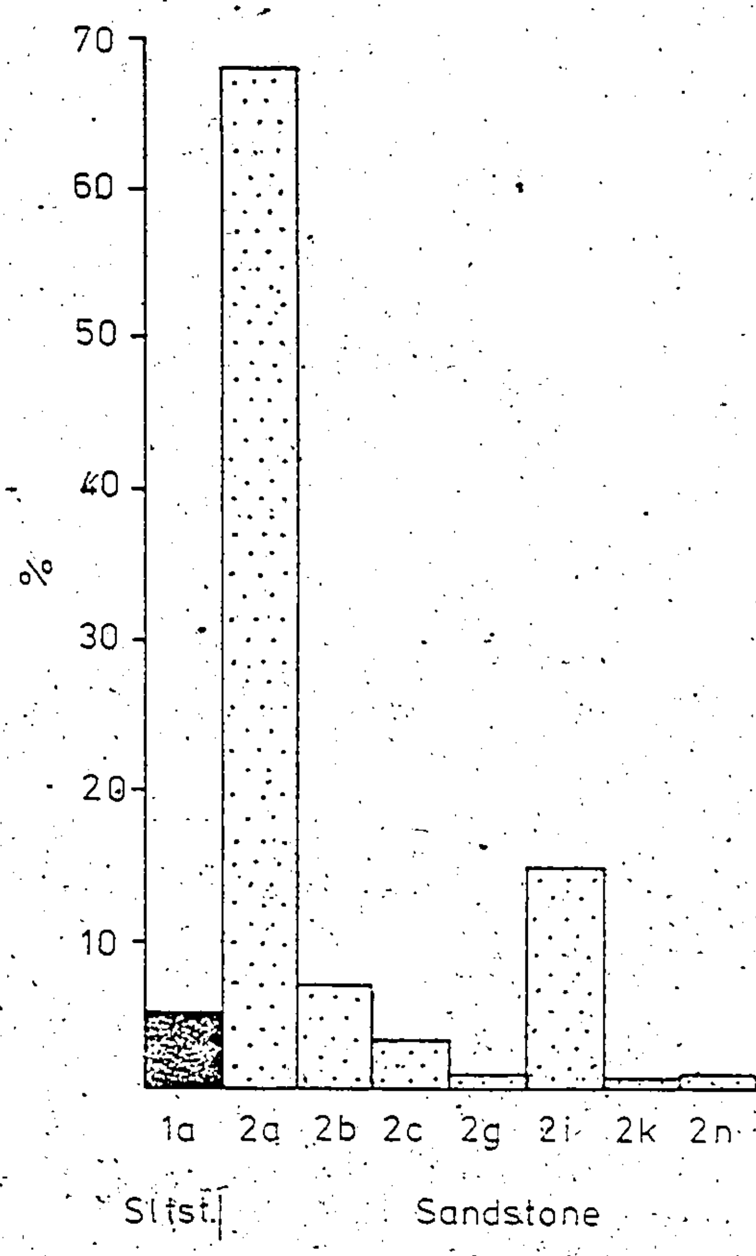

70
60
50
40
30
20
10
%
1a
2a
2b
2c
2g
2i
2k
2n
Sltst.
Sandstone

Table 2.2:5.4.-1 Descriptive Attributes of Sub-Facies Defined in the Hecla Bay Formation at Section F4

<u>Facies 1</u> - Siltstone (4.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	100	0.6; 0.01-1.4	<u>grey</u>, purple, green/<u>grey</u>, green	comminuted plant debris

<u>Facies 2</u> - Sandstone (95.2%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	71.5	3.3; 0.2-9.9	<u>orange</u>, purple/<u>white</u>, grey	comminuted and large plant debris
parallel laminated sandstone	2b	7.5	0.7; 0.1-2.6	orange/<u>white</u>, grey	comminuted plant debris
ripple cross laminated sandstone	2c	3.4	0.5; 0.02-1.2	<u>orange</u>, grey/<u>white</u>, grey	nf
non-stratified sandstone	2i	15.3	1.4; 0.02-5.0	<u>orange</u>, purple/<u>white</u>, grey	fragments of plant casts
bedded sandstone without bedforms	2k	0.3	0.6; one occurrence	purple/grey	nf
sandstone with overturned cross-beds	2n	1.1	0.8; 0.5-1.0	<u>orange</u>, purple/<u>white</u>, grey	nf

<u>NOTE</u>: See comments 3,4, and 5, following Table 2.1.3-1.

Summary descriptions of the facies are given below. Selected features of the Hecla Bay Formation at this location are presented in Plate 2.2.5.4-1.

Facies 1 - Siltstone

Siltstone is a minor lithology in the Hecla Bay Formation, representing only 4.8%. All siltstone at this location is non-stratified (1a). Units weather mainly grey and are grey or green on a fresh surface. Average unit thickness is 0.6 m. Macroscopic fossil evidence consisted of comminuted plant debris.

Facies 2 - Sandstone

Sandstone is the dominant lithology, constituting 95.2% of the formation, by cumulative thickness. Seven sub-facies are defined, most of which weather mainly orange and are white to grey on fresh surfaces. Sub-facies 2k (bedded sandstone without bed forms) weathers purple and is grey on fresh surface. Average unit thickness varies from a minimum of 0.5 m for sub-facies 2g and 2c, to a maximum of 3.3 m for sub-facies 2a. Sub-facies 2a and 2i dominate the formation at this location.

Macroscopic fossil evidence is limited to comminuted

<u>Plate</u> 2.2.5.4 — 1 The Hecla Bay Formation at section F4 located along the western margin of inner Goose Fiord.

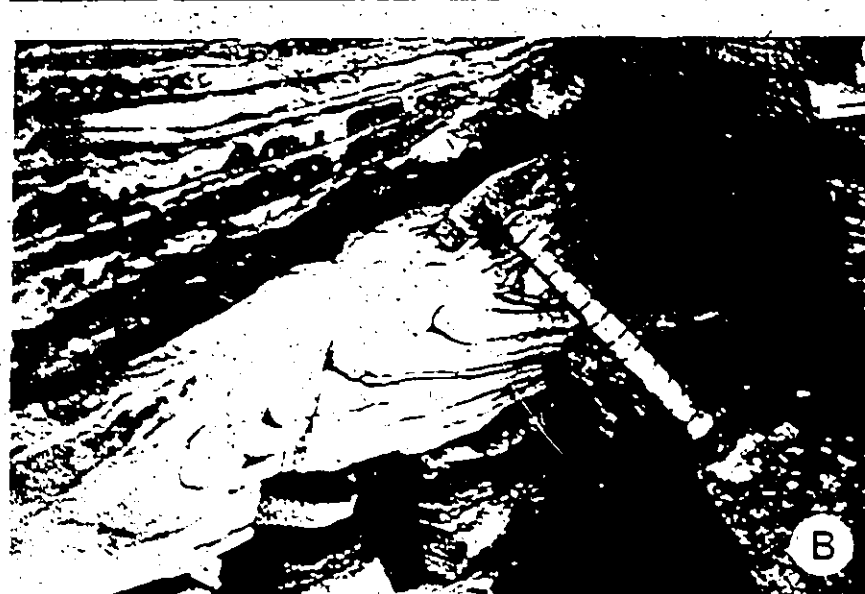
A. Several cross-stratified channel sandstone units in the Hecla Bay Formation separated by darker weathering lensoid caps of siltstone (arrows). The hammer (h) is 30 cm in length.

B. An horizon of overturned cross-strata at the top of a channel sandstone unit. Note the immediately overlying darker siltstone cap. The hammer is 30 cm in length.

C. A large lens of siltstone breccia (siltstone clasts in a sandstone matrix) with clasts up to 25 cm in apparent maximum dimension. A low frequency, high discharge flood event is indicated. The Jacobs Staff is 1.5 m in length.

D. Hydroplastic breaching of an overlying sandstone horizon by darker weathering siltstone indicating relatively rapid deposition. The basal 50 cm of the Jacobs Staff is shown in the photo.


h
A


B


C


D

and large plant debris found only in sub-facies 2a, 2i and 2b.

2.2.6 Section HB2

2.2.6.1 Location, Thickness and Contact Relations

Section HB2 is located in the upper part of a small river valley positioned ca. 19 km up the west coast of North Kent Island (Figure 2.1.1-1). The base of the section is located at 571550E, 8507675N, UTM zone 15X, NTS 59A, Cardigan Strait Sheet. This section consists of 175.7 m of upper Hecla Bay Formation and 44.2 m of the lowermost Fram Formation. The Hecla Bay-Fram contact is exposed and is conformable. A small, isolated outcrop of the Strathcona Fiord Formation is present along the river nearer the coast, indicating that this formation underlies the Hecla Bay Formation in this area. While the contact was not preserved, similar attitudes in this outcrop and the cliff exposures of the Hecla Bay Formation suggest the two formations are conformable. Only the Hecla Bay Formation portion of this section is discussed here. Except the lowermost 33 m, which is highly weathered, this exposure of the Hecla Bay Formation is very well preserved in outcrops adjacent to the river. Figure 2.2.6.1-1 is an aerial photograph of the section location and immediate vicinity, showing the line of section and formation contacts. The drafted section of this exposure is Figure 2.2.6.1-2 (in pocket).

2.2.6.2 Age

Two palynology samples collected from 67 and 93 m above the base of the section contained identifiable spores (GSC Loc C-85288 and C-85289). The former gave an age of early or early Late Givetian while the latter was dated as Late Givetian (McGregor, 1984b, pg. 1-2). Considering their position in the middle of the section, the age range for this exposure of the Hecla Bay Formation could be larger.

2.2.6.3 Paleocurrent Analysis

The directional data recorded from this exposure of the Hecla Bay Formation consists of two parting lineation measurements, one each from near the middle and top of the section, one channel scour axis measurement from near the middle of the section, and seventy-one large scale, planar tabular cross-bed measurements spread reasonably even over the 176 m of the Hecla Bay Formation. Figure 4.1-1 contains the paleocurrent data recorded at section HB2.

Figure 2.2.6.1 - 1 Aerial photograph of section HB2 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16747-50.

The vector mean associated with the paleocurrent rose for the planar tabular cross-beds indicates a southwesterly flow direction (235^0), while the parting lineation and channel scour axis measurements both indicate a northwest-southeast line of movement. As was the case at section HB1, the directional structure with the largest data base is considered the most reliable indicator of overall flow direction, as even the higher order structures, such as channel scours, would be expected to show a large amount of directional variability in the sandy braided fluvial depositional setting which is suggested for the Hecla Bay Formation (2.2.8). Thus, the overall flow direction at this exposure is towards the southwest, based on large scale, planar tabular cross-beds.

2.2.6.4 Facies Content

The Hecla Bay Formation portion of section HB2 is composed of three facies; sandstone (92.8%), siltstone (6.2%) and conglomerate (1.0%). The formation is well exposed at this location with only 25% covered interval. The orange weathering, white to grey, quartz-rich sandstone which dominates the formation may be further divided into six sub-facies; these are summarized in Table 2.2.6.4-1. Siltstone is divisible into two sub-facies and conglomerate only one. These sub-facies are also summarized in Table 2.2.6.4-1, except ripple cross-laminated siltstone (1c), which represents 12.7% of the siltstone, by cumulative thickness. This sub-facies was previously summarized in Table 2.2.3-1, as it is only found in this section. No new sub-facies are required for the description of the formation at this location. The proportion of the formation, by cumulative thickness, represented by each sub-facies is presented in Figure 2.2.6.4-1. Large-scale, planar tabular cross-bedded sandstone (sub-facies 2a) again dominates the formation, representing 55.4%. The constituent lithologies are briefly summarized below. Selected features of the Hecla Bay Formation at this location are presented in Plate 2.2.6.4-1.

Facies 1 - Siltstone

Siltstone is again a minor facies, representing 6.2% of the formation. Nearly all the siltstone is non-stratified (1a) with only one occurrence of a 1.0 m thick unit of ripple cross-laminated siltstone (1c). All siltstone is green or grey on both weathered and fresh surfaces and locally can show nodular weathering. Units of sub-facies 1a average 0.8 m in thickness. Macroscopic fossils are absent.

Figure 2.2.6.4 - 1 Sub-facies in the Hecla Bay Formation at section HB2. Percent of the formation by cumulative thickness is shown on the ordinate scale.

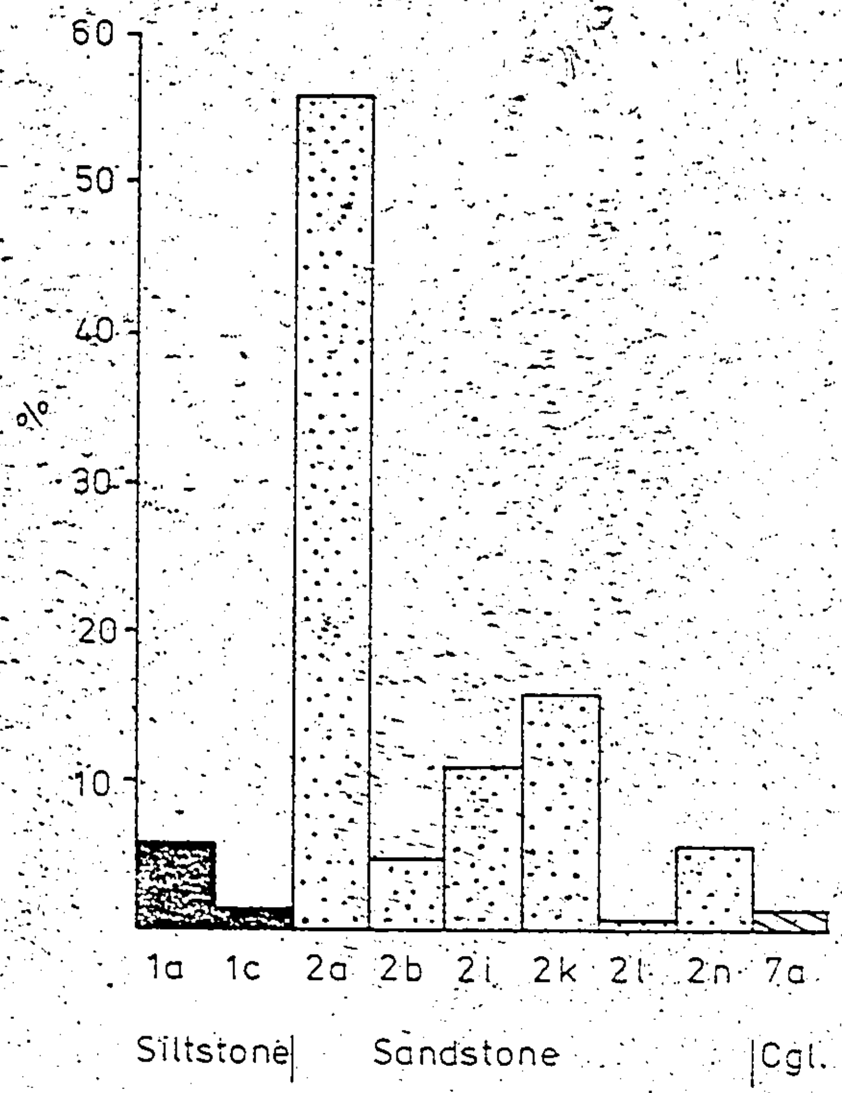

60
50
40
30
20
10
%
1a
1c
2a
2b
2i
2k
2l
2n
7a
Siltstone
Sandstone
Cgl.

Table 2.2.6.4.-1 Descriptive Attributes of Sub Facies Defined in the Hecla Bay Formation at Section HB2.

Facies 1 - Siltstone (6.2%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified siltstone	1a	87.8	0.8; 0.1-1.4	grey, green/grey, green	nf

Facies 2 - Sandstone (92.8%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
planar tabular cross-bedded sandstone	2a	59.7	2.2; 0.2-7.8	orange/white, grey	comminuted and larger plant debris
parallel laminated sandstone	2b	5.1	1.2; 0.3-2.4	orange/white, grey	nf
non-stratified sandstone	2i	12.0	1.8; 0.5-4.0	orange/white, grey	comminuted plant debris
bedded sandstone without bedforms	2k	16.6	1.8; 0.2-4.0	orange/white, grey	comminuted plant debris
trough cross-bedded sandstone	2l	0.7	0.45; 0.4-0.5	orange/white, grey	nf

sandstone with overturned cross-beds	2n	5.9	0.7; 0.3-1.5	orange/<u>white</u>, grey	nf

<u>Facies 7</u> - Conglomerate (1.0%)

SUB-FACIES	CODE	% OF FACIES	THICKNESS (M)	W/F	PALEO.
non-stratified conglomerate	7a	100	1.3; one occurrence	brown/grey	nf

<u>NOTE</u>: See comments 3,4, and 5, following Table 2.1.3-1

Plate 2.2.6.4 - 1 The Hecla Bay Formation at section HB2 located along a valley on the central western coast of North Kent Island.

A. The Hecla Bay Formation at section HB2. Note the darker weathering lens of overbank siltstone in the center of the photograph. The lens is ca. 0.6 m thick and 10 m in length.

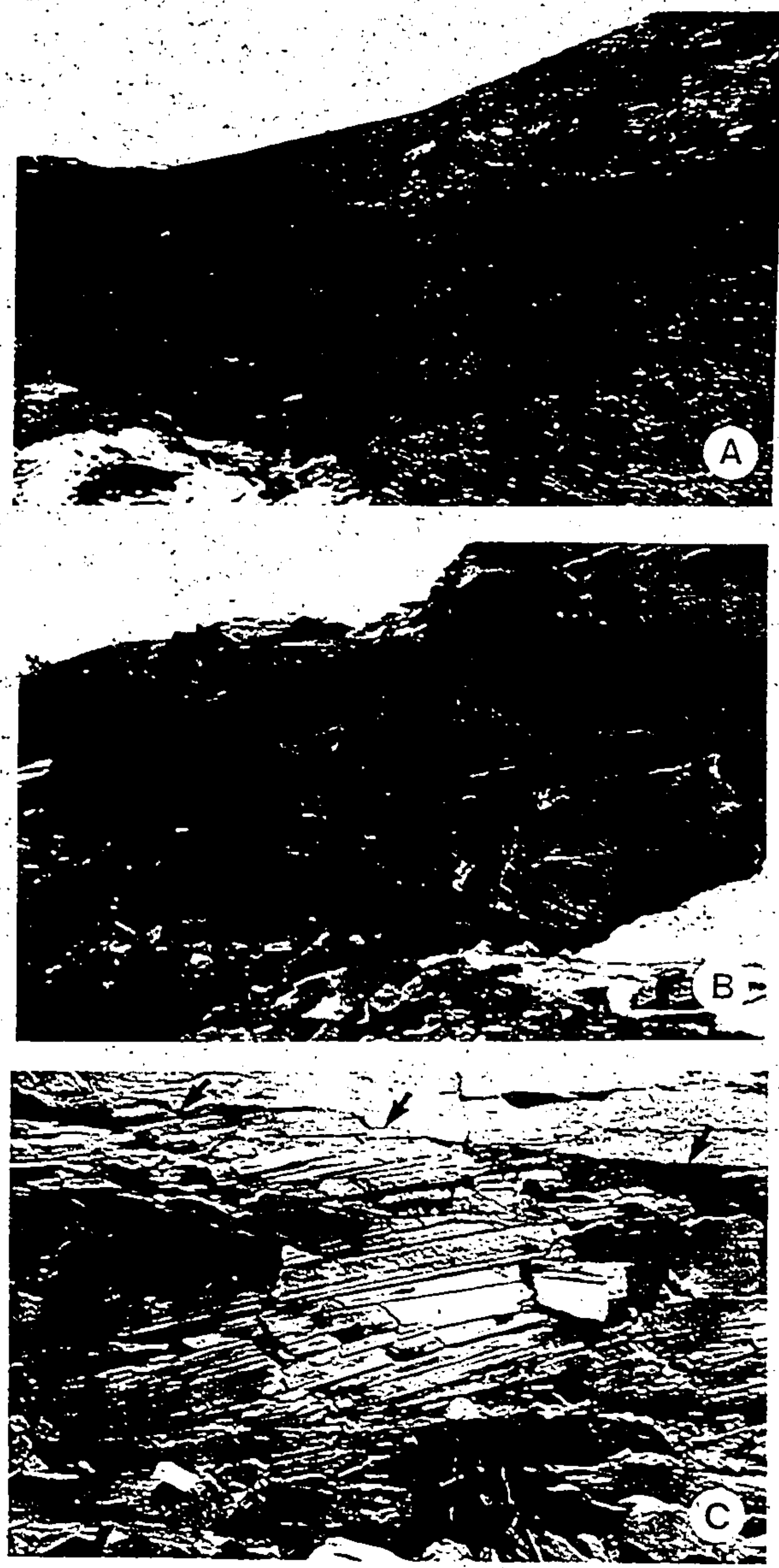
B. A large scale trough cross-stratified unit in the Hecla Bay Formation. The hammer (arrow) is 30 cm in length.

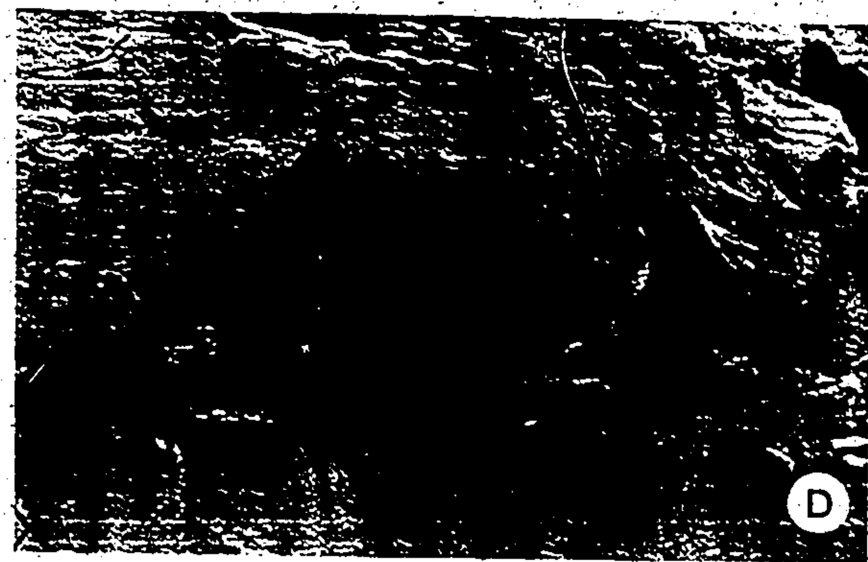
C. Large scale planar tabular cross-stratification. Note the erosional upper bounding surface for the set (arrows). Backpack for scale.

D. An horizon of singly overturned cross-strata overlying a non-stratified sandstone unit. The hammer is 30 cm in length.

E. The very rare preservation of a bar-form in the braided Hecla Bay Formation. The hammer (right arrow) is 30 cm in length.

F. A small lens of siltstone clasts in a sandstone matrix representing the complete erosion of a siltstone cap during the deposition of the overlying channel sandstone. The hammer is 30 cm in length.


A
B
C


D


E


F

Facies 2 - Sandstone

Orange weathering, white to grey, quartz-rich sandstone dominates this exposure of the Hecla Bay Formation as it did at sections HB1 and F4. Six sub-facies are defined; they are described in Table 2.2.6.4-1. Planar tabular cross-bedded sandstone (2a) and bedded sandstone without bedforms (2k) are the two dominant sub-facies, representing 59.7% and 16.6% of the sandstone by cumulative thickness, respectively. Sandstone unit thickness varies from a minimum of 0.45 m for trough cross-bedded sandstone (2l) to a maximum of 2.2 m for planar tabular cross-bedded sandstone (2a). Macroscopic fossils are limited to comminuted and larger plant debris in sub-facies 2a, 2i and 2k.

Facies 7 - Conglomerate

Conglomerate at this location of the Hecla Bay Formation is limited to a single, 1.3 m thick unit. This unit is non-fossiliferous, brownish weathering, grey on fresh surface, non-stratified and contains siltstone, sandstone and chert clasts. It is found at ca. 61 m above the base of the section.

2.2.7 Section HB3

2.2.7.1 Location, Thickness and Contact Relations

Section HB3 is located ca. 2.5 km east of the head of the east arm of Bird Fiord, in a ravine on the south side of the subaerial extension of the fiord. This location is shown on Figure 2.1.1-1. The base of the section is located at 512325E, 8567225N, UTM zone 16X, NTS 49C, Baumann Fiord Sheet. The section consists of 610.6 m of the Hecla Bay Formation. The contact with the underlying Strathcona Fiord Formation was observed in a small outcrop at the base of the section and is conformable. While the Hecla Bay Formation is overlain by the Fram Formation in this area, the contact was not observed as the top of the section ended in the upper Hecla Bay. Figure 2.2.7.1-1 is an aerial photograph of the vicinity of section HB3.

As mentioned previously in 2.2.3, while this section of the formation is well exposed, it consists largely of highly frost heaved blocks. Units could only be crudely defined by splitting trend variations. As a result, facies definition and interpretation was not attempted. Paleocurrent and petrographic data were recorded from the section however. The section consists of the familiar orange weathering, white to grey, quartz-rich sandstone

<u>Figure</u> 2.2.7.1 - 1 Aerial photograph of sections HB3, F2 and vicinity showing the lines of section and relevant formation contacts. EM&R/NAPL A-16756-19.


1 km

containing only an occasional fragment of dark green siltstone. Cross-bedding, both planar tabular and trough, is frequently visible in frost heaved blocks. The abundance of cross-bedding and the similarity in lithological composition with the other sections in the Hecla Bay Formation strongly suggests that the sandy braided fluvial environmental setting suggested for them (2.2.8) is also applicable at this location.

2.2.7.2 Age

As no palynology samples could be collected from the rare siltstone noticed in this section, no age control for the formation at this site is available.

2.2.7.3 Paleocurrent Analysis

Despite the highly frost heaved nature of the section, some paleocurrent data was recovered. The data consists of 41 large scale, planar tabular cross-beds, 2 measurements of axes of trough cross-strata, and 4 parting lineation measurements. This data is presented in Figure 4.1-1. The flow direction indicated by the planar tabular and trough cross-beds is towards the southwest, while the parting lineation indicates a northeast-southwest line of movement. An overall flow direction toward the southwest is therefore suggested.

2.2.8 Interpretation Of Depositional Environment

Relative to the Strathcona Fiord Formation, the interpretation of the Hecla Bay Formation is much simpler due to a far less complicated lithological arrangement and to a uniformity of depositional environment amongst the various sections examined. The Hecla Bay Formation at all four locations, section HB1, HB3, F4 and HB2 is interpreted using the sandy braided fluvial sedimentary model, as originally suggested by Embry and Klovan (1976). Only the formation at sections HB1, F4 and HB2 are discussed in this interpretation. Section HB3, just east of Bird Fiord, is omitted for reasons mentioned previously (2.2.7.1).

The genetic association approach used for the interpretation of the Strathcona Fiord Formation is also used for the Hecla Bay Formation and remaining formations in the Okse Bay Group.

Features of sections HB1, F4 and HB2 which suggest using the sandy braided fluvial model as the interpretive tool are as follows: 1) the regional stratigraphic context places the formation between a tidal flat to fluvial Strathcona Fiord Formation below and an overlying fluvial Fram Formation (2.3.10) 2) the lithological composition is dominated by orange weathering, white to grey, planar tabular cross-bedded, quartz-rich sandstones with only minor siltstone and conglomerate 3) the presence of channel-fill units defined by an erosional base with an intraformational mud clast conglomerate and capped by a residual siltstone lens or horizon 4) the absence of any macroscopic marine fossils.

Palynological analysis of siltstone samples provides supporting evidence for the non-marine nature of the sandstones (McGregor, 1984a).

Relative to our understanding of high sinuosity (meandering) fluvial systems, the understanding of low sinuosity, sandy braided fluvial regimes is far less developed. The number of well studied, modern or ancient, sandy braided stream systems is far less than meandering river studies and few have been sufficiently comprehensive to facilitate model development (Walker and Cant, 1984). References to the best studies of modern and ancient sandy braided systems can be found in Collinson (1978), and Walker and Cant (1984). Perhaps the two most useful studies with respect to model development is the study of the South Saskatchewan River by Cant and Walker (1978) and Allen's (1983) study of the Lower Devonian Brownstones in the Welsh borderlands. An important step toward the understanding of braided stream variability occurred with the publication of Miall's (1977, 1978) summary profiles for various types of braided systems, both gravelly and sandy.

Studies to date suggest that the occurrence of a low sinuosity, multi-channel, braided fluvial style rather than a high sinuosity, single channel meandering system seems to be favored by the following factors (Walker and Cant, 1984, pg. 79):

1. high volume of sediment travelling in traction
2. higher stream gradients
3. non-cohesive and therefore easily erodible bank sediment

Cohesionless bank material permits essentially unrestricted channel shifting. As a result, ancient sandy braided deposits should be expected to display considerable lateral extent in high width to depth ratio tabular sand bodies.

2.2.8.1 <u>Genetic Associations</u>

The various sub-facies previously described from the Hecla Bay Formation may be grouped into two genetic associations, a channel association and a fines association. Their summary characteristics are presented in Table 2.2.8.1-1 and are discussed individually below. All channel associations in this report are designated genetic association I. Definition of a new genetic association, the fines association (K), is necessary since not all siltstone was deposited and preserved in the inactive overbank area of the braided system.

K. Fines Association

This association constitutes only a small portion of the Hecla Bay Formation. It represents 5.8%, 12.6% and 7.1%, by cumulative thickness, at sections HB1, F4 and HB2, respectively, and 8.5% overall. Two components of the fines association are defined, a sand-flat-top (K1) and overbank (K2) component. Their distinction is based on an arbitrary thickness criterion of 0.5 m as indicated in Table 2.2.8.1-1. While arbitrary, such a criterion is realistic as a greater thickness of fines would be preserved in a relatively protected overbank region as compared to an in-channel site, such as the top (sub-aerial) surface of a sand flat complex.

K1 Sand-Flat-Top

Accumulations of siltstone, less than 0.5 m in thickness, occurring as horizons of limited lateral extent

Table 2.2.8.1.-1 Genetic Associations in the Hecla Bay Formation at Sections HB1, F4, and HB2, Ordered From East to West Across S.W. Ellesmere Island.

ASSOCIATION	CODE	CRITERIA		SUB-FACIES CONTENT
Section HB1				
Fines				
sand flat top	K1	< 0.5 m		1a
overbank	K2	≥ 0.5 m	type 1:	1a, 1f
Channel	I			2a, 2b, 2c, 2i, 2k, 2l, 2m, 2n 2o; 7a, 7b
Section F4				
Fines				
sand flat top	K1	< 0.5 m		1a
overbank	K2	≥ 0.5 m	type 1:	1a
			type 2:	1a, 2b, 2c, 2g, 2i
			type 3:	1a, 2c, 2f
			type 4:	1a in sandstone matrix

<u>Channel</u>	I		2a, 2b, 2c, 2g, 2i, 2k, 2n

<u>Section HB2</u>

<u>Fines</u>			
sand flat top	K1	< 0.5 m	1a
overbank	K2	≥ 0.5 m	type 1: 1a, 1c
			type 4: 1a in sandstone matrix

<u>Channel</u>	I		2a, 2b, 2i, 2k, 2l, 2n; 7a

(usually several meters) at the top of erosionally based channel units are interpreted to represent the accumulation and chance preservation of fines deposited on the exposed surface of sand flats within the belt of active channel-switching. Walker and Cant (1984) formally defined sand flats in the South Saskatchewan River as consisting of a bar complex which had nucleated around the exposed portion of a cross-channel bar (their Figure 17 and 18). Allen (1983) used the same concept in his block diagrams used to explain the depositional setting in the Lower Devonian Brownstones (Figure 21 and 22, Walker and Cant, 1984). While Allen does not show any fines accumulation on top of his bar complexes, vertical accretion fines ca. 0.5 m in thickness are shown on top of Walker and Cant's sand flat sequence from the South Saskatchewan River (their Figure 17).

The sand-flat-top component is minor relative to the overbank fines component (K2), representing only 15.3%, 2.6% and 6.5% of the fines association at sections HB1, F4 and HB2, respectively, and 8.1% overall. This component's thickness averages 0.2 m at all three section locations, ranging from 0.06 - 0.4 m. As shown in Table 2.2.8.1-1, this component of the fines association consists only of non-stratified siltstone (1a).

K2 Overbank

Accumulations of siltstone, occasionally with minor, thin, intercalations of sandstone, which equal or exceed 0.5 m in thickness constitute the second component of the fines association. The greater thickness of these deposits is taken to indicate accumulation and preservation in a relatively protected overbank region external to the belt of active channel shifting on the braid plain and subject to relatively infrequent flooding. The overbank component represents 84.7%, 97.4% and 93.5%, by cumulative thickness, of the fines association at sections HB1, F4 and HB2, respectively, and 91.9% overall. As indicated on Table 2.2.8.1-1, four types of this component are defined in the Hecla Bay Formation. Only type 1 is present at section HB1, all four types at section F4, and types 1 and 4 at section HB2.

Type 1 consists almost entirely of non-stratified siltstone (1a) with one occurrence of siltstone with minor unidentified burrows (1f) noted at section HB1 and one occurrence of ripple cross-laminated siltstone (1c) noted at section HB2. This type of overbank fines represents deposition of silt and clay from flood waters. The absence of sandstone is interpreted to indicate a distal overbank position. Type 1 represents 100% of the overbank component at section HB1, only 7.7% at section F4, and 87.4% at section HB2. Unit thicknesses range from 0.6-1.4 m, with one exceptional occurrence of a 9.9 m thick interval at section HB1. Average values are 1.9 m, 1.0 m and 1.1 m at sections HB1, F4 and HB2, respectively, and 1.3 m overall.

Overbank component type 2 occurs three times in the Hecla Bay Formation and only at section F4, representing 24.7% by cumulative thickness, of the overbank fines. Its thickness ranges from 0.8-2.9 m, averaging 2.2 m. This type consists of interbedded sandstone and siltstone without any obvious couplet arrangement. Sandstone beds vary from 20-120 cm and siltstone beds from 20-60 cm. As indicated in Table 2.2.8.1-1, only non-stratified siltstone (1a) occurs with parallel laminated (2b), ripple cross-laminated (2c), non-stratified (2i), and wavy and irregularly laminated (2g) sandstone sub-facies. The siltstone and sandstone of type 2 are interpreted to represent rapidly deposited sediment from overbank flows of varying magnitude. Rapid deposition of sediment is supported by features such as small (cm's) siltstone dikes breaching an overlying sandstone bed and loaded sandstone bases, noted separately in two of the three occurrences of type 2. Rapid deposition is suggested to have prevented the definition of well defined couplets.

Overbank component type 3 occurs only twice in the

Hecla Bay Formation and only at section F4. It represents 44%, by cumulative thickness, of the overbank fines. Its thickness ranges from 4.4 - 7.0 m, averaging 5.7 m. Type 3 also contains interbedded siltstone and sandstone, but in contrast to type 2, an obvious couplet arrangement, with erosional siltstone to sandstone and gradational sandstone to siltstone contacts, is present. The scale of the couplets varies from ca. 4 cm, with a sandstone/siltstone ratio of 1.7:1, to ca. 1.0 m, with sandstone/siltstone ratios varying between 0.6:1 and 11:1. Siltstone is present only as a non-stratified sub-facies (1a) with ripple cross-laminated (2c), and non-stratified (2i) sandstone sub-facies. Type 3 is interpreted to represent deposition from floods that experienced a more gradual decrease in flow intensity. This permitted the sedimentation of turbidite-like sandstone-siltstone couplets.

Overbank component type 4 occurs only twice in the Hecla Bay Formation, once each at sections F4 and HB2. Its thickness at section F4 is 6.1 m representing 23.6% of the overbank fines at that section. At section HB2 it is 1.1 m thick and represents 12.6% of the overbank fines. At both localities this type of overbank deposit consists of large (20-40 cm) angular siltstone clasts in a sandstone matrix. The fabric is variable showing both clast and matrix supported areas. At section F4 several non-stratified sandstone lenses, 20-40 cm thick, are present in the siltstone breccia. The siltstone clasts are non-stratified (1a). This type of overbank deposit is interpreted to represent very high magnitude flood events of low return frequency. At section HB2 the siltstone breccia lies in a scour ca. 26 m wide and 2.5 m deep; this suggests an avulsion and associated channelling of a previous overbank area.

I. Channel Association

This association represents in-channel deposition of sandstone and locally conglomerate with extra-basinal clasts. This association is dominant at all three locations. It represents 94.2%, 87.4% and 92.9%, by cumulative thickness, at sections HB1, F4 and HB2, respectively. In the context of a sandy braided fluvial depositional setting "in-channel" is intended to mean within a belt of active channel switching on the braid plain.

Due to the vagaries of preservation and exposure quality recognition of single channel units is limited and a significant portion of the channel sandstone could only be broken down into thicker multi-channel sequences. An arbitrary thickness criterion of 6.0 m is used to distinguish single (< 6 m) from multiple (> or = 6 m) channel units. The 6 m criterion suggested by the unit thickness data is close to the 5 m channel depth recorded by Walker and Cant (1984) from the South Saskatchewan River.

Conglomerate is a minor component of the channel association in the Hecla Bay Formation. It is limited in occurrence to the basal 23 m and one thin lens near the top of section HB1, and to a single 1.3 m lens near the middle of section HB2. Clasts types are intra-basinal siltstone and sandstone, ostracoderm fragments, and extra-basinal chert. The sandstone/conglomerate ratio for the single channel units defined in the basal 23 m of the formation at section HB1 ranges from 0.4:1 to 12.3:1, averaging 3.2:1.

The sandstone sub-facies composition of the channel association at section HB1, F4 and HB2 is given in Table 2.2.8.1-1. The dominant sub-facies at all three locations are planar tabular cross-stratified (2a) and non-stratified sandstone (2i).

Single channel units identified in the Hecla Bay Formation exhibit a considerable range in thickness (Table 2.2.8.1-2). Thinner channel units represent preservation of falling stage dissection of high flow deposits, while thicker channel units represent major flow conduits within

Table 2.2.8.1.-2 Thickness Characteristics of Single Channel Units in the Hecla Bay Formation at Sections HB1, F4, and HB2, Ordered from East to West Across S.W. Ellesmere Island.

Section	Mean Thickness (m)	Range (m)	Vertical Variation
HB1	3.2	0.7-5.9	bottom: av. = 2.8 m
			middle: av. = 4.2 m
			top: av. = 3.0 m
F4	2.2	0.6-4.5	bottom: av. = 3.2 m
			middle: av. = 2.2 m
			top: av. = 1.9 m
HB2	2.7	0.8-5.5	bottom: av. = 2.7 m
			middle: av. = 2.3 m
			top: av. = 3.3 m

an active channel area on the braid plain. Other than at section F4, the vertical variation in thickness of single channel units shows no trend. The decreasing upward trend which is apparent in section F4 is present at neither a more easterly (HB1) or more westerly (HB2) exposure of the formation. Similarly, average thickness values show no marked trend from east (HB1) to west (HB2) across southwestern Ellesmere Island.

Additional characteristics of the sandy braided system are discussed in 2.2.8.3.

2.2.8.2 <u>Facies Sequence Analysis</u>

The Hecla Bay Formation at section HB1, F4 and HB2 has sufficiently little covered interval and is well enough preserved to warrant a formal contingency table analysis of the facies sequence in search of any dependency between facies and possibly cyclicity. As was the case for the Strathcona Fiord Formation, the statistical software package BMDP-4f (Brown, 1983) is used in this analysis. The use of this particular BMDP program was previously discussed in 2.1.7.2 and should be referred to for computational details. The level of significance is again relaxed to 0.20 in the search for cyclicity in the sections. The observed frequency table for sections HB1, F4 and HB2 are 13 x 13, 8 x 8 and 9 x 9 matrices, with 130, 54 and 73 transitions, respectively. Computation results in probabilities of 0.5463, 0.1307 and 0.5975 for the maximum likelihood-ratio chi-square statistic calculated for the expected frequency matrix as a whole for sections HB1, F4 and HB2, respectively. The results indicate that only the facies sequence in section F4 contains any memory, i.e., the Markov property (0.1307 is < 0.2000). Stepwise cell selection on this matrix produces only one non-random facies transition, non-stratified siltstone (1a) to ripple cross-laminated sandstone (2c), both of which are minor sub-facies in this exposure of the Hecla Bay Formation.

Computations for the facies sequence analyses in the Hecla Bay Formation are shown in Figure 2.2.8.2-1 which contains copies of BMDP-4f printouts.

The most important result of these facies sequence analyses of the Hecla Bay Formation is that it demonstrates that cyclicity is absent at all locations. Miall (1977, 1978) demonstrated that the presence or absence of cyclicity is an important parameter in distinguishing amongst the various types of sandy braided stream deposits. His Figure 1 (1978) presents three types of summary facies sequence for sandy braided rivers:

Figure 2.2.8.2 - 1 Markov Chain analyses of the Hecla Bay Formation at sections HB1, HB2 and F4. Computations performed using BMDP-4F.

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HECLA BAY PORTION OF SECTION H01

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**************************
* TABLE PARAGRAPH    1   *
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***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1F	2A	2B	2C	2I	2K	2L	2M	2N	2O	7A	7B
1A	3	0	16	0	1	5	0	2	0	0	0	0	1
1F	0	0	0	[illegible]	0	0	0	0	0	0	0	0	0
2A	15	0	0	6	1	5	1	[illegible]	2	5	[illegible]	0	0
2B	1	0	6	0	0	0	0	[illegible]	0	[illegible]	[illegible]	1	0
2C	1	0	1	[illegible]	0	0	0	[illegible]	0	[illegible]	[illegible]	0	0
2I	2	0	9	[illegible]	0	0	1	[illegible]	[illegible]	0	[illegible]	5	0
2K	[illegible]	0	1	0	0	0	0	[illegible]	[illegible]	0	0	[illegible]	0
2L	[illegible]	0	2	0	0	0	0	0	3	0	[illegible]	0	0
2M	0	0	4	[illegible]	0	[illegible]	0	0	0	1	[illegible]	0	0
2N	3	0	2	[illegible]	0	1	0	0	[illegible]	0	[illegible]	[illegible]	0
2O	0	1	0	0	0	1	0	0	0	0	[illegible]	0	0
7A	0	0	2	0	0	5	0	0	0	0	0	0	0
7B	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0
TOTAL *	25	1	43	7	2	19	4	4	5	9	2	7	1

BELOW / ABOVE	TOTAL
1A	25
1F	[illegible]
2A	44
2B	4
2C	3
2I	19
2K	[illegible]
2L	[illegible]
2M	6
2N	3
2O	2
7A	7
7B	1
TOTAL	130

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 130
SUMMED OVER 156 CELLS WITHOUT STRUCTURAL ZEROS

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HECLA BAY PORTION OF SECTION #01

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*   MODEL  1   *
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MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	120	117.55	.5463	217.63	.0000	7

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE

	1A	1F	2A	2B	2C	2I	2K	2L	2M	2N	2O	7A	7B
1A	5.5	.2	13.7	1.2	.4	3.8	.7	.7	.9	1.6	.4	1.3	.2
1F	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	14.3	.5	35.9	3.3	.9	9.9	1.3	1.3	2.4	4.2	.9	3.3	.5
2B	1.5	.0	3.8	.3	.1	1.0	.2	.2	.2	.4	.0	.3	.0
2C	.4	.0	.9	.1	.0	.2	.0	.0	.1	.1	.0	.1	.0
2I	3.3	.1	9.7	.8	.2	2.7	.5	.5	.6	.9	.2	.8	.1
2K	.7	.0	1.8	.2	.0	.5	.1	.1	.1	.2	.0	.2	.0
2L	.7	.0	1.8	.2	.0	.5	.1	.1	.1	.2	.0	.2	.0
2M	1.1	.0	2.8	.2	.1	.8	.1	.1	.2	.3	.1	.3	.0
2N	1.5	.0	3.8	.4	.1	1.0	.2	.2	.2	.5	.1	.4	.0
2O	.4	.0	.9	.1	.0	.2	.0	.0	.1	.1	.0	.1	.0
7A	1.3	.0	3.3	.3	.1	.3	.2	.2	.2	.4	.1	.3	.0
7B	.2	.0	.5	.0	.0	.1	.0	.0	.0	.1	.0	.0	.0
TOTAL	26.0	1.0	43.0	7.0	2.0	19.0	4.0	4.0	5.0	9.0	2.0	7.0	1.0

BELOW / ABOVE

	TOTAL
1A	25.0
1F	.0
2A	44.0
2B	4.0
2C	2.0
2I	13.0
2K	4.0
2L	4.0
2M	6.0
2N	8.0
2O	2.0
7A	7.0
7B	1.0
TOTAL	133.0

****** STEPWISE CELL DELETION IS NOT PERFORMED; P-VALUE OF MODEL FIT (.5463) IS GREATER THAN CRITERION PROB (.2000)

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HECLA BAY PORTION OF SECTION HB2

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*************************
* TABLE PARAGRAPH    1  *
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***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW	1A	1C	2A	2B	2I (ABOVE)	2K	2L	2N	7A	TOTAL
1A	0	0	6	0	3	0	0	0	0	9
1C	0	0	1	0	0	0	0	0	0	1
2A	6	0	0	2	4	6	1	8	0	27
2B	1	0	2	0	0	2	0	0	0	5
2I	1	0	0	2	0	3	0	1	0	7
2K	1	0	8	0	0	0	0	1	0	10
2L	0	0	1	0	0	1	0	0	0	2
2N	0	1	5	1	1	1	1	0	1	11
7A	0	0	1	0	0	0	0	0	0	1
TOTAL	9	1	24	5	8	13	2	10	1	73

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 73
SUMMED OVER 72 CELLS WITHOUT STRUCTURAL ZEROS

```
*****************
*   MODEL  1    *
*****************
```

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	55	51.40	.5975	54.17	.5062	7

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW	1A	1C	2A	2B	2I (ABOVE)	2K	2L	2N	7A	TOTAL
1A	1.0	.1	4.7	.5	.5	1.4	.2	1.1	.1	9.0
1C	.1	.0	.5	.1	.1	.1	.0	.1	.0	1.0
2A	5.[illegible]	.5	24.0	2.6	4.3	7.3	1.0	5.7	.5	27.0
2B	.5	.1	2.5	.3	.4	.8	.1	.6	.1	5.0
2I	.7	.1	3.6	.4	.6	1.1	.2	.9	.1	7.0
2K	1.1	.1	5.5	.6	1.3	1.7	.2	1.3	.1	10.0
2L	.2	.0	1.0	.1	.2	.3	.0	.2	.0	2.0
2N	1.[illegible]	.1	5.8	.6	1.0	1.8	.2	1.4	.1	11.0
7A	.1	.0	.5	.1	.1	.1	.0	.1	.0	1.0
TOTAL	9.0	1.0	24.0	5.0	8.0	13.0	2.0	10.0	1.0	73.0

****** STEPWISE CELL DELETION IS NOT PERFORMED. P-VALUE OF MODEL FIT (.5975) IS GREATER THAN CRITERION PROB (.2000)

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HECLA BAY PORTION OF SECTION F4

TABLE PARAGRAPH 1

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	2A	2B	2C	2G	2I	2K	2H	TOTAL
1A	0 *	1	1	3	0	7	0	0	12
2A	4	3 *	4	0	2	3	1	2	16
2B	1	5	0 *	0	0	0	0	0	6
2C	1	1	0	0 *	0	0	0	0	2
2G	1	2	0	0	0 *	0	0	0	3
2I	5	5	0	0	0	0 *	0	0	11
2K	0	1	0	0	0	0	0 *	0	1
2H	0	3	0	0	0	0	0	0 *	3
TOTAL	13	18	5	3	2	10	1	2	54

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 54
SUMMED OVER 56 CELLS WITHOUT STRUCTURAL ZEROS

MODEL 1

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	41	51.27	.1307	47.74	.2179	6

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	2A	2B	2C	2G	2I	2K	2H	TOTAL
1A	3.5 *	6.3	1.2	.7	.5	2.7	.2	.5	12.0
2A	6.2	10.3 *	2.1	1.2	.3	4.6	.4	.8	16.0
2B	1.5	2.6	.5 *	.3	.2	1.1	.1	.2	6.0
2C	.5	.8	.2	.1 *	.1	.4	.0	.1	2.0
2G	.7	1.2	.2	.1	.1 *	.5	.0	.1	3.0
2I	3.1	5.3	1.0	.6	.4	2.3 *	.2	.4	11.0
2K	.2	.4	.1	.0	.0	.2	.0 *	.0	1.0
2H	.7	1.2	.2	.1	.1	.5	.0	.1 *	3.0
TOTAL	13.0	18.0	5.0	3.0	2.0	10.0	1.0	2.0	54.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HECLA BAY PORTION OF SECTION F4

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	51.27	41	.13066	2.626	1A	2G
1	41.57	40	.40228			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	2A	2B	2C	2G	2I	2K	2N
1A	.0 *	5.1	.9	.0 *	.4	2.1	.2	.4
2A	6.5	.0 *	2.3	.0 *	.3	5.1	.4	.9
2B	1.5	2.3	.0 *	.0 *	.2	1.2	.1	.2
2C	.5	.3	.2	.0 *	.1	.4	.0	.1
2G	.7	1.4	.2	.0 *	.0 *	.6	.0	.1
2I	3.0	5.3	2.2	.0 *	.4	.0 *	.2	.4
2K	.2	.4	.1	.0 *	.0	.2	.0 *	.0
2N	.7	1.4	.2	.0 *	.1	.6	.0	.0 *

1) the South Saskatchewan type characterized by the dominance of large scale, trough cross-bedding and by the presence of cycles capped by vertical accretion fines

2) the Platte type characterized by the dominance of planar tabular cross-bedding, only rare vertical accretion fines, and the absence of cyclicity

3) the Bijou Creek type characterized by the dominance of horizontal laminated sandstone deposited under upper flow regime conditions and by superimposed flood cycles, representing flash floods in an ephemeral stream.

The preceding facies description and interpretation, and facies sequence analyses of the Hecla Bay Formation permit the following features to be identified as characteristic of this particular sandy braided fluvial system:

1. the dominance of large scale, planar tabular cross-bedded sandstone (sub-facies 2a)
2. the frequent occurrence of fines (siltstone and silty shale) at the top of single channel units
3. the absence of cyclicity

Considered cumulatively, these characteristics suggest that the sandy braided fluvial system represented by the Hecla Bay Formation was a type of sandy braided stream intermediate between the South Saskatchewan and Platte types.

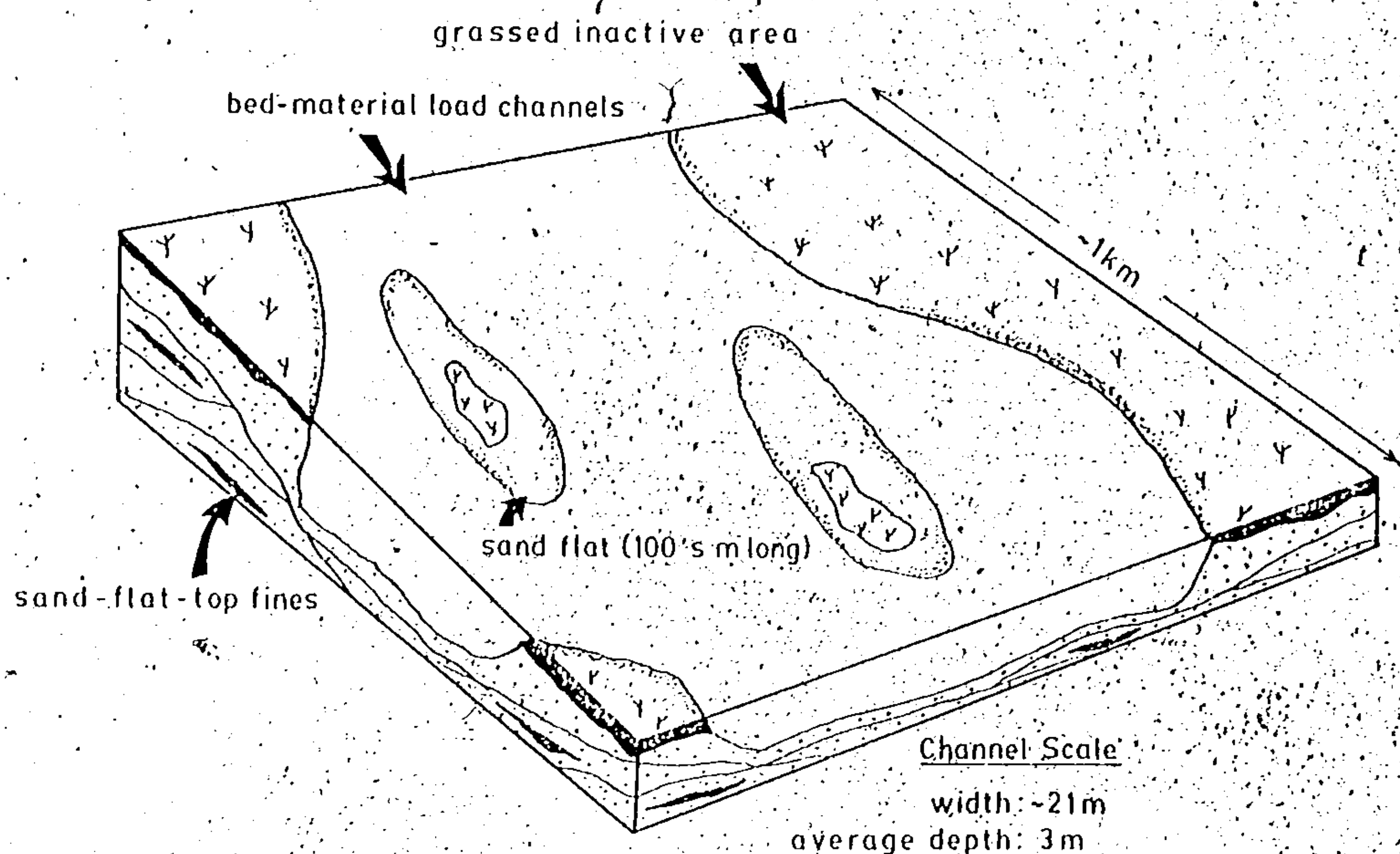
2.2.8.3 Discussion

The purpose of this section is to discuss in more detail the sandy braided fluvial environmental setting envisaged for the Hecla Bay Formation. A block diagram of this fluvial environment is presented as Figure 2.2.8.3-1. This figure depicts the general setting as that of a sandy braid plain with grassed, topographically higher, inactive areas on which significant thicknesses of fines might accumulate and be preserved. A representative single channel unit and the four types of overbank component of the fines association in the Hecla Bay Formation are presented in Figure 2.2.8.3-2. It is suggested that the Hecla Bay braid plain occupied a distal position on a coastal plain. Supportive evidence for a distal coastal plain setting is as follows:

1. The fact that fines are being deposited in significant thicknesses in a sandy braided system suggests a distal as opposed to a more proximal coastal plain setting.

2. Palynological evidence from section HB1, F4 and HB2 supports a distal coastal plain depositional setting.

Figure 2.2.8.3 - 1 Block diagram representation of the depositional setting of the Hecla Bay Formation.


grassed inactive area
bed-material load channels
~1km
sand flat (100's m long)
sand-flat-top fines
Channel Scale
width: ~21m
average depth: 3m

Siltstone samples taken at 394 m above the base of the formation at section HB1 (GSC Loc. C-91998), at 196.5 m above base of the formation at section F4 (GSC Loc. C-91956), and at 66.3 m above the base of the formation at section HB2 (GSC Loc. C-85288) all contained the aneurosporoid-geminosporoid spore assemblage (McGregor, 1984a, pg. 18). In commenting on the environmental significance of this assemblage McGregor notes that some authors "have proposed that the plants that produced them grew most prolifically in marginal marine areas".

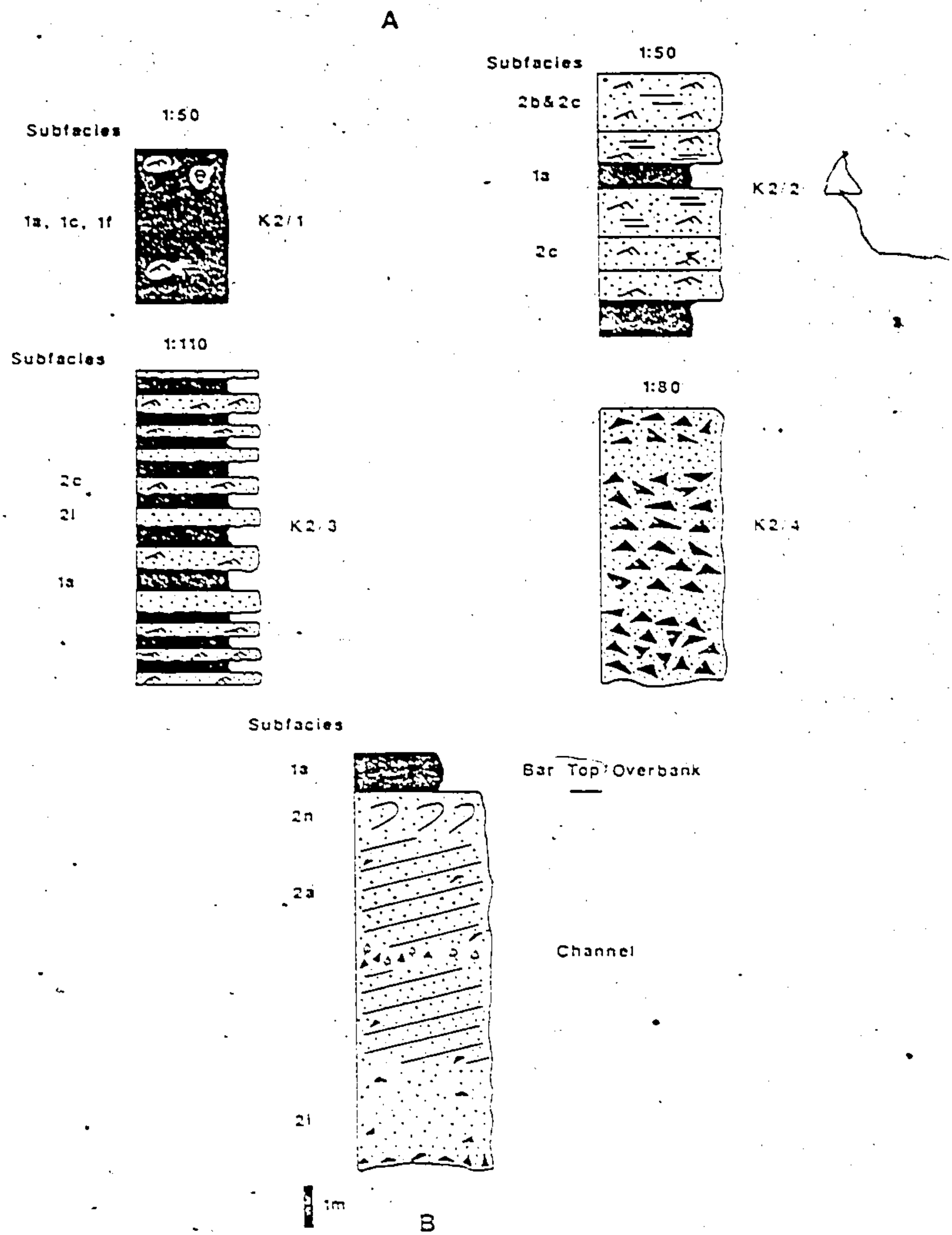
The area(s) of active channel switching on the braid plain must have been slightly incised, perhaps bracketed by grassed inactive areas richer in overbank fines that would create more resistant bank sediment. This is thought to be the case for two reasons:

1. The depth of the braid channels is estimated to have been at least 3.0 m. This estimate of channel depth is derived from the amplitude of an epsilon surface (2.7 m) and depth of a channel scour (2.5 m) located at 77.6 m and 126.5 m above the base of section HB2 and from a channel scour depth (3.0 m) recorded at 89.3 m above the base of the formation at section HB1. This is considered to be a conservative estimate of channel depth since what were

interpreted to be single channel units in the course of measuring a section commonly exceeded 3.0 m (see channel association in 2.2.8.1). Channels of this depth would not be expected to develop unless the bank sediment was somewhat cohesive. Channel adjustment to increased discharge where the bank sediment is cohesionless sand is first an increase in width, not depth, and as such channel depths would be expected to be minimal. Figure 2.2.8.3-2 contains a representative vertical profile of a single channel unit in the Hecla Bay Formation. Its thickness exceeds the arbitrary 6 m used to distinguish between single and multiple channel units (see channel association in 2.2.8.1) because it was constructed using the average thickness of the sandstone sub-facies most commonly found in such units. Sub-facies thickness in the field is frequently less than the average value.

2. The maximum recorded thickness of overbank fines is 9.9 m at 50.9 m above the base of the formation at section HB1. This single occurrence greatly exceeds all other occurrences of non-stratified siltstone (most occurrences are < 1.0 m). It is considered to be an unusual preservation of overbank sediment in an environment where they usually get largely scoured out by avulsion and migration of active channel areas leaving only erosional

Figure 2.2.S.3 - 2 Four types of overbank component of the fines genetic association (A) and a characteristic channel unit (B) in the Hecla Bay Formation. Note the differences in scale in A.


A
Subfacies
1:50
1a, 1c, 1f
K2/1
Subfacies
1:50
2b&2c
1a
2c
K2/2
Subfacies
1:110
2c
2l
1a
K2/3
1:80
K2/4
Subfacies
1a
2n
2a
2l
Bar Top/Overbank
Channel
1m
B

remnants to cap channel sandstone sequences. If it is at all representative of bank sediment in inactive regions of the braid plain, then channel incision would be anticipated.

Accumulation of overbank silt and clay on the order of several meters in thickness requires a prolonged period of time. Evidence exists that indicates that pedogenesis of overbank fines did occur, thus implying a large undisturbed (no floods) time interval. This evidence consists of iridescent purple siltstone nodules, up to 15 cm in apparent maximum dimension, found as part of a lag in channel sandstone units. These occur once at 10.8 m above the base of section HB2 and three times at 12 m, 39.3 m and 70.1 m above the base of section F4.

Evidence is present in Section HB1, F4 and HB2 which suggests that the discharge regime of the Hecla Bay braid channels was quite variable. Low flow to standing water deposition is indicated by horizons of concentrated fine organic debris (plants) usually several centimeters to several tens of centimeters in thickness. At section HB1 these horizons are occasionally found lying in shallow scours suggesting abandonment of smaller falling stage channels. In addition to these organic horizons, section F4 contains occasional thin (5-30 cm), purple weathering, grey, micaceous sandstone intervals which are very enriched in comminuted organic debris. A very rapid flow decrease is suggested to explain the entrapment of the organic material amongst the sand size detritus. In addition to these indicators of low flow to standing water deposition, both in-channel and overbank evidence exists of high magnitude flood events. Highly contorted channel sandstone units are present in section F4 and HBI, and siltstone breccias with angular siltstone clasts to 25 cm are found at section F4 and HB2. The breccia at section F4 occurs at 196.5 m above the base and is 6.1 m thick whereas the unit in section HB2 is only 1.1 m thick. The thickness of these breccias suggests that thick overbank fines deposits were eroded by a major flood, perhaps associated with an avulsive event.

It is suggested that the Hecla Bay Formation contains indicators of contemporary tectonism. The evidence for this is as follows:

1. Accumulation and preservation of overbank fines in a sandy braided system is somewhat unusual. Miall (1978, pg. 603) suggests a mechanism of lateral channel restriction on the floodplain, coupled with rapid subsidence as a possible explanation. As discussed previously, the mechanism of lateral channel restriction for the Hecla Bay Formation is suggested to be grassed inactive areas with more cohesive

bank sediment due to fines accumulation. It is suggested that rapid subsidence, in sympathy with tectonic uplift of the source region, was a significant factor in the preservation of overbank siltstone in the Hecla Bay Formation, (siltstone averages 0.8 m in thickness and in one instance reaches 9.9 m). Melvin (1985) also uses Miall's suggestion of rapid subsidence to explain the preservation of siltstone units varying between 0.1-1.0 m in thickness in the dominantly sandy braided Walls Formation, an Old Red Sandstone unit of the western Shetland Isles.

2. The basal 23 m of the Hecla Bay Formation at section HBI contains pebble conglomerate units, varying from 0.4-2.2 m in thickness, representing basal channel fill. The Hecla Bay-Strathcona Fiord contact is poorly exposed at one other location, section HB3 just east of Bird Fiord, where conglomerate is absent. The clasts in the conglomerate consist of both intrabasinal detritus (siltstone, sandstone and ostracoderm fragments) and extrabasinal detritus (chert). Only one other occurrence of a conglomerate with extrabasinal chert pebbles was noted. It exists as an isolated 1.9 m thick lens at 394.8 m above the base of the formation in section HB1. It is suggested that the basal conglomerates in the Hecla Bay Formation at section HB1

indicate that the onset of Hecla Bay deposition was initiated by tectonism in the source region. The tectonism caused an increase in regional paleoslope which in turn resulted in the change in fluvial style from a meandering Strathcona Fiord Formation to a sandy braided Hecla Bay Formation. The restriction of the basal conglomerate to the easternmost section in the Hecla Bay Formation suggests the source region lay eastward of this location. This inference is supported by the vector mean of 191 planar tabular cross-bed measurements (323^0) obtained from this section which indicate a southeast to northwest paleoslope at this location in the Franklinian Basin during Hecla Bay time. The provenance of the Okse Bay Group detritus is discussed further in a subsequent portion of this report.

3. Sandstone sub-facies 2n contains overturned planar tabular cross-beds. This sub-facies ranges from 0.3-2 m in thickness, averaging 0.8 m. It represents 2.5%, by cumulative thickness, of the total meterage accumulated in the Hecla Bay Formation. It is present at section HB1, F4 and HB2. Usually, the sub-facies occurs in the central and upper portions of channel sequences, but can rarely be found near the base. Allen and Banks (1972) presented an in-depth quantitative evaluation of the origin of this type of

deformed cross-bedding (see their Figure 1a and b) and concluded that the bottom shear stress normally encountered at the bed of rivers could not be expected to cause the overturning of significant thicknesses of planar tabular cross-bedded sand unless that sand is weakened through liquefaction resulting from earthquake shock. Their interpretation of this feature is accepted in this report and the presence of overturned cross-beds (sub-facies 2n) in all sections of the Hecla Bay Formation is taken to indicate that tectonic activity manifested by earthquakes occurred during the deposition of the Hecla Bay Formation (early Middle Eifelian to Late Givetian or Early Frasnian).

In summary, the three points discussed above indicate that this area of the Franklinian Basin during Hecla Bay time was seismically active and rapidly subsiding. It is to be noted that evidence for rapid subsidence is also present in the Strathcona Fiord Formation at section S1 (discussion portion of 2.1.7.1).

2.3 Fram Formation

2.3.1 Introduction

The Fram Formation is stratigraphically the third lowest formation in the Okse Bay Group. The formation is named after the wooden ship of the second Norwegian Polar Expedition of 1898-1902 under the command of Captain Otto Sverdrup. Embry and Klovan (1976) show the formation extending from Grinnell Peninsula on Devon Island in the west to the northern end of Vendom Fiord on Ellesmere Island in the east. The Fram Formation is stratigraphically equivalent to the lower half of the Beverly Inlet Formation in the western Arctic Archipelago (Embry and Klovan,1976, Figure 15).

Where exposed, its contacts indicate that it is overlain and underlain conformably and transitionally by the Hell Gate and Hecla Bay formations, respectively. The lower contact with the Hecla Bay Formation is exposed at section HB2 located on the central west coast of North Kent Island, at section F4 at Goose Fiord and at section F5 located ca. 23 km southwest of the head of Sor Fiord. The upper contact with the Hell Gate Formation is exposed at section F4 at Goose Fiord, at section HG2 in a ravine located ca. 11 km southeast of Bird Fiord, and at section F2 on the southeastern arm of Bird Fiord.

The Fram Formation is the most thoroughly investigated formation of the Okse Bay Group. This is largely due to its intermediate stratigraphic position in the group which results in it being well exposed in the

Schei Syncline. The cumulative meterage measured in the Formation (2354 m) exceeds that recorded from any of the other four formations. This meterage was accumulated from six exposures of the formation. From east to west through the study area the sections are located as follows: section F1 ca. 7.5 km southwest of Sor Fiord, section F5 ca. 23 km southwest of Sor Fiord, section F2 on the southern arm of Bird Fiord, section HG2 ca. 11 km southeast of Bird Fiord, section F4 at Goose Fiord and section F3, approximately halfway up the Ellesmere Island side of Hell Gate. These section locations are indicated in Figure 2.1.1-1. Each locality is discussed separately in subsequent portions of this report.

2.3.2 Summary of Lithological Descriptions and Age Determinations from Previous Studies

2.3.2.1 Lithological Descriptions

The Fram Formation has been looked at, mainly from a reconnaissance perspective, by four previous investigators: Schei (1903, 1904), McLaren (1963a), McGill (1974), and most recently Embry and Klovan (1976).

According to McLaren (1963a, pg. 378), it is unlikely that Schei examined what is now known as the Okse Bay Group north of Goose Fiord. At Goose Fiord, the Hecla Bay and the

Fram Formations are well exposed with siltstone/shale constituting a significant portion of only the latter formation. The siltstone/shale that was extensively sampled by crewmen from Schei's ship must have been from the Fram Formation which would be the upper part of Schei's (1903, 1904) series E...

McLaren (1963a) examined what was then the Okse Bay Formation both at Goose Fiord and in the Okse Bay - Bird Fiord region and defined four informal members which have been previously mentioned (1.4). From their sequence and descriptions it is apparent that McLaren's lower sandstone and shale member is the Fram Formation. McLaren (1963a, pg. 330) only looked at the lowest beds of the member at Goose Fiord due to a time shortage, and the upper 1400 ft. of the member on the east side of the south arm of Bird Fiord (same location as section F2 of this report). He describes only the Bird Fiord exposures. They are described as consisting of "a rhythmic alternation of argillaceous, fine to medium grained, quartzose sandstones, medium and thin bedded, and laminated in 10-15 ft units, grading downwards into greenish grey, sandy mudstones, shales, and siltstones with abundant carbonaceous plant remains in 30-40 ft units."

McGill (1974) examined what is now the Fram Formation in the Vendom Fiord area of south central Ellesmere Island.

It was his upper member and he described it briefly as consisting of red and green shales which were interpreted as a continental fluvial deposit.

Embry and Klovan (1976) elevated the Okse Bay Formation to group status and renamed McLaren's lower sandstone and shale member as the Fram Formation. They established a type section 6.5 km east of the eastward directed arm of Bird Fiord. At the type section, the formation consisted of "a seemingly never-ending alternation of resistant sandstone units and recessive shale/siltstone units" arranged in shale-siltstone dominated fining-upward cycles. Sandstones are described as weathering brownish-yellow to red, with shales and siltstones weathering red, green and grey, and frequently containing much carbonaceous debris.

2.3.2.2 Age Determinations

An initial age assignment of Upper Devonian was established for the formation as a result of work by Nathorst (1904) and Kiaer (1915) on the plant and fish collections, respectively, extracted from the siltstone and shale by Schei's crewmen while wintering at Goose Fiord.

The age assignment determined from Nathorst and Kiaer's work was confirmed by palynological spot samples collected by Embry and Klovan (1976) near the base, middle and top of the formation at the type section, as well as at a locality on Grinnell Peninsula, Devon Island. These samples suggested an Early to Middle Frasnian age (Embry and Klovan, 1976, pg. 548).

2.3.3 Summary Facies Descriptions

The purpose of this section is to summarize the lithological composition of the Fram Formation by combining the facies analyses performed on the various individual sections. The facies and sub-facies of sections F2, F3, F4, F5 and HG2 are combined to this end. Section F1 located ca. 7.5 km southwest of Sor Fiord, was also measured but contained too much covered interval (80%) to warrant a facies breakdown. Only paleocurrent, petrographic and palynologic data from this section in the formation is used in this report. The five usable sections in the formation constitute a total of 1613 m; 25.8% of this meterage is covered interval.

The Fram Formation consists of approximately equal amounts of siltstone (48.3%) and sandstone (51.6%), by cumulative thickness. Nodular weathering horizons occur only twice and are thus a very minor constituent (0.2%). Summary descriptions of the constituent lithologies are given below. The descriptive attributes of the three siltstone and eight sandstone sub-facies, as well as the nodular weathering units (facies 6), are presented in Table 2.3.3-1. Figure 2.3.3-1 presents the relative proportion of the formation, by cumulative thickness, for each of the facies/sub-facies.

It is stressed here for the Fram Formation, as it was for the Strathcona Fiord and Hecla Bay formations (2.1.3 and 2.2.3), that the average thicknesses and ranges stated for the various sub-facies of Table 2.3.3-1, and for similar tables corresponding to individual section locations, are accurate only to the extent that the proper relative order amongst the sub-facies is established. In many instances exposure quality, time constraints and/or weather constraints prohibited actual measurement of sub-facies thickness. Stratigraphic unit thickness was always recorded however, and in such circumstances as mentioned above, sub-facies thickness was estimated.

Facies 1 - Siltstone

Siltstone is marginally second to sandstone with respect to volumetric importance in the formation (48.3% vs 51.6%). Siltstone weathers red, green and grey with red occurring most frequently. On a fresh surface grey and

Figure 2.3.3 - 1 Sub-facies in the Fram Formation (all sections considered cumulatively). Percentage of the formation by cumulative thickness is shown on the ordinate scale.

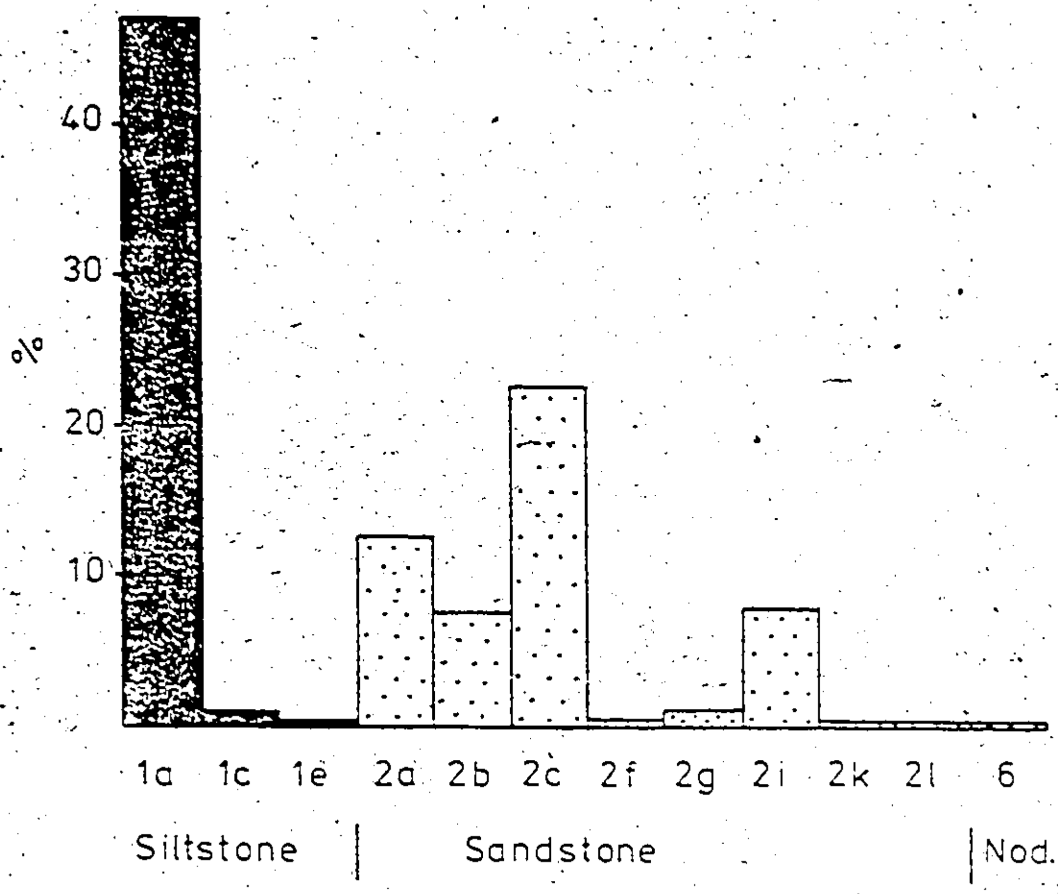

%
40
30
20
10
1a
1c
1e
2a
2b
2c
2f
2g
2i
2k
2l
6
Siltstone
Sandstone
Nod.

TABLE 2.3.3.-1 Descriptive Attributes of Sub-Facies Defined in The Fram Formation (All Sections Considered Cumulatively)

Facies 1 - Siltstone (48.3%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratidied siltstone	1a	97.3	2.1; 0.01-26.3	red, grey, green, white,purple, brown/ grey,green,red	comminuted plant debris
ripple cross-laminated siltstone	1c	2.0	2.2; 0.1-5.5	grey, green/grey,green	comminuted plant debris rare unidentified trace fossils
rooted siltstone	1e	0.5	1.4; 0.3-1.7	red/red	root casts

Facies 2 - Sandstone (51.6%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	24.5	1.4; 0.08-8.8	green, grey, red,white brown/green, grey, white	ostracoderm fragments, partial plant casts and compressions, root casts, unidentified trace fossils (burrows), comminuted plant debris
parallel laminated sandstone	2b	14.3	1.1; 0.02-8.8	green, grey, red,white, brown/green, grey, white	ostracoderm fragments, root casts, partial plant casts and compressions, unidentified trace fossils (burrows)

ripple cross - laminated Sandstone	2c	43.5	1.4; 0.01-51.1	green, grey, red, white, brown/grey, green, white	comminuted plant debris, root casts, unidentified trace fossils (burrows), partial plant casts and compressions
sandstone with climbing ripple drift cross-lamination	2f	0.1	0.1	dark green/dark green	comminuted plond debris
wavy and irregularly laminated sandstone	2g	1.5	2.3; 0.2-4.4	grey, green, red, white/grey, green, white	nf
non-stratified sandstone	2i	15.8	1.0; 0.01-4.0	green, grey, red, white, brown/green, grey, white	partial plant casts and compressions, unidentified feeding trace, root casts, ostracoderm, fragments
bedded sandstone without bed forms	2k	0.2	1.5	white/white	nf
trough cross-bedded sandstone	2l	0.1	0.4;0.3-0.5	white, brown/grey, white	partial plant casts

Facies 6 - Nodular Weathering Units (0.2%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
			0.6; 0.5-0.7	variegated grey, white and red	nf

Note: See comments 3,4, and 5 following Table 2.1.3-1.

green colors are most common. Almost all siltstone in the formation is non-stratified (1a). Ripple cross-laminated (1c) and rooted siltstone (1e) are both relatively very minor sub-facies. Siltstone units vary considerably with respect to thickness, ranging from only a few centimeters to several tens of meters. A maximum average unit thickness of ca. 2 m occurs in both the non-stratified and ripple cross-laminated siltstones (1c).

The most common macroscopic fossil evidence in the siltstone is comminuted plant debris found concentrated along laminae. Occasional roots casts and unidentified trace fossils (crawling traces) are also present.

Facies 2 - Sandstone

Sandstone is the most abundant lithology in the Fram Formation. It weathers dominantly grey and red, and on a fresh surface is mainly grey. Of the eight sandstone sub-facies defined for the Fram, the most important with respect to cumulative thickness is ripple cross-laminated sandstone (2c) which represents 43.5% of the sandstone. Of secondary and tertiary importance are planar tabular cross-bedded (2a) and non-stratified sandstone (2i) representing 24.5% and 15.8%, respectively, of the sandstone. Average unit thickness for sandstone in the Fram reached a maximum of 2.3 m in the wavy to irregularly laminated sub-facies (2g) and a minimum of 0.1 m for sandstone showing climbing ripple drift cross-lamination (2f). Macroscopic fossil evidence noted in Fram sandstones consisted of ostracoderm plate fragments, partial plant casts and compressions, root casts, occasional unidentified trace fossils (burrows and horizontal feeding traces), and comminuted plant debris commonly concentrated on depositional surfaces.

Facies 6 - Nodular Weathering Units

This facies was very rare throughout the Fram Formation only occurring three times at section F4. The facies had a nodular weathering appearance caused by occasionally slightly calcareous siltstone/shale nodules frequently reaching 5-10 cm in apparent maximum dimension. The units weathered a variegated red, grey and white, were unfossiliferous, and averaged 0.6 m in unit thickness.

2.3.4 Section F5

2.3.4.1 Location, Thickness and Contact Relations

This section is the most easterly exposure of the formation examined in detail. Its base is continuous with the top of section HB1 (2.2.4). The section is located ca. 21 km southwest of the head of Sor Fiord, along a river which ultimately debouches into the fiord. The location of the base of the section is 559250E, 8559375N, UTM zone 16X, NTS 49C, Baumann Fiord sheet. This location is shown on Figure 2.1.1-1. The line of section is shown in the aerial photograph presented as Figure 2.1.6.1-1. This section of the Fram Formation represents the basal 478.9 m of the formation south of the axis of the Schei Syncline in the easternmost portion of the study area. The formation thickness in this region was not determined, but is estimated to be ca. 1300 m based on formation thickness measured by Embry and Klovan (1976, Figure 29) in adjacent regions. Covered interval at section F5 is ca. 32.7%.

The basal contact with the Hecla Bay Formation is not exposed but is presumed to be conformable due to similar attitudes above and below the contact. The upper contact with the Hell Gate Formation was not examined as it lay several kilometers north of the top of section F5.

The drafted section of this exposure of the Fram Formation is presented as Figure 2.3.4.1-1 (in pocket).

2.3.4.2 Age

Throughout this section most siltstone units are represented by recessive, highly weathered or covered intervals and as such are not conducive to the acquisition of productive palynology samples. As a result, only two productive samples were obtained (GSC Loc. C-85286 and C-85287) from 58.5 m and 86.3 m above the base of the section, respectively. Both samples give a Late Givetian to Early Frasnian age, with Late Givetian the most probable (McGregor, 1984b, pg. 2-3). This age may be representative of the base of the formation in this area, but considering the estimated formation thickness it is quite probable that the top of the formation is somewhat younger, especially when the Early to Middle Frasnian age obtained by Embry and Klovan (1976, pg. 548) from samples taken from the base, middle and top of the formation are considered.

2.3.4.3 <u>Paleocurrent Analysis</u>

Much of this section consists of moderately to highly weathered resistant sandstone ridges. As such, not many measurable directional structures are available. The paleocurrent data acquired from this section consists of 35 planar tabular cross-bed measurements (24 in-channel and 11 overbank), one trough cross-bed measurement, and one parting lineation measurement. The directional data is presented in Figure 4.1-1. As indicated in this figure, a southwesterly vector mean (221^0) is associated with the in-channel planar tabular cross-beds. Although the data set is small for the thickness of section involved, the measurements are reasonably well distributed and are considered to be a rough approximation of the overall flow direction. Obviously, many more measurements are required to establish this with certainty. No vertical trend exists in the paleocurrent data.

2.3.4.4 Facies Content

This section consists of two facies, sandstone and siltstone, representing 67.4% and 32.6%, respectively, by cumulative thickness. The sandstone can be broken down into five sub-facies while the siltstone is divisible into only two.

No new sub-facies are defined. Descriptive attributes of the sub-facies are presented in Table 2.3.4.4-1. The percentage of the formation, by cumulative thickness, represented by each sub-facies is given in Figure 2.3.4.4-1. Selected features of the formation at this location are presented in Plate 2.3.4.4-1.

Facies 1 - Siltstone

Siltstone at this exposure weathers dominantly red, with subordinate green and grey hues. On a fresh surface

Figure 2.3.4.4 - 1 Sub-facies in the Fram Formation at section F5. Percent of the formation by cumulative thickness is shown on the ordinate scale.

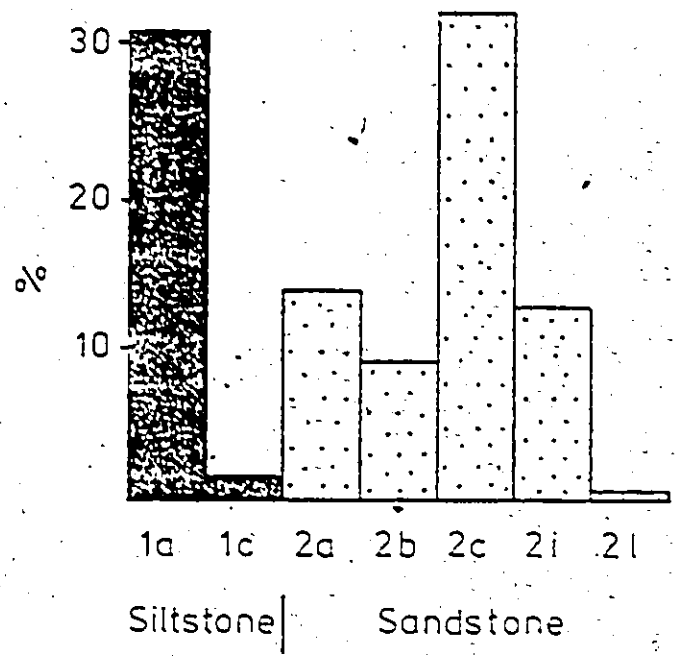

30
20
%
10
1a
1c
2a
2b
2c
2i
2l
Siltstone
Sandstone

Table 2.3.4.4.-1 Salient Attributes of Sub-Facies Defined in the Fram Formation at Section F5.

Facies 1 - Siltstone (32.6%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	94.8	2.4; 0.02-26.3	red, grey, green/ grey, green, red	occasional minor root casts
ripple cross-laminated siltstone	1c	5.2	5.5	grey/green	comminuted plant debris

Comment: one occurrence only.

Facies 2 - Sandstone (67.4%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	20.6	2.1; 0.3-8.8	green, grey, red, brown/grey	partial plant casts and compressions comminuted plant debris
parallel laminated sandstone	2b	13.5	2.2; 0.3-8.8	grey, green, red, brown/grey	nf
ripple cross-laminated sandstone	2c	47.3	3.0; 0.06-51.1	grey, green, red, brown/grey, green	root casts, comminuted plant debris

non-stratified sandstone	2i	18.6	1.9; 0.02-4.0	grey, green, red, brown/grey	ostracoderm fragments comminuted plant debris
trough cross-bedded sandstone	2ℓ	0.1	0.3	brown/grey	nf
Comment: one occurrence only					

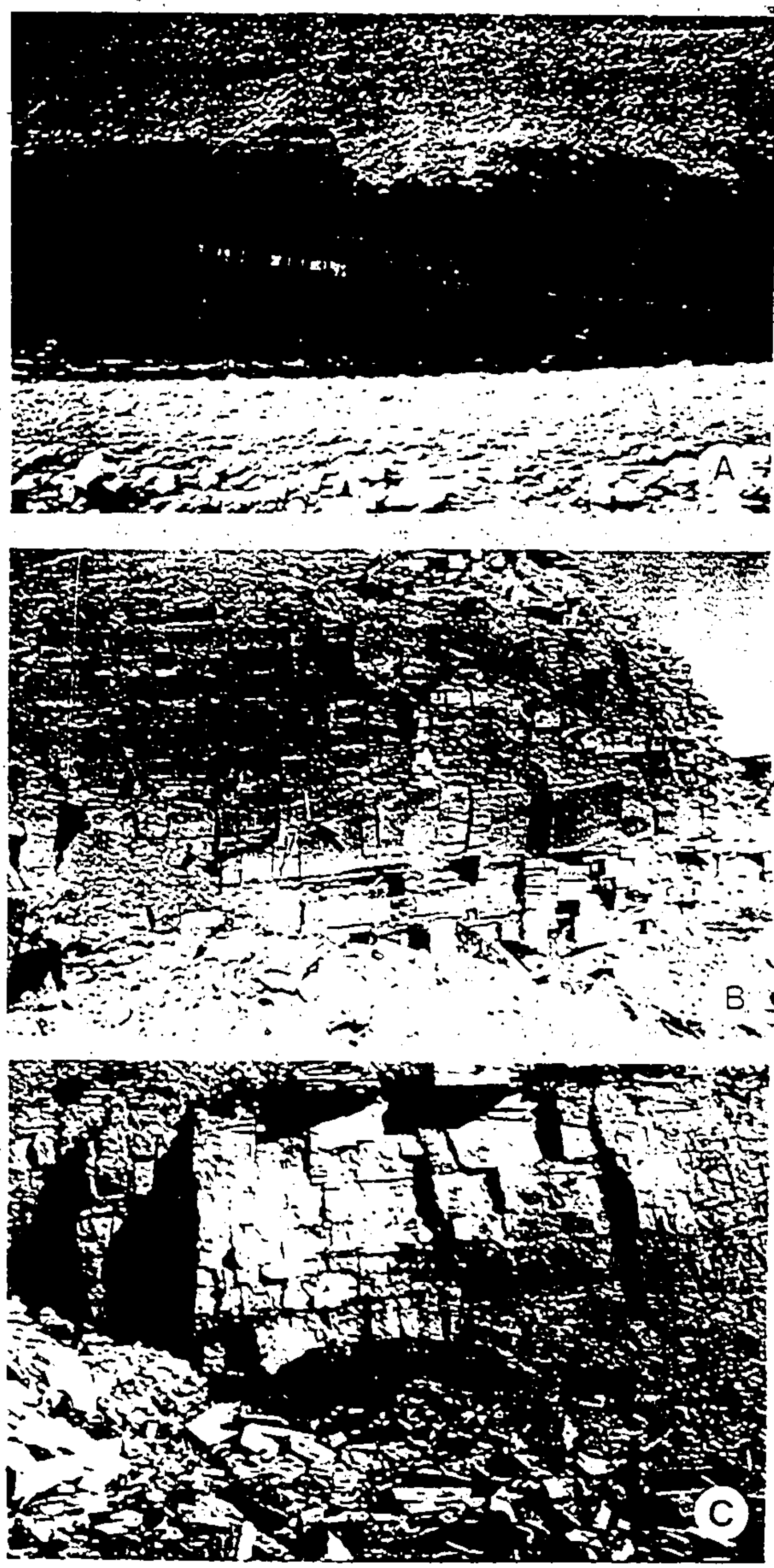
Note: see comments 3,4, and 5 following Table 2.1.3-1.

Plate 2.3.4.4 - 1 The Fram Formation at section F5 located approximately 21 km SSW of the head of Sor Fiord.

A. Floodplain sandstone and siltstone/shale near the base of the Fram Formation. The lighter weathering, thicker sandstone horizon extending across the photograph represents a crevasse splay deposit. It is ca. 1.0 m in thickness.

B. Interstratified floodplain sandstone and siltstone/shale near the middle of the Fram Formation. The thicker, lowest sandstone could represent a trunk-channel sandstone unit. The hammer (arrow) is 30 cm in length.

C. The erosional contact between an overlying trunk-channel sandstone unit and floodplain siltstone/shale. The sandstone is ca. 4.0 m in thickness.


A
B
C

they are mainly grey with subordinate green and red hues. Most siltstone is non-stratified (1a - 94.8%) with only one occurrence of ripple cross-laminated siltstone (1c). Average unit thickness is ca. 2 m but varies from several centimeters to tens of meters. Fossil evidence is restricted to occasional root casts and frequent comminuted plant debris.

Facies 2 - Sandstone

This section consists of approximately twice as much sandstone (67.4%) as siltstone. Sandstones are mainly red with less common grey, green and brown colors; on a fresh surface they are mainly grey and occasionally a greenish color. Ripple cross-laminated sandstone (2c - 47.5%) is the dominant sub-facies with planar tabular cross-bedded (2a - 20.6%) and non-stratified sandstone (2i - 18.6%) of secondary and tertiary importance. Maximum and minimum average unit thickness is 3.0 m and 1.9 m for the ripple cross-laminated and non-stratified sub-facies, respectively. Fossil evidence commonly consists of partial plant casts and/or compressions and comminuted plant debris found along bedding planes. Occasionally, ostracoderm fragments or root casts are also present. Parallel laminated (2b) and trough cross-bedded sandstone (2l) contain no fossil evidence.

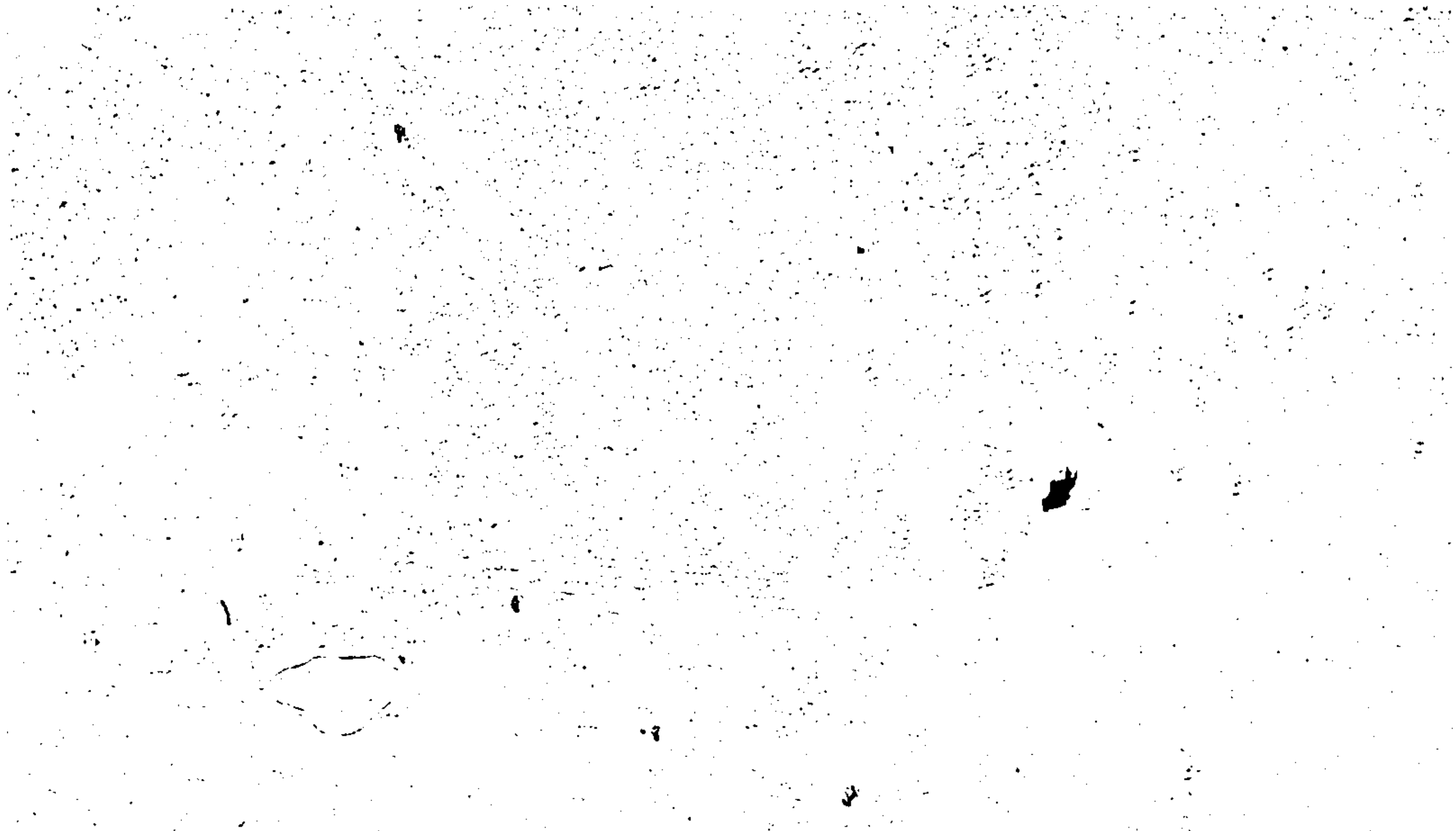
2.3.5 Section HG2 (Fram Formation portion)

2.3.5.1 Location, Thickness and Contact Relations

Section HG2 was measured along a river occupied ravine located ca. 12.5 km southeast of the south directed arm of Bird Fiord. The base of the section is located at 515500E, 8550875N, UTM zone 16X, NTS 49C, Baumann Fiord sheet. This location is shown in Figure 2.1.1-1.

The upper 154.9 m of the Fram Formation constitutes the lower part of this section. Only 24.6 m (15.9%) is covered interval. Embry and Klovan (1976, Figure 29) report the formation to be 1125 m thick at their type section located ca. 6.5 km east of Bird Fiord. Considering the proximity of this location to section HG2, the latter represents approximately the upper 14% of the formation in this area. Figure 2.3.5.1-1 is an aerial photograph of the area of section HG2 with the line of section indicated.

The Fram Formation in this area, as elsewhere, is underlain by the Hecla Bay Formation and overlain by the Hell Gate Formation. The area of the lower contact is removed from the section location and it is not known if the contact is exposed. The upper contact is well exposed on



<u>Figure</u> 2.3.5.1 - 1 Aerial photograph of section HG2 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16756-47&49.


Sydkap
Icecap

both sides of the ravine and is both conformable and transitional.

The drafted section of this exposure of the Fram Formation is presented as Figure 2.3.5.1-2 (in pocket).

2.3.5.2 Age

Six productive palynology samples were collected from this exposure of the Fram Formation (GSC Loc. C-91972 to C-91977, inclusive). They are reasonably distributed between 35.5 - 111.3 m above the base of the section. McGregor (1984a, pg. 11-12) assigns an age of "Frasnian but not earliest or latest Frasnian" to the three lowest samples taken within 46 m of the base of the section and a more definite age of mid-Frasnian for the remaining three samples from higher up in the formation. The consistency of the age determinations for these six samples indicates that the uppermost Fram Formation in this region is mid-Frasnian in age. Nothing can be said concerning the age of the base of the formation in this area. This age is compatible with the Early to Middle Frasnian age obtained by Embry and Klovan (1976, pg. 548) for the base, middle and top of the formation from the type section just east of Bird Fiord and also from a section on eastern Grinnell Peninsula.

2.3.5.3 Paleocurrent Analysis

Exposures in this section are commonly moderately to highly weathered. While this reduced the number of measurable directional structures, these features are not abundant. Two channel scours, 17 planar tabular cross-beds (eight in-channel and nine overbank) and one parting lineation measurement are all that could be obtained. This data is presented in Figure 4.1-1. No vertical trends exist in the directional data at this location. The two channel scours, located at ca. 39 m and 76 m above the base, are the most reliable indicators of paleoflow direction. Both (one of which has a 55 m oblique channel width) give a northeast-southwest line of movement. This evidence, in combination with a northeasterly oriented vector mean (039^0) from the in-channel planar tabular cross-beds (these are reasonably distributed throughout the Fram portion of the section) suggests a northeasterly paleoflow direction at this location.

2.3.5.4 Facies Content

While both sandstone and siltstone are important lithologies in this exposure (54.5% and 46.5%, respectively), sandstone is again slightly more prominent.

All siltstone at this exposure is non-stratified (1a) while the sandstone is divisible into six sub-facies. The relative proportion, by cumulative thickness, of these sub-facies in the Fram Formation at this location is indicated in Figure 2.3.5.4-1. It is apparent that non-stratified siltstone is the dominant sub-facies. Table 2.3.5.4-1 presents the descriptive attributes of these sub-facies. Bedded sandstone without bed-forms (2k), occurs once and only in this section, representing 2.1%. It is therefore omitted from Table 2.3.5.4-1 since it has been previously described in Table 2.3.3-1 which considered all sections in the Fram Formation cumulatively.

Summary descriptions of the facies are provided below. Selected features of the formation at this location are presented in Plate 2.3.5.4-1.

Facies 1 - Siltstone

As mentioned above, only non-stratified siltstone (1a) is present in this section of the Fram Formation. Its dominant weathered and fresh surface colors are red and grey, respectively. Unit thickness averages 1.6 m. Macroscopic fossil evidence is restricted to comminuted plant debris and occasional root casts.

Figure 2.3.5.A - 1 Sub-facies in the Fram Formation at section HG2. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

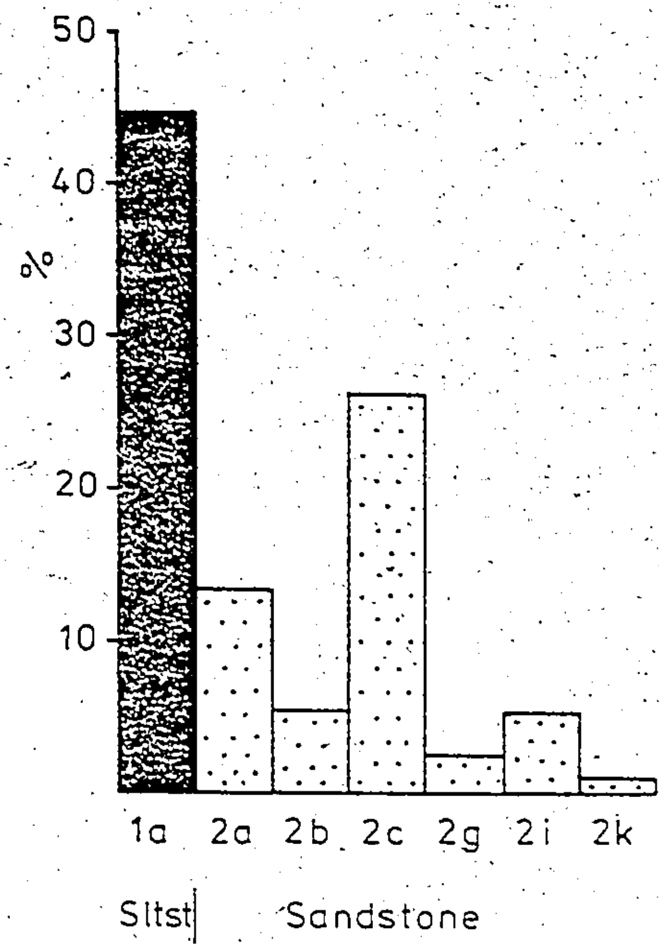

50
40
%
30
20
10
1a
2a
2b
2c
2g
2i
2k
Sltst
Sandstone

Table 2.3.5.4.-1 Salient Attributes of Sub-facies Defined in The Fram Formation At Section HG2

Facies 1 - Siltstone (45.6%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	1.6; 0.02-5.1	green, grey, red/green, grey, red	root casts, comminuted plant debris

Facies 2 - Sandstone (54.5%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	24.9	1.3; 0.08-8.0	grey, green, red, white/grey, white	ostracoderm fragments; partial plant casts and compressions, root casts
parallel laminated sandstone	2b	10.4	0.8; 0.1-2.1	grey, green, red/grey	root casts partial plant casts and compressions
ripple cross-laminated sandstone	2c	48.5	1.1; 0.01-5.0	grey, green, red, white/grey, white	comminuted plant debris partial plant casts and compressions, root casts unidentified trace fossils (burrows)
wavy and irregular laminated sandstone	2g	4.4	1.55; 1.5-1.6	red, white/grey white	nf

non-stratified sandstone	2i	9.7	0.6; 0.01-1.0	green,grey, red, white/grey, white	partial plant casts and compressions, root casts
bedded sandstone with no bedforms Comment: one occurrence only	2k	2.1	1.5	grey-white/ grey-white	nf

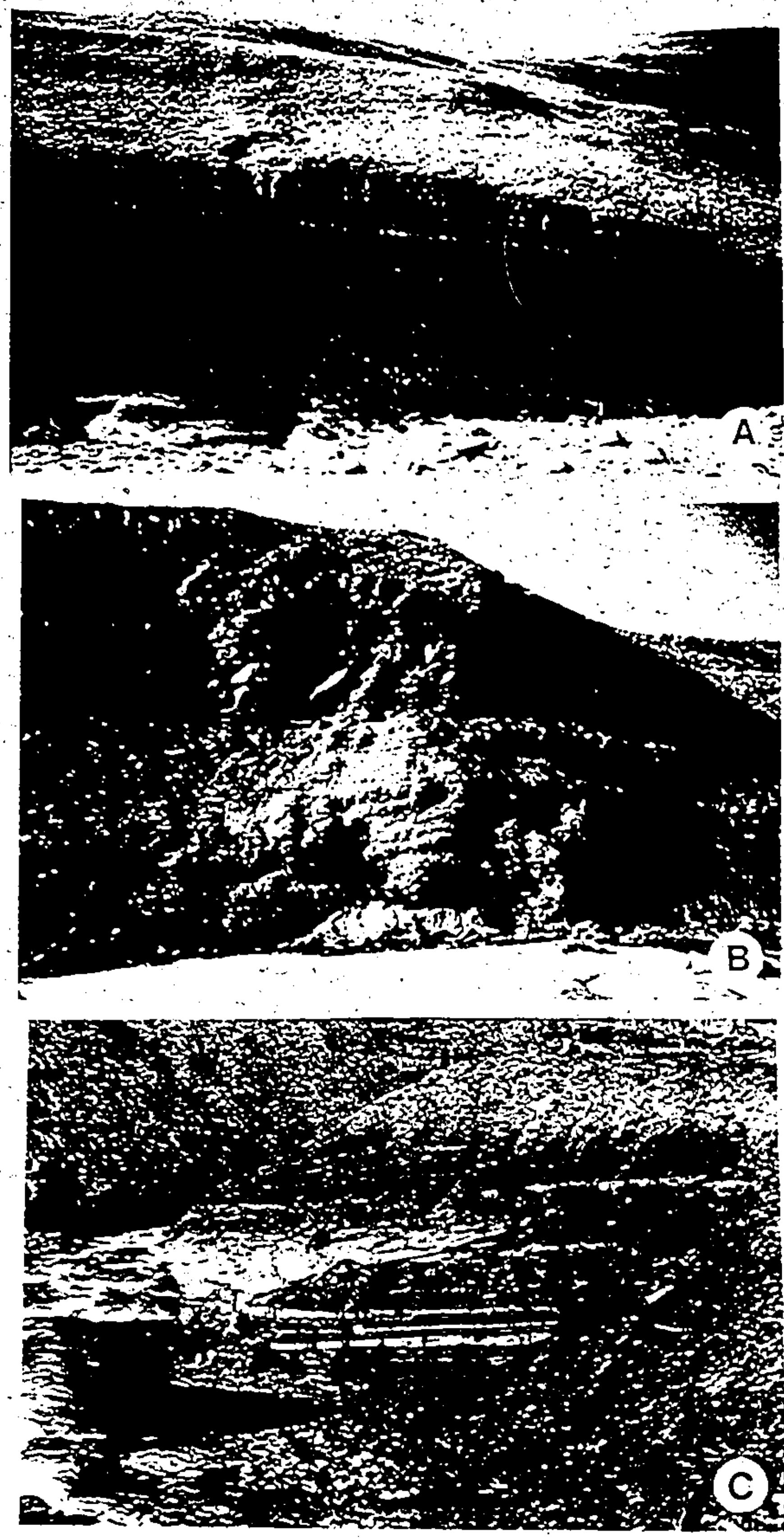
Note: see comments 3,4, and 5 following Table 2.1.3-1.

Plate 2.3.5.4 - 1 The Fram Formation at section HG2 located along a ravine approximately 12.5 km southeast of the southeastern arm of Bird Fiord.

A. Interstratified floodplain sandstone and siltstone/shale near the middle of the Fram Formation. The thicker sandstone could be a trunk-channel sandstone. It is ca. 4.0 m in thickness.

B. Interstratified floodplain sandstone and siltstone/shale with a thicker trunk-channel sandstone unit near the top of the outcrop. The exposure is ca. 20 m in height.

C. An oblique cut through a trunk-channel sandstone which is underlain and overlain by interstratified floodplain sandstone and siltstone/shale. Field assistant (arrow) for scale.


A
B
C

Facies 2 - Sandstone

Sandstone in the Fram Formation at section HG2 weathers mainly grey with less common red, white and green hues. Fresh surfaces are dominantly grey in color. Of the six sub-facies defined ripple cross-laminated sandstone (2c) is dominant, representing 48.5% by cumulative thickness. Maximum and minimum average unit thickness of 1.6 m and 0.6 m occurs in the wavy and irregularly laminated sub-facies (2g) and the non-stratified sub-facies (2i), respectively. Macroscopic fossil evidence consists of ostracoderm fragments, root casts, partial plant casts and compressions, comminuted plant debris and occasional unidentified trace fossils (burrows). Only sub-facies 2g (wavy and irregularly laminated sandstone) and 2k (bedded sandstone without bed-forms) are unfossiliferous.

2.3.6 Section F2 (Fram Formation portion)

2.3.6.1 Location, Thickness and Contact Relations

Section F2 is located on the eastern side of the inner part of the south arm of Bird Fiord. This location is shown in Figure 2.1.1-1. The base of the section is located at 505250E, 8562675N, UTM zone 16X, NTS 49c, Baumann Fiord sheet. This section consists of 383.1 m of the upper Fram Formation overlain by 36 m of the lowermost Hell Gate Formation. An aerial photograph of the vicinity of section F2 is presented as Figure 2.2.7.1-1. Embry and Klovan (1976) report a formation thickness of 1125 m at the type section for the Fram Formation only 6.5 km east of Bird Fiord. In this context, the Fram Formation at section F2 constitutes approximately the upper third (34.1%) of the formation in this area.

The upper contact with the Hell Gate Formation is well exposed near the top of the section. It is both conformable and transitional. The Hecla Bay Formation underlies the Fram Formation in this area, as elsewhere. This contact was located ca. 4 km north of the section but was not investigated.

The drafted section of this exposure is presented as Figure 2.3.6.1-1 (in pocket).

2.3.6.2 Age

Eleven productive palynology samples were collected within the lower 180 m of the section (GSC Loc. C-91911 to 91921, inclusive). McGregor (1982, pg. 4-9), reports an age of Late Givetian to Early Frasnian for C-91911 located 0.5 m above the base of the section and an age of Middle Frasnian for C-91921 sampled at 180.1 m above the base. Since the highest sample is still 204 m below the Fram-Hell Gate contact, this data indicates that the upper third of the Fram Formation at this location ranges from Late Givetian to at least Middle Frasnian and possibly younger. This is entirely consistent with the Early to Middle Frasnian age determined by Embry and Klovan (1976) at the type section.

2.3.6.3 Paleocurrent Analysis

The directional data recorded from this section in the Fram Formation is presented in Figure 4.1-1. It consists of 57 planar tabular cross-beds (39 in-channel and 18 overbank), one trough axis and four parting lineation measurements. A vector mean oriented toward the northwest (281^0) was determined for the in-channel planar tabular cross-beds. This is considered the most reliable paleoflow indicator due to the even distribution of the measurements throughout the section and the larger sample size. An overall westerly paleoflow is supported by the parting lineation which indicates a northeast-southwest line of movement. No vertical trends are present in the directional data.

2.3.6.4 Facies Content

The Fram Formation at section F2 is composed of sandstone (60.7%) and siltstone (39.3%) which are divisible into five and two sub-facies, respectively. The relative proportion of these sub-facies, by cumulative thickness, is given in Figure 2.3.6.4-1. Their descriptive attributes are provided in Table 2.3.6.4-1. It is apparent from this figure that the dominant sub-facies are non-stratified siltstone (1a) and ripple cross-laminated sandstone (2c). Summary descriptions of the facies are provided below.

Facies 1 - Siltstone

Siltstone is almost entirely non-stratified (1a - 99.7%). Only two occurrences (0.3%) of ripple cross-laminated siltstone (1c) exist. Their weathering colors include grey, green, red, purple and brown; green is dominant. Fresh surfaces are mainly a grey color, with minor green and red hues. Units of non-stratified siltstone average 1.4 m in thickness, varying from several centimeters to just over 7 m. Macroscopic fossil evidence is limited to infrequent root casts in the non-stratified siltstone.

Facies 2 - Sandstone

Figure 2.3.6.4 - 1 Sub-facies in the Fram Formation at section F2. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

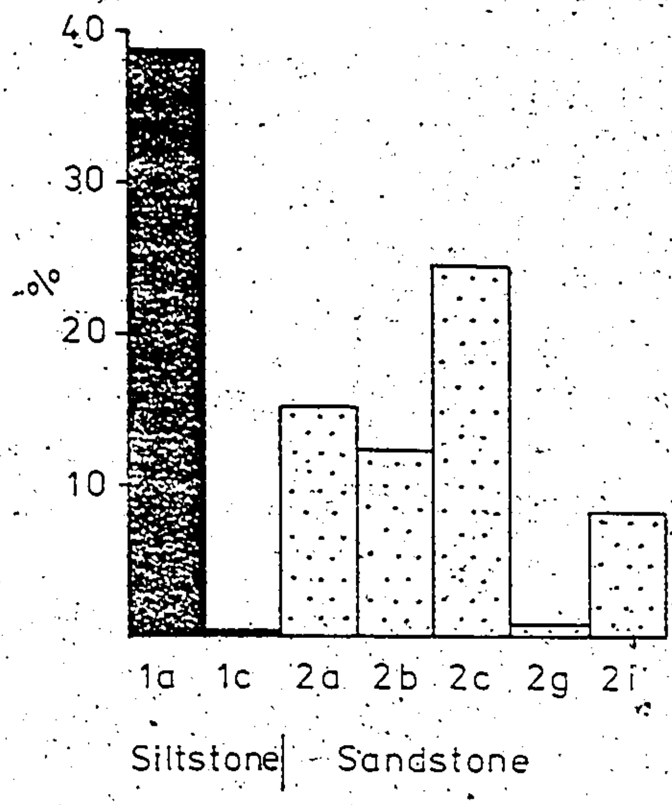

40
30
%
20
10
1a
1c
2a
2b
2c
2g
2i
Siltstone
Sandstone

Table 2.3.6.4.-1 Descriptive Attributes of Sub-facies Defined in the Fram Formation at section F2.

Facies 1 - Siltstone (39.3%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	99.7	1.4; 0.02-7.5	green, grey, red, brown, purple/green, grey, red	occasional root casts
ripple cross-laminated siltstone	1c	0.3	0.15; 0.1-0.2	green, grey/green, grey	nf

Facies 2 - Sandstone (60.7%)

Sub Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	25	1.0; 0.1-4.0	green, grey, red, white, brown/green grey, white	partial plant casts and compressions, ostracoderm fragments, unidentified trace fossils (burrows)
parallel laminated sandstone	2b	20	0.9; 0.02-4.2	green, grey, red, white, brown/green, grey, white	partial plant compressions, root casts, unidentified trace fossils (burrows)
ripple cross-laminated sandstone	2c	40.7	1.0; 0.02-5.0	grey, green, red, white, brown/green, grey, white	comminuted plant debris, root casts, ostracoderm fragments, unidentified trace fossils (burrows)
wavy and irregularly sandstone	2g	1.1	1.0; 0.2-1.7	grey/grey, green.	nf
non-stratified sandstone	2i	13.2	1.2; 0.1-2.8	green, grey, red, white, brown/green grey, white	unidentified trace fossil (horizontal grazing trace), partial plant casts and compressions

Note: see explanations following table 2.1.3.-1.

Sandstone weathers green, grey, red, brown and white; grey is most prominent. Fresh surfaces display green, grey and white colors with grey and white both common. The variety of weathering colors is a function of stratigraphic position, i.e., the upper Fram contains a transition from red and grey to mainly grey and white sandstone representing the initial clastic input of grey and white sand size detritus of the transitionally overlying Hell Gate Formation. The sandstone is dominated by ripple cross-laminated (2c) and planar tabular cross-bedded sub-facies (2a) which constitute 40.7% and 25%, by cumulative thickness, respectively. Average unit thickness is quite consistent amongst the sub-facies (0.9 - 1.2 m). Unit thickness ranges from several centimeters to several meters. Macroscopic fossil evidence in the sandstone consists of ostracoderm fragments, occasional unidentified trace fossils (burrows and bedding plane trace), partial plant casts and compressions, root casts and comminuted plant debris. Only the wavy and irregularly laminated sub-facies (2g) is non-fossiliferous.

2.3.7 <u>Section F4</u> (Fram Formation portion)

2.3.7.1 <u>Location, Thickness and Contact Relations</u>

Section F4 is located along the western margin of inner Goose Fiord. The base is found at 456500E, 853400N, UTM zone 16X, NTS 59A, Cardigan Strait sheet. The location of this section relative to the other sections measured during this study is presented in Figure 2.1.1-1. The line of section along the inner, western margin of the fiord was previously indicated in Figure 2.2.5.1-1 which is an aerial photograph of the vicinity of section F4. This sections exposes the upper 210.3 m of the Hecla Bay Formation, previously discussed in 2.2.5, and the entire overlying Fram Formation (489.7 m). Covered interval constitutes 25.4% of the Fram Formation. This formation thickness fits well in Figure 29 of Embry and Klovan (1976, pg. 544) which suggests a regional east-west thinning trend throughout the areal extent of the formation. At the type section, 6.5 km east of Bird Fiord, its thickness is 1125 m, whereas at the western extremity of its outcrop area, at Grinnell Peninsula on Devon Island, the formation is only 300 m thick. Such a thickness trend is strongly suggestive of an easterly source region. The source region of the Okse Bay Group will be discussed in a subsequent portion of this report.

Both the lower contact with the Hecla Bay Formation and the upper contact with the Hell Gate Formation are exposed. Each is conformable and transitional.

The drafted section containing the Fram Formation at this location is Figure 2.2.5.1-2 (in pocket).

2.3.7.2 Age

Twelve palynology samples were recovered from the Fram Formation at this location (GSC Loc. C-91958 to C-91967 inclusive, and C-91970 to C-91971, inclusive), eight of which are productive. McGregor (1984a, pg. 8-11) reports an age of the upper third of the Givetian or lowermost Frasnian for the basal sample taken 19.7 m above the base of the formation and an age of probably the middle third of the Frasnian for the highest sample taken 21.2 m below the Hell Gate-Fram contact. This age bracket is consistent with that obtained by Embry and Klovan (1976) for the type section 6.5 km east of Bird Fiord.

2.3.7.3 Paleocurrent Analysis

Much of this section of the Fram Formation is highly weathered and not conducive to paleocurrent measurements. The directional data at this site consists of 69 planar tabular cross-bed measurements (39 in-channel, 30 overbank), ten parting lineation (three in-channel, seven overbank), and a single trough axis measurement. This data is presented in Figure 4.1-1. The planar tabular cross-beds are the more reliable paleoflow indicators due to their larger data base. They are reasonably evenly distributed throughout the formation and do not display any vertical trend. The vector mean for the in-channel measurements (290^0) indicates a paleoflow to the west. This is crudely supported by a northwest-southeast line of movement indicated by the parting lineation. The one trough axis is oriented toward the southeast and must be considered to represent smaller, secondary flow vortices in the river which circulate at high angles to the overall flow direction.

2.3.7.4 Facies Content

At section F4 the Fram Formation is composed dominantly of siltstone (66.5% by cumulative thickness) with a significant amount of sandstone (33%) and a very minor amount of nodular weathering horizons (0.5%). Siltstone and sandstone are divisible into three and six sub-facies, respectively; no new sub-facies are defined. The relative proportion of these sub-facies, by cumulative thickness, in the formation at this section is presented in Figure 2.3.7.4-1. It is apparent from this figure that non-stratified siltstone (1a) dominates this section with ripple cross-laminated sandstone (2c) the most important sandstone sub-facies. Table 2.3.7.4-1 presents the descriptive attributes of the various sub-facies. Sub-facies le (rooted siltstone), 2f (sandstone with climbing ripple drift cross-lamination) and facies 6 (nodular weathering units) occur only at this section and therefore are not included in this table since they were previously described in Table 2.3.3-1 which considers all sections of the Fram Formation cumulatively. All three sub-facies are only minor at this location, representing 0.8%, 0.2% and 0.5%, respectively, by cumulative thickness.

Summary descriptions of the facies are provided below. Selected features of the formation at this location are presented in Plate 2.3.7.4-1.

Facies 1 - Siltstone

The siltstones are commonly recessive weathering. They most commonly occur either intercalated on a centimeter to decimeter scale with sandstone, frequently resulting in couplets, or as a recessive interval overlying resistant sandstone ridges. The prominent weathering and fresh surface color is red, with green and grey colors occurring less frequently. Non-stratified siltstone (la) constitutes

Figure 2.3.7.4 - 1 Sub-facies in the Fram Formation at section F4. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

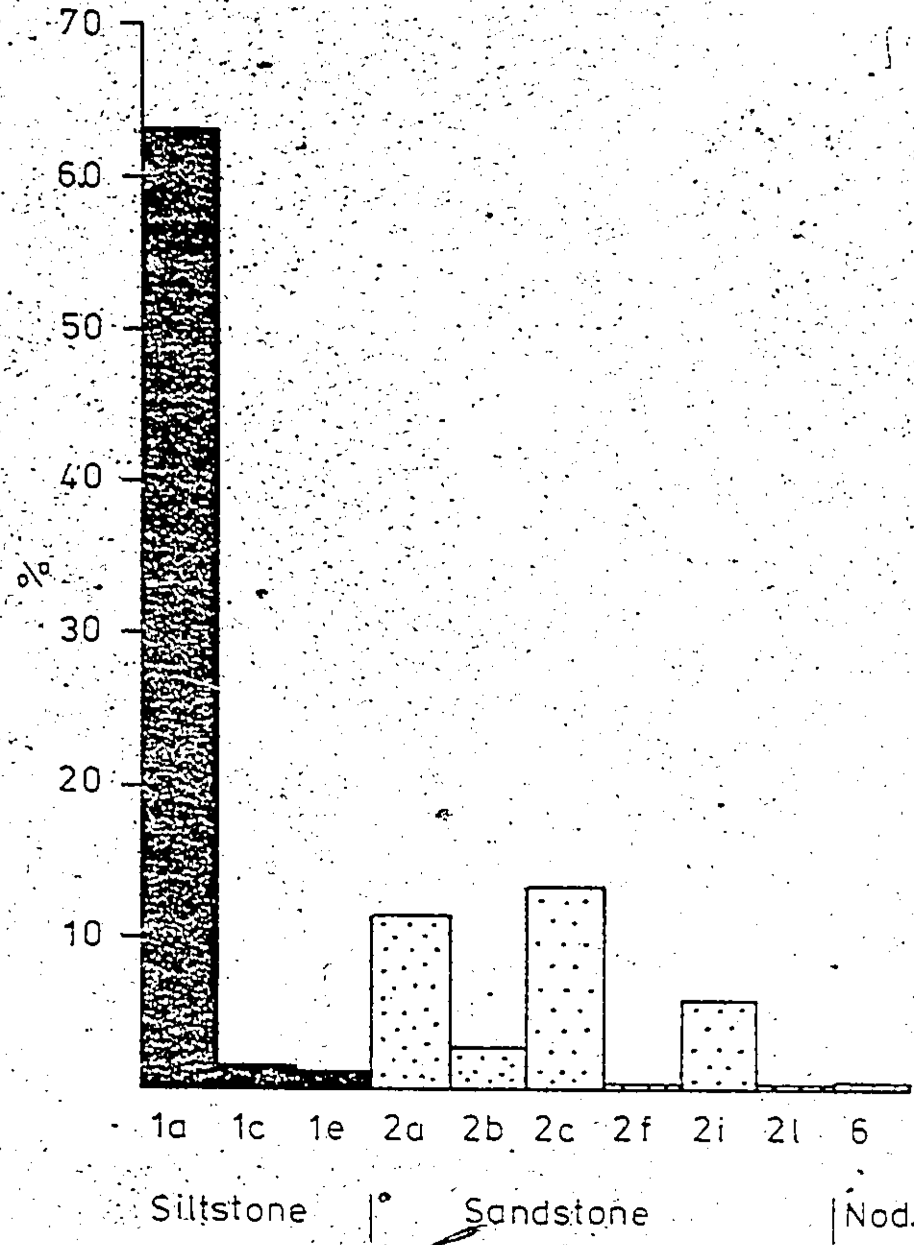

70
60
50
40
30
20
10
%
1a
1c
1e
2a
2b
2c
2f
2i
2l
6
Siltstone
Sandstone
Nod.

Table 2.3.7.4.-1 Descriptive Attributes of Sub-Facies Defined in The Fram Formation at Section F4

Facies 1 - Siltstone (66.5%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	96.5	2.4; 0.01-18.2	green, grey, red/green grey, red	comminuted plant debris
ripple cross laminated siltstone	1c	2.3	0.8	dark green/dark green	comminuted plant debris unidentified trace fossils (horizontal crawling)
Comment: one occurrence only					
rooted siltstone	1e	1.2	1.4; 0.3-1.7	red/grey	root casts

Facies 2 - Sandstone (33%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross bedded sandstone	2a	32	1.1; 0.1-3.0	green, grey, red, white/green, grey, white	root casts, ostracoderm fragments unidentified trace fossils partial plant casts and compressions
parallel laminated sandstone	2b	7.4	0.6; 0.08-1.0	green, grey, red, whit/green, grey, white	ostracoderm fragments, root casts, partial plant casts

ripple cross-laminated sandstone	2c	41	1.1; 0.03-2.5	green, red, grey, white/green, grey, white	comminuted plant debris root casts, ostracoderm fragments
sandstone with climbing ripple drift cross lamination	2f	0.7	0.1	dark green/dark green	comminuted plant debris
Comment: one occurrence only					
non-stratified sandstone	2i	18.6	0.7; 0.02-1.8	green, grey, red, white/ green grey, white	root casts,ostracoderm fragments
trough cross bedded sandstone	2ℓ	0.4	0.5	grey-white/ grey-white	partial plant casts.

Comment: one occurrence only.

Facies 6 - Nodular Weathering Units (0.5%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
			0.6; 0.5-0.7	variegated red, grey, white	nf

Note: see comments 3,4, and 5, following Table 2.1.3-1.

Plate 2.3.7.4 - 1. The Fram Formation at section F4 located along the western margin of inner Goose Fiord.

A. Trough cross-bedding at the base of a main-channel sandstone. The Jacobs Staff is 1.5 m in length.

B. Thinly interstratified floodplain sandstone and siltstone. The hammer is 34 cm in length.

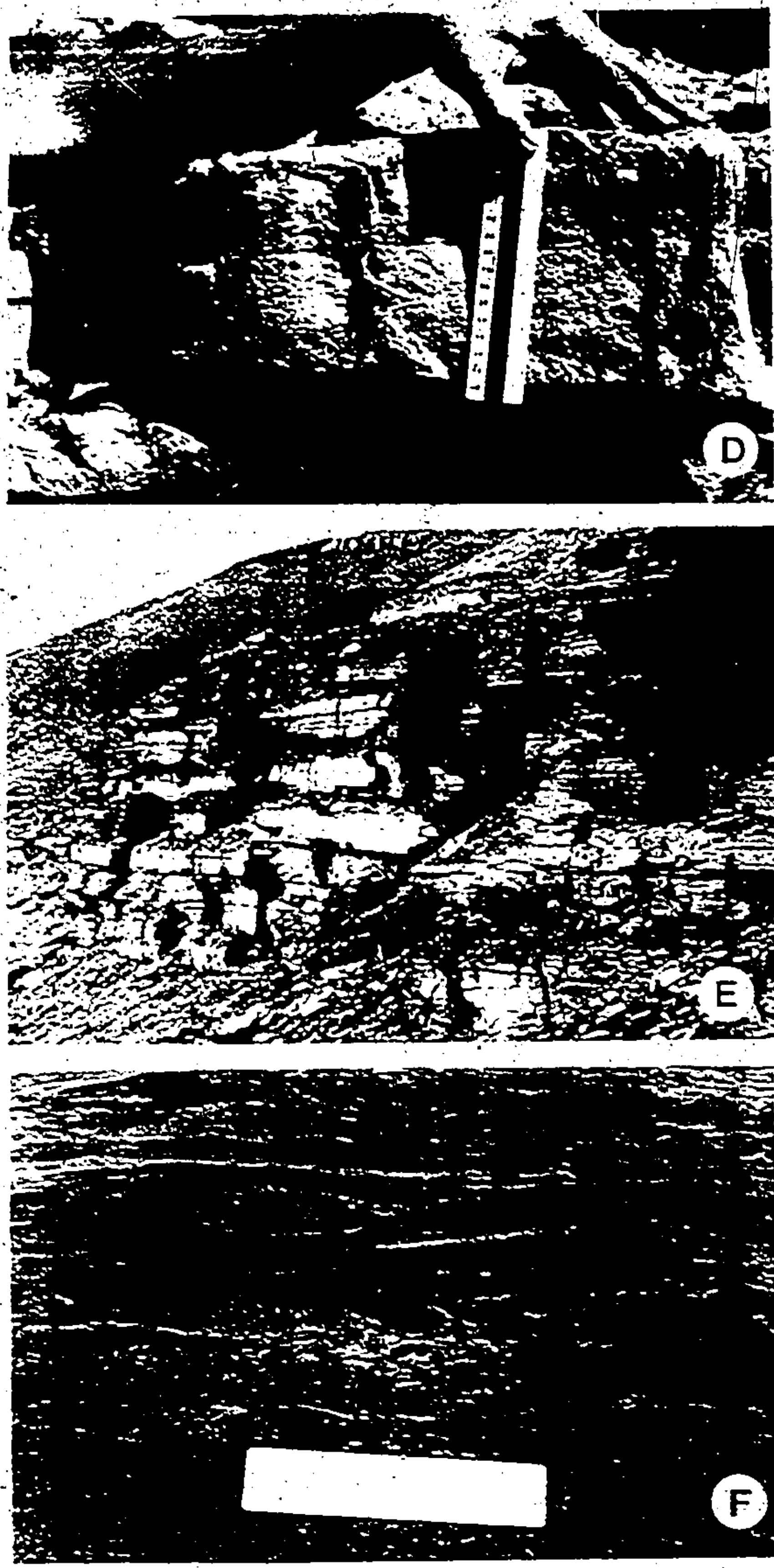
C. A resistant weathering main-channel sandstone unit near the top of the Fram Formation. The sandstone is ca. 6 m in thickness.

D. The trace fossil Cylindrichnus in a sandstone unit near the middle of the Fram Formation. The scale is 15 cm in length.

E. An interval of lacustrine siltstone and sandstone near the base of the Fram Formation. The outcrop is ca. 12 m in height.

F. Ripple cross-laminated siltstone/silty sandstone in the lacustrine unit near the base of the formation. Note the stoss side preservation indicating high rates of sedimentation. The scale is 15 cm in length.


A
B
C


D
E
F

96.5% of the siltstone, by cumulative thickness. Ripple cross-laminated (1c) and rooted siltstone (1e) are present as minor sub-facies representing 2.3% and 1.2%, respectively. A maximum average unit thickness of 2.4 m occurs in the non-stratified siltstones with unit thickness varying from several centimeters to tens of meters. Macroscopic fossil evidence consists of comminuted plant debris, an unidentified trace fossil and root casts.

Facies 2 - Sandstone

Sandstone occurs either as resistant ridges amongst recessive weathering siltstone intervals or as thicker resistant intervals with only minor interstratified siltstone. The sandstone weathers green, grey, red or white; red is the most dominant color. Fresh surfaces are commonly grey, but green and white sandstones are also present. White sandstone becomes more common in the upper Fram as the contact with the overlying Hell Gate Formation is approached.

Ripple cross-laminated sandstone (2c) is most prominent representing 41% of the sandstone by cumulative thickness. Of secondary and tertiary importance are planar tabular cross-bedded sandstone (2a) and non-stratified sandstone (2i) representing 32% and 18.6%, respectively. A maximum average unit thickness of 1.1 m occurs in both the planar tabular cross-bedded (2a) and ripple cross-laminated (2c) sub-facies. Unit thickness varies between several centimeters and several meters.

Sandstones contain ostracoderm fragments, comminuted plant debris, root casts, partial plant casts and compressions, and occasional unidentified trace fossils. All sub-facies are fossiliferous.

Facies 6 - Nodular Weathering Units

These slightly calcareous, variegated red, white and grey horizons occur only several times at this location. They vary from 0.5 - 0.7 m in thickness and are non-fossiliferous.

2.3.8 Section F3 (Fram Formation portion)

2.3.8.1 Location, Thickness and Contact Relations

Section F3 is located ca. 6 km north of Ren Bay along the eastern side of Hell Gate. The base of the section is found at 438750E, 8518250N, UTM zone 16X, NTS 59A, Cardigan Strait sheet. This section includes 105.4 m of the upper Fram Formation and 189.1 m of the overlying basal Hell Gate Formation. Only the Fram Formation portion is discussed below. The Fram Formation contains 12% covered interval at this location. Refer to Figure 2.1.1-1 for the location of section F3 within the study area. Figure 2.3.8.1-1 is an aerial photograph of the vicinity of section F3 showing the line of section.

The thickness of the Fram Formation at this location is not known, however,its proximity to section F4 (ca. 18 km west of F4) would suggest that the formation thickness there is also representative of the formation at section F3. If so, the105.4 m of Fram Formation exposed at F3 constitutes the upper 22% of the formation in that area.

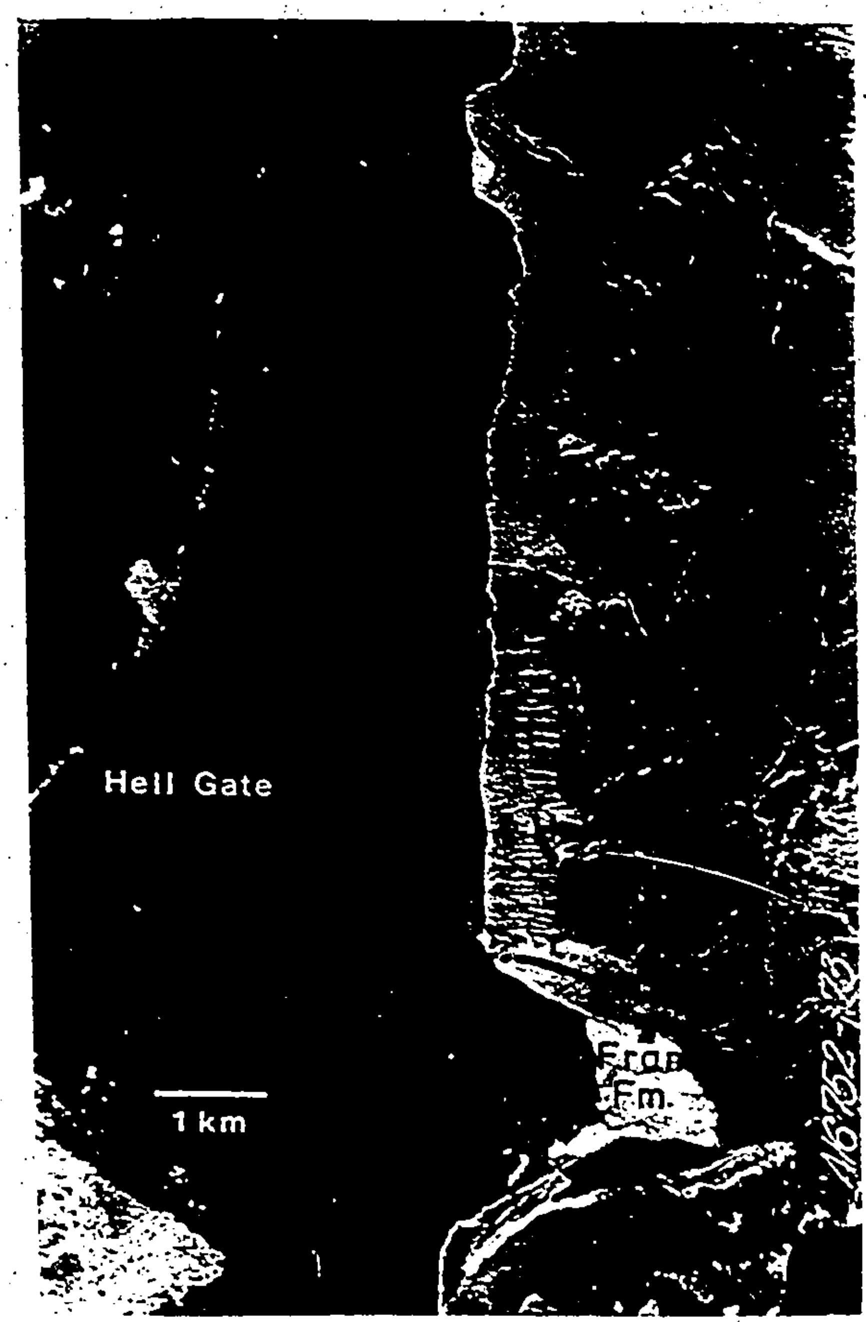
The lower contact with the Hecla Bay Formation was not seen. It is presumed to be conformable and transitional, as it was at section F4. The upper contact with the Hell Gate Formation is exposed but highly weathered. It is both conformable and transitional.

The drafted section containing the Fram Formation at this location is presented as Figure 2.3.8.1-2 (in pocket).

2.3.8.2 Age

The Fram Formation at section F3 yielded six productive palynology samples (GSC loc. C-91934 to C-91936, inclusive and C-91938 to C-91940, inclusive). Only three could be assigned a precise age. McGregor (1984a, pg. 1-2)

Figure 2.3.8.1 - 1 Aerial photograph of section F3 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16752-73.


Hell Gate
1 km
Fm.

assigned an Early Frasnian age to C-91934, C-91939 and C-91940 taken from 2.5 m, 77.9 m and 80.2 m above the base, respectively. Since the highest sample is only 25.2 m below the Hell Gate-Fram contact it is probable that the uppermost Fram at section F3 is Early Frasnian in age.

2.3.8.3 Paleocurrent Analysis

This short exposure of the upper Fram Formation yielded sparse paleocurrent data. Twenty-four planar tabular cross-beds (seven in-channel, 17 overbank) and a single groove mark are all that were noted. This data is presented in Figure 4.1-1. The measurements are reasonably evenly distributed throughout the Fram and displayed no vertical trend. As Figure 4.1-1 indicates, the vector mean of the in-channel cross-beds is to the southeast (164^{0}) while the single groove mark implies at least a local northwest-southeast line of movement.

The available paleocurrent data for the Fram at section F3 is complimentary and suggests a southeasterly paleoflow direction.

2.3.8.4 Facies Content

The Fram Formation at section F3 consists of siltstone and sandstone representing 62.1% and 37.9%, respectively, of the formation by cumulative thickness. The siltstone is present only as non-stratified siltstone (sub-facies 1a) whereas five sandstone sub-facies can be defined. The proportion of the formation, by cumulative thickness, represented by each sub-facies is presented in Figure 2.3.8.4-1. It is apparent that non-stratified siltstone (1a) and ripple cross-laminated sandstone (2c) are the prominent sub-facies in the Fram at this location. The descriptive attributes of the various sub-facies are presented in Table 2.3.8.4-1. Summary descriptions of the siltstone and sandstone facies are presented below. Selected features of the formation at this location are presented in Plate 2.3.8.4-1.

Facies 1 - Siltstone

All siltstone in this exposure of the Fram Formation is non-stratified (1a). It occurs either interstratified with sandstone on a scale of centimeters to decimeters or is found as thicker recessive intervals separating resistant sandstone outcrops. In this respect, the facies organization at section F3 is similar to all other exposures of the Fram Formation examined during this study. Siltstone is dominantly grey with minor red colors on both weathered and fresh surfaces. Unit thickness varies considerably,

Figure 2.3.8.4 - 1 Sub-facies in the Fram Formation at section F3. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

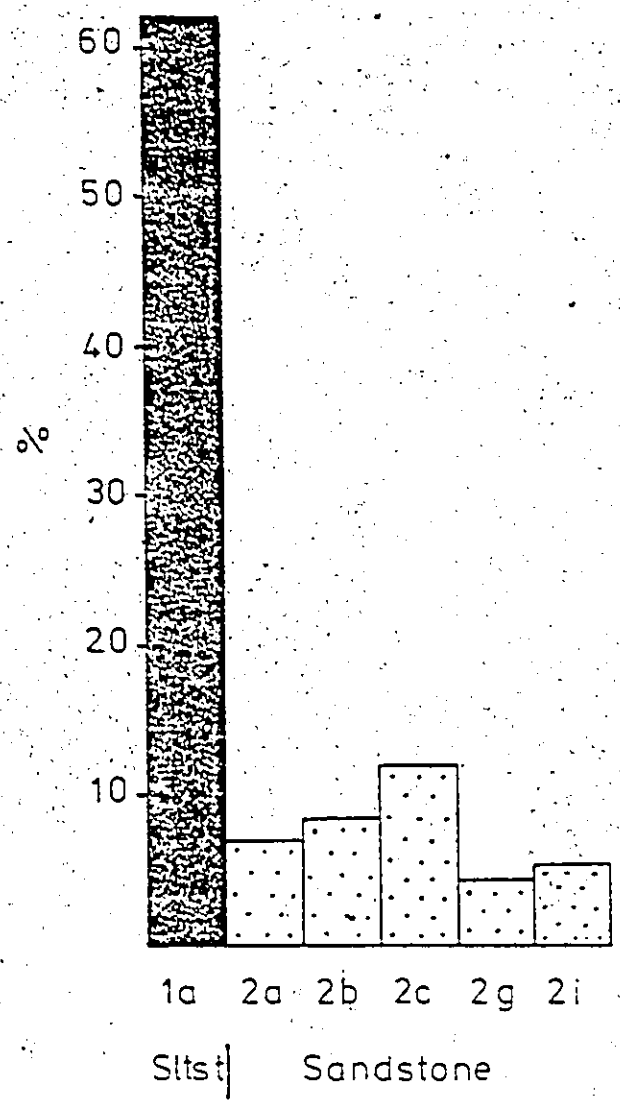

60
50
40
%
30
20
10
1a
2a
2b
2c
2g
2i
Sltst
Sandstone

Table 2.3.8.4.-1 Descriptive Attributes of Sub-Facies Defined in The Fram Formation At Section F3

Facies 1 - Siltstone (62.1%)

Sub-facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	2.6; 0.03-15.8	red, green, <u>grey</u>/ red, <u>grey</u>	nf

Facies 2 - Sandstone (37.9%)

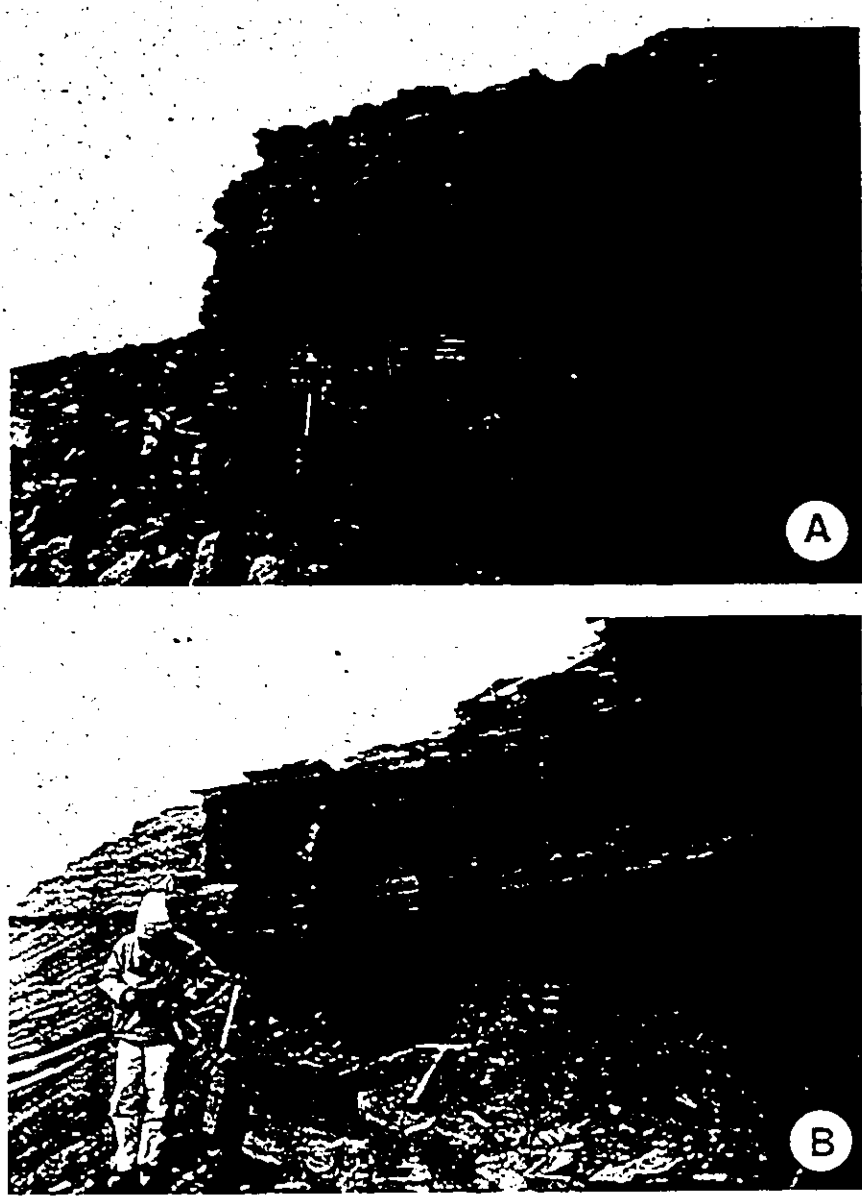
Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	19.0	1.3; 0.2-4.4	green, <u>grey</u>, white/ <u>grey</u>, white	ostracoderm fragments, partial plant casts and compressions
parallel laminated sandstone	2b	22.4	0.9; 0.05-4.3	<u>green</u>, <u>grey</u>, white/<u>grey</u>, white	ostracoderm fragments
ripple cros-laminated sandstone	2c	32.1	0.7; 0.03-0.4	<u>green</u>, grey, white/<u>grey</u>, white	comminuted plant debris root casts, unidentified trace fossils
wavy and irregular laminated sandstone	2g	12.5	4.4	grey-white/ grey-white	nf
Comment: one occurrence only					
Non-stratified sandstone	2i	13.9	0.7; 0.05-0.2	<u>green</u>, white/ <u>grey</u>, white	partial plant casts and compressions, root casts, ostracoderm fragments

<u>Note</u>: see comments 3,4, and 5 following Table 2.1.3-1.

Plate 2.3.8.4 - 1 The Fram Formation at section F3 located approximately 6 km north of Ren Bay along the eastern (Ellesmere) side of Hell Gate.

A. A trunk-channel sandstone unit. The Jacobs Staff at the base of the intact outcrop is 1.5 m in length.

B. Interstratified floodplain sandstone and siltstone/shale. The hammer is 30 cm in length.


A
B

ranging from 0.03 m to 15.8 m and averaging 2.6 m. Macroscopic fossil evidence is absent.

Facies 2 - Sandstone

Sandstone in the Fram Formation at section F3 occurs principally as resistant ridges of outcrop separating recessive weathering siltstone intervals. The sandstone weathers green, grey and white; the latter color becomes more frequent as the base of the overlying Hell Gate Formation is approached. Fresh surfaces are grey or white with the former more common. Five sub-facies could be defined with ripple cross-laminated sandstone (2c) the most prominent (32.1%). A maximum average unit thickness of 1.3 m occurs in the planar tabular cross-bedded sandstones (2a). The other sub-facies have an average unit thickness varying from 0.7 m to 0.9 m. In general, sandstone units vary from several centimeters to several meters in thickness.

Fossil evidence in the sandstone consists of partial plant casts and compressions, ostracoderm fragments, comminuted plant debris, root casts and rare unidentified trace fossils (burrows). Only sub-facies 2g, wavy and irregularly laminated sandstone, is non-fossiliferous.

2.3.9 Section F1

2.3.9.1 Location, Thickness and Contact Relations

This section is located along a small stream located ca. 7.5 km southwest of the head of Sor Fiord. The base of the section is found at 556975E, 8576575N, UTM zone 16X, NTS 49c, Baumann Fiord sheet. Refer to Figure 2.1.1-1 for this location in the study area. The line of section is shown in Figure 2.3.9.1-1, an aerial photograph of the area. The section consists of 697.5 m of the Fram Formation representing approximately the lower 76% of the formation in this area based on an estimated formation thickness of 900 m.

Neither the lower contact with the Hecla Bay Formation or the upper contact with the Hell Gate Formation was observed. For the former, the area of the contact is covered but similar attitudes on each side of the contact zone suggest it to be conformable. The area of the upper contact was not investigated but it is suspected to be conformable and transitional as it is elsewhere on southwestern Ellesmere Island.

The exposure quality in this section of the Fram Formation is very poor with the sandstone occurring as highly weathered, resistant ridges separated by numerous

Figure 2.3.9.1 - 1 Aerial photograph of section F1 and vicinity showing the line of section and relevant formation contacts. EM&R/NAPL A-16778-107.

thick intervals of tundra. Covered interval is estimated to represent 70-80% of the section. For this reason, a drafted section was not constructed.

2.3.9.2 <u>Age</u>

Most of the siltstones in this section are highly weathered, thus rendering them poor candidates for identifiable spores due to oxidation. Of ten samples submitted for analysis, representing the interval from 100-580 m in the section, only three were productive (GSC Loc. C-91903 from 103.9-104.8 m, C-91905 from 148.3-150.0 m, and C-91907 from 169.5 m above the base of the section). McGregor (1982, pg. 1-4) assigns the first two a probable age of Late Givetian with the possibility that they may also range into the Early Frasnian. The highest sample is dated as Late Givetian to Early Frasnian. Considering its proximity to the base of the formation (ca. 104 m) the lowest sample suggests an age of Late Givetian and possibly Early Frasnian for the basal Fram Formation. The highest sample is ca. 528 m below the top of the formation. It is possible therefore, that the top of the Fram Formation in this area is somewhat younger than Early Frasnian. This is consistent with the Middle Frasnian age assigned to the top of the formation at the type section and on Grinnell

Peninsula by Embry and Klovan (1976).

2.3.9.3. Paleocurrent Analysis

Due to the highly weathered nature of the resistant sandstone ridges at section F1 the directional data consists of only 33 planar tabular cross-bed measurements (21 in-channel, 12 overbank). This data is presented in Figure 4.1-1. The cross-beds are reasonably evenly distributed throughout the section and show no vertical trends. The vector mean for the in-channel cross-beds indicates a paleoflow to the northwest (285^0) for the Fram Formation at this site.

2.3.9.4 Facies Content

The high percentage of covered interval and poor outcrop quality in this section precludes a facies analysis. The section consists of siltstone and sandstone arranged into fining-upward cycles. In most instances, the siltstone/shale intervals are thicker (several meters to ca. 10 m) than the sandstone ridges (several meters) and are represented by recessive tundra covered portions of the section with only occasional run-off gullies revealing the underlying bedrock. Ripple cross-lamination seems to be the most common sedimentary structure in the sandstones with planar tabular and trough cross-bedding found in the middle and basal portions of the thicker sandstone ridges. While the siltstone is poorly exposed, that which could be observed appeared to be entirely non-stratified (1a).

Sandstone weathers a dull brownish-red color throughout the section and is grey or red on a fresh surface. Siltstones commonly weather to a dull red as well, but the rare, relatively unaltered bedrock that was found is dark grey in color.

Fossil evidence consists of partial plant casts and compressions, and ostracoderm fragments occasionally found as a lag in the cross-bedded to non-stratified basal portion of the resistant sandstone ridges.

2.3.10 Interpretation of Depositional Environment

As was the case for the two previous formations, the definition and interpretation of several genetic associations constitutes the environmental interpretation offered for the Fram Formation on southwestern Ellesmere Island. Sub-facies and facies defined in the formation at sections F5, HG2, F2, F4 and F3 are utilized in the definition of genetic associations. As discussed in 2.3.9.4, the exposure quality at section F1 is insufficient for a facies analysis.

The facies/sub-facies composition and their stratigraphic arrangement at the five section locations mentioned above is very similar. As such, the same sedimentary model may be used to interpret the Fram Formation throughout the study area. While facies analysis at section F1 was not warranted due to poor outcrop quality, the stratigraphic arrangement of the sandstone and siltstone in this section is like that observed at the other exposures of the formation. The same sedimentary model may therefore be applied in its environmental interpretation.

The sedimentary model developed for highly sinuous, undivided fluvial channel systems (meandering) is used to interpret the Fram Formation. This is consistent with the interpretation offered for the formation by Embry and Klovan (1976).

The most important aspects of the development of the meandering fluvial model have been previously reviewed (2.1.7.2).

2.3.10.1 Genetic Associations

The meandering fluvial depositional setting envisaged for the Fram Formation is depicted in Figure 2.3.10.1-1. As shown in this figure, the meandering channels are considered to be occupying a distal coastal plain very near to the strandline. Additional details of the depositional setting are provided below as the constituent genetic associations are separately discussed.

Since the Strathcona Fiord Formation at sections S2 and HB1 is also interpreted using a meandering fluvial model, the channel (I) and overbank (J) genetic associations previously defined may be used to interpret the Fram Formation. A new lacustrine association (L) is also defined for the interpretation of the basal Fram Formation at sections F4 and F5.

The genetic associations constituting the Fram Formation at each section in which it is exposed are presented in Table 2.3.10.1-1. An interval of the Fram Formation in section F4, which displays the channel association and the components of the overbank association is presented as Figure 2.3.10.1-2.

L - Lacustrine Association

The initial 12 m of the formation at section F4 and a 51.1 m interval at 55 m above the base of the formation at section F5 is interpreted to represent a lacustrine environment at or near the transition from the underlying

Figure 2.3.10.1 - 1. Block diagram representation of the depositional setting of the Fram Formation. Five components of the overbank genetic association (J) are shown in the diagram.

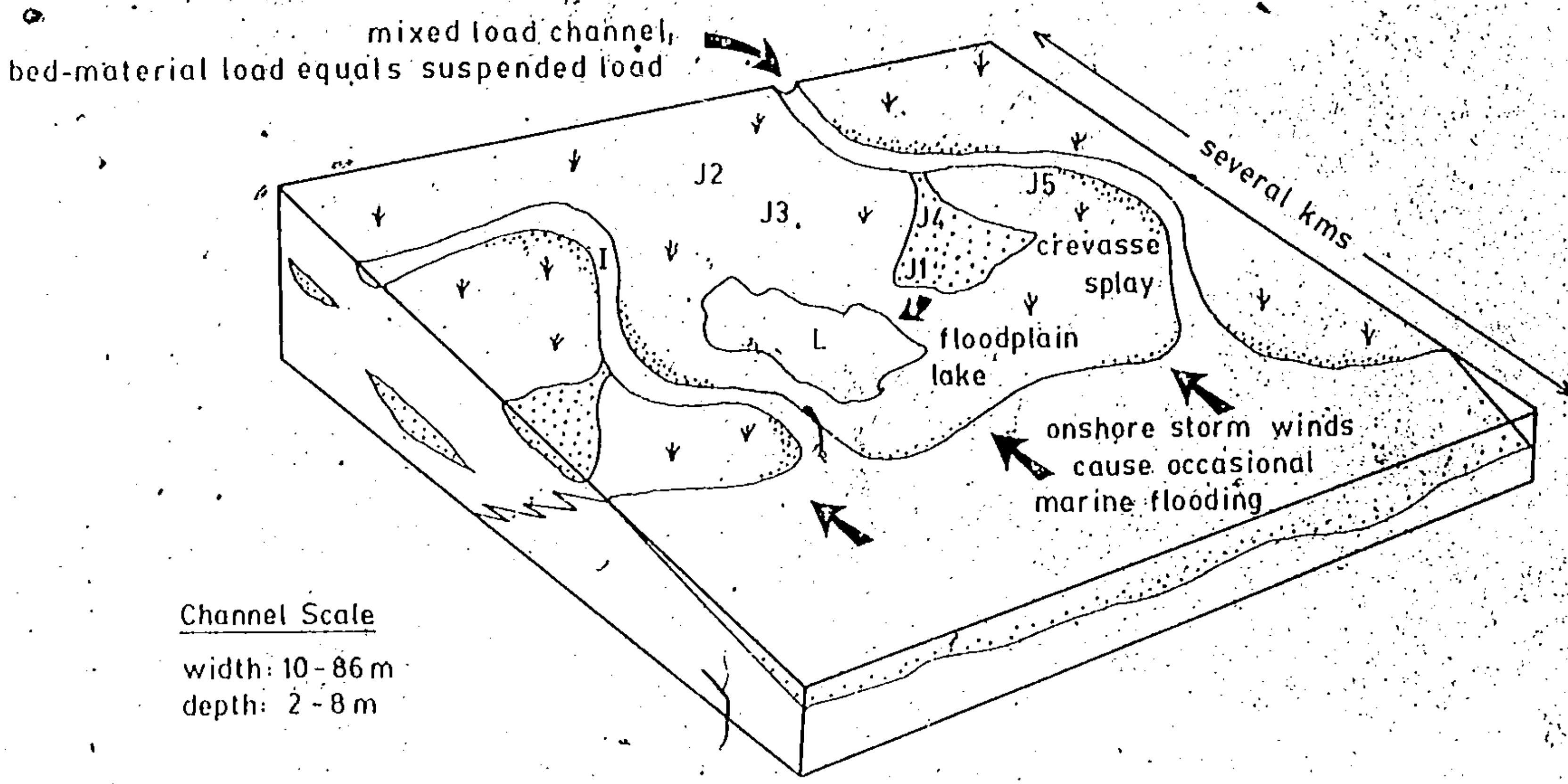

mixed load channel,
bed-material load equals suspended load
several kms
J2
J3
J4
J1
J5
crevasse
splay
I
L
floodplain
lake
onshore storm winds
cause occasional
marine flooding
Channel Scale
width: 10 - 86 m
depth: 2 - 8 m

Table 2.3.10.1.-1 Genetic Associations in the Fram Formation at Sections F5, HG2, F2, F4 and F3 Ordered from East to West Across Southwestern Ellesmere Island

Section F5

Assoc.	Code	%	Thickness(m)	Facies/Sub-Facies Content
Channel	I	28.3	3.6;2.0-6.7	I_1-2a, 2b, 2i, 2ℓ
				I_2-2c
Overbank	J	55.8		
	J_1	1.6	0.7;0.3-0.9	2a, 2b, 2c, 2i
	J_2	21.9	2.9;0.1-28.3	1a, 1c
	J_4	6.9	1.5;1.0-1.9	2a, 2b, 2c, 2i
	J_5	25.4	5.1;0.6-34.5	2a, 2c, 2i; 1a
Lacustrine	L	15.9	51.1 (1 only)	2c; 1c

Section HG2

Assoc.	Code	%	Thickness(m)	Facies/Sub-Facies Content
Channel	I	32.9	4.3; 2.9-8.0	I_1-2a, 2b, 2c
				I_2-2b, 2c, 2g
Overbank	J	67		
	J_1	5.4	0.5;0.2-0.9	2a, 2b, 2c, 2i
	J_2	35.8	1.7;0.2-5.1	1a
	J_4	6.8	1.5;1.0-1.9	2a, 2c, 2i, 2k
	J_5	19	2.8;0.8-5.9	2a, 2b, 2c, 2i; 1a

Section F2

Assoc.	Code	%	Thickness(m)	Facies/Sub-Facies Content
Channel	I	29.2	3.3;2.0-7.0	I_1-2a, 2b, 2c, 2i
				I_2-2c
Overbank	J	69.5		
	J_1	3.3	0.6;0.2-0.9	2a, 2b, 2c, 2i, 2g
	J_2	29.9	1.8;0.1-7.5	1a, 1c
	J_3	1.0	2.8 (1 only)	6
	J_4	13.2	1.5;1.0-1.9	2a, 2b, 2c, 2i, 2g
	J_5	22.1	2.1;0.3-6.3	2a, 2b, 2c, 2i; 1a, 1c

Section F4

Assoc.	Code	%	Thickness(m)	Facies/Sub-Facies Content
Channel	I	8.8	2.9;2.0-4.2	I_1-2a, 2b, 2c, 2i, 2ℓ
				I_2-2c
Overbank	J	87.9		
	J_1	2.6	0.6;0.2-0.9	2a, 2b, 2c, 2i
	J_2	51.9	3.5;0.3-18.2	1a, 1e
	J_3	0.5	0.6;0.5-0.7	6
	J_4	4.5	1.4;1.0-1.8	2a, 2b, 2c, 2i
	J_5	28.4	2.3;0.2-21.0	2a, 2b, 2c, 2i; 1a, 1e, 1c
Lacustrine	L	3.3	12.0 (1 only)	2c, 2f; 1c

Section F3

Assoc.	Code	%	Thickness(m)	Facies/Sub-Facies Content
Channel	I	6.1	5.7 (1 only)	I_1-2a, 2b
Overbank	J	93.9		
	J_1	2.5	0.4;0.2-0.6	2a, 2b, <u>2c</u>
	J_2	55.4	4.3;1.2-15.8	1a
	J_4	1.5	1.4 (1 only)	2a, 2c
	J_5	34.5	2.5;0.2-6.4	2a, 2b, <u>2c</u>, 2i; 1a

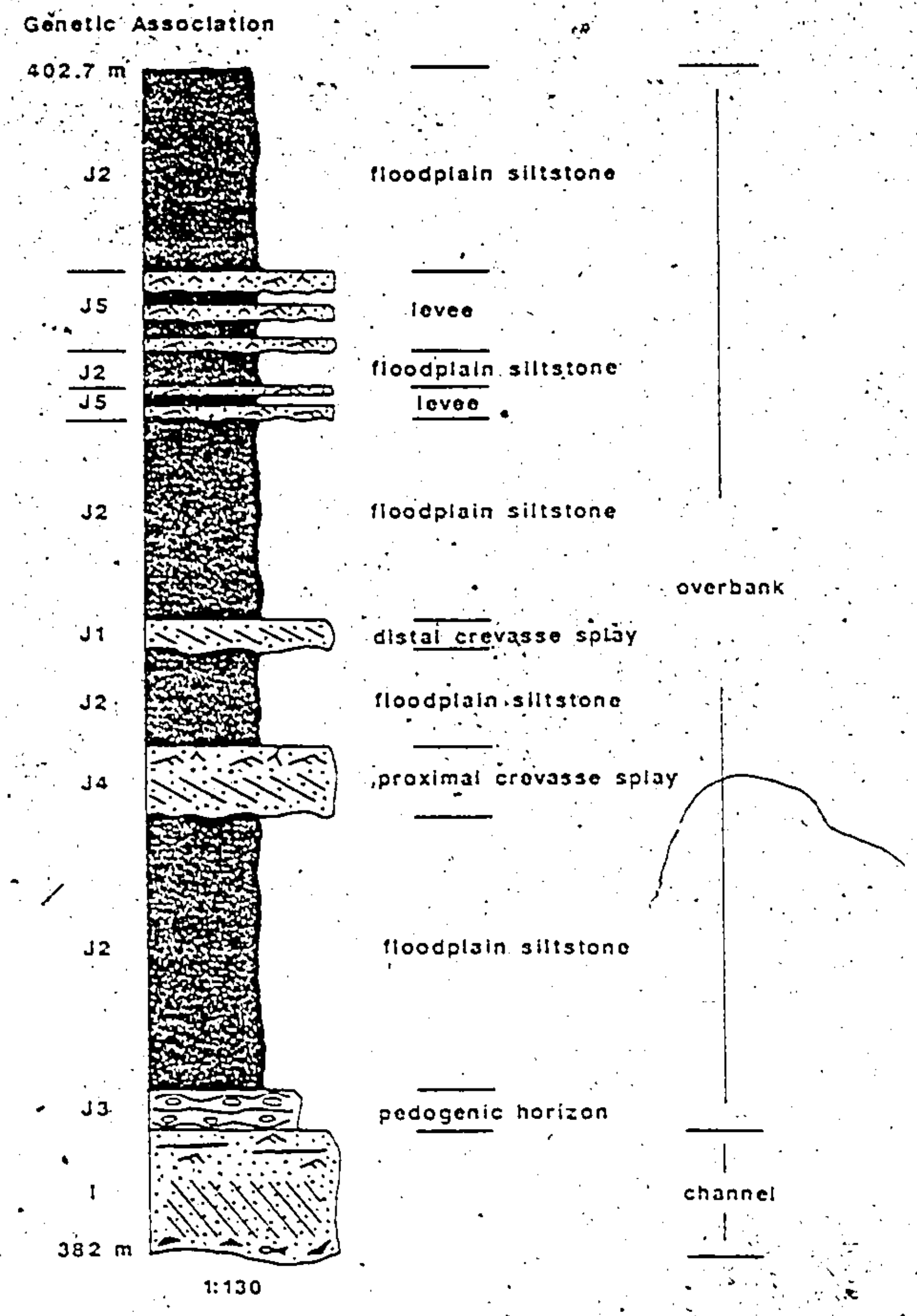
Note:

% - percentage of Fram, by cumulative thickness, represented by a genetic association or a component of a genetic association

Thickness - average thickness and range, in meters

Sub-Facies Content - all possible sub-facies in a genetic association or a component of a genetic association; not all sub-facies found at each occurrence; dominant sub-facies, if any, underscored.

Figure 2.3.10.1 - 2 Genetic associations in the Fram Formation. A representative interval from the formation at section F4 is shown.


Genetic Association
402.7 m
J2
floodplain siltstone
J5
levee
J2
floodplain siltstone
J5
levee
J2
floodplain siltstone
overbank
J1
distal crevasse splay
J2
floodplain siltstone
J4
proximal crevasse splay
J2
floodplain siltstone
J3
pedogenic horizon
I
channel
382 m
1:130

Hecla Bay Formation. In both instances the rock is a dark green to dark greenish grey, very fine grained sandstone to coarse siltstone. The sandstone and siltstone are arranged into poorly defined resistant and recessive pairs by subtle changes in the percentage of very fine sand. These pairs average ca. 1.6 m in thickness and display a considerable range in the sandstone to siltstone ratio. Occasional, isolated, 10-18 cm thick sandstone horizons displaying ripple cross-lamination and/or parallel lamination are also present amongst the resistant-recessive pairs at section F5. At both localities, the sandstone and siltstone are thoroughly ripple cross-laminated (2c and 1c, respectively) with common preservation of the ripple bedform and occasionally, at section F4, the presence of climbing ripple drift cross-lamination (2f). Subtle load structures are occasionally present at the base of the resistant sandstone intervals at both locations. Evidence of faunal activity (bioturbation and/or trace fossils) is noticeably absent from both exposures and the only macroscopic fossil evidence consists of abundant comminuted organic debris concentrated along the lamination. The interpretation of these intervals at sections F4 and F5 as lacustrine is considered justifiable for the following reasons:

1. The stratigraphic context sandwiches both intervals between either fluvial overbank and/or channel deposits.

2. A siltstone sample (GSC Loc. C-91958) from the lacustrine unit at section F4 contained abundant spores and other land plant debris without any marine palynomorphs and was suggested (McGregor, 1984a, pg.8) to be close to an abundant supply of vascular land plants.

3. The absence of any indication of sub-aerial exposure (root casts, dessication cracks, etc.) at both localities precludes a sub-aerial overbank interpretation.

4. The ripple cross-laminated resistant-recessive pairs described above readily fit a repetitive density underflow hypothesis whereby the sediment laden floodwaters expand into an overbank depression subsequent to bursting through a levee break. Rapid deposition would be anticipated in such a scenario and evidence for this is found in the presence of loading at the base of sandier units and occasional climbing ripple drift cross-lamination. The inclusion of ripped up plant material, as is represented by the abundant comminuted organic debris found along the laminations, into the floodwaters would also be anticipated. The 10-18 cm thick, isolated sandstone horizons noted in the lacustrine unit at section F5 could easily represent sand-rich density underflows.

Anderton (1985) has used the thickness of lacustrine deposits as an approximation of the depth of the lake. Application of this approach to the Fram Formation would indicate an alluvial plain lake ca. 12 m and 51 m deep at sections F4 and F5, respectively. While the lateral extent of the lacustrine units is unknown due to poor outcrop quality and the absence of additional exposures, the areal extent of each lake on its floodplain must have been significant if the estimated depths are in any way a representative scaling factor. In each case the lake was probably initiated by freshwater flooding from adjacent rivers and may have grown to such an extent on the floodplain that it was both fed and drained by one or more river channels. The longevity of lakes of this scale is suggested to be in the range of several decades to > 100 years. In the absence of any indication of subaerial exposure, such as root casts, it is suggested that each lake at no time dried up due to seasonal or longer term climatic fluctuations. The absence of body fossils, trace fossils, or any indication of bioturbation in combination with the preservation of abundant comminuted organic (plant) debris would suggest that the bottom waters of the lakes were anoxic and that the lakes were stratified. Anderton (1985) points out that while stratification is often restricted to deeper lakes which experience little mixing, shallower lakes (even as shallow as several meters) may become temporarily stratified during periods of warm, calm weather. The thickness of the lacustrine unit in the basal Fram Formation at sections F4 and E5 indicates that these lakes were intermediate, with respect to depth, between very deep, tropical, eutrophic lakes and the very shallow, small, floodplain lakes discussed by Anderton. It is therefore likely that they were at least periodically stratified with anoxic bottom waters. A contributing factor to what appears to have been a rather hostile lacustrine environment may have been the near strandline position postulated for the Fram Formation (discussed subsequently). A freshwater lake in this position on a floodplain could be subject to occasional, sudden, influxes of salt water associated with temporary inundations of the coastal plain caused by strong on shore storm winds. The resulting sudden change in water chemistry would not be conducive to the establishment of an indigenous fauna.

The occurrence of relatively large floodplain lakes at the same stratigraphic position in the Fram Formation, at widely spaced localities, suggests a common regional control. Since both lacustrine units are found at or near the transition from a braided fluvial Hecla Bay Formation to a meandering fluvial Fram Formation, it is possible that a reduction in regional slope may have been the cause.

I. Channel Association

Main-channel sandstone units are defined for all exposures of the Fram Formation. The establishment of a set of criteria which provided unequivocal distinction between main-channel sandstone units and overbank sandstones, presumably associated with crevasse splays and which may or may not have been deposited from channelized flows, was problematic. Both Collinson (1978) and Bridge (1985) have commented on this difficult distinction. Collinson notes that both overbank and main-channel sands can be erosionally based and contain a similar assemblage of sedimentary structures; he suggests using an arbitrary, but reasonable, thickness criterion of 2.0 m for the distinction, believing that "most" overbank sandstones could be expected to be thinner. Bridge acknowledges the difficulty by noting that both could be erosionally based, display a cyclicity when preserved, and that there could be a complete gradation between them with respect to thickness. For the Fram Formation, the use of an assemblage of criteria such as stratigraphic context, basal contact, fossil content, sedimentary structures, etc., does not provide a consistent and reasonable interpretation. As a result, the 2.0 m thickness criterion suggested by Collinson (1978, pg. 54) is adopted. This contrasts with the 1.0 m criterion established for the Strathcona Fiord Formation at sections S2 and HB1. This is not considered to be an inconsistency in the application of the meandering fluvial model, since highly sinuous, undivided channel systems should certainly not be expected to display a uniformity of channel scale.

As shown in Table 2.3.10.1-1, the importance of main-channel sandstone units in the Fram Formation varies somewhat across southwestern Ellesmere Island from a minimum of 6.1%, by cumulative thickness, in section F3, to a maximum of 32.9% at section HG2. The average thickness of channel sandstones in the Fram Formation does not display much variation throughout the study area, ranging only between 2.9 m at section F4 and 4.3 m at section HG2. It is difficult to evaluate the presence or absence of areal trends in the Fram Formation since different stratigraphic levels in the formation are exposed at different sections. However, within this constraint, neither average channel thickness or the percentage of the formation represented by channel sandstone units displays an areal trend across southwestern Ellesmere Island.

The channel sandstones in the Fram Formation all display erosional basal contacts where exposed and, as was the case for the channel sandstones in the Strathcona Fiord Formation at section S2 and HB1, may be divided into a lower and upper channel fill designated I1 and I2, respectively. The sub-facies content of each of these components at each exposure of the formation is also presented in Table 2.3.10.1-1. It is stressed that this table presents the maximum number of sub-facies possible in each component and that individual occurrences of the lower or upper channel fill only contain a sub-set of the possible sub-facies. This is not as significant for the upper channel fill (I2) since it usually only consisted of ripple cross-laminated sandstone (2c). Planar tabular cross-bedded sandstone (2a) is the most frequently occurring sub-facies in the lower channel fill at all exposures of the Fram Formation. Of equal importance, at section F5, is non-stratified sandstone (2i). While the sequence of primary sedimentary structures in the lower channel fill is variable, the basal sub-facies is usually either non-stratified or planar tabular cross-bedded sandstone.

The most frequent macroscopic fossils found in the channel sandstones are ostracoderm plate fragments and partial plant casts occurring as part of the basal lag.

Rarely, root casts and/or unidentified burrows are found in the top of channel sandstone units.

J. Overbank Association

Overbank sediments consist of sandstone and siltstone. As was the case for the Strathcona Fiord Formation at sections S2 and HB1, five types of overbank sediment packages are defined in the Fram Formation (J1 to J5) and are given similar genetic interpretations. Overbank components J1, J2, J4 and J5 are identified at all exposures of the formation studied in detail. Component J3, interpreted as indicative of flood plain pedogenesis, is present at sections F2 and F4 only. As indicated in Table 2.3.10.1-1, all exposures of the Fram Formation are dominated by overbank sediments. They represent from 55.8% of the exposed formation, by cumulative thickness, at section F5 to 93.9% at section F3. The position within the coastal plain meandering fluvial setting envisaged for each of the overbank components is shown in Figure 2.3.10.1-1.

Overbank component J2 is interpreted to represent the background or "normal" overbank fines deposit. As shown in Table 2.3.10.1-1, this component consists almost entirely of non-stratified siltstone (1a) with minor occurrences of ripple cross-laminated siltstone (1c) and rooted siltstone (le). The basal contact of this overbank component is always gradational where exposed. It occurs either directly overlying channel sandstone or interstratified amongst other overbank sediments. Overbank component J2 dominates the overbank sediments in all sections of the formation except F5 where it is secondary in importance after J5 sediments. Average unit thickness for this component varies amongst the exposures from a minimum of 1.7 m in section HG2 to a maximum of 4.3 m in section F3. Fossil evidence considered supportive of the overbank interpretation consists of occasional root casts and abundant comminuted plant debris. Palynological analyses are also supportive of the genetic interpretation. GSC Loc. C-91976 from section HG2, C-91913, 91915, 91919 and 91921 from section F2 and C-91938 from section F3 all contain terrestrial spores and associated woody land plant tissue (McGregor, 1982, 1984a).

As mentioned above, overbank component J3, considered indicative of floodplain pedogenesis, is only present in sections F2 and F4. At both localities it is a minor component of the overbank sediments constituting only 1.0 and 0.5% by cumulative thickness, respectively. It is a nodular weathering, variegated grey,red and white sandstone. Average unit thickness varies from 0.6 m at section F4 to 2.8 m (one only) at section F2. It occurs interstratified amongst other overbank sediments and contains no fossils.

Figure 2.3.10.1-1 indicates that overbank components J4 and J1 are considered to be proximal and distal crevasse splay sandstones, respectively. They occur interstratified amongst other overbank sediments and as Table 2.3.10.1-1 indicates are represented by a similar array of sandstone sub-facies in all sections of the Fram Formation. Of course, individual occurrences of either component consists of only a sub-set of the possible sub-facies shown in this table. The prominent sub-facies for J4 sediments is ripple cross-laminated sandstone (2c), while for J1 sediments it is either ripple cross-laminated (2c) or non-stratified sandstone (2i). The paucity of planar tabular cross-bedded sandstone (2a) in either J1 or J4 sediments is suggested to be a reflection of the rapid decrease in both flow strength and depth with expansion subsequent to breaking through the levee. Due to the similarity in sub-facies composition an arbitrary thickness criterion was established to distinguish J4 and J1 deposits. It is likely that the thinner overbank sandstone units (i.e., < 1.0 m) are representing the most distal crevasse splay deposits while sandstone units > 1.0 m and up to 2.0 m in thickness are likely more proximal deposits. Where exposed, the basal contact of J1 and J4 sandstones is commonly erosional and rarely sharp, as would be anticipated for overbank flood units. Proximal overbank sandstone deposits constitute from 1.5% (section F3) to 13.2% (section F2) of the Fram Formation, by cumulative thickness. They display an average unit thickness of ca. 1.5 m across southwestern Ellesmere Island. Distal overbank sandstones represent 1.6% (section F5) to 5.4% (section HG2) of the formation, by cumulative thickness. They display an average unit thickness of 0.4 m (section F3) to 0.7 m (section F5) throughout the study area. Macroscopic fossil material noted in J1 and J4 sandstones is similar. It consists of partial plant casts and ostracoderm fragments usually found near the base of units and root casts or occasional unidentified burrows noted at the top of some units. Both proximal and distal sandstones occasionally display internal scours interpreted as indicative of multiple depositional episodes.

Overbank component J5 consists of couplets of sandstone and siltstone usually several centimeters to several decimeters in thickness. As indicated on Figure 2.3.10.1-1, it is interpreted to represent an episodically deposited proximal overbank deposit (levee deposit). J5 couplets occur either directly overlying channel sandstone or interstratified amongst other overbank sediments. The couplet arrangement is suggested to reflect a more passive overtopping of channel margins by floodwaters as opposed to a catastrophic levee break associated with crevasse splay formation. The basal sandstone of the couplets is suggested to represent rising stage deposition while the siltstone is interpreted as a falling stage to standing flood water deposit. The couplets are usually sandstone dominant throughout southwestern Ellesmere Island with only one location, section F3, having an average siltstone to sandstone ratio in excess of unity (1.3). The maximum range displayed by this ratio varies from 0.2 (section F2) to 4.3 (section F3). While the basal contacts of the J5 couplets are frequently covered, they are most frequently gradational and rarely erosional, as might be anticipated for a more passive flooding mechanism. J5 couplets usually constitute the second most dominant overbank component in the Fram Formation. At section F5, they are dominant. As indicated in Table 2.3.10.1-1, their importance varies from 19% at section HG2 to 34.5% at section F3. Average unit thickness varies from 2.1 m at section F2 to 5.1 m at section F5. Table 2.3.10.1-1 also indicates that compositionally the couplets are dominated by ripple cross-laminated sandstone (2c) and non-stratified siltstone(1a). Macroscopic fossil material noted in the J5 couplets consists of comminuted plant debris and ostracoderm fragments occasionally found in the basal sandstone, plus occasional root casts and rare, unidentified, burrows in the siltstone. Palynological analyses by McGregor (1982, 1984a) on siltstone samples from this overbank component commonly found terrestrial spores and associated, miscellaneous land plant debris (GSC Loc. C-91911, 91912, 91914, 91916, 91917, 91918 at section F2; C-91934, 91936, 91940 at section F3; C-91965, 91966, 91971 at section F4; C-91975, 91977 at section HG2).

2.3.10.2 Facies Sequence Analysis

All sections in the Fram Formation that were investigated in detail were also subjected to a contingency table analysis of their facies transitions using the statistical software package BMDP-4f (Brown, 1983). As was the case for the Strathcona Fiord and Hecla Bay Formations, the purpose of the statistical analyses is to isolate non-random transitions and possibly cyclicity which may exist in sections in the Fram Formation. If found, these features provide objective insight into the sedimentary processes operating within the depositional environment, which in turn may aid in its identification. A discussion of the use of this particular BMDP program was presented previously in 2.1.7.2.

The results of the computation for sections F5, F2, HG2, F3 and F4 are shown in Figure 2.3.10.2-1 which presents copies of BMDP-4f printouts. Using the same criterion probability (0.20) that was used previously for the Strathcona Fiord and Hecla Bay Formations, all sections in the Fram Formation are found to contain the Markov property (i.e., a memory) except section HG2, where the maximum likelihood-ratio chi-square statistic had a probability (0.2764) that exceeded the criterion value. Stepwise cell selection on the expected value matrices for the remaining sections in the formation indicated that cyclicity is present only in section F2. Figure 2.3.10.2-2 presents the preferred facies relationship diagrams (PFD) for the sections containing a memory and accompanying summary sections for the locations at which the formation exhibited a more complex dependency amongst a number of sub-facies/facies.

It should be noted, that for the sake of simplicity in constructing the observed frequency tables and to help clarify which depositional processes are displaying a dependency, the siltstone and sandstone of the proximal overbank couplets, J5, interpreted as levee deposits, are grouped together and considered as Povb (proximal overbank) in the contingency table computations.

Figure 2.3.10.2 - 1 Markov Chain analyses of the Fram Formation at sections F5, HG2, F2, F4 and F3. Computations performed using BMDP-4F.

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM FORMATION AT SECTION FS

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*************************
* TABLE PARAGRAPH    1  *
*************************
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***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE 1A	1C	POVB	2A	2B	2C	2I	2L	TOTAL
1A	0 *	0	1	5	2	5	5	0 -	18
1C	0	0 *	0	0	0	0	1	0 -	1
POVB	[illegible]	0	0 *	1	0	0	1	0 -	12
2A	[illegible]	0	2	0 *	4	6	2	1 -	17
2B	1	0	0	1	0 *	1	2	0 -	11
2C	5	0	4	2	1	0 *	0	0 -	15
2I	[illegible]	1	5	2	1	4	0 *	0 -	14
2L	[illegible]	0	0	0	0	0	0	0 *	0
TOTAL	22	1	12	[illegible]	10	18	11	1 -	48

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 48
SUMMED OVER 56 CELLS WITHOUT STRUCTURAL ZEROS

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*****************
*   MODEL  1    *
*****************
```

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB.	PEARSON CHI-SQUARE	PROB.	ITER.
A.J.	35	54.53	.0193	55.25	.0161	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE 1A	1C	POVB	2A	2B	2C	2I	2L	TOTAL
1A	[illegible] *	.2	3.2	3.7	2.6	5.1	3.0	.2 -	18.0
1C	.3	.0 *	.1	.2	.1	.2	.1	.0 -	1.0
POVB	1.7	.2	1.6 *	[illegible]	1.5	2.9	1.7	.1 -	12.0
2A	[illegible]	.2	[illegible]	[illegible] *	2.1	4.1	2.4	.2 -	17.0
2B	1.3	.1	[illegible]	1.4	[illegible] *	2.5	1.3	.1 -	11.0
2C	[illegible]	.2	[illegible]	[illegible]	2.0	[illegible] *	2.3	.2 -	15.0
2I	[illegible]	.2	2.1	[illegible]	1.7	1.3	1.3 *	.1 -	14.0
2L	.2 *	.3	.3	.3	.3	.0	.3	.0 *	.0
TOTAL	22.[illegible]	1.0	12.0	13.0	[illegible]	14.[illegible]	11.0	[illegible] -	48.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM FORMATION AT SECTION FS

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE =(OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	ABOVE
0	54.53	35	.01878	3.274	POVB	1A
1	36.73	34	.34353			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1C	POVB	2A	2B	2C	2I	2L
1A	.0 *	.2	2.4	3.9	2.6	5.2	3.0	.2
1C	.2	.6 *	.1	.2	.1	.2	.1	.0
POVB	.3 *	.0	.0 *	.5	.3	.7	.4	.0
2A	1.5	.2	2.7	.0 *	2.5	4.9	2.3	.2
2B	2.1	.1	1.6	2.2	.0 *	3.0	1.4	.1
2C	1.4	.2	2.6	1.5	2.4	.0 *	2.4	.2
2I	2.3	.2	2.1	2.9	2.0	3.9	.0 *	.2
2L	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION HG2

****
* TABLE PARAGRAPH 1 *
****

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVB	2A	2B	2C	2G	2I	2K	TOTAL
1A	3 *	3	2	3	5	0	6	0	19
POVB	6	0 *	0	8	1	0	1	0	8
2A	1	1	0 *	1	4	1	0	0	8
2B	1	0	1	6 *	4	1	0	0	7
2C	8	3	2	3	0 *	0	1	1	18
2G	0	0	0	0	2	0 *	0	0	2
2I	3	0	2	0	3	0	0 *	0	8
2K	0	1	0	0	0	0	0	0 *	1
TOTAL	19	8	7	7	19	2	8	1	71

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 71
SUMMED OVER 56 CELLS WITHOUT STRUCTURAL ZEROS

****
* MODEL 1 *
****

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B,	41	45.30	.2764	48.64	.1926	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVB	2A	2B	2C	2G	2I	2K	TOTAL
1A	3.3 *	2.7	2.3	2.1	5.0	.6	2.7	.2	19.0
POVB	2.7	.3 *	.4	.4	2.6	.2	.3	.1	8.0
2A	2.7	.3	.4 *	.7	2.6	.2	.3	.1	8.0
2B	2.3	.3	.7	.7 *	2.3	.2	.4	.1	7.0
2C	7.7	2.5	2.2	2.2	7.5 *	.6	2.5	.3	18.0
2G	.6	.2	.2	.2	.6	.0 *	.2	.0	2.0
2I	2.7	.3	.4	.4	2.6	.2	.3 *	.1	8.0
2K	.3	.1	.1	.1	.3	.0	.1	.0 *	1.0
TOTAL	[illegible]	8.0	7.0	7.0	[illegible]	2.0	8.0	1.0	71.0

****** STEPWISE CELL DELETION IS NOT PERFORMED. P-VALUE OF MODEL FIT (.2764) IS GREATER THAN CRITERION PROB (.2000)

IHOP+F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F2

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1C	POVB	2A	2B	2C	2G	2I	TOTAL
1A	0 *	0	18	12	2	8	0	5	45
1C	1	0 *	0	[illegible]	0	0	0	0	1
POVB	15	0	0 *	2	2	1	2	0	22
2A	5	0	0	0 *	12	19	0	2	38
2B	2	1	0	11	0 *	14	0	2	30
2C	21	0	5	6	7	0 *	0	1	40
2G	1	0	0	0	0	1	0 *	0	2
2I	2	0	0	5	4	1	0	0 *	13
TOTAL	47	1	23	37	27	44	2	10	191

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 191
SUMMED OVER 56 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	41	125.43	.0001	127.55	.0000	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1C	POVB	2A	2B	2C	2G	2I	TOTAL
1A	16.4 *	.3	6.7	12.9	4.2	24.6	.5	2.7	45.0
1C	.3	.3 *	.1	.2	.1	.2	.0	.3	1.0
POVB	3.3	.1	2.7 *	4.8	3.1	5.9	.2	1.1	22.0
2A	12.6	.2	5.1	9.2 *	6.3	11.3	.4	2.1	38.0
2B	9.3	.1	3.7	6.7	5.9 *	9.3	.3	1.5	30.0
2C	14.1	.2	5.7	10.2	7.3	12.5 *	.4	2.4	40.0
2G	.5	.0	.2	.4	.3	.5	.0 *	.1	2.0
2I	3.6	.1	1.5	2.7	1.4	3.2	.1	.6 *	13.0
TOTAL	47.0	1.0	23.0	37.0	27.0	44.0	2.0	10.0	191.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F2

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	125.43	41	.00000	4.839	1A	POVB
1	96.00	40	.00000	3.646	POVB	2B
2	86.44	39	.00002	4.054	POVB	1A
3	63.46	38	.00540	2.639	2C	1A
4	46.23	37	.14073	3.624	2C	POVB
5	30.21	36	.73393			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	1C	POVB	2A	2B	2C	2G	2I
1A	.3 *	.2	.0 *	3.4	6.1	9.0	.0 *	1.3
1C	.1	.0 *	.0 *	.1	.2	.3	.0 *	.1
POVB	.0 *	.0	.0 *	1.4	2.1	1.7	.0 *	.4
2A	5.6	.3	.0 *	.3 *	11.5	16.9	.0 *	3.6
2B	3.7	.2	.0 *	12.3	.3 *	11.3	.0 *	2.7
2C	.0 *	.1	.0 *	7.6	4.8	.0 *	.0 *	1.5
2G	.2	.0	.0 *	.7	.4	.6	.0 *	.1
2I	1.4	.1	.0 *	4.5	2.3	4.2	.0 *	.0 *

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F4

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1E	POVB	2A	2B	2C	2I	2L	6	TOTAL
1A	0 *	0	29	10	2	4	8	0	0	53
1E	0	0 *	0	1	0	0	0	0	0	1
POVB	34	0	0 *	5	2	0	2	0	0	43
2A	0	0	4	3 *	4	6	4	1	1	23
2B	2	0	2	3	0 *	4	0	0	0	11
2C	7	1	6	1	0	0 *	0	0	2	17
2I	4	0	2	2	2	4	0 *	0	0	14
2L	0	0	1	0	0	0	0	0 *	0	1
6	3	0	0	[illegible]	0	0	0	0	0 *	3
TOTAL	53	1	44	22	10	18	14	1	3	166

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 166
SUMMED OVER 72 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	55	95.42	.0006	113.17	.0000	7

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	1E	POVB	2A	2B	2C	2I	2L	6	TOTAL
1A	14.3 *	.4	23.5	3.6	4.1	7.7	5.3	.4	1.2	53.0
1E	.4	.0 *	.3	.1	.0	.1	.1	.0	.0	1.0
POVB	13.1	.3	15.6 *	9.9	2.9	5.2	4.0	.3	.4	43.0
2A	13.2	.1	7.3	2.9 *	1.2	2.3	1.7	.1	.4	23.0
2B	4.5	.1	3.1	1.3	.5 *	1.0	.8	.1	.2	11.0
2C	7.3	.1	5.6	2.1	.3	1.6 *	1.3	.1	.3	17.0
2I	5.3	.1	4.0	1.7	.7	1.3	1.3 *	.1	.2	14.0
2L	.4	.0	.3	.1	.0	.1	.1	.0 *	.0	1.0
6	1.2	.0	.6	.3	.1	.3	.2	.0	.0 *	3.0
TOTAL	53.0	1.0	44.0	22.0	10.0	18.0	14.0	1.0	3.0	166.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F4

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP #	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	95.46	55	.00057	3.454	2C	6
1	90.33	54	.00131	3.375	2C	1E
2	83.75	53	.00451	2.966	2B	23
3	77.03	52	.01345	3.039	2A	2C
4	68.01	51	.05651	3.365	2I	2C
5	58.33	50	.19470	3.118	2A	23
6	51.13	49	.39121			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL,

ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	1E	POVH	2A	2B	2C	2I	2L	6
1A	.2 *	.4 *	23.6	11.0	3.1	2.4	5.3	.5	.5
1E	.5	.3 *	.3	.1	.3	.3	.1	.3	.8
POVB	23.1	.3 *	.3 *	6.7	1.3	1.5	4.2	.3	.3
2A	7.3	.3 *	4.5	.2 *	.3 *	.0 *	1.1	.1	.1
2B	3.4	.3 *	2.1	.8	.3 *	.0 *	.5	.0	.6
2C	6.7	.3 *	4.2	1.6	.5	.3 *	1.0	.1	.0 *
2I	5.1	.3 *	3.2	1.2	.3	.0 *	.0 *	.1	.1
2L	.5	.3 *	.3	.1	.3	.0	.1	.3 *	.0
6	1.4	.0 *	.3	.3	.1	.1	.2	.0	.0 *

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F3

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW	1A	POVB	2A (ABOVE)	2B	2C	2G	TOTAL
1A	0 *	8	2	1	0	1	12
POVB	7	0 *	0	1	3	0	11
2A	0	0	0 *	2	1	0	3
2B	2	1	0	0 *	1	0	4
2C	3	2	0	0	0 *	0	5
2G	0	0	1	0	0	0 *	1
TOTAL	12	11	3	4	5	1	36

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 36
SUMMED OVER 30 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	13	28.62	.0721	37.36	.0071	6

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW	1A	POVB	2A (ABOVE)	2B	2C	2G	TOTAL
1A	7.5 *	6.4	1.3	1.7	2.2	.4	12.0
POVB	6.4	5.3 *	1.0	1.4	1.9	.3	11.0
2A	1.3	1.0	.2 *	.3	.4	.1	3.0
2B	1.7	1.4	.3	.4 *	.5	.1	4.0
2C	2.2	1.8	.4	.5	.6 *	.1	5.0
2G	.4	.3	.1	.1	.1	.0 *	1.0
TOTAL	12.0	11.0	3.0	4.0	5.0	1.0	36.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE FRAM PORTION OF SECTION F3

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	28.62	19	.07214	3.666	2G	2A
1	22.79	18	.15860	3.279	2A	2B
2	15.78	17	.53373			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

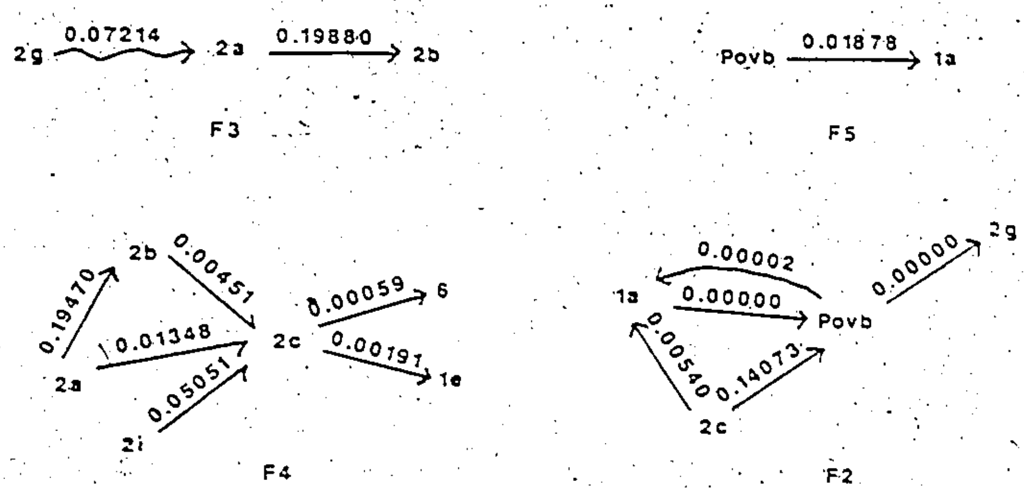
***** EXPECTED VALUES USING ABOVE MODEL.

ASTERISK INDICATES MISSING VALUE

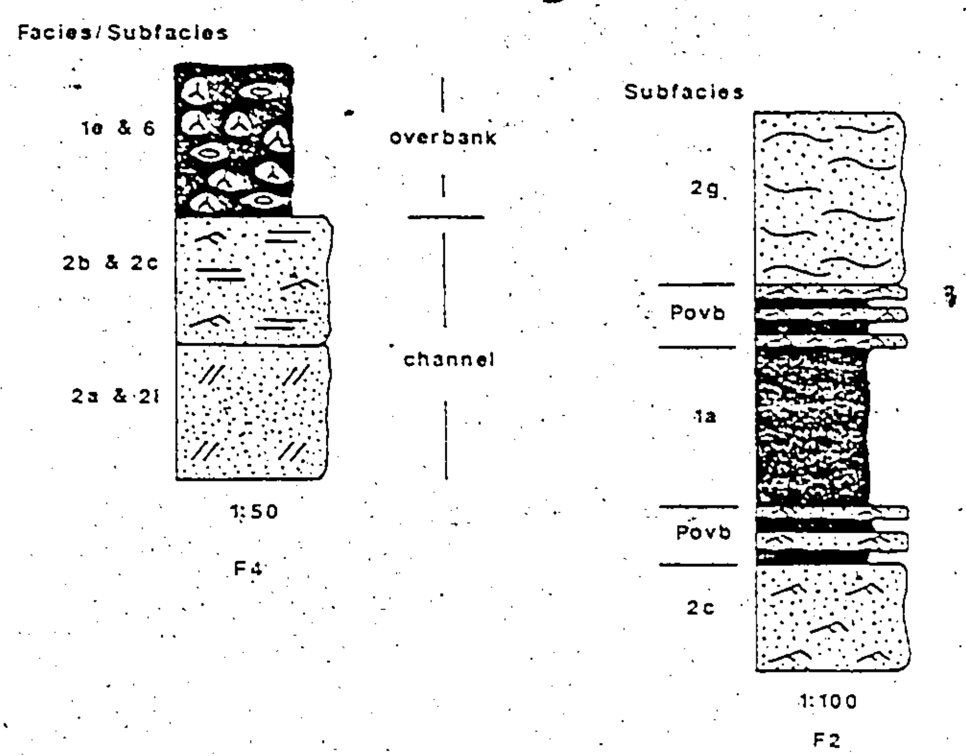
BELOW \ ABOVE	1A	POVB	2A	2B	2C	2G
1A	.0 *	7.3	.9	1.0	2.5	.4
POVB	7.3	.0 *	.7	.3	1.9	.3
2A	.5	.4	.0 *	.0 *	.2	.0
2B	1.3	1.4	.2	.0 *	.5	.1
2C	2.5	1.1	.2	.3	.0 *	.1
2G	.0 *	.6 *	.0 *	.0 *	.0 *	.6 *

Figure 2.3.10.2 - 2 Preferred facies relationship diagrams (A) and summary sections (B) for the Fram Formation. Summary sections are provided only for those sections that have a complex PFD (F4 & F2). Average sub-facies thickness was used in the construction of the summary sections.

A


2g
0.07214
2a
0.19880
2b
F3
Povb
0.01878
1a
F5
2b
0.19470
0.00451
0.01348
2c
0.00059
6
0.00191
1e
2a
0.05051
2i
F4
0.00002
2g
1a
0.00000
Povb
0.00000
0.00540
0.14073
2c
F2

B


Facies/Subfacies
1e & 6
2b & 2c
2a & 2i
overbank
channel
1:50
F4
Subfacies
2g
Povb
1a
Povb
2c
1:100
F2

The PFD for sections F5 and F3 is relatively simple. In the former a dependency is indicated between two overbank deposits, Povb and siltstone sub-facies 1a. At section F3, the dependency is between sandstone sub-facies 2g, 2a and 2b which occur in either an overbank or channel setting in the formation, but are more frequently found in the latter. At both sections the PFD is supportive of the depositional elements contained in the block diagram representing the sedimentary environment envisaged for the Fram Formation (Figure 2.3.10.1-1).

As indicated in Figure 2.3.10.2-2, the PFD for sections F2 and F4 is more complex. As a result, accompanying summary sections are provided. At section F2, overbank sediments Povb and siltstone sub-facies 1a display a cyclicity and are bracketed between sandstone sub-facies 2c and 2g; the sandstone could represent either channel fill or crevasse splay deposition. At section F4, sandstone sub-facies 2a and 2i are overlain by 2b and 2c, which in turn are overlain by siltstone sub-facies 1e and facies 6, both indicative of floodplain pedogenesis. This sequence of non-random facies transitions is readily interpreted as indicative of decreasing flow strength upward through a channel fill followed by the onset of soil forming processes in the overlying floodplain sediments. As was the case for the PFD from sections F3 and F5, the application of Walthers Law to the depositional elements portrayed in Figure 2.3.10.1-1, representing the sedimentary environment envisaged for the Fram Formation, could easily produce the PFD for sections F2 and F4.

In conclusion, the preferred facies relationship diagrams (PFD) determined for sections F2, F3, F4 and F5 are considered to constitute objective support for the meandering fluvial interpretation suggested for the Fram Formation.

2.3.10.3 Discussion

Additional details of the depositional environment of the Fram Formation are discussed below in point form:

1. Trends in Fluvial System Parameters

The gross aspects of a fluvial system may be characterized through the examination of three related parameters: 1) channel size as scaled by coarse member thickness 2) coarse member to fine member ratio (c/f) 3) fining-upward cycle thickness. An examination of these parameters was conducted both vertically, at each section, and areally throughout southwestern Ellesmere Island in search of trends in the Fram Formation fluvial system(s).

At-a-section vertical trends exist in sections F2 and HG2 only. At section F2 the thickest fining-upward cycles occur in the basal 150 m of the section. Recalling that only the upper Fram Formation is exposed in this section, this could be interpreted as an indication of a greater fluvial system stability away from the Fram-Hell Gate contact. Since this section is in the Fram-Hell Gate transition zone a decrease in stability would be anticipated as the contact between the two fluvial systems is approached. At section HG2, two features are noted. Both the largest channels and the largest c/f ratios (all greater than 1.0) occur within the basal 28 m of the section. As at section F2, this section exposes only the upper Fram. These two features, if not fortuitous, indicate a decrease in channel size and an increase in overbank flows in the upper Fram Formation. The latter compliments the decreased fining-upward cycle thickness noted in the upper Fram Formation at section F2 as a further indication of a reduced fluvial system stability.

An examination of the three parameters mentioned above amongst the sections in the Fram Formation for the presence of areal trends is facilitated by construction of Table 2.3.10.3-1 and 2.3.10.3-2. Table 2.3.10.3-1 presents averages and ranges for fining upward cycle thickness and c/f ratio in the Fram Formation. Table 2.3.10.3-2, to be discussed subsequently, contains the maximum channel size, as scaled by coarse member thickness, noted at each section in the formation. Examination of these tables indicates that maximum channel size is the smallest (4.2 m) and average fining-upward cycle thickness is the largest (39.5 m) at section F4 (Goose Fiord).

It is uncertain whether the Fram Formation represents one or several similar meandering fluvial systems within this area of the Franklinian Basin. In consideration of the approximate maximum east-west extent of the study area (150 km), one fluvial system is possible. If this is the case, then the presence of the maximum average fining-upward cycle thickness at section F4 could be taken to indicate a maximum system stability in the west, which in turn could be interpreted to imply an easterly source region. In this context, the smallest maximum channel size at section F4 would seem to be a contradiction since channel scale would be expected to increase, not decrease, with the size of the drainage basin. While the Fram Formation may constitute only one fluvial system, the various channel sandstone units may not represent deposition from the same channel within

Table 2.3.10.3.-1 Characteristics of the Fluvial Fining-Upward Cycles Found in the Fram Formation at Sections F5, HG2, F2 and F4, Ordered From East To West Across Southwestern Ellesmere Island.

	F5	HG2	F2	F4
Average Thickness and Range (m)	15.9; 4.3-37.2 (av. 12.6 if outliers exclud.)	16.3; 6.9-45.9 (av. 9.8 if outliers exclud.)	13.8; 5.6-27.2	39.5; 3.8-76.1
Crs.Mbr/Fine Mbr. (average and range)	0.60; 0.08-2.31 (most < 1.0)	0.92; 0.08-2.29 (most < 1.0)	0.47; 0.16-7.0 (most < 1.0)	0.66; 0.04-3.8 (av. 0.14 if outlier exclud.)

Table 2.3.10.3.-2 Estimates of Paleochannel Morphology and Flow Characteristics for the Fram Formation Ordered From East to West Across Southwestern Ellesmere Island.

Section	Db(m)	Dbc(m)	Wb(m)	F	P	Qm(m^3/s)	L(m)
F5							
min.	2.0	1.3	10.2	7.8	2.0	0.8	183.7
max.	6.7	4.4	65.5	14.9	1.7	34.5	934.0
HG2							
min.	2.9	1.9	18.3	9.6	1.9	2.6	306.9
max.	8.0	5.2	86.1	16.6	1.6	59.4	1194.4
F2							
min.	2.0	1.3	10.2	7.8	2.0	0.8	183.7
max.	7.0	4.6	70.1	15.2	1.7	39.8	989.1
F4							
min.	2.0	1.3	10.2	7.8	2.0	0.8	183.7
max.	4.2	2.7	31.9	11.8	1.8	7.8	502.4

Db - bankfull depth from coarse member thickness; min. and max. correspond to the smallest and largest coarse member observed at a particular section and thus represent the range in paleochannel scale at that location.
Dbc - corrected bankfull depth (X 0.585/0.9 = 0.65)
Wb - bankfull width from Dbc and Leeder (1973), equation 1.
F - width/depth ratio
P - sinuosity from Ethridge and Schumm (1978, pg. 706).
Qm - mean annual discharge from Ethridge and Schumm.
L - meander wave length from Ethridge and Schumm.

that system. A possible explanation of the apparent contradiction would be that the channel deposits in section F4 represent lower order streams within the Fram fluvial system.

2. Estimates of Paleochannel Morphology and Flow Characteristics

To provide a better impression of the meandering fluvial system constituting the Fram Formation paleohydraulic calculations were completed using method two of Ethridge and Schumm (1978, pg. 706-707). These calculations were previously performed and discussed for the Strathcona Fiord Formation at section S2 (2.1.7.2). As for the Strathcona Fiord Formation, the calculations for the Fram Formation are not intended to represent an accurate reconstruction of channel size or flow magnitude, rather they can only be considered as rough approximations. Table 2.3.10.3-2 presents these calculations for the thinnest and thickest single channel sandstone noted at each section of the formation that was broken down into facies. The overall range in mean annual discharge (Qm) is 0.8 - 59.4 m^3/s indicating that the channel deposits currently exposed are representing only small to moderate size rivers. By comparison, Cant and Walker (1978) report a mean annual discharge of ca. 275 m^3/s for the South Saskatchewan River at Saskatoon. The calculated sinuosities (P) indicate that in all cases but one the channels were highly sinuous (P > or = 1.7) with rather short meander wavelengths. A consideration of the overall, average, coarse member to fine member ratio (0.66; determined from Table 2.3.10.3-1), which indicates a very overbank dominant fluvial system, with the small to moderate channel size indicated by the estimates of mean annual discharge, suggests that larger, currently unexposed, channels must have been active in this fluvial system in order to account for the high volume of overbank fines. This conclusion was also reached for the Strathcona Fiord Formation at section S2.

3. Evidence of a Marine Influence

As depicted in Figure 2.3.10.1-1, the meandering fluvial depositional environment of the Fram Formation is envisaged as occupying a distal position on a coastal plain immediately adjacent to the strandline. The proximity to a marine environment is suggested by fossil evidence recovered in sections F2, F3, F4 and HG2.

At section F2, McGregor (1982, pg. 6) notes the abundance of geminospores in a siltstone sample (GSC Loc. C-91913) taken at 31.5 m above the base of the section from overbank component J2. In a discussion of the sample McGregor notes that a concentration of geminospores has been suggested to indicate a marginal marine setting by some investigators.

Evidence for a marine influence at section F3 consists of leiosphaerid acritarchs noted by McGregor (1984a, pg. 2), in a siltstone (GSC Loc. C-91938) sampled at 73.3 m above the base of the section from another J2 deposit. These palynomorphs are commonly thought to be indicative of marine conditions.

At section HG2, scolecodonts were noted by McGregor (1984a, pg. 12), in a siltstone sample (GSC Loc. C-91975) taken at 13.1 m above the base of the section from a 2.0 m thick interval of overbank component J5 representing levee sedimentation. While the paleoecology of the soft bodied worm-like organisms from which the scolecodonts are thought to be derived (scattered jaw elements) is largely unknown, they are thought to represent shallow marine conditions.

Macroscopic evidence of a marine influence at section F4 consists of one occurrence of the trace fossil Cylindrichnus noted in a 1.6 m thick sandstone unit at 493.8 m above the base of the section representing overbank component J4, a proximal crevasse splay deposit. This sandstone unit has a gradational basal contact and also displays minor nodular weathering, root casts and mudcracks at its top, all subaerial indicators. It is sandwiched between other overbank components (J5 below and J2 above). This trace fossil is a feeding structure cited by Ekdale, Bromley and Pemberton (1984, pg. 179) as one of an assemblage of trace fossils that are used to identify ancient tidal flat deposits. In the context of the other features in its containing unit, and its stratigraphic context, its presence can only be interpreted as indicative of temporary marine incursions, perhaps quite frequent, into the floodplain environment.

The fossil and trace fossil evidence mentioned above does not jeopardize the non-marine interpretation offered for the Fram Formation across southwestern Ellesmere Island. It is readily overshadowed by an abundance of stratigraphic, sedimentologic and other palynologic evidence which indicates a fluvial environment. It must be taken as indicative of an intermittent marine influence however, which forces a distal coastal plain setting. The mechanism(s) responsible for the presence of the marginal marine trace fossil, and the deposition of the marine microfossils, in a floodplain environment could have been: 1) an estuarine behavior of distributary channels during unusually high tides and/or storms during which time the salt wedge could move farther inland and overtop the channel banks depositing marine microfossils in proximal or distal floodplain settings 2) simple flooding of low lying interchannel areas by marine waters during strong on shore storm winds.

4. Evidence of Weak Epeirogenesis

One of the principal conclusions reached during the preceding discussion of the Hecla Bay Formation (2.2.8.3) is that the Franklinian Basin was tectonically unstable during its deposition. It was suggested above (2.3.10.1) that the occurrence of lacustrine deposits near or at the base of the Fram Formation at widely spaced locations (sections F4 and F5) indicates a reduced regional paleoslope. Considered cumulatively, these two lines of evidence suggest a scenario whereby an uplifted source region, which causes braided stream Hecla Bay deposition, is gradually worn down by erosion during Hecla Bay time until a minimum regional paleoslope is reached which promotes lake development at the beginning of Fram time. It is suggested that the return to fluvial deposition throughout the remainder of Fram time (Late Givetian or Early Frasnian to Middle Frasnian) can be considered as evidence of renewed weak epeirogenesis. The overbank dominant fluvial architecture of the Fram Formation suggests that the magnitude of source region uplift never equaled that which occurred during Hecla Bay time.

5. Comparison to the Strathcona Fiord Formation

The Fram Formation is the second formation in the Okse Bay Group to be interpreted as a meandering fluvial deposit, the first being the Strathcona Fiord Formation at sections S2 and HB1. Despite this similarity, the Fram fluvial system differs from that of the Strathcona Fiord in two important respects:

1. While consideration of coarse member/fine member ratios and channel size estimates from paleohydraulic calculations for each formation would suggest that both the Fram and Strathcona Fiord Formations contain larger, as yet unexposed channels, facies analysis and interpretation indicates that currently the scale of the channels in the Fram fluvial system exceeds that noted in the Strathcona Fiord.
2. Although both meandering fluvial systems are considered to have occupied a coastal plain, microfossil and trace fossil evidence in the Fram Formation suggests that its position on an coastal plain was more distal which permitted infrequent, temporary marine flooding, possibly during storms.

2.4 Hell Gate Formation

2.4.1 Introduction

The Hell Gate Formation is the second highest formation in the Okse Bay Group. It is stratigraphically equivalent to the central portion of the Beverley Inlet Formation in the western Arctic Islands and has a limited areal extent between eastern Grinnell Peninsula on northwestern Devon Island and the region just south of Sor Fiord on southwestern Ellesmere Island (Embry and Klovan, 1976).

Characteristically it is a quartz-rich, grey-white, resistant weathering formation which from the air appears very similar to the Hecla Bay Formation. It is underlain and overlain by the Fram Formation and the Nordstrand Point Formation, respectively, the latter being the highest formation in the Okse Bay Group. Where exposed, the formation contacts are transitional and conformable. The contact with the Fram Formation is exposed at four locations: at the top of section F2 (Bird Fiord), 155 m above the base of section HG2 (southeast of Bird Fiord), 105 m above the base of section F3 (Hell Gate), and at the top of section F4 (inner Goose Fiord). The contact with the Nordstrand Point Formation is exposed at one location, ca. 91 m above the base of section HG3 (southeast of Okse Bay).

The Hell Gate Formation was examined at five locations on southwestern Ellesmere Island. Ordered from east to west, these locations are section HG2, F2, HG1, HG3 and F3. These section locations are shown in Figure 2.1.1-1. A total of 955 m was measured in the Hell Gate Formation. Each section location exposing the Hell Gate Formation is discussed individually.

2.4.2 Summary of Lithological Descriptions and Age Determinations from Previous Studies

2.4.2.1 Lithological Descriptions

McLaren (1963a) states that it is unlikely that per Schei examined what is now known as the Okse Bay Group north of Goose Fiord. If such is the case, then Schei (1903, 1904) did not investigate what is now known as the Hell Gate Formation.

McLaren defined four informal members for what was then the Okse Bay Formation at his type area in the region of Okse Bay and the south arm of Bird Fiord. From his descriptions and the stratigraphic arrangement of the members it is apparent that the Hell Gate Formation corresponds to his upper sandstone member. He describes that member as consisting of sandstone and shale, as did the preceding lower sandstone and shale member (now the Fram

Formation), but with the amount of sandstone increased significantly to the point where it constitutes more than half of the total thickness of the member. The upper 700 ft of the member are described as consisting of "thick-bedded, massive, ferruginous, quartzose sandstones with some thin shale beds."

The only other investigation, prior to this study, to examine what is now known as the Hell Gate Formation is that of Embry and Klovan (1976). These authors defined the Hell Gate Formation based on a type section located along the east side of Okse Bay. At the type section, the formation is described as consisting mainly of white, fine grained sandstone with interbedded siltstone and shale. Sandstone units have basal scour surfaces with shale-chip conglomerates, can contain trough and/or planar tabular cross-beds, ripple cross-lamination, or be entirely massive; they vary from 5 - 25 m in thickness. The recessive weathering shale/siltstone units are described as carbonaceous, grey in color and varying from 3 - 7 m in thickness. These authors also examined the Hell Gate Formation on eastern Grinnell Peninsula where its lithological characteristics are the same as at the type section.

2.4.2.2 Age Determinations

McLaren (1963a, pg. 331) reports work by Fry on plant impressions collected from the lower beds of the upper sandstone member (now the Hell Gate Formation) which suggested a Late Devonian age.

Embry and Klovan (1976, pg. 554) obtained no palynological age control from the formation itself at either the Grinnell Peninsula locality or at the type section . At both locations, the formation is dated as Middle Frasnian based on palynological evidence from overlying and underlying formations.

2.4.3 Summary Facies Descriptions

The lithological composition of the Hell Gate Formation is summarized below by combining the results of the facies analysis performed on the formation at each of the five section locations. Of the 955 m measured, only 6.4% was covered.

Contrasting with the underlying Fram Formation, which consists of approximately equal amounts of sandstone and siltstone/shale (2.3.3), the Hell Gate Formation is composed dominantly of sandstone (69.9% by cumulative thickness) with a relatively less important volume of siltstone (30%). One, 0.5 m thick, chert pebble conglomerate unit was noted in section HG1 constituting 0.1% of the formation by cumulative thickness.

Table 2.4.3-1 provides the descriptive attributes of each of seven sandstone, one siltstone and one conglomerate sub-facies. Figure 2.4.3-1 shows the relative proportion of the formation, by cumulative thickness, represented by each of the sub-facies.

Again, it is stressed that the average thickness and ranges stated for the sub-facies of Table 2.4.3-1, and for similar tables corresponding to individual section locations, are accurate only to the extent that the correct relative order between the sub-facies is established. While stratigraphic unit thickness was always measured, in some instances sub-facies thickness within the unit had to be estimated due to time, weather or outcrop quality constraints.

Facies 1 - Siltstone

Siltstone in the Hell Gate Formation has two principal modes of occurrence. It is found in centimeter thick horizons interstratified with sandstone horizons of comparable thickness forming siltstone-sandstone couplets several tens of centimeters thick, or it can occur in much

Figure 2.4.3 - 1 Sub-facies in the Hell Gate Formation (all sections considered cumulatively). Percentage of the formation by cumulative thickness is shown on the ordinate scale.

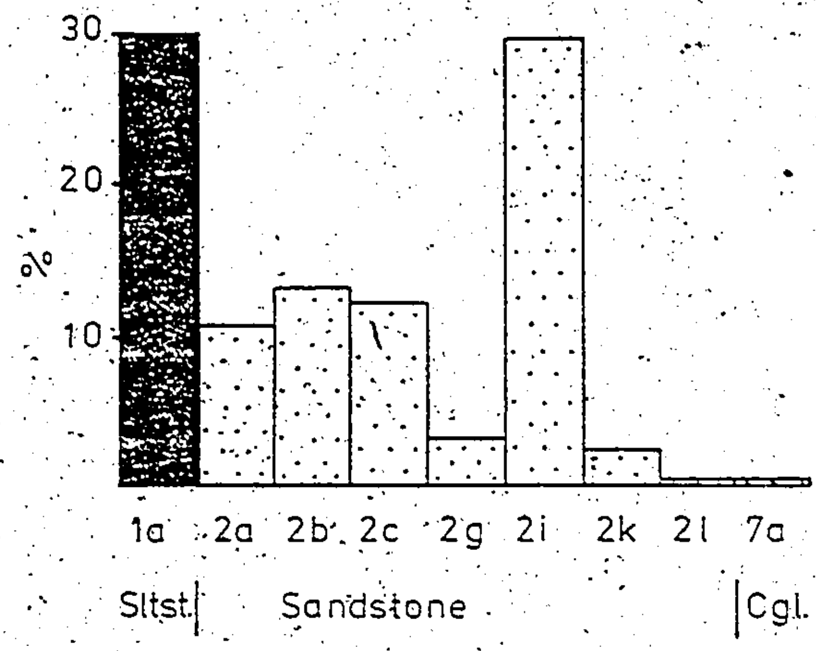

30
20
%
10
1a
2a
2b
2c
2g
2i
2k
2l
7a
Sltst.
Sandstone
Cgl.

Table 2.4.3-1 Descriptive Attributes of Sub-Facies Defined in the Hell Gate Formation (all sections considered cumulatively)

Facies 1 - Siltstone (30.0%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	2.0; 0.01-10.1	grey, green, red/ grey, green red	comminuted plant debris

Facies 2 - Sandstone (69.9%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	15.0	2.2; 0.05-15.0	tan, green, grey/ green, grey, white	ostracoderm fragments, partial plant casts, comminuted plant debris, coal partings
parallel laminated sandstone	2b	18.9	1.5; 0.01-6.0	tan, green, grey/ green, grey, white	rare root casts, partial plant casts, comminuted plant debris, ostracoderm fragments, coal partings
ripple cross-laminated sandstone	2c	17.0	1.0; 0.01-3.7	tan, green, grey/ green, grey, white	rare root casts, partial plant casts, comminuted plant debris, ostracoderm fragments, coal partings rare burrows

wavy and irregular laminated sandstone	2g	4.0	1.2; 0.1-2.0	<u>tan</u>, green, grey/grey green, <u>white</u>	partial plant casts, coal partings, burrows
non-stratified sandstone	2i	42.0	1.8; 0.03-5.5	<u>tan</u>, green, grey/grey green, <u>white</u>	partial plant casts and compressions, coal partings, comminuted plant debris, ostracoderm fragments
bedded sandstone with no bed-forms	2k	2.7	1.6; 0.3-5.0	tan/white	partial plant compressions, comminuted plant debris
trough cross-bedded sandstone	2ℓ	0.3	1.1; 0.8-1.3	tan/white	nf

Facies 7 - Conglomerate (0.1%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified conglomerate	7a	100	0.5(1 only)	green/black	nf

<u>Note</u>: see comments 3,4, and 5 following Table 2.1.3-1.

thicker units, up to 10 m thick, forming the recessive upper portion of fluvial fining upward cycles. Occasionally, isolated lenses are also found within a thick sandstone unit.

Siltstone is minor in the Hell Gate Formation constituting only 30% by cumulative thickness. All siltstone is non-stratified (1a) and displays green, grey or red colors on both weathered and fresh surfaces. Siltstone units average 2.0 min thickness. The only macroscopic fossil evidence noted is comminuted plant debris.

Facies 2 - Sandstone

The Hell Gate Formation is characterized by laterally extensive, resistant, thick, massive, tan to grey weathering, white quartzose sandstone. In this respect, it is very similar to the Hecla Bay Formation. Sandstone dominates the Hell Gate Formation constituting 69.9% by cumulative thickness. From a distance, thick sandstone intervals reaching up to ca. 30 m in thickness appear to be indivisible. However, in most instances, closer examination permits division into single channel units on the basis of siltstone clasts accentuating major scour horizons within the sandstone interval.

Seven sandstone sub-facies are defined in the Hell

Gate Formation. The most prominent amongst these is non-stratified sandstone (2i) which constitutes 42% of the sandstone by cumulative thickness. Average unit thickness varies from a maximum of 2.2 m for planar tabular cross-bedded sandstone (2a) to a minimum of 1.0 m for ripple cross-laminated sandstone (2c). While most sandstone weathers a tan or grey color and is white on a fresh surface, both weathered and fresh surfaces less commonly display a green color.

Macroscopic fossil evidence in the sandstones consists of ostracoderm fragments occasionally found as lag near unit bases and several types of plant remains, including partial plant casts or compressions, comminuted plant debris along depositional surfaces and less frequently coal partings. Trace fossils noted include occasional root casts and vertical burrows found near or at unit tops.

Facies 7 - Conglomerate

As indicated in Table 2.4.3-1, only one conglomerate unit is present in the Hell Gate Formation. It is a dark green weathering, 0.5 m thick, lens of non-stratified chert-pebble conglomerate found 5.8 m above the base of section HG1. As a result, this facies only constitutes 0.1% of the formation by cumulative thickness.

2.4.4 Section HG2 (Hell Gate Formation portion)

2.4.4.1 Location, Thickness and Contact Relations

Section HG2 is the most easterly section of the Hell Gate Formation. It is located just south of the axis of the Schei Syncline along a river ca. 12.5 km southeast of Bird Fiord. The section consists of 154.9 m of the upper Fram Formation (2.3.5) overlain by 511.3 m of the Hell Gate Formation. The location of the base of the section is 515500E, 8550875N, UTM zone 16X, NTS 49c, Bauman Fiord sheet. This position is shown in Figure 2.1.1-1. The line of section is indicated on the aerial photograph presented previously as Figure 2.3.5.1-1.

Based on a formation thickness of 637 m at the type section located along the eastern side of Okse Bay (Embry and Klovan, 1976, pg. 551) this section represents the lower 80.3% of the formation. It is the highest quality exposure of the Hell Gate Formation and has only 3.0% (15.5 m) covered interval.

The basal contact with the Fram Formation is well exposed and is both conformable and gradational. The contact with the overlying Nordstrand Point Formation was not observed as it lay several kilometers north of the top of the section .

The drafted section for this exposure of the formation is presented in Figure 2.3.5.1-2 (in pocket).

2.4.4.2 Age

Only five of ten palynology samples collected from the Hell Gate Formation at this location contained sufficiently well preserved spores to be of biostratigraphic value (McGregor, 1984a, pg. 13 - 14). Samples GSC Loc. C-91978, 91979, 91981, 91984 and 91986 all indicate an age within about the upper third of the Frasnian. Since the lowest (C-91978) was collected only 26.9 m above the Fram-Hell Gate contact and the highest (C-91986) came from 414.8 m above the base of formation (still ca. 222 m from the top of the formation in this area) most of the Hell Gate Formation at this location appears to lie within the top third of the Frasnian, with the top of the formation possibly even younger. This age is slightly younger than the Middle Frasnian age stated for the formation at both the type section and on eastern Grinnell Peninsula on Devon Island where the formation was dated by palynological control in overlying and underlying formations (Embry and Klovan, 1976, pg. 554).

2.4.4.3 Paleocurrent Analysis

The directional data recovered from this section in the formation is presented in Figure 4.1-1. It consists of 80 planar tabular cross-bed measurements (70 in-channel and ten overbank), five in-channel parting lineation measurements, one in-channel trough cross-bed measurement, and two channel scours (one main channel and one overbank). The planar tabular cross-beds are considered the best indicator of paleoflow direction due to their much larger sample size and to their reasonably even distribution throughout the section. The vector mean associated with the rose diagram of the 70 in-channel planar tabular cross-beds is oriented towards the southeast (158^0). However, as indicated in Figure 4.1-1, both the vector strength (R) and consistency (L) of this data is very low with measurements obtained from all points of the compass (the standard deviation about the vector mean is 94^0). The breadth of this distribution can be explained by an examination of the vertical directional distribution of the measurements. A vertical trend exists in the data. The lower two thirds of the formation has dominantly easterly oriented paleoflows which shift to dominantly westward oriented paleoflows in the upper third of the formation. Meander migration is ruled out as a possible cause of this trend due to the thickness of section associated with each direction (ca. 350 m for the eastward paleoflows and 160 m for the westward paleoflows). If the data set is assumed to be reliable (i.e., the sample size is large enough), then a possible explanation could be that the Hell Gate Formation at section HG2 represents two distinct but similar fluvial systems flowing in opposing directions. This explanation would require highly similar source regions since, as discussed in 3.2.2.2, the Hell Gate Formation is compositionally homogeneous. It would also require an initial uplift of a western source region to produce an eastward flowing fluvial system followed by an uplift of an eastern source region to produce the westward paleoflows found in the upper third of the formation. The alternative to this rather extravagant explanation is to simply consider the planar tabular cross-bed data set unreliable.

Unfortunately, the other types of directional data do not help resolve the issue. Only one southwesterly oriented trough cross-bed was recovered from the formation, and the five in-channel parting lineations and one main channel scour give only a northeast-southwest and east-west line of movement, respectively.

The number of measurements required for a set of directional data to be representative of the overall paleoflow trend is likely to vary from one formation to the next. While the sample size (n=70) for the in-channel planar tabular cross-bed data is one of the largest obtained from a formation in the Okse Bay Group, it is suggested to be inadequate to provide a reliable indication of the overall paleoflow trend. The necessity of having a larger data set for a reliable overall paleoflow direction may be a characteristic of the Hell Gate Formation since the in-channel planar tabular cross-bed data set (n=50) recovered from the formation at section F3 (2.4.8.3) also produced a directionally unconvincing paleocurrent rose diagram. This explanation is considered to be more reasonable than requiring two directionally opposed, but otherwise similar, fluvial systems to explain the paleocurrent data.

2.4.4.4 Facies Content

The Hell Gate Formation at this locality consists of two facies, sandstone and siltstone. Sandstone is the dominant lithology representing 73.4% of the formation by cumulative thickness while siltstone constitutes only 26.6%. One siltstone and six sandstone sub-facies have been defined. The percentage of the formation, by cumulative thickness, represented by each sub-facies is given in Figure 2.4.4.4-1. The descriptive attributes of each sub-facies is presented in Table 2.4.4.4-1. Selected features of the formation at this location are presented in Plate 2.4.4.4-1.

Facies 1 - Siltstone

Only non-stratified siltstone (1a) occurs in this section of the Hell Gate Formation. Both weathered and fresh surfaces show grey, green or red coloration with grey and green dominating the former and later, respectively. Siltstone units vary considerably in thickness, ranging from several centimeters to several meters. Average unit thickness is 2.1 m. The only macroscopic fossil evidence is comminuted plant debris.

Facies 2 - Sandstone

Of the six sandstone sub-facies identified in this exposure of the formation, non-stratified sandstone (2i) is most abundant. It represents 46.8% of the sandstone by cumulative thickness. Sandstone weathers dominantly a

Figure 2.4.4.4 - 1 Sub-facies in the Hell Gate Formation at section HG2. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

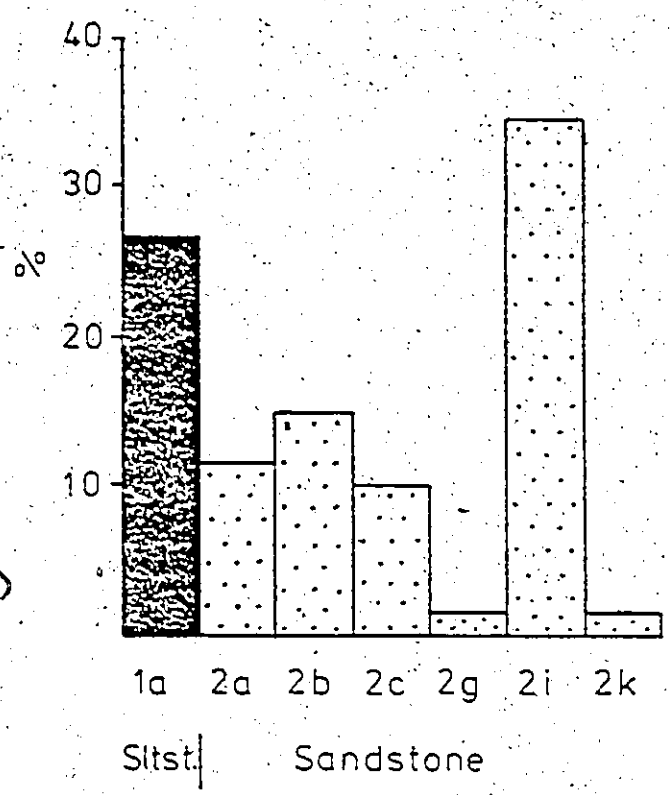

40
30
%
20
10
1a
2a
2b
2c
2g
2i
2k
Sltst.
Sandstone

Table 2.4.4.4.-1 Descriptive Attributes of Sub-facies Defined in the Hell Gate Formation at Section HG2

Facies 1 - Siltstone (26.6%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	2.1; 0.03-6.7	grey, green, red grey, green, red	comminuted plant debris

Facies 2 - Sandstone (73.4%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross bedded sandstone	2a	15.6	1.0; 0.2-3.8	tan, grey, green/grey green, white	partial plant casts, coal partings ostracoderm fragments,
parallel laminated sandstone	2b	20.1	1.1; 0.02-3.5	tan, grey, green/white, grey, white	partial plant casts, comminuted plant debris, coal partings, ostracoderm fragments, rare root casts
ripple cross-laminated sandstone	2c	13.5	0.7; 0.02-3.7	grey, green, tan/grey green, white	burrows, rare root casts, comminuted plant debris, partial plant casts, coal partings
wavy and irregular laminated sandstone	2g	1.8	0.7; 0.1-1.8	grey, tan/grey, white	burrows, partial plant compressions, coal partings

non-stratified sandstone	2i	46.8	1.8, 0.03-4.7	grey, tan/grey green, white	partial plant compressions comminuted plant debris, ostraccoderm fragments, coal partings
bedded sandstone with no bedforms	2k	2.2	1.4; 0.3-2.4	tan/white	partial plant compressions

Note: see comments 3,4, and 5 following Table 2.1.3-1.

Plate 2.4.4.4 - 1 The Hell Gate Formation at section HG2 located along a ravine approximately 12.5 km southeast of the southeastern arm of Bird Fiord.

A. The middle to upper Hell Gate Formation showing the characteristic fluvial architecture to consist of both laterally extensive (km) channel belt sandstones and floodplain deposits. The height of the ravine is ca. 300 m.

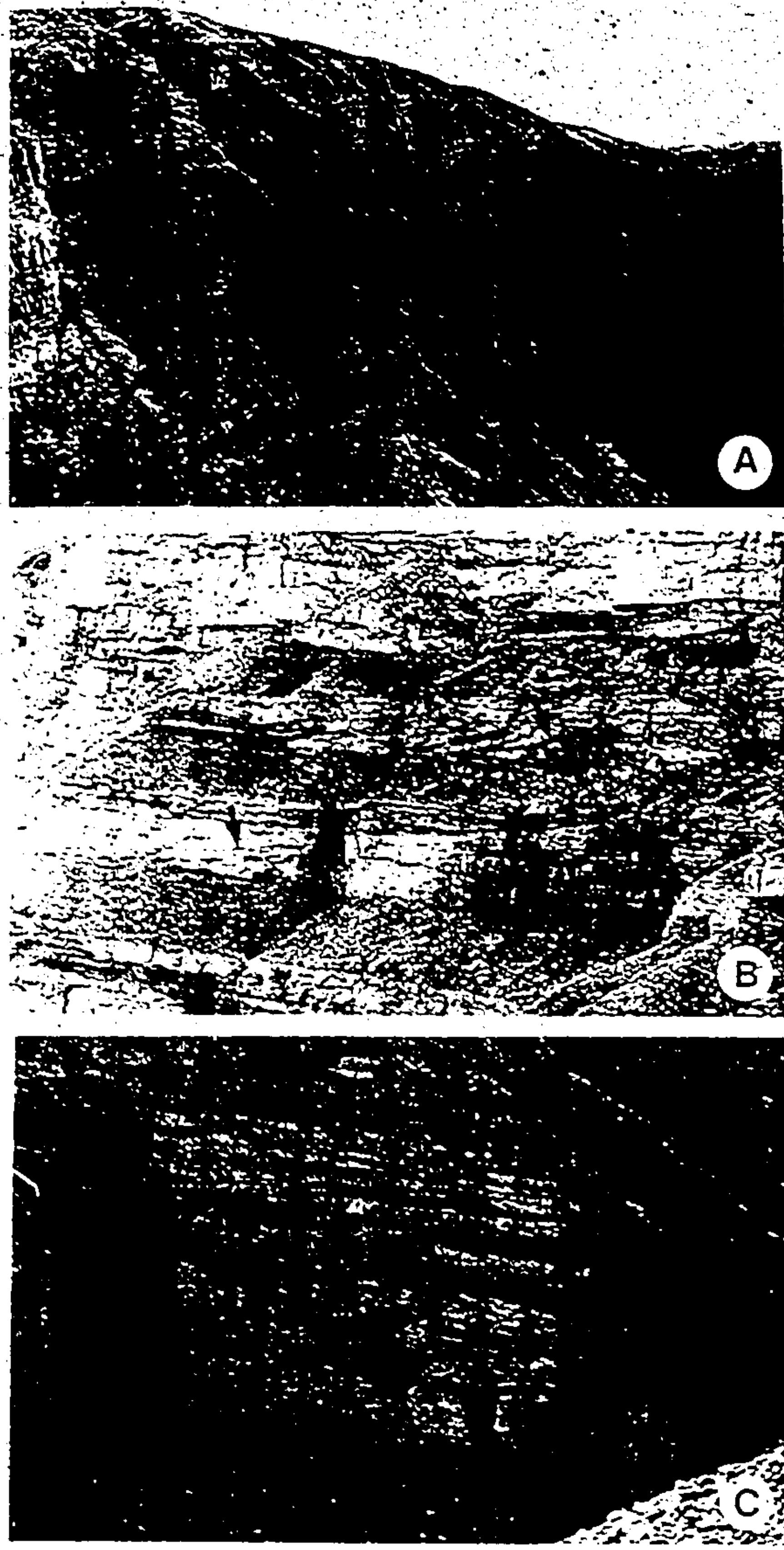
B. Interstratified single-story, trunk-channel sandstones and recessive weathering floodplain siltstone/shale with minor sandstone. Note the lateral accretion surfaces (arrows) in the channel sandstone. The second lowest channel sandstone is ca. 8 m in thickness.

C. An amalgamated, multi-story, trunk-channel sandstone interval ca. 25 m in thickness. Note the lateral accretion surfaces (arrows) in individual trunk-channel sandstones.

D. A sharp topped, erosionally based (arrows) trunk-channel sandstone in the middle Hell Gate Formation. The sandstone is ca. 9 m in thickness.

E. Thinly interstratified floodplain sandstone and siltstone/shale overlain by an ca. 6 m thick, light-weathering, trunk-channel sandstone. Note the small floodplain channel fill (arrow) in the center of the photograph.

F. An ca. 25 m thick interval of recessive weathering interstratified floodplain sandstone and siltstone/shale in the middle Hell Gate Formation.


A
B
C


D
E
F

tan-grey color and is white on a fresh surface. Subordinate weathered and fresh surface colors are grey or green. Sandstone unit thickness varies considerably ranging from 2 cm for ripple cross-laminated sandstone (2c) to 4.7 m for non-stratified sandstone (2i). Maximum and minimum average unit thickness is 1.8 m and 0.7 m. In contrast to the siltstone, several types of macroscopic fossil evidence is present in the sandstones. This consists of partial plant casts and compressions, comminuted plant debris, coal partings, and ostracoderm fragments. Trace fossils are not abundant. Vertical burrows and occasionally root casts occur at the top of some units.

2.4.5 Section F2 (Hell Gate Formation portion)

2.4.5.1 Location, Thickness and Contact Relations

Section F2 consists almost entirely of the upper Fram Formation (2.3.6). Only the lowermost 36 m of basal Hell Gate Formation is present at the top of the section . Additional Hell Gate Formation could have been examined at this location had severe time constraints not existed. As stated in 2.3.6, this section is located on the eastern margin of the southeastern arm of Bird Fiord; its base is at 505250E, 8562675N, UTM zone 16X, NTS 49c, Baumann

Fiord sheet. The location of the section is shown in Figure 2.1.1-1. An aerial photograph of the area of section F2 was presented previously as Figure 2.3.6.1-1. The Fram-Hell Gate contact at this location is conformable and gradational. The upper contact with the Nordstrand Point Formation lay south of section F2 and was not examined.

The drafted section containing this exposure of the Hell Gate Formation is Figure 2.3.6.1-2.

2.4.5.2 Age

This exposure of the formation consists of only sandstone so its age must be approximated by the closest palynology sample collected from the underlying Fram Formation. GSC Loc. C-91921 was collected at 204 m below the Fram-Hell Gate contact and gave a Middle Frasnian age (McGregor, 1982, pg. 9). In consideration of the stratigraphic interval separating this sample from the contact, a better indication of the age of the base of the Hell Gate Formation in this region would be the lowest sample (26.9 m above the basal contact) collected from the formation in section HG2. As stated in 2.4.4.2, the age of this sample is the upper third of the Frasnian.

2.4.5.3 Paleocurrent Analysis

Due to the shortness of the Hell Gate Formation interval examined at this location only a small number of directional structures were recorded. The data consists of 11 in-channel planar tabular cross-bed measurements and a single in-channel parting lineation measurement. The rose diagram for the planar tabular cross-beds is presented in Figure 4.1-1. It has a vector mean of 294^0 with a standard deviation about the vector mean of 21^0. Combined with the parting lineation, which indicates a northeast-southwest line of movement, the directional data at this location indicate an overall westerly paleoflow direction. Obviously, many more supportive paleocurrent measurements are required before this direction can be considered reliable.

2.4.5.4 Facies Content

This exposure of the Hell Gate Formation consists entirely of sandstone which is divisible into four sub-facies. The relative proportion of each sub-facies, by cumulative thickness, is presented in Figure 2.4.5.4-1 and the descriptive attributes of the sub-facies are contained in Table 2.4.5.4-1. As indicated in this table, the most abundant sub-facies at this location is planar tabular

Figure 2.4.5.4 - 1 Sub-facies in the Hell Gate Formation at section F2. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

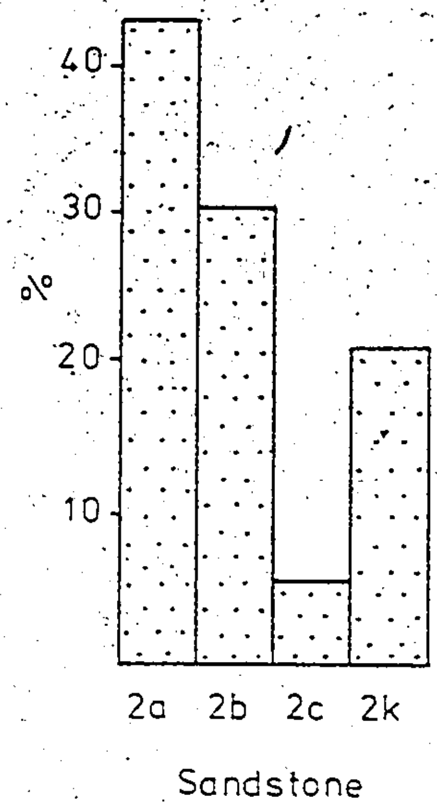

40
30
20
10
%
2a
2b
2c
2k
Sandstone

Table 2.4.5.4.-1 Descriptive Attributes of Sub-facies Defined in the Hell Gate Formation at Section F2

Facies 2 - Sandstone (100%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross bedded sandstone	2a	43.1	7.8;0.5-15.0 (2 only)	tan/white	comminuted plant debris
parallel laminated sandstone	2b	30.6	3.7;1.0-6.0	tan/white	comminuted plant debris
ripple cross-laminated sandstone	2c	5.5	2.0(1 only)	tan/white	nf
bedded sandstone with no bed forms	2k	20.8	3.8;2.6-5.0	tan/white	comminuted plant debris

Note: See comments 3,4, and 5 following Table 2.1.3-1.

cross-bedded sandstone (2a) which constitutes 43.1% of the sandstone by cumulative thickness. All sandstone weathers tan-grey and is white on a fresh surface. Maximum and minimum average unit thickness is 7.8 m and 2.0 m for planar tabular cross-bedded (2a) and ripple cross-laminated sandstone (2c), respectively. The only fossil material recovered from the sandstone is comminuted plant debris.

2.4.6 Section HG1

2.4.6.1 Location, Thickness and Contact Relations

Section HG1 is located ca. 44 km northeast of the head of Muskox Fiord. Its position relative to the other section locations of this study is shown on Figure 2.1.1-1. The base of the section is at 496825E, 8545500N, UTM Zone 16X, NTS 49B, Baad Fiord sheet. Figure 2.4.6.1-1 is an aerial photograph of the vicinity of section HG1 showing the line of section .

This section consists of 127.5 m of the middle third of the Hell Gate Formation. In the context of the 637 m formation thickness recorded by Embry and Klovan (1976) at the type section at Okse Bay, this section represents ca. 20% of the formation thickness in this region. Covered interval totalled 13.7% of the section .

Figure 2.4.6.1 - 1 Aerial photograph of sections HG1, HG3 and vicinity showing the lines of section and relevant formation contacts. EM&R/NAPL A-16756-97&98.


I

This section both began and finished in the Hell Gate Formation. Neither the lower contact with the Fram Formation nor the upper contact with the Nordstrand Point Formation was in the vicinity of the section.

The drafted section is presented as Figure 2.4.6.1-2 (in pocket).

2.4.6.2 Age

No palynology samples were obtained from the siltstone in this section of the formation. As a result, no age can be assigned to the Hell Gate Formation at this location.

2.4.6.3 Paleocurrent Analysis

The directional data obtained from this section of the Hell Gate Formation is presented in Figure 4.1-1. The data set is small due to a genuine paucity of cross-bedding plus the highly frost heaved nature of the outcrop. The data consists of four planar tabular cross-bed measurements obtained from overbank deposits and one, 24 m wide, main channel scour. The channel scour gives a northwest-southeast line of movement while the vector mean for the overbank cross-bed measurements indicates a southeast paleoflow (116^{0}). A large number of in-channel cross-bed measurements would be required to reliably choose which of the two directions suggested by the channel scour constituted the overall paleoflow trend.

2.4.6.4 <u>Facies Content</u>

Sandstone, siltstone and conglomerate constitute this section of the Hell Gate Formation. Sandstone is dominant representing 74.5%, by cumulative thickness. Siltstone and conglomerate constitute 25.0% and 0.5% of the formation, respectively. Five sandstone sub-facies and one siltstone and conglomerate sub-facies can be defined. The descriptive attributes of each sub-facies is presented in Table 2.4.6.4-1. Their relative proportion, by cumulative thickness, is indicated in Figure 2.4.6.4-1. The one occurrence of non-stratified chert-pebble conglomerate (7a) found in this section is unique for the formation within the study area of this report. It has been previously described in Table 2.4.3-1.

Facies 1 - Siltstone

As indicated in Table 2.4.6.4-1, all siltstone in section HG1 is non-stratified (1a). Unit thickness varies between several centimeters and several tens of centimeters. Siltstones contain no macrofossils and are grey, green and

Figure 2.4.6.4 - 1 Sub-facies in the Hell Gate Formation at section HG1. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

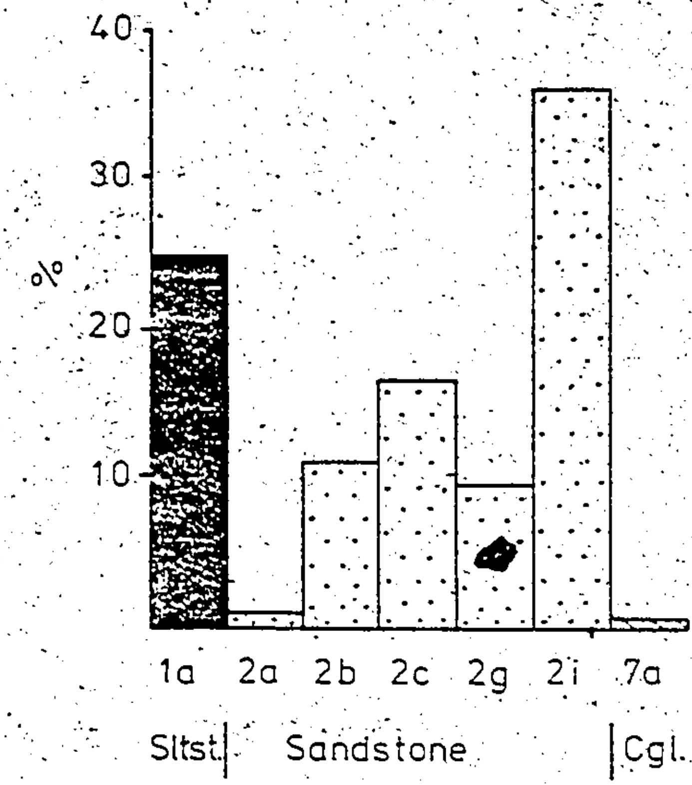

40
30
20
10
%
1a
2a
2b
2c
2g
2i
7a
Sltst.
Sandstone
Cgl.

Table 2.4.6.4.-1 Descriptive Attributes of Sub-Facies defined in the Hell Gate Formation at section HG1

Facies 1 - Siltstone (25.0%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	0.05-0.2	green, grey, red/green, grey, red	nf

Facies 2 - Sandstone (74.5%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	1.3	0.4;0.1-0.8	grey, green, tan/ green, white	partial plant casts
parallel laminated sandstone	2b	14.9	1.2;0.1-3.0	grey, green, tan/ green, white	partial plant casts, ostracoderm fragments
ripple cross-laminated sandstone	2c	22.4	1.2;0.05-1.8	grey, green, tan/grey green, white	rare root casts comminuted plant debris
wavy and irregular laminated sandstone	2g	12.9	2.1;0.1-1.8	green, tan/ green, white	partial plant casts
non-stratified sandstone	2i	48.4	2.3;0.1-5.5	grey, green, tan/ green, white	partial plant casts, comminuted plant debris

Facies 7 - Conglomerate (0.6%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified conglomerate	7a	100	0.5(1 only)	green/black	nf

Note: see comments 3,4, and 5, following Table 2.1.3-1.

red on both weathered and fresh surfaces. The latter two colors dominate in each instance.

Facies 2 - Sandstone

Sandstone is the dominant lithology in section HG1. Of the five sub-facies defined, the most abundant is non-stratified sandstone (2i) which represents 48.4% of the sandstone by cumulative thickness. Average unit thickness varies from a maximum of 2.3 m for non-stratified sandstone to a minimum of 0.4 m for the planar tabular cross-bedded sub-facies (2a). Weathered surfaces are mainly grey to tan in color and less commonly green. Fresh surfaces are most commonly white. Macroscopic fossil evidence consists of comminuted plant debris, partial plant casts and infrequent ostracoderm fragments. Rarely, root casts occur at or near the top of some units.

Facies 7 - Conglomerate

As mentioned above, only one chert-pebble conglomerate horizon is present at this location. It is non-stratified (7a) and weathers dark green. It is black on a fresh surface and contains no macrofossils.

2.4.7 <u>Section HG3</u> (Hell Gate Formation portion)

2.4.7.1 Location, Thickness and Contact Relations

Section HG3 is located just south of the axis of the Schei Syncline ca. 8 km southeast of the southeast corner of Okse Bay. The base of the section is at 494750E, 8551000N, UTM zone 16X, NTS 49C, Baumann Fiord sheet. This location is shown on Figure 2.1.1-1. The line of section is shown on Figure 2.4.6.1-1, an aerial photograph of the region of section HG3.

Section HG3 consists of two parts separated by approximately one kilometer of very poor to no exposure. The lower portion contains 91.4 m of the upper middle to lower upper Hell Gate Formation and the top portion contains 107.8 m of the lower Nordstrand Point Formation. By comparison to Embry and Klovan's (1976) type section just east of Okse Bay, the Hell Gate Formation examined at this location represents ca. 14.3% of the upper portion of the formation in this area. Covered interval constitutes 29.2% of the formation at this section.

The contact with the underlying Fram Formation was not observed as it lay well south of the area of section HG3. The upper contact with the overlying Nordstrand Point Formation is very poorly delineated in a tundra and felsenmeer covered interval just below the upper portion of the section. It is conformable.

The drafted section is presented as Figure 2.4.7.1-1 (in pocket).

2.4.7.2 <u>Age</u>

Of the two palynology samples collected from the formation at this location only one was productive (GSC Loc. C-85291). The sample was collected at 13.8 m above the base of the section and indicated an age within about the middle third of the Frasnian (McGregor, 1984b, pg. 3-4). This age compares reasonably well with an upper third of the Frasnian age obtained for the upper portion of the formation at section HG2 and with the Middle Frasnian age suggested by Embry and Klovan (1976, pg. 554).

2.4.7.3 <u>Paleocurrent Analysis</u>

Cross-bedding is not abundant in this exposure of the formation due to a high percentage of the sandstone being non-stratified (32.0%; see 2.4.7.4). The data base consists of only ten planar tabular cross-bed measurements, one of which came from a main-channel sandstone unit. Figure 4.1-1 presents the rose diagram for the nine overbank measurements which give a vector mean toward the northeast (067^{0}). The single main-channel planar tabular cross-bed is also inclined toward the northeast (077^0). The overall paleoflow direction for the formation at this location will remain unknown until more in-channel data are obtained.

2.4.7.4 <u>Facies Content</u>

The Hell Gate Formation at section HG3 consists dominantly of sandstone which represents 59.8% of the formation by cumulative thickness. Secondary in abundance, siltstone constitutes 40.2% of the formation by cumulative thickness. Five sandstone and one siltstone sub-facies are defined. Their descriptive attributes are presented in Table 2.4.7.4-1 and their relative proportion in the formation, by cumulative thickness, is shown in Figure 2.4.7.4-1. Sandstone sub-facies 21 (trough cross-bedded sandstone) is only present in the formation at section HG3 where it constitutes 5.4% by cumulative thickness. As a result, its description has been previously given in Table 2.4.3-1. Selected features of the formation at this location are presented in Plate 2.4.7.4-1.

Facies 1 - Siltstone

Figure 2.4.7.4 - 1 Sub-facies in the Hell Gate Formation at section HG3. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

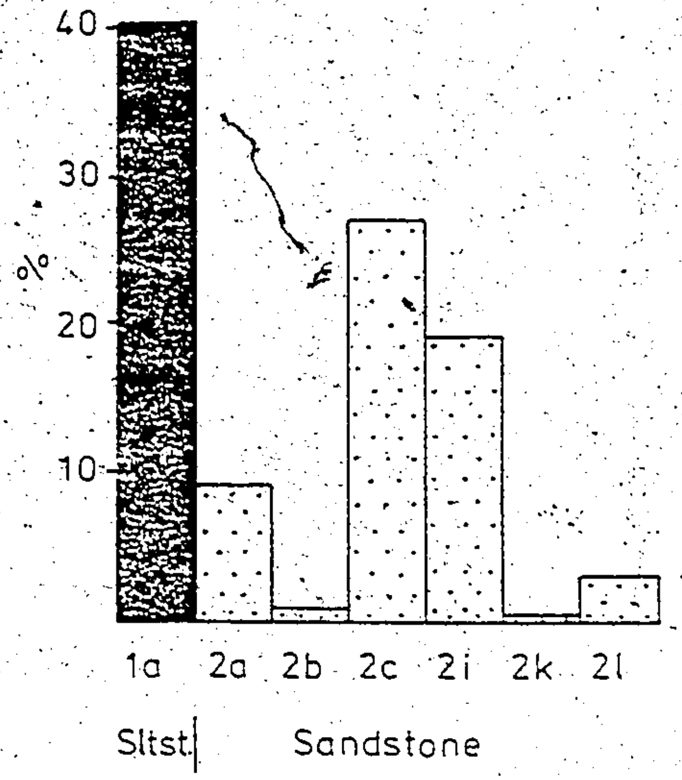

40
30
%
20
10
1a
2a
2b
2c
2i
2k
2l
Sltst.
Sandstone

Table 2.4.7.4.-1 Descriptive Attributes of Sub-Facies Defined in the Hell Gate Formation at Section HG3

Facies 1 - Siltstone (40.2%)

Sub-Facies	Code	% of. Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	1.4;0.02-7.5	grey,red/grey, green, red	comminuted plant debris

Facies 2 - Sandstone (59.8%)

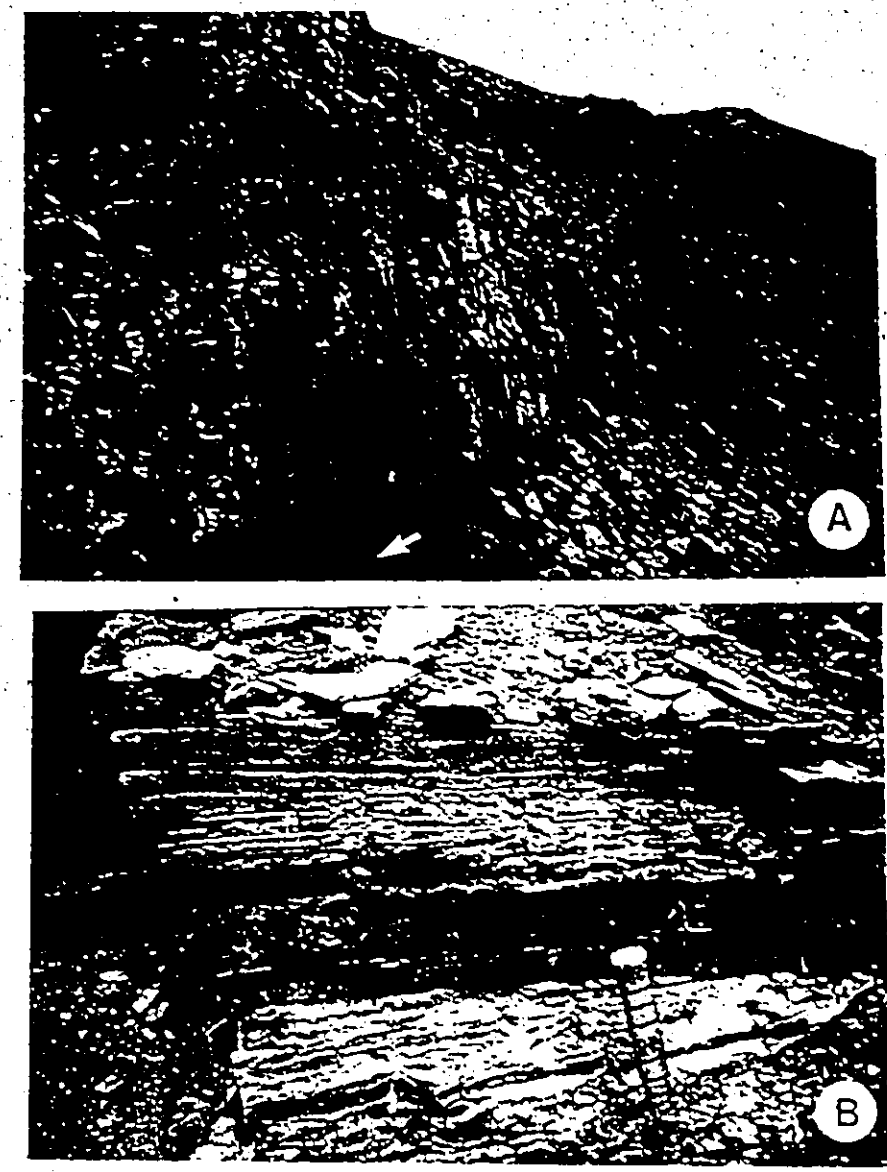
Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	15	1.2;0.05-3.0	grey,tan/white, green	partial plant casts, comminuted plant debris
parallel laminated sandstone	2b	1.8	0.4;0.01-0.5	grey,tan/green white	rare root casts
ripple cross-laminated sandstone	2c	45.0	1.3;0.01-0.8	grey,tan/grey, green, white	rare root casts, comminuted plant debris
non-stratified sandstone	2i	32.0	1.1;0.03-4.6	grey,tan/grey, green, white	partial plant casts, comminuted plant debris
bedded sand-stone with no bedforms	2k	0.8	0.3(1 only)	tan/white	nf
trough,cross bedded sandstone	2ℓ	5.4	1.1;0.8-1.3	tan/white	nf

Note, see comments 3,4, and 5, following Table 2.1.3-1.

Plate 2.4.7.4 - 1 The Hell Gate Formation at section HG3 located approximately 8 km southeast of the southeast corner of Okse Bay.

A. A well preserved, ca. 4 m thick, single-story, trunk-channel sandstone in the upper Hell Gate Formation erosionally overlying a recessive weathering floodplain siltstone/shale interval. The hammer (arrow) is 30 cm in length.

B. Thinly interstratified floodplain sandstone and siltstone/shale. The exposed portion of the hammer handle is 25 cm in length.


A
B

The siltstone at section HG3 weathers grey and red, with the former most common. It is mainly green on a fresh surface with subordinate grey and red colors. Siltstone is entirely non-stratified (1a) and has an average unit thickness of 1.4 m, although individual units vary considerably in thickness. The only macroscopic fossil material recovered is comminuted plant debris.

Facies 2 - Sandstone

As mentioned above, sandstone is the dominant facies. Sandstone weathers either grey or tan and is mainly white on a fresh surface. Of the five sandstone sub-facies defined, ripple cross-laminated sandstone (2c) and non-stratified sandstone (2i) are the most abundant representing 45.0% and 32.0% of the sandstone by cumulative thickness, respectively. Average unit thickness varies from a maximum of 1.3 m in ripple cross-laminated sandstone to a minimum of 0.4 m in parallel laminated sandstone (2b). Macroscopic fossil evidence consists of comminuted plant debris, partial plant casts and rarely, root casts near or at unit tops.

2.4.8 <u>Section F3</u> (Hell Gate Formation portion)

2.4.8.1 <u>Location, Thickness and Contact Relations</u>

Section F3 contains the westernmost exposure of the Hell Gate Formation that was examined in this study. The section is located in the sea cliffs of the eastern (Ellesmere Island) side of Hell Gate, on the northern side of the first bay north of Ren Bay (ca. 6 km north of Ren Bay). As was the case for previous section locations, this position is shown on Figure 2.1.1-1. The base of the section is at 438750E, 8518250N, UTM zone 16X, NTS 49A, Cardigan Strait sheet. Figure 2.3.8.1-1 is an aerial photograph of the area of section F3 showing the line of section.

The initial 105.4 m of this section is the uppermost Fram Formation while the remaining 189.1 m are in the lowermost Hell Gate Formation. Relative to the type section thickness (637 m) as measured by Embry and Klovan (1976) at Okse Bay, the Hell Gate Formation portion of this section represents the basal 29.7% of the formation. The section is well exposed with only 1.0% covered interval.

The Fram-Hell Gate contact at this location is both conformable and gradational. The contact between the Hell Gate Formation and overlying Nordstrand Point Formation lies several kilometers to the north of the area of section F3 and was not examined.

The drafted section for the Hell Gate Formation at this location is presented in Figure 2.3.8.1-2 (in pocket).

2.4.8.2 Age

Six of the nine palynology samples collected from the Hell Gate Formation at this location were productive (GSC Loc. C-91941, 91943, 91944, 91945, 91946, 91947). The samples ranged from 2.3 m to 83.9 m above the base of the formation thus dating approximately the lower 50% of the formation exposed at this location. The spores of the lowest three samples (2.3 m to 32.0 m above base) while identifiable, were not well preserved, and were few in number. They gave an age range of Late Givetian or Early Frasnian to the lower two-thirds of the Frasnian (McGregor, 1984a, pg. 2-4). Spores of the remaining three samples were more plentiful and better preserved. All gave a middle third of the Frasnian age (McGregor, 1984a, pg. 3-4).

The age of the base of the formation at this location is considered tentative due to the small number of only poorly preserved spores in the lowest three samples. The Middle Frasnian age suggested for the entire formation by Embry and Klovan (1976, pg. 554) is also considered tentative since it is based on samples obtained from overlying and underlying formations rather than from the Hell Gate Formation itself. The age of the upper Hell Gate

Formation in this area is likely somewhat younger, possibly ranging into the upper third of the Frasnian, as was the case for the upper Hell Gate Formation at section HG2.

2.4.8.3 Paleocurrent Analysis

The directional data at this location consists of 73 planar tabular cross-bed measurements (50 in-channel, 23 overbank) and three channel scours (two overbank channels and one main channel). The data is presented in Figure 4.1-1. The vector mean for the in-channel planar tabular cross-beds is oriented toward the southwest (255^{0}). In consideration of the relatively large sample size and the reasonably even distribution of the measurements throughout the formation, this paleoflow direction is considered reliable. When combined with the northwest-southeast line of movement indicated by the single main-channel scour, an overall westerly paleoflow direction is indicated.

No vertical trend exists in the planar tabular cross-bed measurements.

2.4.8.4 Facies Content

The Hell Gate Formation at section F3 is dominated by sandstone which constitutes 55.8% of the formation by cumulative thickness. Siltstone is of secondary importance constituting 44.2%. One siltstone and six sandstone sub-facies are defined and their descriptive attributes are provided in Table 2.4.8.4-1. The relative proportion of the formation, by cumulative thickness, represented by each sub-facies is presented in Figure 2.4.8.4-1. As this figure indicates, non-stratified siltstone (1a) and non-stratified sandstone (2i) are the dominant sub-facies representing 44.2% and 21.5% of the formation, respectively, by cumulative thickness. Selected features of the formation at this location are presented in Plate 2.4.8.4-1.

Facies 1 - Siltstone

All siltstone in section F3 is non-stratified (1a). The units are grey, green or red on both weathered and fresh surfaces with green being the dominant color for each. The thickness of siltstone units varies considerably, ranging from several centimeters to ca. 10 m; the average thickness is 2.0 m. No macroscopic fossil evidence is present in the siltstone.

Figure 2.4.8.4 - 1 Sub-facies in the Hell Gate Formation at section F3. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

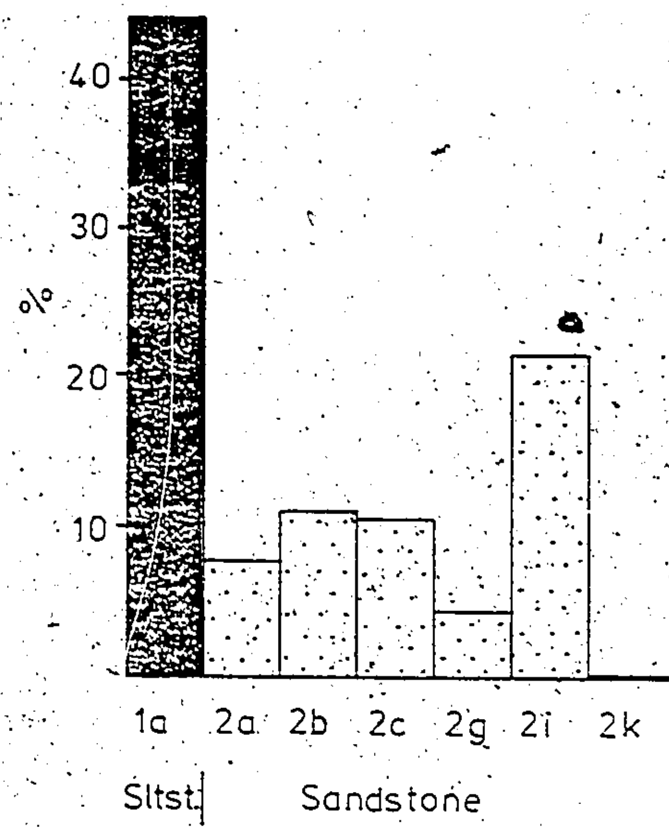

40
30
%
20
10
1a
2a
2b
2c
2g
2i
2k
Sltst.
Sandstone

Table 2.4.8.4.-1 Descriptive Attributes of Sub-Facies Defined in the Hell Gate Formation at Section F3

Facies 1 - Siltstone (44.2%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	2.0;0.01-10.1	grey, _green_, red/grey, _green_, red	nf

Facies 2 - Sandstone (55.8%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	14.2	0.7;0.05-2.4	grey,green,_tan_/ green, _white_	ostracoderm fragments, comminuted plant debris, partial plant casts, coal partings
parallel laminated sandstone	2b	20.0	1.0;0.01-2.6	grey, green, _tan_/green, _white_	comminuted plant debris, rare root casts, partial plant casts, coal partings, ostracoderm
ripple cross-laminated sandstone	2c	18.5	0.8;0.01-0.7	grey,_green_, tan/_green_ white	coal partings, ostracoderm fragments, partial plant compressions, comminuted plant debris, rare root casts

wavy and irregular laminated sandstone	2g	7.7	0.9;0.2-2.0	tan/white	partial plant compressions
non-stratified sandstone	2i	38.6	2.0;0.03-4.5	green, tan/green, white	partial plant compressions, coal partings
bedded sandstone with no bedforms	2k	1.0	1.0 (1 only)	tan/white	partial plant compressions

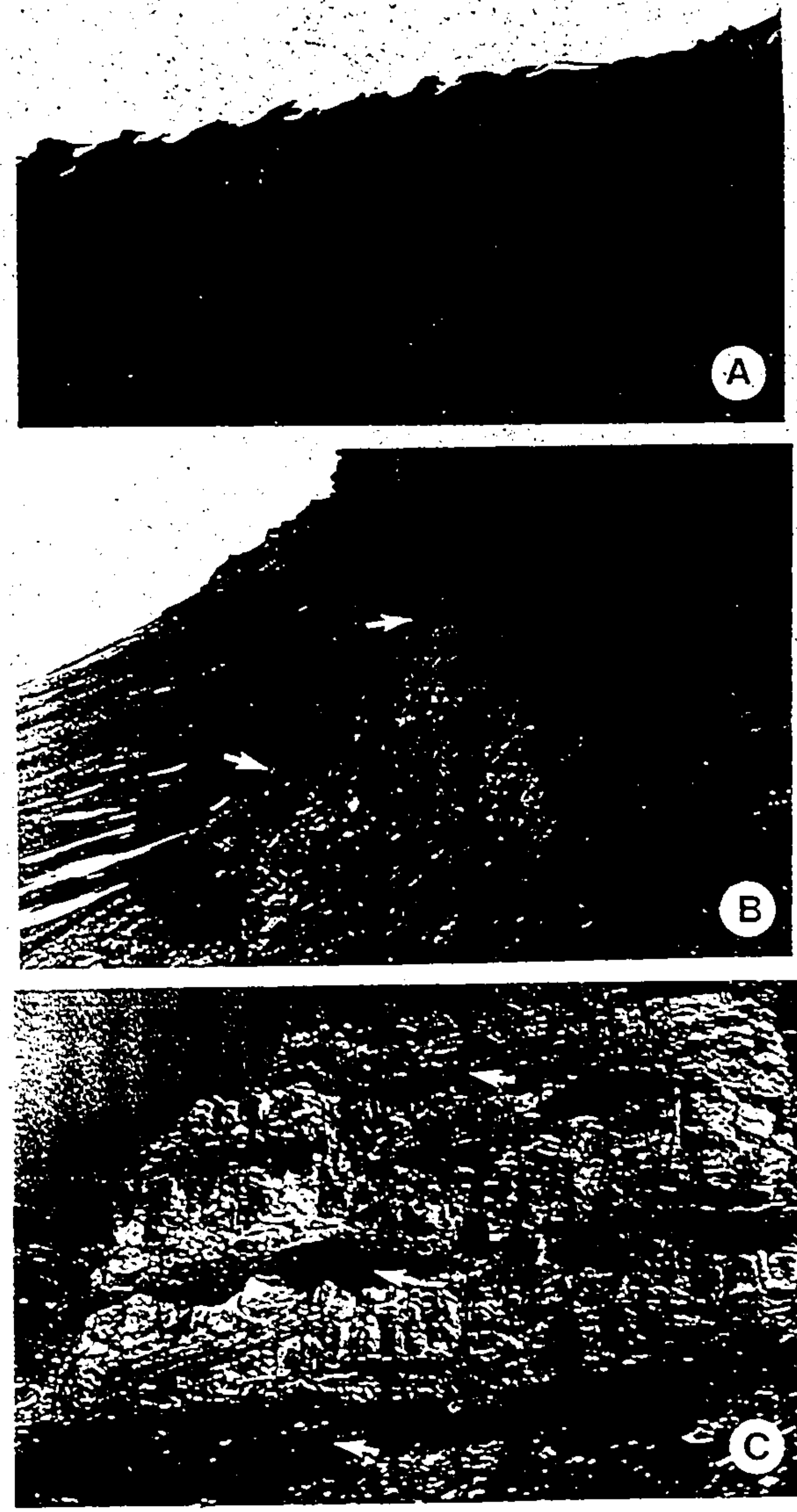
Note: see comments 3,4, and 5, following Table 2.1.3-1.

Plate 2.4.8.4 - I The Hell Gate Formation at section F3 located approximately 6 km north of Ren Bay along the eastern (Ellesmere) side of Hell Gate.

A. The characteristic fluvial architecture of the Hell Gate Formation. Both the resistant weathering channel-belt sandstone intervals and the recessive weathering floodplain sediments display a lateral extent on the order of kilometers. The resistant weathering channel-belt sandstones are ca. 15 - 20 m in thickness.

B. A light colored, resistant weathering, trunk-channel sandstone unit erosionally overlain (upper arrow) by interstratified floodplain sandstone and siltstone/shale. Field assistant (lower arrow) for scale.

C. Light colored, resistant weathering, trunk-channel sandstones separated by darker colored, less resistant weathering floodplain deposits (white arrows). Note the erosional contact (black arrow) between the lowest channel sandstone and the overlying floodplain deposits. The height of the outcrop is ca. 18 m.



Facies 2 — Sandstone

Sandstones weather grey, green, or tan with the former dominating. On a fresh surface the sandstones are mainly white and less commonly pale green. As indicated in Table 2.4.8.4-1, of the six sub-facies defined, non-stratified sandstone (2i) is the most common representing 38.6% of the sandstone by cumulative thickness. Average unit thickness varies from a maximum of 2.0 m for non-stratified sandstone to a minimum of 0.7 m for planar tabular cross-bedded sandstone (2a). Macroscopic fossil evidence consists of coal partings, comminuted plant debris, partial plant casts, ostracoderm fragments and occasional root casts.

2.4.9 Interpretation Of Depositional Environment

The genetic associations discussed individually below (2.4.9.1) represent facies/sub-facies packages of environmental significance noted in one or more of the sections in the Hell Gate Formation. The stratigraphic arrangement of the facies/sub-facies and the resulting genetic associations is similar amongst the Hell Gate Formation exposures. This indicates that the depositional environment remained the same across southwestern Ellesmere Island. The sedimentary model considered appropriate for the interpretation of the Hell Gate Formation is the fluvial model developed for sinuous, undivided, channel systems, i.e., the meandering river model. This conflicts with a braided fluvial interpretation previously suggested for the Hell Gate Formation by Embry and Klovan (1976, pg. 554). It must be remembered that there is a great deal of variability possible within the meandering portion of the fluvial spectrum. As will be discussed in detail in 2.4.9.3, the Hell Gate fluvial system was a very different type of meandering system than that already suggested for the Strathcona Fiord Formation (at sections S2 and HB1), the Fram Formation, and which will be suggested for the Nordstrand Point Formation. The principle reason for picking the meandering model over the braided model is the presence of numerous, well defined, fining-upward cycles at sections F3 (Hell Gate) and HG2 (southeast of Bird Fiord). These two sections are the best exposures of the formation on southwestern Ellesmere Island and were not examined by Embry and Klovan (1976). At both locations the fining upward cycles display well defined and frequently thick recessive intervals of green, grey and/or red siltstone, with minor shale, containing such indicators of subaerial exposure as roots and mudcracks. Siltstone is too important a lithology at each of these locations (44.2% by cumulative thickness at section F3 and 26.6% at section HG2) for the braided fluvial model to be applicable.

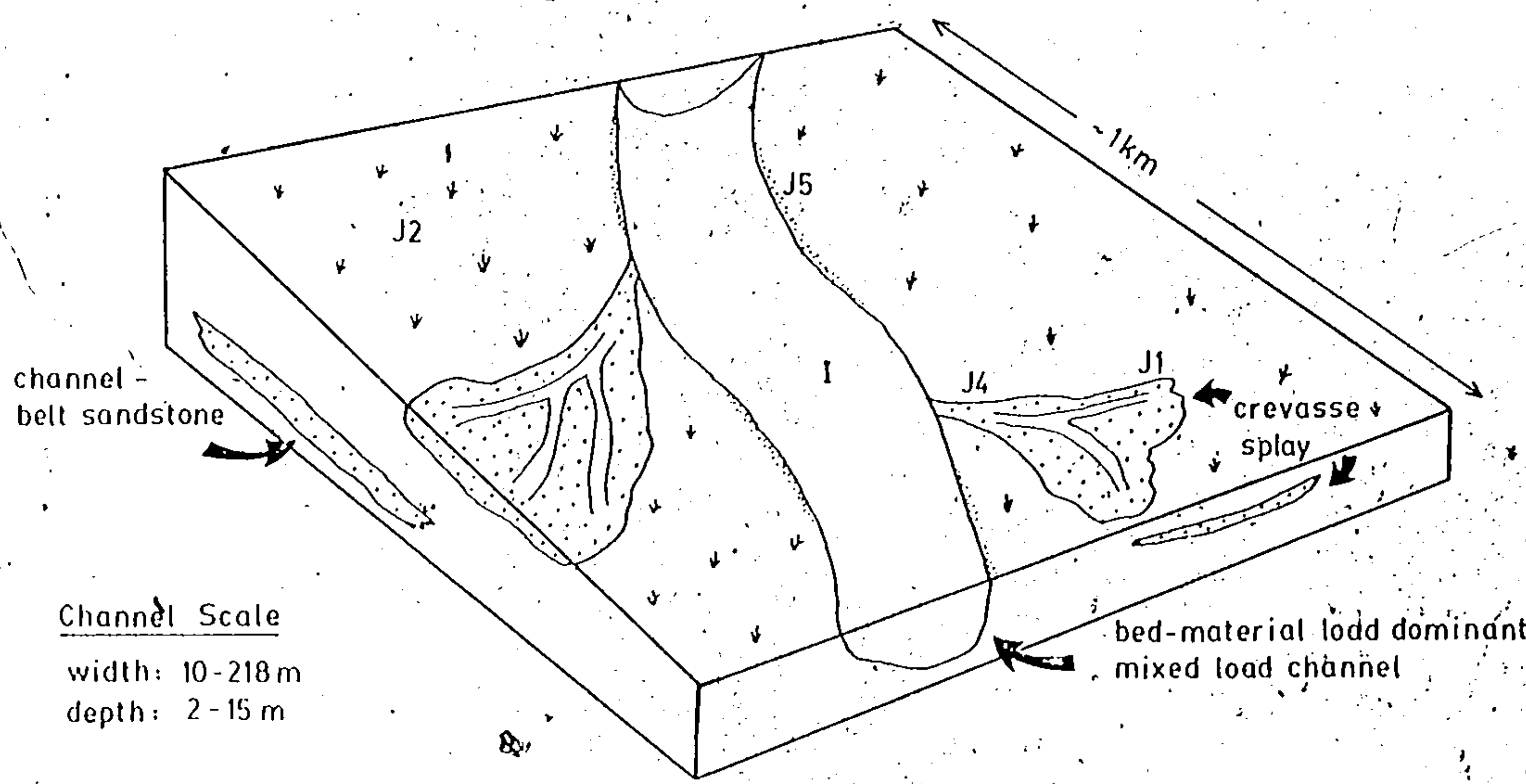
An overview of the development of the meandering fluvial model was presented during the interpretation of the Strathcona Fiord Formation at section S2 (2.1.7.2).

2.4.9.1 Genetic Associations

The meandering fluvial depositional setting envisaged for the Hell Gate Formation on southwestern Ellesmere Island is depicted in Figure 2.4.9.1-1. Like the underlying Fram Formation, the Hell Gate fluvial system is thought to have been part of a distal coastal plain setting (at least locally) on the basis of palynological evidence discussed subsequently (2.4.9.3). The Hell Gate meandering fluvial system is also thought to have been considerably more robust than that of the preceding Strathcona Fiord or Fram Formations on the basis of paleoflow calculations which indicate longer meander wavelengths, larger channels (as scaled by channel depth), slightly lower sinuosities and larger mean annual discharges (2.4.9.3).

As for the two previous meandering systems, the various sections representing the Hell Gate fluvial system may be organized into either an overbank (J) or a channel (I) association. The important attributes of the genetic

Figure 2.4.9.1 - 1 Block diagram representation of the depositional setting of the Hell Gate Formation. Four components of the overbank genetic association (J) are shown in the diagram along with the channel association (I).


~1km
J1
J2
J4
J5
I
crevasse
splay
channel -
belt sandstone
bed-material lodd dominant
mixed load channel
Channel Scale
width: 10-218 m
depth: 2-15 m

associations at each section are presented in Table 2.4.9.1-1. A representative interval in the Hell Gate Formation at section HG2 showing both channel and overbank genetic associations is presented as Figure 2.4.9.1-2.

I. Channel Association

All sections in the Hell Gate Formation contain main-channel sandstone units. The distinction between main-channel deposits and overbank deposits formed by channelized flow, presumably associated with crevasse splays, is made with the use of the same arbitrary thickness criterion (2.0 m) that was used for this distinction in the Fram Formation. As was mentioned for the Fram Formation, this criterion was suggested by Collinson (1978). It is not an ideal approach to this distinction since some main-channel sands could be less than 2.0 m thick and crevasse splay sands might exceed the criterion. However, it is suggested that most are successfully distinguished through its use. Use of other criteria, either individually or in aggregate, do not provide a consistent interpretation. The reader is referred to 2.3.10.1 for additional comments on the difficulty of this distinction.

The channel association is variable with respect to its abundance in a given section of the formation. Much of

Table 2.4.9.1-1 Genetic Associations in the Hell Gate Formation at Sections HG2, F2, HG1, HG3 and F3 Ordered From East to West Across Southwestern Ellesmere Island

Section HG2

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	54.5	4.1;2.0-10.0	I_1-2a, 2b, 2c, 2g, 2i, 2k I_2- 2b, 2c
Overbank	J	45.5		
	J_1	7.3	0.6;0.2-0.9	2a, 2b, 2c, 2g, 2i, 2k
	J_2	23.7	1.4;0.3-6.7	1a
	J_4	5.0	1.5;1.0-1.8	2a, 2b, 2c, 2g, 2i
	J_5	9.5	2.2;0.4-6.8	1a, 2a, 2b, 2c, 2g, 2i

Section F2

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	100	13.0(1 only)	I_1- 2a, 2b, 2c, 2k

Section HG1

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	24.3	3.3;2.1-6.2	I_1-2b, 2g, 2i, 7a I_2-2c
Overbank	J	76.7		
	J_4	9.3	1.3;1.0-1.8	2a, 2b, 2c, 2g, 2i
	J_5	67.4	7.4;0.5-15.0	1a; 2a, 2b, 2c, 2g, 2i

Section HG3

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	16.5	5.35;5.3-5.4	I_1-2a, 2i, 2l
Overbank	J	83.5		
	J_1	2.0	0.7;0.5-0.8	2a, 2c, 2i
	J_2	18.5	2.0;0.2-7.5	1a
	J_4	5.9	1.3;1.1-1.5	2a, 2b, <u>2i</u>, 2k
	J_5	57.0	3.7;0.7-16.0	1a; 2a, 2b, <u>2c</u>, 2i

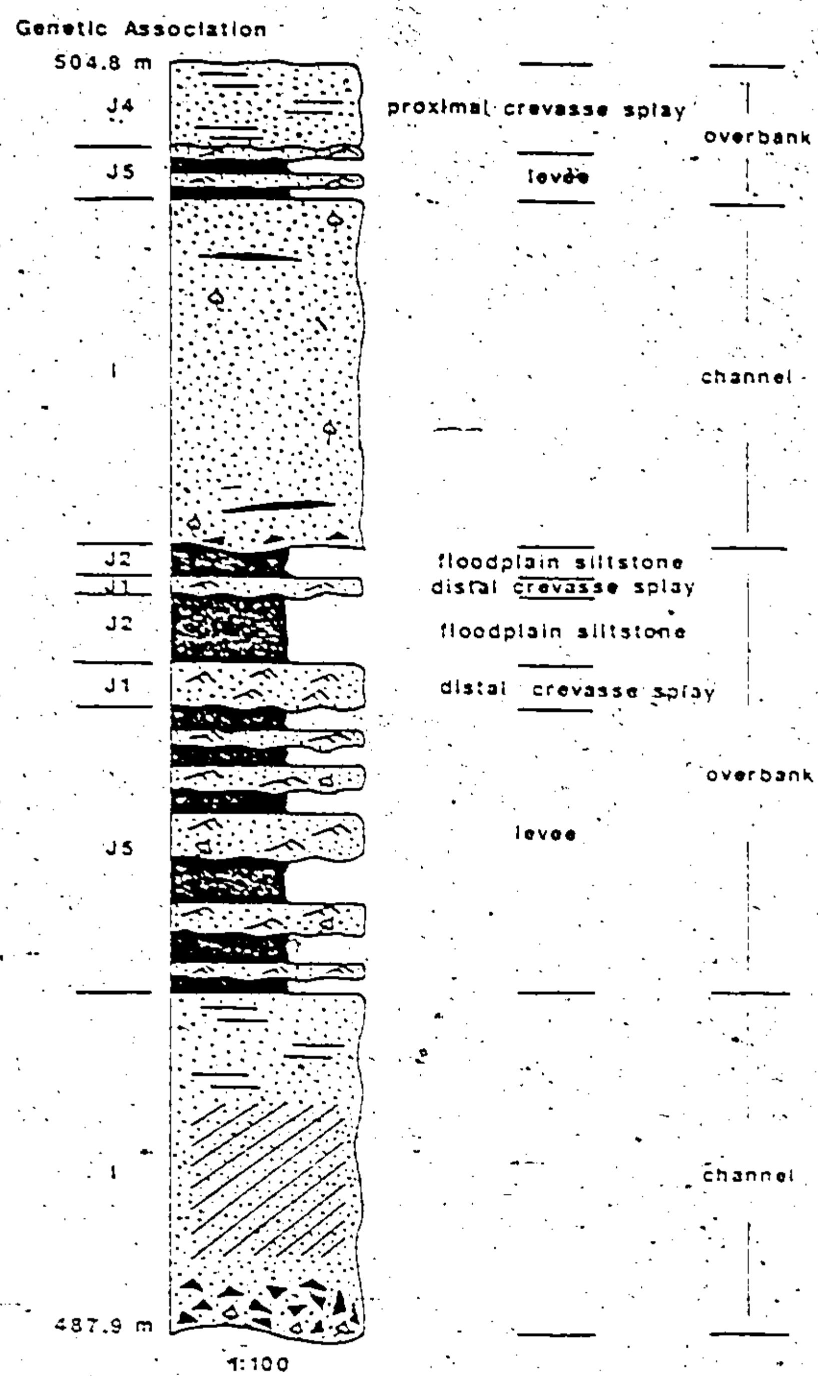
Section F3

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	33.0	6.2;2.2-14.5	I_1-2a, 2b, 2g, 2i, 2k I_2-2c
Overbank	J	67.0		
	J_1	2.1	0.8;0.5-0.9	<u>2a</u>, <u>2b</u>, 2c
	J_2	32.2	3.4;0.2-10.1	1a
	J_4	3.4	1.3;1.2-1.4	<u>2a</u>, <u>2b</u>, 2c, 2g, 2i
	J_5	29.3	2.5;0.3-11.4	1a; 2a, 2b, <u>2c</u>, 2i

Note:

% - percentage of Hell Gate, by cumulative thickness, represented by a genetic association or a component of a genetic association
<u>Thickness</u> - average thickness and range in meters
<u>Sub-Facies Content</u> - all possible sub-facies in a genetic association or a component of a genetic association; not all sub-facies found at each occurrence; dominant sub-facies, if any, underscored

Figure 2.4.9.1 - 2 Genetic associations in the Hell Gate Formation. A representative interval from the formation at section HG2 is shown.



Genetic Association
504.8 m
J4
proximal crevasse splay
overbank
J5
levee
I
channel
J2
floodplain siltstone
J1
distal crevasse splay
J2
floodplain siltstone
J1
distal crevasse splay
overbank
J5
levee
I
channel
487.9 m
1:100

this variation (Table 2.4.9.1-1) is a function of the thickness of the formation exposed at a particular location. The average thickness of main-channel sandstone units in the formation varies little across southwestern Ellesmere Island. As presented in Table 2.4.9.1-1, the maximum and minimum average thickness for the channel association is 6.2 m (section F3) and 3.3 m (section HG1). Channel fills in the formation are always erosionally based and frequently have a lag of siltstone or other clasts immediately overlying the scour surface. Occasionally, a distinction can be made between a lower and upper channel fill on the basis of a persistent change in sedimentary structures. As for the previous formations, these two components of the channel association in the Hell Gate Formation are designated I1 and I2, respectively. Their maximum possible sub-facies composition is presented in Table 2.4.9.1-1. The upper channel fill (I2) is dominated by ripple cross-laminated sandstone (2c) indicative of a weaker current flow during the latter stages of channel abandonment. As indicated in Table 2.4.9.1-1, the distinction between I1 and I2 cannot be made at all sections in the formation. Of the possible sub-facies in the lower channel fill (I1), non-stratified sandstone (2i), parallel laminated sandstone (2b) and planar tabular cross-bedded sandstone (2a) are the most frequently occurring.

Macroscopic fossil evidence found in channel associations in the Hell Gate Formation consists of ostracoderm fragments and partial plant casts as part of basal lags, coal partings, comminuted plant debris, root casts and rarely, burrows at the top of some channel associations.

J. Overbank Association

The overbank association dominates three of the five sections in the Hell Gate Formation (sections F3, HG1 and HG3). Only at section HG2 is the overbank association of secondary importance. Section F2 consists solely of channel sandstone but this is simply due to its containing only the basal 36 m of the formation. Overbank components J1, J2, J4 and J5 are present. They are defined and interpreted in the same fashion that they were in the Strathcona Fiord Formation and the Fram Formation. All four components are present at section HG2, HG3 and F3 but only J4 and J5 occur at section HG1. While occasional, slightly calcareous nodules are present in some siltstones, nodular weathering horizons (facies 6) constituting overbank component J3 do not occur.

The position of the overbank components within the depositional setting of the Hell Gate Formation is shown in Figure 2.4.9.1-1.

Overbank component J2, representing floodplain fines deposition, consists entirely of non-stratified siltstone (1a). J2 horizons vary considerably in thickness (0.2 m - 10.1 m). Their average thickness ranges from a minimum of 1.4 m at section HG2 to a maximum of 3.4 m at section F3. J2 strata are the most abundant overbank component at sections F3 and HG2 where they represent 32.2% and 23.7%, respectively, by cumulative thickness. J2 siltstone occurs either interstratified with sandstone, most commonly near the tops of units, or in thicker intervals representing the recessive portion of a fining-upward cycle. Their basal contact is always either gradational or sharp when exposed.

Macroscopic fossil evidence is absent from this overbank component except at section HG2 where occasional partial plant casts occur. Palynological evidence supportive of a terrestrial depositional setting occurs at sections F3 and HG2. Fragments of conducting tissue (wood) of large land plants occurs in siltstone samples (GSC Loc. C-91945 and 91947) at 49.8 m and 83.9 m above the base of the formation at section F3 and in a siltstone (GSC Loc. C-91984) at 260.1 m above the base of the formation at section HG2 (McGregor, 1984a).

Overbank components J1 and J4 are discussed together since they are interpreted to represent distal and proximal crevasse splay settings, respectively. These two components occur in sections HG2, HG3 and F3 while only J4 occurs in section HG1. As for the Fram Formation, these overbank components commonly consist of a similar array of sandstone sub-facies. The distinction between a proximal and distal crevasse splay deposit is again made by the use of an arbitrary thickness criterion (1.0 m), whereby a distal deposit is less than 1.0 m in thickness and a proximal deposit equal to or greater than 1.0 m and up to 2.0 m in thickness. As indicated in Table 2.4.9.1-1, the common dominant sandstone sub-facies for J4 sediments is non-stratified sandstone (2i). Planar tabular cross-bedded sandstone (2a) and parallel laminated sandstone (2b) are also important sub-facies at section F3. These three dominant sub-facies reflect the high energy flows associated with deposition in a proximal crevasse splay setting. The dominant sub-facies for J1 deposits are also sub-facies 2a, 2b and 2i but also includes ripple cross-laminated sandstone (2c) at section HG2. The relative importance of these overbank components, as scaled by the proportion of the formation they represent by cumulative thickness, is quite similar. J4 deposits range from 3.4% at section F3 to 9.3%

at section HG1. J1 deposits vary between 2.0% at section HG3 and 7.3% at section HG2. Average unitl thickness for both J1 and J4 deposits is similar. J1 deposits range between 0.6 m at section HG2 and 0.8 m at section F3. J4 deposits vary from 1.3 - 1.5 m at sections F3 and HG2, respectively. Basal contacts for both J1 and J4 deposits are most often erosional and occasionally either gradational or sharp.

The macroscopic fossil evidence is similar for J1 and J4 deposits. This includes ostracoderm fragments (section F3 only), comminuted plant debris, partial plant casts, coal partings and rarely, root casts and possible burrows (section HG2 only).

The J1 and J4 sandstones frequently form thin (usually ca. 1 - 1.5 m in thickness) fining-upward cycles with J2 siltstones. At sections F3 and HG2 the basal contact of these overbank fining-upward cycles is occasionally a small amplitude channel scour thereby providing supportive evidence for a channelized crevasse splay depositional setting.

Overbank component J5 is present in all sections of the formation. The centimeter to decimeter scale sandstone and siltstone couplets composing this overbank component are interpreted in the same fashion as they were in the

Strathcona Fiord and Fram Formations, i.e., as episodically deposited proximal overbank sediment representing levee deposition. The average siltstone to sandstone ratio for these couplets varies from 0.35 at section HG1 to slightly in excess of unity at section HG2. At all sections but HG2 the couplets are sandstone dominant. Where exposed, the basal contact for J5 intervals can be either sharp, gradational or erosional indicating that the initial overbank flows varied considerably in intensity. The importance of intervals of J5 couplets varies somewhat amongst the sections. At section HG1, J5 sediments constitute 67.4% of the exposed formation, by cumulative thickness. At section HG2, the most complete exposure of the formation, they only constitute 9.5%. The average thickness for an interval of J5 couplets ranges from a maximum of 7.4 m at section HG1 to 2.2 m at section HG2. The sub-facies composition given for overbank component J5 in Table 2.4.9.1-1 represents, as it did for the other overbank components, the maximum number of sub-facies which occur in J5 deposits. Individual occurrences of J5 deposits consist of a sub-set of these sub-facies. As indicated in Table 2.4.9.1-1, the sandstone portion of J5 couplets is dominantly the ripple cross-laminated sub-facies (2c) while only non-stratified siltstone (1a) constitutes the upper portion of the couplets.

Macroscopic fossil evidence in this overbank component occurs mainly in the basal sandstone portion of each couplet. It consists of ostracoderm fragments, partial plant compressions, comminuted plant debris, coal partings, occasional root casts and rare burrows. Only comminuted plant debris occurs along depositional surfaces in the siltstones.

Occasional features in J5 deposits which are considered to be supportive of episodic, proximal, overbank deposition are: 1. loaded sandstone bases indicating rapid deposition onto wet silt 2. internal angular discordances amongst the couplets indicative of scouring by flood waters 3. mudcracked sandstone surfaces indicating subaerial exposure 4. rare mottling in the siltstones indicating pedogenesis and subaerial exposure.

2.4.9.2 Facies Sequence Analysis

A contingency table analysis (Markov Chain analysis) of facies transitions was performed on the Hell Gate Formation exposed at sections HG2, F3, HG1 and HG3. Due to its brevity (36 m), the Hell Gate Formation at section F2 was not analyzed in this fashion. The BMDP-4f program (Brown, 1983) used for similar analyses on the underlying formations in the Okse Bay Group is used for the Hell Gate Formation. As stated previously for the underlying formations, the objective of these analyses is to determine if the formation in question has the Markov property, i.e., does it have any non-random facies transitions (a memory). If present, this provides an objective characterization of depositional processes operating within that particular sedimentary environment which ultimately aids its identification. The details of the use of this BMDP program were provided previously (2.1.7.2).

The results of the contingency table analyses on the Hell Gate Formation are presented in Figure 2.4.9.2-1 which contains copies of BMDP-4f printouts for section F3, HG1, HG2, and HG3. With the criterion probability set at 0.20, as it was for underlying formations, only sections HG2 and F3 contain non-random facies transitions. The absence of the Markov property at sections HG1 and HG3 is indicated by the probability associated with the maximum likelihood-ratio chi-square statistic (0.2297 and 0.4134, respectively) exceeding the criterion probability. Stepwise cell selection performed on the expected value matrices for

Figure 2.4.9.2 - 1 Markov Chain analyses of the Hell Gate Formation at sections HG2, HG1, HG3 and F3. Computations performed using BMDP-4F.

BHOPNF CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION HG2

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVO	FUC	2A	2B	2C	2G	2I	2K	TOTAL
1A	6 *	2	2	3	4	1	0	13	0	25
POVO	5	0 *	4	2	0	0	1	8	0	20
FUC	1	3	6 *	4	0	0	0	4	0	13
2A	5	1	1	2 *	15	6	2	19	0	48
2B	5	4	1	24	3 *	11	1	13	4	57
2C	6	5	2	2	6	0 *	0	3	0	24
2G	0	0	0	5	1	1	0 *	0	0	7
2I	6	4	1	16	33	6	2	0 *	2	67
2K	0	0	0	2	3	0	1	2	0 *	5
TOTAL	27	20	11	48	56	25	7	68	6	266

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 266
SUMMED OVER 72 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A.O.	55	115.25	.0000	119.91	.0000	5

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVO	FUC	2A	2B	2C	2G	2I	2K	TOTAL
1A	2.5 *	[illegible]	1.6	4.9	9.1	2.3	.6	7.4	.5	25.0
POVO	1.9	1.4 *	.8	3.8	4.7	1.4	.5	6.1	.4	20.0
FUC	1.2	.9	.5 *	2.5	3.0	1.1	.3	3.2	.3	13.0
2A	5.3	3.9	2.1	15.5 *	13.3	4.9	1.3	16.6	1.1	48.0
2B	6.5	4.3	2.6	13.1	16.2 *	6.1	1.6	20.8	1.4	57.0
2C	[illegible]	[illegible]	.9	4.7	5.4	2.2 *	.5	7.4	.5	24.0
2G	.5	.5	.3	1.3	1.6	.6	.2 *	2.3	.1	7.0
2I	4.5	6.1	3.3	16.4	20.7	7.4	2.1	26.6 *	1.7	67.0
2K	.5	.3	.2	.9	1.1	.4	.1	1.6	.1 *	5.0
TOTAL	27.3	[illegible]	[illegible]	[illegible]	56.3	25.0	7.1	66.3	6.0	266.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION HG2

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	111.25	55	.00000	3.741	POVB	FUC
1	103.54	54	.00001	3.247	2G	2A
2	93.42	53	.00010	2.641	2K	2G
3	87.03	52	.00015	2.631	POVB	1A
4	81.13	51	.00046	2.681	2C	1A
5	84.77	50	.00155	2.996	2C	POVB
6	77.71	49	.00560	2.498	2C	FUC
7	73.67	48	.00462	-2.248	2B	2I
8	59.13	47	.10944	2.521	1A	FUC
9	55.13	46	.16630	2.043	2G	2C
10	52.77	45	.19383	1.900	2K	2A
11	49.81	44	.25311			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL. STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVB	FUC	2A	2B	2C	2G	2I	2K
1A	.0 *	1.1	.0 *	3.2	5.7	1.6	.4	10.6	.4
POVB	.0 *	.0 *	.0 *	1.6	2.3	.8	.2	5.3	.2
FUC	.7	.6	.0 *	1.7	3.1	.9	.2	5.7	.2
2A	2.7	2.4	.5	.0 *	12.3	3.7	.3	24.0	.9
2B	6.6	5.7	1.3	17.3	.0 *	8.9	2.2	.0 *	2.1
2C	.0 *	.0 *	.0 *	1.7	3.1	.0 *	.2	5.8	.2
2G	.1	.1	.0	.3 *	.3	.0 *	.0 *	.6	.0
2I	5.1	5.1	1.1	15.5	27.6	7.9	1.3	.0 *	1.9
2K	.1	.1	.0	.0 *	.6	.2	.0 *	1.0	.0 *

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION HG1

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	POVB	2A	2B	2C	2G	2I	7A	TOTAL
POVB	0*	0	3	0	1	3	0	7
2A	0	0*	1	0	0	1	0	2
2B	1	0	0*	3	2	3	0	9
2C	[illegible]	0	1	0*	0	1	1	7
2G	2	0	1	0	0*	1	0	4
2I	0	2	3	4	1	0*	0	10
7A	1	0	0	0	0	0	0*	1
TOTAL	[illegible]	2	9	7	4	9	1	40

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 40
SUMMED OVER 42 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
[illegible]	[illegible]	34.27	.2237	31.71	.3330	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	POVB	2A	2B	2C	2G	2I	7A	TOTAL
POVB	[illegible]*	.4	2.2	1.5	.8	2.1	.2	7.0
2A	.4	.1*	.5	.4	.2	.5	.0	2.0
2B	2.3	.5	2.4*	2.0	1.0	2.9	.2	9.0
2C	1.5	.4	2.0	.4*	.7	2.1	.2	7.0
2G	.9	.2	1.0	.7	.4*	1.1	.1	4.0
2I	2.5	.6	3.2	2.0	1.2	3.1*	.3	10.0
7A	[illegible]	.0	.2	.2	.1	.3	.0*	1.0
TOTAL	[illegible]	2.0	9.0	7.0	4.0	9.0	1.0	40.0

****** STEPWISE CELL DELETION IS NOT PERFORMED. P-VALUE OF MODEL FIT (.2237) IS GREATER THAN CRITERION PROB (.2100)

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION HG2

****
* TABLE PARAGRAPH 1 *
****

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE							
	1A	POV3	2A	2B	2I	2K	2L	TOTAL
1A	0 *	4	1	0	1	0	0	6
POV3	2	0 *	1	0	1	0	0	4
2A	0	0	0 *	0	2	0	1	3
2B	0	0	0	0 *	0	0	0	1
2I	1	1	1	1	0 *	0	1	5
2K	0	1	0	0	0	0 *	0	1
2L	2	0	0	0	0	0	0 *	2
TOTAL	5	6	3	1	4	1	2	22

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 22
SUMMED OVER 42 CELLS WITHOUT STRUCTURAL ZEROS

****
* MODEL 1 *
****

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	29	30.01	.413.	46.49	.0191	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE							
	1A	POV3	2A	2B	2I	2K	2L	TOTAL
1A	2.1 *	2.6	1.6	.3	1.5	.3	.6	6.0
POV3	1.4	1.5 *	.7	.2	1.0	.2	.4	4.0
2A	.9	.9	.4 *	.1	.6	.1	.3	3.0
2B	.3	.3	.1	.1 *	.2	.0	.1	1.0
2I	1.6	1.7	.8	.2	1.2 *	.2	.5	5.0
2K	.3	.3	.1	.3	.2	.0 *	.1	1.0
2L	.5	.6	.3	.1	.4	.1	.2 *	2.0
TOTAL	5.0	6.0	3.0	1.0	4.0	1.0	2.0	22.0

****** STEPWISE CELL DELETION IS NOT PERFORMED. P-VALUE OF MODEL FIT (.4134) IS GREATER THAN CRITERION PROB (.2000)

SHOP4F CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION F3

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVB	2A	2B	2C	2G	2I	2K	TOTAL
1A	0 *	10	5	1	1	0	1	0	18
POVB	11	0 *	1	2	0	2	5	0	21
2A	1	2	0 *	5	2	1	3	0	14
2B	4	3	1	0 *	1	2	4	0	15
2C	0	3	1	0	0 *	0	0	0	4
2G	2	1	4	1	0	0 *	1	0	9
2I	3	3	1	6	0	3	0 *	1	14
2K	0	0	0	0	0	1	0	0 *	1
TOTAL	13	22	13	15	4	9	14	1	96

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 96
SUMMED OVER 56 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
1,1.	41	69.14	.0039	73.51	.0014	4

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW / ABOVE	1A	POVB	2A	2B	2C	2G	2I	2K	TOTAL
1A	4.3 *	5.6	2.4	3.4	.4	1.9	3.1	.2	18.0
POVB	5.4	7.1 *	3.7	4.3	2.0	1.4	4.0	.2	21.0
2A	3.1	4.1	2.1 *	2.5	.6	1.4	2.3	.1	14.0
2B	3.4	4.5	2.3	2.7 *	.6	1.5	2.5	.2	15.0
2C	.4	2.0	.5	.6	.1 *	.4	.6	.0	4.0
2G	1.4	3.5	1.3	1.5	.4	.8 *	1.4	.1	9.0
2I	3.1	4.1	2.1	2.5	.6	1.4	3.3 *	.1	14.0
2K	.2	.3	[illegible]	[illegible]	.3	.1	.1	.3 *	1.0
TOTAL	[illegible]	22.0	13.0	15.0	4.0	9.0	14.0	2.0	96.0

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE HELL GATE FORMATION AT SECTION F3

***** CRITERION TO SELECT CELLS IS MAXIMUM STANDARDIZED DEVIATE = (OBS. - EXP.) /SQRT(EXP.).

STEP	CHISQUARE	D.F.	PROB	MAXIMUM DEVIATION	FOUND IN CELL BELOW	FOUND IN CELL ABOVE
0	69.44	41	.00389			
				3.118	2K	2G
1	64.12	40	.00909			
				2.393	2G	2A
2	58.56	39	.02284			
				2.219	2I	2K
3	54.07	38	.03905			
				2.243	2I	2B
4	48.33	37	.10052			
				2.554	2I	2G
5	42.40	36	.20241			

P-VALUE EXCEEDS SPECIFIED PROBABILITY LEVEL, STEPPING STOPS.

***** EXPECTED VALUES USING ABOVE MODEL

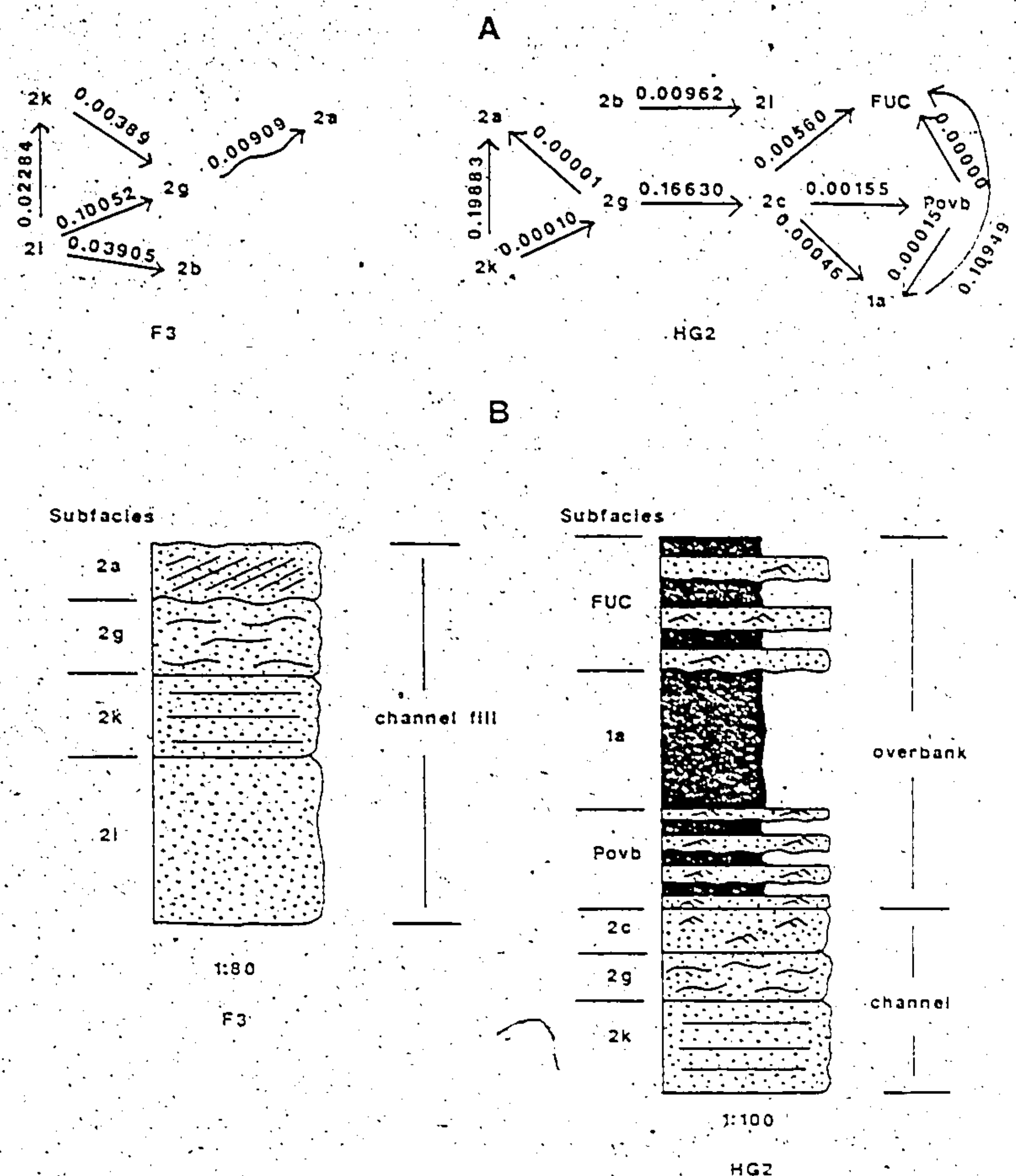
ASTERISK INDICATES MISSING VALUE

BELOW \ ABOVE	1A	POVB	2A	2B	2C	2G	2I	2K
1A	.0 *	7.1	2.6	2.6	1.0	1.3	3.4	.0 *
POVB	6.3	.0 *	3.4	3.4	1.2	1.7	4.4	.0 *
2A	3.6	4.8	.0 *	1.4	.6	.9	3.3	.0 *
2B	3.9	5.2	1.9	.0 *	.7	.9	3.5	.0 *
2C	1.0	1.3	.5	.5	.0 *	.2	.6	.0 *
2G	1.4	1.4	.0 *	.7	.2	.0 *	.3	.0 *
2I	1.3	1.4	.7	.0 *	.2	.0 *	.0 *	.0 *
2K	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *	.0 *

sections HG2 and F3 indicates that at neither location is cyclicity present. The preferred facies relationship diagrams (PFD) and accompanying summary sections are presented in Figure 2.4.9.2-2. It must be noted that more than one pathway (facies sequence) is possible for each PFD. The pathway involving the maximum number of sub-facies was chosen for display as a summary section since this transition sequence is most representative of the observed stratigraphic arrangement.

The explanation given previously (2.3.10.2) regarding the use of the Povb state (proximal overbank) in the facies sequence analysis of the Fram Formation is equally applicable to the Hell Gate Formation. This state is included in the matrices for sections HG2 and F3. An additional compound state, FUC (fining-upward cycle) is also included in the matrix for section HG2. At this location, numerous overbank fining-upward cycles, ca. 1 - 1.5 m in thickness, are present in addition to the much thicker main-channel fining-upward cycles. The thinner cycles consist of sandstone of overbank components J1 or J4, interstratified with siltstone of overbank component J2. The thinner fining-upward cycles were sufficiently numerous at section HG2 that time often only permitted the measuring of the cycle thickness, not the exact facies sequence. As a

Figure 2.4.9.2 - 2 Preferred facies relationship diagrams (A) and summary sections (B) for the Hell Gate Formation. Average sub-facies thickness was used in the construction of the summary sections.



A
2k
0.00389
0.02284
2g
0.00909
2a
0.10052
2l
0.03905
2b
F3
2b
0.00962
2l
2a
0.00001
0.19883
2g
0.16630
2c
0.00560
FUC
0.00155
Povb
0.00000
2k
0.00010
0.00046
0.00015
0.10949
1a
HG2
B
Subfacies
2a
2g
2k
2l
channel fill
1:80
F3
Subfacies
FUC
1a
Povb
2c
2g
2k
overbank
channel
1:100
HG2

result, the only way to include these important overbank deposits in a facies sequence analysis is to represent them by a compound state (FUC).

The PFD for section HG2 is complex. Despite this complexity, cyclicity is absent. The accompanying summary section, constructed from the sub-facies constituting the most complex pathway in the PFD, reflects the stratigraphic style of the Hell Gate Formation at this location.

The PFD and accompanying summary section for section F3 is not as complex a facies sequence as that at section HG2. It consists of only five sandstone sub-facies. Again, cyclicity is absent. The summary section is readily interpreted as a channel fill sequence. As for the Fram Formation, the PFD and accompanying summary sections for the Hell Gate Formation at sections F3 and HG2 can readily result from the application of Walthers Law to the depositional elements shown to constitute the environmental setting of the Hell Gate Formation in Figure 2.4.9.1-1. This constitutes objective support for the meandering fluvial interpretation.

2.4.9.3 Discussion

Additional details of the meandering fluvial depositional environment envisaged for the Hell Gate

Formation are discussed below.

1. Hell Gate Formation Fluvial Architecture and Paleochannel Pattern

The transition from the underlying Fram Formation to the Hell Gate Formation is marked by a change in fluvial architecture caused by a greater percentage of sandstone in the Hell Gate Formation (50.7% vs 65.9%). The sandstones of the fining upward cycles in the Fram Formation are characteristically much thinner and do not have a large lateral extent. The Hell Gate Formation is characterized by thick, tan-white, channel-belt sandstones with a large lateral extent separated by often equally thick intervals of recessive floodplain sandstone and siltstone. The Hell Gate Formation at section F3 and at section HG2 indicates that the lateral extent of these channel-belt sandstones is on the order of kilometers. This difference in fluvial architecture is a direct consequence of differences in the nature of the sediment load carried by Fram and Hell Gate channels. Since both fluvial styles contain significant amounts of sandstone and siltstone the channels of both formations must have been mixed-load channels. The differences in the architecture result from the Fram channels being mixed-load, suspended load dominant while the Hell Gate channels were mixed-load, bed-material load dominant. The cause of the difference in sediment load between Fram and Hell Gate channels is suggested to be tectonism. A discussion of why this is thought to be the determining factor is presented in 2.6.2.

The meandering fluvial interpretation suggested for the Hell Gate Formation contrasts sharply with the braided fluvial interpretation given to the formation by Embry and Klovan (1976). As previously mentioned, the meandering interpretation is based largely on the examination of the two best exposures of the formation found on southwestern Ellesmere Island (sections F3 and HG2), which Embry and Klovan were not aware of. The evidence for this interpretation is as follows:

a) The work of fluvial geomorphologists, in particular Schumm, in the 1960's and 70's, has established that in general, low sinuosity, multi-channel systems (braided) are favored by bed-material load channels whereas highly sinuous, undivided channel systems (meandering) are promoted by mixed load channels in which both the suspended load and the bed-material load constitute significant portions of the entrained sediment. In the Hell Gate Formation the recessive overbank portion of the fining-upward cycles averages 68.2% overall and the mean siltstone content of the overbank deposits is 34.0%. Both of these figures are too high to have resulted from deposition in a braided bed-material load system. The Hell Gate fluvial system must have consisted of mixed-load, sinuous, undivided channels.

b) In a recent critical evaluation of criteria in alluvial deposits which may be used to infer paleochannel pattern, Bridge (1985, pg. 582) refers to a model developed by himself which predicts that the spatial variability of mean bed-material size is directly proportional to the transverse bed slope which is in turn directly proportional to sinuosity. While information regarding the spatial variation in mean bed-material size for the Hell Gate channels is lacking, information indicative of their transverse bed slope is present at sections F3 and HG2. At both locations, in particular the latter, epsilon surfaces are present with estimated inclinations of up to 19^0. The high dip of these surfaces indicates that the Hell Gate channels developed large transverse bed slopes indicative of high sinuosity. Since transverse bed slopes in braided river channels are characteristically much lower than those of meandering river channels this evidence supports a meandering fluvial interpretation.

2. Estimates of Paleochannel Morphology and Flow Characteristics

Using method two of Ethridge and Schumm (1978) the paleochannel morphology and flow characteristics for the Hell Gate Formation can be estimated. Similar calculations were performed on the channel sandstones of the Strathcona Fiord and Fram Formations. As for those two formations, the figures presented for the Hell Gate Formation are not intended to be considered as accurate reconstructions, rather they are simply meant to convey an impression of the scale of the Hell Gate fluvial system. For this reason, the standard error of the estimate was not included in the determination of each parameter. It must be remembered however, for all the paleohydraulic calculations presented in this study, that the single figure that results from this approach gives a false sense of accuracy to the calculations. In reality a range of values, as determined by the appropriate standard error given in Ethridge and Schumm (1978), is the best that can be provided for any of the parameters. Table 2.4.9.3-1 presents the results of the

Table: 2.4.9.3.-1 Estimates of Paleochannel Morphology and Flow Characteristics for the Hell Gate Formation at Sections HG2, F2, HG1, HG3 and F3 Ordered from East to West Across Southwestern Ellesmere Island

Section	Db(m)	Dbc(m)	Wb(m)	F	P	Qm(m^3/s)	L(m)
HG2							
min.	2.0	1.3	10.2	7.8	2.0	0,8	183.7
max	10.0	6.5	121.4	18.7	1.6	119.7	1612.6
F2							
	13.0	8.5	183.6	21.6	1.5	277.9	2315.5
HG1							
min.	2.1	1.4	11.4	8.1	2.0	1.0	202.3
max.	6.2	4.0	57.5	14.4	1.7	26.2	838.4
HG3							
min.	5.3	3.4	44.8	13.2	1.7	15.7	673.9
max.	5.4	3.5	46.8	13.4	1.7	17.2	700.1
F3							
min.	2.2	1.4	11.4	8.1	2.0	1.0	202.3
max.	14.6	9.5	217.9	22.9	1.5	394.5	2688.1

Note:

Db bankfull depth from coarse member thickness; min. and max. correspond to the smallest and largest coarse member observed at a particular section and thus represent the range in paleochannel scale at that location

Dbc corrected bankfull depth (x 0.585/0.9 = 0.65)

Wb bankfull width from Dbc and Leeder (1973), equation 1

F width/depth ratio

P sinuosity from Ethridge and Schumm (1978, pg.706)

Qm mean annual discharge from Ethridge and Schumm

L meander wave length from Ethridge and Schumm calculations for the Hell Gate Formation. As indicated in the table, the calculations were performed for the thickest and thinnest single channel sandstone unit found in each section of the Hell Gate Formation. At section F2, only one main-channel sandstone unit is present.

For the Strathcona Fiord Formation at section S2, and for the Fram Formation, the conclusion was reached that a few larger channels must exist that are currently unexposed in order to account for such an overbank dominant fluvial architecture. This is not considered to be the case for the Hell Gate Formation due to the exceptional exposures at sections HG2 and F3, and the thick, single channel sandstone units also noted at other less well exposed locations. Maximum single channel sandstone unit thicknesses of 10.0 m, 13.0 m and 14.6 m are present at sections HG2, F2 and F3, respectively. These represent the largest, single channel sandstone units defined in the Okse Bay Group within the limits of the study area of this report. As will be discussed subsequently in 2.6, the calculations presented in Table 2.4.9.3-1 suggest that the Hell Gate meandering fluvial system was a slightly less sinuous system with somewhat larger channels than those which seem to characterize the Strathcona Fiord (at section S2) and Fram Formations.

3. Evidence of a Marine Influence

Evidence of at least a local marine influence in the Hell Gate Formation is present in a 1.0 m overbank siltstone unit at 491.7 m above the base of the formation at section HG2. Palynological analysis of a sample of this unit (GSC Loc. C-91987) showed that it contained rare, poorly preserved spores and a few acritarchs (McLaren, 1984a, pg. 14). This constitutes the only indication of proximity to a marine environment found in the Hell Gate Formation. The suggestions offered to account for the presence of marine microfossils in the Fram Formation (2.3.10.3) are again offered for the Hell Gate Formation at section HG2. These are: 1) the Hell Gate meandering fluvial system must have occupied (at least locally) a distal position on a coastal plain immediately adjacent to a marine environment 2) the acritarchs found in the floodplain siltstone were deposited by either a temporary marine incursion into the low lying floodplain area during strong onshore storm winds or by the estuarine behavior of the channel during such storms which might force a salt wedge further up river than usual and result in the overtopping of the channel margins by saline, microfossil bearing waters.

4. Fluvial System Trends

The Hell Gate Formation was examined for at-a-section vertical trends and for areal trends amongst the sections which could be indicative of source region direction. The three parameters used previously for a similar analysis of the Fram Formation were used again for the Hell Gate Formation, i.e., thickness of single channel sandstone units, and the thickness and coarse member to fine member ratio of the channel-belt fining-upward cycles. With respect to vertical variation upwards through the formation, no trends are present at any of the sections for any of the parameters. Areal trends were sought by examining Table 2.4.9.3-1, presented previously, and Table 2.4.9.3-2 presented below. The data presented in these tables indicates that areal trends amongst the sections are also absent.

2.5 Nordstrand Point Formation

2.5.1 Introduction

The Nordstrand Point Formation is the highest formation in the Okse Bay Group. The formation was defined in the eastern Arctic Islands by Embry and Klovan (1976). It is equivalent to the upper portion of the Beverley Inlet

Table 2.4.9.3.-2 Characteristics of the Fluvial Fining-Upward Cycles Found in the Hell Gate Formation at Sections HG2, HG1, HG3 and F3, Ordered From East to West Across Southwestern Ellesmere Island.

	HG2	HG1	HG3	F3
Average Thickness and Range (m)	10.9; 2.6-31.7	15.2; 5.1-27.5	37.9 (1 only)	20.4; 3.9-37.6
Crs.Mbr./Fine Mbr. (average and range)	1.46; 0.19-6.0	0.34; 0.11-2.70	0.17 (1 only)	0.57; 0.09-12.0

Note: overbank fining-upward cycles excluded.

Formation in the western Arctic Islands. As shown in Embry and Klovan (pg. 555), the areal extent of the formation is limited to between Grinnell Peninsula on Devon Island and the Bird Fiord - Okse Bay region of southwestern Ellesmere Island.

The Nordstrand Point Formation represents the third red weathering formation of the Okse Bay Group. In this respect, it is similar to the Strathcona Fiord (at section S2) and Fram Formations. All three formations produce a ridged topographic surface caused by alternating resistant sandstone ridges and recessive siltstone intervals.

While the Nordstrand Point Formation is well exposed, the quality of all exposures is very poor. Only one short section was measured in the formation southeast of Okse Bay.

2.5.2 Summary of Lithological Descriptions and Age Determinations from Previous Studies

2.5.2.1 Lithological Descriptions

The first description of what is now known as the Nordstrand Point Formation was given by McLaren (1963a, pg. 331-332) as a result of investigations conducted during Operation Franklin. McLaren considered the Okse Bay Group to be a formation and what is now the Nordstrand Point Formation was termed the upper sandstone and shale member.

A minimum thickness of 1850 ft (564 m) was given for the member in the area just south of the Okse Bay - Bird Fiord region where it was described as consisting of a "rhythmically alternating series of shales and sandstones with thin coal seams." The sandstones were grey and occurred in 5 - 30 ft (1.5 - 9.1 m) cross-bedded units separated by greenish-grey sandy and silty shale, 30 - 60 ft (9.1 - 18.2 m) thick with occasional thin (2 - 3 in) coal seams at the base.

The most recent description of the Nordstrand Point Formation was that given by Embry and Klovan (1976, pg. 554-556). They describe the formation at the type section south of Okse Bay as consisting of alternating resistant sandstone units and recessive shale-siltstone units arranged into shale-siltstone dominant fining-upward cycles. Sandstones weathered brown and occurred in 3 - 10 m units whereas shale-siltstone units weathered red, grey and green and were up to 12 m in thickness with coal seams to 30 cm.

2.5.2.2 Age Determinations

McLaren (1963a, pg. 331-332) notes that the fossil evidence in his upper sandstone and shale member consisted only of numerous plant remains and unidentifiable fish fragments. Palynological work on spores found in coal from this member suggested a Devonian age.

Embry and Klovan (1976, pg. 556) give a Middle to Late Frasnian age for the formation based on palynological analyses of spot samples collected from the type section.

2.5.3. Section HG3 (Nordstrand Point Formation portion)

2.5.3.1 Location, Thickness and Contact Relations

The upper portion of section HG3 consists of 107.8 m of the Nordstrand Point Formation. This section is located ca. 8 km southeast of the southeast corner of Okse Bay (Figure 2.1.1-1). The position of the base of the section is given in 2.4.7.1. The line of the section is shown on the aerial photograph presented as Figure 2.4.7.1-1.

Relative to the type section thickness (675 m) measured by Embry and Klovan (1976) near Okse Bay, the 107.8 m examined at this location constitutes approximately the basal 16.0% of the formation in this area. The exposure is of reasonable quality with 22.5% covered interval.

As stated in 2.4.7.1, the basal contact zone with the underlying Hell Gate Formation is conformable and transitional. The drafted section is contained in Figure

2.4.7.1-2 (in pocket).

2.5.3.2 Age

No productive palynology samples were recovered from the Nordstrand Point Formation at section HG3. It is anticipated that the age of the base of the formation at this location would be comparable to the Middle Frasnian age determined for most of the formation at the nearby type section by Embry and Klovan (1976).

2.5.3.3 Paleocurrent Analysis

Directional data are scarce in the Nordstrand Point Formation due to the fact that this exposure consists almost entirely of overbank sediments. The data set consists of only three planar tabular cross-bed measurements. Two were measured in overbank sandstone and one from a main-channel sandstone unit found at the top of the section. While the one main-channel cross-bed is inclined toward the southwest (189^{0}), many more measurements are required to confirm if this direction is a representative paleoflow direction for the Nordstrand Point Formation.

2.5.3.4 Facies Content

The Nordstrand Point Formation at this location consists dominantly of siltstone which constitutes 64.1% of the formation by cumulative thickness. The only other lithology in the formation is sandstone representing 35.9% by cumulative thickness. One siltstone and four sandstone sub-facies are defined. Their descriptive attributes are given in Table 2.5.3.4-1 and their relative proportion in the formation, by cumulative thickness, is shown in Figure 2.5.3.4-1.

Facies 1 - Siltstone

All siltstone at this location is non-stratified (1a). Siltstone units are mainly grey colored on both fresh and weathered surfaces with minor red and green colors also present. Siltstone is found either as thicker recessive intervals or thinly interstratified with sandstone. As a result, unit thickness varies considerably ranging between 0.02 - 14.2 m. Macroscopic fossil evidence is absent.

Facies 2 - Sandstone

Sandstone weathers mainly red-brown and occasionally grey-green. On a fresh surface it is grey. As indicated in Table 2.5.3.4-1, ripple cross-laminated (2c) and

Figure 2.5.3.4 - 1 Sub-facies in the Nordstrand Point Formation at section HG3. Percentage of the formation by cumulative thickness is shown on the ordinate scale.

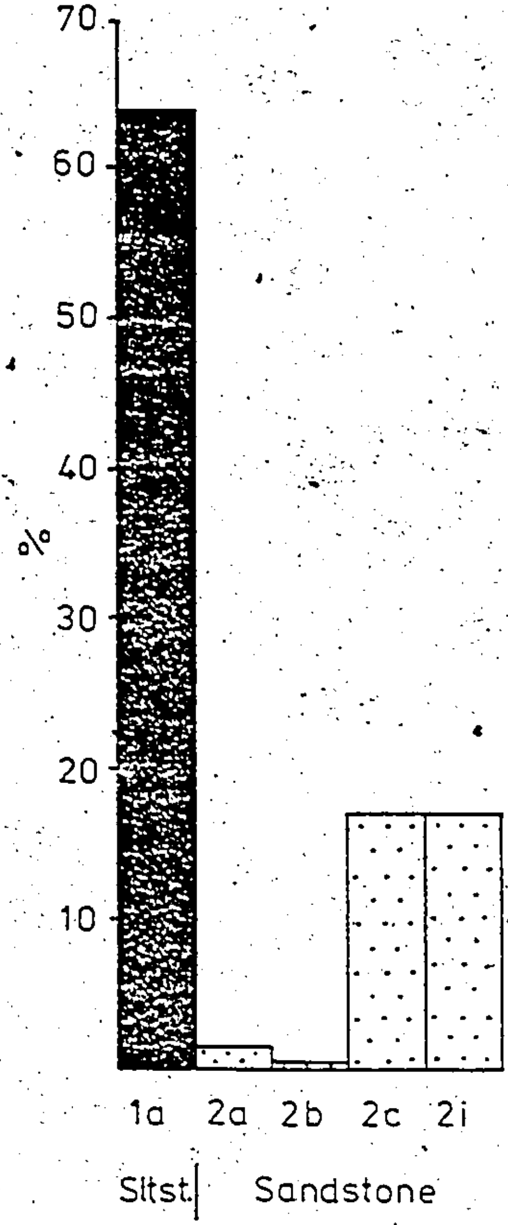

70
60
50
40
%
30
20
10
1a
2a
2b
2c
2i
Sltst.
Sandstone

Table 2.5.3.4.-1 Descriptive Attributes of Sub-Facies Defined in the Nordstrand Point Formation at Section HG3

Facies 1 - Siltstone (64.1%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
non-stratified siltstone	1a	100	2.3‡;0.02-14.2	red, green, grey/ red, green, grey	nf

Facies 2 - Sandstone (35.9%)

Sub-Facies	Code	% of Facies	Thickness(m)	W/F	Paleo.
planar tabular cross-bedded sandstone	2a	4.0	0.15;0.1-0.2	brown/grey	plant compressions
parallel laminated sandstone	2b	1.0	0.3(1 only)	brown/grey	nf
ripple cross-laminated sandstone	2c	48.0	1.0‡;0.04-1.6	green, brown/grey	comminuted plant debris partial plant fragments root, burrows
non-stratified sandstone	2i	47.0	1.8‡;0.1-2.3	brown/grey	partial plant compressions, roots, burrows

Note: 1. ‡average value too high due to poor data
2. see comments 3,4, and 5 following Table 2.1.3-1.

non-stratified sandstone (2i) are of approximately equal importance representing 48.0% and 47.0%, respectively, by cumulative thickness. These two sub-facies constitute almost all of the sandstone examined in the formation. Average unit thickness varies considerably amongst the sub-facies. Ripple cross-laminated and non-stratified sandstone are dominant with average unit thicknesses in the 1-2 m range while planar tabular cross-bedded (2a) and parallel laminated sandstone (2b) units are only tens of centimeters thick.

Macroscopic fossil evidence is present in all sub-facies but parallel laminated sandstones. It consists of comminuted plant debris, partial plant compressions, occasional root casts and rare burrows.

2.5.4 Interpretation of Depositional Environment

The Nordstrand Point Formation characteristically consists of resistant sandstone ridges and recessive siltstone intervals arranged into fining-upward cycles. Features of these fining-upward cycles such as erosive sandstone bases with siltstone rip-up clasts, occasional root casts and rare burrows at the top of thin sandstones found in the recessive intervals, abundant plant debris in the sandstones and siltstones, and root casts in the siltstones cumulatively indicate that the Nordstrand Point Formation may also be interpreted according to the meandering fluvial sedimentary model. While the formation is highly similar to both the Fram Formation and the Strathcona Fiord Formation (at section S2 and HB1) in terms of the presence of a sequence of fining-upward cycles, it lacks any evidence to suggest it was in close proximity to a marine environment such as was found in the Fram Formation. For this reason, it is considered most similar to the Strathcona Fiord Formation at sections S2 and HB1. The block diagram representation of the meandering fluvial depositional setting for the Strathcona Fiord Formation (Figure 2.1.7.2-4) is equally applicable to the Nordstrand Point Formation.

2.5.4.1 Genetic Associations

The sediments composing the Nordstrand Point Formation may also be interpreted as belonging to either an overbank (J) or channel association (I). Table 2.5.4.1-1 presents the descriptive attributes of these genetic associations. A larger scale version of an interval in the formation at section HG3 is presented as Figure 2.5.4.1-1 to show some of the components of the genetic associations.

Table 2.5.4.1.-1 Genetic Associations in the Nordstrand Point Formation at Section HG3

Assoc.	Code	%	Thickness(m)	Sub-Facies Content
Channel	I	3.0	2.5 (1 only)	I1 - 2a, 2i
Overbank	J	97.0		
	J_1	8.1	0.4;0.2-0.5	2b, <u>2c</u>, 2i
	J_2	61.2	2.4;0.1-14.2	1a
	J_4	6.6	1.4;1.2-1.6	2c, 2i
	J_5	21.1	1.4; 0.1-6.4	1a; 2a, <u>2c</u>, 2i

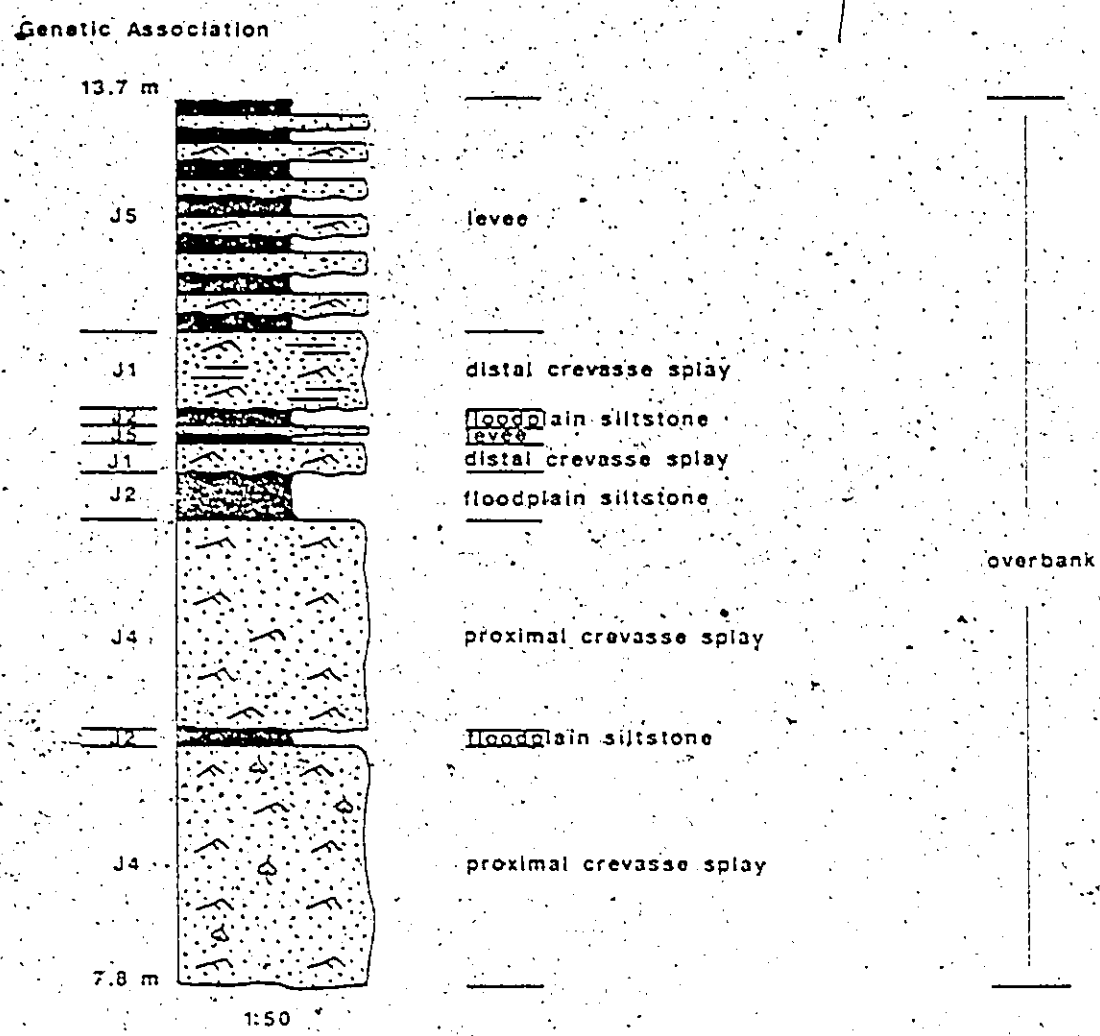
<u>Note</u>:

% - percentage of Nordstrand Point, by cumulative thickness, represented by a genetic association or a component of a genetic association

<u>Thickness</u> - average thickness and range, in meters

<u>Sub-facies content</u> - all possible sub-facies in a genetic association or a component of a genetic association; not all sub-facies found at each occurrence; dominant sub-facies, if any, underscored.

Figure 2.5.4.1 - 1 Genetic associations in the Nordstrand Point Formation. A representative interval from the formation at section HG3 is shown.


Genetic Association
13.7 m
J5
levee
J1
distal crevasse splay
J2
floodplain siltstone
J5
levee
J1
distal crevasse splay
J2
floodplain siltstone
J4
proximal crevasse splay
J2
floodplain siltstone
J4
proximal crevasse splay
overbank
7.8 m
1:50

Selected features of the formation at this location are presented as Plate 2.5.4.1-1.

I. Channel Association

The criterion used to distinguish between channel-belt sandstone units and overbank sandstones in the Nordstrand Point Formation is the same as that used for the Fram and Hell Gate formations, i.e., an arbitrary lower thickness limit of 2.0 m. The reasons given for its use in these formations are equally applicable for the Nordstrand Point Formation. With respect to channel-belt sandstone units, section HG3 provides an unreliable indication of their thickness in the formation since only a single 2.5 m unit is present at the top of the section.

As given in Table 2.5.4.1-1, the one channel-belt sandstone unit identified at section HG3 is a basal channel fill composed of non-stratified (2i) and planar tabular cross-bedded sandstone (2a) representing only 3.0% of the formation by cumulative thickness.

J. Overbank Association

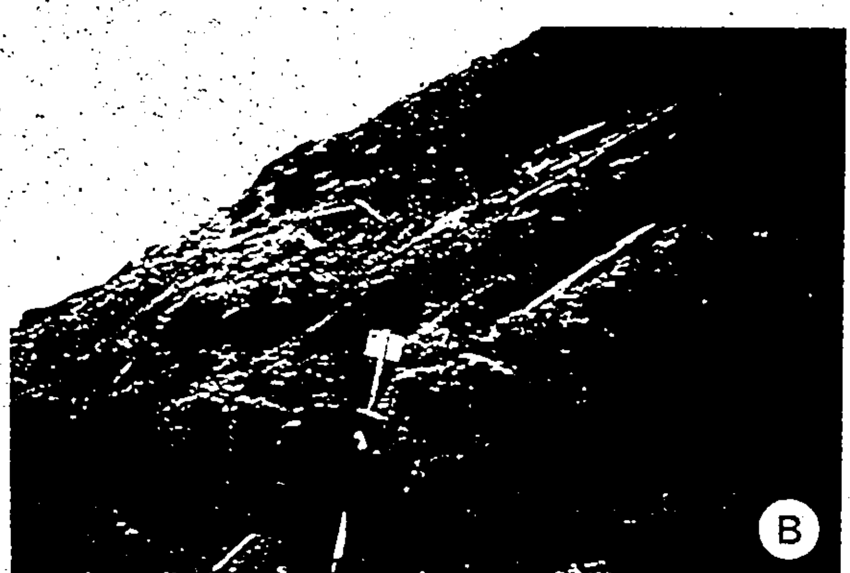
Sandstone and siltstone belonging to the overbank association constitute the majority of the Nordstrand Point Formation at section HG3 representing 97.0% by cumulative

Plate 2.5.4.1 - 1 The Nordstrand Point Formation at section HG3 located approximately 8 km southeast of the southeast corner of Okse Bay.

A. A poorly preserved trunk-channel sandstone in the basal Nordstrand Point Formation. The hammer (arrow) is 30 cm in length.

B. Highly weathered, interstratified floodplain sandstone and siltstone/shale in the basal Nordstrand Point Formation. The exposed portion of the Jacobs Staff is 1.2 m in length.


A


B

thickness. Overbank components J1, J2, J4 and J5 are identified and interpreted in exactly the same fashion as they were for the Strathcona Fiord, Fram and Hell Gate formations. Overbank component J3 (nodular weathering horizon) is not present at this location. For brief review purposes, overbank components J1 and J4 represent distal and proximal crevasse splay sandstones, respectively. The distinction between them is based on an arbitrary thickness criterion of 1.0 m due to a highly similar sub-facies composition. Overbank component J2 consists of siltstone and represents floodplain fines deposition. The sandstone and siltstone couplets constituting overbank component J5 represent proximal overbank deposits, likely levee deposition.

The floodplain siltstones (J2) are the most prominent overbank component constituting 61.2% of the formation by cumulative thickness. They have no macroscopic fossil content. They have either gradational or sharp basal contacts and display the largest average thickness value (2.4 m) amongst the overbank components.

The sandstone and siltstone couplets constituting overbank component J5 are secondary in importance constituting 21.1% of the formation by cumulative thickness. The couplets are usually sandstone dominant and most commonly have a gradational basal contact. Occasionally however, erosional basal contacts are present and result in slight angular discordances amongst individual couplets. The sandstone of the couplets is most commonly ripple cross-laminated (2c) and rarely contains planar tabular cross-bedding (2a). The siltstone is always non-stratified (1a). J5 units average 1.4 m in thickness and contain comminuted plant material with occasional root casts and burrows.

Overbank components J1 and J4 are minor constituents of the formation representing 8.1% and 6.6%, respectively, by cumulative thickness. Both components always display slightly erosional basal contacts, if exposed, and are composed mainly of ripple cross-laminated (2c) and non-stratified sandstone (2i). As indicated in Table 2.5.4.1-1, average unit thickness is 0.4 m and 1.4 m for component J1 and J4, respectively. Macroscopic fossil evidence is similar in both components and consists of abundant comminuted and occasionally larger plant debris and rare root casts.

2.5.4.2 Facies Sequence Analysis

The Nordstrand Point Formation at section HG3 was subjected to the same contingency table analysis

(Markov Chain analysis) using BMDP-4f (Brown, 1983) that was used previously on the other formations of the Okse Bay Group. For an overview of this statistical software package the reader is referred to 2.1.7.2. The results of the computations are presented in Figure 2.5.4.2-1 which presents copies of computer printouts from BMDP-4f. The probability associated with the maximum likelihood-ratio chi-square statistic (0.3216) exceeds the criterion probability (0.20) indicating that there are no non-random facies transitions in the Nordstrand Point Formation at this location.

2.5.4.3 Discussion

Channel-belt sandstone units are very poorly represented in the Nordstrand Point Formation at section HG3. Similarly, the section itself is poorly representative of the formation in this area since it represents only the basal 16%. Nevertheless, if the dominance by overbank siltstone and sandstone in this exposure is characteristic of the formation then there must be larger (i.e., greater thickness), single, channel-belt sandstone units unexposed in the formation to account for the deposition of such a high volume of overbank sediment. Embry and Klovan (1976, pg. 555) report sandstone intervals up to 10 m in thickness

Figure 2.5.4.2 - 1 Markov Chain analysis of the Nordstrand Point Formation at section HG3. Computations performed using BMDP-4F.

BMDP4F CONTINGENCY TABLE ANALYSIS OF THE NORDSTRAND POINT FORMATION AT SECTION HG3

* TABLE PARAGRAPH 1 *

***** OBSERVED FREQUENCY TABLE 1

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE 1A	POVB	2A	2B	2C	2I	FUC	TOTAL
1A	0*	5	1	1	2	0	0-	9
POVB	5	0*	0	0	0	2	0-	8
2A	0	0	0*	0	1	1	0-	2
2B	0	0	0	0*	1	0	0-	1
2C	2	2	0	0	0*	0	0-	4
2I	0	2	0	0	0	0*	0-	2
FUC	1	0	0	0	0	0	0*	1
TOTAL	9	9	1	1	4	3	0 -	27

TOTAL OF THE OBSERVED FREQUENCY TABLE IS 27
SUMMED OVER 42 CELLS WITHOUT STRUCTURAL ZEROS

* MODEL 1 *

MODEL	D.F.	LIKELIHOOD-RATIO CHI-SQUARE	PROB	PEARSON CHI-SQUARE	PROB	ITER.
A,B.	24	26.64	.3216	26.85	.3113	5

***** EXPECTED VALUES USING ABOVE MODEL

ASTERISK INDICATES MISSING VALUE

BELOW	ABOVE 1A	POVB	2A	2B	2C	2I	FUC	TOTAL
1A	5.7*	5.2	.4	.4	1.4	1.2	.0 -	9.0
POVB	4.3	4.4*	.3	.3	1.5	1.0	.0 -	8.3
2A	.3	.7	.1*	.1	.2	.2	.0 -	2.0
2B	.4	.4	.0	.0*	.1	.1	.0 -	1.0
2C	1.3	1.6	.1	.1	.5*	.4	.0 -	4.0
2I	.3	.8	.1	.1	.3	.2*	.0 -	2.0
FUC	.4	.4	.0	.0	.1	.1	.0*	1.0
TOTAL	9.0	9.0	1.0	1.0	4.0	3.0	.0 -	27.0

****** STEPWISE CELL DELETION IS NOT PERFORMED. P-VALUE OF MODEL FIT (.3216) IS GREATER THAN CRITERION PROB (.2000)

in the formation but it is uncertain if these are multiple or single channel-belt sandstone units. The Nordstrand Point Formation exposed in section HG3 is therefore highly similar to the Strathcona Fiord Formation at section S2 where it was also suggested that larger, single channel-belt sandstone units must be present to account for the fine-member-dominant fining-upward cycles.

In passing from the Hell Gate Formation into the Nordstrand Point Formation the change from thick, laterally extensive, grey-white channel-belt sandstone units characteristic of the Hell Gate Formation into thinner, less laterally extensive, red-grey channel-belt sandstone units found in the Nordstrand Point Formation reflects a decrease in the supply of sand size detritus to the Nordstrand Point fluvial system. Whereas the Hell Gate channels were bed-material load dominant mixed-load channels the dominance of Nordstrand Point stratigraphy by overbank siltstone indicates that the channels reverted back to the suspended-load-dominant mixed-load channels that were responsible for the deposition of the underlying Fram Formation. It is suggested that the cause of the change in the nature of the sediment load carried by the river system that prompted the onset of the Nordstrand Point fluvial style was the erosional reduction of a source region that had been subjected to moderate epeirogenesis throughout most of Hell Gate time. As the uplift of the source region declined late in Hell Gate time regional paleoslope was gradually reduced through erosion and the supply of sand size detritus diminished.

2.6 Variable Fluvial Deposition in the Okse Bay Group

The objective of this section is to discuss changes in the gross characteristics of the fluvial deposits upward through the Okse Bay Group on southwestern Ellesmere and North Kent Islands and to then suggest what the ultimate control was over these changes.

2.6.1 Channel Characteristics in the Okse Bay Group

The environmental setting for each formation of the Okse Bay Group has been previously presented and discussed. With the exception of the basal Strathcona Fiord Formation at Stenkul Fiord (section S1), which is interpreted as a tidal inlet - lagoon - tidal flat depositional setting, all formations of the group elsewhere in the study area represent deposition in fluvial sedimentary environments. The Okse Bay Group constitutes an intermediate to distal coastal plain sequence composed of four meandering

(Strathcona Fiord, Fram, Hell Gate and Nordstrand Point) and one braided (Hecla Bay) fluvial formation. Calculation of paleochannel morphology and flow characteristics for each of the four meandering formations indicates that while the Strathcona Fiord (at sections S2 and HB1) and Nordstrand Point formations represent high sinuosity, single channel systems of approximately equal scale, the Fram and the Hell Gate Formations represent progressively more robust meandering systems with deeper channels, longer meander wavelengths, larger mean annual discharges and slightly reduced sinuosities. Table 2.6.1-1 presents these calculations based on the average corrected bankfull depth determined for each formation from fining-upward cycle coarse member thickness. The value of 4.4 m given for the Hell Gate Formation represents a maximum for the Okse Bay Group since the average corrected bankfull depth for the braided Hecla Bay Formation is only 3.0 m. As mentioned previously, the immediate cause of this variation in scale amongst the meandering formations of the Okse Bay Group and the change in fluvial style between them and the braided Hecla Bay Formation are changes in the bed-material load to suspended load ratio accompanying relative changes in the total volume of detritus carried by the channels. Schumm (1968) has emphasized the importance of the nature of the

Table 2.6.1.-1 A Comparison of Paleochannel Morphology and Flow Characteristics Amongst the Four Meanderig Fluvial Formations of the Okse Bay Group.

Formation	n	av.Dbc	Wb	P	L(m)	Qm(m^3/s)
Strathcona Fiord	4	1.6	14.0	1.9	243.6	1.5
Fram	8	2.8	33.2	1.8	518.7	8.5
Hell Gate	9	4.4	66.6	1.7	951.5	35.4
Nordstrand Point	1	1.6	14.0	1.9	251.4	1.5

Note: 1. n = number of data used for average Dbc calculation; P, L and Qm values based on average Dbc value using method two of Ethridge and Schumm, 1978.

2. Dbc - corrected bankfull depth
P - sinuosity
L - meander wavelength
Qm - mean annual discharge
Wb - bankfull width

sediment load as a determinant of fluvial style. As suggested by Schumm (1963), rivers carrying a high proportion of bed-material load relative to suspended load tend to develop low sinuosity divided channel networks (i.e., braided) whereas those with a high proportion of suspended load develop high sinuosity single channel systems (i.e., meandering). In the Okse Bay Group variations in the bed-material load to suspended load ratio amongst the fluvial formations are reflected by variations in the sandstone content. The average percent sandstone, by cumulative thickness, for each meandering formation of the group is as follows: Strathcona Fiord - 41.6%, Fram - 50.7%, Hell Gate - 65.9% and Nordstrand Point - 35.9%. For the braided Hecla Bay Formation the average percent sandstone is 93.3%. The increase in sandstone content (i.e., bed-material load) amongst the formations in the Okse Bay Group is depicted in Figure 2.6.1-1. As shown in this figure, all formations were deposited by mixed load channels. For the meandering Hell Gate Formation and especially the braided Hecla Bay Formation the channels were dominated by bed-material load. For the meandering formations of the group, the cause-effect relationship between the average percent sandstone and the scale of the meandering system can be seen by comparing Figure 2.6.1-1 to

Figure 2.6.1 - 1 The position of the constituent formations of the Okse Bay Group in a fluvial spectrum defined by the nature of the sediment load and relative to the rate of source terrane uplift.

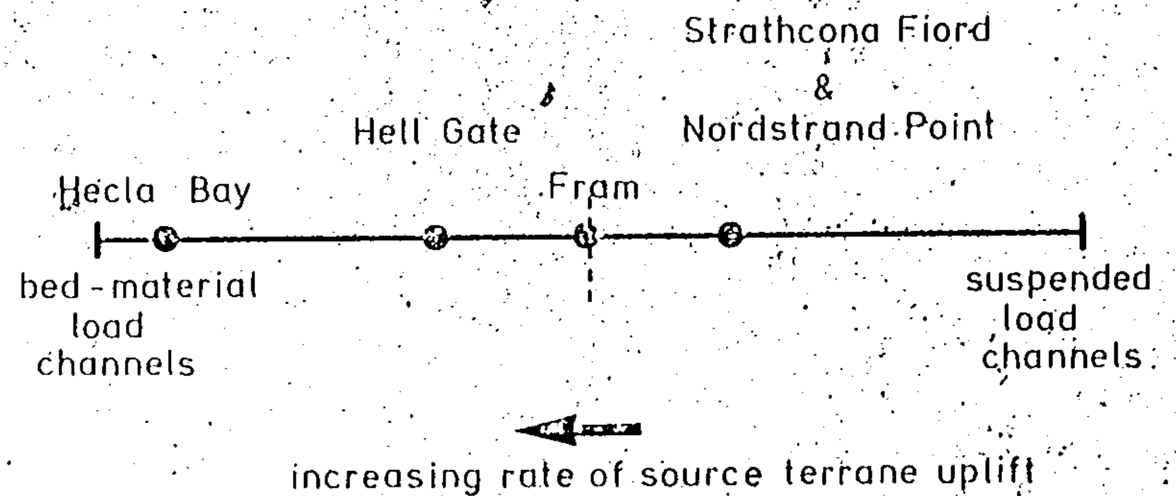

Strathcona Fiord
&
Nordstrand Point
Hell Gate
Hecla Bay
Fram
bed-material
load
channels
suspended
load
channels
increasing rate of source terrane uplift

Table 2.6.1-1. The calculations presented in Table 2.6.1-1 demonstrate that as the proportion of sand size detritus carried as bed-material load increases (associated with a relative increase in the total volume of detritus as well) there is a corresponding increase in the scale of the meandering channel. For the Hecla Bay Formation; bed-material load constituted almost all of the sediment load and resulted in a change in channel pattern from a highly sinuous undivided channel in the underlying Strathcona Fiord Formation to a lower sinuosity divided channel network.

2.6.2 Determinant of Change

It is apparent from the preceding discussion that the essential question which must be addressed in order to determine the ultimate cause of changing channel characteristics in the Okse Bay Group is as follows:

- what factor(s) produced a variation in the supply of sand size detritus during Okse Bay time?

Three possibilities exist: 1) a change in source rocks 2) a change in climate 3) tectonic uplift. These factors could produce such a change in sediment load either independently or in combination.

Data will be presented in 3.0 which demonstrates an extremely homogeneous composition, both areally and stratigraphically, throughout the Okse Bay Group. This is considered to constitute a strong argument against a significant change in source rocks as the reason for the variable supply of sand size detritus. This leaves either climate or tectonism as the causative mechanism.

Embry and Klovan (1976, pg. 602-606) have presented an argument in favor of a climatic control over the changing channel characteristics in the Okse Bay Group. Their argument is rejected in this report in favor of a tectonic control. These two mechanisms are discussed individually below in the context of the Okse Bay Group.

Climate

Embry and Klovan (1976) base their argument favoring long term climatic change as the ultimate control over Okse Bay Group fluvial deposition principally on the dominant oxidation state (i.e., color) of the siltstone and shales. They defined three types of fluvial strata in the Okse Bay Group: 1) meandering with red and green shales (Strathcona Fiord Formation) 2) meandering with green and grey shales (Fram and Nordstrand Point formations) 3) braided with grey to black shale (Hell Gate and Hecla Bay formations). To each type of fluvial strata a causative climatic setting was suggested. Formations with red shales were associated with a lowered water table and drier climate, those with mainly grey and green shales were associated with a slightly elevated water table of a somewhat more humid climate, and those with grey and black shales were associated with reducing conditions caused by a high water table in a very humid climate. By combining this association of shale color and climate with the stratigraphic arrangement of the formations composing the Okse Bay Group, they were able to define three asymmetric climatic cycles in the group (see their Figure 54, pg. 605). Each cycle represented a gradual change from savanna to a very humid climate followed by an abrupt change back to a savanna setting. The Strathcona Fiord (savanna) and Hecla Bay (very humid) formations constituted the first cycle, the Fram (savanna) and Hell Gate (very humid) formations the second cycle and the Nordstrand Point Formation (savanna) the beginning of the third cycle.

Their argument in favor of long term climatic change being the most important control on the variability of the fluvial strata in the Okse Bay Group is considered to be erroneous on the grounds that it is based on a very equivocal and overly simplistic association between the present oxidation state of shales and siltstones and the prevailing climatic conditions at the time of deposition.

The origin of red beds has been a controversial topic for many years. They have long been presumed to document the effect of a unique climate with highly oxidizing conditions (Van Houten, 1973). The origin of red beds has been reviewed several times, most notably by Dunbar and Rodgers (1957), Glennie (1970) and Van Houten (1973). The seminal papers on the origin of red beds are those of Walker (1967, 1974), the former dealing with their origin in a desert environment and the latter in a moist climate. The main conclusion of both of these papers, which is of critical importance with respect to the validity of Embry and Klovan's climatic hypothesis for the Okse Bay Group, is that conditions conducive to the formation and preservation of red pigmentation (iron oxides) can occur independent of the climatic setting. The critical factor in determining whether or not iron occurs in the ferric (red) or ferrous (grey or green) state is the interstitial Eh-pH conditions. Climate is but one factor in the determination of the interstitial chemistry and its role can be easily overshadowed by local factors. Nor are the interstitial Eh-pH conditions fixed at the time of deposition of the sediments, rather they are subject to both early and late diagenetic changes which can result in a change of pigmentation.

Factors other than climate, possibly local in nature, which are important in determining the interstitial Eh-ph conditions of the sediments and the stability of these conditions are: 1) longevity of sub-aerial exposure (a function of the rate of sedimentation) 2) drainage 3) bedrock lithology 4) temperature 5) organic matter content 6) topography as it effects the local water table level (this would be a common factor (i.e., flat) for the overbank shales and siltstones in the Okse Bay Group) 7) the chemistry and flow patterns associated with both early and late post-depositional ground water conditions.

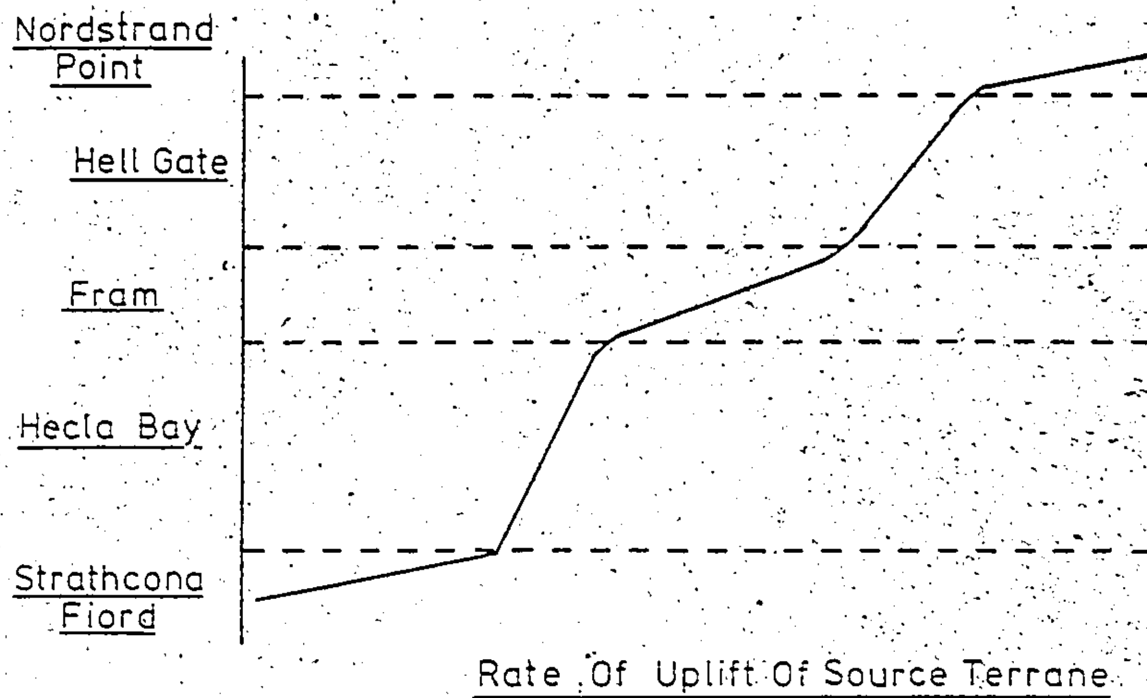
The importance of diagenesis in determining the stability of a sediment's pigment has been stressed by many authors. The focus of Van Houten's most recent review (1973) of the origin of red beds is the importance of diagenesis in determining the pigment of a sedimentary rock. Dunbar and Rodgers (1957) note that the Early Permian Dunkard Series of Pennsylvania, Ohio and West Virginia contains grey shales in one area and red shales in another due to differences in the drainage and organic matter content of the sediments, as opposed to differences in climate, which is considered to have been the same in both areas. Glennie (1970) notes that reddening can occur during late diagenesis and as an example notes that the Carboniferous Barren Red Measures of Britain were likely reddened post-depositionally as a result of desertification during the deposition of the overlying Permian strata. Adler (1970) emphasized the importance of variable and repeated local changes in the Eh-pH of interstitial water that produce late post-depositional modifications of a sediments pigmentation. Back and Barnes (1965) noted that interstitial Eh was a function of the direction of groundwater flow and that it increased toward a recharge area.

In light of the above mentioned examples, which serve to highlight the importance of factors other than climate in the determination and preservation of a sediments color, it is suggested that subtle, local variations in sub-areal exposure time, drainage, organic matter content, and early to late post-depositional ground water conditions, both between differing fluvial environments and within the same fluvial environment, are the cause of the color differences noted in the shales and siltstones of the Okse Bay Group, not climatic cyclicity as proposed by Embry and Klovan (1976). These factors determined the interstitial Eh-pH conditions which thereby governed whether the iron present in the sediment adopted a ferric or ferrous state. The simple fact that the overbank shales and siltstones occurring in most of the five formations in the Okse Bay Group display a variety of oxidation states attests to the overriding influence of factors other than climate.

Tectonism

Tectonism is considered to be the ultimate control over the variable sandstone content displayed by the formations of the Okse Bay Group. An eastern source region, the Ellesmere Island-northwest Greenland craton (discussed in 4.1.1), is considered to have been an area of continuous but variable rates of uplift throughout Okse Bay Group time (Early Eifelian to Late Frasnian). This concept is given qualitative graphical expression in Figure 2.6.2-1, in which the inclination of each line segment represents the rate of uplift during the period of deposition of a specific formation in the Okse Bay Group. The relative amount of time associated with the deposition of each formation (i.e., the length of an ordinate interval in this figure) is based on the maximum age range of each formation as determined by dated palynology samples collected during this study. As indicated in Figure 2.6.1-1, the greater the sandstone content the greater is the inferred rate of uplift. An

Figure 2.6.2 - 1 Relative amounts of source terrane uplift during the period of deposition of each formation in the Okse Bay Group.


Nordstrand Point
Hell Gate
Fram
Hecla Bay
Strathcona Fiord
Rate Of Uplift Of Source Terrane

amount of uplift is also implied in this figure since for formations such as the Strathcona Fiord and Fram, which have comparable maximum periods of deposition, an increased rate of uplift means a greater amount of uplift as well. The continuous nature of the uplift is necessary to account for the continued growth of the clastic wedge throughout the Middle and Late Devonian.

A tectonic control over the variability displayed in the fluvial deposits of the Okse Bay Group is supported by the following evidence derived from the environmental analysis:

1. The basal 293 m of the Strathcona Fiord Formation at section S1 (Stenkul Fiord) represents deposition in a tidal inlet-lagoon-tidal flat sedimentary environment. While the depositional environment of the overlying portion of the formation is uncertain due to poor outcrop quality, the top of the formation only 44 km to the southwest, at section HB1, represents deposition in a meandering fluvial sedimentary environment. Assuming the top of the formation at section HB1 is representative of the top of the formation at section S1, then the transition from a paralic to a fluvial depositional setting is indicative of an increased supply of sediment which could be explained by uplift in the

source region.

The Strathcona Fiord Formation was also examined at section S2. At this location the formation is entirely meandering fluvial and conformably overlies the Bird Fiord Formation which represents deposition in a near shore marine environment. As discussed above, this transition to a fluvial depositional environment indicates an increased supply of detritus which could be due to uplift of a source region. The proximity of the shield area of eastern Ellesmere Island and northwest Greenland make it a reasonable candidate for a source region.

2. Recumbent-folded deformed planar tabular cross-bedding (overturned cross-bedding), constituting sandstone sub-facies 2n, is present in the Hecla Bay Formation at several localities. As discussed previously (2.2.8.3), Allen and Banks (1972) have convincingly argued in favor of a seismically induced genesis for this structure as opposed to simple basal shear at the bed of a river, which they feel is much too weak. This structure possibly constitutes evidence of seismic activity in the basin during the deposition of the Hecla Bay Formation. Due to the immediate proximity of the Ellesmere Island-northwest Greenland craton it is reasonable to associate this activity

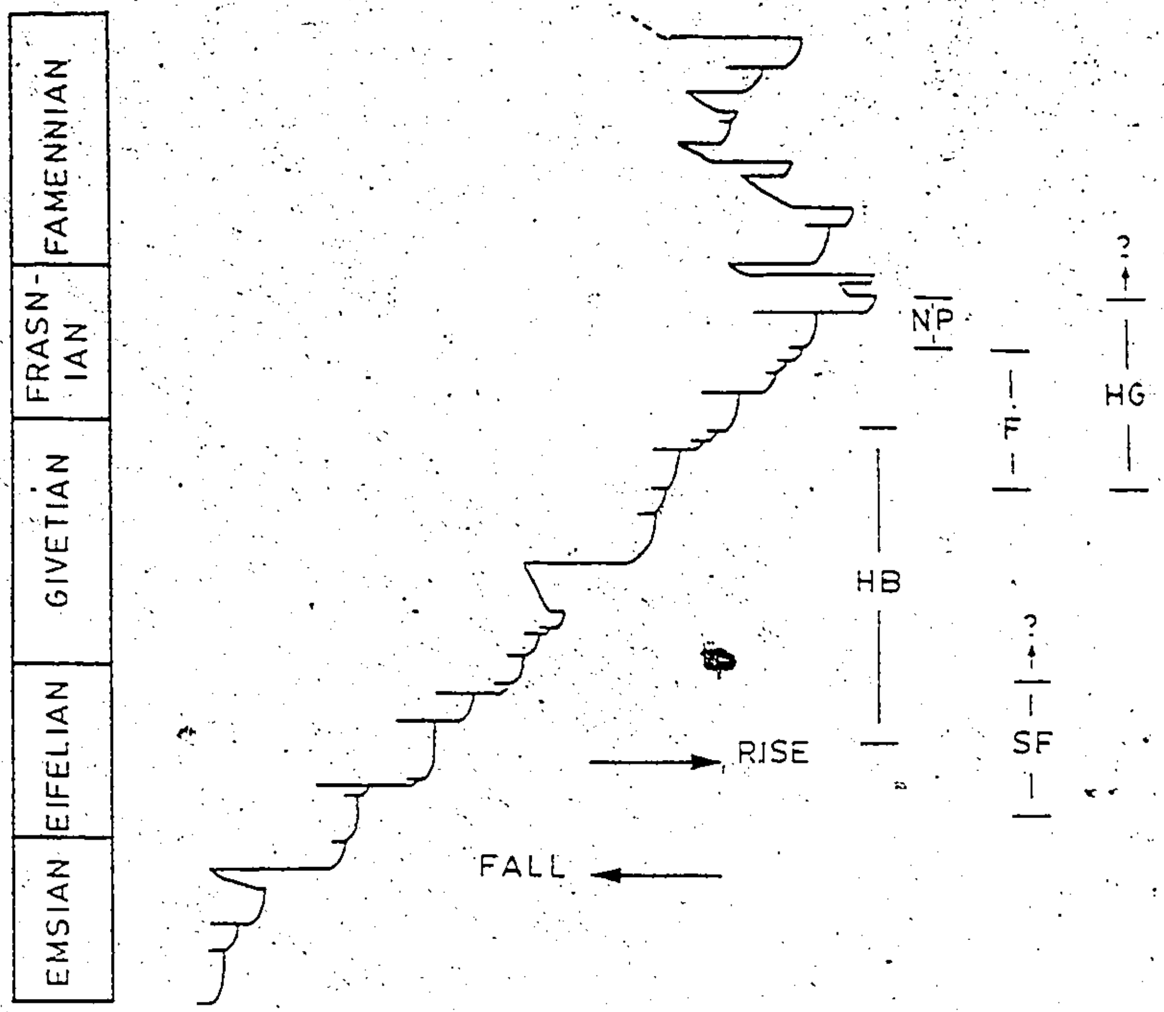
with cratonic diastrophism involving regional uplift. Since the overturned cross-beds are present only in the Hecla Bay Formation it is also reasonable to infer that the tectonism involving uplift was most severe during Hecla Bay time. This is supported by the fact that the only basal conglomerates noted in the Okse Bay Group occur at the base of the Hecla Bay Formation at section HB1. A maximum rate of uplift during Hecla Bay time is indicated in Figure 2.6.2-1 by a greater slope.

3. The Hell Gate Formation is best exposed at section HG2 and at section F3. As mentioned previously, at each of these localities the formation consists of thick, recessive weathering, overbank intervals alternating with thick (10's m), resistant, laterally extensive, multi-story, channel-belt sandstones. The lateral extent of the channel-belt sandstones at each locality is especially noteworthy as it is on the scale of several kilometers. This type of fluvial architecture is unusual in that it is uncommon to find both thick overbank deposits and thick, laterally extensive, channel-belt sandstones occurring together. Usually, channel-belt sandstones are crudely lensoid in shape and restricted in their areal extent when overbank deposition is prominent. Bridge (1985, pg. 586)

has suggested that the main controls over fluvial architecture are: 1) channel-belt width relative to floodplain width 2) tectonic tilting 3) the rate of overbank aggradation relative to the frequency of avulsion. In an earlier paper (Bridge and Leeder, 1979) dealing with simulation models of alluvial stratigraphy he demonstrated the importance of tectonic tilting to the avulsion process. The only way to develop the thickness and lateral extent of channel-belt sandstones displayed in the Hell Gate Formation in the presence of high rates of overbank aggradation is to have an over compensating high frequency of avulsion. Based on the work of Bridge and Leeder (1979) this would in turn imply the development and maintenance of a steeper regional channel profile through tectonic uplift of a source area. Again, the proximity of the Ellesmere Island-northwest Greenland craton would seem to make it a likely candidate for the source region.

In addition to the direct evidence resulting from the environmental analysis of the Okse Bay Group, indirect but strong evidence in support of a tectonic control results from the recent publication of the Devonian eustatic sea level curve (Johnson, Klapper and Sandberg, 1985). The period of deposition of the Okse Bay Group relative to this sea level curve is presented in Figure 2.6.2-2. Assuming that the ocean adjacent to the depositional region of the Okse Bay Group was connected to the Devonian world ocean, this figure indicates that the growth of that portion of the Devonian clastic wedge represented by the Okse Bay Group occurred during a worldwide rise in sea level. This would be expected to produce transgressive rather than regressive deposits. That the clastic wedge on Ellesmere Island could develop during a period of eustatic sea level rise is considered to be strong evidence of tectonic uplift. Figure 2.6.2-1 indicates that the Hecla Bay and Hell Gate formations may be thought of as the "tectonic formations" in the Okse Bay Group, in the sense that the highest average sandstone contents belong to these formations implying the highest rates of uplift during their deposition. While direct evidence of tectonism was not found in either the Fram (overlying the Hecla Bay Formation) or the Nordstrand Point formations (overlying the Hell Gate Formation), their stratigraphic position relative to the tectonic formations makes it reasonable to suggest that uplift continued during their period of deposition but at a reduced rate. The total sediment volume and the proportion of sand transported as bed-material load was reduced accordingly as is reflected by

Figure 2.6.2 - 2 Eustatic sea level curve for the Devonian relative to the period of deposition of the Okse Bay Group. Modified from Johnson, Klapper and Sandberg, 1985.


FAMENNIAN
FRASN-IAN
GIVETIAN
EIFELIAN
EMSIAN
RISE
FALL
HB
NP
F
SF
HG
?
?

the lower sandstone content in the Fram and Nordstrand Point formations.

Having stated the evidence in favor of a tectonic control over the variation displayed by the fluvial deposits of the Okse Bay Group it is necessary to specify the nature of the tectonism thought to be responsible. Based on biostratigraphic evidence (palynology) resulting from this study, Okse Bay Group deposition on North Kent and southwestern Ellesmere Islands can be bracketed between the Early Eifelian and Late Frasnian. This time interval is intermediate between the main pulse of the Caledonian Orogeny (Late Silurian to Early Devonian) of east Greenland and the Ellesmerian Orogeny (Late Devonian (Famennian) to Early Mississippian) on Ellesmere Island. While late Caledonian spasms occurred throughout the Devonian in east Greenland, it is unlikely that they would have affected Okse Bay Group deposition since they were restricted to intramontane regions along the suture belt south of 76^{0}N. latitude, i.e., southeastern Greenland (Haller, 1971, pg. 132). This necessitates that the proposed tectonic uplift be epeirogenic rather than orogenic in nature. Although the environmental analysis does not specifically point to the Ellesmere Island-northwest Greenland craton as the source region for the Okse Bay Group, the proximity of this cratonic region to the site of Okse Bay Group deposition in light of the evidence favoring epeirogenesis must make it a strong candidate. In this context, epeirogenesis of a cratonic area is suggested as the style of tectonic uplift controlling the variation in fluvial deposition in the Okse Bay Group.

Evidence exists which confirms that uplift of this cratonic area did occur, at least locally, during the period of deposition of the Okse Bay Group. The Cornwallis Fold Belt is a linear belt of north-south trending fold axes in the south-central Arctic Islands caused by uplift of a north-south elongated promonotory of the Canadian Shield (Kerr, 1977; a different style of uplift from that suggested by Kerr was recently suggested by Okulitch, Packard and Zolnai, 1986). In discussing the history of the Cornwallis Fold Belt, Kerr (his Table 1) indicates that the Boothia Uplift was active from Lower Silurian (Llandoverian) to Upper Devonian (Frasnian) time with four pulses of peak activity. The time interval bracketed by the third and fourth pulses of this uplift (Middle Emsian to Middle Frasnian), which were both of moderate strength, is approximately equivalent to the duration of deposition of the Okse Bay Group (Early Eifelian to Late Frasnian). In addition, Kerr (1967) has also documented an Eifelian age uplift of the northernmost portion (Bache Peninsula area) of the eastern Ellesmere craton based on the occurrence of the Vendom Fiord Formation, a clastic red-bed unit which flanks the craton on central eastern Ellesmere Island and lies unconformably on rocks of Early Devonian age. Uplift of these areas of the craton is considered to demonstrate that the shield of the eastern Arctic Islands and Greenland was not immobile during Middle and Upper Devonian time and to therefore provide support for the hypothesis of epeirogenesis.

2.6.3 Summary Statement

In light of the epeirogenic hypothesis presented above it is apparent why relative changes in the total volume of sediment in transport must have been associated with changes in the bed-material load to suspended load ratio (discussed in 2.6.1). It is stressed that it is this ratio which was the immediate determinant of fluvial characteristics in the Okse Bay Group. While variations in this ratio, as well as in the total volume of sediment in transport, could be attributed just as easily to changes in the source rock or climate of the source region, or to a change of source region, as to epeirogenesis, it was shown that these other possible controls provide unsatisfactory explanations of changing fluvial characteristics in the Okse Bay Group.

This section is not intended to provide a final statement on the source region(s) of the Okse Bay Group. This is provided in 4.1.1. In the context of suggesting epeirogenesis as the ultimate control over Okse Bay Group deposition, it was reasonable to suggest that the adjacent shield areas of Ellesmere Island and northwestern Greenland should be considered as likely areas of uplift. It is emphasized however, that the environmental analysis of the Okse Bay Group only indicates that tectonism was the ultimate determinant of sedimentation. It does not specifically indicate the nature or the location of the area(s) of tectonic uplift. This can only be specified subsequent to an evaluation of the petrologic characteristics of the Okse Bay Group presented in 3.0 and a regional synthesis of the paleocurrent data presented in 4.0.

3.0 Petrology of the Okse Bay Group

3.1 Introduction and Objective

This chapter is intended to present the results of a petrographic examination of the five formations composing the Okse Bay Group. Only the light mineral crop was examined. Heavy minerals are present in very small percentages and cursory observations made during the point counting process indicates that at least some belong to the ultramature zircon-tourmaline-rutile suite as anticipated on the basis of the quartz rich light mineral fraction. With the exception of the Strathcona Fiord Formation at section S1 (outer Stenkul Fiord) thin sections of coarse siltstone and/or sandstone were examined from each formation, at each section at which an environmental analysis of the formation had been performed. The Strathcona Fiord Formation at section S1 was omitted from the petrographic analyses due to its contrasting environmental setting (tidal inlet-lagoon-tidal flat) which would preclude a comparison of its siltstone and arenite compositions with the Okse Bay Group exposed at the remaining section locations, all representing deposition in a fluvial environment. A total of 137 thin sections from the Okse Bay Group were examined for this study with the following distribution by formation: Strathcona Fiord Formation - 14, Hecla Bay Formation - 34, Fram Formation - 51, Hell Gate Formation - 35, Nordstrand Point Formation - 3. The number of thin sections examined per formation was determined by three factors: 1) the total meterage measured 2) the degree of weathering of the outcrop 3) the objectives of the petrographic study as outlined subsequently. Many more satisfactory outcrops could have been sampled in each formation if the thrust of the study had been strictly petrographic. However, since this study is concerned with both a facies and a petrographic analysis of the Okse Bay Group, the location of petrographic sampling was determined by the number of exposures of a formation considered to be of sufficient quality for environmental analysis.

Although an attempt was made to have a common sample interval amongst the samples chosen for thin-sectioning at each section location this was again ultimately determined by outcrop quality. As a result, the sample interval was quite variable, but in all cases a sufficient number of thin sections were examined to permit the average modal compositions derived from the point counting to be representative of a formation's mineralogical makeup. The average sample spacing was usually in the range of 20-40 m, but in sections of highly weathered outcrop it ranged as high as 87 m.

The principal objective of the petrologic study of the Okse Bay Group is to document the mineralogic makeup of the group throughout the study area, and to use this information to help delineate the source terrane.

3.2 Transmitted Light Microscopy

3.2.1 Point-Count Methodology

3.2.1.1 The Gazzi-Dickinson Technique

The choice of point-counting technique must be determined by the objective of the petrographic study. Since the concern of this study is primarily with the determination of source rock type(s) as an aid in the location of the source region(s) the Gazzi-Dickinson point-counting technique (Ingersoll et al., 1984) is the appropriate method. This method originated from the independent work of Gazzi (1966) and Dickinson (1970). It is a technique which attempts to maximize information on source rocks, ideally from rapidly deposited sediments in tectonically active settings (Ingersoll et al, 1984). In the light of the previously discussed hypothesis of an epeirogenic control over fluvial deposition in the Okse Bay Group the choice of this technique is appropriate. The plot position on ternary diagrams of modal compositions determined with this technique are indicative of the plate tectonic setting of the source region at the time of deposition of the clastic unit. As pointed out by Velbel (1985), one must always ensure that the source region(s) and depositional basin were tectonically linked (i.e., similar plate tectonic setting) before extending the paleo-plate tectonic setting inferred from the sandstone composition to the basin of deposition. Once the tectonic setting of the source rocks is established this information can aid immensely in the isolation of a source region. The boundaries defining the fields of the various plate tectonic settings in the ternary diagrams have been established empirically by determining the modal composition of sandstones from known plate tectonic settings. The seminal paper in this respect is that of Dickinson and Suczek (1979). Initially, the use of this approach in determining the tectonic setting of a unit's source region seems overly simplistic because it is derived from a simple diagram. However, it must be remembered that the basic concept that sandstone composition should be grossly related to the tectonic setting of the source region did not originate with the work of Dickinson and his students on the Great Valley sequence (a late Cretaceous fore-arc basin) in central and northern California in the early 1970's. Rather, the principle can be found in the work of Krynine and was effectively contemporaneous with his popularization of the use of thin sections in the study of sedimentary rocks (Pettijohn, 1985). The field boundaries on the ternary diagrams have been established through the cumulative efforts of many petrographers and represent modal analyses of sandstones from many different areas. While Dickinson et al. (1983) demonstrated that the approach was generally valid for many (233) North American Phanerozoic sandstone suites, subsequent research has shown that under certain geological conditions sandstone composition can be a misleading indication of the plate tectonic setting of the source region (Franzinelli and Potter, 1983, Mack, 1984, and Velbel, 1985). This emphasizes the importance of combining the use of this approach with an otherwise thorough petrographic study as opposed to a mindless use of the ternary diagrams. The ternary diagrams from Figure 1 of Dickinson et al. (1983) are used subsequently in this report.

The Gazzi-Dickinson point-counting method must be employed if sandstone composition is to be used to suggest a tectonic setting for the source rocks of the Okse Bay Group. As discussed by Ingersoll et al. (1984), this point-counting method is unique in both philosophical and operational respects. It differs philosophical from the traditional school of thought in its contention that modal composition may be determined independently of grain size. Traditionally, grain size has been considered to exert a fundamental control over the modal composition of a clastic deposit via mechanical breakage and hydraulic sorting. Operationally the technique has three unique characteristics: 1) the dependance of composition on grain size is reduced by counting monomineralic crystals of sand size (>0.0625 mm) that are found within larger rock fragments as members of that particular grain category rather than counting the large lithic grain; for example, if the cross-hairs land on a monocrystalline quartz grain of sand size within a larger sedimentary rock fragment the point is counted as monocrystalline quartz rather than a sedimentary lithic 2) only non-quartzose lithics (labile lithics) are included in the lithic category; quartzose lithic grains such as chert and polycrystalline quartz are included in the quartzose grain category; on a ternary composition diagram this difference in lithic classification is indicated by a QFL designation as opposed to the standard QFR designation 3) a 0% cutoff is applied to minor components as opposed to a 10% cutoff which is used by some advocates of the traditional point-counting technique (Ingersoll et al., 1984, pg. 106); this difference can have a profound effect on the classification of lithics where minor but genetically important mineral components may only constitute a few percent of the grain in question (for example several mica flakes in a low rank metamorphic rock fragment).

In attempting to determine the dominant bedrock type(s) of the source region, from which information its plate tectonic setting may be inferred, it is essential to realize that every attempt must be made to determine the detrital composition (i.e., the composition at the time of final deposition) of the sediment as opposed to the diagenetic composition. This approach is not unique to the Gazzi-Dickinson method and involves the mental removal of diagenetic effects in an attempt to restore the pre-diagenetic mineral composition of the sediment. For instance, an altered alkali feldspar is counted as alkali feldspar rather than the alteration product. As might be expected, the determination of the altered framework grain frequently becomes subjective and time consuming. The degree of success a petrographer has in removing the diagenetic effects and arriving at a reliable estimate of the detrital composition is difficult to evaluate since there is no independent means of knowing the detrital composition. However, in general it is a function of how severe and complete the diagenetic alterations have been and the skill of the petrographer, which is in turn largely a function of his or her petrographic experience.

3.2.1.2 Okse Bay Group Point-Counts

The purpose of this section is to describe the operational techniques employed in point-counting the Okse Bay Group. As mentioned previously, the Gazzi-Dickinson technique was adopted since the purpose of the petrographic study was the determination of source rock type. The use of this methodology has recently been criticized as promoting too simplistic an approach to the study of sandstone provenance (Suttner and Basu, 1985, Decker and Helmold, 1985). For this reason, it is stressed that while the technique was adopted it was accompanied by an otherwise thorough study of all source rock diagnostic framework grains (see petrographic work sheets, Figure 3.2.1.2-1). The practice of counting all grains of sand size occurring within coarser lithic grains as belonging to the grain category representing their composition, rather than as a lithic, made no difference in this study since no thin section was examined which included large lithics containing sand size grains.

Thin sections prepared for this study were given as fine a polish as possible prior to mounting on the glass slide in order to increase the overall textural clarity, and in particular, that of the fine interstitial material and lithic grains. They were also left uncovered for subsequent feldspar staining and cathodoluminescence microscopy. Cover slips were floated in clove oil drawn under them by capillary action when examination of the thin section was necessary. The clove oil is easily washed off the thin section and cover slip with a gentle stream of warm water and does not adversely affect the thin sections. All thin sections were half-stained for both alkali and plagioclase feldspar following the detailed description of the staining procedure given in Houghton (1980). Only one-half of the thin section was stained because of the difficulty of controlling the plagioclase stain which tends to leave a thin residue across the thin section which can mask fine lithic textures and thereby hinder their identification.

Using a mechanical stage, a total of 300 grain points were accumulated as a first count for each thin section. Both the stained and unstained halves of the thin section were included in this count. If the percentage of feldspar from the first count was high enough to warrant a second count of feldspar grains only, this was performed on the doubly stained half of the thin section where the number of feldspar grains counted equalled the number of feldspar grains accumulated in the first count. For both first and second counts the point spacing greatly exceeded the grain size in the thin section so as to ensure any grain was not counted more than once. A third count of lithic grains only was never necessary in the Okse Bay Group as the number of lithics tallied in the first count was always very low or zero.

The following microscope operations were routinely performed in the process of point-counting to facilitate grain identification; they are listed in decreasing order of frequency: 1) switching between plane and polarized light 2) stage rotation for examination of birefringence and pleochroism 3) subtle changes in focus 4) changing objectives 5) diaphragm adjustment. Interference figures were not used for the identification of grains due to the difficulty of obtaining good figures in the size of sediment normally encountered in the Okse Bay Group (coarse silt to fine sand size detritus).

Figure 3.2.1.2-1 presents the petrographic work sheets used to record the point-count data from the Okse Bay Group. A definition of the grain parameters contained in this figure and of the derived parameters used in plotting

Figure 3.2.1.2 - 1 Petrographic work sheets used for point-counting the Okse Bay Group sandstones.

A. First Count - Detrital Framework

Section:

Sample:

Height Above Base:

Age:

Geographic Location:

Date:

Objective:

Grains Counted:

Hand Sample Description:

% Framework - Matrix - Cement (Visual Estimate)

Framework:

Qm

Qp

low rank metamorphic

high rank meta./ign.

Qc

deep water

shallow water replacement

Ls

sandstone

siltstone

shale

F

Lv

felsitic

microlitic

lathwork

vitric

Lm

low rank

high rank

Lf (labile framework)

Recalculated Diagenetic QFL%: Q

F

L

Cement Types (visual estimate; major type underscored)

Detrital Textures (visual estimate)

	Rounding	Sorting	Mean Grain Size
Quartz			
Feldspar			

B. Second Count - Feldspar

Date:

Potassium feldspar

Twinned plagioclase feldspar

Twinned plagioclase/total feldspar

Remarks:

C. Tabulation of Diagenetic Features

Date:

the data on ternary composition diagrams is presented in Table 3.2.1.2-1. As indicated in Figure 3.2.1.2-1, the initial count utilized seven framework grain categories: mono-crystalline quartz (Qm), polycrystalline quartz (Qp), chert (Qc), feldspar (F), and metamorphic (Lm), volcanic (Lv) and sedimentary rock fragments (Ls). In addition to this first level classification all the grain categories, excepting Qm and F, received a second order classification as shown in Figure 3.2.1.2-1. This data was then recalculated to QFL percentages for plotting on ternary composition diagrams according to the three additive equations contained in Table 3.2.1.2-1. It will be noticed that two types of QFL percentages are defined in this table, a diagenetic QFL % and a detrital QFL%. As mentioned previously, in order to arrive at an estimate of the detrital composition the diagenetic alteration of the labile framework grains must be mentally removed during point-counting. In general, two situations arise during this process: 1) the labile framework grain has been only partially altered and an identification of the grain can still be made from remaining unaltered portions (often staining helps considerably in this situation) 2) the labile framework grain has been completely removed through dissolution producing an oversize pore space constituting a

Table 3.2.1.2.-1 Grain Parameters

1. Q = Qm + Qp + Qc

where: Q = total quartzose grains

Qm = monocrystalline quartz grains

Qp = polycrystalline aphanitic quartz grains of low rank metamorphic (1) and/or high rank metamorphic-igneous derivation (2)

Qc = polycrystalline aphanitic quartz grains of biogenic-diagenetic derivation, i.e., chert grains; nodular chert derived from local replacement of shallow shelf carbonate (1); argillaceous chert of presumed deep water origin (2); non-diagnostic chert (3)

2. F = P + K

where F = total feldspar grains

P = plagioclase feldspar grains

K = potassium feldspar grains

3. L = Lm + Lv + Ls

where L = unstable aphanitic lithic grains

Lm = metamorphic aphanitic lithic gains of low rank (1) - eg. slate, phyllite, schist and/or high rank (2) - eg. gneiss.

Lv = volcanic-hypabyssal aphanitic lithic grains; felsitic (1), microlitic (2), lathwork (3) and vitric (4) - as per Dickinson (1970).

Ls = sedimentary aphanitic lithic grains; sandstone (1), siltstone (2), shale (3)

4. Lf = non-quartzose labile framework grains; identity unknown due to diagenesis; Lf breakdown estimated to be approximately 85% feldspar and 15% lithic grains.

5. % QFL (1) = diagenetic QFL%; Lf not taken into consideration.

6. % QFL (2) = detrital QFL%; determined by subtracting Lf from diagenetic QFL% (see text for additional explanation)

type of secondary porosity which may or may not be subsequently infilled with a cement; alternatively the labile grain may be replaced by a cement without the intermediate dissolution phase in which case secondary porosity is never developed; in either case no clue remains as to the identity of the dissolved or replaced framework grain. Both of the above situations must be taken into consideration when attempting to arrive at a reliable estimate of the detrital composition. It is here that the distinction between the diagenetic QFL% and detrital QFL% lies. The former incorporates only the first situation discussed above and as a result does not attempt to completely remove diagenetic effects; thus its designation as a diagenetic modal composition. The latter incorporates both situations and therefore represents an estimate of the detrital modal composition at the final depositional site. The second situation discussed above cannot be incorporated directly into the point-count since the framework grain category represented by the secondary porosity or cement is unknown. For this situation a separate tally was recorded, designated labile framework (Lf) on the petrographic work sheet (Figure 3.2.1.2-1) and the table of grain parameters (Table 3.2.1.2-1). Since the labile grains represented in this category were in all probability either feldspar or some type of lithic this data was proportionately allocated to these two classes of framework grains according to a feldspar to lithic ratio estimated from the remaining relative amounts of these grains in the thin section. This is a crude approach since it assumes that the remaining relative amounts of these grains are, roughly representative of the ratio at the time of final deposition. It is however, the only way to arrive at a non-arbitrary estimate of the ratio. As will be demonstrated subsequently, the Okse Bay Group is compositionally very homogeneous (both vertically and areally) throughout the study area. For this reason and because of the inherent inaccuracy of the method in general, using a separate ratio for each thin section examined was considered pointless. For the Okse Bay Group a 85/15 feldspar to lithic ratio was applied to the labile framework (Lf) tally. The detrital QFL% is then derived from the diagenetic QFL% by first subtracting the Lf% from the Q% of the diagenetic mode and then adding the Lf% to the feldspar (F) and unstable lithic (L) categories according to the ratio given above to arrive at an estimate of the detrital feldspar and lithic components in each thin section.

Following the first count a visual estimate of the percentage of framework, matrix, and cement was made using the comparison chart of Terry and Chilingar (1955). In this study the upper size limit for matrix is 30 microns, as suggested by Dott (1964).

Cement types, their paragenesis, and a visual estimate of their relative percentages was also made at this time using the comparison chart mentioned above.

Detrital texture (grain size, roundness and sorting) was also visually estimated for both quartz and feldspar grains. With transmitted light the roundness of detrital quartz can only be estimated from those few grains exhibiting "dust rims" due to the presence of common authigenic silica cement throughout the Okse Bay Group. For this reason, cathodoluminescence microscopy was used to determine the degree of rounding exhibited by the detrital framework grains (3.3.3) by comparison with the roundness scale of Powers (1953). Visual sorting estimates were based on a comparison with the sorting standards provided for each sand size class in Beard and Weyl (1973). The mean grain size of each thin section was estimated by measuring the size of four roughly equidimensional monocrystalline quartz grains chosen as representative of the sample. Since the majority of the Okse Bay Group thin sections were moderately well sorted to well sorted this method of estimating the mean grain size was sufficiently accurate to reliably distinguish between the different size classes. Information on feldspar grain size was limited to observations on the size of the feldspar grains relative to the surrounding monocrystalline quartz grains.

As discussed above, a second count of feldspar grains was performed on the doubly stained half of the thin section if the number of feldspar grains accumulated from the first count was sufficient to warrant it. As shown on the petrographic work sheet, alkali feldspar and twined plagioclase feldspar were counted and the plagioclase to total feldspar ratio calculated. As discussed by Dickinson (1970) and Ingersoll (1978), this ratio is important in distinguishing between volcanic (a high plagioclase to total feldspar ratio) or plutonic and metamorphic (a low plagioclase to total feldspar ratio) source terranes for first cycle detritus. In the Okse Bay Group twined plagioclase is considered to be indicative of a non-diagenetic (i.e., non-albitized) origin for the following reasons: 1) while Gorai (1951) demonstrated that untwined detrital plagioclase can be supplied by metamorphic and intrusive igneous rocks, the untwined plagioclase observed in the Okse Bay Group is considered to represent diagenetic albitization of predominantly alkali feldspar; this is inferred from the fact that staining showed numerous instances of partial albitization of alkali feldspar (while no instances of partial albitization of twinned plagioclase grains were noted, the fact that twinned plagioclase grains were observed (albeit very rarely) indicates that they could also have been albitized) which implies that the untwinned plagioclase grains represent those cases where the albitization has gone to completion 2) the untwinned to twinned plagioclase ratio was invariably very high in the Okse Bay Group and in most thin sections twinned plagioclase was absent; Walker (1984) cites this as one of his indicators of diagenetic albitization.

As will be discussed in 3.4, the feldspar ratio as well as feldspar rounding and grain size relative to associated monocrystalline quartz grains constitutes important information with respect to a source terrane interpretation for the Okse Bay Group.

The final step involved in the examination of each thin section was the recording of all diagenetic features observed during the first and second point counts. Most importantly, a diagenetic paragenesis was always attempted so that a generalized sequence of diagenetic events might ultimately be proposed for the Okse Bay Group.

The petrographic data set for the Okse Bay Group, containing both primary and secondary parameters (such as

P/F and QFL%), is presented as Table 3.2.1.2-2. For any large data set accumulated over a prolonged period of time (in this case approximately three months) by one or more investigators it is important to be able to demonstrate that differences between samples are real and not due to operator variation. As discussed by Griffiths and Rosenfeld (1954), operator variation involves both a consistent and an inconsistent bias. The former is a persistent characteristic of each operator and can only be evaluated through a comparison of experimental results obtained by different operators using the same methodology on the same set of samples. With regards to the petrographic study of the Okse Bay Group, this would involve having a reference set of thin sections point-counted by another petrographer according to the format used in this study as a means of evaluating the reproducibility of the modal analyses presented in Table 3.2.1.2-2. This aspect of operator variation was not determined for this study. However, the extent to which the latter type of operator variation prejudiced the petrographic data set was evaluated. This type of operator variation amounts to inconsistencies in judgement or interpretation during the course of an experiment. In order to evaluate this, a reference set of five thin sections was chosen which were point-counted near

Table 3.2.1.2-2 DETRITAL MODAL POINT-COUNT DATA. Values shown are usually based on 300 total grain points. % Lf based on 300 + Lf total grain points.
See Table for explanation of symbols and Figure for petrographic work sheets.

Section	Fm	spl	a.b.	Qm	Cp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL % (1)	QFL % (2)	mgs.
F1	F	1	18.8	88.7	2.0	7.0	1.7	--	0.7	--	0.7	97.7	0	5.7	97.7/1.7/0.7	92/7/2	vf
		17	149	93.3	1.0	4.7	0.3	--	0.7	--	0.7	99.0	0	12.8	99.0/0.3/0.7	86/11/3	vf
		34	211.4	90.3	1.0	1.3 (2) 6.4 (3)	0.7	--	0.3	--	0.3	90.3	0	12.7	99.0/0.7/0.3	86/12/2	vf
		40	272.1	91.7	0.3	0.3 (2) 3.0 (3)	4.7	--	--	--	--	95.3	0	18.1	95.3/4.7/0	77/20/3	cs
		47	331.5	90.7	1.7	6.7	0.3	--	0.7	--	0.7	99.1	0	16.9	99.3/0.3/0.7	82/15/3	vf
		62	402.5	85.2	3.4	0.7 (2) 8.4 (3)	0.7	--	1.7	0.7 (1)*	1.7	97.7	0	12.8	97.7/0.7/1.7	85/12/4	vf
		76	470.5	96.7	1.7	1.3	--	--	0.3	--	0.3	99.7	--	13.3	99.7/0/0.3	86/11/2	vf
		86	534	83.3	0.3	6.0	10.0	--	0.3	--	0.3	89.6	0	11.8	89.6/10.0/0.3	78/20/2	cs
		116	658.5	91.3	1.7	0.3 (2) 0.3 (1) 5.4 (3)	--	--	1.0	--	1.0	99.0	--	12.6	99.0/0/1.0	86/11/3	vf
		129	697.4	84.0	1.3	9.0	5.3	--	0.3	--	0.3	94.3	0	16.9	94.3/5.3/0.3	77/20/3	cs
		Mean and one standard deviation for QFL% (2):						Q - 83 ± 5 F - 14 ± 5 L - 3 ± 1									
HB1	SF	761	0.8	97.6	1.0	0.7	--	--	0.7	--	0.7	99.3	--	19.4	99.3/0/0.7	80/17/4	vf
		764	24.5	97.0	2.0	1.0	--	--	--	--	--	100	--	16.2	100/0/0	84/14/2	vf
		766	43.3	85.3	6.0	0.7 (1) 1.3 (3)	6.7	--	--	--	--	93.3	0	2.3	93.3/6.7/0	91/9/0	vf
		Mean and one standard deviation for QFL% (2):						Q - 85 ± 6 F - 13 ± 4 L - 2 ± 2									
	HB	768	47.5	96.7	3.0	0.3 (1)	--	--	--	--	--	100	--	18.3	100/0/0	82/16/3	f
		770	57.8	90.3	0.7	0.7	8.3	--	--	--	--	91.7	0	9.9	91.7/8.3/0	82/17/2	vf
		774	92.4	81.0	2.7	--	16.3	--	--	--	--	83.7	0.02	8.0	83.7/16.3/0	76/23/1	f
		776	116.7	85.0	0.7	1.0	13.0	--	0.3	--	0.3	86.7	0.03	19.8	86.7/13/0.3	67/30/3	f
		782	144.4	85.3	2.3	0.7	11.0	--	0.7	0.3 (1)*	0.7	88.3	0	11.8	88.3/11.0/0.7	77/21/3	vf
		784	177.7	79.3	--	0.3	20.3	--	--	--	--	79.6	0.02	12.5	79.6/20.3/0	67/31/2	f
		785	212.8	88.7	0.7	0.3	10.3	--	--	--	--	89.7	0	6.5	89.7/10.3/0	83/16/1	m
		788	251.4	83.0	1.0	0.3	15.3	--	0.3	--	0.3	84.3	0	11.5	84.3/15.3/0.3	73/25/2	f

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lt	QFL % (1)	QFL % (2)	mgs
		792	289.0	84.3	0.3	0.7	14.7	--	--	--	--	85.3	0	12.0	85.3/14.7/0	73/25/2	f
		794	360.4	93.7	0.3	--	6.0	--	--	--	--	94.0	0	11.8	94.0/6.0/0	82/16/2	f
		795	390	87.0	0.3	0.3	12.3	--	--	--	--	87.6	0	12.0	87.6/12.3/0	76/23/2	vf
		799	457.2	85.3	1.0	0.3	13.3	--	--	--	--	86.6	0	11.0	86.6/13.3/0	76/23/2	f
		800	499.4	89.0	0.3	1.7	9.0	--	--	--	--	91.0	0	12.5	91.0/9.0/0	79/20/2	vf
		802	524.3	93.3	3.0	0.7	3.0	--	--	--	--	97.0	0	7.1	97.0/3.0/0	90/9/1	f
		Mean and one standard deviation for QFL% (2): Q - 77 ± 6; F - 21 ± 6; L - 2 ± 1															
FS	F	865	43.0	89.3	2.0	1.6	6.3	--	1.0	--	1.0	92.9	0	8.0	92.9/6.3/1.0	85/13/2	vf
		869	97.6	93.7	--	3.3	3.0	--	--	--	--	97.0	0	22.7	97/3/0	74/23/3	cs
		871	151.5	90.0	2.7	1.7	5.3	--	0.3	--	0.3	94.4	0	26.1	94.4/5.3/0.3	68/28/4	cs
		873	210.3	83.7	7.7	8.3	--	--	0.3	--	0.3	99.7	--	25.9	99.7/0/0.3	74/22/4	vf
		876	258.5	88.7	2.0	8.0	0.7	--	0.7	--	0.7	98.7	--	27.2	98.7/0.7/0.7	72/24/5	vf
		877	319.8	95.7	0.3	0.3 (1) 3.4 (3)	0.3	--	--	--	--	99.7	--	21.0	99.7/0.3/0	79/18/3	cs
		878	374.3	85.0	1.0	14.0	--	--	--	--	--	100.0	--	24.4	100/0/0	76/21/4	cs
		880	475.6	90.0	1.7	8.0	--	--	0.3	--	0.3	99.7	--	17.2	99.7/0/0.3	83/15/3	vf
		Mean and one standard deviation for QFL% (2): Q - 76 ± 6; F - 20 ± 5; L - 4 ± 1															
HG2	F	669	11.0	91.7	1.7	3.3	1.0	--	0.3	--	0.3	98.7	--	9.9	98.7/1.0/0.3	89/9/2	vf
		675	36.6	90.7	1.7	0.3 (2) 6.4 (3)	--	--	1.0	--	1.0	99.1	--	4.1	99.1/0/1.0	95/4/2	vf
		685	72.2	95.0	0.3	4.7	--	--	--	0.3 (3)*	--	100.0	--	0	100/0/0	100/0/0	vf
		693	101.7	99.0	--	1.0	--	--	--	--	--	100.0	--	10.5	100/0/0	90/9/2	vf
		702	145.0	94.7	0.3	2.7	2.3	--	--	--	--	97.7	0	13.8	97.7/2.3/0	84/14/2	vf
		Mean and one standard deviation for QFL% (2): Q - 92 ± 6; F - 7 ± 5; L - 2 ± 1															
	HG	703	156.4	98.0	0.3	1.7	--	--	--	--	--	100	--	12.3	100/0/0	88/11/2	vf
		709	185.6	96.3	--	2.3	1.3	--	--	--	--	98.6	--	9.9	98.6/1.3/0	89/10/2	vf
		716	217.2	90.3	3.4	6.3	--	--	--	--	--	100	--	18.2	100/0/0	82/16/3	cs
		721	247.9	97.0	1.0	2.0	--	--	--	--	--	100	--	23.0	100/0/0	77/20/4	cs
		726	289.3	98.0	0.7	1.3	--	--	--	--	--	100	--	22.7	100/0/0	77/19/3	f

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL% (1)	QFL% (2)	mgs
		732	322.5	96.0	2.3	--	1.3	--	0.3	--	0.3	98.3	--	17.1	98.3/1.3/0.3	81/16/3	vf
		738	354.5	95.3	2.3	2.4	--	--	--	--	--	100	--	20.3	100/0/0	80/17/3	vf
		742	399.2	95.6	0.7	3.7	--	--	--	--	--	100	--	13.6	100/0/0	86/12/2	vf
		745	425.6	93.3	0.3	6.0	0.3	--	--	--	--	99.6	--	18.3	99.6/0.3/0	81/16/3	vf
		748	459.8	94.7	1.0	4.0	0.3	--	--	--	--	99.7	--	18.2	99.7/0.3/0	82/16/3	cs
		750	522.3	98.0	0.3	1.3	0.3	--	--	--	--	99.6	--	12.3	99.6/0.3/0	87/11/2	f
		752	650.3	97.0	1.7	1.3	--	--	--	--	--	100	--	10.7	100/0/0	89/9/2	vf
		756	596.3	97.0	1.0	1.0	1.0	--	--	--	--	99.0	--	12.8	99.0/1.0/0	86/12/2	f
		758	610.9	98.0	0.3	1.0	0.7	--	--	--	--	99.3	--	15.2	99.3/0.7/0	84/14/2	f
		760	661.4	96.7	1.7	1.3	0.3	--	--	--	--	99.7	--	19.3	99.7/0.3/0	80/17/3	vf

Mean and one standard deviation for QFL% (2): Q - 83 ± 4
F - 14 ± 3
L - 3 ± 1

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL% (1)	QFL% (2)	mgs
HB3	HB	846	1.5	85.0	0.7	1.3	13.0	--	--	--	--	87.0	0	17.1	87.0/13.0/0	70/28/3	vf
		847	87.0	90.0	1.3	--	8.3	--	0.3	--	0.3	91.3	0	12.8	91.3/8.3/0.3	79/19/2	f
		849	118.3	90.7	2.3	1.3	5.7	--	--	--	--	94.3	0	14.8	94.3/5.7/0	80/18/2	f
		851	214.2	95.0	0.3	--	4.7	--	--	--	--	95.3	--	16.2	95.3/4.7/0	79/19/2	f
		854	289.0	98.3	1.3	0.3	--	--	--	--	--	100	--	24.1	100/0/0	76/21/4	vf
		858	435.0	96.7	3.3	--	--	--	--	0.3 (3)*	--	100	--	8.0	100/0/0	92/7/1	m
		862	529.2	90.0	7.3	0.3	2.0	--	0.3	--	0.3	97.6	--	10.4	97.6/2.0/0.3	87/11/2	vf
		864	609.8	89.0	2.7	0.7	7.3	--	0.3	--	0.3	92.4	0	13.0	92.4/7.3/0.3	79/18/2	vf

Mean and one standard deviation for QFL% (2): Q - 80 ± 7
F - 18 ± 6
L - 2 ± 1

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL% (1)	QFL% (2)	mgs
F2	F	134	0.9	91.0	0.3	5.3	3.3	--	--	--	--	96.6	0	14.3	96.6/3.3/0	82/16/2	cs
		138	30.6	96.6	2.7	0.7	--	--	--	--	--	96.6	--	11.5	100/0/0	89/10/2	vf
		148	62.0	97.3	2.7	--	--	--	--	--	--	100	--	17.1	100/0/0	83/15/3	vf
		165	92.5	92.7	0.3	6.7	--	--	0.3	--	0.3	99.7	--	20.4	99.7/0/0.3	79/17/3	vf
		332	123.0	92.0	3.7	3.7	--	--	0.7	--	0.7	99.4	--	17.4	99.4/0/0.7	82/15/3	vf
		343	154.8	97.3	0.7	2.0	--	--	--	--	--	100	--	17.0	100/0/0	83/15/3	vf
		360	181.0	92.7	--	5.7	1.7	--	--	--	--	98.4	0	18.0	98.4/1.7/0	80/17/3	cs
		370	209.1	97.7	1.3	1.0	--	--	--	--	--	100	--	7.7	100/0/0	92/7/1	vf
		379	242.3	91.7	6.3	0.7	1.3	--	--	--	--	98.7	--	2.0	98.7/1.3/0	97/3/0	vf
		390	275.8	98.0	1.7	--	0.3	--	--	--	--	99.7	--	11.5	99.7/0.3/0	88/10/2	vf
		397	309.4	95.7	3.0	0.3 (2) 0.7 (3)	--	--	0.3	--	0.3	99.7	--	16.2	99.7/0/0.3	84/14/3	vf
		400	339.5	96.0	1.0	2.7	--	--	0.3	--	0.3	99.7	--	17.6	99.7/0/0.3	82/15/3	vf

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL % (1)	QFL % (2)	mgs
		423	382.7	96.7	0.3	3.0	--	--	--	--	--	100	--	7.7	100/0/0	92/7/1	vf
		Mean and one standard deviation for QFL% (2):						Q - 86 ± 5 F - 12 ± 5 L - 2 ± 1									
	HG	424	388.7	97.3	2.7	--	--	--	--	--	--	100	--	7.7	100/0/0	92/7/1	vf
		436	419.6	98.7	1.0	--	--	--	0.3	--	0.3	99.7	--	8.3	99.7/0/0.3	91/7/1	vf
		Mean and one standard deviation for QFL% (2):						Q - 92 ± 1 F - 7 ± 0 L - 1 ± 0									
HG1	HG	231	1.0	94.6	0.3 (2) 0.4 (1)	3.7	1.0	--	--	0.3 (1)*	--	99.0	--	9.9	99.0/1.0/0	89/9/2	vf
		237	30.5	98.3	0.7	0.7	0.3	--	--	--	--	99.7	[illegible]	8.8	99.7/0.3/0	91/8/1	vf
		241	41.8	89.2	2.5 (1) 0.7 (2)	7.6	--	--	--	4.4 (2)* 0.7 (3)*	--	100	--	6.4	100/0/0	94/5/1	f
		249	65.1	98.7	0.3	--	1.0	--	--	--	--	99.0	--	9.1	99.0/1.0/0	90/9/1	vf
		256	91.0	97.7	2.0	--	--	--	0.3	--	0.3	99.7	--	4.8	99.7/0/0.3	95/4/1	vf
		263	123	95.7	2.0	1.0	1.3	--	--	--	--	98.7	--	12.5	98.7/1.3/0	86/12/2	vf
		Mean and one standard deviation for QFL% (2):						Q - 91 ± 3 F - 8 ± 3 L - 1 ± 1									
HG3	HG	829	1.5	94.3	0.3	5.0	0.3	--	--	--	--	99.6	--	18.3	99.6/0.3/0	81/16/3	cs
		832	12.6	98.0	1.3	0.3	--	--	0.3	0.3 (2)*	0.3	99.6	--	9.9	99.6/0/0.3	90/8/2	f
		835	51.2	88.0	0.3	11.7	--	--	--	--	--	100	--	20.8	100/0/0	79/18/3	vf
		839	79.3	94.4	1.3	4.3	--	--	--	--	--	100	--	14.8	100/0/0	85/13/2	cs
		844	83.9	93.0	1.7	5.3	--	--	--	--	--	100	--	28.9	100/0/0	71/25/4	vf
		Mean and one standard deviation for QFL% (2):						Q - 81 ± 7 F - 16 ± 6 L - 3 ± 1									

Section	Fm	spl	s.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL % (1)	QFL % (2)	mgs
	HP	840	92.2	92.7	1.0	6.3	--	--	--	--	--	100	--	15.5	100/0/0	85/13/2	vf
		843	136.3	93.7	--	4.7	1.7	--	--	--	--	98.4	--	14.1	98.4/1.7/0	84/14/2	cs
		845	198.2	92.7	0.3	7.0	--	--	--	--	--	100	--	25.4	100/0/0	75/22/4	f
		Mean and one standard deviation for QFL% (2):						Q - 81 ± 6 F - 16 ± 5 L - 3 ± 1									
S2	SP	288	15.7	93.0	--	2.0	5.0	--	--	--	--	95.0	0	14.0	95/5.0/0	81/17/2	cs
		292	44.1	95.4	2.3	2.3	--	--	--	--	--	100	--	14.8	100/0/0	85/13/2	vf
		293	58.8	99.0	--	0.3	0.7	--	--	--	--	99.3	--	14.0	99.3/0.7/0	85/13/2	f
		295	75.3	95.3	2.0	1.7	--	--	0.3	--	0.3	99.7	--	3.5	99.7/0/0.3	96/3/1	vf
		310	111.4	96.7	0.7	2.3	--	--	0.3	--	0.3	99.7	--	14.5	99.7/0/0.3	85/12/3	cs
		313	128.1	97.3	0.3	1.7	--	--	0.7	0.3 (2)*	0.7	99.3	--	19.4	93.3/0/0.7	80/17/4	vf
		319	140.0	97.7	--	1.7	--	--	0.7	--	0.7	99.4	--	21.0	99.4/0/0.7	78/18/4	cs
		322	148.7	96.6	0.7	1.7	0.3	--	0.7	0.3 (1)* 1.7 (2)*	0.7	99.0	--	22.7	99/0.3/0.7	76/20/4	vf
		325	154.2	95.3	0.7	0.7	3.0	--	0.3	--	0.3	96.7	0	2.6	96.7/3.0/0.3	94/5/1	f
		329	170.0	89.7	--	4.0	6.0	--	0.3	--	0.3	93.7	0	30.7	93.7/6.0/0.3	63/32/5	cs
		331	187.0	96.7	0.3	2.7	0.3	--	--	--	--	99.7	--	12.0	99.7/0.3/0	88/11/2	cs
		Mean and one standard deviation for QFL% (2):						Q - 81 ± 9 F - 15 ± 9 L - 3 ± 1									
F4	HB	576	1.1	94.0	--	2.0	4.0	--	--	0.3 (3)*	--	96.0	0	8.3	96.0/4.0/0	88/11/1	f
		584	31.5	93.5	1.0 (1) 0.3 (2)	0.7	1.8	--	0.7	3.0 (2)*	0.7	95.5	0.3	6.3	95.5/3.8/0.7	89/9/1	vf
		590	73.4	94.7	0.3	0.3	4.7	--	--	--	--	95.3	0	13.5	95.3/4.7/0	82/16/2	f
		593	101.3	94.0	0.3	0.3	5.3	--	--	--	--	94.6	0	9.9	94.6/5.3/0	85/14/2	f
		598	145.5	97.7	1.3	0.7	0.3	--	--	--	--	99.7	--	10.7	99.7/0.3/0	89/9/2	f
		608	175.5	99.3	--	0.7	--	--	--	--	--	100	--	10.2	100/0/0	90/9/2	f
		616	207.4	94.0	1.0	4.7	--	--	0.3	0.3 (2)*	0.3	99.7	--	10.7	99.7/0/0.3	89/9/2	vf
		Mean and one standard deviation for QFL% (2):						Q - 87 ± 3 F - 11 ± 3 L - 2 ± 1									
	F	619	234.1	95.0	1.3	0.3 (1) 2.4 (3)	1.0	--	--	--	--	99.0	--	30.3	99.0/1.0/0	69/27/5	vf
		621	264.4	89.7	3.3	6.7	0.3	--	--	--	--	99.7	--	20.5	99.7/0.3/0	79/18/3	vf

Section	Fm	spl	a.b.	Qm	Qp	Qc	F	Lv	Lm	Ls	L	Q	P/F	Lf	QFL % (1)	QFL % (2)	mgs
		624	331.1	88.3	1.7	9.7	--	--	0.3	--	0.3	99.7	--	20.6	99.7/0/0.3	79/18/3	vf
		631	374.0	84.3	12.0	2.6	0.7	--	0.3	--	0.3	98.9	--	17.2	98.9/0.7/0.3	82/15/3	cs
		635	431.9	94.3	0.3	4.7	0.7	--	--	--	--	99.3	--	13.7	99.3/0.7/0	86/12/2	vf
		643	458.1	90.3	--	9.7	--	--	--	--	--	100	--	21.0	100/0/0	79/18/3	cs
		646	491.4	89.5	4.7	5.4	0.3	--	--	1.3 (3)*	--	99.6	--	18.7	99.6/0.3/0	81/16/3	cs
		655	548.9	88.3	4.0	7.7	--	--	--	--	--	100	--	16.2	100/0/0	84/14/2	cs
		657	601.3	88.7	--	10.3	1.0	--	--	--	--	99.0	--	24.9	99.0/1.0/0	74/22/4	vf
		662	631.8	92.7	1.0	6.3	--	--	--	--	--	100	--	32.4	100/0/0	68/28/5	cs
		668	684.2	89.7	0.3	9.7	0.3	--	--	--	--	99.7	--	11.7	99.7/0.3/0	88/10/2	cs
		Mean and one standard deviation for QFL% (2):						Q - 79 ± 6									
								F - 18 ± 6									
								L - 3 ± 1									
F3	F	489	0.6	88.9	0.7	9.1	--	--	1.3	0.3 (1)* 0.4 (3)*	1.3	98.7	--	10.2	98.7/0/1.3	89/9/3	vf
		494	29.0	89.9	1.0	1.0 (2) 3.7 (3)	1.7	--	0.7	0.3 (1)* 0.4 (3)*	0.7	95.6	--	10.2	95.6/3.7/0.7	85/12/2	vf
		505	61.0	95.0	0.3 (2)	4.3	0.3	--	--	--	--	99.6	--	12.3	99.6/0.3/0	87/11/2	vf
		517	84.3	87.7	0.3	2.3 (2) 7.4 (3)	0.3	--	2.0	--	2.0	97.7	--	15.7	97.7/0.3/2.0	82/14/4	cs
		Mean and one standard deviation for QFL% (2):						Q - 86 ± 3									
								F - 12 ± 2									
								L - 3 ± 1									
	HG	522	105.5	93.3	0.7	4.7	1.3	--	--	--	--	98.7	--	18.4	98.7/1.3/0	80/17/3	vf
		538	134.2	92.3	--	6.3	1.0	--	0.3	--	0.3	98.6	--	14.2	98.6/1.0/0.3	84/13/2	cs
		551	167.7	89.3	0.7	9.7	0.3	--	--	--	--	99.7	--	14.3	99.7/0.3/0	85/13/2	vf
		557	199.3	93.3	--	6.7	--	--	--	--	--	100	--	19.6	100/0/0	80/17/3	vf
		564	232.1	96.3	0.7	0.3 (1) 0.3 (2) 2.4 (3)	--	--	--	--	--	100	--	12.8	100/0/0	87/11/2	vf
		568	258.3	98.3	0.3	0.3	1.0	--	--	--	--	98.9	--	11.8	98.9/1.0/0	87/11/2	f
		575	294.2	97.7	1.7	0.6	--	--	--	--	--	100	--	17.8	100/0/0	82/15/3	f
		Mean and one standard deviation for QFL% (2):						Q - 84 ± 3									
								F - 14 ± 1									
								L - 2 ± 1									

Section	Fm	spl	a.b.	Qm	Qp	Qc	P	Lv	Lm	Ls	L	Q	P/F	Lf	QFL % (1)	QFL % (2)	mgs
HB2	HB	801	14.4	98.0	2.0	--	--	--	--	--	--	100	--	14.0	100/0/0	86/12/2	f
		809	60.6	97.3	2.0	0.3	--	--	0.3	--	0.3	99.6	--	13.3	99.6/0/0.3	86/11/2	f
		815	88.0	98.0	1.3	0.7	--	--	--	--	--	100	--	8.3	100/0/0	92/7/1	vf
		821	110.8	96.3	0.3 (2) 1.7 (1)	1.7	--	--	--	--	--	100	--	8.5	100/0/0	92/7/1	f
		826	175.3	89.3	0.3	0.3 (2) 6.7 (3)	0.3	--	3.0	--	3.0	96.6	--	10.8	96.6/0.3/3.0	86/10/5	vf

Mean and one standard deviation for QFL% (2): Q - 88 ± 3
F - 9 ± 2
L - 2 ± 2

NOTE:

1. Since the concern of this study was primarily with determination of source rock the Gazzi-Dickinson technique for handling coarse (large) lithics with constituent crystals larger than 0.0625 mm was adopted. However, only two samples contained coarse lithics and in neither was the internal crystal size in the sand range, therefore in practice the technique did not artifically reduce the number of polymineralic polycrystalline lithics noted in the point count. Also, as the work sheets indicate, more information was recorded than is usually the case in a strict application of the data efficient Gazzi-Dickinson technique. Most significantly an attempt was made to estimate the percentage of unidentifiable labile framework grains.

2. The table is arranged by section, from east to west through the study area (see 4 below) and stratigraphically by formation from bottom to top at each section location; samples are arranged vertically from bottom to top within each formation at each section location.

3. SF: Strathcona Fiord Fm
   HB: Hacia Bay Fm
   F: Fram Fm
   HG: Hell Gate Fm
   NP: Nordstrand Point Fm

4. The eastern most section, section S1, exposing the Strathcona Fiord Fm at Stenkul Fiord was not point counted for the purpose of comparison with other sections due to a marked difference in environment of deposition between section S1 and other section locations (i.e. tidal flat vs fluvial).

5. Estimated mean grain size (mgs) of samples point counted ranged from coarse silt to medium grained sand; most were very fine grained; m - medium, f - fine, vf - very fine, cs - coarse silt.

6. a.b. refers to distance above base of section in meters.

7. An asterisk (*) indicates presumed intrabasinal grains not included in QFL% calculations; total grain points in these instances would be less than 300 by the number of intrabasinal grains counted.

8. Qp is all low rank metamorphic grains (1) unless otherwise specified.
Qc is all non-diagnostic chert grains (3) unless otherwise specified.
Lm is all low rank metamorphic grains (1) unless otherwise specified.

9. QFL% (2) values have been rounded for plotting purposes; this occasionally causes rounding error where QFL% is slightly greater or less than 100.

the beginning, middle and end of the petrographic study with no less than ten days between replicate point-counts. In order to assure that differences do not arise due to difficult grain identifications only monocrystalline quartz grains were counted. Three hundred points were accumulated for each thin section in ten equally spaced traverses (ten replications) of thirty points each. The same objective was used for each point-count. A two-way ANOVA was used as a means of evaluating the significance of this type of operator variation in the petrographic data set from the Okse Bay Group. Table 3.2.1.2-3 contains the data for the operator variation study and Table 3.2.1.2-4 presents the ANOVA. Three assumptions are involved in the use of any variance analysis; they are: 1) randomness of samples 2) normality of populations 3) homogeneity of variances among the populations sampled (Li, 1957, pg. 173). The first of these assumptions was addressed in this study by covering all sample numbers with dummy numbers so that the sample's true identity was unknown during point-counting. The assumption of normality was not tested, however, Li (1957, pg. 173) points out that non-normality of the populations does not introduce serious error in the F-test. Similarly, Li (1957) also notes that if the population variances are not extremely different the F-test is not seriously affected

Table 3.2.1.2-3 Data Table for Operator Variation Study

Measurements (point-counts)	Thin Sections 18	84	75	93	87
	23	20	20	15	15
	21	26	22	17	14
	24	23	21	16	17
	18	18	25	20	19
1	23	19	20	21	17
	24	22	21	17	16
	17	18	20	17	18
	19	18	23	20	15
	24	23	18	22	18
	17	19	26	25	19
	16	16	20	19	11
	24	15	20	14	20
	25	20	21	13	16
	23	18	24	12	18
2	15	13	21	19	13
	20	24	23	15	17
	21	27	20	15	18
	21	25	22	12	18
	21	18	19	17	18
	23	20	19	16	15
	21	19	16	14	17
	24	20	22	15	18
	23	19	20	11	14
	24	21	23	15	18
3	21	23	22	17	16
	21	19	23	12	17
	25	19	19	14	19
	15	25	21	13	16
	17	19	20	11	16
	21	21	22	18	18

Note: 1. 1, 2, and 3 refer to point counts of monocrystalline quartz made on the reference set of five thin sections at the beginning, middle and finish of the petrographic study, respectively.

2. Each measurement constitutes a point-count wherein 300 points were accumulated in 10 equally spaced traverses of 30 points each.

3. Thin section numbers represent dummy identifiers and not real sample numbers; the true identity of the sampels during the operator variation study and in general, was not known until after the point-counts were completed; the true sample numbers of the samples used in the operator variation study are as follows:

18: HB1-799
84: F2-343
75: HB3-858
93: HB1-766
87: F2-379

Table 3.2.1.2-4 BMDP2V ANOVA TABLE FOR OPERATOR VARIATION STUDY BASED ON MONOCRYSTALLINE QUARTZ CONTENT

ANALYSIS OF VARIANCE FOR 1-ST
DEPENDENT VARIABLE - MONOQTZ

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROB.
MEAN	54302.10667	1	54302.10667	7410.82	.0000
THINSECT	718.69333	4	179.67333	24.52	.0000
POINTCNT	45.01333	2	22.50667	3.07	.0496
TP	102.98667	8	12.87333	1.76	.0910
ERROR	989.20000	135	7.32741		

and that the assumption of homogeneity of population variances may be violated without serious risk if the number of observations in each group is equal. For the five groups (i.e., thin sections) in Table 3.2.1.2-3 a maximum variance of 11.51 for sample 93 was only 2.92 X the minimum variance of 3.94 for sample 87. In addition to this, it will also be noted that the number of observations for each row-column combination is equal (i.e., equal cell size). It is therefore concluded that the ANOVA is an appropriate technique for testing the data presented in Table 3.2.1.2-3.

The computations were performed with the statistical software package BMDP-2V (Jennrich, Sampson, and Frane, 1983) using a fixed effect (i.e., the population means don't change) factorial design model (i.e., two or more factors are considered simultaneously; for the data in Table 3.2.1.2-3, this means both thin section and point-count are considered simultaneously) discussed on pages 360-361. The null hypotheses for these tests, stated in a non-technical fashion, are as follows:

1) <u>thin sections</u>: there is no significant variation in monocrystalline quartz content caused by differences between thin sections

2) <u>point-counts</u>: there is no significant variation in monocrystalline quartz content caused by operator in

consistency during point-counting

3) thin section - point-count interaction: there is no significant variation in monocrystalline quartz content caused by interaction between thin sections and point counts.

The results of the ANOVA presented in Table 3.2.1.2-4 show that the null hypothesis for point-counts and the interaction may be accepted at the 5% level, whereas the null hypothesis for thin sections must be rejected. The variance component attributed to mean in the ANOVA may be ignored for this data set as it is only of significance when the dependent variable in the analysis represents a difference between two other numbers (Jennrich, Sampson, and Frane, 1983, pg. 363). These are precisely the desired results since one wants variability in the petrographic data to be attributable to differences between thin sections and not to operator inconsistency. The favorable results of the ANOVA are especially important for the Okse Bay Group petrographic data set since the variation among the modal compositions is small and thus is highly susceptible to accusations that it is not real.

In summary, the results of the operator variation study indicate that the interpretative usage of the petrographic data from the Okse Bay Group is warranted.

3.2.2 Petrographic Descriptions

3.2.2.1 Detrital Texture

Estimated mean grain size and sorting are the only two textural attributes discussed in this section. As previously mentioned, authigenic quartz cement was common throughout the Okse Bay Group obscuring detrital grain roundness except in those rare instances where "dust rims" accentuated the detrital cores. Rounding estimates recorded for the Okse Bay Group were all obtained using CL microscopy and are presented subsequently in 3.3. No grain size curves were determined for any of the Okse Bay Group samples. Mean grain size was visually estimated according to the method previously described (3.2.1.2). It is likely that the visual estimates tend to be slightly biased toward the coarser end of the size distribution as was determined by Hiscott (1977) for a selected number of Tourelle sandstones by comparison of visual grain size estimates with their corresponding grain size curves.

Figures 3.2.2.1-1 and 3.2.2.1-2 present bar graphs depicting the relative percentage of the estimated mean grain size classes and estimated sorting classes in the Okse

Figure 3.2.2.1 - 1 Bar graphs of grain size in the Okse Bay Group. Percentage by number is shown on the ordinate scale.

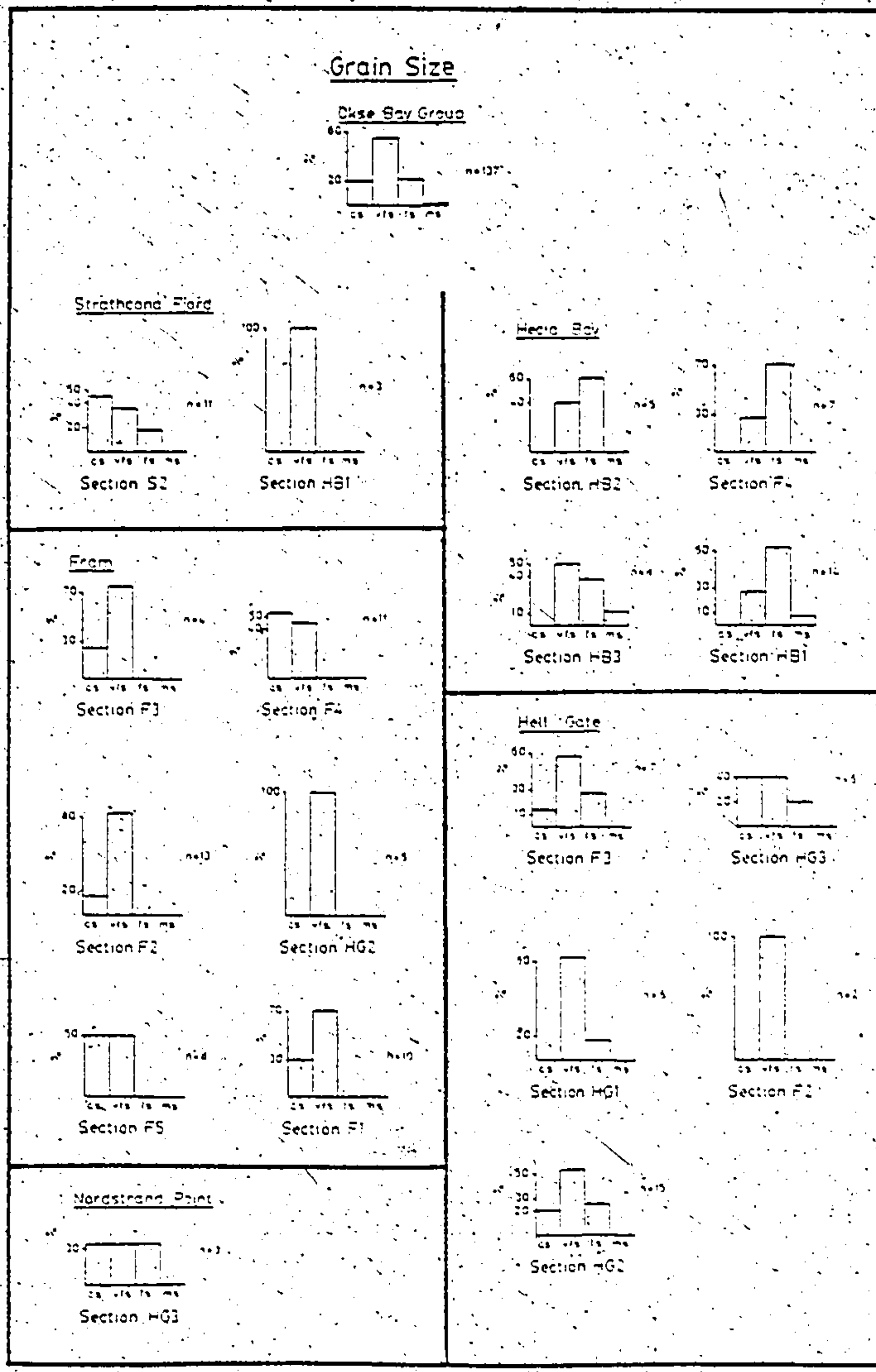
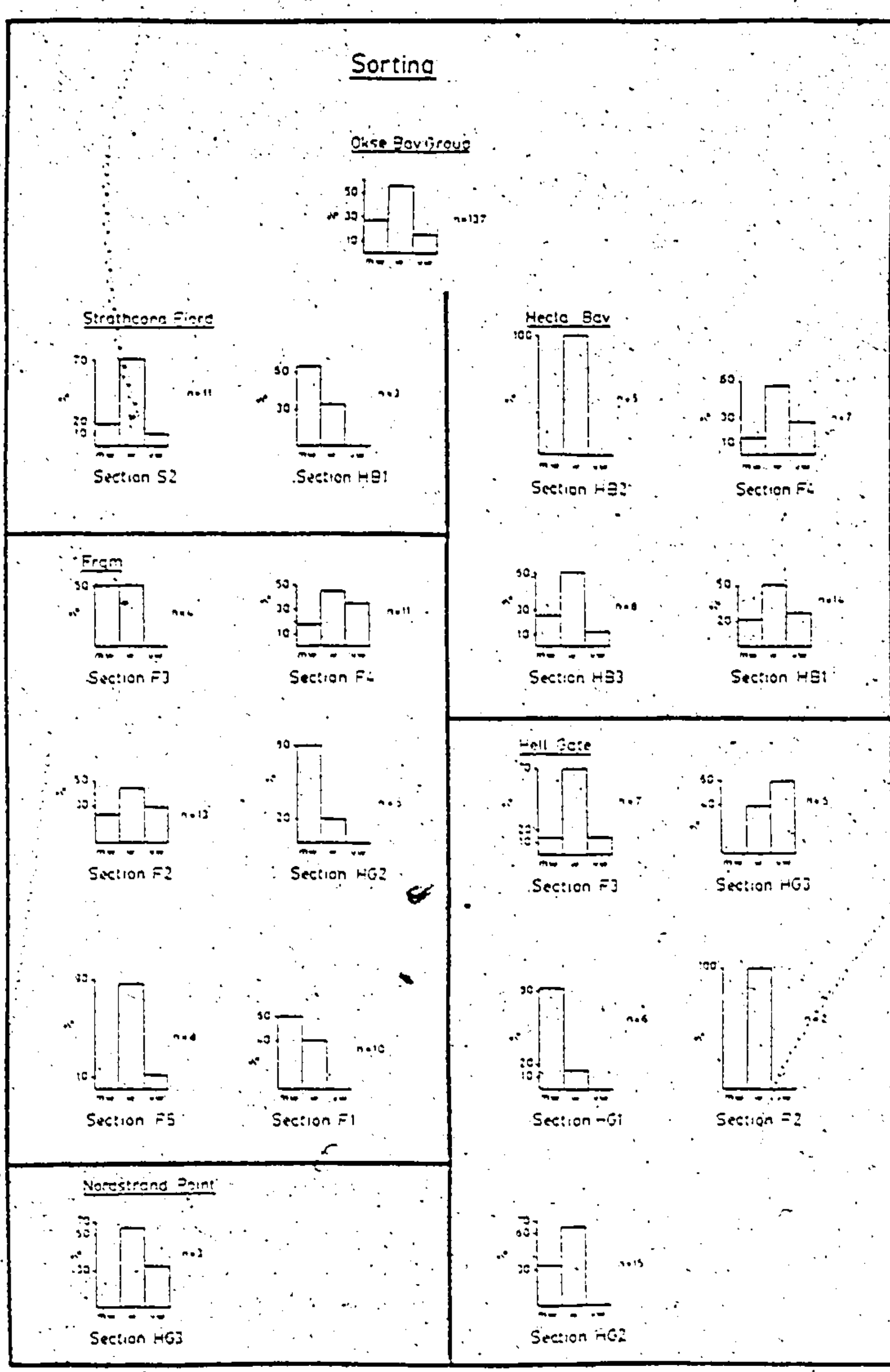

Grain Size
Okse Bay Group
Strathcona Fiord
Section S2
Section HB1
Hecla Bay
Section HB2
Section F4
Section HB3
Section HB1
Fram
Section F3
Section F4
Section F2
Section HG2
Section F5
Section F1
Hell Gate
Section F3
Section HG3
Section HG1
Section F2
Section HG2
Nordstrand Point
Section HG3

Figure 3.2.2.1 - 2 Bar graphs of sorting in the Okse Bay Group. Percentage by number is shown on the ordinate scale.


Sorting
Okse Bay Group
n=137
Strathcona Fiord
Section S2
Section HB1
Hecla Bay
Section HB2
Section F4
Section HB3
Section HB1
Fram
Section F3
Section F4
Section F2
Section HG2
Section F5
Section F1
Hell Gate
Section F3
Section HG3
Section HG1
Section F2
Nordstrand Point
Section HG3
Section HG2

Bay Group, respectively. The grain size and sorting data are arranged stratigraphically beginning with the lowest formation in the Okse Bay Group, the Strathcona Fiord Formation, and also areally, from east to west, within each formation.

Estimated Mean Grain Size

The data presented in Figure 3.2.2.1-1 indicates that, overall, the Okse Bay Group may be characterized as consisting dominantly of very fine grained sandstone (55.5%; all percentages given for estimated mean grain size represent percentage by number). Coarse siltstone and fine grained sandstone are both minor representing only 20.4% and 22.6%, respectively. Medium grained sandstone is very uncommon and is the estimated mean grain size in only two of the thin sections examined (15%), both belonging to the Hecla Bay Formation.

Unfortunately, the comparison of dominant estimated mean grain size among section locations for any one of the five formations in the Okse Bay Group was not possible due to large disparities in the percentage of formation thickness and which portion of a formation (i.e., bottom, middle, top) is exposed at a section location. This precludes the use of areal trends in mean grain size as an indicator of source region direction since a grain size change would be anticipated in the proximity of formation contacts as a reflection of the change in the nature of the detritus which would precede the change in channel pattern.

The disparity in the representativeness of the different section locations among each formation also precludes the pooling of the mean grain size estimates for the determination of the characteristic mean grain size for each formation. Rather, this was achieved by taking the dominant estimated mean grain size from the most complete exposure of the formation as characteristic of that formation. The characteristic grain size for each formation and the section location from which it was derived are presented below:

Strathcona Fiord Fm.: Coarse siltstone (cs); from section S2 where the complete formation is exposed.

Hecla Bay Fm.: Fine grained sandstone (f); from section HB1 where the complete formation is exposed.

Fram Fm.: Coarse siltstone (cs); from section F4 where the complete formation is exposed.

Hell Gate Fm.: Very fine grained sandstone (vf); from section HG2 where ca. 80% of the formation thickness was examined.

Nordstrand Point Fm.: not enough data from section HG3.

The preceding chapter of this report dealt with environmental analysis and the determination of the ultimate control over variations in fluvial style within the Okse Bay Group. The principle conclusion reached regarding the ultimate control over sedimentation during Okse Bay time was that tectonism, not climatic variation as had been suggested by Embry and Klovan (1976), is the determinant. Specifically, evidence was presented and discussed which indicated that continuous but episodic epeirogenesis had occurred in the source region for the duration of Okse Bay time. Two of the five formations composing the Okse Bay Group, the Hecla Bay Formation and the Hell Gate Formation, were suggested to represent "tectonic formations" in the sense that the evidence indicated that the epeirogenesis was the greatest during their deposition, with that occurring during Hecla Bay time being most severe. The sequence of characteristic mean grain sizes previously presented for the five formations of the Okse Bay Group constitutes strong support for the tectonic control hypothesis. The two "tectonic formations", the Hecla Bay (fine grained) and the Hell Gate (very fine grained), have the two coarsest mean grain sizes. In this context, it should also be noted that: 1) the only two medium grained sandstone samples examined during the petrographic study belonged to the Hecla Bay Formation 2) while fine grained sandstone is relatively minor in the Hell Gate Formation (Figure 3.2.2.1-1) it is considered significant that it was present in four out of five section locations whereas it was conspicuously absent from all exposures of the underlying Fram Formation based on this study's sampling; this lends additional support to the proposal that Hell Gate time constitutes a period of increased epeirogenesis in the source area.

Estimated Sorting

The data presented in Figure 3.2.2.1-2 indicates that the Okse Bay Group is dominantly well sorted (56.2%; sorting percentages are by number, as was the case for mean grain size) with less important moderately well sorted (27.7%) and very well sorted (16.1%) siltstone and sandstone.

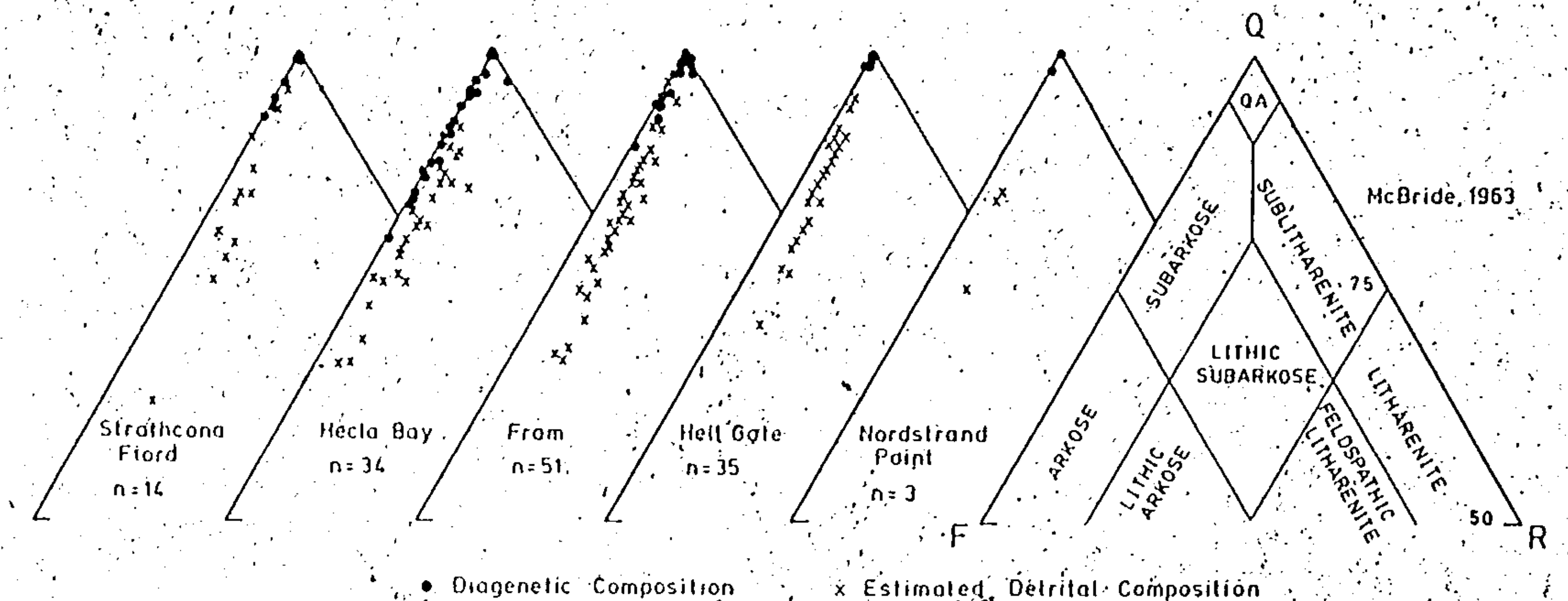
Figure 3.2.2.1-2 also indicates that sorting was a very consistent textural parameter throughout the Okse Bay Group. Data taken from the same section locations that were considered to be most representative of each formation in the preceding discussion of mean grain size indicates that well sorted detritus dominates each of the five formations. As was the case for mean grain size, a comparison of different section locations in search of areal sorting trends within any of the formations is precluded by the great disparity in representativeness among the locations arising out of very large differences in the exposed thickness of a formation.

3.2.2.2 Detrital Composition

Diagenetic and estimated detrital modal analyses for each formation in the Okse Bay Group are plotted on ternary composition diagrams presented together in Figure 3.2.2.2-1. Comparison of ternary diagrams for each formation indicates an extreme compositional homogeneity amongst the formations. Using the classification of McBride (1963), the majority of detrital modes for each formation fall within the subarkose field. If diagenetic modes are considered, the majority of these fall within the quartz arenite field for all formations except the Hecla Bay whose diagenetic modes also fall mainly within the subarkose field. For all formations except the Nordstrand Point (for which there is very little data) a small number of detrital modes plot within the arkose field.

The compositional homogeneity within the Okse Bay Group is also indicated on Figure 3.2.2.2-2 (in pocket) which presents QFL% compositions as pie diagrams for each formation at each section location at which it was examined.

Figure 3.2.2.2 - 1 Estimated detrital and diagenetic modal compositions for sandstone in each formation of the Okse Bay Group.



Q
QA
SUBLITHARENITE
SUBARKOSE
LITHIC SUBARKOSE
LITHARENITE
FELDSPATHIC LITHARENITE
LITHIC ARKOSE
ARKOSE
75
50
F
R
McBride, 1963
Strathcona Fiord
n = 14
Hecla Bay
n = 34
From
n = 51
Hell Gate
n = 35
Nordstrand Point
n = 3
• Diagenetic Composition
x Estimated Detrital Composition

It should be noted that the diagenetic and detrital modal analyses from the Okse Bay Group represents QFL percentages. Plotting of these modes on the QFR classification scheme of McBride (1963) is therefore not strictly correct. However, the percentage of quartzose lithic grains is sufficiently small as to not significantly change the classification suggested above. A small number of samples with unusually high percentages of quartzose lithics could possibly fall just within the sublitharenite or lithic subarkose fields if their modes were recalculated to QFR percentages.

The compositional homogeneity amongst the formations of the Okse Bay Group, in light of their variation in characteristic estimated mean grain size discussed previously (3.2.2.1), indicates that the amount of compositional variation attributable to changes in grain size is very small. This is not surprising however, due to the overall highly impoverished nature of the detritus with respect to the more labile framework elements, i.e., feldspar and lithic grains. Marked compositional differences arising from changes in grain size would only be anticipated in more feldspathic and/or lithic rich detritus.

Each framework grain category considered while point-counting the Okse Bay Group is described separately.

In light of the extreme compositional homogeneity displayed by the group it is not necessary to provide a separate discussion of detrital composition for each formation. The following discussion is addressed to the Okse Bay Group as a whole and is equally applicable to both the coarse siltstones and the sandstones.

Quartzose Grains

Monocrystalline Quartz

Mono crystalline quartz is the dominant framework grain in all thin sections of the Okse Bay Group. It averages 92.9% and ranging from 79.3% to 99.3%. Contact types amongst monocrystalline quartz grains vary within any one thin section. Usually all types from tangential to concavo-convex are found. A separate count of contact types was not kept, however, the most common types seemed to be long and sutured with only occasional tangential and concavo-convex types. However, the use of contact types amongst monocrystalline quartz grains as an indicator of the degree of framework deformation is considered unreliable in transmitted light due to the presence of common authigenic monocrystalline quartz overgrowths. An evaluation of the degree of framework deformation is provided in 3.3.3 using cathodoluminescence microscopy. While grain morphologies indicate the common presence of authigenic monocrystalline quartz, dust rims are uncommon to very rare and as such an evaluation of detrital rounding and sphericity was only possible using cathodoluminescence (3.3.3). Multiple overgrowths (double and very rarely triple) are only present on a few grains in each thin section, however, since the point-counting was not done using the highest power objective it is likely that a considerable number of additional multiple overgrowths went unnoticed. The multiple overgrowths are rounded in all instances and indicate re-cycling of detritus. They are of considerable importance with respect to the source region interpretation discussed subsequently in 3.4. Semi-composite and composite (discussed below) quartz grains are present in most thin sections but their abundance is always much less than single crystal quartz grains. Undulosity was not separately evaluated for the Okse Bay Group. While grains showing both unit extinction and undulosity are present in all thin sections, the proportion of undulose (>5^{0} of stage rotation is required for the extinction shadow to sweep across the quartz grain) to non-undulose (<5^{0} of stage rotation is required) quartz grains is not known. Inclusions (microlites and/or vacuoles) are common but not abundant in the monocrystalline quartz of the Okse Bay Group.

Microlites are often needle shaped but their identity is uncertain as several minerals (sillimanite, rutile, actinolite) can adopt this morphology. Vacuoles most commonly occur as Boehm lamellae. Since this type of inclusion is not present in all thin sections, and was not abundant in those in which it does occur, it is likely that the lamellae constitute inherited inclusions. This conclusion is supported by observations using cathodoluminescence which indicate a generally undeformed framework throughout the Okse Bay Group (3.3.3).

Source rock diagnostic monocrystalline quartz grains are almost virtually absent throughout the Okse Bay Group. Only two instances of quartz with vermicular chlorite (indicative of vein quartz) were noted throughout the entire study and no volcanic quartz grains were seen. In this context, a separate study of polycrystallinity and undulosity of quartz adopting the methodology of Basu and others (1975) is warranted for the Okse Bay Group as it would provide an indication of primary provenance. Its utility as an indicator of immediate provenance is precluded however by evidence indicating the presence of a prominent re-cycled component in the Okse Bay detritus (3.4).

Polycrystalline Quartz

Polycrystalline quartz is a minor framework grain occurring in all formations of the Okse Bay Group. Its abundance ranges from 0% to 12.0%, averaging only 1.4%. Nearly all polycrystalline quartz grains observed within the Okse Bay Group consist of more than three crystals per grain indicating derivation from a metamorphic source rock. Polycrystalline quartz grains with only two or three crystals are characteristic of plutonic source rocks. They are present in only five thin sections (representing the Hecla Bay, Fram and Hell Gate Formations) wherein they average only 0.4%. Certainly, the small dominant mean grain sizes in the Okse Bay Group have artificially reduced the amount of polycrystalline quartz. Polycrystalline quartz can originate in situ (Young, 1976). However, for the following reasons the polycrystalline quartz grains observed in the Okse Bay Group are considered to be inherited as opposed to having originated by in situ deformation: 1) they would be expected to be much more abundant than they are if they had originated by in situ deformation 2) if the grains had an in situ genesis they should be accompanied by a deformed framework, however, as mentioned previously and discussed subsequently in 3.3, cathodoluminescent microscopy indicates only minor framework deformation throughout the

Okse Bay Group.

Chert

Grains composed of micro-crystalline quartz are present in 91% of the thin sections examined during this study representing all the formations of the Okse Bay Group. Chert grain abundance varies from 0% to 14%, averaging 3.2%. Separate tallies of deep-water (i.e., below carbonate compensation depth) and shelfal replacement chert (i.e., nodular chert resulting from local replacement of shelf carbonate) were kept during the point-counting. The criteria used fora deep-water classification are: 1) the presence of ghosts of tests of silica only secreting planktonic micro-organisms such as radiolarians and/or 2) a dirty (muddy) chert grain, without shallow water fossils, is interpreted as representing an admixture of hemipelagic fines in a deep-water siliceous ooze; this criteria can be considered equivocal since some clay could be found in shelf carbonates. Criteria used for a shelfal replacement origin were: 1) the presence of ghosts of portions of tests of shelfal organisms and/or 2) the presence of isolated, euhedral carbonate rhombs located within the chert grain interpreted as representing either residual carbonate not replaced by silica during the formation of the chert nodule in the shelf carbonate unit or incipient replacement of the chert nodule by the host carbonate (as opposed to diagenetic carbonate replacement, in which case peripheral corrosion by carbonate would be anticipated rather than a few isolated rhombs found within the grain). Most chert grains are non-diagnostic of origin. Possible deep water chert grains were identified in only ten thin sections representing the Hecla Bay, Fram and Hell Gate Formations wherein they average only 0.7% and constitute an average of 13.2% of the total detrital chert. It is stressed that the presence of deep water chert is considered to be highly tentative since all the identifications were based on the dirty (muddy) chert criteria mentioned above which is equivocal. Shelfal replacement chert is present in only six thin sections representing the Strathcona Fiord, Hecla Bay, Fram and Hell Gate Formations. It averages only 0.4% amongst these thin sections and constitutes an average of 13.8% of the total detrital chert. A distinction between authigenic and detrital microcrystalline quartz is based largely on grain morphology. Detrital chert grains would be expected to have a more regular morphology arising from abrasion whereas grains resulting from authigenic replacement of a labile framework grain are more likely to display an irregular morphology which could not have persisted if fluvial transport had occurred.

<u>Feldspar</u>

Feldspar is a minor mineral in Okse Bay Group detritus averaging only 2.2% overall and ranging from 0.3% to 20.3%. While it occurs in all formations, it is distinctly more abundant in the Hecla Bay Formation where it averages 6.2%. The greater abundance of feldspar in this formation is interpreted to be the result of two factors: 1) an increase in the supply of feldspar from the source terrane associated with the overall increase in the volume of sand size detritus that resulted from the maximum rate of source terrane tectonic uplift that is suggested for that formation's period of deposition (2.6.2) 2) a drastic reduction in the severity of diagenetic modification of Hecla Bay sandstones due to the paucity of interstratified siltstone in this formation relative to its abundance in the other formations of the Okse Bay Group. With respect to the latter factor, it is well established that formation waters driven out of shales and siltstones (principally by compaction) interstratified with sandstone are a principal cause of sandstone diagenesis. When these fluids enter the more porous and permeable, relatively clay impoverished, environment of the sandstones they react with the more labile framework grains, such as feldspar, and result in either their dissolution or their replacement. As discussed previously in 2.2.3, the Hecla Bay Formation is almost entirely sandstone with only ca. 7% siltstone in the form of laterally discontinuous lenses. As a result, the severity of diagenetic modifications of the sandstone in the Hecla Bay Formation is greatly reduced relative to the other formations of the Okse Bay Group in which siltstone constitutes an abundant lithological component. This point will be raised again in the discussion of composition trends in 3.5.

The staining technique of Houghton (1980) facilitated the rapid distinction between untwinned feldspar and monocrystalline quartz, as well as between plagioclase and alkali feldspar. Alkali feldspar dominates Okse Bay Group detritus almost to the complete exclusion of plagioclase. Only four thin sections, all from the Hecla Bay Formation, contain detrital albite twinned plagioclase. The maximum plagioclase to total feldspar ratio amongst these thin sections is 0.3. The detrital plagioclase grains are invariably smaller than the associated monocrystalline quartz grains and are always subangular to subrounded. Albite twinning is used as a detrital criteria for plagioclase in this study. While untwinned detrital plagioclase can be derived from low grade metamorphic rocks (Lajoie, 1973), using criteria suggested by Walker (1984) all the untwinned plagioclase identified by staining is considered to represent burial metamorphic albitization. Walker (1984, pg. 16) suggested six criteria which he considers indicative of diagenetic albitization; those used in this study are: 1) high percentages of untwinned plagioclase grains 2) residual, anhedral islands of alkali feldspar (yellow stain) in the untwinned plagioclase indicative of partial albitization 3) the occurrence of chessboard twinning in albite which indicates albitization of albite-pericline twinned microcline. The presence of numerous instances of partially albitized alkali feldspar in those thin sections with a significant total feldspar content makes it entirely reasonable to infer that the untwinned plagioclase grains merely represent complete albitization.

As mentioned previously, detrital alkali feldspar dominates Okse Bay Group detritus to the near exclusion of detrital plagioclase. While the greater susceptibility of plagioclase to chemical breakdown under burial metamorphic conditions would undoubtedly be a contributing factor to this imbalance it is also considered to reflect a source rock control since, as discussed in 3.4, a mixed plutonic and metamorphic source terrane (i.e., a craton) is likely at least part of the immediate and ultimate (source region of re-cycled detritus) source for the Okse Bay Group detritus. Such terranes are known to produce detritus with very low plagioclase to total feldspar ratios (Dickinson, 1970, Dickinson and Rich, 1972, Ingersoll, 1978).

Alkali feldspar in the Okse Bay Group occurs in two crudely defined size populations, one which approximates or exceeds the grain size of the largest monocrystalline quartz grains in the same thin section and one which is smaller than the estimated mean grain size of the associated monocrystalline quartz. The former size population is characteristically subangular to angular while the latter is characteristically subrounded to subangular. As discussed in 3.4, these two size populations are interpreted to represent first and second cycle feldspar, respectively.

Both twinned and untwinned alkali feldspar are present in the Okse Bay Group. The dominant twin type is the albite-pericline polysynthetic twin which can occur in either microcline or anorthoclase. No attempt to distinguish between these two alkali feldspar was made during point-counting. It was assumed that the mineral was microcline since such twinning is often more difficult to detect in anorthoclase and since that mineral is relatively rare compared to microcline (Kerr, 1959). Carlsbad twinned alkali feldspar is only rarely present throughout the Okse Bay Group. These twins are used to identify orthoclase since they are known to commonly occur in that mineral (Kerr, 1959, pg. 255). While twinning was not uncommon amongst the alkali feldspar, most were untwinned. Due to the relative rarity of adularia and anorthoclase, and presuming that sanidine would retain some characteristic morphologic feature that would reflect its volcanic origin, the untwinned alkali feldspar were assumed to be orthoclase. Since orthoclase is perhaps the most common alkali feldspar derived from plutonic igneous rocks (Kerr, 1959, pg. 262) the plutonic-metamorphic source terrane suggested subsequently in 3.4 constitutes support for the validity of this assumption.

As mentioned subsequently in a discussion of diagenesis in the Okse Bay Group, alkali feldspar are frequently partially albitized. This is a common replacement associated with burial metamorphism.

Unstable Rock Fragments

Unstable rock fragments includes volcanic, metamorphic and sedimentary lithic grains that are susceptible to mechanical and/or chemical breakdown either during transport prior to final deposition or during diagenesis resulting from burial subsequent to final deposition. For the Okse Bay Group this category includes only metamorphic and sedimentary rock fragments (MRF and SRF, respectively) as no volcanic rock fragments were noted during any point-count. Unstable rock fragments are found in all formations of the Okse Bay Group except the Nordstrand Point Formation. Their absence from this formation is likely solely a function of the fact that only three thin sections from a single, short, poor quality exposure were examined (section HG3). Due to their inherent mechanical instability during fluvial transport metamorphic and sedimentary lithics cannot be carried any great distance without breaking down into their constituent grains due to collisions with the bed of the river and with other grains in transport. For this reason all sedimentary rock fragments noted in the Okse Bay Group are considered to represent intrabasinal grains. As such they are of no relevance to the reconstruction of the bedrock character of the source region and are therefore not included in the QFL% calculations presented in Table 3.2.1.2-2. Since there were no volcanic rock fragments, the L in the QFL% therefore represents only the abundance of metamorphic rock fragments.

Unstable rock fragments constitute a very small percentage of the framework grains throughout the Okse Bay Group. They occur in 39.4% of the thin sections and average only 0.8%, ranging from a minimum of 0.3% to a maximum of 5.1%. In light of evidence discussed subsequently in 3.4 which supports the presence of a significant re-cycled component in Okse Bay Group detritus, it is considered that this low percentage is not representative of the erosional composition. Rather, it is suggested to reflect a grain size control. Due to their mechanical instability their abundance in the <0.125 mm size class has been shown to decrease sharply (Allen, 1962, Blatt and Christe, 1963, Blatt, Middleton and Murray, 1980). Since the estimated mean grain size of ca. 76% of the Okse Bay Group samples point-counted during this study is 0.125 mm it is not surprising that unstable lithics should be so rare a framework element. As discussed in 3.6, even the estimated detrital compositions (QFL%(2) in Table 3.2.1.2-2) are suspected to be significant underestimates of the lithic content of the sediment at the time of initial erosion of the source rocks.

Metamorphic Rock Fragments

Metamorphic rock fragments are found in all formations of the Okse Bay Group except the Nordstrand Point

Formation. Their absence in that formation is likely apparent and is explained above. While both high (gneissic) and low (slate, phyllite, schist) rank metamorphic rock fragments were looked for, only low rank types were observed. These rock fragments are aggregates of quartz and minor mica with the mica displaying a preferred alignment (quartz-mica tectonites of Ingersoll and Suczek, 1979). They are interpreted to represent schists as opposed to slates or phyllites due to their low mica content. Schistose rock fragments are present in 35% of the thin sections wherein they average only 0.6%, ranging from 0.3 to 3.0%. These lithic grains are commonly deformed around monocrystalline quartz grains due to framework compaction with burial in the absence of significant matrix. They also show partial to complete replacement by authigenic cementing materials such as quartz and calcite.

Sedimentary Rock Fragments

As discussed previously, all sedimentary rock fragments are considered to represent intrabasinal grains and are therefore of no relevance to the reconstruction of the source terrane. Sedimentary lithics are present in 10.9% of the thin sections wherein they average only 1.1%, ranging from 0.3-5.1%. Three types of sedimentary lithics are present in the Okse Bay Group. Siltstone is the most common type. It is present in six thin sections where it ranges from 0.3-4.4%. Sandstone and shale (the distinction between shale and a clay clast is based on the degree of recrystallization of the micas, and if visible, the extent of their alignment; this is a difficult and subjective distinction) are present in six and seven thin sections, respectively. The former ranges from 0.3-0.7% while the latter ranges from 0.3-1.3%. The siltstone and shale rock fragments commonly display partial to complete diagenetic replacement and are deformed amongst the harder framework grains. The sandstone rock fragments show only minor replacement and no deformation.

3.2.3 Sandstone Diagenesis

The object of this section is to summarize the post-depositional textural and compositional modifications observed in the sandstones of the Okse Bay Group and to suggest a general paragenesis for these changes. The diagenetic modifications discussed herein are applicable to the sandstones and are not intended to be extended to the interstratified siltstones and finer material. Post-depositional modification of these sediments is commonly more severe due to their finer grain size (and therefore increased surface area) and the associated increase in clay mineral content making the recognition and unravelling of diagenetic processes much more difficult. It is well established that the dewatering of these finer grained sediments, principally by compaction (Burst, 1976), into the relatively more permeable and clay impoverished environment of the interstratified sandstones results in the modification of the more labile framework grains. Thus, the key to understanding arenite diagenesis lies in understanding the chemical evolution of the interstitial fluids in associated finer grained sediments.

The sandstones of the Okse Bay Group, as previously discussed, are extremely compositionally homogeneous. Since the nature and severity of diagenetic modifications is determined to a large extent by the mineralogical makeup of the sandstones it is unnecessary to discuss the diagenesis of each formation in the Okse Bay Group separately. Okse Bay Group sandstones have not been regionally metamorphosed, nor was any occurrence of the lower grade minerals prehnite or pumpellyite noted. The zeolite laumontite was tentatively identified on several occasions however, which if correct would suggest that burial metamorphic (i.e., deep diagenesis) conditions were attained. Additional evidence is presented subsequently that supports the suggestion of deep burial.

Diagenesis of Okse Bay Group sandstones has involved both neomorphism (Fuchtbauer, 1974) and replacement. Table 3.2.3-1 presents the distribution of cements and matrix in the Okse Bay Group, both in general as well as amongst the five formations composing the group. As indicated in this table, cement averages ca. 9% overall. Three types of cement are present, authigenic quartz, calcite, and hematite. Secondary quartz, while not as volumetrically important as less frequently found calcite, is ubiquitous and constitutes the principal lithifying agent. Calcite cement is not as common but when both cements occur together usually it is the more abundant. Hematite cement is commonly only present in trace amounts in the thin sections. As such it is not included in the summary table. Such finely disseminated hematite cement is undoubtedly the cause of the frequent red weathering color displayed by the Strathcona Fiord, Fram and Nordstrand Point Formations. Those instances in which hematite is present in greater than trace amounts are very infrequent and represent local breakdown of iron-bearing minerals. As mentioned previously, in this study matrix is considered to be any

Table 3.2.3.-1 Distribution of Cement and Matrix in the Okse Bay Group.

			Cements			
		Total	SiO_2	$CaCO_3$	Fe_2O_3	Matrix
Okse	OC(%)		100	61	8	60
Bay	X (%)	8.7	1.9	10.1	6.9	3.8
Group	S	9.2	0.8	9.7	8.2	4.6
Strathcona	OC		100	86	21	79
Fiord	X	14.9	1.6	12.0	16.7	2.6
	S	10.0	0.6	8.4	10.4	2.7
Hecla	OC		100	18	6	68
Bay	X	2.5	1.8	2.9	2.5	1.8
	S	2.2	0.8	2.7	0.7	1.1
Fram	OC		100	82	10	63
	X	9.7	2.0	9.2	4.0	3.9
	S	8.8	1.0	9.1	3.7	4.3
Hell	OC		100	74	6	51
Gate	X	10.8	2.0	12.2	0.8	5.2
	S	11.0	0.6	11.4	0.4	5.5
Nordstrand	OC		100	100	0*	33
Point	X	10.3	1.7	7.7	/	25.0
	S	8.4	0.6	6.4	/	(only one thin section with matrix)

*-hematite is present in the Nordstrand Point, as indicated by its common red weathering colour, but was absent in the samples point-counted.

Note: 1) OC - % occurrence; the percentage of thin sections from the Okse Bay Group, or from a particular formation within the group, that contained a particular cement or matrix; intended to indicate how common a specific cement or matrix is within a formation or within the Okse Bay Group.

2) X - sample mean; the percentages represent the mean value calculated only from amongst those thin sections in which that component was present (i.e., zero values not included).

3) S - sample standard deviation; statistical outliers are present in some data sets

4) Total - the total cement content

5)

Formation	Number of thin sections point-counted
Strathcona Fiord	14
Hecla Bay	34
Fram	51
Hell Gate	35
Nordstrand Point	3
Okse Bay Group	137

6) A cement or matrix present, but estimated at less than 1% abundance, was treated as being absent from that thin section.

7) All percentages given in this table represent visual estimates using the comparison chart of Terry and Chilingar (1955), given in Scholle (1979).

interstitial material that is less than 0.30 mm in size, as per Dott (1964). Matrix is a fairly frequent component in the Okse Bay Group occurring in 60% of the thin sections. Visual estimates of its abundance range from trace amounts to ca. 25% with an average of ca. 4%. Using the genetic matrix classification given in Dickinson (1970), matrix in the Okse Bay Group consists of epimatrix, orthomatrix and pseudomatrix in decreasing order of abundance. Only occasional thin sections contained what was considered to be orthomatrix (recrystallized detrital matrix). These thin sections contain the greatest percentages of matrix observed in the Okse Bay Group and represent the finest grain sizes included in the petrographic study. Their matrix is reasonably evenly distributed and display subtle compositional variations, features considered indicative of a detrital origin. Pseudomatrix is the least abundant matrix type, as would be anticipated from the paucity of mechanically unstable lithic grains in the Okse Bay Group. The frequent occurrence of very low percentages of matrix in Okse Bay Group sandstones is considered to result mainly from the breakdown of labile framework grains such as feldspar and lithics and as such to constitute an epimatrix. Matrix of this type is very unevenly distributed throughout a thin section as would be expected in light of its suggested genesis.

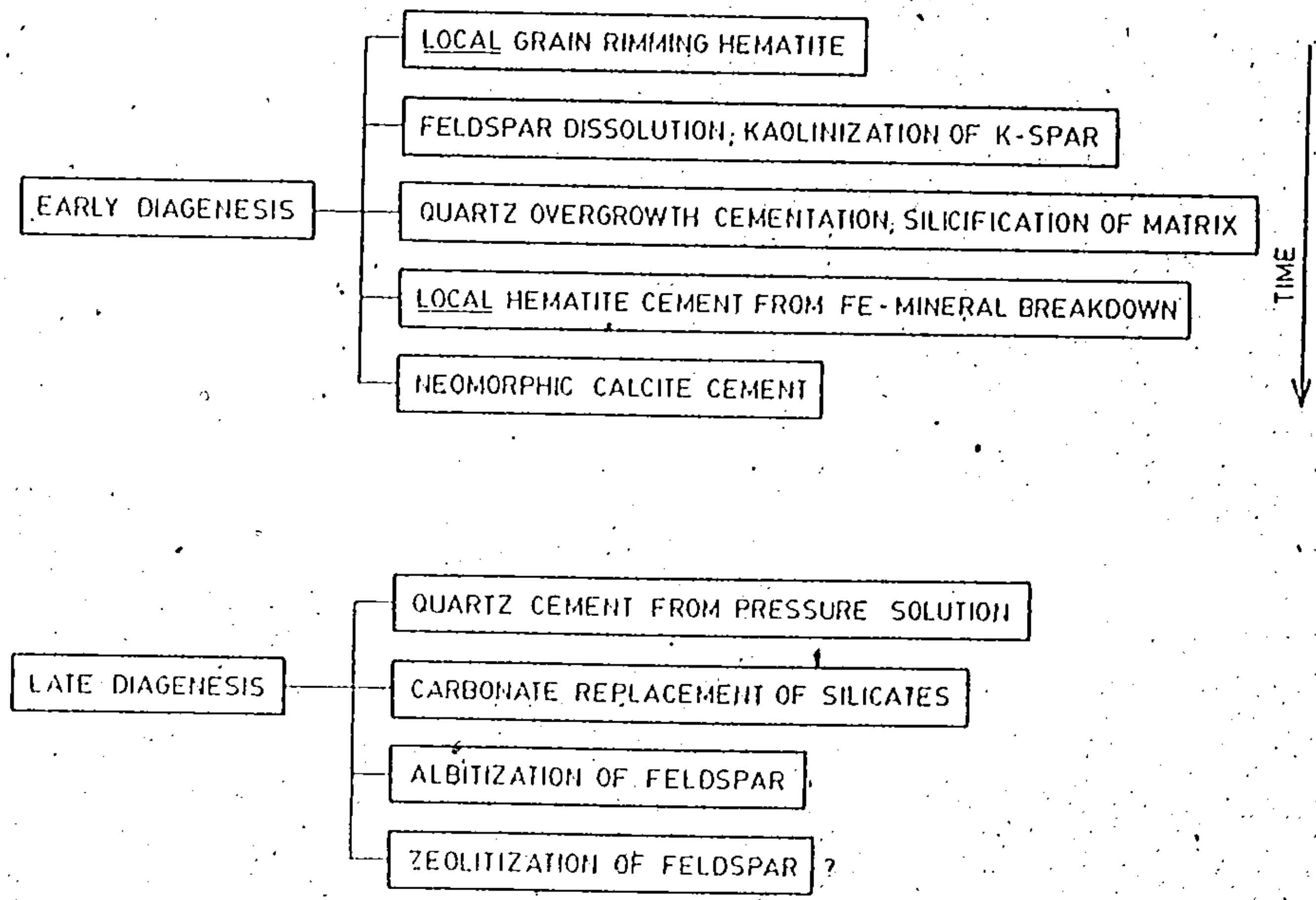
Post-depositional modifications to Okse Bay Group sandstone may be conveniently partitioned into an early and late diagenetic interval corresponding to shallower and deeper burial conditions, respectively. Following Blatt, Middleton and Murray (1980, pg. 352) early diagenesis may be considered to imply temperatures less than 100°C while late diagenesis may be considered to imply modifications occurring between 100°-200°C. Without knowing what the geothermal gradient was in the Franklinian Miogeocline during the burial of Okse Bay Group sediments it is impossible to attach accurate depth limits to early and late diagenesis. Nevertheless, rough estimates are presented at the end of this section based on a comparison with other studies. Early and late diagenesis of Okse Bay Group sandstones is discussed separately below. Early and late diagenetic processes are listed in Figure 3.2.3-1.

3.2.3.1 Early Diagenesis (<100°C)

The following paragenesis is suggested for textural and compositional modifications occurred during early diagenesis:

Textural

Figure 3.2.3 - 1 Early and late diagenetic modifications of Okse Bay Group sandstones.


EARLY DIAGENESIS
LOCAL GRAIN RIMMING HEMATITE
FELDSPAR DISSOLUTION; KAOLINIZATION OF K-SPAR
QUARTZ OVERGROWTH CEMENTATION; SILICIFICATION OF MATRIX
LOCAL HEMATITE CEMENT FROM FE-MINERAL BREAKDOWN
NEOMORPHIC CALCITE CEMENT
LATE DIAGENESIS
QUARTZ CEMENT FROM PRESSURE SOLUTION
CARBONATE REPLACEMENT OF SILICATES
ALBITIZATION OF FELDSPAR
ZEOLITIZATION OF FELDSPAR
?
TIME

1. Compaction and porosity reduction due to burial
2. Deformation of mechanically unstable lithic grains

Compositional

1. Early, local, grain rimming hematite cement
2. Kaolinization of alkali feldspar; feldspar dissolution
3. Quartz cementation resulting from the precipitation of syntaxial overgrowths; lithification was aided at this time by contemporaneous silicification of matrix as well as other labile framework grains
4. Later, local, hematite cementation resulting from the breakdown of iron bearing minerals
5. Calcite cementation in any remaining primary porosity and in any secondary porosity resulting from dissolution of feldspar and/or lithic grains

Compositional Modifications

The paragenesis suggested above for compositional modifications is based on observations accumulated during point-counting Okse Bay Group sandstones and on published generalizations of the temporal arrangement of diagenetic processes, in particular, that found in Blatt, Middleton and Murray (1980, Table 9-2, pg. 360) and in Fuchtbauer (1974, pg. 149).

Grain rimming hematite cement is only present occasionally in the thin sections. As previously stated, it is the principal cause of the common red weathering color displayed by sandstones in the Strathcona Fiord, Fram and Nordstrand Point Formations. This type of hematite cement has been interpreted to represent microcrystalline particulate iron oxide deposited with the coarser framework grains (Blatt, Middleton and Murray, 1980) and has been suggested to be indicative of arid climatic conditions. Such an interpretation would compliment the hot but highly seasonal climatic interpretation suggested previously for the Strathcona Fiord Formation (2.1.7).

Pore filling kaolinite resulting from the breakdown of alkali feldspar is rarely present in the sandstones of the Okse Bay Group. A greater abundance was anticipated and its paucity may reflect replacement by later cements such as quartz and/or calcite.

As stated previously, authigenic silica is the principal lithifying agent in the Okse Bay Group. It is found replacing matrix and labile framework grains and as syntaxial overgrowths on detrital monocrystalline cores. Commonly suggested sources of secondary silica are: 1) pressure solution of framework quartz 2) dissolution of chert grains 3) kaolinization of alkali feldspar 4) carbonate replacement of silicates under deep burial conditions 5) clay mineral transformations in interstratified siltstones (for example the montmorillonite to illite transformation) 6) dissolution of quartz in interstratified siltstones.

Invariably, whenever calcite and quartz cements occur together in the Okse Bay Group, calcite is always later than quartz. This relationship precludes carbonate replacement of silicates as the source of the lithifying silica cement. Pressure solution of quartz grains, known to be a deep burial phenomena (2500-5000 m according to Pettijohn, Potter and Siever, 1972), may also be ruled out as a principal source of silica since cathodoluminescence microscopy indicates very little deformation of the quartzose framework throughout the Okse Bay Group (3.3.4). All of the remaining four processes could have supplied secondary silica to the Okse Bay Group sandstones under early diagenetic conditions. However, kaolinization of alkali feldspar and dissolution of chert grains must both be considered only as minor sources of secondary silica in light of the paucity of both feldspar and chert grains in Okse Bay Group sandstones. The principal source of secondary silica in the Okse Bay Group is considered to be the siltstones which are commonly interstratified with the sandstone in all formations except the Hecla Bay where siltstone only constitutes ca. 7% of the formation, by cumulative thickness. Pressure solution of silt size quartz is enhanced by the clay enriched environment in the siltstones. Silica derived from this process, as well as from clay mineral transformations, is flushed into the sandstones during compactional dewatering of the siltstones. Precipitation of this silica is promoted in the sandstones by the relative paucity of clay.

A later, very local hematite cement is rarely present. It occurs only in isolated patches in the thin sections and is directly related to the breakdown of labile iron bearing grains (for example, biotite). On the rare occasions that this cement is present it always is later than the authigenic silica but precedes the calcite cement.

Calcite is an important cement in the Okse Bay Group sandstones and is invariably the latest. It commonly is more abundant than the earlier quartz cement but it is not as common an occurrence. Table 3.2.3-1 indicates that calcite cement is found in only 61% of the thin sections while secondary quartz cement is always found. The source of the calcium carbonate is suggested to be the interstratified siltstones which are invariably slightly calcareous. Calcite forms in these finer sediments as a result of clay mineral transformations which free-up Ca^{++}

(for instance the montmorillonite to illite transformation) and the oxidation of organic matter which provides the $CO_3^=$. Under the low temperature and low pH conditions of shallow burial carbonate is soluble and is transported into the sandstones during compactional dewatering of the siltstones, as is the remobilized silica discussed above. Once in the sandstones the calcite is precipitated in any remaining primary porosity and in secondary porosity. Supporting evidence for the derivation of the calcite cement from the interstratified siltstones is found in Table 3.2.3-1. This table indicates that calcite cement is least frequent in the Hecla Bay and the Hell Gate Formations (18% and 74% occurrence, respectively). As discussed in 2.6.2, these two formations also contain the least amount of interstratified siltstone (ca. 7% and 30%, respectively, by cumulative thickness). This direct correspondence between the frequency of calcite cementation and the abundance of siltstone would certainly seem to support a siltstone source for this cement.

The presence of interstratified siltstone is thus seen to be of paramount importance to the cementation of Okse Bay Group sandstone. Early diagenetic allochthonous cementation may be said to characterize the sandstone of those formations which contain significant amounts of interstratified siltstone. This includes all formations in the Okse Bay Group except the Hecla Bay Formation. As a result, the sandstone of these formations is always well cemented. In contrast to this, the sandstone of the Hecla Bay Formation is frequently poorly cemented to the extent that it often can be crumbled in your hands. Without abundant interstratified siltstone only low volume, mainly autochthonous cements are available for lithification. This would include dissolution of chert grains and kaolinization of alkali feldspar under shallow burial conditions and pressure solution of quartz and carbonate replacement of silicates under deep burial conditions. Only minor amounts of cement could be expected to be generated by any of these processes, even if considered cumulatively, and the result is poorer lithification of Hecla Bay sandstone.

The difference in cementation history amongst the formations in the Okse Bay Group is summarized in Figure 3.2.3.1-1. Selected petrographic features of each formation in the Okse Bay Group are presented in Plates 3.2.3.1-1 to 3.2.3.1-5.

3.2.3.2 Late Diagenesis (100-200^{0}C)

Late diagenetic modifications to Okse Bay Group sandstones are entirely compositional in nature. It

Figure 3.2.3.1 - 1 Cementation history for the formations of the Okse Bay Group as determined by the abundance of interstratified siltstone.

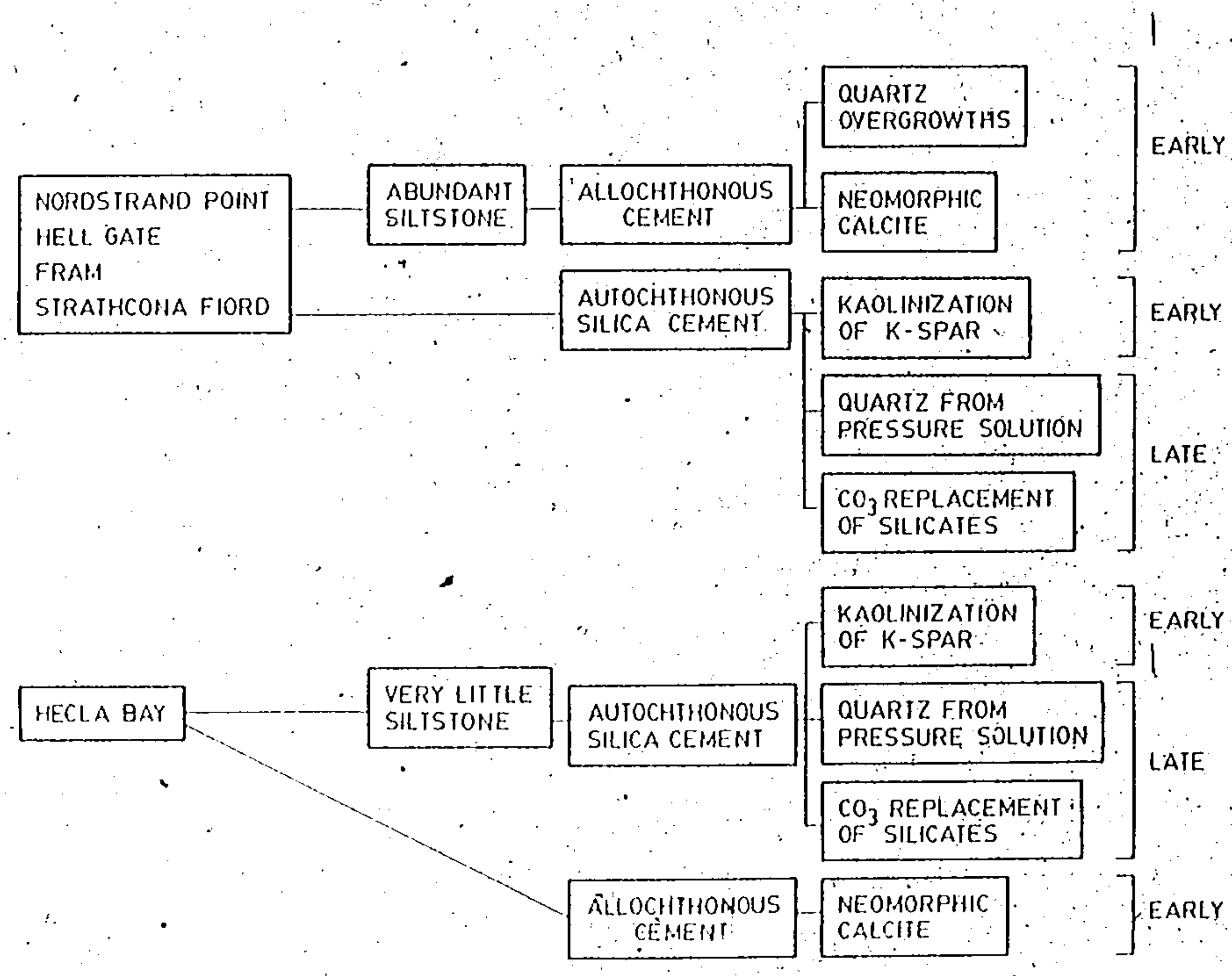

NORDSTRAND POINT
HELL GATE
FRAM
STRATHCONA FIORD
ABUNDANT SILTSTONE
ALLOCHTHONOUS CEMENT
QUARTZ OVERGROWTHS
NEOMORPHIC CALCITE
EARLY
AUTOCHTHONOUS SILICA CEMENT
KAOLINIZATION OF K-SPAR
EARLY
QUARTZ FROM PRESSURE SOLUTION
CO3 REPLACEMENT OF SILICATES
LATE
HECLA BAY
VERY LITTLE SILTSTONE
AUTOCHTHONOUS SILICA CEMENT
KAOLINIZATION OF K-SPAR
EARLY
QUARTZ FROM PRESSURE SOLUTION
CO3 REPLACEMENT OF SILICATES
LATE
ALLOCHTHONOUS CEMENT
NEOMORPHIC CALCITE
EARLY

Plate 3.2.3.1 - 1 Petrographic features of the Strathcona Fiord Formation on southwestern Ellesmere Island.

A. A low power photomicrograph showing a quartz rich framework and common calcite cement (cal). The patchy distribution of the calcite suggests that it may have replaced a labile framework grain such as feldspar.

Section S2, sample 310, 111.4 m above base of section. Width of field of view is ca. 1.7 mm.

B. Another low power photomicrograph showing the same quartz rich framework and patchy calcite cement from a different exposure of the Strathcona Fiord Formation.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 1.7 mm.

C. The grain in the center of the photomicrograph is almost entirely replaced by calcite (C). Its detrital character is indicated by staining which reveals residual islands of alkali feldspar (K). Note also the earlier, grain-rimming, hematite cement (H).

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

D. A large polycrystalline quartz grain (Qp) showing peripheral replacement by calcite (C).

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

E. A rare schistose metamorphic rock fragment (M) showing only minor deformation by surrounding framework grains.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.


Ca
A
B
H
C
C

F. The framework grain in the center of the photomicrograph is almost completely replaced by calcite (C). Staining reveals a residual island of alkali feldspar (K). In determining the detrital mode the grain is counted as alkali feldspar, not calcite.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

G. Hematite (H) and calcite cement (C) have completely replaced labile framework grains in this photomicrograph. Calcite is interstitial to hematite indicating that it is a later cement.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

H. An example of cement paragenesis. Interstitial relationships indicate the following cementation sequence: early, grain rimming hematite cement (H) - authigenic silica cement (Q) - calcite cement (C).

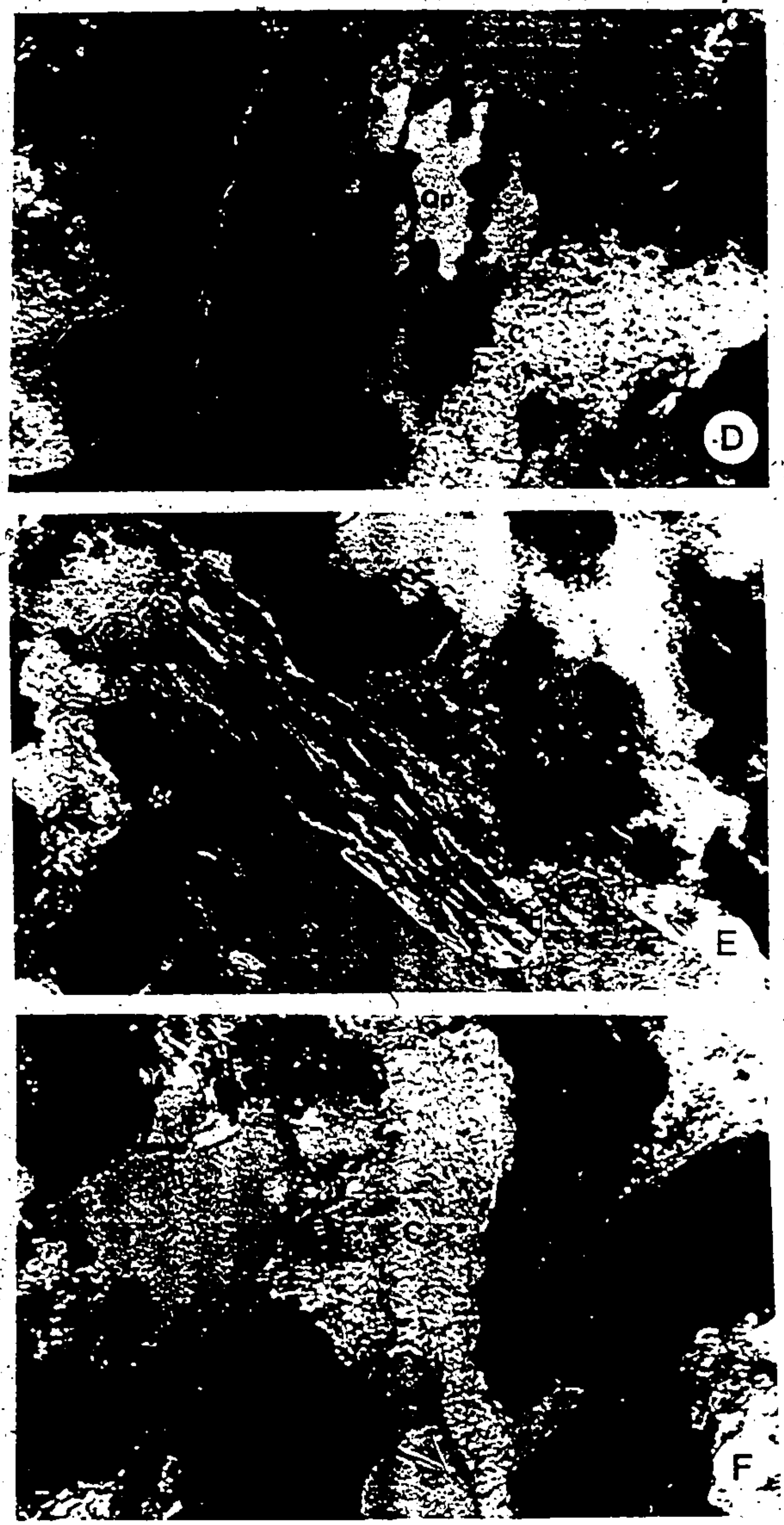
Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

I. The presence of early diagenetic, grain rimming hematite cement (H) surrounding both the rounded monocrystalline quartz grain in the center of the photomicrograph and its secondary overgrowth (O) indicates that this single overgrowth and its parent grain are recycled. The calcite cement (C) is interstitial to the grain rimming hematite and therefore later.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.

J. A large grain of detrital chert (Ch) showing incipient peripheral replacement by calcite cement (C).

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.


Qp
D
E
C
F

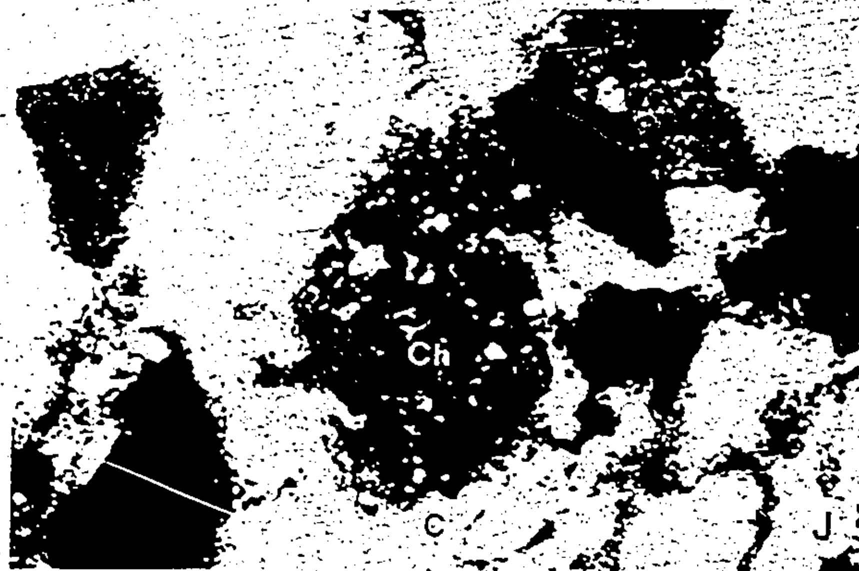
K. A chert grain (Ch) showing more advanced replacement by calcite cement (C). Peripheral replacement has proceeded to the point where the grain boundaries are indistinct.

Section HB1, sample 761, 0.8 m above base of section. Width of field of view is ca. 0.26 mm.


H
G


H


I


Ch
C
J

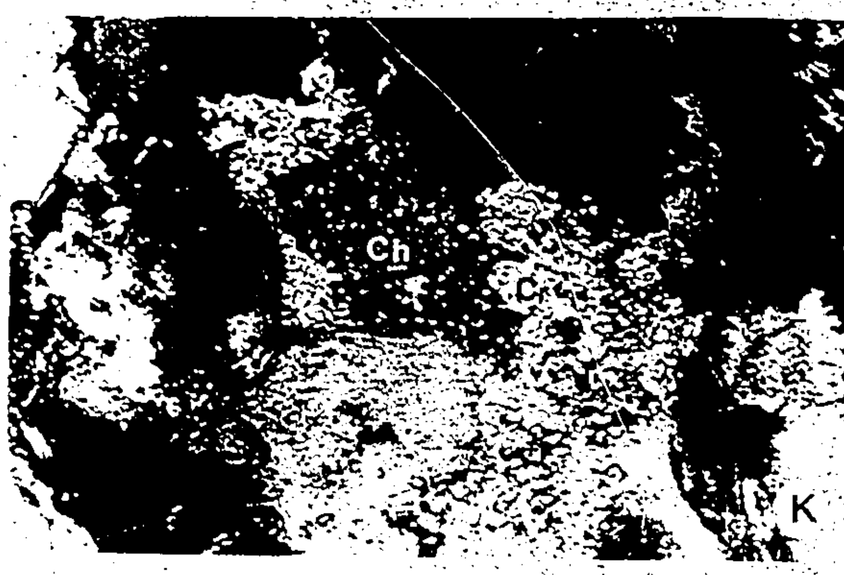

Ch
C
K

Plate 3.2.3.1 - 2 Petrographic features of the Hecla Bay Formation on southwestern Ellesmere Island.

A. A general photomicrograph of the Hecla Bay Formation at section HB1 showing a quartz rich framework (Q) with relatively minor chert (Ch) and alkali feldspar grains (K).

Section HB1, sample 792, 289 m above base of section. Width of field of view is ca. 1.7 mm.

B. A type of secondary porosity (P) created by the partial corrosion of a large alkali feldspar grain (K).

Section HB1, sample 792, 289 m above base of section. Width of field of view is ca. 0.7 mm.

C. Secondary porosity (P) created by the partial dissolution of an alkali feldspar grain (K).

Section HB1, sample 792, 289 m above base of section. Width of field of view is ca. 0.7 mm.

D. An interlocking quartzose framework resulting from secondary silica cementation. A relatively rare polycrystalline quartz grain (Qp) is present in the bottom left of the photomicrograph.

Section HB2, sample 809, 60.6 m above base of section. Width of field of view is ca. 1.7 mm.

E. Contrasting siliceous microcrystalline textures of detrital chert (Ch) and metamorphic polycrystalline quartz (Qp). The quartz grain (Q) beneath the polycrystalline quartz shows incipient, peripheral, in-situ recrystallization. If carried to completion the distinction between in-situ and inherited metamorphic polycrystalline quartz would rely upon an alignment of quartz crystals in the latter.

Section HB2, sample 809, 60.6 m above base of section. Width of field of view is ca. 1.7 mm.


K
Q
Ch
A
P
K
B
K
P
C

F. The morphology of the large chert grain in the center of the photomicrograph suggests that it may represent replacement of a labile framework grain.

Section HB2, sample 809, 60.6 m above base of section. Width of field of view is ca. 1.7 mm.

G. A sericitized grain of alkali feldspar is shown in the center of the photomicrograph. The replacement mineral has been partially corroded to create a small amount of secondary porosity.

Section HB1, sample 792, 289 m above base of section. Width of field of view is ca. 0.7 mm.

H. A large, untwinned plagioclase grain (P) representing burial metamorphic albitization of what was likely a detrital alkali feldspar grain.

Section HB1, sample 792, 289 m above base of section. Width of field of view is ca. 0.7 mm.

I. A large polycrystalline quartz grain in the upper center of the photomicrograph shows no preferred alignment of its crystals suggesting that it could represent replacement of a labile framework grain by secondary silica. A large area of secondary porosity (P) created by grain corrosion is also present.

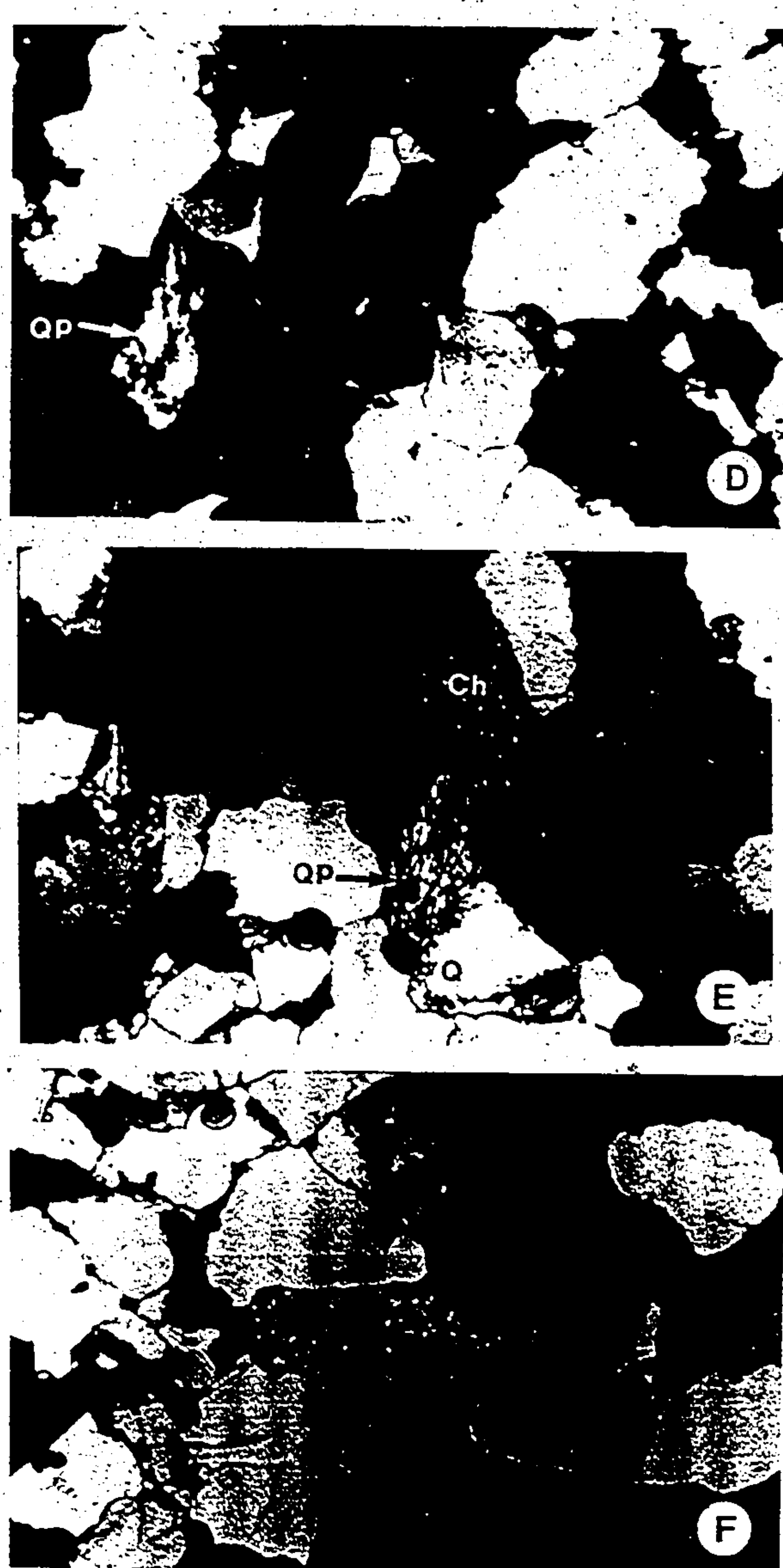
Section HB2, sample 809, 60.6 m above base of section. Width of field of view is ca. 1.7 mm.

J. The large grain of chert in the right of the photomicrograph displays a morphology which suggests that it could represent replacement of a detrital labile framework grain.

Section F4, sample 593, 101.3 m above base of section. Width of field of view is ca. 0.7 mm.

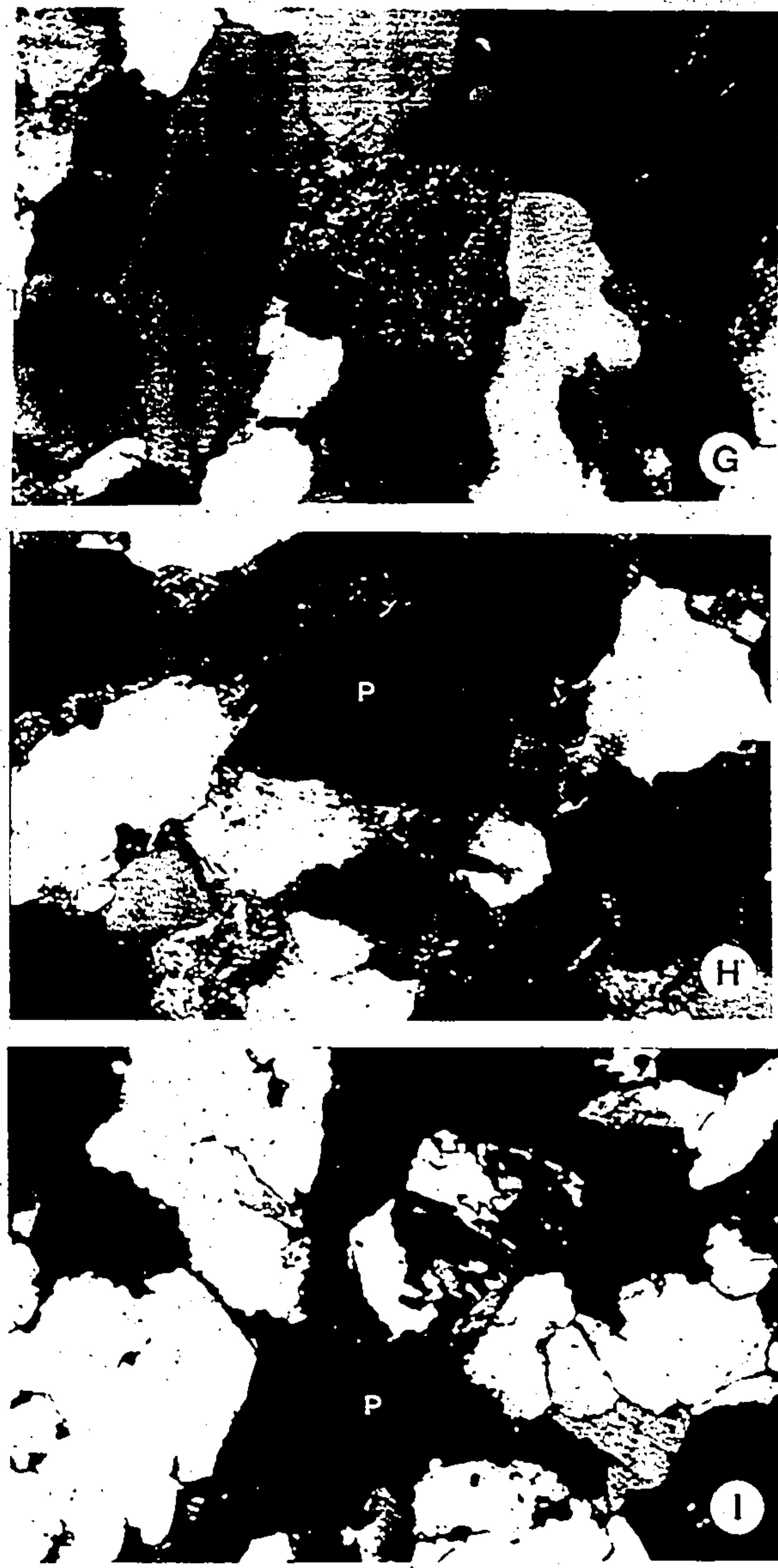
K. A low power photomicrograph of the Hecla Bay Formation at section F4 showing an interlocking quartz rich framework as a result of silica cementation and possible minor orthomatrix (arrow).

Section F4, sample 593, 101.3 m above base of section. Width of field of view is ca. 1.7 mm.


QP
D
Ch
QP
Q
E
F

L. While single overgrowths are not proof of recycling, multiple overgrowths (arrows) such as those shown on the quartz grain in the right of the photomicrograph indicate the grain has been recycled.

Section HB3, sample 858, 435 m above base of section. Width of field of view is ca. 0.7 mm.


G
P
H
P
I

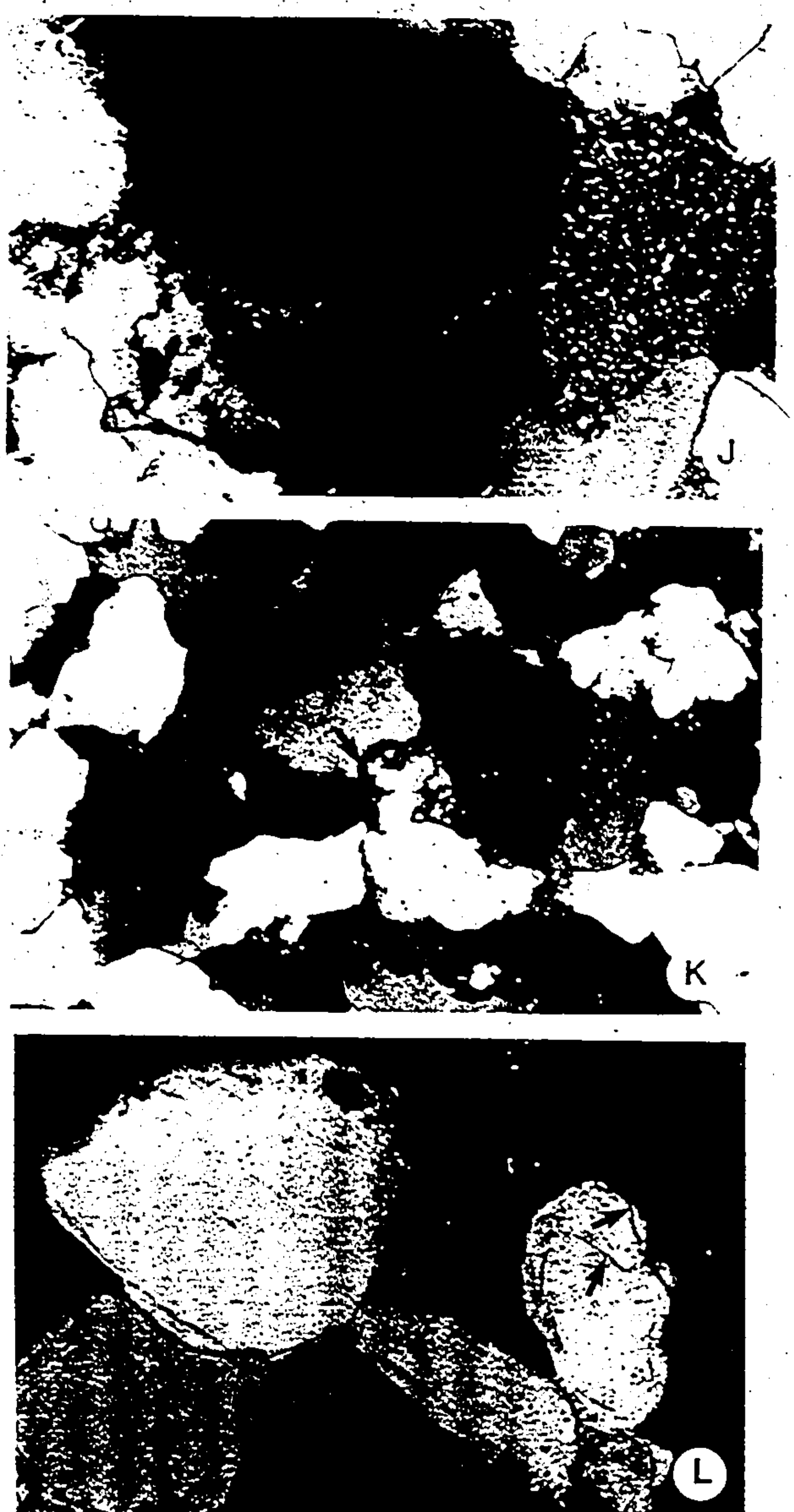

J
K
L

Plate 3.2.3.1 - 3 Petrographic features of the Fram Formation on southwestern Ellesmere Island.

A. A low power photomicrograph of the Fram Formation at section F5 showing a quartz rich framework with abundant silica and calcite cement.

Section F5, sample 876, 258.5 m above base of section. Width of field of view is ca. 1.7 mm.

B. A photomicrograph of the Fram Formation at section F3. Note the similarity with the Fram shown in A. These two photomicrographs represent the Fram Formation at the eastern (F5) and western (F3) extremities of the study area on southwestern Ellesmere Island.

Section F3, sample 505, 61 m above base of section. Width of field of view is ca. 1.7 mm.

C. The Fram Formation at section F4 is very similar to the formation in photomicrographs A and B. This location is intermediate between sections F5 (A) and F3 (B).

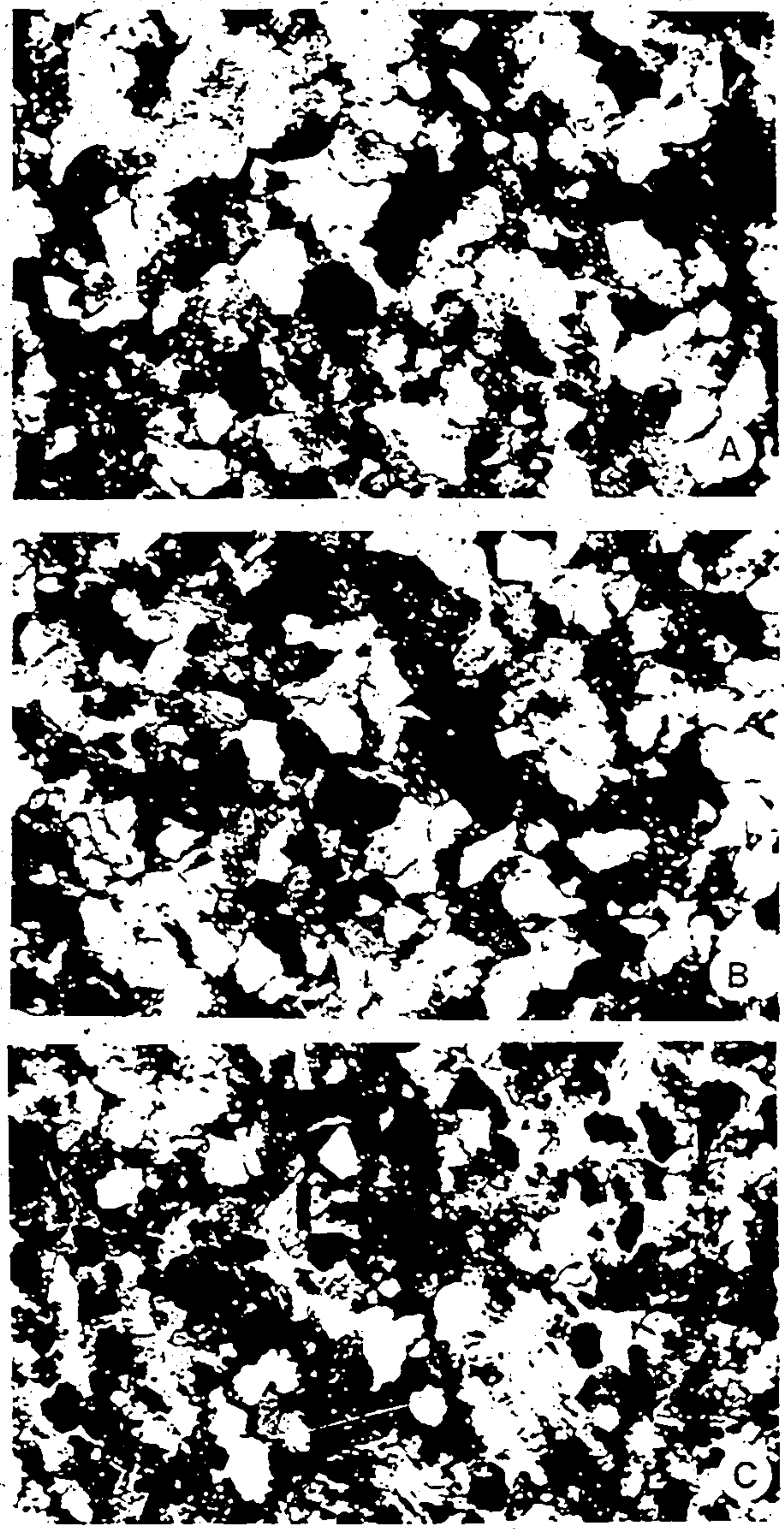
Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 1.7 mm.

D. The polycrystalline quartz grain in the center of the photomicrograph is in an advanced stage of replacement by calcite. This replacement is common throughout the Okse Bay Group.

Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 0.26 mm.

E. The large area of calcite (C) in the center of the photomicrograph represents the complete replacement of a labile framework grain.

Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 0.26 mm.



F. Authigenic calcite (C) and quartz (Q) represent successive replacement at a location occupied by a labile framework grain at the time of deposition. Cement paragenesis elsewhere in the Okse Bay Group suggests that silica probably replaced the labile grain and was in turn later partially replaced by calcite.

Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 0.26 mm.

G. The characteristic cement paragenesis in the Okse Bay Group is shown in this photomicrograph where calcite cement (C) is interstitial to (and therefore later than) secondary silica cement in the form of a monocrystalline quartz overgrowth (arrow).

Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 0.26 mm.

H. The chert grain (Ch) in the center of the photomicrograph displays peripheral replacement by calcite cement. Calcite cement is also replacing monocrystalline quartz grains in this sample.

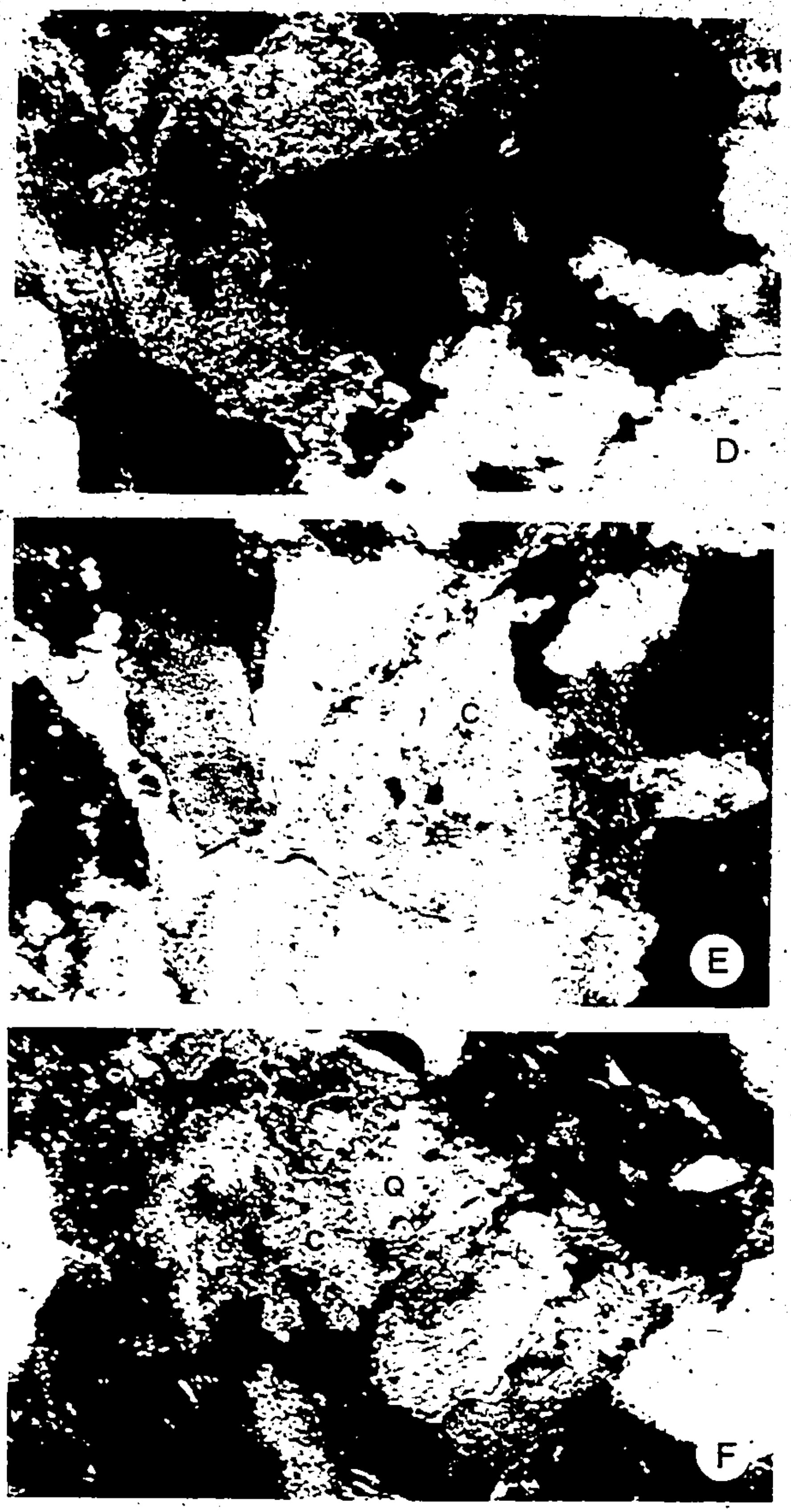
Section F4, sample 643, 458.1 m above base of section. Width of field of view is ca. 0.26 mm.

I. A photomicrograph of the Fram Formation at section F1 showing a quartz rich framework cemented by both secondary silica and calcite cement. A large secondary pore space (P) created by labile grain dissolution is present at the top of the photomicrograph.

Section F1, sample 47, 331.5 m above base of section. Width of field of view is ca. 1.7 mm.

J. Occasional grains showing multiple monocrystalline quartz overgrowths (arrows) indicate the presence of recycled quartz in the Fram Formation. The presence of such grains suggests that many more recycled grains are present.

Section F1, sample 47, 331.5 m above base of section. Width of field of view is ca. 0.7 mm.

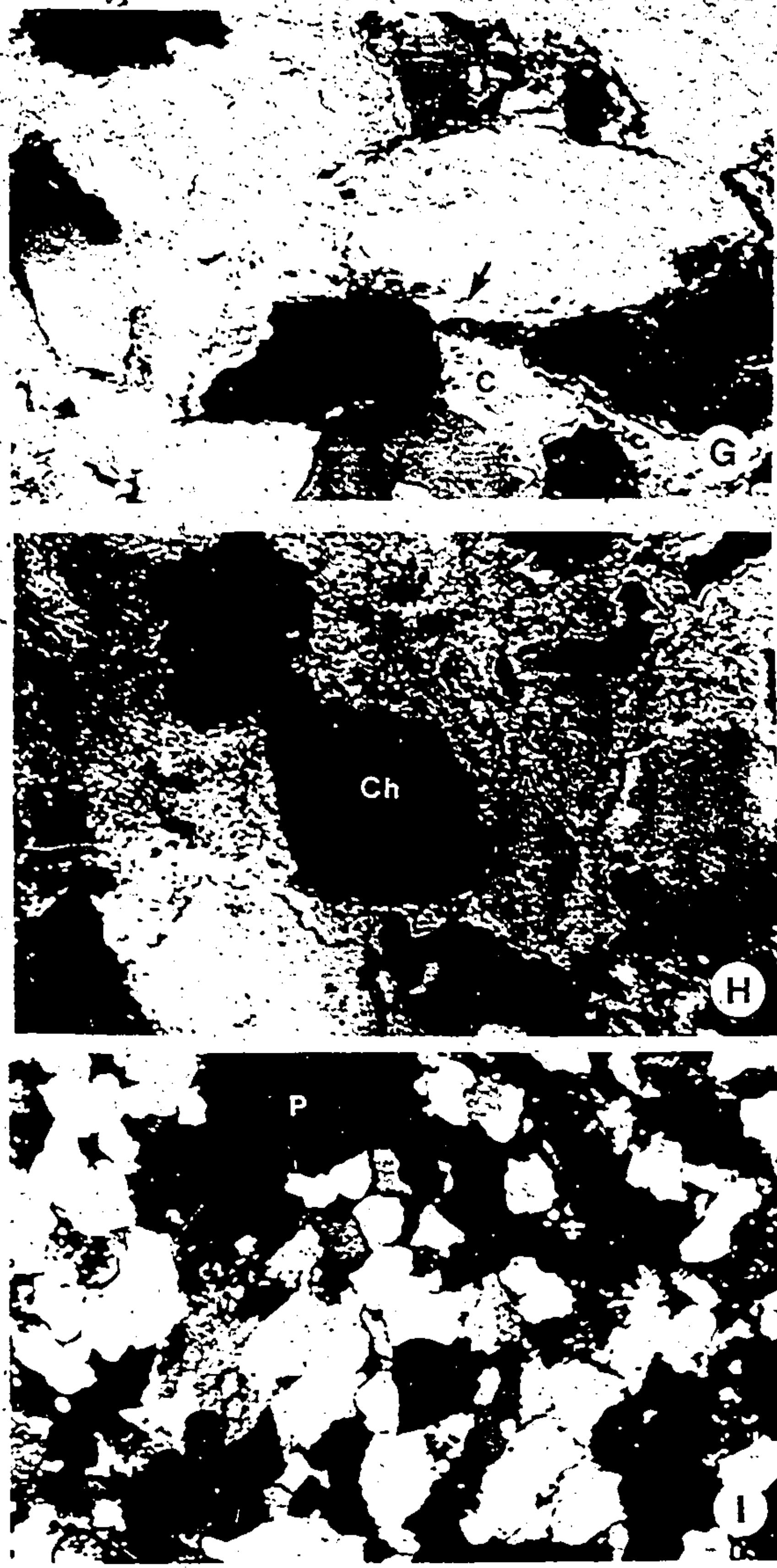

D
C
E
Q
C
F

K. A photomicrograph of the Fram Formation at section F2 showing a quartzose framework cemented entirely by secondary silica.

Section F2, sample 370, 209.1 m above base of section. Width of field of view is ca. 1.7 mm.

L. A photomicrograph of the Fram Formation at section HG2 showing the same silica cemented quartzose framework that was displayed by the Fram at section F2 (K above).

Section HG2, sample 675, 36.6 m above base of section. Width of field of view is ca. 1.7 mm.


C
G
Ch
H
P
I

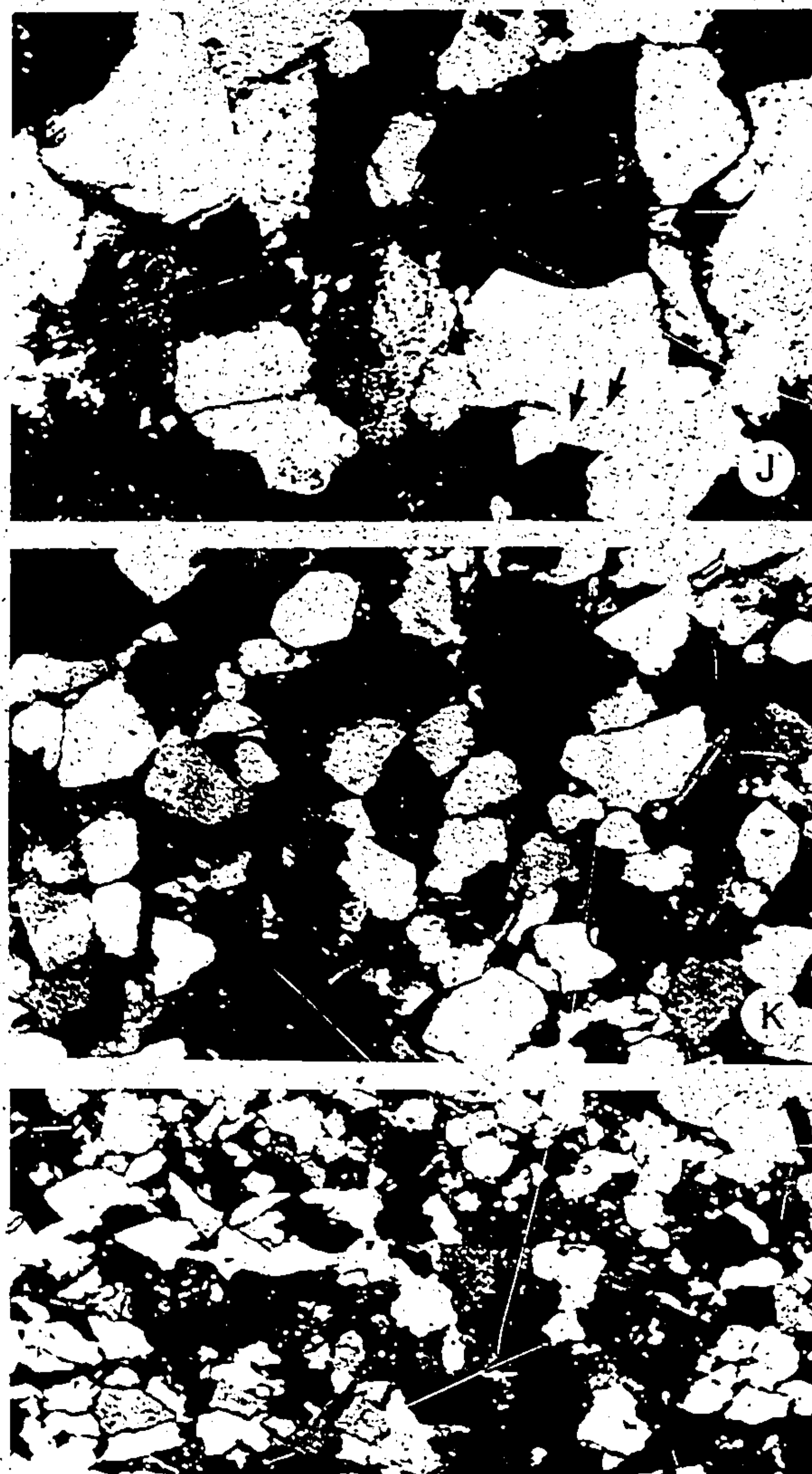

J
K
L

Plate 3.2.3.1 - 4 Petrographic features of the Hell Gate Formation on southwestern Ellesmere Island.

A. A photomicrograph of the Hell Gate Formation at section F2 showing a silica cemented quartzose framework. The polycrystalline quartz grain in the center of the photomicrograph represents diagenetic replacement of a labile framework grain, likely feldspar, by secondary silica.

Section F2, sample 436, 419.6 m above base of section. Width of field of view is ca. 1.7 mm.

B. A photomicrograph of the Hell Gate Formation at section HG1 showing a mainly silica cemented quartzose framework. A metamorphic polycrystalline quartz grain (Qp) is shown in the upper center of the photomicrograph.

Section HG1, sample 249, 65.1 m above base of section. Width of field of view is ca. 1.7 mm.

C. A photomicrograph of the Hell Gate Formation at section HG3 showing a silica cemented quartzose framework similar to that shown in photomicrographs A and B.

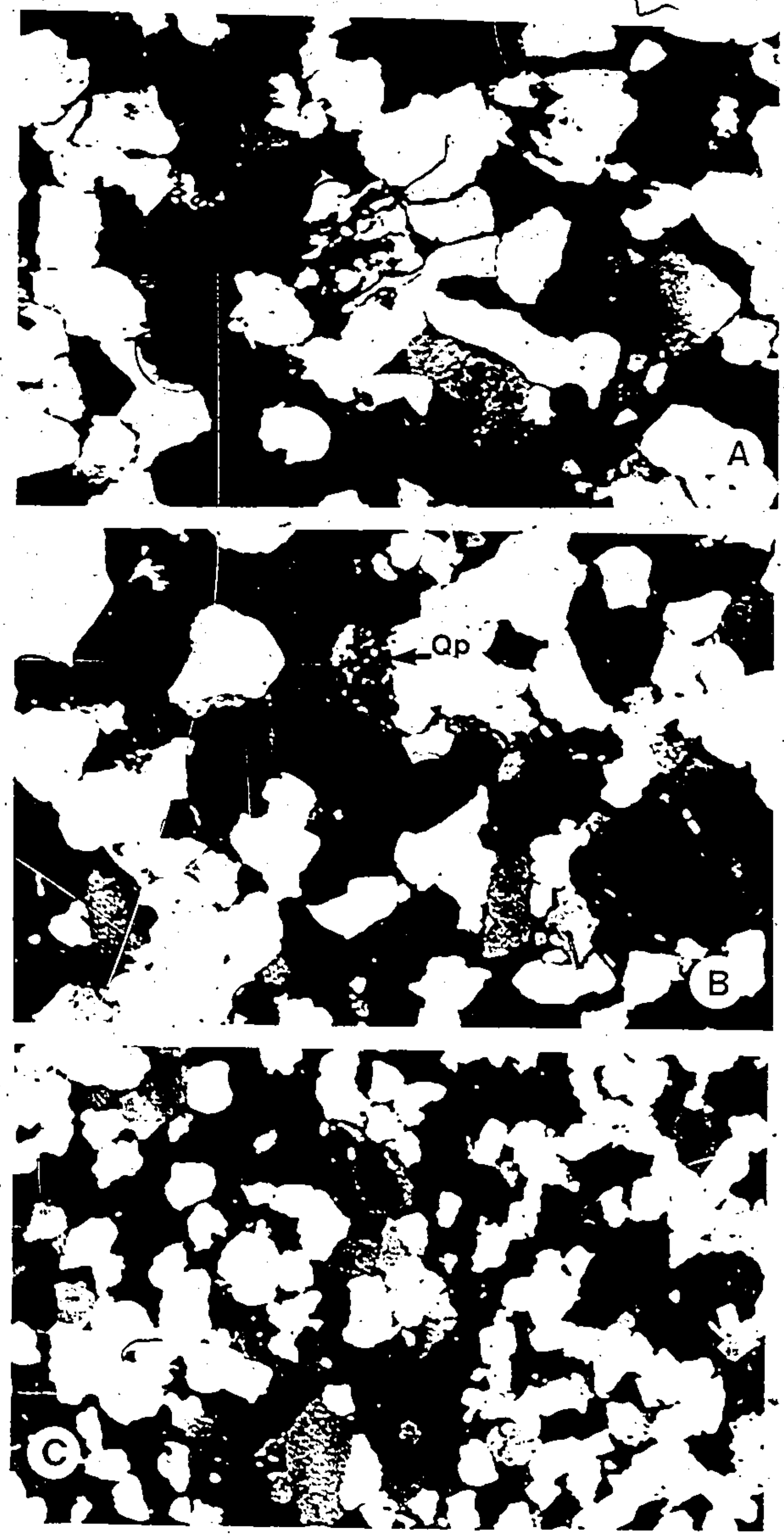
Section HG3, sample 832, 32.6 m above base of section. Width of field of view is ca. 4.2 mm.

D. A photomicrograph of the Hell Gate Formation at section HG2. The quartzose framework is cemented by both secondary silica and calcite. Note the similarity amongst photomicrographs A - D representing different sections in the Hell Gate Formation across southwestern Ellesmere Island.

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 1.7 mm.

E. A large grain of detrital chert (Ch) in the Hell Gate Formation at section HG2 showing incipient peripheral replacement by calcite.

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.


A
Qp
B
C

F. The area of chert (Ch) in the center of this photomicrograph displays a morphology which suggests that the chert is a cement which has replaced a labile framework grain or occupied a void left by framework grain dissolution.

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.

G. A photomicrograph of the Hell Gate Formation at section F3 showing the same silica cemented quartzose framework that was displayed in photomicrographs A - D. Rare, deformed, sedimentary lithic grains (Ls) are shown in the bottom right of the photomicrograph.

Section F3, sample 564, 232.1 m above base of section. Width of field of view is ca. 1.7 mm.

H. A well rounded grain of polycrystalline quartz is shown in the center of the photomicrograph. Since polycrystalline quartz does not have a high survival potential with recycling the well rounded morphology of this grain and the lack of alignment of its crystals suggests that it could represent silica replacement of a labile framework grain.

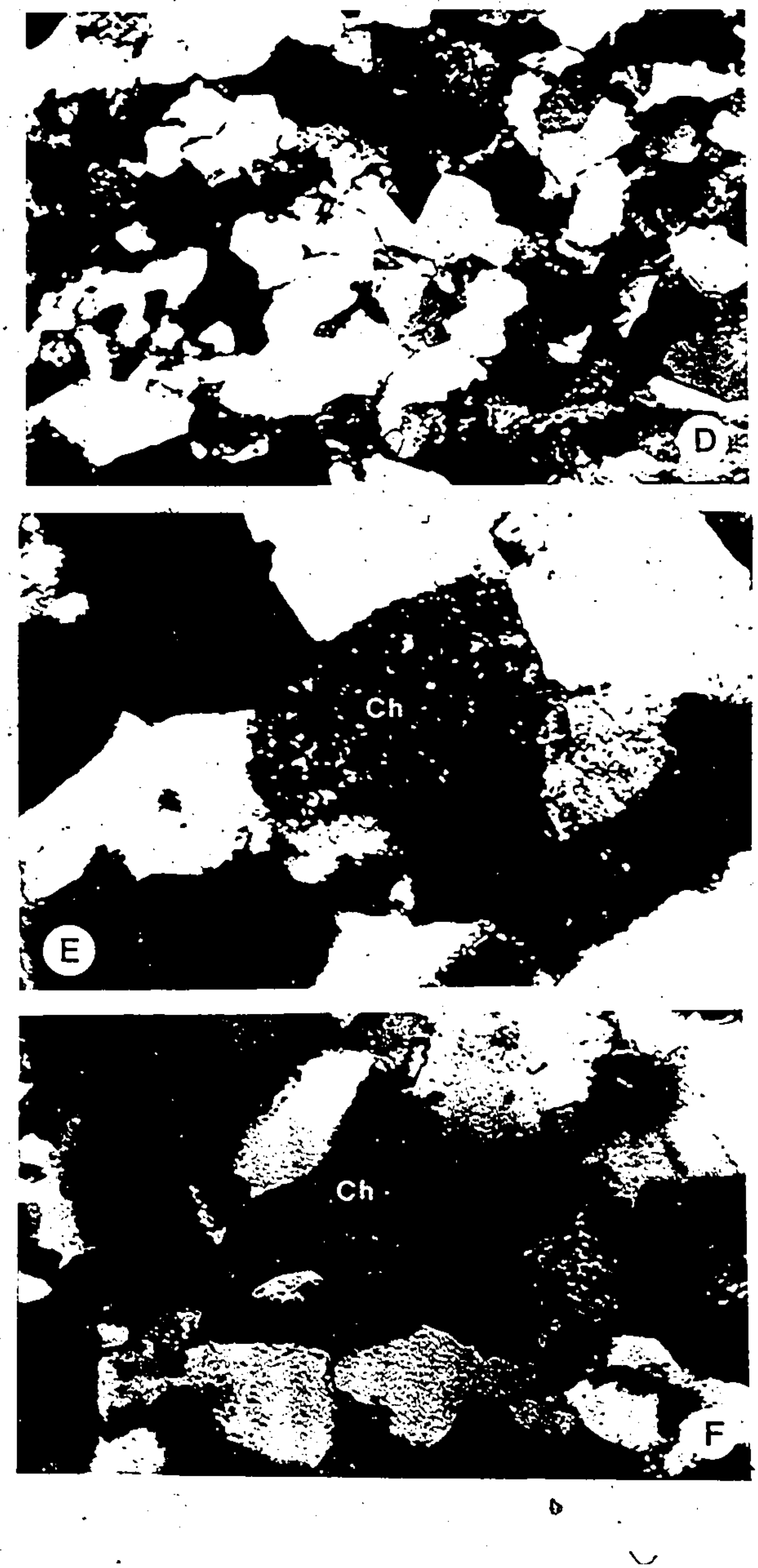
Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.

I. The cement paragenesis in the Hell Gate Formation is shown in this photomicrograph where calcite (C) is interstitial to, and therefore later than, secondary silica cement in the form of a syntaxial overgrowth (O).

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.

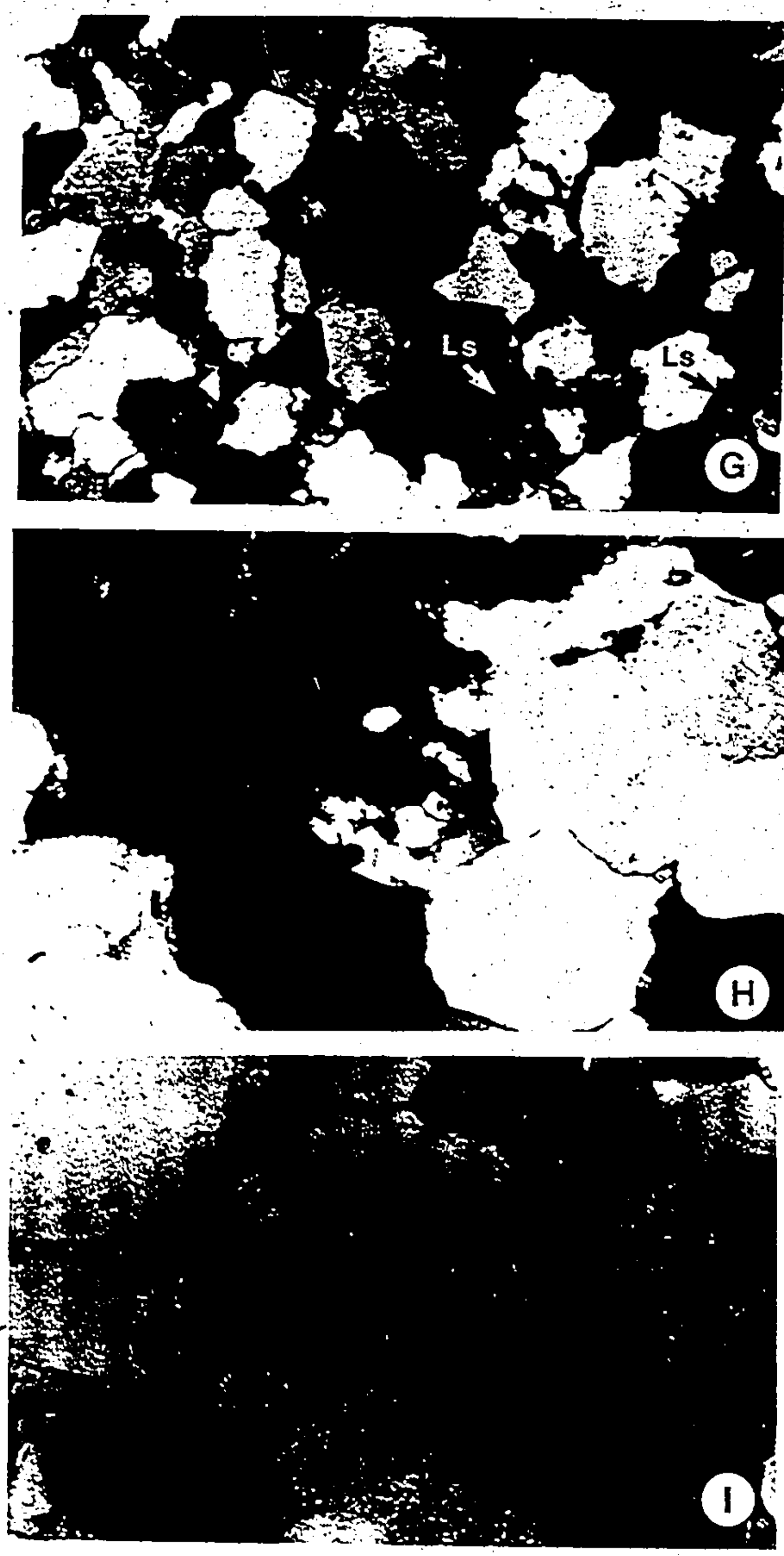
J. Small, residual islands of yellow stain indicate that secondary quartz (Q) has almost completely replaced a detrital alkali feldspar grain. Subsequent corrosion has created secondary porosity (P) in this grain as well as a large secondary pore space (P) in the right of the photomicrograph.

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.


D
Ch
E
Ch
F

K. The large area of calcite (C) in the center of the photomicrograph represents either calcite replacement of a labile framework grain or infilling of the void created by its dissolution. The latter is more likely since some islands of secondary porosity remain (arrows). However, it is possible that these islands represent a later corrosive event.

Section HG2, sample 738, 354.5 m above base of section. Width of field of view is ca. 0.7 mm.


Ls
Ls
G
H
I


P
p
Q
J


C
K

Plate 3.2.3.1 - 5 Petrographic features of the Nordstrand Point Formation on southwestern Ellesmere Island.

A. A photomicrograph of the Nordstrand Point Formation at section HG3 showing its silica cemented quartzose framework. A small amount of orthomatrix (arrows) is also present in this sample.

Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 1.7 mm.

B. The non-alignment of the crystals in the polycrystalline quartz grains in the upper left and lower right of the photomicrograph suggests that these grains represent silica replacement of labile framework grains rather than constituting detrital metamorphic polycrystalline quartz.

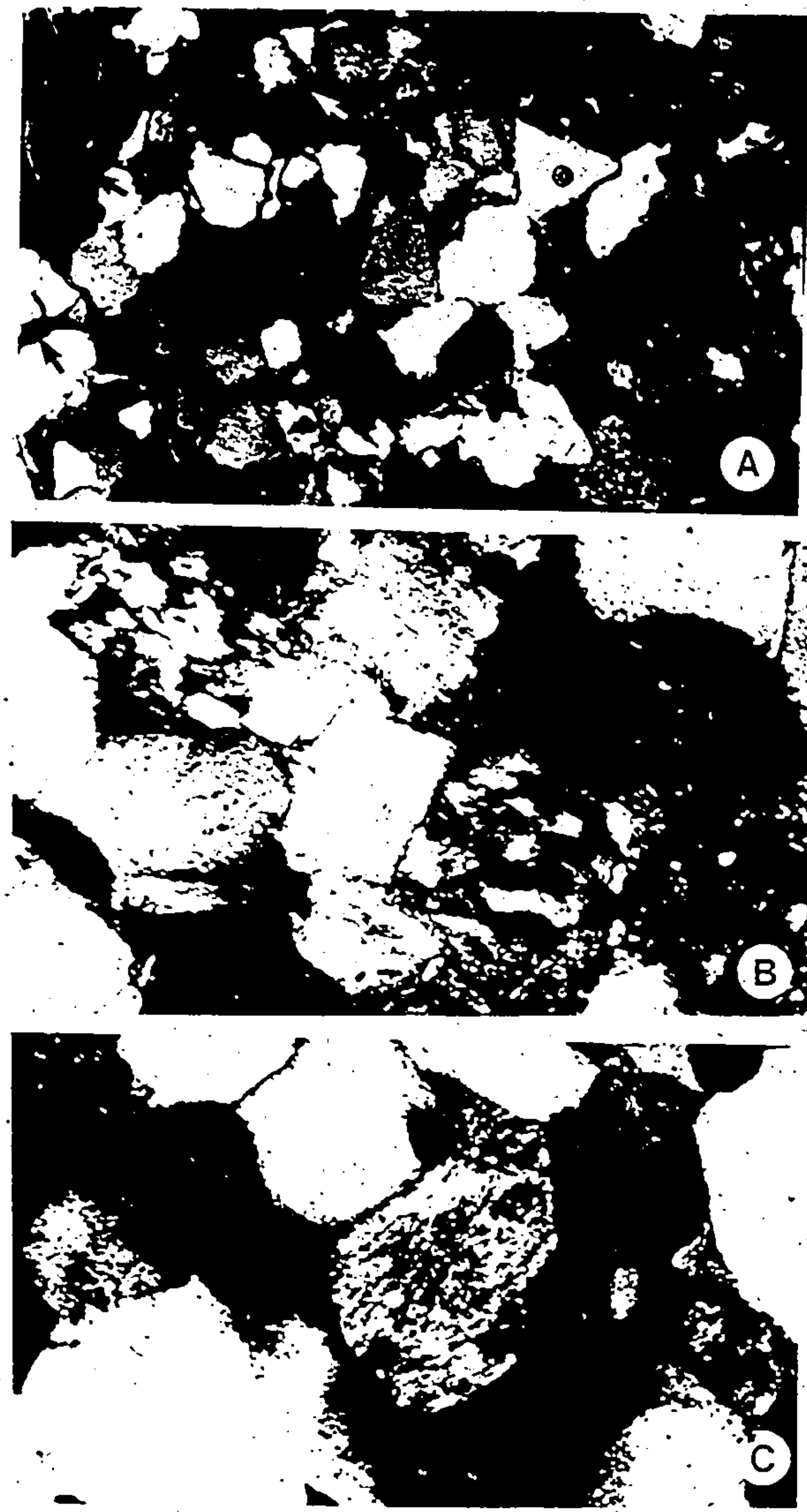
Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 0.7 mm.

C. The large grain in the center of the photomicrograph has been completely replaced by calcite. No indication of its detrital identity remains.

Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 0.7 mm.

D. A large grain of detrital chert (Ch) occupies the center of the photomicrograph. A deformed and partially recrystallized sedimentary lithic grain (Ls) is shown at the bottom left of the photomicrograph.

Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 0.7 mm.

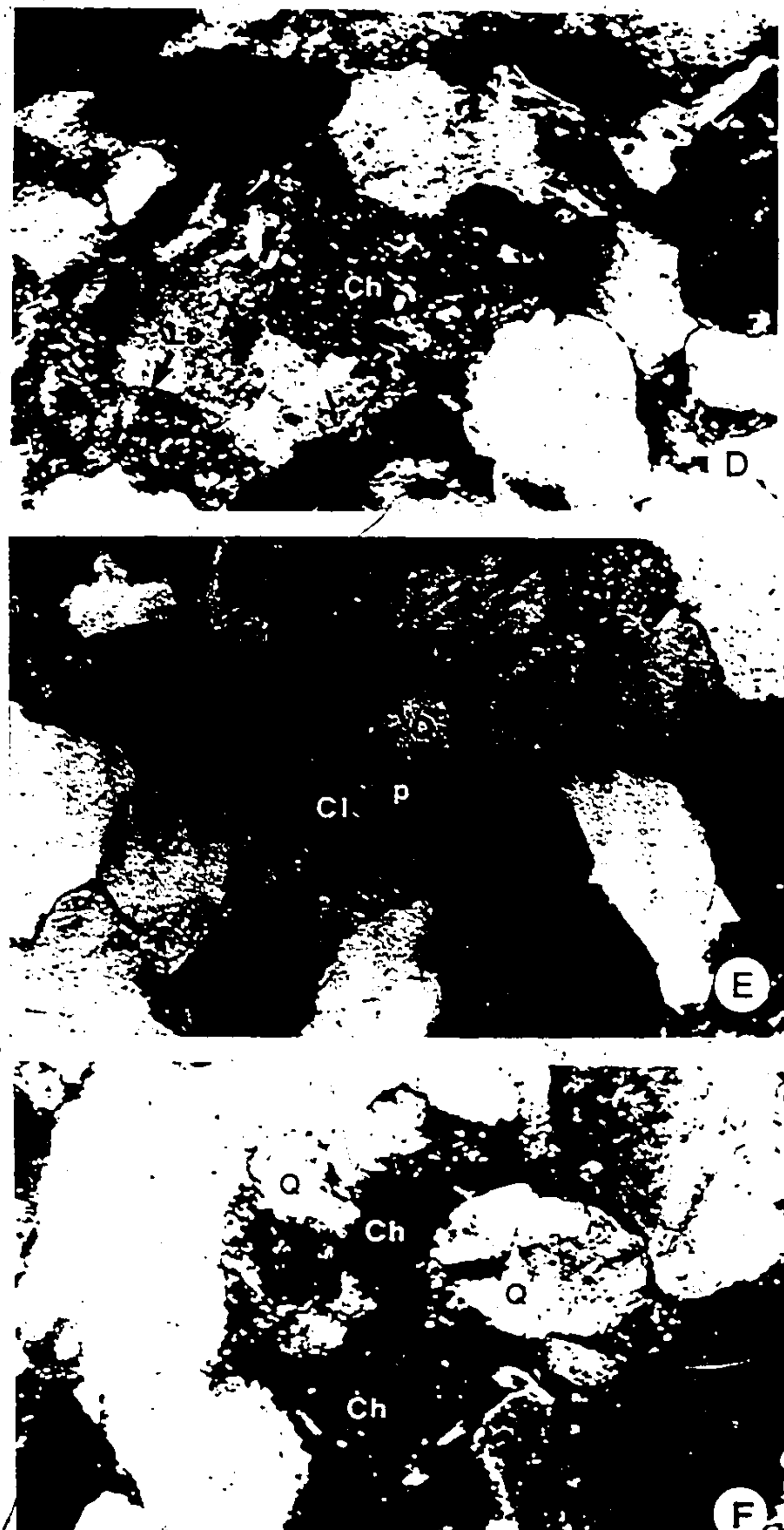

A
B
C

E. The area of secondary clay mineral (cl) in the center of the photomicrograph could represent clay mineral replacement of monocrystalline quartz, a residual island of which remains (Q). Alternatively, the clay mineral could represent replacement of a detrital labile grain and the island of monocrystalline quartz might indicate incipient silica replacement of the secondary clay mineral. Some secondary porosity (P) also exists at this site.

Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 0.7 mm.

F. The chert (Ch) in this photomicrograph is considered to represent a diagenetic cement infilling an irregular void created by corrosion of monocrystalline quartz grains and/or a more labile grain. This is a more probable scenario than having the monocrystalline quartz grains (Q) constitute incipient silica replacement of a detrital chert grain. This is the more likely situation due to the presence of the concavo-convex contact (arrow) which indicates that these two quartz grains are in their detrital position.

Section HG3, sample 845, 106.8 m above base of section. Width of field of view is ca. 0.7 mm.


Ch
D
Cl
P
E
Q
Ch
Q
Ch
F

involved the following processes; no paragenetic sequence is suggested:

1. pressure solution of framework quartz
2. carbonate replacement of silicates
3. albitization of feldspar
4. zeolitization of feldspar

As mentioned above, cathodoluminescence microscopy (3.3.3) indicates that very little framework deformation occurred in Okse Bay Group sandstones. As a result, this process is considered to be a very minor source of secondary quartz cement. It may assume some significance in the induration of Hecla Bay sands however, since they would not have been well cemented during early diagenesis.

Walker (1960, 1962) demonstrated that in the high pH environment (>9.0) often associated with deep burial conditions the solubility of carbonates goes down and that of silicates increases so that calcite is often found replacing quartz and/or feldspar at depth. This constitutes a source of secondary silica cement. In Okse Bay Group sandstones calcite is commonly observed replacing monocrystalline quartz grains as well as feldspar. While the secondary silica generated by this process would contribute to the cementation of the sands (probably sandstone by this time) it would not constitute a source of lithifying quartz cement since lithification would have been completed during early diagenesis. As stated above however, this was not the case for Hecla Bay sands. Carbonate replacement of silicates constituted an important source of autochthonous silica cement for this formation. It should be noted that the calcite under discussion is not newly introduced. It is the same pore filling calcite that entered the sandstone as a result of siltstone dewatering during early diagenesis. It did not start to replace the silicate framework grains until the higher temperatures and possibly the higher pH conditions of deep burial were attained.

Blatt, Middleton and Murray (1980, Chapter 9) indicate that high temperature and/or high pH (pH >9.0) conditions favor the precipitation of calcite and the dissolution of silica. While high pH values are not necessarily restricted to deep burial conditions, certainly increased temperatures would be a result of deep burial. As such, carbonate replacement of silicates as a source of secondary silica cement is likely a late diagenetic process occurring under deep burial conditions. This interpretation was also suggested for this diagenetic process by Fuchtbauer (1974, pg. 149) and by Levine (1984). Albitization of alkali feldspar is common throughout the Okse Bay Group.

While this late diagenetic process would not free-up silica for cementation it would constitute a source of potassium for other reactions (Helmold, 1985) such as illitization of interstitial clay.

As mentioned previously, the zeolite laumontite is only rarely,and tentatively, identified in Okse Bay Group sandstone. X-ray diffraction would be required to confirm its presence. The formation of laumontite is a by-product of albitization of plagioclase feldspar (Helmhold, 1985) and does not constitute a source of silica. It might be expected to very-locally cause an increase in compaction however, due to its low mechanical strength.

Late diagenetic processes are thus seen to be of minor significance for Okse Bay Group sandstones relative to the early diagenetic modifications. An exception is the Hecla Bay sandstones for which late diagenetic processes would have constituted a small, but important, source of autochthonous silica cement.

3.2.3.3 Depth of Burial

The maximum depth of burial attained by Okse Bay Group sandstones can be estimated using geothermal gradients determined for modern, miogeoclinal, passive margin settings. Using Table 9-2 of Blatt, Middleton and

Murray (1980, pg. 360), the late diagenetic processes previously discussed would suggest that a maximum diagenetic temperatures attained were between 150-200^{0}C. Geothermal gradients from two modern miogeoclinal settings can be used to provide a range of probable maximum burial depths. Blatt, Middleton and Murray (1980, Fig. 9-1) provide a range for the geothermal gradients determined from the northwest Gulf of Mexico. Using the gradient constructed from maximum recorded temperatures in this region with the probable maximum temperature attained a during late diagenesis (200^{0}C), a maximum burial depth of ca. 5600 m is obtained. A much higher geothermal gradient of 70^{0}C km has been suggested for the Nova Scotia margin by MacKenzie et al. (1985). Use of this gradient suggests that the maximum depth of burial attained by Okse Bay Group sediments was ca. 3000 m. This suggested range for maximum burial depth (3000-5600 m) agrees with the depths associated with late diagenetic processes. Pettijohn, Potter and Siever (1972) suggest that pressure solution of monocrystalline quartz occurs between 2500-5000 m and Fuchtbauer (1974, pg. 149) reported carbonate replacement of silicate framework only at depths exceeding 3500 m.

3.3 Cathodoluminescence Microscopy

3.3.1 Objectives

A study of Okse Bay Group sandstones and coarse siltstones using cathodoluminescence microscopy (CL) was undertaken to secure important petrologic information not otherwise obtainable with transmitted light microscopy. The CL study was organized with the following objectives in mind:

1. To determine the degree of rounding of the quartz and feldspar grains; the former is effectively impossible to evaluate under transmitted light due to the extensive secondary quartz cement.
2. To determine the extent to which the framework of Okse Bay Group sandstones has been deformed by pressure solution of quartz grains and in so doing evaluate the importance of this process as a source of secondary silica cement in the Okse Bay Group.
3. To confirm the sandstone cementation history suggested from transmitted light observations.
4. To evaluate the bedrock composition (igneous to metamorphic ratio) of the source terrane and the extent of its variation throughout Okse Bay Group time by a quantitative investigation of quartz CL colors.

3.3.2 Methodology and Operating Conditions

A review of the physical principles of the origin of luminescence is not provided in this report. Interested readers may refer to Leverenz (1968) for a more thorough explanation or to Matter and Ramseyer (1985) for a recent overview.

The CL study of Okse Bay Group detritus was conducted by constructing a cumulative section through the group that consisted of the most complete exposures of the constituent formations found within the study area. Twenty-one samples representing all formations in the Okse Bay Group were selected for study from this constructed section with an average stratigraphic spacing of ca. 107 m. The cumulative thickness of the constructed section is 1860 m.

The thin sections used for the CL study were not specially prepared, rather they were drawn from the set of thin sections made for the transmitted light study. They were of standard thickness (0.03 mm) and were left uncovered. The finest polish put on the thin sections was attained using 0.03 micron aluminum oxide powder. The thin sections had been stained for both plagioclase and alkali feldspar but this produced no noticeable detrimental effects during electron bombardment.

Marshall (1978) has suggested the standardization of reported cathodoluminescence results. Following his suggestions the following operating conditions were established for this CL study:

Equipment Type: ELM-2b Nuclide Luminoscope and an Olympus Petrographic Microscope equipped with a 4X objective and either a 7x or a 20x ocular

Beam Voltage: 12.5 kv, D.C.

Beam Current: 0.2 ma

Spot Diameter: When scanning the slide ca. 30% ~~of the~~ focusing current was used

Gun Type: Cold cathode electron gun

Ambient Gas: Air at 20 millitorr or less

Quartz characteristically has a very low luminescence intensity. In combination with the small mean grain size of the Okse Bay Group detritus this makes the luminescence very difficult to detect at low beam currents. In order to both clearly see the framework and distinguish between detrital cores and secondary cement the beam current must be increased by bleeding air into the specimen chamber and allowed to stabilize at 0.8-0.9 ma and the strength of the focusing current must be increased to ca. 50%. CL photomicrographs were taken under the above conditions with exposure times varying according to grain size.

Characteristic exposure times required for a crossed nicols and CL pair of photomicrographs for the coarse siltstones was seven minutes and eleven minutes, respectively. For fine grained sandstone they were ten seconds and ninety seconds, respectively. The thin sections were slightly burned as a result of the long exposures but not to the extent that subsequent transmitted light microscopy was impaired.

3.3.3 Observations and Interpretations

Table 3.3.3-1 presents the CL observations from the sandstones and coarse siltstones of the Okse Bay Group. Cross nicol-cathodoluminescence photomicrograph pairs for each formation of the group are presented as Plates 3.3.3-1 to 3.3.3-5. The observations and their interpretation are discussed below with respect to each of the objectives of the CL study stated in 3.3.1.

Degree of Rounding

An index of rounding (round family/angular family) was determined for both monocrystalline quartz and feldspar grains for each sample by visually estimating grain roundness using the Powers (1953) roundness categories presented in Scholle (1979). This was facilitated by Table

Table 3.3.3.-1 Cathodoluminescence data table for sandstones and coarse siltstones from the Okse Bay Group on Southwestern Ellesmere Island.

Fm	Sect.	Spl.	abf(m)	mgs	IRq	IRf	df	v/b	$CaCO_3$	SiO_2
SF	S2	288	2.2	vcs	?	2	m	V	l,L	l,L
		310	97.9	cs	?	/	m	V	l,h	l,L
		331	173.5	cs	?	1	/	0.06	l,h	l,L
HB	HBI	768	0.6	f	1.8	/	/	0.35	/	l,L
		776	69.8	f	3.6	A	m	0.33	/	l,L
		788	206.5	f	6.8	?	m	0.39	/	l.L
		794	313.5	f	R	?	m	0.39	/	l,L
		799	410.3	f	27.0	R	m	0.41	/	l,L
		802	477.4	f	26.0	1.6	m	0.06	/	l,L
F	F4	619	23.8	vf	5.3	/	/	v	/	l,h
		624	120.8	vf	1.3	/	/	v	l,h	/
		635	221.6	vf	7.5	/	/	v	l,L	l,L
		655	338.6	cs	70	/	/	v	l,L	l,h
		662	421.5	cs	3.0	/	/	v	l,L	l,h
		668	473.9	cs	2.5	R	/	v	l,L	l,L
HG	HG2	703	1.5	vf	?	/	m	v	l,h	l,L
		721	93.0	cs	1.4	/	/	v	l,h	/
		748	304.9	cs	3.3	/	/	v	l,h	/
		760	506.5	vf	28.0	/	m	v	l,L	l,L
NP	HG3	840	0.8	vf	6.8	/	/	v	l,L	l,L
		845	106.8	f	2.5	/	m	0.08	/	l,L

<u>Note</u>:

1. SF - Strathcona Fiord Fm
   HB - Helca Bay Fm
   F - Fram Formation
   H - Hell Gate Formation
   NP - Nordstrand Point Formation

2. abf - distance above base of formation, in meters

3. mgs - visually estimated mean grain size; cs-coarse siltstone ,vf - very fine sandstone f - fine sandstone

4. IRq and IRf - index of roundness for quartz and feldspar, respectively; IR is a ratio of round (well rounded,rounded,sub rounded) to angular (sub angular,angular,very angular)grains; ? - indeterminate R - all round , A - all angular, / - feldspar absent from thin section

5. df - deformed quartz framework ; m - minor, a - abundant , / - absent

6. v/b - ratio of violet (blue to red) to brown luminescing monocrystalline quartz grains ; v - violet only, b - brown only

7. $CaCO_3$ and SiO_2 - number of periods of SiO_2 or $CaCO_3$ cementation; H - high volume, L -low volume, / - not present.

Plate 3.3.3 - 1 Cathodoluminescence in the Strathcona Fiord Formation.

A & B. A plane polarized light (PL) and cathodoluminescent (CL) pair of photomicrographs for a coarse siltstone in the Strathcona Fiord Formation. Despite prolonged bombardment (five minutes and six minutes, respectively) the cathodoluminescence is very weak. The blue-white grains (arrows) are alkali feldspar. Several of these are partially replaced by calcite (orange). Grain cores and secondary quartz overgrowths cannot be clearly distinguished.

Section S2, sample 288, 2.2 m above base of section.
Width of field of view is 0.87 mm.

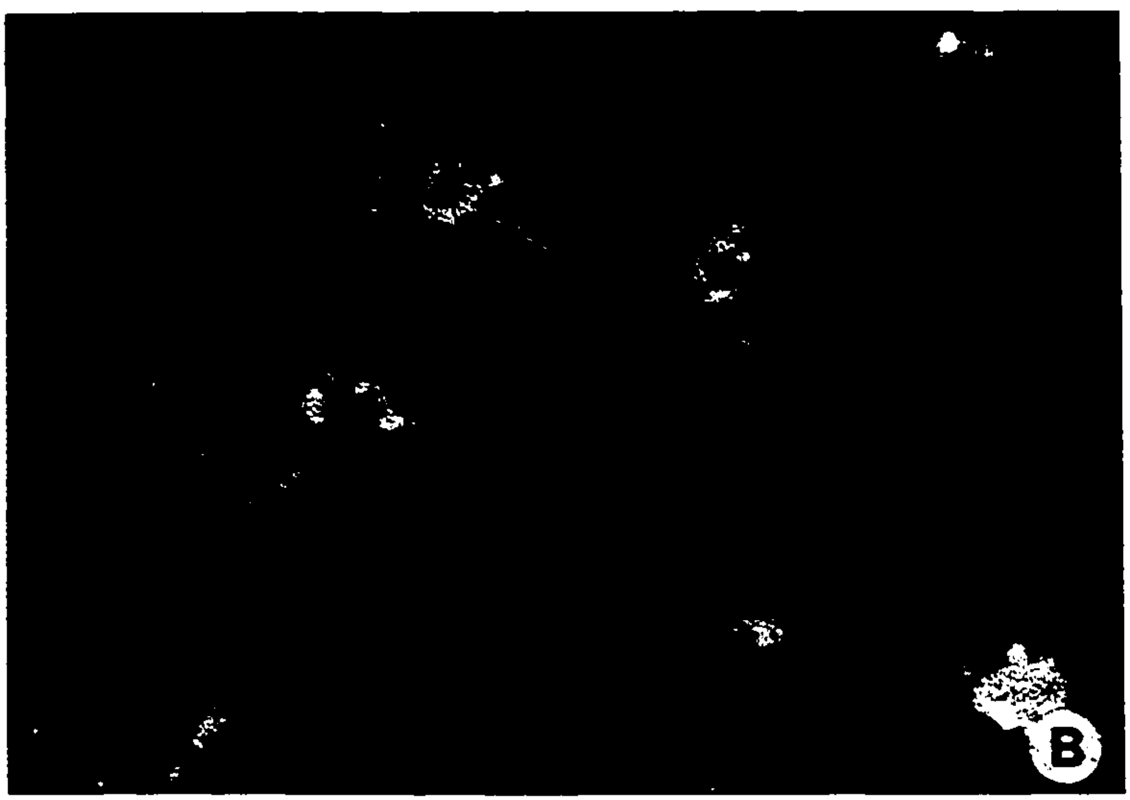


Plate 3.3.3 - 2 Cathodoluminescence in the Hecla Bay Formation.

A & B. PL - CL photomicrograph pair for a Hecla Bay sandstone. A moderately well sorted, undeformed, detrital framework with both rounded and angular grains is displayed. Syntaxial quartz overgrowths (arrows) are readily distinguishable from their detrital grain cores. The bright green grain is likely hydrothermal quartz.

Section HB1, sample 768, 0.6 m above base of section.
Width of field of view is 2.56 mm.

C & D. A second CL - PL photomicrograph pair from the Hecla Bay Formation. A violet luminescing, monocrystalline quartz grain framework with very little secondary silica cement contrasts markedly with large, partially corroded, blue -white alkali feldspar grains. A slight amount of grain deformation is present locally.

Section HB1, sample 794, 313.5 m above base of section.
Width of field of view is 2.56 mm.


A


B


C

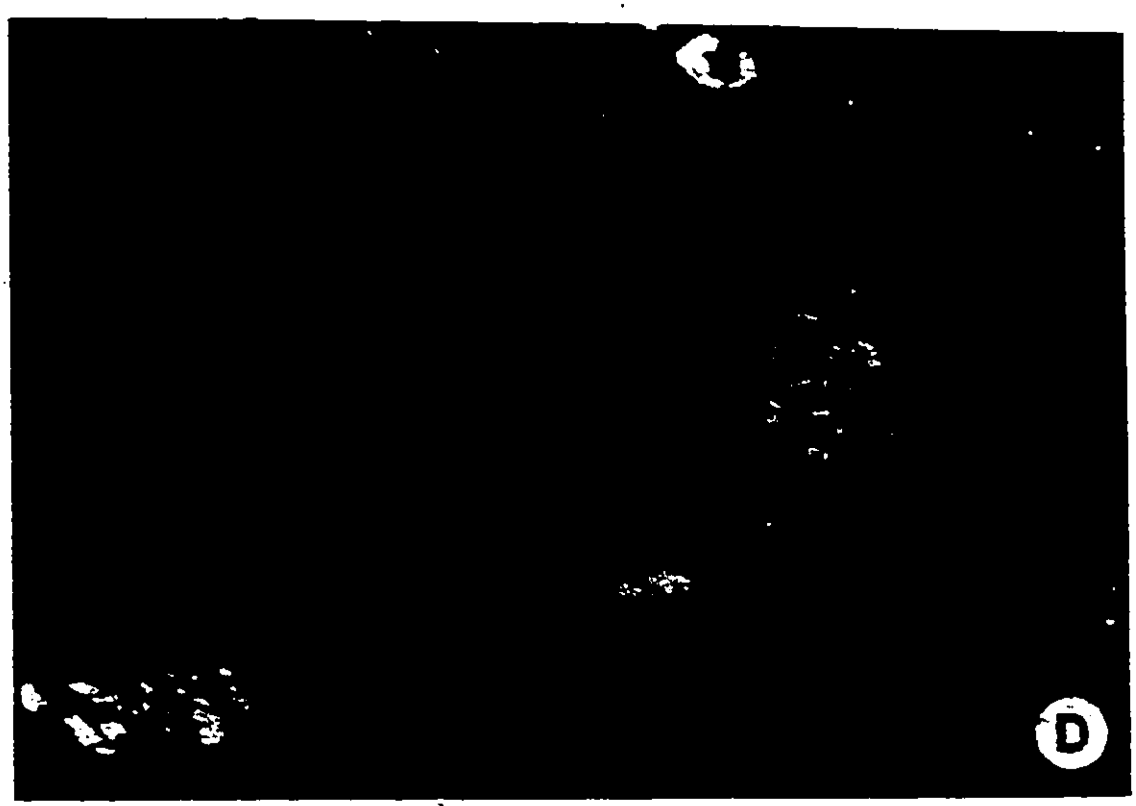

D

Plate 3.3.3 - 3 Cathodoluminescence in the Fram Formation.

A & B. PL - CL photomicrograph pair for a Fram Formation sandstone showing an undeformed calcite (orange) and quartz cemented quartzose framework. Both angular and round grains are present suggesting a mixture of first cycle and recycled detritus.

Section F4, sample 635, 221.6 m above base of section.
Width of field of view is 0.87 mm.


A

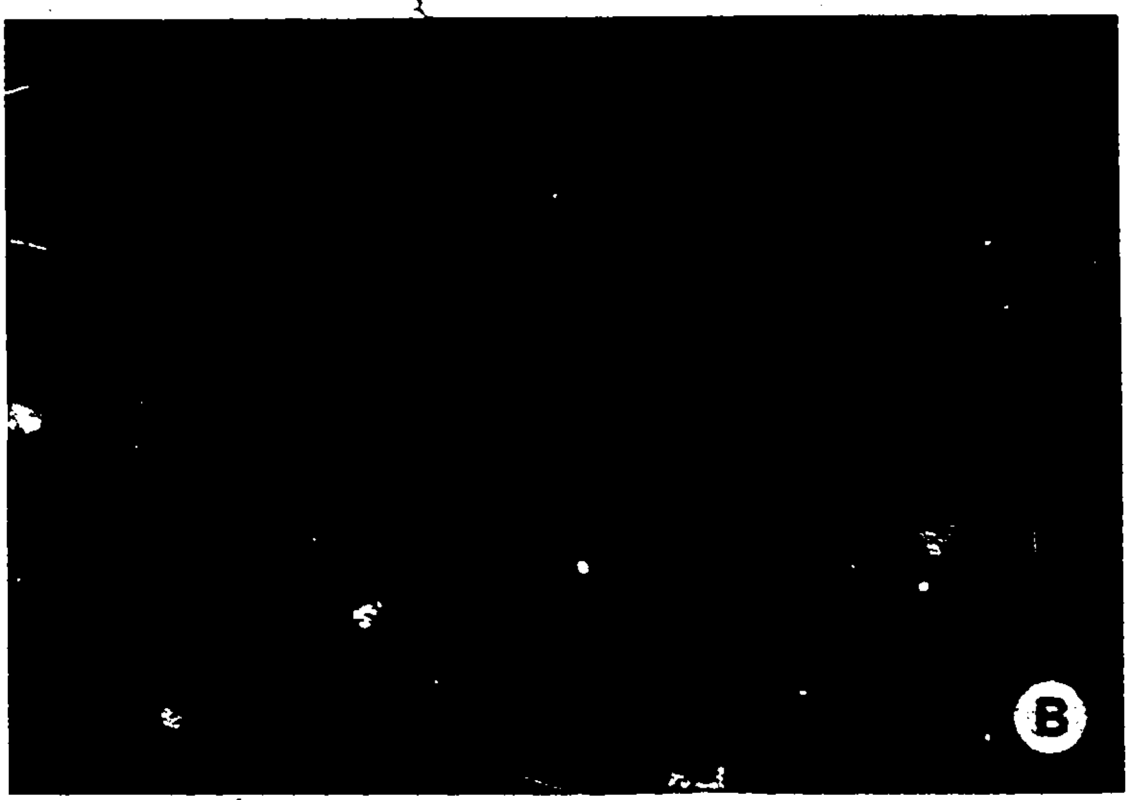

B

Plate 3.3.3 - 4 Cathodoluminescence in the Hell Gate Formation.

A & B. PL - CL photomicrograph pair for a Hell Gate Formation sandstone. The CL photomicrograph (B) shows an undeformed, violet luminescing, quartzose framework with no clear distinction of secondary silica cement. The bright orange grain in the right center of the photomicrograph likely represents a calcite replaced feldspar grain. The smaller bright orange spots are small areas of calcite cement. The uniform CL color displayed by the quartzose framework may be due to prolonged bombardment caused by the extended exposure time (11 minutes) required for the photomicrograph.

Section HG2, sample 760, 506.5 m above base of section.
Width of field of view is 0.87 mm.

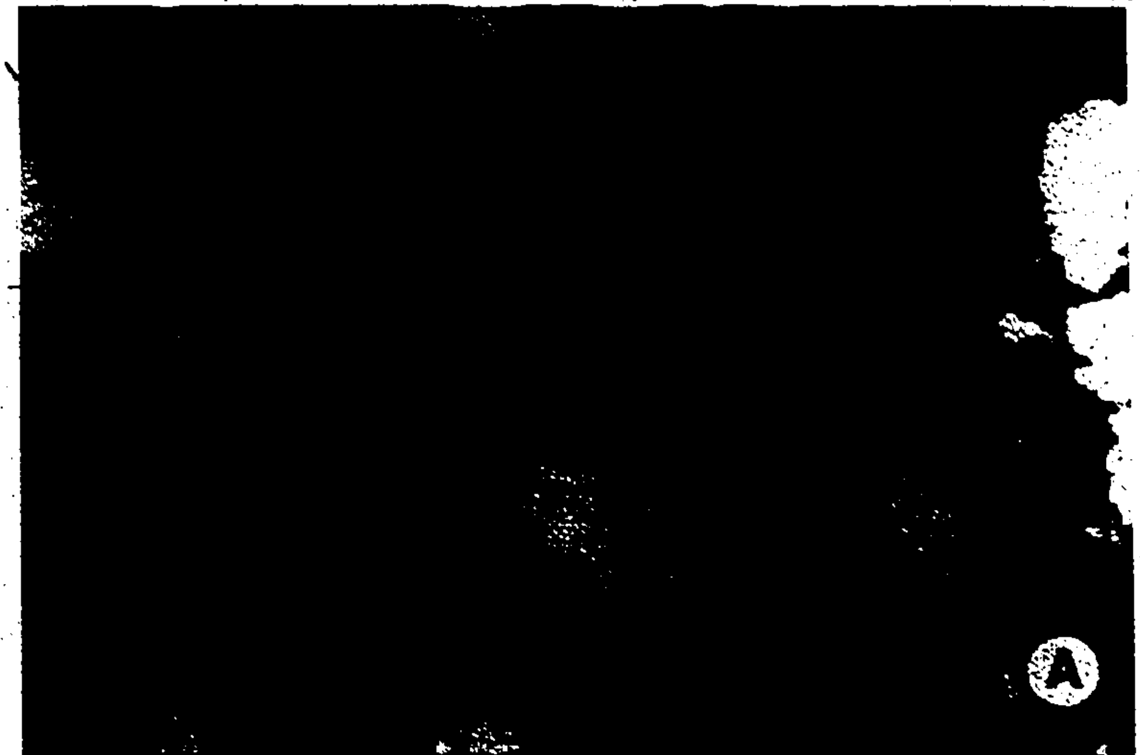

A

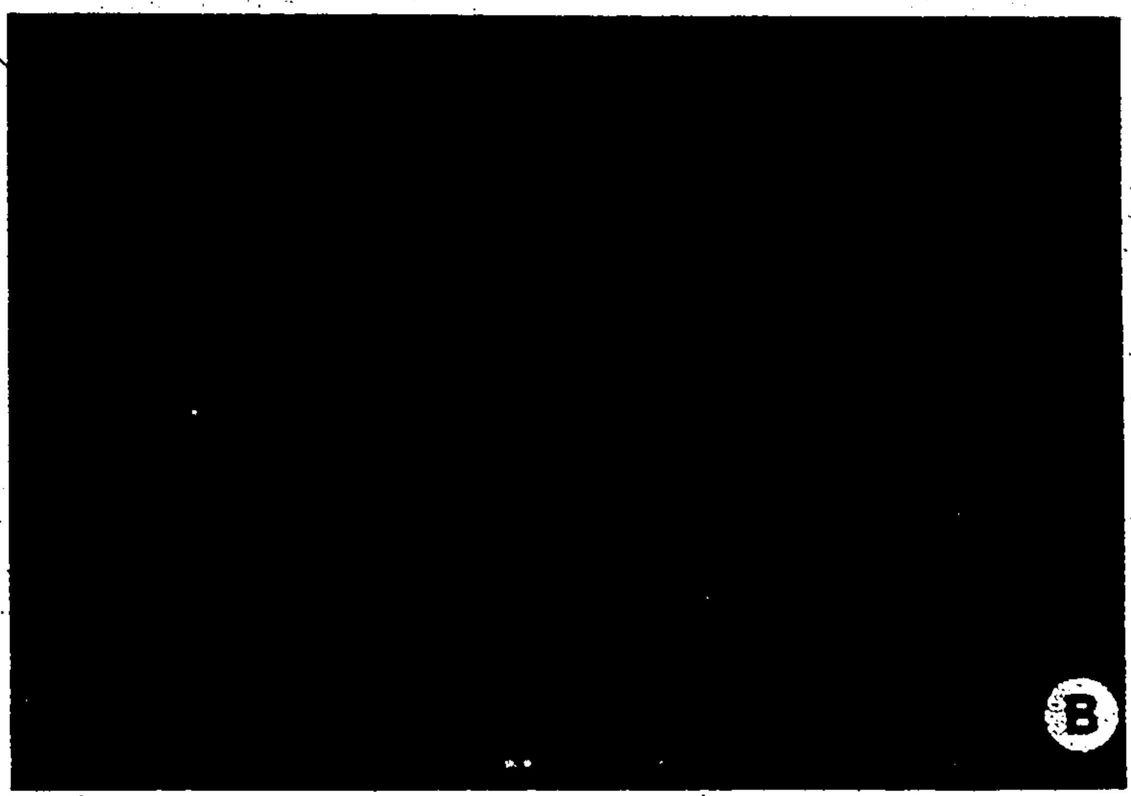

B

Plate 3.3.3 - 5 Cathodoluminescence in the Nordstrand Point Formation.

A & B. PL - CL photomicrograph pair for a coarse siltstone in the Nordstrand Point Formation. A violet luminescing quartzose framework with spotty calcite cement is shown in photomicrograph B. As for plate 3.3.3 - 4, the uniform CL color is likely the result of a lengthy bombardment caused by allowing sufficient exposure time for the photomicrograph. Recognition of secondary silica overgrowths is uncertain due to the poor luminescence.

Section HG3, sample 840, 0.8 m above base of section.
Width of field of view is 0.87 mm.


A


B

placing a square grid over the projection of the CL photomicrograph and then point-counting it. Unexpectedly, quartz grain boundaries are commonly not well defined for the coarse siltstone or very fine grained sandstone samples. In those samples with large amounts of calcite cement this was due to peripheral corrosion of the quartz grains. However, in the samples lacking calcite cement it is suspected that the prolonged bombardment caused by the excessive exposure times (up to eleven minutes) caused the secondary quartz cement to luminesce and become difficult to distinguish from the detrital cores. Diagenetic quartz will also luminesce if buried to depths that cause the temperature to exceed 300°C (Zinkernagel, 1978). However, this is not considered feasible for Okse Bay Group detritus since this would place the sediments in the lower end of regional metamorphism for which the associated mineral assemblages (such as phrenite and pumpellyite) were not observed in any Okse Bay Group thin section. Feldspar grain roundness was also not always determinable due to grain corrosion. As a result of these difficulties, the index of rounding was not always determinable and frequently is highly subjective. Nevertheless, the data presented in Table 3.3.3-1 indicates that for both quartz and feldspar, grains belonging to the round family (well rounded, rounded, subrounded) dominate the thin sections (two samples had a significant number of angular feldspar grains).

While the roundness study under CL demonstrates that round grains dominate, angular grains are commonly present in the thin sections. Evidence will be discussed subsequently that indicates that both first cycle and recycled detritus exists in the Okse Bay Group. In this context, it would seem worthwhile to investigate the relationship between grain size and roundness. One might anticipate a larger, more angular population of quartz grains representing first cycle detritus and a smaller, more rounded population representing recycled detritus. Unfortunately, time restraints prohibited the inclusion of such a study.

Framework Deformation

Features considered to constitute evidence of a deformed framework are: 1) stressed (i.e., fractured) monocrystalline quartz grains 2) pressure solution at quartz-quartz contacts. Stressed quartz grains are only occasionally present in the samples examined. In these instances the stressed grains always constitute a very small percentage of the grains in the CL photomicrograph. The stressed grains show very fine hairline fractures running irregularly through themselves. In all cases the healing cement in the fractures shows the same CL color and intensity as the secondary overgrowth cement found elsewhere in the thin section. This indicates that the fracturing was an in-situ event due to burial pressure rather than inherited fractures from a previous sedimentary cycle. Under CL pressure solution is indicated by the presence of long, sutured or concavo-convex contacts between adjacent quartz grains. As indicated in Table 3.3.3-1, pressure solution is always either absent from the thin section or only slight amounts are indicated. The only evidence of this intermediate to deep diagenetic process in the Okse Bay Group samples is long contacts between isolated pairs of quartz grains. It can therefore be stated that pressure solution of the quartz framework did not constitute a high volume source of autochthonous cement for Okse Bay Group detritus.

It is of some significance with respect to the regional geologic history of this part of the Arctic Archipelago to note that minor amounts of pressure solution were also observed in a Nordstrand Point Formation sample. Following Pettijohn, Potter and Siever (1972), its presence would indicate burial depths of at least 2.5 km. Since the Nordstrand Point Formation is the highest formation in the

Okse Bay Group, this indicates that significant amounts of post-Devonian erosion have occurred and that the Okse Bay Group therefore constituted an important source of recycled sediment for some younger formation in the Arctic Islands. A likely candidate is the Upper Triassic - Lower Jurassic Heiberg Formation found in the central and eastern regions of the Sverdrup Basin. This formation represents a delta system whose source region is thought to be located, in part, in what is now the region of southwestern Ellesmere Island (Ricketts and Embry, 1986, Figure 2). As such, the Okse Bay Group was likely a principal source of multi-cycle detritus to the Heiberg delta.

Cementation History

For those samples in which secondary quartz cement could be clearly distinguished from detrital cores and in which calcite cement also occurred, observations under CL confirmed the cement paragenesis suggested by transmitted light microscopy. Only one period of secondary silica and calcite cementation is present, the latter always occurring interstitial to the former.

Bedrock Composition

Zinkernagel (1978) associated the luminescence color of quartz with its temperature history. He states that violet (red-blue) luminescing quartz is caused by crystallization at temperatures exceeding 573^{0}C indicating an igneous origin while brown luminescing quartz is caused by crystallization at temperatures ranging between 300-573^{0}C indicating a regional metamorphic origin. Evidence is presented subsequently (3.4 and 3.5) which will indicate that the Okse Bay Group detritus is in part made up of first cycle cratonic derived sediment and in part of recycled detritus whose ultimate source terrane is likely the same cratonic area that supplied the first cycle sediment. In this context, it was hoped to be able to specify an approximate ratio of igneous to regional metamorphic rocks in the craton by determining what Zinkernagel (1978) referred to as the luminescence quotient which is simply the ratio of violet to brown luminescing quartz. Also, by examining the stratigraphic change in this ratio upward through the Okse Bay Group it was hoped to be able to state whether the oratonic composition varied throughout Okse Bay Group time. Since the source terrane for the first cycle and recycled sediment is suspected of being one in the same, this approach remains valid for a mixture of the two types of detritus. Unfortunately, two difficulties arose which in part jeopardized the usefulness of this ratio for the Okse

Bay Group. First, as mentioned above, over bombardment due to prolonged photographic exposure times is suspected of artificially enhancing the luminescence observed in the coarse siltstones and very fine sandstones. In most of these samples nothing but violet CL colors were observed. This is suspect since this is precisely the opposite trend relative to that determined by Zinkernagel (1978, Figure 11, pg. 32) who found that violet CL colors were favored by the coarser grain sizes. For this reason only the luminescence quotients presented for the Hecla Bay Formation in Table 3.3.3-1 (all fine grained sandstones) are considered to be reliable indicators of the likely proportion of igneous to metamorphic rocks in the source terrane. The second difficulty with the use of this ratio is the general problem associated with subjective color sensation. Reddish-brown luminescence for instance, is problematic in that it becomes highly subjective in deciding whether to place such grains in the violet (blue-red) or brown category. Nevertheless, with due "weighting" of the reliability of the luminescence quotients determined through the Hecla Bay Formation due to subjective color sensation, the data in Table 3.3.3-1 indicates that brown luminescing quartz is more abundant than violet. Therefore metamorphic rocks were more abundant in the immediate (for first cycle detritus) and ultimate (for recycled detritus) source terrane than igneous rocks. These luminescence quotients are suggested to be representative of the Okse Bay Group in light of its extreme compositional homogeneity which indicates that no change in source terrane occurred during its deposition.

3.3.4 Summary of Conclusions

The CL study of Okse Bay Group detritus permits the following statements if it is assumed that the samples examined may be considered as representative of the Okse Bay Group:

1. The Okse Bay Group consists dominantly of "round" (includes well rounded, rounded and subrounded categories) detritus
2. Pressure solution of monocrystalline quartz framework grains provided only a very low volume of autochthonous secondary silica cement
3. Metamorphic rocks were more abundant than igneous rocks in the source terrane of the Okse Bay Group
4. The cementation history suggested from observations under transmitted light (i.e., one period of silica cementation followed by one period of calcite cementation) is corroborated.

3.4 Bedrock Composition of the Source Terrane

In this section one aspect of the provenance of the Okse Bay Group is addressed, namely the composition of the bedrock in the source terrane. Information derived from each framework grain category investigated under transmitted light is discussed separately below.

Monocrystalline Quartz

Monocrystalline quartz is the dominant framework grain in the Okse Bay Group. Since the dominant grain size range for Okse Bay Group detritus is coarse silt to fine sand, which is the optimum size interval for the occurrence of monocrystalline quartz (Blatt, Middleton and Murray, 1980, Figure 8-21), its abundance may be taken as representative of erosional compositions. Unequivocal evidence of the presence of recycled detritus exists with those few monocrystalline quartz grains found in nearly every thin section that showed multiple rounded overgrowths. In light of such evidence, it is a certainty that many more monocrystalline quartz grains that lack such definite evidence of recycling are also derived from older sedimentary rocks. Single overgrowths are not considered to be certain indicators of recycling due to the frequency of secondary quartz cement throughout the Okse Bay Group.

Despite their abundance monocrystalline quartz grains very rarely display any features that are diagnostic of their origin. In transmitted light occasional grains are present that are vacuole enriched suggesting a hydrothermal vein origin. Supporting evidence for the presence of such quartz is provided by occasional bright green luminescing quartz grains seen during the CL study. Zinkernagel (1978) claims that such a CL color can be indicative of a hydrothermal origin. Also noted during the CL study are occasional quartz grains that display resorption embayments which have been filled in by secondary quartz cement. In isolation, such features are more indicative of porphyry quartz than volcanic quartz. Numerous quartz grains contain needle shaped microlites, but since many minerals can assume this crystal form their identification with a petrographic microscope remains uncertain.

Monocrystalline quartz in the Okse Bay Group indicates the following:

1. A source of recycled sediment (i.e., an older sedimentary basin) existed in the source terrane
2. In consideration of the overwhelming dominance by quartz as a framework grain it is considered that the bedrock types in the source terrane were enriched with respect to this mineral

3. The presence of hydrothermal and porphyry quartz indicates that plutonic igneous rocks constituted part of the source terrane

Polycrystalline Quartz

The current amount of polycrystalline quartz in Okse Bay Group detritus (the average is only 1.4%) cannot be considered representative of its proportion at the time of erosion from the source terrane. It has been demonstrated by several authors (Blatt, Middleton and Murray, 1980, Figure 8-21; Blatt and Christie, 1963) that polycrystalline quartz decreases abruptly in abundance in very fine grained sand and finer sediment due to mechanical breakdown into its constituent crystals. Therefore, since the dominant grain size range in the Okse Bay Group is coarse silt to very fine sand the amount of this framework grain is not a reliable indicator of the importance of its parent rocks in the source terrane. As discussed earlier, polycrystalline quartz derived from plutonic igneous rocks may be distinguished from that eroded from metamorphic rocks by the number of constituent crystals, with the former being identified by a smaller number (less than three) of coarser crystals. While the overall importance of the parent rock types in the source terrane may not be reliably estimated due to the grain size control mentioned above, it is still reasonable to presume that the relative proportions have been retained by the deposits. This is especially valid for the relative amounts of coarsely polycrystalline quartz and finely polycrystalline quartz for the following reason. Harrell and Blatt (1978) have demonstrated that the survival potential of polycrystalline quartz grains in fluvial transport increases with increasing coarseness of polycrystallinity. Therefore, plutonic polycrystalline quartz would be favored to survive transportation over metamorphic polycrystalline quartz. In the Okse Bay Group detritus finely polycrystalline quartz is much more abundant relative to coarsely polycrystalline quartz which is only present in a few thin sections. Since this is exactly the opposite ratio to that which would be anticipated from a consideration of the relative survival potentials, it is thought to be a reliable indicator of the relative amount of plutonic igneous and metamorphic rocks in the source terrane. In this context then, metamorphic bedrock is suggested to have been considerably more abundant than plutonic igneous bedrock in the source terrane of the first cycle detritus found in the Okse Bay Group. It is significant that this is the same interpretation as that indicated by the luminescence quotients determined from monocrystalline quartz in the Hecla Bay Formation which are suggested to be representative of the entire Okse Bay Group. Whereas in the latter case it was unknown if the interpretation applied to only first cycle or recycled sediment, or both, in this case the inability of polycrystalline quartz grains to survive more than one sedimentary cycle necessitates that the interpretation applies to only the source rocks of the first cycle detritus.

Chert

The control exerted by grain size on the abundance of detrital chert found in a sedimentary rock is similar but less severe than its control over the abundance of polycrystalline quartz (Blatt, Middleton and Murray, 1980, Figure 8-21, pg. 321). Consequently, for a given grain size detrital chert grains might be expected to be a little more abundant than polycrystalline quartz grains assuming equal abundance in the source region. Also, since detrital chert grains are somewhat more durable during fluvial transport they can survive more than one sedimentary cycle whereas polycrystalline quartz grains are likely not to survive recycling.

Detrital chert averages only 3.2% in the Okse Bay

Group. However, in light of the grain size control mentioned above this should not be taken as an accurate indicator of the abundance of the parent rock in the source terrane. The presence of detrital chert grains in the Okse Bay Group constitutes the second piece of unequivocal evidence which indicates that an older sedimentary basin existed in the source terrane. The chert grains could have been derived by erosion of shelf carbonates or bedded cherts or by reworking an older siliciclastic sandstone. As discussed in 3.2.2.2, only chert of carbonate replacement origin can be unequivocally identified in Okse Bay Group detritus.

Feldspar

In contrast to the quartzose framework grain categories discussed previously feldspar abundance in Okse Bay Group detritus is not artificially reduced by a grain size control. As shown by Odom, Doe and Dott (1976) and Blatt, Middleton and Murray (1980, Figure 8-21) the fine sandstone to coarse siltstone estimated mean grain size range of the Okse Bay Group is optimum for the occurrence of detrital feldspar. Feldspar-quartz grain size relations are of great significance in the Okse Bay Group. While feldspar is certainly capable of withstanding recycling (Blatt, Middleton and Murray, 1980 pg. 298), given similar transport histories feldspar of the same sedimentary cycle as quartz, and certainly recycled feldspar, should be reduced by abrasion to a grain size which is smaller than that of the associated quartz grains. Qualitative observation of feldspar grain size during point-counting indicated the presence of two size populations in Okse Bay Group detritus:

1. feldspar grains that are smaller than the estimated mean grain size of the associated quartz grains
2. feldspar grains that are either equal to or exceed the estimated mean grain size of the associated quartz grains

Membership in the former population is far smaller than that in the latter. The finer grained population is subrounded to rounded and staining indicates it consists almost exclusively of alkali feldspar. The coarser population ranges from subround to angular and contains only alkali feldspar (some of these coarser grains are albitized and it is presumed that they are alkali; see discussion in 3.2.2.2). Unless there are large differences in transport history, for which there is no evidence, the two populations of feldspar grains cannot be of the same sedimentary cycle. It is suggested that the finer grained population represents recycled sediment while the coarser grained feldspar population represents first cycle detritus. It is of great significance with respect to determining the principal source terrane of the Okse Bay Group to note that the coarsest feldspar grains invariably approximate the coarsest monocrystalline quartz grains. In light of the marked differential to size reduction by abrasion that exists between quartz and feldspar this has to indicate that the majority of the quartz has been recycled. Obviously, not all can be recycled since if there is first cycle feldspar, as suggested above, then there certainly is first cycle quartz as well. However, the quartz-feldspar grain size relationship does indicate that the majority of detritus in the Okse Bay Group has been recycled from an older sedimentary basin located in the source terrane.

Of significance to the nature of the parent rocks of the first cycle feldspar is the plagioclase to total feldspar ratio (P/F). As mentioned above, the coarser size population likely contains no detrital plagioclase. In addition, the data in Table 3.2.1.2-2 indicates that for those thin sections where there is sufficient feldspar to warrant a second count, irrespective of grain size, the largest P/F value is 0.3 and that frequently this ratio is zero. Certainly, some of this bias toward alkali feldspar can be attributed to the greater susceptibility of plagioclase to chemical and mechanical breakdown, however, the extreme paucity of detrital plagioclase throughout the Okse Bay Group is suggested to have source rock significance. Low P/F ratios are considered indicative of a mixed plutonic and metamorphic terrane of granitic composition (Dickinson, 1970; Dickinson and Rich, 1972; Ingersoll, 1978). Such a source terrane is therefore suggested for the first cycle feldspar in the Okse Bay Group. While similar low P/F ratios exist within the finer feldspar size population as well, it cannot be stated with certainty that they carry similar meaning with respect to the ultimate source rocks of the recycled detritus since plagioclase could have been preferentially filtered out by the recycling.

In summary, feldspar in the Okse Bay Group indicates the following with respect to a source terrane:

1. A sedimentary source (i.e., an older sedimentary basin) and a source of first cycle sediment (i.e., crystalline rocks) existed in the source terrane
2. The principal source of sediment is the older sedimentary basin
3. A mixed plutonic and metamorphic terrane of granitic composition supplied the first cycle feldspar, and by logical extension, any first cycle quartz

Rock Fragments

Of the three types of rock fragments only metamorphic (mrf) and sedimentary (srf) types are present in the Okse Bay Group. Volcanic rock fragments (vrf) are absent. Possible felsic vrf were checked with either an EDAX unit or under cathodoluminescence and in all cases turned out to be chert grains. Only the mrf are of any source terrane significance. The srf, which, as discussed previously in 3.2.2.2, included shale, siltstone and sandstone, are all taken to represent intra-basinal grains in consideration of their very low survival potential during fluvial transport. As such, they are of no significance with respect to the bedrock composition in the source terrane.

As discussed in 3.2.2.2, the mrf constitute only a very small percentage of the framework grains, averaging only 0.6%. Their low abundance cannot be taken as indicative of the importance of the parent rock in the source terrane however, due to the fine sand to coarse silt estimated mean grain size range found in the Okse Bay Group. Blatt, Middleton and Murray (1980, Figure 8-21) show a marked decrease in the abundance of polymineralic rock fragments in this grain size range. Although mrf have a high resistance to chemical breakdown, which gives them a high survival potential during diagenesis, their mechanical durability is extremely low. This is demonstrated by Cameron and Blatt (1971) who found that the schistose rock fragments are destroyed very quickly during fluvial transport in Elk Creek, South Dakota.

All the mrf noted in the Okse Bay Group are fragments of schists, which have been termed quartz-mica tectonites by Ingersoll and Suczek (1979). In light of their very low mechanical durability, they most certainly represent first cycle detritus. Their presence in the Okse Bay Group implies the following with respect to a source terrane:

1. Low rank, metasedimentary, supracrustal rocks constituted a portion of the parent rocks for the first cycle detritus
2. Very short distance fluvial transport existed for an unknown percentage of first cycle sediment.

<u>Summary</u>

The Okse Bay Group contains first cycle detritus and recycled detritus. The framework grains belonging to each category are as follows:

<u>First Cycle</u>

1. Polycrystalline quartz
2. Schistose rock fragments
3. Large, subangular to angular feldspar

4. Coarser, non-diagnostic monocrystalline quartz

<u>Recycled</u>

1. Chert
2. Monocrystalline quartz with multiple, rounded quartz overgrowths
3. Small, subround to subangular feldspar
4. Finer, non-diagnostic monocrystalline quartz

The last member of each category of framework grains is there entirely by logical inference since most monocrystalline quartz in the Okse Bay Group is non-diagnostic of origin. Certainly, first cycle quartz would accompany first cycle feldspar and it would be expected to be coarser grained than recycled quartz. Also, most certainly more recycled quartz is present than just those grains displaying multiple rounded quartz overgrowths and it would be finer grained.

The presence of both types of sediment means that crystalline bedrock and an older sedimentary basin are both present in the source terrane. The nature of the first cycle terrane may be specified as follows, accompanied by the framework grain category that supplied the information:

Coarser monocrystalline quartz: the crystalline bedrock is enriched with respect to quartz

Polycrystalline quartz: metamorphic rocks are much more abundant than plutonic igneous rocks and the transport distance to the basin of deposition of the Okse Bay Group (Franklinian Miogeocline) is short

Coarser feldspar population: the first cycle terrane consisted of plutonic igneous and metamorphic rocks of granitic composition.

Schistose rock fragments: low rank, metasedimentary, supracrustal rocks are present above the crystalline basement and the transport distance to the Franklinian Miogeocline is short.

The fill of the older sedimentary basin cannot be specified to any great extent, but the following can be stated:

Finer monocrystalline quartz: the basin contained numerous siliciclastic formations

Chert of shelfal replacement origin: the basin contained a small amount of shallow water shelf carbonates

Finer feldspar population: the basin contained feldspathic formations, probably the same siliciclastic formations mentioned above

It is significant to note that the presence of polycrystalline quartz and especially schistose metamorphic rock fragments indicates that the source rocks of at least this portion of the first cycle sediment are not very distant. Since the first cycle terrane is also plutono-metamorphic and of granitic composition, it is not unreasonable to consider the Ellesmere Island - Greenland craton lying immediately to the east of the Franklinian Miogeocline as a likely candidate for the source of the first cycle detritus. Similarly, since the Proterozoic, intra-cratonic Thule Basin containing the appropriate type of basin fill (Frisch and Christie, 1982) is also lying immediately to the east, straddling Nares Strait, it is not unreasonable to consider it as a likely candidate for the source of recycled detritus. It must be stressed however, that at this point in this report this is speculation since information regarding the direction of the source terrane has yet to be presented.

Several lines of evidence exist which suggest that the Okse Bay Group is composed principally of recycled detritus derived from an older sedimentary basin in the source terrane. The evidence is as follows:

1. The extreme mineralogic maturity of the Okse Bay Group detritus, as indicated by the very large quartz to feldspar ratio, is commonly considered characteristic of recycled sediment that is originally derived from a cratonic source terrane (Dickinson et al., 1983).

2. The Okse Bay Group can be characterized as consisting predominantly of well sorted, very fine grained sandstone (3.2.2.1). Directional evidence will be presented subsequently that indicates that the Ellesmere Island - Greenland craton and the intra-cratonic Thule Basin constitute the most probable source terrane for the Okse Bay Group. The high degree of textural maturity displayed by Okse Bay Group detritus in consideration of the short transport distance (ca. 140-570 km) thereby implied for both first cycle and recycled sediment can only be explained if the majority of the sediment has been recycled from older

sedimentary rocks.

3. The feldspar-quartz grain size relation, discussed earlier in this section, reveals that the coarsest feldspar grains approximate the largest monocrystalline quartz grains in the thin sections examined. Quartz of the same sedimentary cycle as associated feldspar grains should be considerably larger, given similar transport histories. That this is not so in the Okse Bay Group necessitates that the majority of the quartz is recycled detritus.

3.5 Stratigraphic and Areal Composition Trends

Composition trends are looked for in the Okse Bay Group for the following reasons: 1) the presence or absence of stratigraphic composition trends upward through the Okse Bay Group would indicate if there has been a change in source terrane, or a change in the dominant bedrock type within a single source terrane, during Okse Bay time 2) if present, areal composition trends could be significant with respect to the location of the source terrane.

Stratigraphic Trends

The irregular occurrence and very low abundance of metamorphic rock fragments and feldspar in the Okse Bay Group detritus precluded their being used as indicators of stratigraphic composition trends. Instead the three ratios of monocrystalline quartz (Qm), polycrystalline quartz (Qp) and chert (Qc) to total quartzose grains (Qt) are determined for this purpose. Mean values of each ratio are determined for each formation at each section location at which it is exposed. These means are then combined to give an overall grand mean value for each ratio, for each formation, of the Okse Bay Group. This data is presented in Table 3.5-1.

Based on the conclusions reached previously in 3.4, the Qm/Qt and Qc/Qt ratios are both representing recycled sediment input into the Franklinian Miogeocline on southwestern Ellesmere Island while the Qp/Qt ratio represents input of first cycle sediment. Comparison of the grand mean values of each of these ratios amongst the five formations clearly indicates that there has been no change in source terrane or in the dominant bedrock type within a single source terrane during the period of deposition of the Okse Bay Group. However, comparison of only Qc/Qt values

Table 3.5.-1 Stratigraphic variation in quartzose grain ratios through the Okse Bay Group, on southwestern Ellesmere Island.

Formation	Section	n	Qm/Qt	Qc/Qt	Qp/Qt
Strathcona	HB1	3	0.95	0.01	0.03
Fiord	S2	11	0.97	0.02	0.01
		Grand Mean	0.96	0.015	0.02
Hecla Bay	HB1	14	0.98	0.01	0.01
	HB3	8	0.97	0.005	0.02
	F4	7	0.98	0.02	0.01
	HB2	5	0.96	0.02	0.01
		Grand Mean	0.97	0.01	0.01
Fram	F1	10	0.91	0.06	0.01
	F5	8	0.89	0.06	0.02
	HG2	5	0.95	0.04	0.01
	F2	13	0.95	0.03	0.02
	F4	11	0.88	0.07	0.03
	F3	4	0.91	0.07	0.01
		Grand Mean	0.92	0.06	0.02
Hell Gate	F2	13	0.95	0.03	0.02
	F4	11	0.88	0.07	0.03
	F3	4	0.91	0.07	0.01
		Grand Mean	0.92	0.06	0.02
Nordstand Point	HG3	3	0.92	0.06	0.004

Note:

1. n - the number of thin sections involved in the calculation of the mean value.

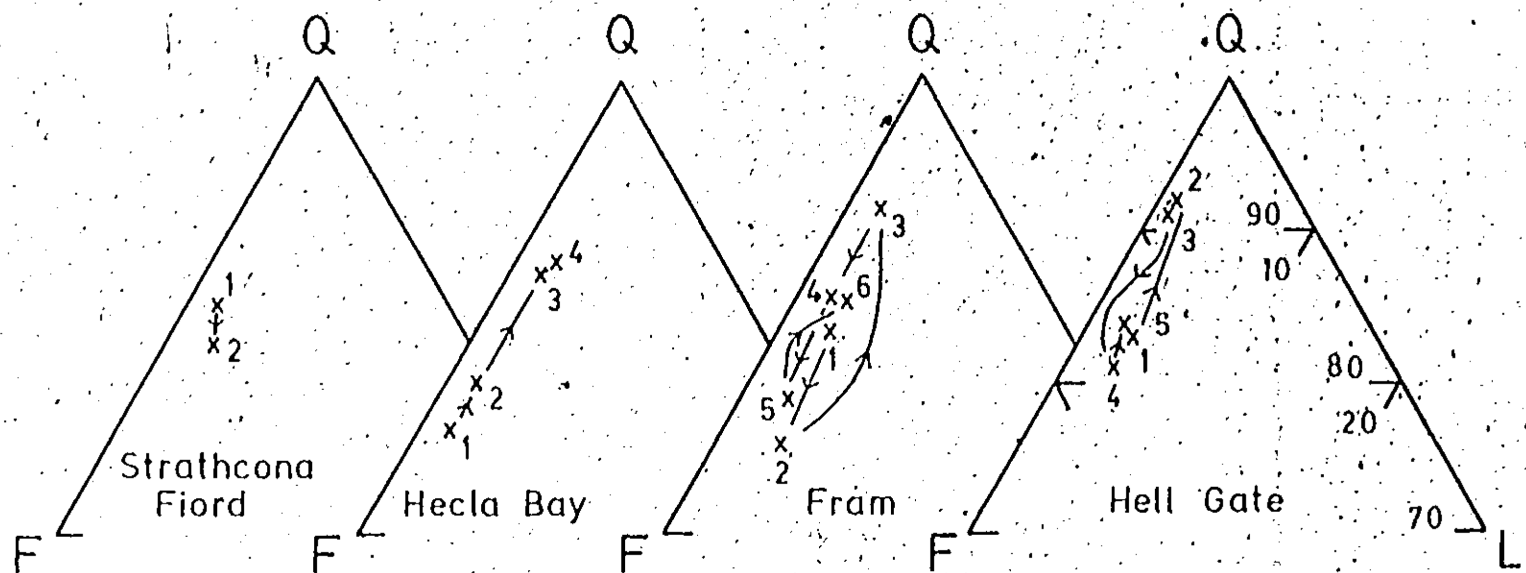
2. Qm - monocrystalline quartz, Qc - chert, Qp - polycrystalline quartz, Qt - total quartzose grains;

does suggest that chert bearing carbonate rocks are slightly more exposed to erosion in the older sedimentary basin during the deposition of the Fram and Nordstrand Point Formations.

Areal Trends

The existence of areal composition trends within each formation is evaluated by determining the mean detrital modal composition for each formation, at each section location at which it is exposed, and then plotting these values on ternary QFL composition diagrams. The results for each formation are presented in Figure 3.5-1. Since only one exposure of the Nordstrand Point Formation is examined, the presence or absence of areal composition trends within this formation could not be evaluated. Examination of this figure indicates that while areal patterns in composition are erratic and uninterpretable for the Fram and Hell Gate Formations both the Strathcona Fiord and the Hecla Bay Formations display trends. The trend is most obvious in the Hecla Bay Formation which shows a progressive depletion of feldspar from the easternmost exposure, section HB1 near Sor Fiord, to section HB2 on North Kent Island, the westernmost exposure. The reason for the preservation of a compositional trend in the Hecla Bay Formation and not in

Figure 3.5 - 1 Areal variation in detrital sandstone composition for the constituent formations of the Okse Bay Group.



1 HB1, n= 3
2 S2 , n=11

1 HB1 , n=14
2 HB3 , n= 8
3 F4 , n= 7
4 HB2 , n=5

1 F1, n=10
2 F5, n= 8
3 HG2, n=5
4 F2, n=13
5 F4, n=11
6 F3, n=4

1 HG2 , n=15
2 F2 , n=2
3 HG1, n= 6
4 HG3, n= 5
5 F3 , n= 7

x Mean Formation Detrital Composition

the Fram or Hell Gate Formations is the paucity of interstratified siltstone in the Hecla Bay. As discussed in 2.2.3, the Hecla Bay Formation contains only ca. 7% siltstone, by cumulative thickness, compared with ca. 49% and 34% siltstone in the Fram and Hell Gate Formations, respectively. As a result, compactional dewatering of siltstone into sandstone and the resulting modification (replacement or dissolution) of labile framework grains, such as feldspar, is not a significant early diagenetic process affecting the Hecla Bay Formation, but is significant for the Fram and Hell Gate formations.

A similar east to west impoverishment in feldspar is indicated for the Strathcona Fiord Formation between section HB1, near Sor Fiord, and section S2 near Muskox Fiord in the western part of the study area. This westward depletion of feldspar may be fortuitous however, since it is based on only two locations whose modal compositions show only a slight difference with respect to feldspar content. More exposures of the Strathcona Fiord Formation would have to be examined to confirm the existence of this composition trend.

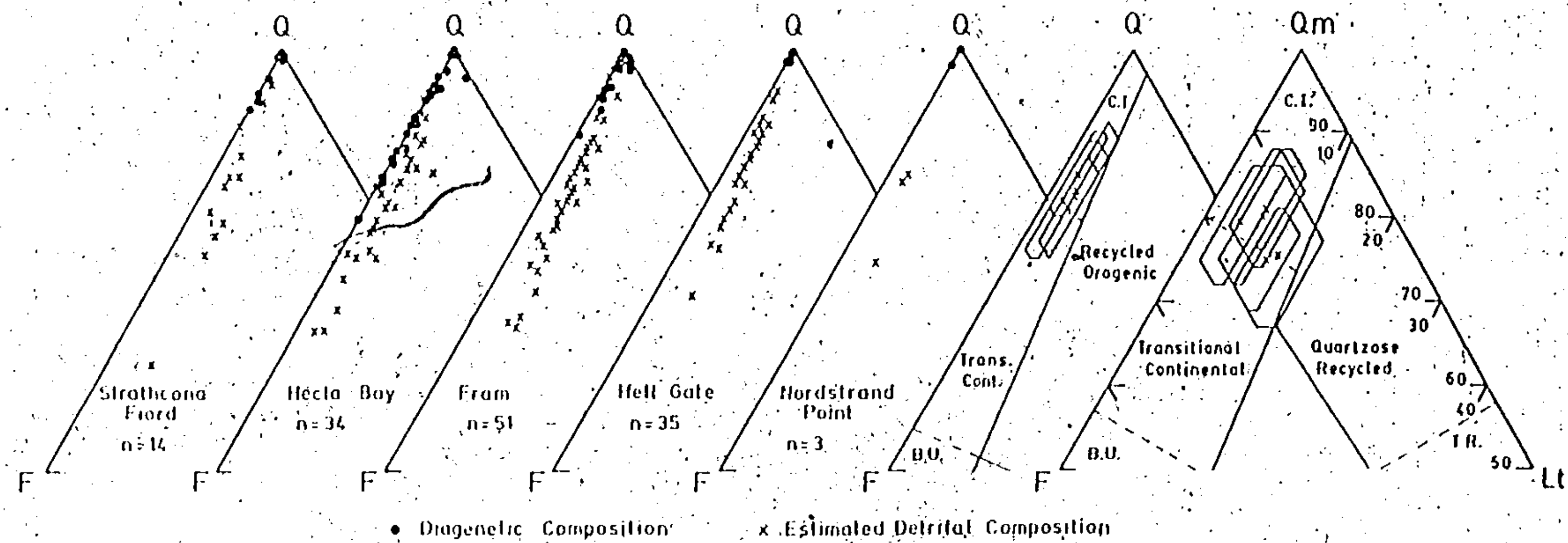
Nevertheless, the westward depletion of feldspar displayed by the Hecla Bay Formation is considered to be genuine and as such it constitutes the first direct evidence pertaining to the direction of the source terrane of the

Okse Bay Group. It indicates that the source terrane lay to the east of the outcrop area of the Okse Bay Group. Additional directional evidence in the form of a regional synthesis of paleocurrent data will be presented subsequently in 4.1.

3.6 Plate Tectonic Setting of the Source Terrane

Under favorable conditions, i.e., a tectonically active source terrane and rapid deposition, sandstone composition is known to be grossly related to the plate tectonic setting of the source terrane (Dickinson and Suczek, 1979; Dickinson et al., 1983). However, exceptions to this principle do exist as outlined by Mack (1984) and Velbel (1985). Although the bedrock composition and the tectonic behavior of the source terrane of the Okse Bay Group have already been determined in this report, it is considered worthwhile to investigate the applicability of this principle to the Okse Bay Group. To do this the mean detrital composition determined for each formation from the data presented in Table 3.2.1.2-2 is plotted on QFL and QmFLt ternary diagrams that are partitioned according to the field boundaries of Dickinson et al., (1983, Figure 1). This is presented as Figure 3.6-1. On both diagrams the mean detrital mode of each formation plots within the craton

Figure 3:6 - 1 QFL and QmFLt ternary diagrams for the Okse Bay Group. Refer to text for discussion of why these are misleading indicators of the tectonic setting of the source terrane of the Okse Bay Group.


Q
Q
Q
Q
Q
Q
Qm
F
F
F
F
F
F
F
Lt
Strathcona Fiord
n=14
Hecla Bay
n=34
Fram
n=51
Hell Gate
n=35
Nordstrand Point
n=3
Trans. Cont.
B.U.
C.I
Recycled Orogenic
Transitional Continental
B.U.
C.I.
90
10
80
20
70
30
60
40
50
T.R.
Quartzose Recycled
• Diagenetic Composition
x Estimated Detrital Composition

interior field, except for one mode which plots just within the transitional continental field of the QmFLt diagram. This is not what would be anticipated from the discussion of source terrane bedrock composition presented previously in 3.4. The conclusion reached in 3.4 is that the source terrane of the Okse Bay Group consisted of: 1) plutonic igneous and metamorphic crystalline basement with supracrustal low rank metasedimentary rocks 2) an older, non-metamorphosed, sedimentary basin as the principal supplier of detritus. In 2.6.2 it was concluded that the source terrane experienced continuous but variable rates of tectonic uplift during Okse Bay time and it is hypothesized that the style of the uplift is epeirogenic. In consideration of these conclusions regarding the behavior and composition of the source terrane it would be expected that the formation means would plot within the recycled orogenic and the quartzose recycled fields of the QFL and QmFLt diagrams, respectively. In both cases, the lithic component is too low for the means to plot within these plate tectonic fields. Since the only type of extra-basinal, polymineralic rock fragments noted in the Okse Bay Group are schistose metamorphic rock fragments the low lithic values are considered to be a function of the pronounced grain size control over the occurrence of this type of rock fragment as a framework grain. Blatt, Middleton and Murray (1980, Figure 8-21) indicate that the dominant mean grain size range of the Okse Bay Group (coarse silt to fine sand) should contain very low percentages of polymineralic rock fragments.

While feldspar abundances would not be expected to be high enough to cause the formation means to plot within the basement uplift field since the majority of Okse Bay Group sediment is recycled from older sedimentary rock, it is likely that they were slightly greater at the time of erosion than shown on the diagrams. This is suggested to be the case based on the paleomagnetic work of Lapointe and Dankers (1982) who have shown that the study area of this report is within 5^0 of the Lower Devonian equator. For the Middle and early Upper Devonian, which is the period of deposition of the Okse Bay Group, very low latitudes would still have characterized the study area. Under such hot and moist climatic conditions (based on common plant casts in the Okse Bay Group) feldspar would breakdown quite rapidly and a certain percentage would not make it to the final site of deposition.

It is concluded that the use of QFL and QmFLt diagrams to determine the plate tectonic setting of the source terrane of the Okse Bay Group gives erroneous results, principally because of the strong grain size control over the presence of polymineralic rock fragments. In short, the detrital composition of the Okse Bay Group is not representative of its erosional composition.

3.7 Summary of Conclusions

The principal conclusions regarding the petrology of the Okse Bay Group may be stated as follows:

1. The Okse Bay Group may be characterized as consisting predominantly of well sorted, very fine grained sandstone. Estimates of detrital compositions indicate that the sediment is predominantly subarkosic and occasionally arkosic at the time of final deposition. However, the detrital compositions determined for the Okse Bay Group are not considered to be wholly representative of the erosional compositions due principally to the effect of grain size on the abundance of polymineralic rock fragments and less significantly due to the rapid breakdown of feldspar in a hot, moist, near equatorial climate.
2. Burial metamorphism has resulted in the dissolution and/or the replacement of many labile framework grains in the Okse Bay Group. Estimates of maximum burial depth vary between 3000-5600 m depending on which geothermal gradient

is considered appropriate. The presence or absence of interstratified siltstone is the determinant of the severity of diagenetic modifications to the sandstones. Early diagenetic (<100°C) lithification via allochthonous secondary quartz and calcite cementation (in that order) occurred for all formations in which siltstone is a significant lithological component. Only the Hecla Bay Formation lacks significant interstratified siltstone and as a result it is only poorly cemented by mainly autochthonous late diagenetic (100-200°C) silica cement. However, the result of this reduction in the severity of diagenetic modification was that composition trends reflective of source terrane direction are preserved in the Hecla Bay Formation whereas they are destroyed in the other formations of the Okse Bay Group.

3. Cathodoluminescence microscopy of selected thin sections, representing all formations in the Okse Bay Group, indicates that the majority of grains belong to the round family and that pressure solution of framework quartz in sandstones constituted only a very minor source of secondary silica cement. Evidence of pressure solution in the Nordstrand Point Formation (uppermost formation in the Okse Bay Group) is considered significant since it implies that a significant thickness of sediment has been eroded and that

therefore the Okse Bay Group is an important source of multi-cyclic sediment for some younger rock units in the Arctic Islands. Luminescence quotients (Zinkernagel, 1978) determined through the Hecla Bay Formation indicate that the source terrane contained more metamorphic rocks than intrusive igneous rocks.

4. An evaluation of bedrock composition in the source terrane leads to the conclusion that the source terrane of the Okse Bay Group consisted of: 1) plutonic igneous and metamorphic rocks of granitic composition with low rank metasedimentary supracrustal rocks 2) an older, non-metamorphosed, sedimentary basin. It is concluded that the latter supplied most of the sediment to the Okse Bay Group.

5. The Okse Bay Group is compositionally very homogeneous. An evaluation of the stratigraphic variation in quartzose grain ratios through the group indicates that a change in source terrane did not occur during Okse Bay deposition. Areal composition trends are preserved in the Hecla Bay Formation where a westward depletion in feldspar content indicates that the source terrane lay to the east of the outcrop region of the Okse Bay Group.

6. Use of QFL or QmFLt ternary diagrams provides a misleading indication of the plate tectonic setting of the

source terrane of the Okse Bay Group. This is due principally to the effect of grain size on the abundance of polymineralic rock fragments. This conclusion underlines the importance of not relying solely on these diagrams for a provenance interpretation.

It is appropriate to note that at this point in this report the bedrock composition (3.4) and the tectonic behavior (2.6.2) of the source terrane may be specified. Also, an indication of its direction has been provided. The final statement as to the location of the source terrane will accompany the evaluation of a regional synthesis of paleocurrent data presented in 4.1.

4.0 Regional Synthesis

The purpose of this chapter is to provide a larger perspective on the depositional basin of the Okse Bay Group, i.e, the Franklinian Miogeocline of southwestern Ellesmere Island. Two topics will be addressed in the course of constructing this regional perspective: 1) a regional synthesis of directional data 2) biostratigraphic correlation.

4.1 Regional Synthesis of Paleocurrent Data

In 2.0 paleocurrent data is presented and discussed for each formation, at each section location from which measurements were obtained. In total, 860 paleocurrent measurements were recorded from the Okse Bay Group, 155 of which represent overbank measurements. Table 4.1-1 presents the distribution of this data with respect to section location, formation, type of sedimentary structure and whether it is found in in-channel or overbank strata. Figure 4.1-1 (in pocket) is a stratigraphic cross section through the Okse Bay Group showing all directional structures plotted according to formation and section location. Upon perusal of Table 4.1-1 it is immediately obvious that most paleocurrent measurements are planar tabular cross-strata and that trough cross-stratification is

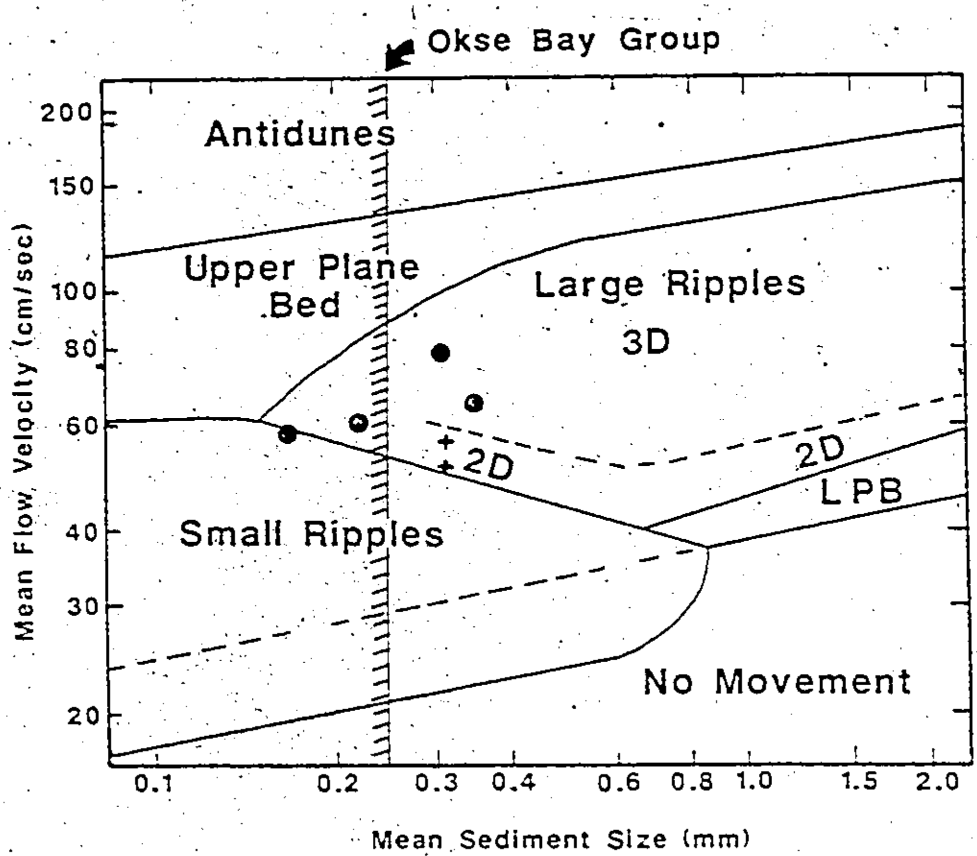
Table 4.1.-1 Distribution of Paleocurrent Data Obtained from the Okse Bay Group

		PT		Troughs		Chevron		PL		Channels	
Section	Formation	ch	ovb	ch	ovb	ch	ovb	ch	ovb	ch	ovb
HB2	Fram	3									
	Hecla Bay	71						2		1	
F3	Hell Gate	50	23							1	2
	Fram	7	17								
F4	Fram	39	30	1				3	7		
	Hecla Bay	39									
S2	Strathcona Fiord	21	7								
HG1	Hell Gate	4								1	
HG3	Nordstrand Point	1	2								
	Hell Gate	5	5								
HG2	Hell Gate	70	10	1				5		1	2
	Fram	8	9					1		2	
F2	Hell Gate	11						1			
	Fram	39	18					4			
HB3	Hecla Bay	41		2				4			
HB1	Hecla Bay	191		7		2		6		1	
	Strathcona Fiord	4									
F5	Fram	24	11	1				1			
F1	Fram	21	12								

Note: 1. ch - in-channel (main channel) measurements
ovb - overbank measurements
2. PT - planar tabular cross strata
3. PL - parting lineation

relatively infrequent throughout the Okse Bay Group. Some of this imbalance is considered to be due to a bias towards measurement of planar tabular cross-stratification in the field. It is somewhat easier to maintain an impression of overall flow direction from measurements of planar tabular cross-strata than from trough cross-strata measurements. However, this can only be considered to explain a small portion of the imbalance; the dominance by planar tabular cross-strata is real. Grain size considerations are suggested to explain the abundance of planar tabular cross-strata in the Okse Bay Group. As presented in 3.2.2.1, the estimated mean grain size of the majority (55%) of Okse Bay Group thin sections is very fine grained sandstone, with only 20% coarse siltstone, 23% fine grained sandstone and 2% medium grained sandstone. The thin sections examined are considered to be representative of the grain size characteristics of the Okse Bay Group. An examination of the size-velocity diagram of Harms, Southard and Walker (1982, Figure 2-5, pg. 2-14) in light of these mean grain size characteristics provides the most probable explanation of the relative paucity of trough cross-strata. A copy of this diagram showing only the stability fields of the various bedforms and not all of the data points used to establish the field boundaries is presented as Figure 4.1-2.

Figure 4.1 - 2 Grain size - velocity bedform stability diagram adapted from Harms, Southard and Walker, 1982. The upper limit of the coarsest grain size of any volumetric significance in the Okse Bay Group (fine grained sand is the estimated mean grain size for ca. 22% of the Okse Bay Group thin sections) is indicated on the diagram. See text for a discussion of this figure.


Okse Bay Group
Antidunes
Upper Plane Bed
Large Ripples
3D
2D
2D
LPB
Small Ripples
No Movement
Mean Flow Velocity (cm/sec)
200
150
100
80
60
40
30
20
0.1
0.2
0.3
0.4
0.6
0.8
1.0
1.5
2.0
Mean Sediment Size (mm)

The mean grain size characteristics restated above indicate that the coarsest mean grain size of any volumetric significance in the Okse Bay Group is fine grained sandstone. Figure 4.1-2 indicates that sediment of this caliber occupies that portion of the large ripple stability field in which both two and three-dimensional bedforms might be expected. However, Harms, Southard and Walker (1982, pg. 2-18) state that the relationship between two and three-dimensional bedforms in this portion of the large ripple field is unclear due to a paucity of studies of these bedforms in these finer grain sizes. Examination of their Figure 2-5, shows that only two data points, both for three-dimensional bedforms, extend the large ripple stability field into fine grained sand. The absence of data points for two-dimensional large ripples in fine grained sand is not a reflection of their inability to form in these finer grain sizes, but is solely due to flume experiments concerned with their behavior being conducted only with medium and coarse sands (Harms, Southard and Walker, 1982, pg. 2-18). Thus, the size-velocity diagram does not provide an unequivocal answer as to what the dominant type of large ripple should be in fine grained sand. A similar situation results if the flow depth-velocity-size diagram of Rubin and McCulloch (1980) is used which extends the stability fields of the different bed phases into flow depths representative of what would be encountered in natural flows. Therefore, all that can be stated is that the dominance of planar tabular cross-strata over trough cross-strata in the Okse Bay Group, would suggest that two-dimensional bedforms as opposed to three-dimensional bedforms are the dominant large ripple bed phase in fine grained sand.

The paleocurrent data acquired during this study may be examined regionally, from an intra-formational perspective, as well as for an overall trend in the Okse Bay Group.

Intra-formational Variation

Table 4.1-1 indicates that regardless of the formation or section location the most abundant sedimentary structure is always planar tabular cross-strata. For this reason, an evaluation of intra-formational variation in flow direction is based on an areal comparison of vector mean orientations determined for in-channel planar tabular cross-strata (see Figure 4.1-1, in pocket). Two serious shortcomings in data quality jeopardize a meaningful interpretation of the areal variation in vector mean orientation within each formation; they are:

1) For each formation the validity of such an areal

comparison is seriously impaired by marked differences in sample size between the different section locations.
2) Usually, the number of measurements of planar tabular cross-strata obtained is sufficiently small to place in question the representativeness of the vector mean as an indication of the overall flow direction.

An areal comparison of vector means is not applicable to the Nordstrand Point Formation since only one exposure is examined. The remaining four formations of the Okse Bay Group are discussed separately below (refer to Figure 4.1-1).

Strathcona Fiord Formation

Only two fluvial exposures of this formation are examined, both of which have vector means oriented toward the northeast. However, the small sample sizes and the disparity in sample size between the two locations jeopardizes the significance of this consistency. If this data is considered reliable, the southwest to northeast flow direction immediately suggests that sediment could have been derived from a still active cratonic Boothia Arch. Since the composition of such detritus would be the same as the first cycle sediment of possible easterly derivation discussed previously in 3.4, it would be petrographically indistinguishable. This possibility remains an open question and should be examined further in any future studies of the Okse Bay Group.

Hecla Bay Formation

If the data quality problems mentioned above are ignored, then the fact that three out of four vector means showed an overall east to west orientation should be considered as significant with respect to a characteristic flow direction.

Fram Formation

The situation in the Fram Formation is similar to that in the Hecla Bay Formation in that, data quality problems aside, there does appear to be a dominant flow direction. Four out of six vector means showed an east to west orientation suggesting that this could be considered as the characteristic flow direction for the formation.

Hell Gate Formation

A dominant flow direction cannot be suggested for the Hell Gate Formation since the five locations at which it is investigated show little consistency amongst their vector means with both easterly and westerly orientations present.

The intra-formational variation in flow direction displayed by the Hecla Bay, Fram and Hell Gate Formations may be the result of the following factors, considered either individually or in combination:

1. Poor data quality, as discussed above.
2. It may not be realistic to assume that one fluvial system is responsible for the deposition of a formation. Instead, perhaps several fluvial systems of similar channel patterns but differing overall flow directions are responsible for the basin-wide presence of a formation. This would imply an irregular basin topography with several drainage divides.
3. If a single fluvial system is responsible for the deposition of a formation, its flow direction could experience significant deflections due to regional variation in bedrock structural trends.

Overall Trend

The existence of an overall trend in the paleocurrent data acquired from the Okse Bay Group is best evaluated by the examination of Figure 4.1-1 (in pocket). The large intra-formational variability is obvious in this figure.

However, if any overall trend is to be ascribed to the directional data in the Okse Bay Group it is suggested that a careful examination of this figure indicates that the most probable overall flow direction is westerly, i.e., from east to west.

4.1.1 <u>Location of the Source Terrane</u>

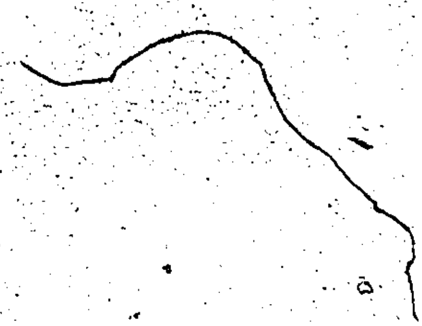
The source terrane of the Okse Bay Group has been characterized as to its tectonic behavior (2.6.2) and its bedrock composition (3.4). Its direction relative to the outcrop region of the Okse Bay Group is suggested to be to the east based on feldspar abundance trends in the Hecla Bay Formation. The overall east to west paleocurrent trend obtained from the Okse Bay Group corroborates the suggestion of an eastward lying source terrane. Also, as presented subsequently in 4.2, an eastward lying source terrane is suggested from biostratigraphic correlation based on spores, which shows that the base of the Strathcona Fiord Formation youngs westward across southwestern Ellesmere Island from Early Eifelian at Stenkul Fiord to Late Eifelian at Muskox Fiord. A source terrane positioned eastward of the Okse Bay Group is therefore suggested based on: 1) compositional 2) paleocurrent and 3) biostratigraphic evidence. Since, the Ellesmere Island - northwestern Greenland craton with its intra-cratonic Proterozoic Thule Basin meets the source terrane requirements with respect to bedrock composition, and since it is positioned immediately to the east of the Okse Bay Group, as shown in Figure 4.1.1-1, this region is suggested to be the source terrane for the siliciclastic detritus composing the Okse Bay Group.

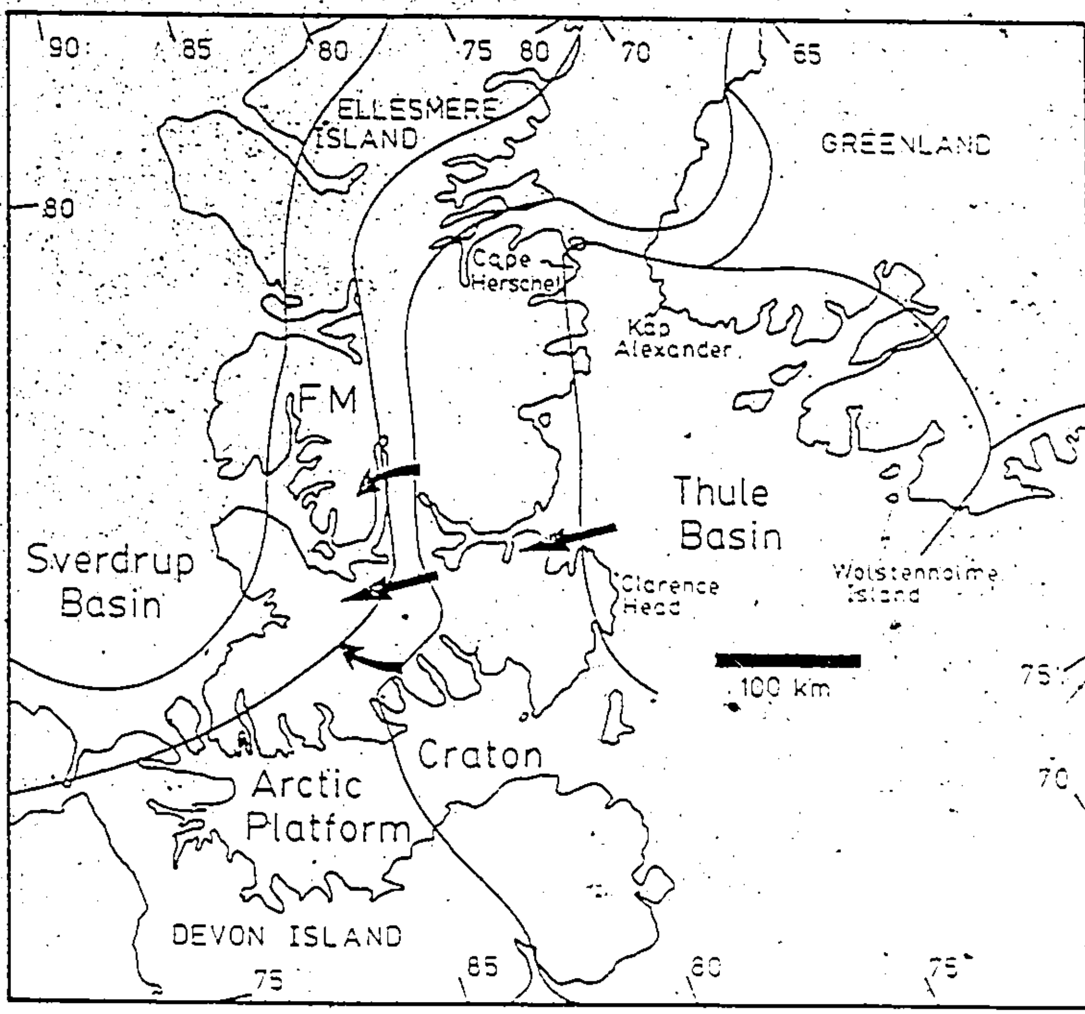
Discussion

Petrographic criteria are presented in 3.4 which indicate that the Thule Basin is likely the principal supplier of quartz-rich detritus to the Okse Bay Group. It is therefore appropriate to review the composition of the strata in this basin and compare it with the lithological makeup of the Okse Bay Group.

As indicated in Figure 4.1.1-1, Thule Basin strata are exposed between Clarence Head and Cape Herschel, on eastern Ellesmere Island, and between Wolstenholm Island and Kap Alexander on northwestern Greenland. The basin is ca. 90,000 km^2 in areal extent and straddles the southernmost part of Nares Strait. Thule Basin strata on eastern Ellesmere Island have been recently described by Frisch and Christie (1982). An overview of Thule Basin strata on northwestern Greenland has recently been presented by Dawes,

Figure 4.1.1 - 1 Principal source terranes (Ellesmere Island-northwest Greenland craton and the Proterozoic intracratonic Thule Basin) for Okse Bay Group detritus. FM - Franklinian Miogeocline.




90
85
80
75
80
70
65
ELLESMERE
ISLAND
GREENLAND
80
Cape
Herschel
Kap
Alexander
FM
Thule
Basin
Sverdrup
Basin
Clarence
Head
Wolstenholme
Island
100 km
75
70
Craton
Arctic
Platform
DEVON ISLAND
75
85
80
75

Frisch and Christie (1982). The following description of the strata are taken from these papers.

Thule Basin strata are unmetamorphosed and are best preserved in northwestern Greenland where they reach a thickness of at least 4.5 km. In southeastern Ellesmere Island they are less than 1100 m in thickness and are preserved only in downfaulted blocks of the Canadian Shield. Strata of the Thule Basin constitute the Thule Group. An upper and lower Thule Group is recognised, the former consisting of the Dundas Formation and the overlying Narssarssuk Formation and the latter consisting of the Wolstenholme Formation. Stratigraphic correlations across Nares Strait indicate that only lower Thule Group strata are preserved on southeastern Ellesmere Island. The Wolstenholme Formation consists mainly of sandstone and conglomerate with less important siltstone and shale and very minor dolomite near the base. On Ellesmere Island the dolomite is reported as being cherty only at the Gale Point exposure. It is considered to represent deposition in a shallow marine to terrestrial environment. The Dundas Formation is at least 1000 m thick and consists mainly of sandstone, siltstone and shale with less important evaporites and chert. It is considered to represent deposition in a shallow water deltaic to coastal plain environment. The Narssarssuk Formation reaches a minimum of 2500 m in thickness in northwest Greenland and consists of cyclic carbonate-siliciclastic (sandstone, siltstone, and shale) deposits with minor evaporites and chert. It is thought to represent deposition in a sabkha-like environment. In addition to the sedimentary strata, all three formations contain hypabyssal and extrusive basaltic igneous rocks. On Ellesmere Island the extrusive basalts are terrestrial and tholeiitic.

From the above descriptions it is apparent that the Thule Basin contained an adequate volume of siliciclastic strata to have acted as a principal source of sediment to the Okse Bay Group. It is likely that the Narssarssuk and Dundas Formations supplied most of the sediment for the following two reasons: 1) they are stratigraphically the two highest formations in the Thule Group and would therefore be eroded first; they could easily have supplied the required volume of sediment since their cumulative minimum thickness of 3500 m exceeds the total thickness of the Okse Bay Group and 2) detrital chert occurs in all five formations of the Okse Bay Group, albeit in small amounts; since chert is effectively absent from the Wolstenholme Formation but present as a minor constituent in both the Dundas and Narssarssuk Formations this would suggest that they are the source formations.

Conspicuous by their absence from Okse Bay Group detritus are basaltic rock fragments. Since basaltic igneous rock occurs as either dykes, sills, or flows in all three formations of the Thule Group, and since the transport distance from the Thule Basin to southwestern Ellesmere Island is short (140-570 km), volcanic rock fragments with lathwork textures would be an anticipated first cycle framework grain in Okse Bay Group detritus. Their complete absence from all point-counts could be due to the following two reasons, likely acting in combination: 1) the dominant mean grain size range of Okse Bay Group sediment (coarse siltstone to fine sandstone) is not conducive to the presence of polymineralic rock fragments 2) in 3.2.3.3 the maximum burial depth obtained by Okse Bay Group sediment is suggested to range between 3000-5600 m; since basaltic rock fragments are composed chiefly of calcic plagioclase and clinopyroxene they have a low resistance to chemical breakdown; Blatt, Middleton and Murray (1980, Table 9-2, pg. 360) indicate that mafic volcanic rock fragments are likely to be destroyed (altered to clay, calcite or a zeolite) at depths exceeding 3000 m.

Figure 4.1.1-1 indicates that the Franklinian Miogeocline and the eastern Ellesmere Island craton are separated by a relatively narrow belt of older rocks belonging to the Arctic Platform. On southwestern Ellesmere Island these are effectively entirely carbonates. It might therefore be anticipated that carbonate clasts would constitute a portion of the framework grains in the Okse Bay Group. However, no carbonate clasts were counted. As for basaltic rock fragments, diagenesis is suggested to be the reason for their not showing up in point-counts. Because of their high susceptibility to chemical breakdown carbonate clasts could easily have been dissolved or replaced during the lower temperature and pH conditions of shallow burial. Even if this diagenetic purging of carbonate clasts did not occur, or if it did not remove all of the clasts, their distinction in the presence of allochthonous calcite cement, which is common in most formations of the Okse Bay Group, would be difficult.

An essential aspect of the evaluation of the likelihood of the Thule Basin (specifically the Dundas and Narssarssuk Formations) being the principal supplier of detritus to the Okse Bay Group is the grain size of its siliceous sediment. Due to the short transport distance between the Thule Basin and southwestern Ellesmere Island quartz grains would not be expected to suffer any significant further reduction in grain size. It is therefore critical that the grain size of the sandstones in the Dundas and Narssarssuk Formations be similar to the grain size of Okse Bay Group sandstones. The sandstones of the Dundas and Narssarssuk Formations are fine grained (Dawes, Frisch and Christie, 1982; Dawes, 1976). As stated previously in 3.2.2.1, the dominant estimated mean grain size of Okse Bay Group detritus is very fine grained sand. This comparison constitutes strong support for the upper Thule Group being the principal source of sediment for the Okse Bay Group since a mixture of quartz derived from the siltstones and fine grained sandstones of the Dundas and Narssarssuk Formations would be expected to produce very fine grained detritus.

The evidence discussed above supports the derivation of the recycled sediment in the Okse Bay Group from the Thule Basin. There is also independent evidence which supports the suggestion that the first cycle sediment in the Okse Bay Group was derived from the southeastern Ellesmere Island - northwestern Greenland craton; the evidence is as follows:

1. The Vendom Fiord Formation is defined by Kerr (1967) as a new red-bed unit of Eifelian age on east-central Ellesmere Island that is derived from an uplifted land mass thought to be the shield area of eastern Ellesmere Island.

Smith and Roblesky (1984) have restated this theory and have referred to the land mass as the Inglefield Uplift. The Vendom Fiord Formation of east-central Ellesmere Island is the same age as the Strathcona Fiord Formation in the Sor Fiord - Stenkul Fiord region of central southern Ellesmere Island. The suggested derivation of the Vendom Fiord Formation from the shield area of eastern Ellesmere Island therefore supports the contention that this area is a sediment source and that the first cycle sediment in the Okse Bay Group was derived from it.

2. Roblesky (1979) has reported finding boulder size clasts of granitic composition in the Hecla Bay Formation exposed along the west side of Vendom Fiord in central southern Ellesmere Island. This constitutes unequivocal proof that first cycle sediment was supplied to the Okse Bay Group from the southeastern Ellesmere Island - northwestern Greenland craton.

Why Not Pearya?

The source terrane interpretation suggested in this study differs from previous interpretations in two important respects: 1) the suggestion that the Proterozoic Thule Basin is the principal source of detritus for the Okse Bay Group of southwestern Ellesmere Island 2) the complete exclusion of the Pearya Geanticline (Trettin, 1978; now considered to be a composite terrane of Caledonian affinity, Trettin, 1987) of northernmost Ellesmere Island as a source region for the Okse Bay Group of <u>southwestern</u> Ellesmere Island.

The question of a source terrane(s) for the Okse Bay Group of southwestern Ellesmere Island has been a controversial topic for a number of years. Reviews of the history of the debate can be found in Embry and Klovan (1976, pg. 594) and Trettin (1978, pg. 77-78). The essence of the problem centers around the importance of Pearya as a source region for the Okse Bay Group of southwestern Ellesmere Island. The existence of a metamorphic crystalline terrane discontinuously exposed along the north coast of Ellesmere Island was known since the work of Feilden and de Rance in 1878 (Trettin, 1971). Schuchert (1923) considered that this terrane constituted a crystalline borderland that is continuous with the Canadian Shield beneath the sediments of the Franklinian Geosyncline and that most of this crystalline borderland, which he named Pearya, is covered beneath the continental shelf off the northern coast of Ellesmere Island. The concept of Pearya has been in and out of favor since its introduction (Trettin, 1971). Currently, it is favored as an important element in the tectonic development proposed for northern Ellesmere Island (Trettin and Balkwill, 1979; Trettin, 1987). Both Embry and Klovan (1976) and Trettin (1978) consider Pearya to have been a significant supplier of detritus to the Okse Bay Group of southwestern Ellesmere Island. The discovery of Frasnian age sediments unconformably overlying lower Paleozoic rocks at Yelverton Pass on northern Ellesmere Island is unequivocal proof that Pearya was shedding sediment in Upper Devonian time (Trettin and Balkwill, 1979). Strong compositional evidence favoring the incorporation of some of this detritus into the Okse Bay Group of west-central Ellesmere Island is presented by Trettin (1978, pg. 77-78). Trettin found both radiolarian and laminated chert clasts, and volcanic rock fragments in the Okse Bay Group of this region. Since neither the carbonate rocks of the Arctic Platform nor the strata of the Thule Basin could have supplied the deep water chert clasts their derivation from the Hazen Formation of northern Ellesmere Island seems undeniable. While the volcanic rock fragments reported by Trettin (1978, pg. 65) from the Strathcona Fiord Formation are highly altered, their composition is thought to range from siliceous to basic. If this is indeed the case, then a northern Ellesmere source is again indicated since only basaltic volcanic rocks are known from the Thule Basin whereas both andesitic and basaltic volcanics are known to exist in Pearya.

It is the contention of this study, that while detritus of northern derivation is apparently incorporated into the Okse Bay Group of west-central Ellesmere Island it did not reach any farther south. There are several lines of evidence that mitigate against Pearya being a source terrane for the Okse Bay Group of southwestern Ellesmere Island:

1. The overall paleocurrent trend in Figure 4.1-1 is east to west with no reliable indications of an interacting north to south flowing depositional system.

2. There are no volcanic rock fragments in the Okse Bay Group. However, even though somewhat more chemically resistant andesitic rock fragments would be anticipated from Pearya, it is conceivable that they could have been thoroughly altered during the deep burial conditions (at least 3000 m) thought to have been attained by Okse Bay Group detritus.

3. There are no unequivocal identifications of deep water chert grains. The grains classified as possible deep water chert in the petrographic data table (Table 3.2.1.2-2) are all argillaceous but showed no laminations. The origin of such grains is equivocal. While they could originate from the inclusion of hemipelagic fines into the siliceous

ooze of a deep water environment, it is also conceivable that they are the result of siliceous nodular replacement of a slightly argillaceous, shallow water carbonate.

The conclusion reached by this study that Pearya is not a source terrane for the Okse Bay Group is only applicable to southwestern Ellesmere Island. The Okse Bay Group of west-central Ellesmere Island (Strathcona Fiord and Hecla Bay Formations only) was not examined for this study. Therefore, while it would seem highly reasonable to suggest that the Upper Thule Group of the Thule Basin and the southeastern Ellesmere Island - northwestern Greenland craton are also the only source terranes for the Okse Bay Group of this region, Trettin's (1978, pg. 77-78) compositional evidence cannot be ignored; it necessitates that some Pearya detritus must have been fed into this region of the Franklinian Miogeocline during Okse Bay Group time.

It must be stated that the conclusion reached by this study leaves a very important regional question unanswered. Approximately 8-30 km of middle Paleozoic strata have been stripped from the Cape Columbia Uplift of northern Ellesmere Island (Trettin et al., 1972). The diastrophism responsible is dated as post Late Silurian to pre Middle Pennsylvanian, coinciding with the depositional period of the Okse Bay

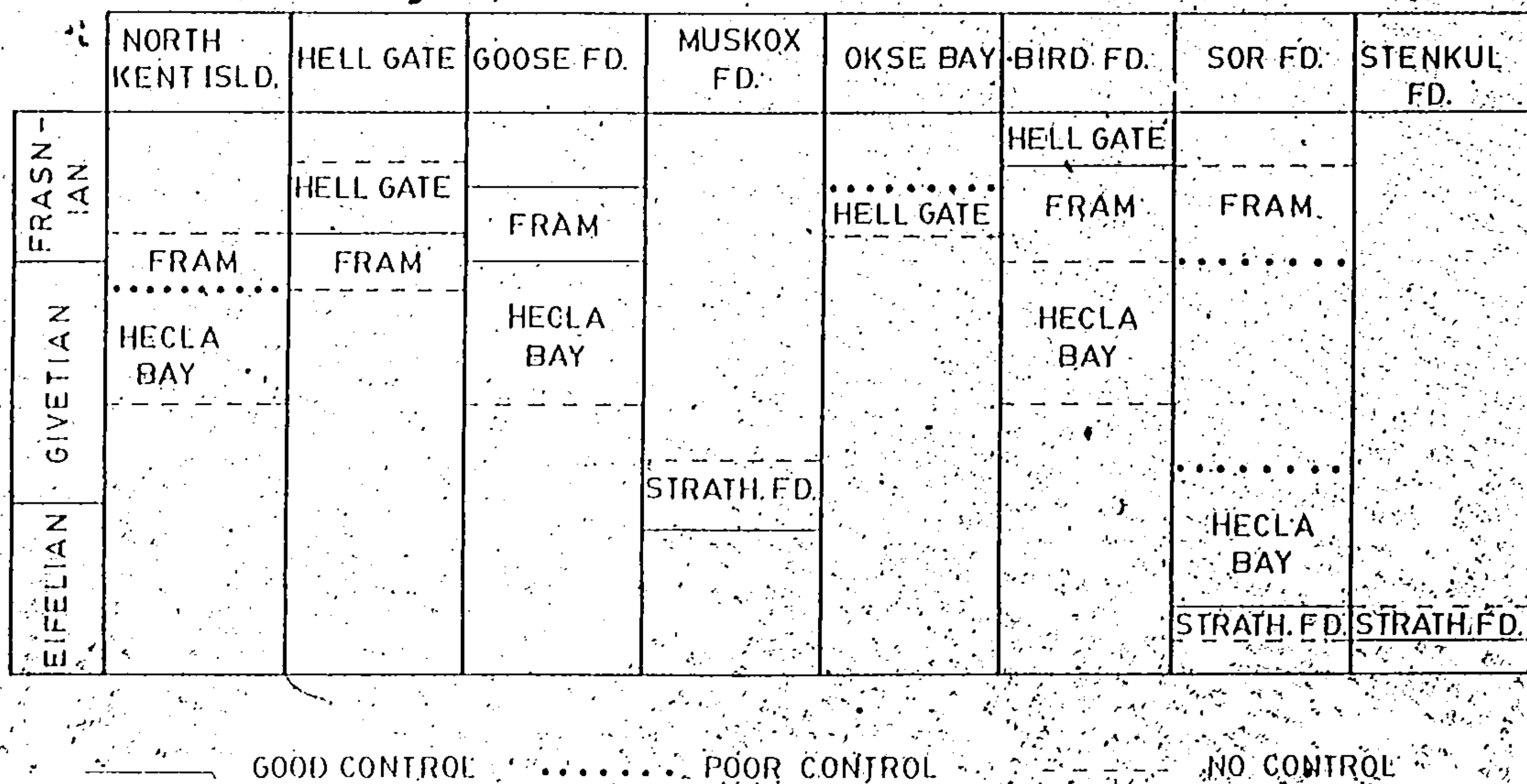
Group. As such, it is entirely reasonable to assume that these sediments fed the clastic wedge of southwestern Ellesmere Island. The results of this study strongly suggest that this is not the case. However, a great deal of rock was eroded from Pearya and if it was not incorporated into the Okse Bay Group then where did it go?

4.2 Biostratigraphic Correlation

The discussion of intra-basinal correlation presented in this section is based on palynological age determinations provided by Dr. D.C. McGregor of the Geological Survey of Canada, Ottawa. Lists of spores recovered from Okse Bay Group siltstones together with comments regarding their age and environmental implications, if any, can be found in Geological Survey of Canada internal reports F1-7-1982-DCM, F1-2-1984-DCM, and F1-6-1984-DCM.

A correlation chart for the Okse Bay Group on southwestern Ellesmere Island and North Kent Island is provided as Table 4.2-1. As indicated on this table, the quality of palynologic control over the ages of the base and top of the formations constituting the Okse Bay Group varies considerably amongst section locations. Two younging trends

Table 4.2-1 Correlation Table for the Okse Bay Group on Southwestern Ellesmere Island



are indicated in the table: 1) the base of the Strathcona Fiord Formation is Early Eifelian at Stenkul Fiord and Late Eifelian near Muskox Fiord indicating an east to west younging 2) the top of the Fram Formation shows an apparent west to east younging trend with ages of early, middle and late Frasnian at Hell Gate, Goose Fiord and Bird Fiord, respectively.

As mentioned previously, the east to west younging of the base of the Strathcona Fiord Formation compliments the overall paleocurrent trend for the Okse Bay Group in suggesting an easterly source terrane. The west to east younging trend indicated for the top of the Fram Formation is considered to be fortuitous since it is contradicted by the paleocurrent evidence from the formation which shows a dominance by westerly directed vector means. It can only be suggested that the spores examined were not accurately representative of the age of the top of the formation.

Figure 4.2-1 (in pocket) presents the intra-basinal correlation within the Okse Bay Group based on the available spore control. As indicated by the number of question marks on the correlation lines, these correlations should only be considered as tentative and subject to revision should any additional palynologic control be obtained from the Okse Bay Group in this area. Figure 4.2-1 indicates that the middle

Givetian is not represented in the Okse Bay Group. The absence of spores of this age suggests that the middle Givetian may have been a time of net erosion in this part of the Franklinian Basin. It was hoped to be able to reconstruct the evolution of that part of the Franklinian Basin which is currently southwestern Ellesmere Island during Okse Bay Group time by combining the chronostratigraphic intervals defined in Figure 4.2-1 with the environmental analyses of each formation at each section location (presented in 2.0). However, due to the poor palynologic control no meaningful reconstruction and interpretation of the areal variation in depositional environment within or between chronostratigraphic intervals is possible. It is impossible to determine if the areal variations are valid or are solely a function of the variation in the amount of palynologic control and/or the portion of the Okse Bay Group exposed amongst the section locations.

5.0 Study Summary and Recommendations for Future Research

5.1 Study Summary

The purpose of this study of the Okse Bay Group of southwestern Ellesmere and North Kent Islands is to conduct a more detailed environmental and petrologic analysis of the group than Embry and Klovan (1976) are capable of doing in their Arctic wide stratigraphic and sedimentologic study of the Devonian Clastic Wedge. In this context, this study is a follow-up study of only a small portion of the clastic wedge. At this point it is worthwhile to briefly restate the objectives of the study that are given in 1.6:

1. To confirm and refine the environmental interpretations suggested for the five formations of the Okse Bay Group by Embry and Klovan (1976).
2. To address the problem of the source terrane for the Okse Bay Group by conducting a more thorough petrologic study.
3. To improve the understanding of the basin architecture in that area of the Franklinian Miogeocline through palynologic correlation and in so doing permit a reconstruction of the middle and early Upper Devonian paleogeographic evolution of that part of the basin.

The results of the environmental analysis are presented in 2.0 of this report. The Okse Bay Group is interpreted as entirely fluvial throughout the study area with the exception of local, geologically short lived, interchannel lacustrine deposits at the base of the Fram Formation at section F4 (Goose Fiord) and section F5 (southwest of Sor Fiord), and the base of the Strathcona Fiord Formation at section S1 (outer Stenkul Fiord) which represents tidal inlet to tidal flat depositional environment. While undoubtedly fluvial, the isolated occurrence of leiosphaerid acritarchs in overbank fines of the Hell Gate Formation at section HG2 (Bird Fiord) and F3 (Hell Gate), and similar isolated occurrences of both leiosphaerid acritarchs and scolecodonts in overbank fines of the Fram Formation at the same two locations indicates that the fluvial systems of each formation must have occupied a distal coastal plain setting, at least in these two areas. All fluvial formations in the group, excepting the Hecla Bay Formation, are interpreted as representing deposition by undivided, single channel fluvial systems of moderate to high sinuosity (i.e., meandering fluvial deposits). The Hecla Bay Formation contrasts with the other four formations of the group in representing deposition by a divided channel, lower sinuosity, fluvial system (i.e., braided). Differences can be detected amongst the four meandering formations of the group (Strathcona Fiord

Formation at sections S2 and HB1, Fram Formation, Hell Gate Formation and Nordstrand Point Formation). Although the same genetic facies associations, representing in-channel and overbank deposition, can be detected in the meandering formations, paleohydraulic calculations indicate differences in the characteristic channel scale which suggest that the robustness of the meandering systems varied somewhat. The Strathcona Fiord and Nordstrand Point fluvial systems are of similar overall scale and are the least robust of all. The Hell Gate meandering system is the most robust with larger (i.e., deeper and wider), slightly less sinuous channels and the Fram fluvial system occupies an intermediate position. The differences in the scale of the meandering systems corresponds to differences in the average sandstone content of each formation. The Strathcona Fiord and Nordstrand Point Formations have the smallest percent sandstone, the Fram Formation an intermediate sandstone content and the Hell Gate Formation the largest percent sandstone. In turn, the average percent sandstone of each formation is interpreted to be a reflection of the nature of the sediment load characteristically carried by its channels during its deposition. The greater the sandstone content, the larger the characteristic bed-material load/suspended load ratio of the channels. Thus, variations in the scale of the meandering systems are interpreted to be the consequence of corresponding variations in the characteristic bed-material load/suspended load ratio of each formation. As would be expected, the braided Hecla Bay Formation contained the highest average percent sandstone since its channels would be strongly bed-material load dominant. The ultimate determinant over the variation in the average sandstone content amongst the five formations of the Okse Bay Group is interpreted to be a continuous but variable rate of tectonic uplift of the source terrane, probably epeirogenic in nature, as opposed to either long term climatic variation or a change in source terrane or the dominant bedrock type within a given source terrane. While an inferred high frequency of avulsion in the Hell Gate Formation supports such an interpretation, the strongest evidence in support of a tectonic control over Okse Bay Group deposition is the fact that its period of deposition (early Eifelian to late Frasnian) coincides precisely with an eustatic rise in sea level (Johnson, Klapper and Sandberg, 1985). Tectonic uplift is the only mechanism likely to override the influence of a rise in sea level and cause the progradation of a clastic wedge. The Hecla Bay and the Hell Gate Formations are interpreted to represent deposition during periods of maximum tectonic uplift of the source terrane since they contain the two largest average sandstone contents. The highest rate of uplift occurred during Hecla Bay time since that formation contains the most sandstone (93% versus only 66% for the Hell Gate Formation). This interpretation is supported by the fact that the Hecla Bay Formation is the only formation in the Okse Bay Group to have a basal conglomerate (section HB1).

The interpretations presented in 2.0 of this report, while considerably more refined than those of Embry and Klovan (1976), in most respects support these authors analysis of Okse Bay Group deposition. However, two glaring differences arise between this study and their work. Firstly, they interpreted the Hell Gate Formation as representing deposition by a braided fluvial system rather than a robust meandering one, as is suggested by this study, and secondly they consider long term climatic cyclicity to be the ultimate determinant over Okse Bay Group deposition. In keeping with the purpose of a summary section the reader is referred to 2.4.9 and 2.6.2, respectively, for a review of the arguments against these interpretations.

The results of the petrographic study of the light mineral fraction of the coarse siltstones and sandstones of the Okse Bay Group are presented in 3.0 of this report. The interpretations are based on transmitted light point-counts of 137 thin sections representing all fluvial exposures of each formation in the group, and on the examination of 21 thin sections, representing each formation in the group, using cathodoluminescence. The Okse Bay Group is shown to consist of compositionally and texturally mature siliciclastic sediment which displays a high degree of homogeneity, both areally within a formation, and stratigraphically between formations. The group may be characterized as consisting dominantly of well sorted, very fine grained sandstone. The grain size characteristics of each formation supports the tectonic uplift hypothesis for the source terrane; i.e., the sandstone enriched formations (Hecla Bay and Hell Gate) have more coarser grained detritus than those formations which contain less sandstone (Strathcona Fiord, Fram and Nordstrand Point). Using the classification of McBride (1963) diagenetic compositions plot within the quartz arenite field or straddle the quartz arenite-subarkose field boundary for all formations. A significant number of Hecla Bay Formation thin sections plotted well within the subarkose field. Estimates of detrital compositions plotted mainly within the subarkose field for all formations, with a smaller number of thin sections plotting as arkoses, most commonly those of the Hecla Bay Formation. However, due to the small characteristic grain size of the Okse Bay Group the final depositional compositions are not considered to be wholly representative of the initial erosional composition. Okse Bay Group detritus was likely somewhat more lithic rich than even the detrital estimates would suggest.

Extra-basinal grains in the Okse Bay Group consist of quartzose grains, feldspar and rock fragments. The quartzose grain population overwhelmingly dominates and is composed principally of non-diagnostic monocrystalline quartz with only very small amounts of effectively entirely metamorphic, inherited, polycrystalline quartz and detrital chert. While there has been diagenetic albitization, the small amount of feldspar present is considered to be almost entirely alkali feldspar. Extra-basinal rock fragments consist entirely of quartz-mica tectonites representing schistose parent rocks. Very small amounts of sandstone, siltstone and possibly shale rock fragments are thought to constitute intra-basinal grains due to their very low survival potential during fluvial transport.

All formations in the Okse Bay Group are interpreted to have been buried to a depth of at least 3 km and as such have been burial metamorphosed. This is of some significance since it means that the Okse Bay Group was an important source of multi-cyclic detritus for a younger rock unit. The late Triassic-Jurassic Heiberg Formation of the central and eastern Sverdrup Basin is a possible candidate. As a consequence of the deep burial conditions attained by the group, the small population of labile framework grains were easily removed creating secondary porosity or replaced. Both early and late diagenetic processes are delineated and a paragenesis is suggested for the former based principally on textural evidence. For all formations in the Okse Bay Group, except the Hecla Bay Formation, the principal lithifying agents are allochthonous cements introduced into the sandstones by compactional dewatering of interstratified siltstones during shallow burial, early diagenetic conditions. In all thin sections secondary quartz cement in the form of syntaxial overgrowths is the most important lithifying agent. It invariably preceded a calcite cement which is reasonably common in all formations but the Hecla Bay as either a neomorphic cement or replacing a labile grain. Locally, calcite cement is more voluminous than silica cement. Hematite, either as an early grain rimming cement or a later cement produced by the breakdown of iron bearing minerals, is commonly finely dispersed in the thin sections of the finer grained formations (Strathcona Fiord, Fram and Nordstrand Point). When it resulted from the breakdown of iron bearing minerals it is always temporally intermediate between the secondary quartz and calcite cements. In contrast to most of the Okse Bay Group the Hecla Bay Formation is commonly poorly cemented. This is interpreted to be a direct consequence of the paucity of interstratified siltstone in this formation (only ca. 7% by cumulative thickness). In the near absence of interstratified siltstone the high volume source of early diagenetic allochthonous cements is lost. As a consequence of this, Hecla Bay lithification resulted predominantly from mainly late diagenetic, low volume sources of autochthonous silica cement. The late diagenetic processes involved are minor pressure solution of framework quartz grains and carbonate replacement of silicates. Early diagenetic kaolinization of alkali feldspar is also a low volume source of autochthonous silica cement. Uncommon, minor, early diagenetic, allochthonous calcite cement derived from the siltstone is also present in the Hecla Bay Formation.

The cathodoluminescence (CL) study of the Okse Bay Group was undertaken principally to determine the detrital texture of the Okse Bay Group detritus (degree of rounding of the quartz grains) which is obscured by the secondary quartz cement. It was also hoped to both confirm and augment diagenetic interpretations made under transmitted light and to contribute to the interpretation of the bedrock composition of the source terrane. Observations under CL indicate that the majority of quartz grains belong to the round family (well rounded, rounded, subrounded). CL microscopy also confirms the presence of only one period each of quartz and calcite cementation and validated the paragenesis suggested under transmitted light. Only occasional long contacts are observed between adjacent quartz grains in the thin sections chosen for the CL study. This indicates that, in general, the framework of the Okse Bay Group is undeformed and that pressure solution of framework quartz grains could not have been a significant source of secondary quartz cement. Luminescence quotients for monocrystalline quartz (Zinkernagel, 1978) are not considered to be reliable indicators of the plutonic igneous/metamorphic ratio of the bedrock in the source terrane for those formations characterized by coarse siltstone and very fine grained sandstone due to the prolonged exposure times (up to eleven minutes) required for photographs. Only the luminescence quotients determined for the Hecla Bay Formation (fine grained sandstones) are considered to be reliable indicators of this ratio. They indicate that metamorphic crystalline rocks dominated over plutonic igneous rocks in the source terrane of the Okse Bay Group.

The evaluation of source terrane bedrock composition is based on an analysis of the extra-basinal grain population. Two genetic groups of grains are distinguished. Okse Bay Group detritus is interpreted to consist of first cycle sediment derived from a plutonic igneous and metamorphic source region (mainly metamorphic based on the CL study) of granitic composition that also included schistose supracrustal rocks and recycled sediment derived from an older non-metamorphosed sedimentary basin. Compositional and textural evidence is interpreted to indicate that the majority of the detritus has been recycled from older sedimentary rocks with only a relatively minor first cycle contribution from plutonic igneous and metamorphic source rocks.

The direction of the source terrane relative to the outcrop area of the Okse Bay Group is interpreted to be to the east based on paleocurrent, composition trend and biostratigraphic evidence. Paleocurrents in the Okse Bay Group are frequently not reliable indicators of overall flow direction if only acquired locally. Vector means display considerable interformational and intraformational variation. Nevertheless, at a regional scale, there is an indication of a crude preferred east to west flow direction. The only composition trend found in the Okse Bay Group is an east to west decrease in the feldspar content of the Hecla Bay Formation which supports the easterly source terrane direction indicated by the regional paleocurrent trend. An eastern source terrane is also indicated by the east to west younging of the base of the Strathcona Fiord Formation as determined from palynology.

The source terrane of the Okse Bay Group on southwestern Ellesmere Island is interpreted to be the southwestern Ellesmere Island - northwestern Greenland craton (first cycle sediment) and its Proterozoic, intra-cratonic, Thule Basin (recycled sediment) since these sources satisfy both the directional and compositional requirements of the source terrane. Furthermore, compositional and textural evidence indicates that the Narssarssuk and Dundas Formations, composing the Upper Thule Group of the Thule Basin, are the <u>source formations</u> for the recycled sediment in the Okse Bay Group.

There is no unequivocal compositional petrographic evidence from this study which supports the presence of Pearya derived detritus in the Okse Bay Group of southwestern Ellesmere Island. However, the compositional evidence (radiolarian and laminated chert grains) reported by Trettin (1978) from west-central Ellesmere Island proves that some Pearya detritus is incorporated into the Okse Bay

Group in the more northerly region of its depositional extent.

A first attempt to an intra-group biostratigraphic correlation for southwestern Ellesmere Island, based on spores, is presented. Unfortunately, the control is not sufficient to permit a meaningful reconstruction of the areal variation in depositional environment within each chronostratigraphic interval.

5.2 Recommendations for Future Research

Successive studies of any topic should always strive to utilize the knowledge acquired from the preceding studies in an attempt to increase the understanding of the topic. In many instances, an increased understanding results from doing more detailed work on a small portion of the original study area. This is the case for the Devonian Clastic Wedge of the Canadian Arctic Archipelago. This wedge of sediment extends across the entire breadth of the archipelago from Ellesmere Island in the east to Banks Island in the west and has been correlated with mainland rock units lying to the southwest of the archipelago. It is thus an important tectono-stratigraphic entity which figures prominently in the geologic evolution of this area which is currently an Arctic Archipelago. Up until this study investigations were necessarily principally stratigraphic in nature with little sedimentologic emphasis beyond a reconnaissance level environmental interpretation. Exceptions to this are the studies of Trettin (1978) and Roblesky (1979) who investigated the Strathcona Fiord and Hecla Bay Formations of west-central and central-southern (Vendom Fiord region) Ellesmere Island, respectively. The stratigraphy and regional environmental setting of the Devonian clastic strata has been unravelled principally through the Arctic wide efforts of Embry and Klovan (1976), with earlier stratigraphic contributions from southwestern Ellesmere Island by Schei (1904) and McLaren (1963). This study of the Okse Bay Group of southwestern Ellesmere Island and North Kent Island is the first regional scale, sedimentologically oriented, study of these deposits. It should be considered as a smaller scale follow-up study to the work of Embry and Klovan (1976). This study firmly establishes the depositional settings and the petrographic characteristics of the five formations composing the Okse Bay Group. Also, it is felt that it satisfactorily resolves the issue of the location of the principal source terrane. Southwestern Ellesmere Island is but one small portion of the outcrop area of the Devonian Clastic Wedge. What is needed first are similar, regional scale, sedimentologically oriented studies of other areas of the wedge. Subsequently, intensive investigations of the best exposures within each area should be conducted. Such small scale studies would be conducted best by federally funded university research since the benefits reaped would be directed principally toward furthering our detailed understanding of the depositional processes within a sedimentary environment. It is this type of study which should be conducted next on the Okse Bay Group of southwestern Ellesmere Island. However, the principal difficulty with this approach to the Okse Bay Group in this area is the quality of the exposures. While the Okse Bay Group is well exposed (some formations better than others) the rock is sufficiently frost heaved in many areas to render the determination and examination of a vertical succession of facies and the acquisition of paleocurrent data very difficult to impossible. The success of this study is principally the result of having the helicopter hours to locate those sections which are most amenable to this type of detailed work. For more intensive local investigations only the best preserved exposures could be used and these are not abundant on southwestern Ellesmere Island. More intensive investigations of these exposures should concentrate on <u>lateral</u> facies variability. Time constraints during this study allowed only the assessment of the vertical facies succession along one line of section at each location. Four locations within the study area would permit a more intensive study of this type; they are:

1) The Hecla Bay Formation exposed in the lower portion of section HB2 located approximately half-way up the western coast of North Kent Island; this is a short exposure (143 m) but the lateral facies variation is excellently preserved.

2) The Fram Formation exposed at section F4 on the inner, western margin of Goose Fiord; the Fram is moderately to well preserved in an ca. 300 m high exposure which has good lateral continuity and which could supply a reasonable three dimensional perspective due to two cliff faces which are at moderately high angles to each other.

3) The Hell Gate Formation at section F3 located approximately half-way up the Ellesmere side of Hell Gate; the preservation at this location is very good to excellent and the sea cliffs are easily climbed; cliff faces oriented at high angles to each other would provide a good three dimensional perspective and the lateral continuity of the channel-belt sandstones northward along the sea cliffs is on the order of kilometers.

4) The Hell Gate Formation at section HG2, located south of Bird Fiord; this is a spectacular ravine exposure of the formation ca. 300 m high and 1 km long. It is the best exposure in the Okse Bay Group on southwestern Ellesmere Island. While the preservation and lateral continuity is superb, lateral and vertical mobility on the ravine walls is limited and highly treacherous.

In addition to studies of lateral facies variability at the locations mentioned above, two other topics warrant additional investigation; they are:

1. The northeasterly directed vector mean determined for the fluvial Strathcona Fiord Formation at section S2, located northeast of the head of Muskox Fiord, is intriguing in its suggestion that Strathcona Fiord detritus in this area may have been derived from the Boothia Uplift. As mentioned previously, this sediment could be compositionally indistinguishable from sediment of eastern derivation. This possibility could be further investigated by acquiring paleocurrent and petrographic information from the formation on eastern Grinnell Peninsula and from outliers of the formation on Cornwallis Island.

2. Specialized petrologic work needs to be done to

attempt to confirm the origin of detrital chert grains in the Okse Bay Group of west-central and southwestern Ellesmere Island. Comparison of the trace element content of chert from these two areas of the Okse Bay Group with chert from the Hazen Formation of northern Ellesmere, the Narssarssuk and Dundas Formations of the Thule Basin, and any chert occurring in the carbonate rocks of the Arctic Platform could indicate which of these areas fed chert grains into the Okse Bay Group.

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Appendix A - Markov Chain Analysis

The following is an example of a contingency table analysis (Markov Chain Analysis) using BMDP-4F (Brown, 1983) on McMaster University's Vax computer. This program is an updated version of that used by Carr (1982). In the following example the input data is contained within the same file as the BMDP commands.

```
/PROBLEM TITLE IS 'MARKOV CHAIN ANALYSIS OF STRATHCONA FIORD
                   FORMATION AT SECTION S2'.
/INPUT VARIABLES ARE 2. TABLE = 9,9. FORMAT IS FREE.
/VARIABLE NAMES ARE ABOVE, BELOW.
/CATEGORY NAMES(1 TO 2) = '1A', '1B', '1C', '2A', '2C',
                          '2E', '2I', '2J', '6'.
          CODES(1 TO 2) = 1 TO 9.
/TABLE INDICES ARE ABOVE, BELOW.
      EMPTY ARE 1,1, 2,2, 3,3, 4,4, 5,5, 6,6, 7,7, 8,8, 9,9.
/FIT MODEL = A,B. CELL IS STANDARDIZED.
     STEP = 9. PROB = 0.20.
/PRINT EXPECTED.
/END
0 0 0 2 18 0 1 1 1
0 0 0 1 0 0 1 0 0
0 0 0 0 2 0 0 0 0
0 0 0 0 5 0 0 0 2
14 0 1 0 0 4 0 0 10
1 0 0 0 0 0 0 0 3
0 0 0 0 0 0 0 0 2
0 0 0 1 0 0 0 0 0
10 2 0 3 2 0 0 0 0
```

Contents Of Pocket

Figure 3.2.2.2-2

Figure 4.1-1

Explanation Diagram For Figure 4.1-1

Figure 4.2-1

Legend For Stratigraphic Sections

Stratigraphic Sections (11):

- Figure 2.1.4.4-2 (Section S1)
- Figure 2.1.5.4-2 (Section S2)
- Figure 2.1.6.4-2 (Section HB1)
- Figure 2.2.5.1-2 (Section F4)
- Figure 2.2.6.1-2 (Section HB2)
- Figure 2.3.4.1-1 (Section F5)
- Figure 2.3.5.1-2 (Section HG2)
- Figure 2.3.6.1-1 (Section F2)
- Figure 2.3.8.1-2 (Section F3)
- Figure 2.4.6.1-2 (Section HG1)
- Figure 2.4.7.1-1 (Section HG3)

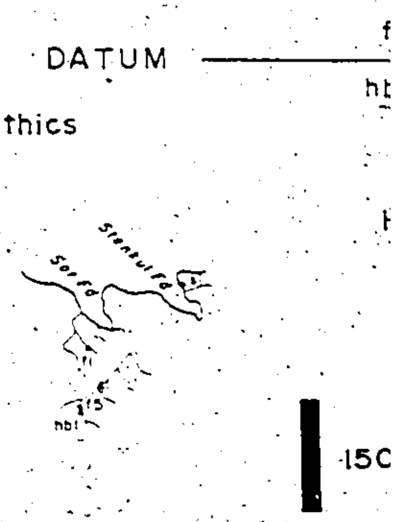
LEGEND

Formations

bl - Blue Fiord Fm.
b - Bird Fiord Fm.
sf - Strathcona Fiord Fm.
hb - Hecla Bay Fm.
f - Fram Fm.
hg - Hell Gate Fm.
np - Nordstrand Point Fm.

Mineralogy

quartzose grains
feldspar
non-quartzose lithics



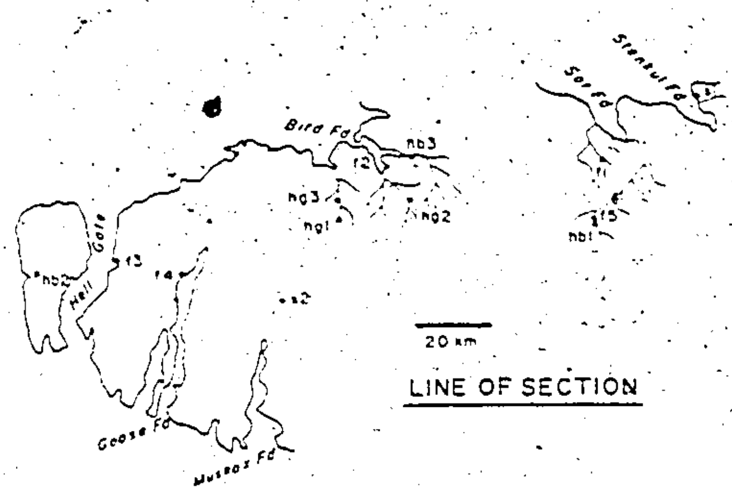
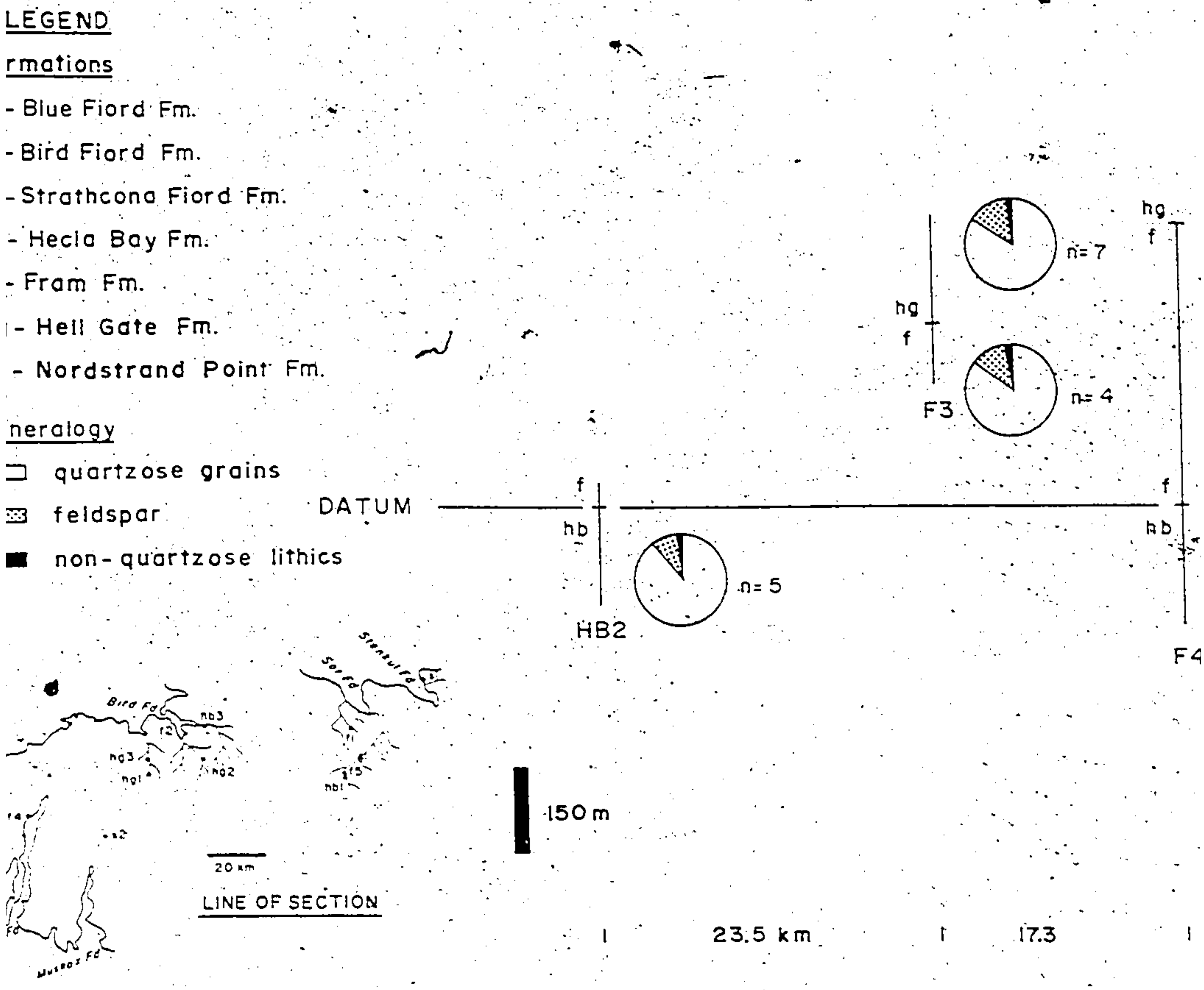
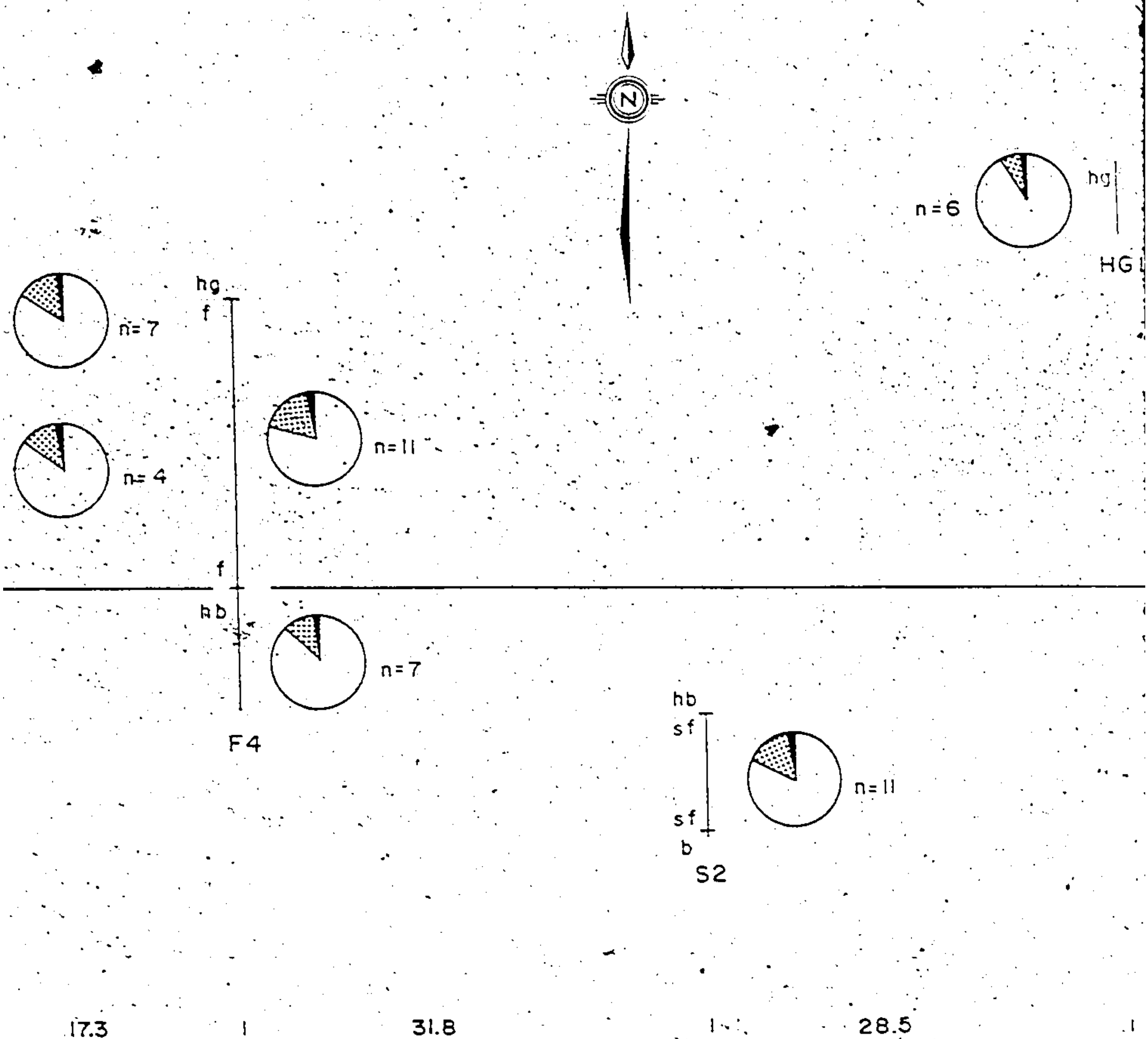


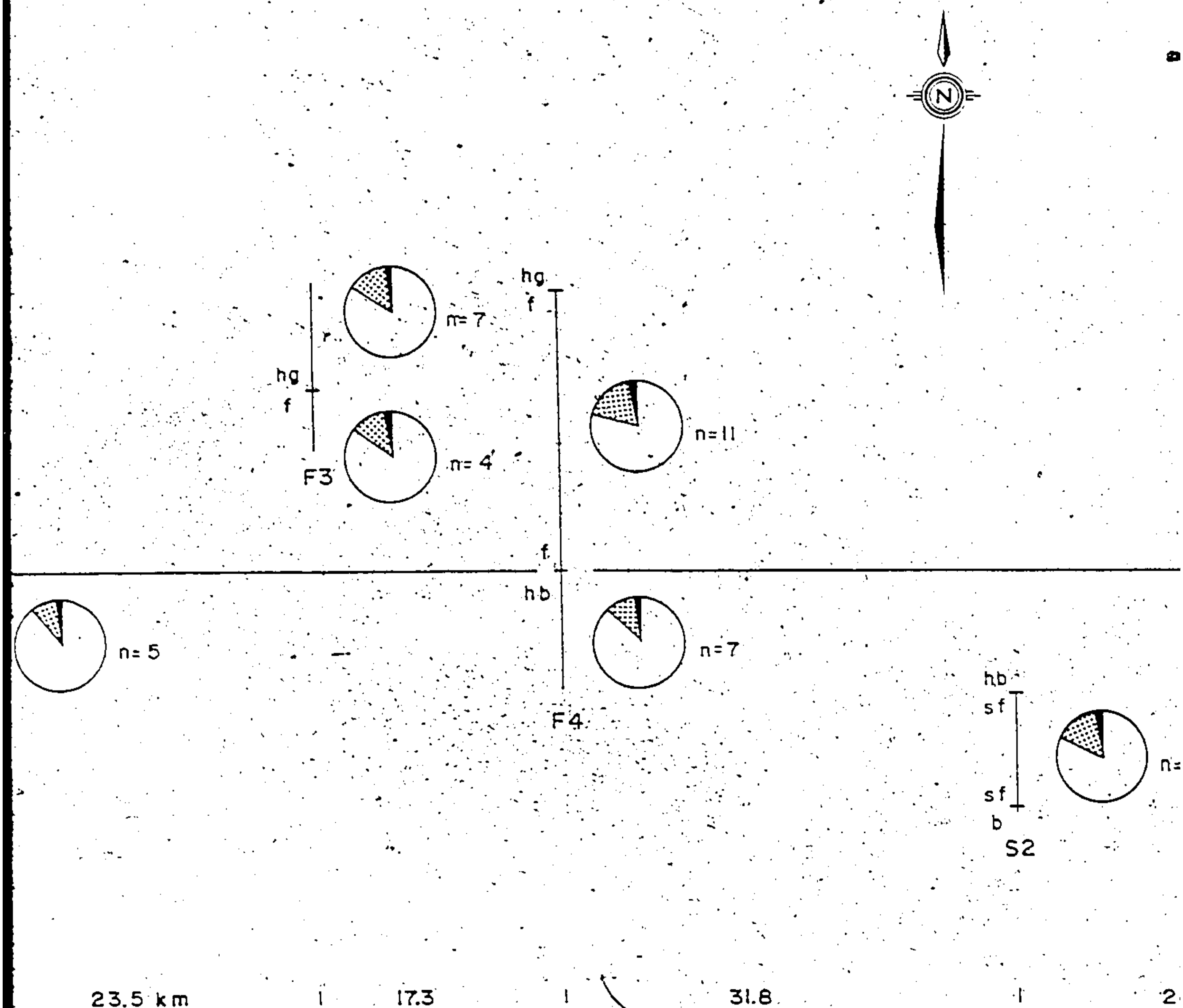
Figure 3.2.2.2-2 ESTIMATED DETRITAL QFL IN THE OKSE BAY GROUP



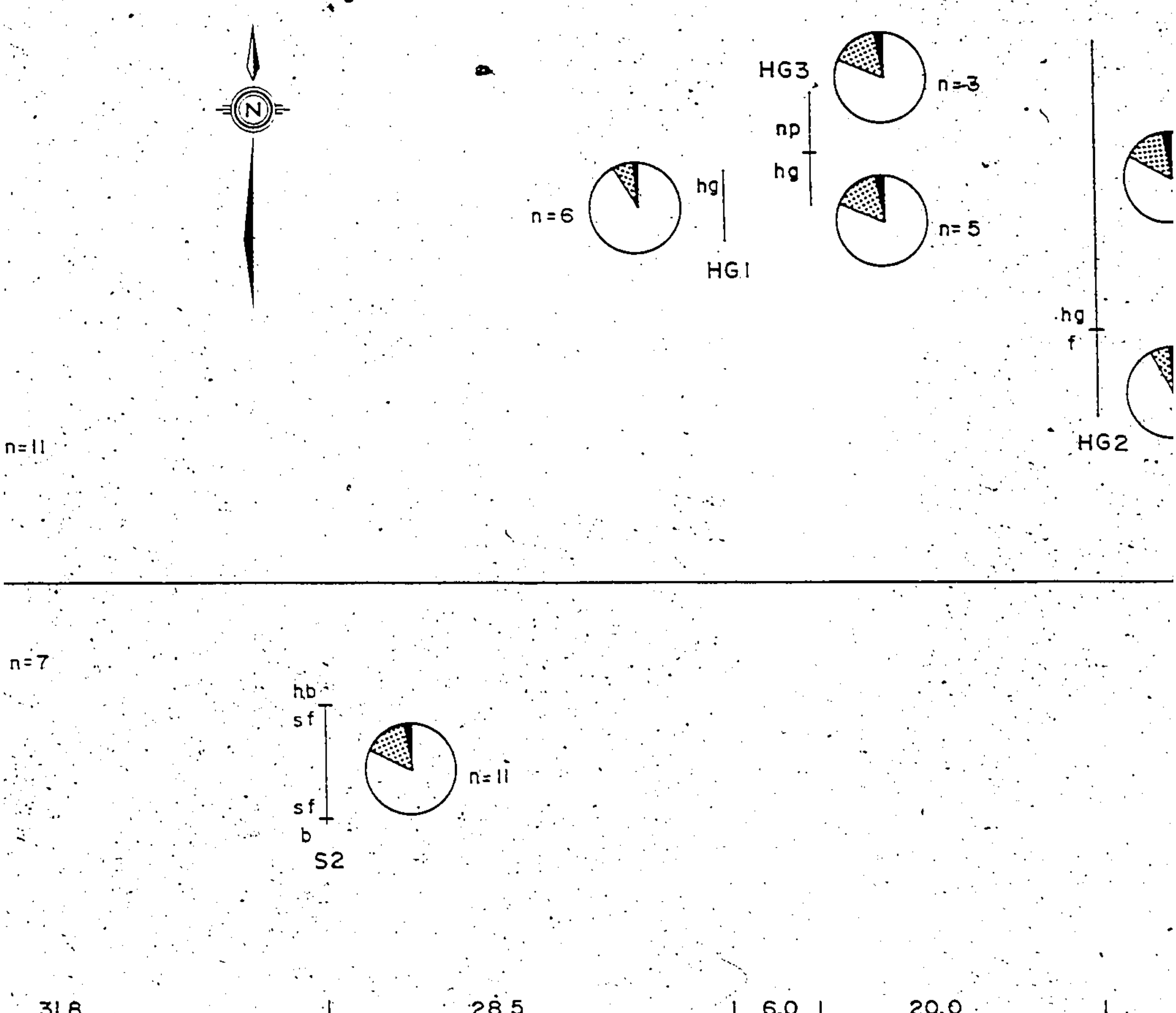
.2.2-2 ESTIMATED DETRITAL QFL % COMPOSITION OF COARSE SILTS IN THE OKSE BAY GROUP ON SOUTHWESTERN ELLESMERE



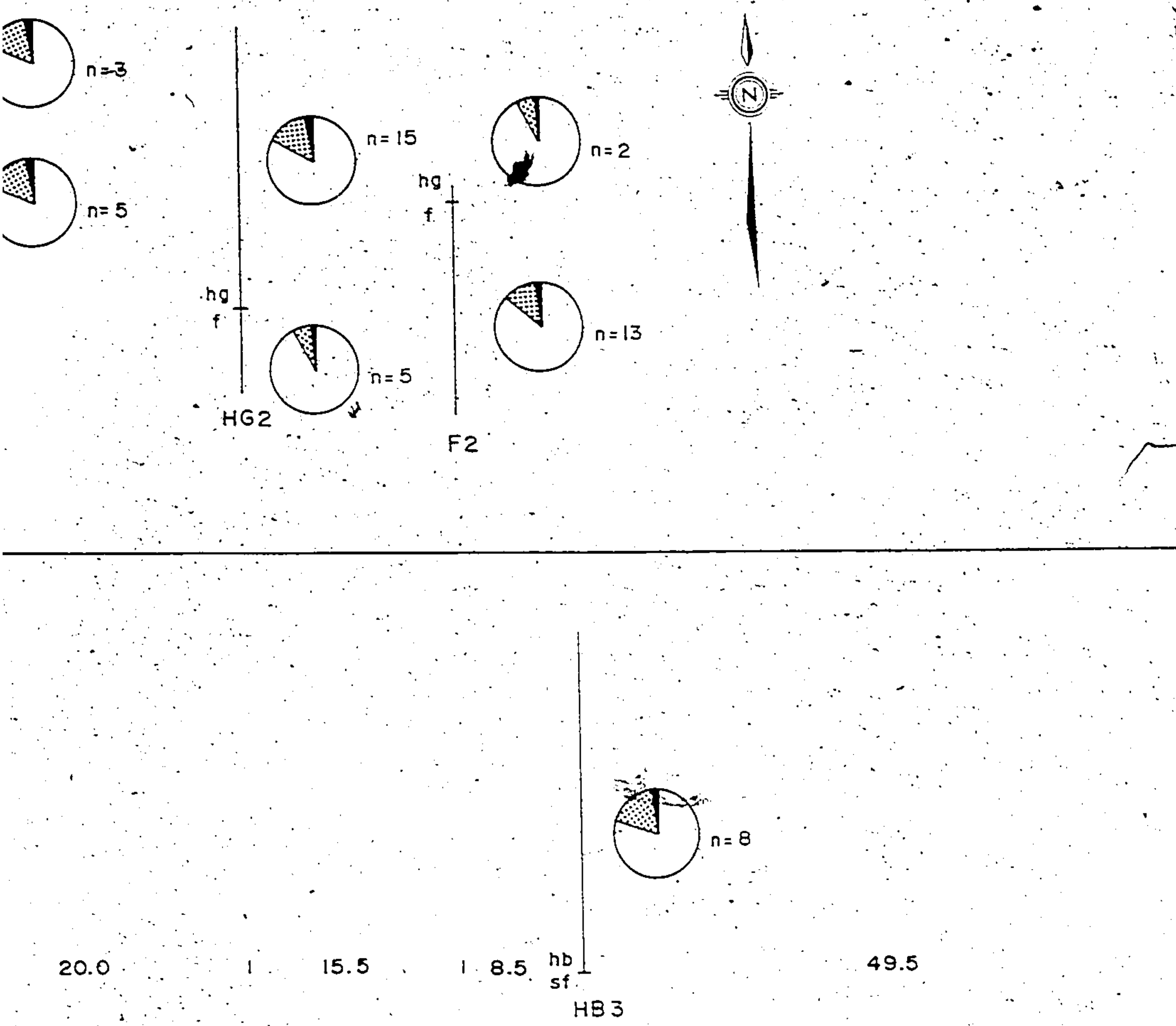
COARSE SILTSTONE AND SANDSTONE
ELLESMERE ISLAND AND NORTH KENT ISLAND



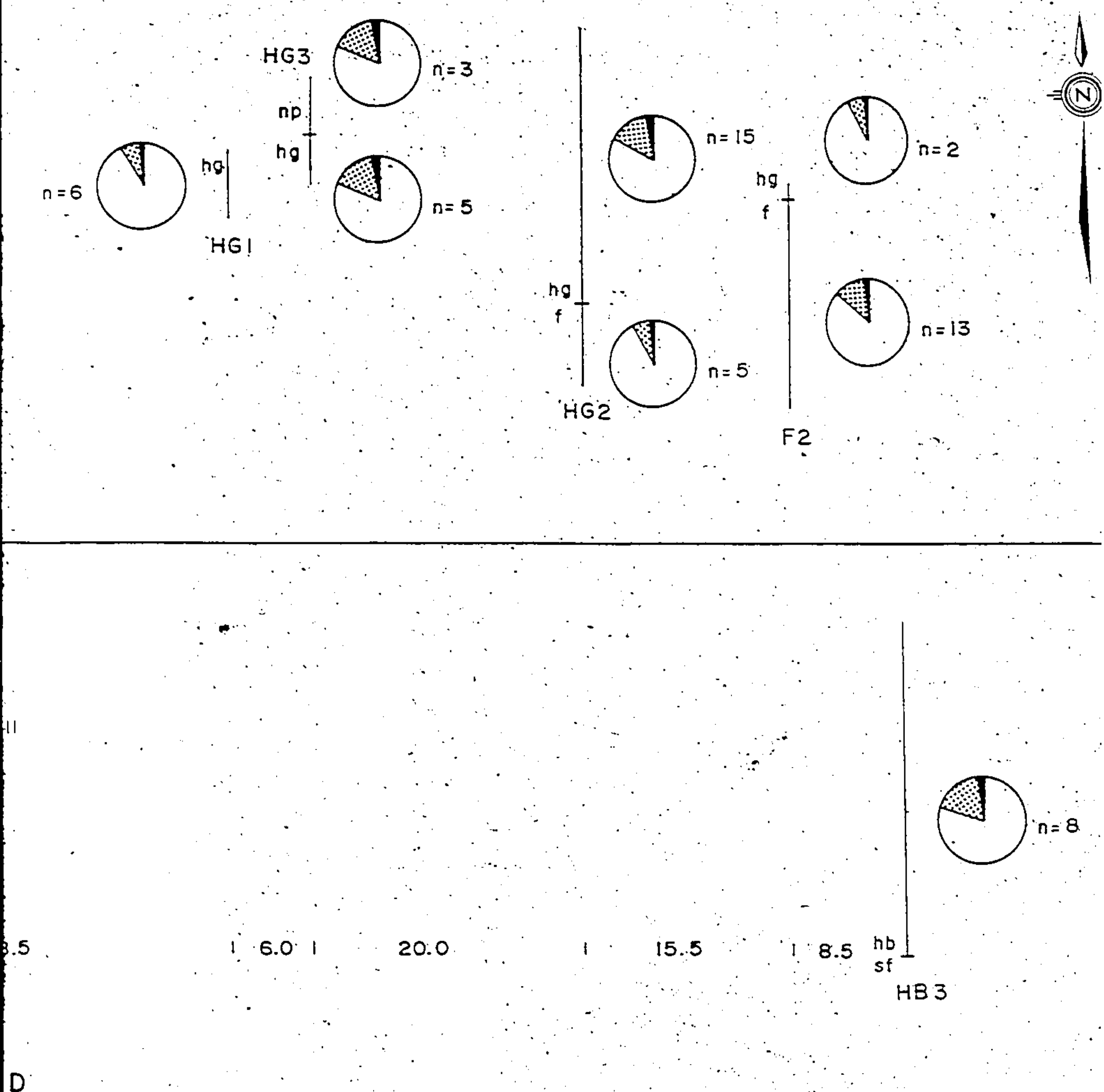
COMPOSITION OF COARSE SILTSTONE AND SANDSTONE
SOUTHWESTERN ELLESMERE ISLAND AND NORTH KENT ISLAN



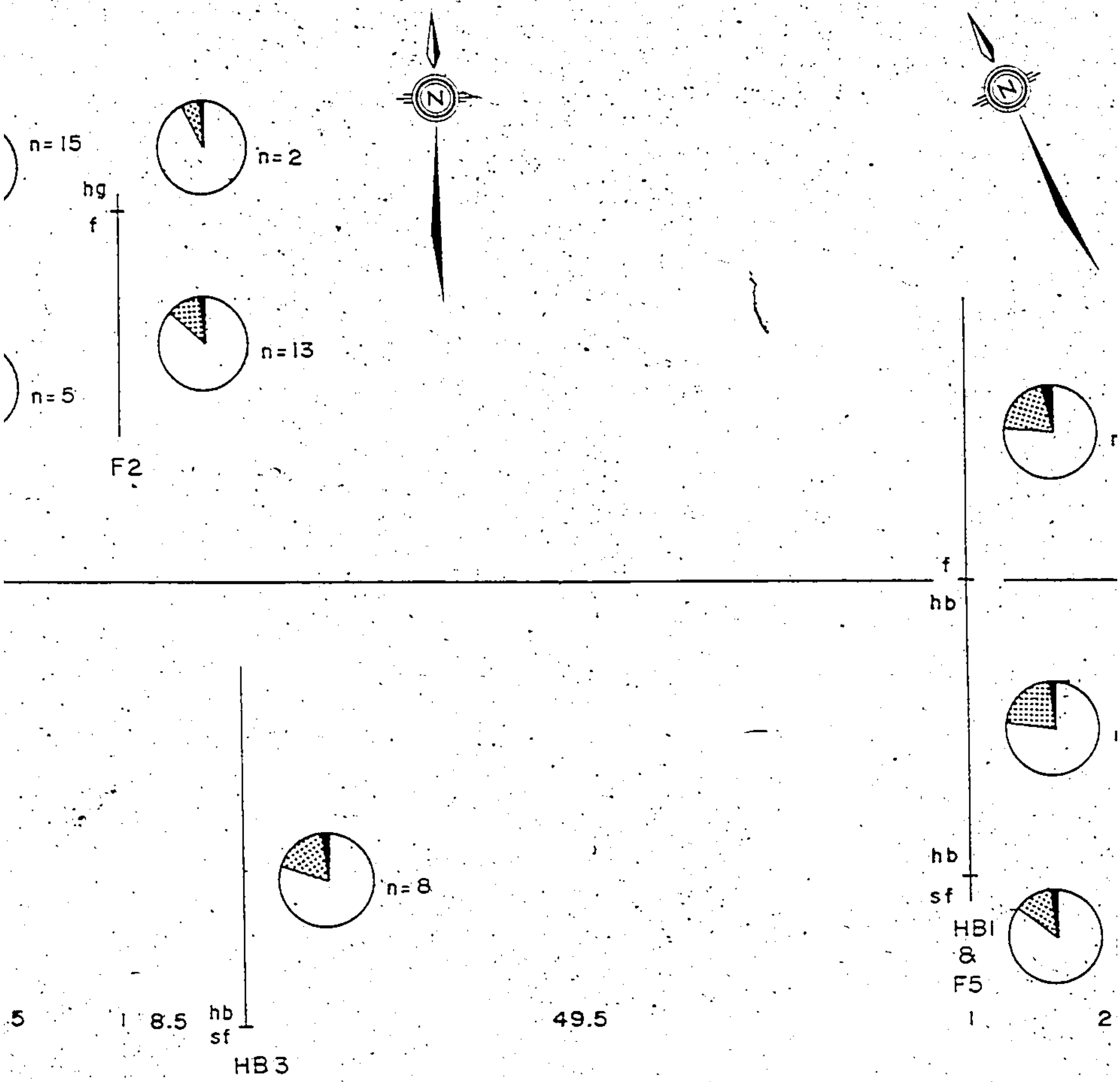
AND SANDSTONE
D AND NORTH KENT ISLAND

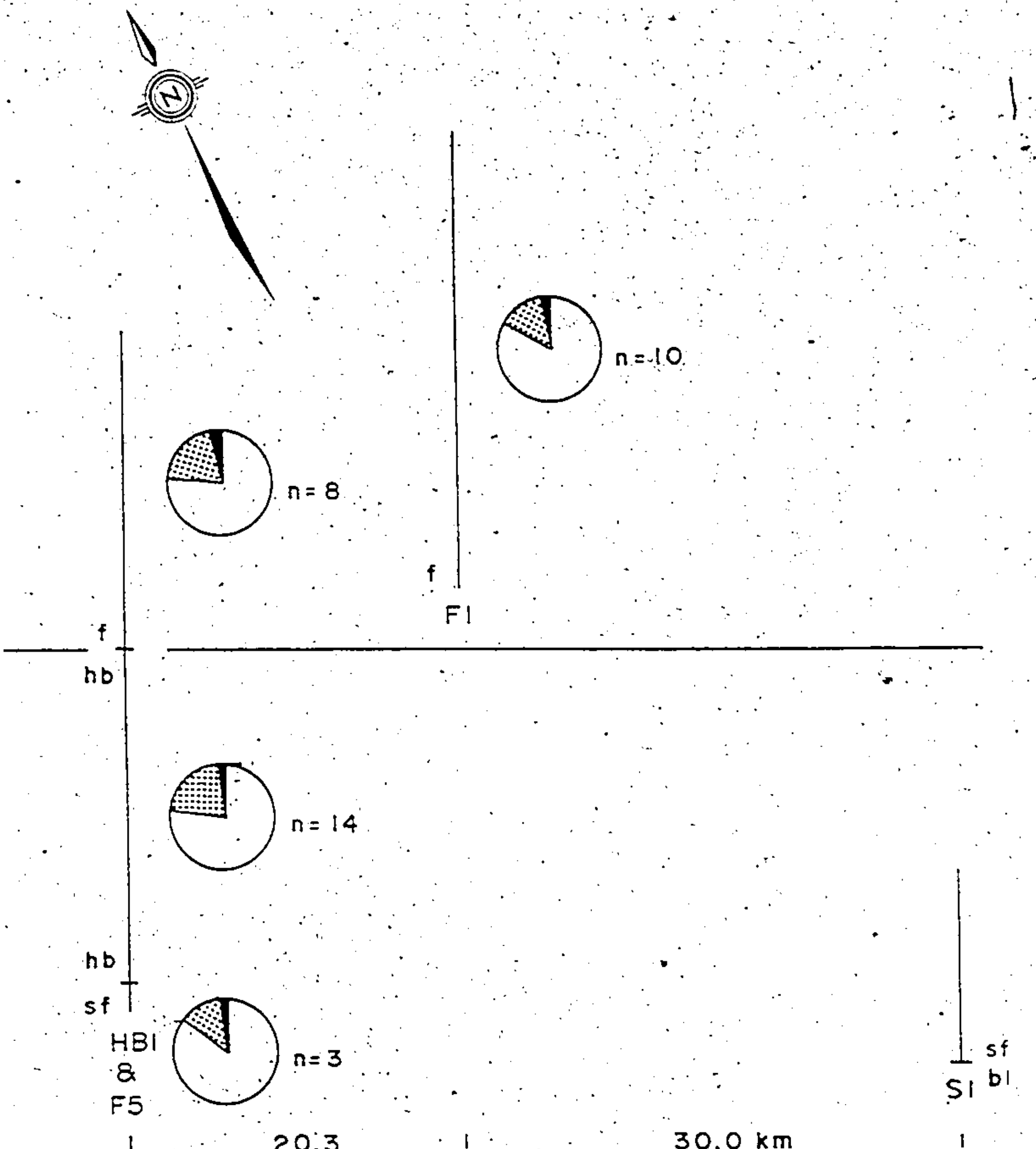


n=3
n=5
n= 15
hg
f
n= 5
HG2
n= 2
hg
f
n= 13
F2
N
n= 8
20.0
15.5
8.5
hb
sf
HB3
49.5



HG3
n=3
np
hg
n=6
hg
HG1
n=5
n=15
hg
f
n=5
HG2
n=2
hg
f
n=13
F2
N
n=8
6.0
20.0
15.5
8.5
hb
sf
HB3
D


n= 15
n= 2
hg
f
n= 13
n= 5
F2
f
hb
n= 8
hb
sf
HB1
&
F5
.5
1
8.5
hb
sf
HB3
49.5
1
2



N
n=10
n= 8
f
F1
f
hb
n= 14
hb
sf
HB1
&
F5
n=3
sf
bl
S1
20.3
30.0 km

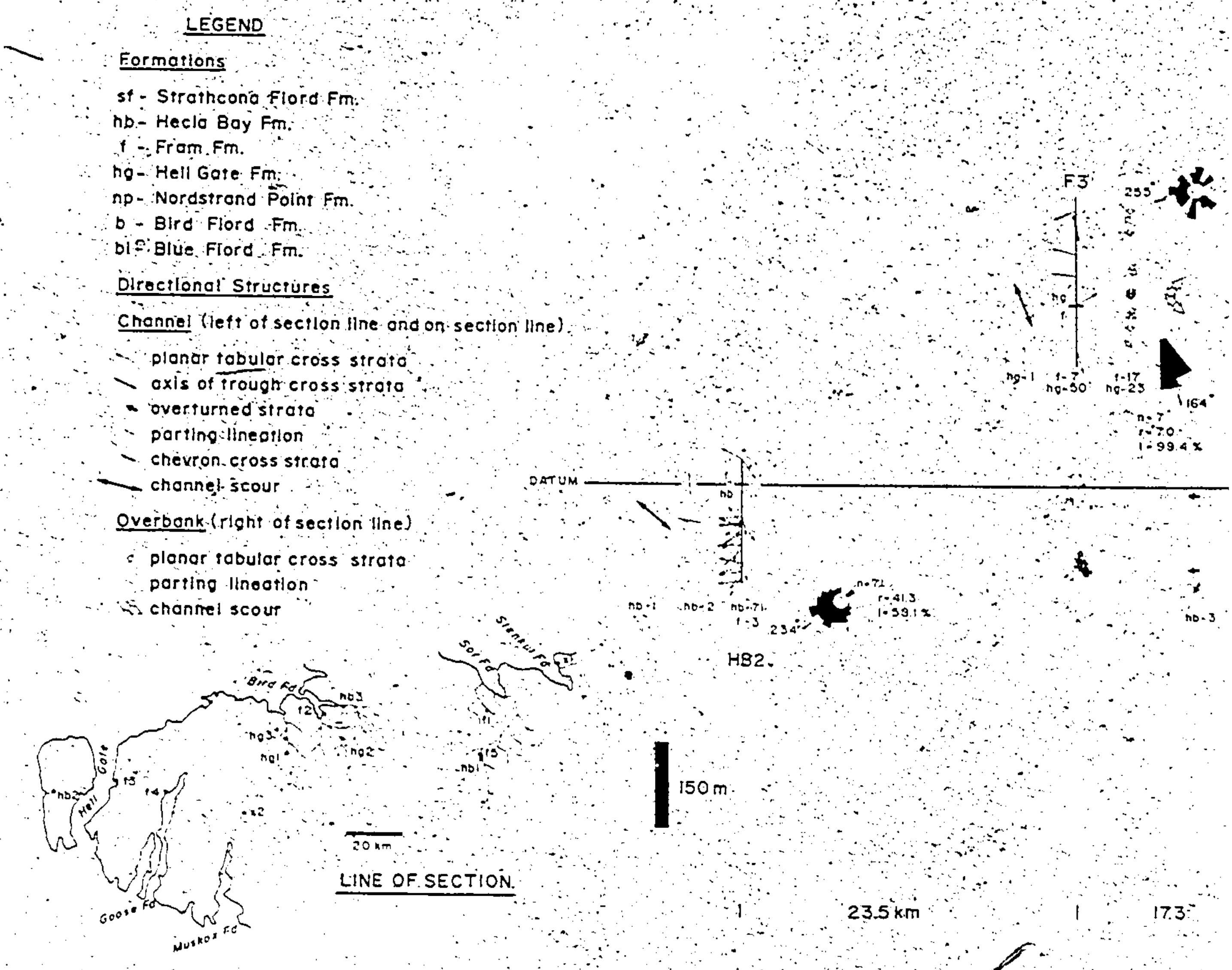
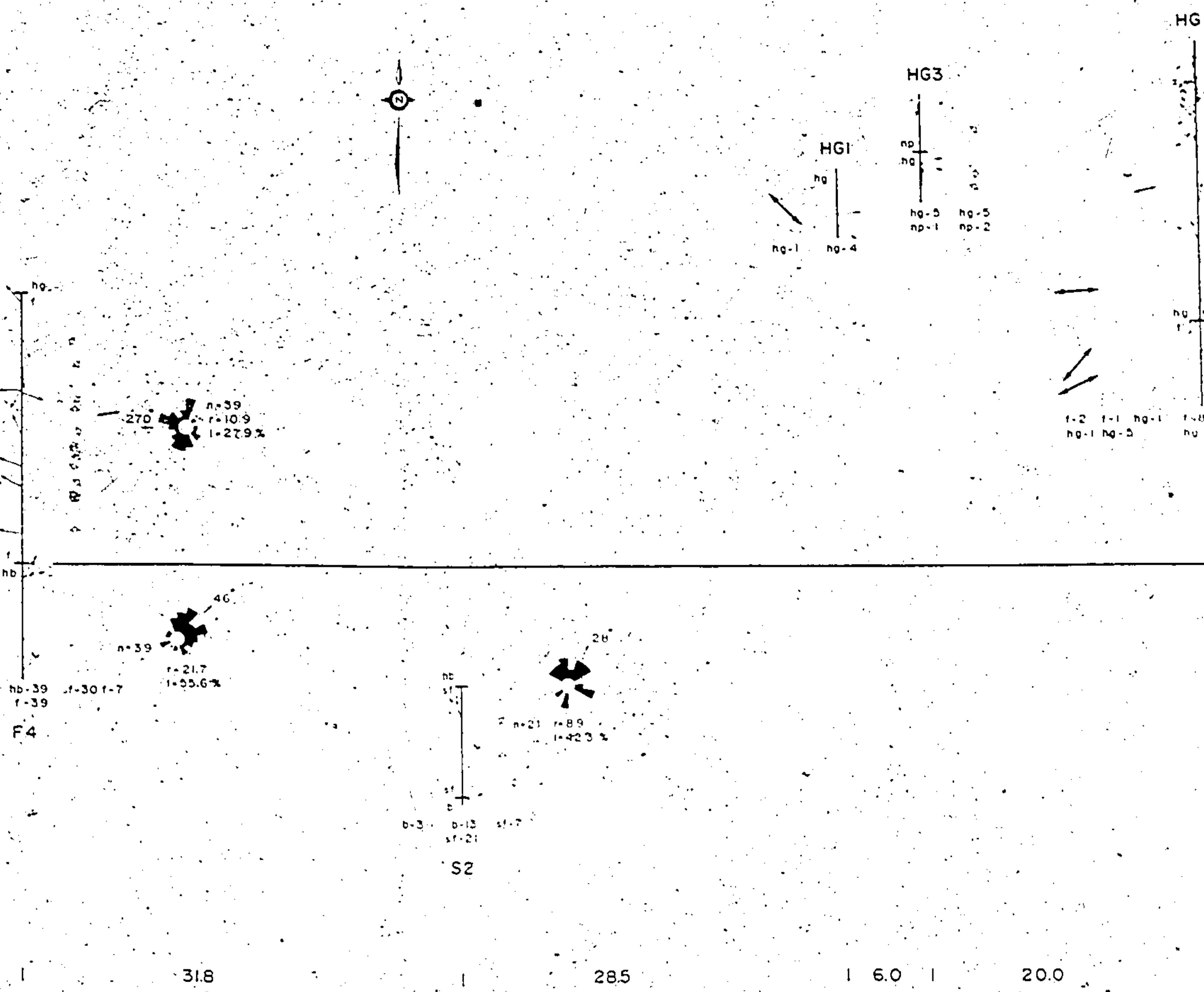
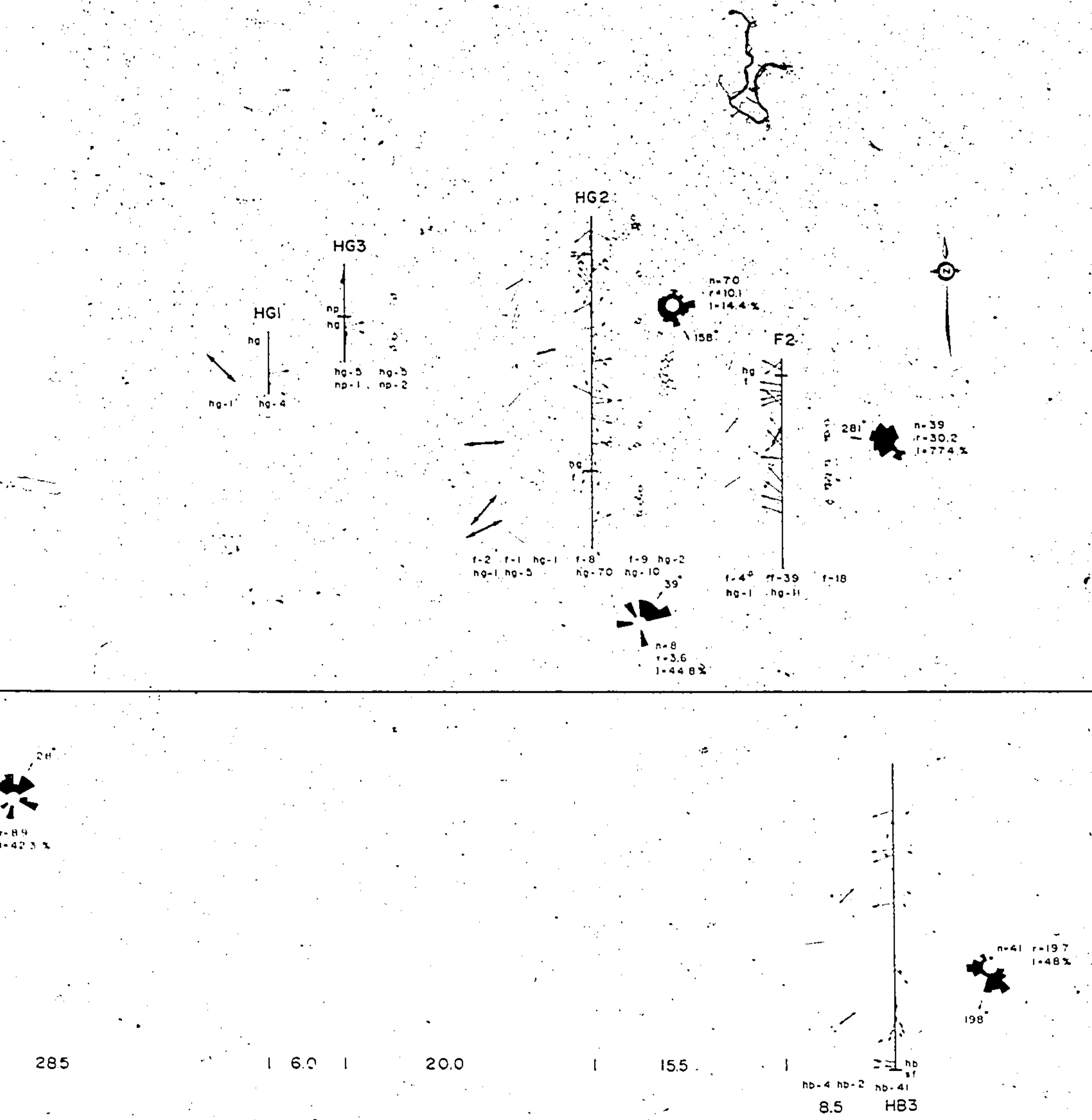


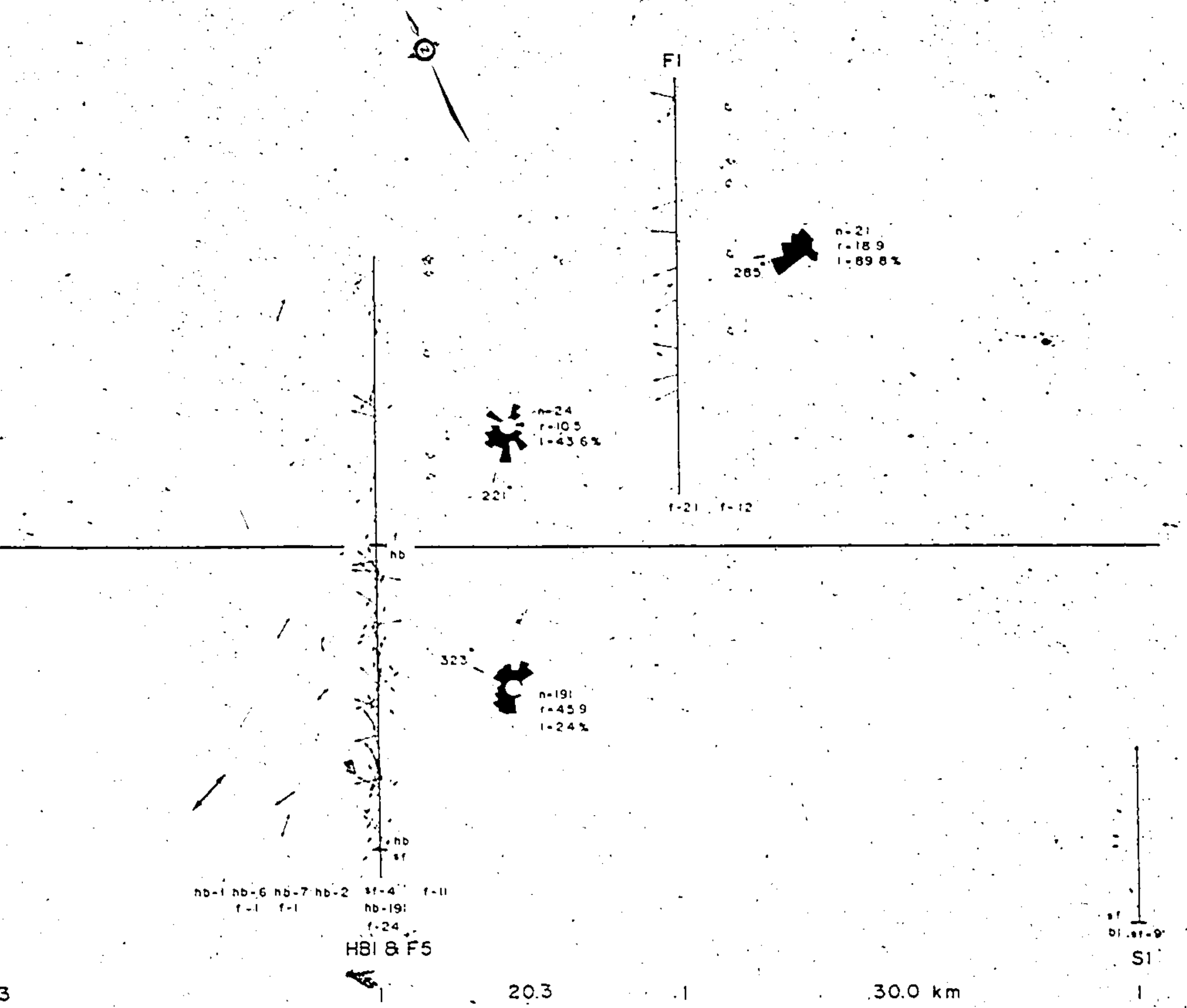
Figure 4.1-1 DIRECTIONAL STRUCTURES IN THE OKSE BAY GROUP ON SOUTHWESTERN ELLESMERE ISLAND AND NORTH KENT ISLAND

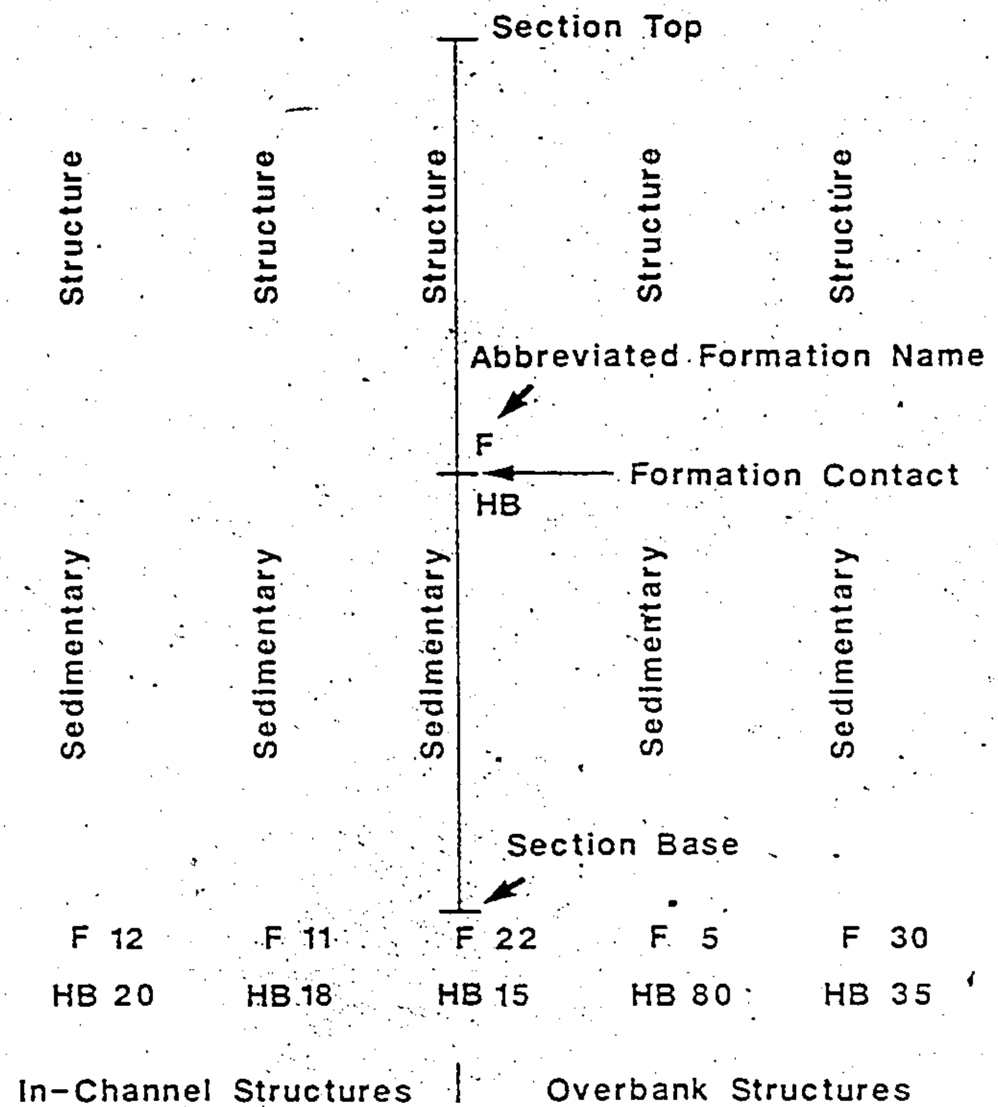


HG3
HG1
HG
hg-1
hg-4
hg-5
np-1
hg-5
np-2
n=39
r=10.9
l=27.9%
270
46
n=39
r=21.7
l=55.6%
hb-39
f-39
sf-30
f-7
F4
28
n=21
r=8.9
l=42.3%
b-3
b-13
sf-21
sf-7
S2
f-2
hg-1
f-1
hg-5
hg-1
31.8
28.5
6.0
20.0



HG1
hg
hg-1
hg-4
HG3
np
hg
hg-5
np-1
hg-5
np-2
HG2
hg
f
f-2
hg-1
f-1
hg-5
hg-1
f-8
hg-70
f-9
hg-10
hg-2
n=70
r=10.1
I=14.4 %
158°
39°
n=8
r=3.6
I=44.8%
F2
hg
f
f-4
hg-1
ff-39
hg-11
f-18
281°
n=39
r=30.2
I=77.4 %
28°
r=8.9
I=42.3 %
285
6.0
20.0
15.5
8.5
hb
sf
hb-4
hb-2
hb-41
HB3
n=41
r=19.7
I=48 %
198°


F1
n-21
r-18.9
I-89.8%
285
n-24
r-10.5
I-43.6%
221
f-21
f-12
f
hb
323
n-191
r-45.9
I-24%
hb
sf
hb-1
hb-6
hb-7
hb-2
sf-4
f-11
f-1
f-1
hb-191
f-24
HB1 & F5
sf
bl sf-9
S1
3
20.3
30.0 km



Abbreviated formation name and number of measurements per formation are aligned vertically under each type of sedimentary structure

Explanation Of Figure 4.1-1

LEGEND FOR STRATIGRAPHIC SECTIONS IN THE OKSE BAY GROUP ON S.W. ELLESMERE ISLAND AND NORTH KENT ISLAND

Colour

orange – o
brown – b
grey – g
black – k
white – w
green – n
red – r

Sedimentary Structures

cross stratification,
planar tabular and trough –
parallel lamination –
ripple cross lamination –
climbing ripple drift cross lamination –
soft sediment deformation –
mudcracks –

Paleontology

ostracoderm fragments –
plant remains –
trace fossils –
pelecypods –
brachiopods –
stromatolites –
cephalopods –
gastropods –
trilobites –
roots –

Other

shale/siltstone clasts –
pedogenic nodules –
chert clasts –
internal scours –

Scale: 1 : 787.40

Base of section : 5

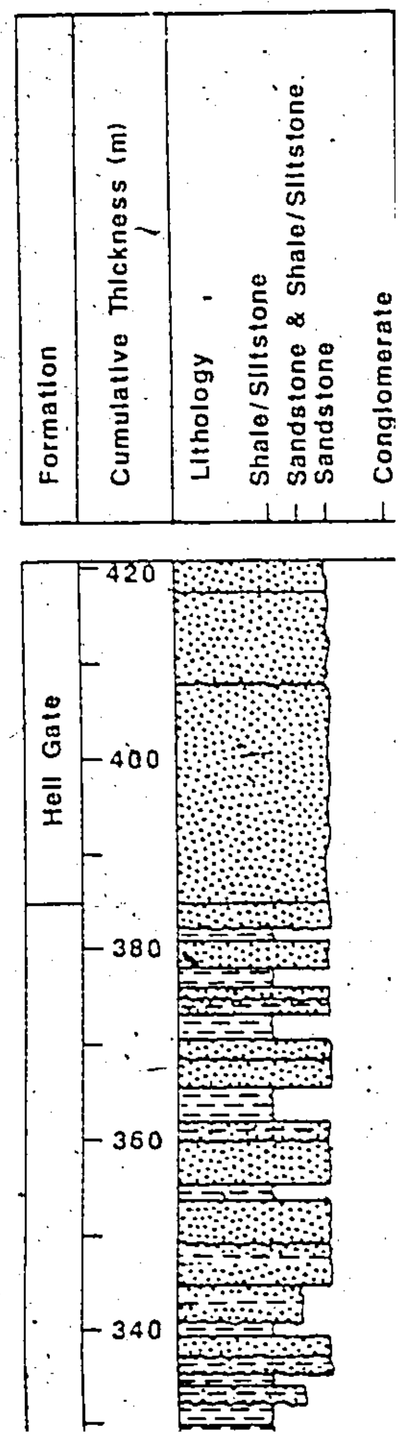


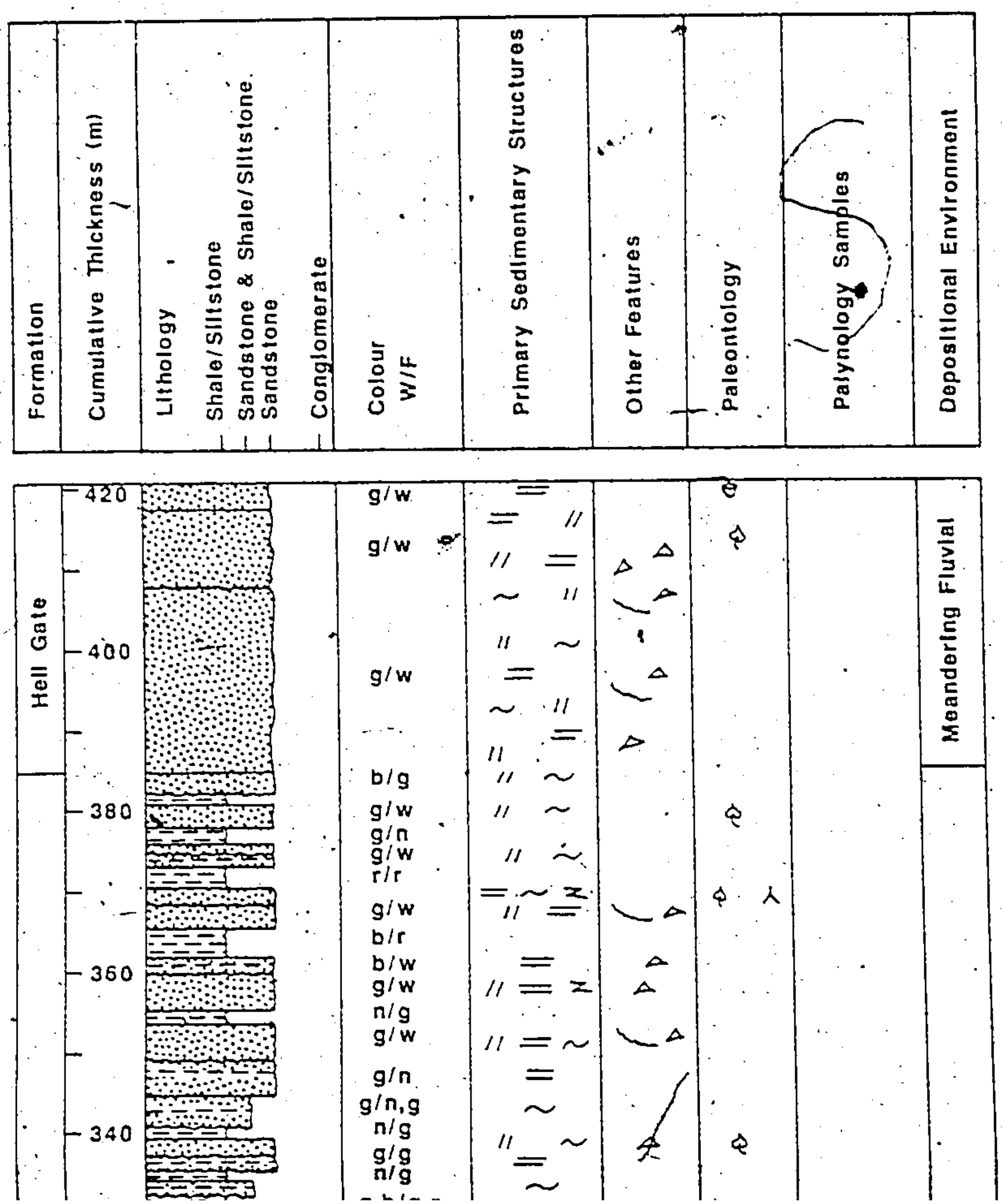
Figure 2.3.6.1-1

SECTION F2

Base of section : 505250 E., 8562675 N., UTM Zone 16x

NTS 49C

Baumann Fiord Sheet



-1

'5 N., UTM Zone 16x

eet

Other Features	Paleontology	Palynology Samples	Depositional Environment
			Meandering Fluvial

F

Base of section : 51

B

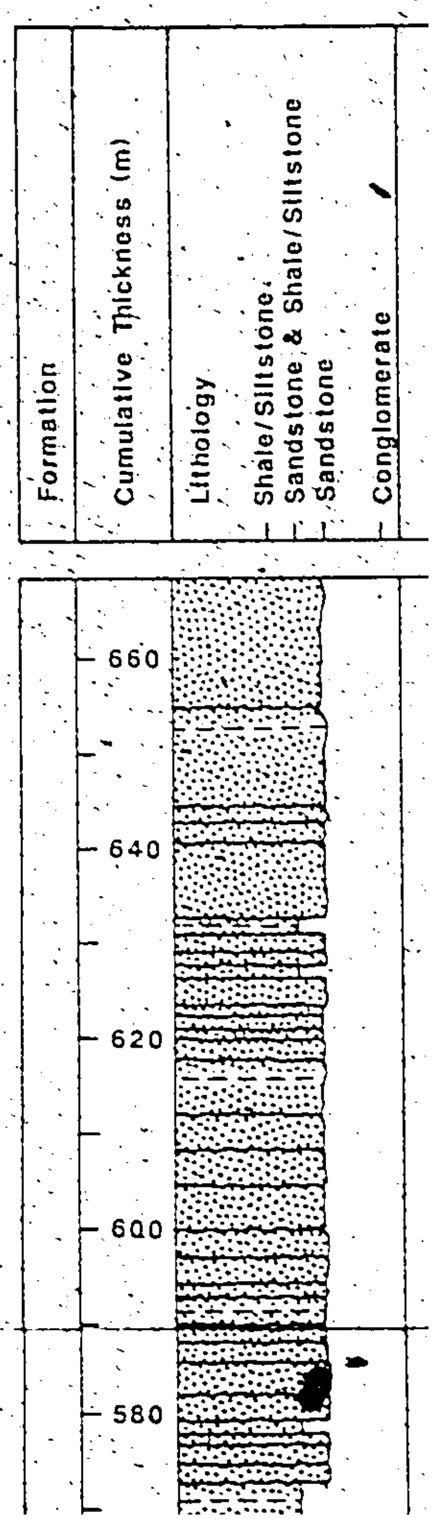


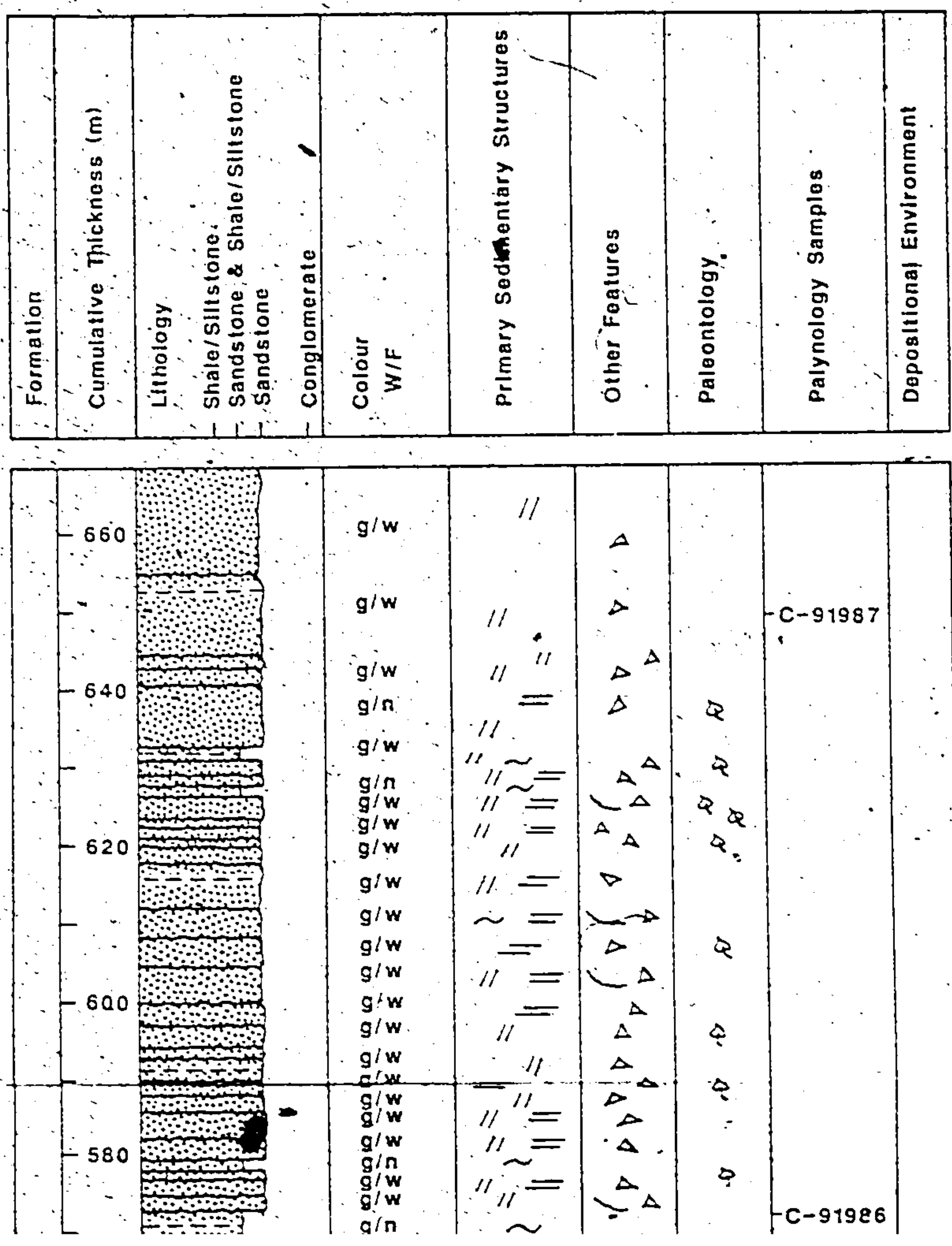
Figure 2.3.5.1-2

SECTION HG2

Base of section : 515500 E., 8550875 N., UTM Zone 16x

NTS 49C

Baumann Fiord Sheet



.1–2

HG2

0875 N., UTM Zone 16x

C

Sheet

Other Features	Paleontology	Palynology Samples	Depositional Environment
		C-91987	
		C-91986	

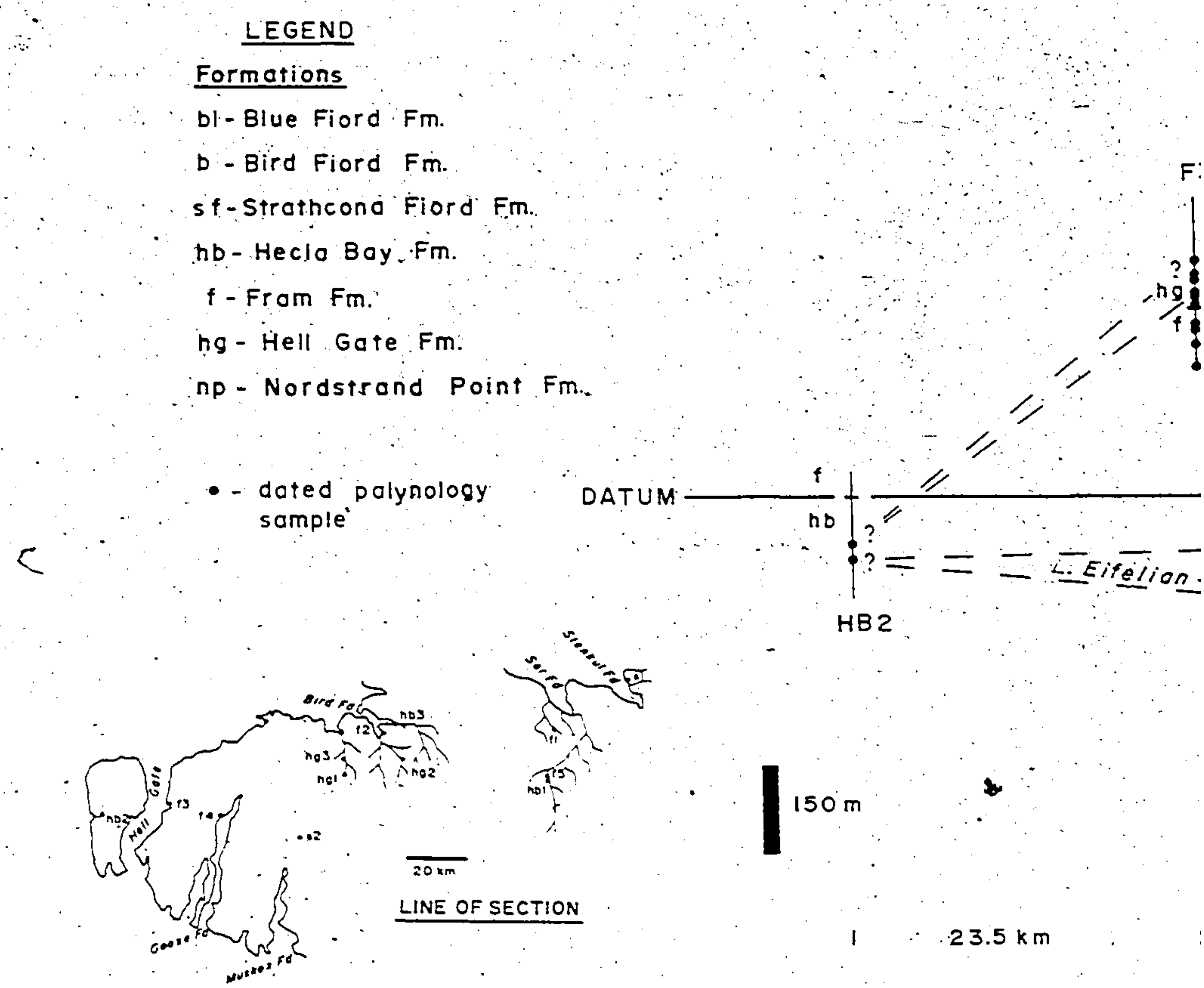
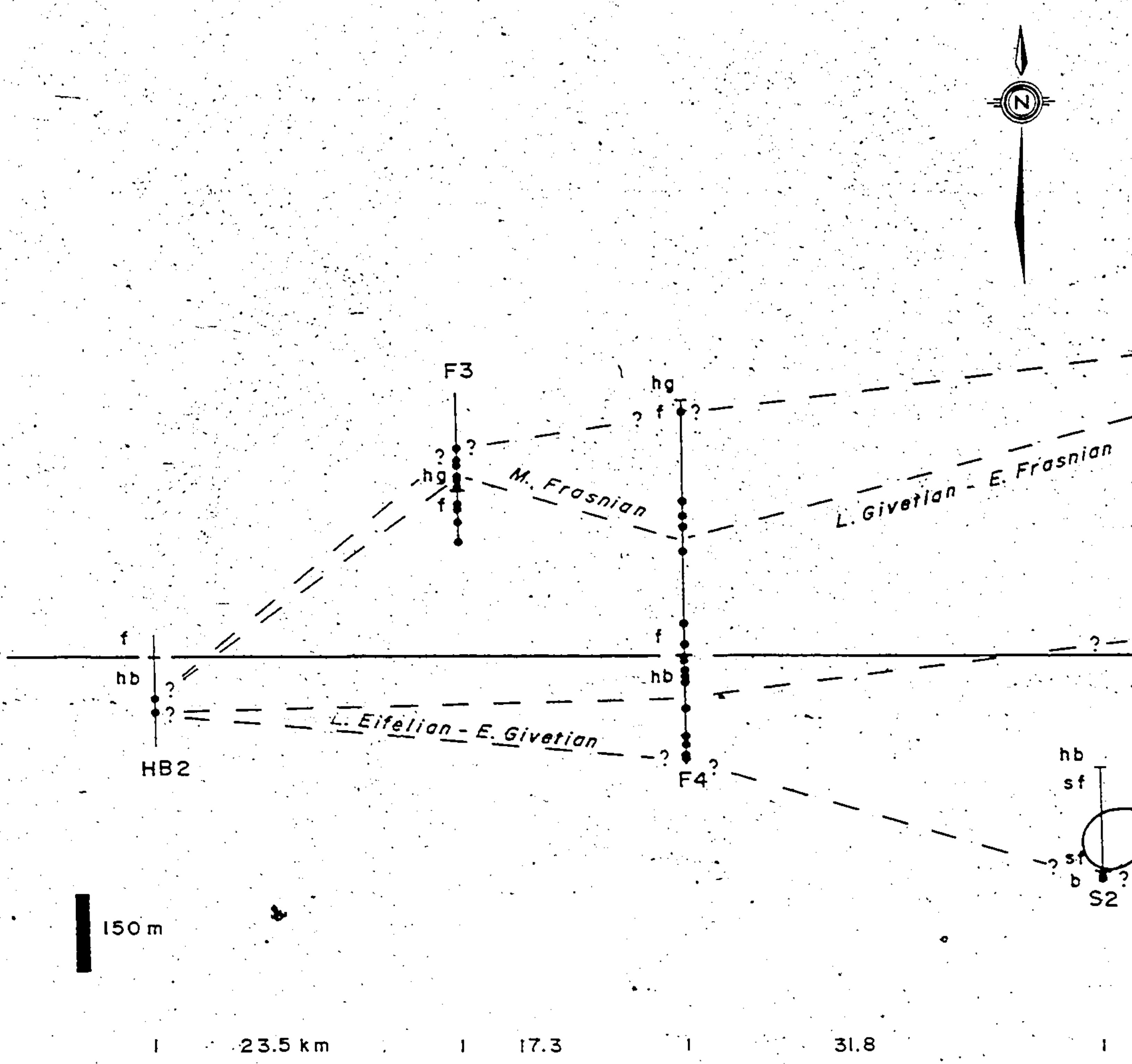
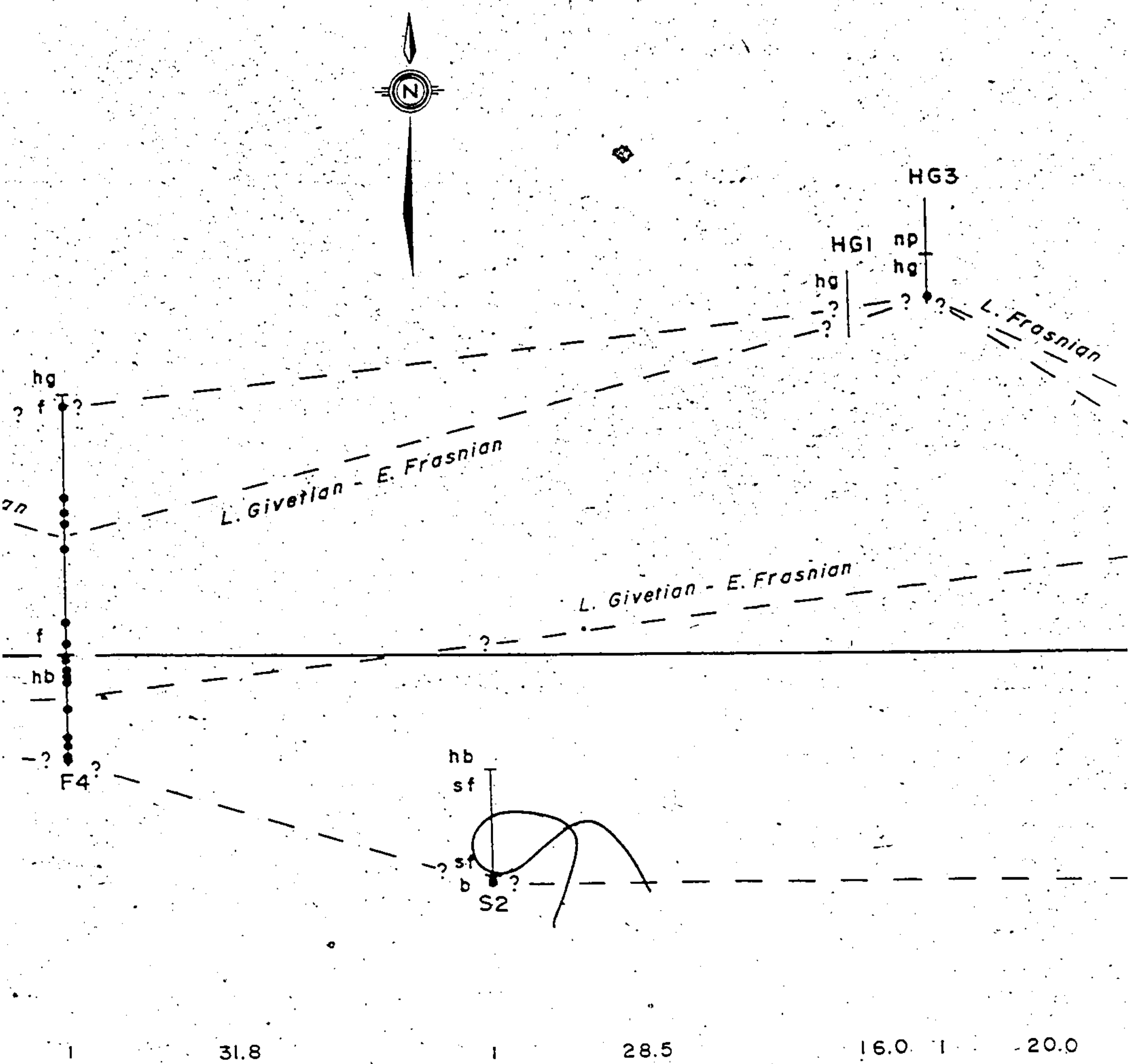


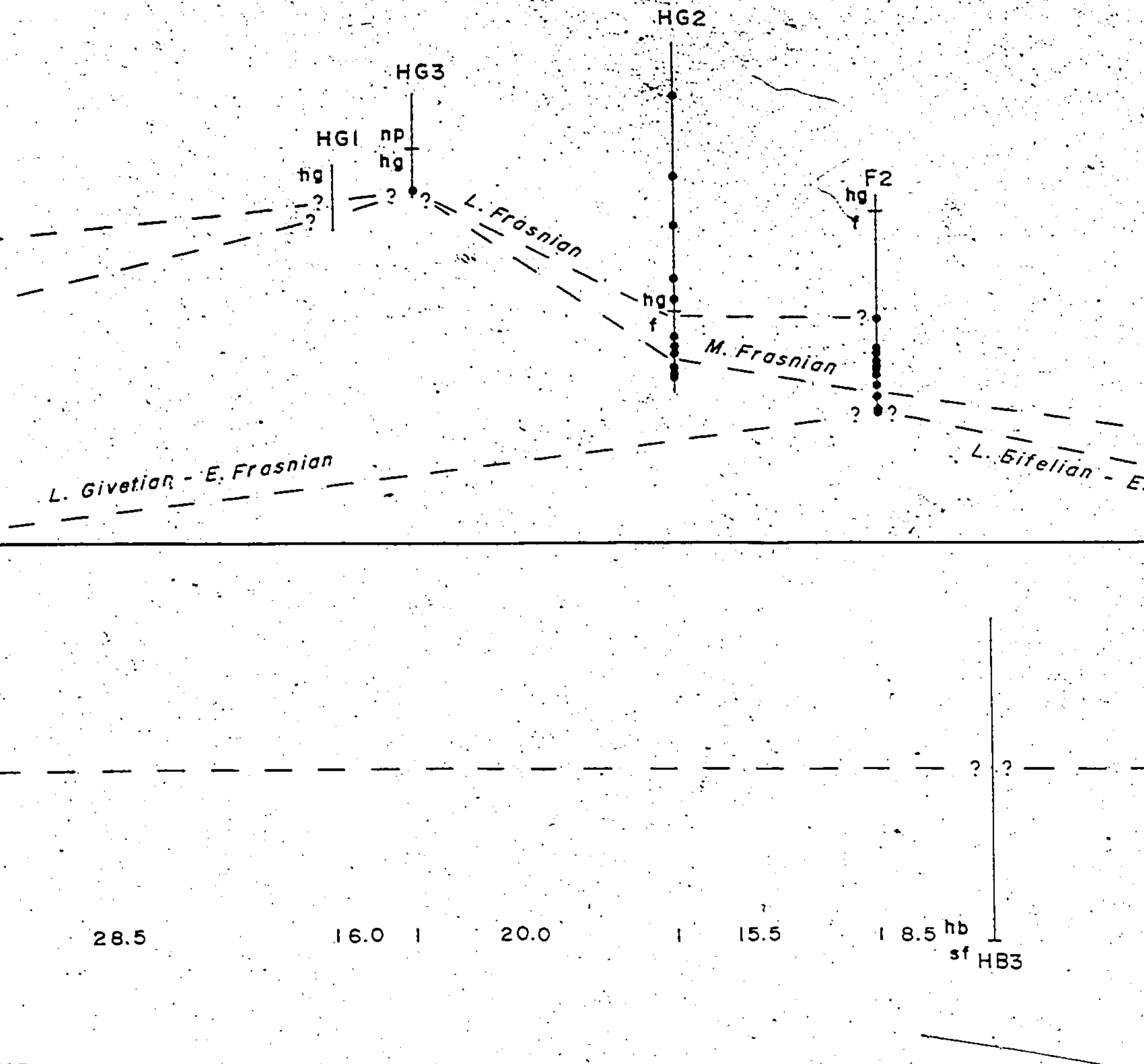
Figure 4.2-1 BIOSTRATIGRAPHIC CORRELATION IN THE OKSE BAY GRC
AND NORTH KENT ISLAND



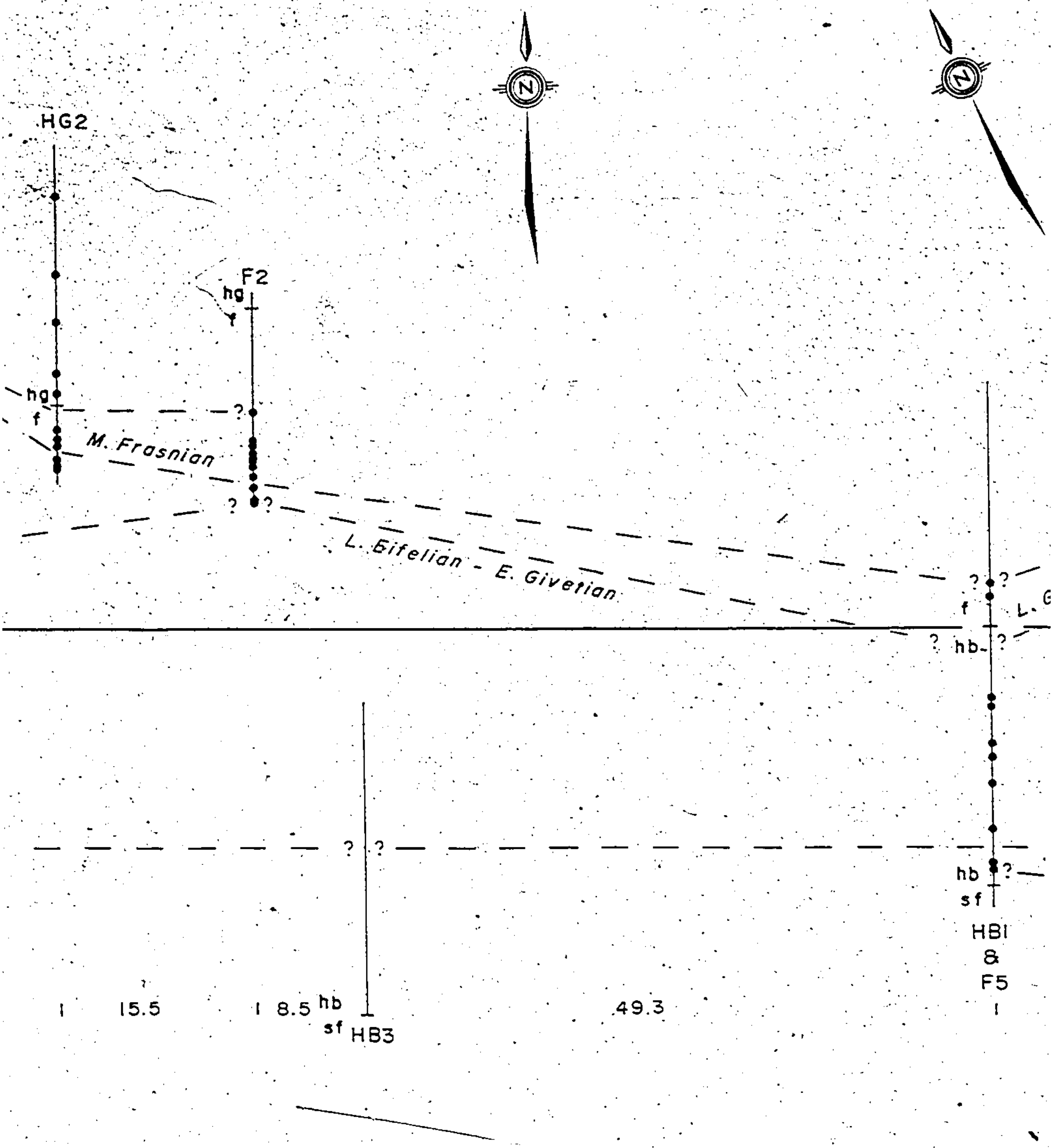
TION IN THE OKSE BAY GROUP ON SOUTHWESTERN ELLESMERE ISLA

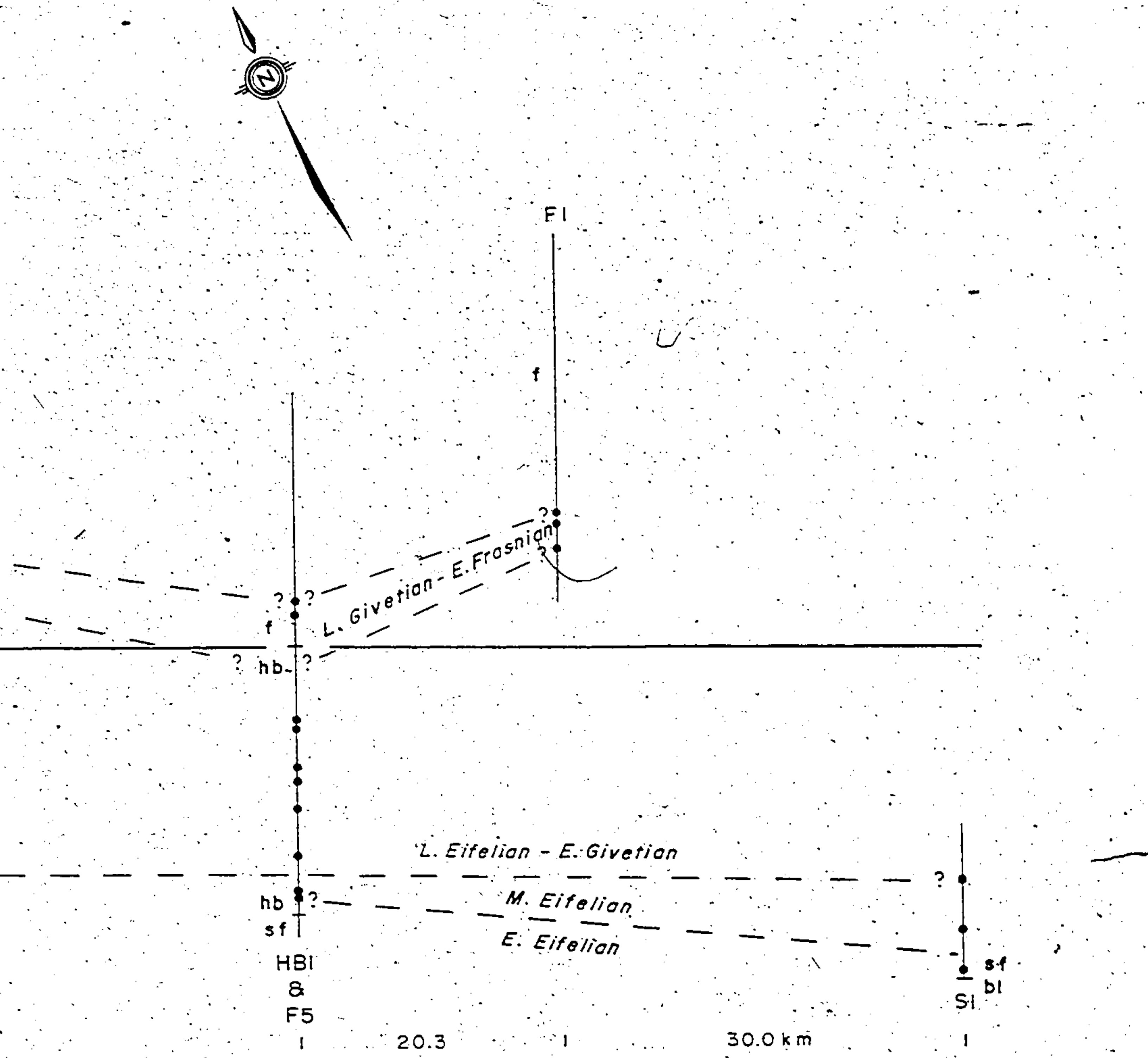


)UTHWESTERN ELLESMERE ISLAND

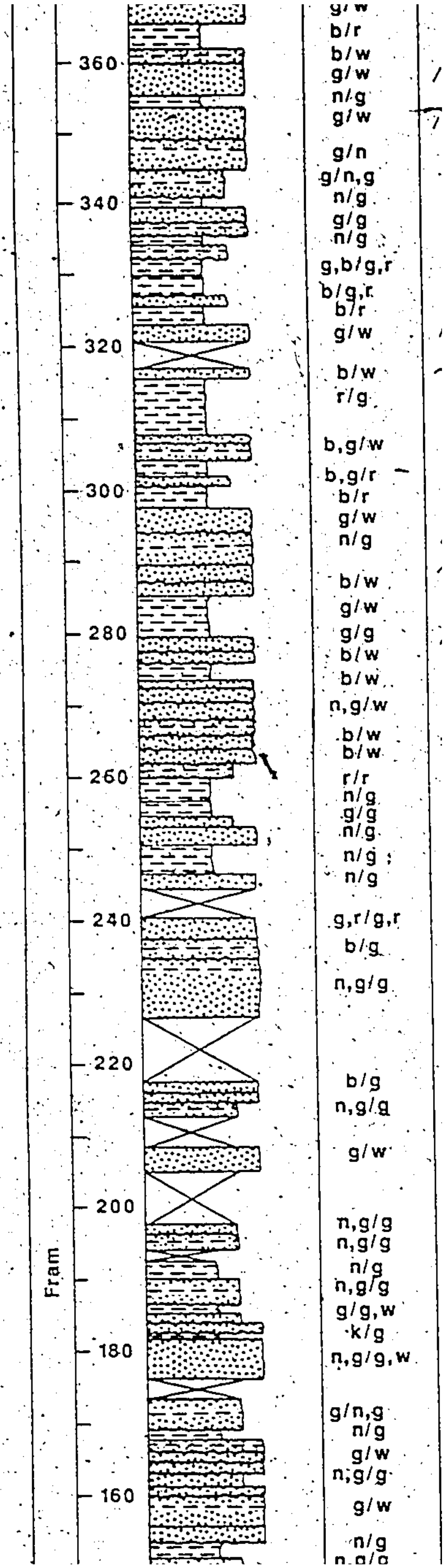

HG2
HG3
HG1
np
hg
hg
?
?
?
?
L. Frasnian
F2
hg
f
hg
f
?
M. Frasnian
?
?
L. Eifelian - E
L. Givetian - E. Frasnian
?
?
28.5
16.0
20.0
15.5
8.5
hb
sf
HB3

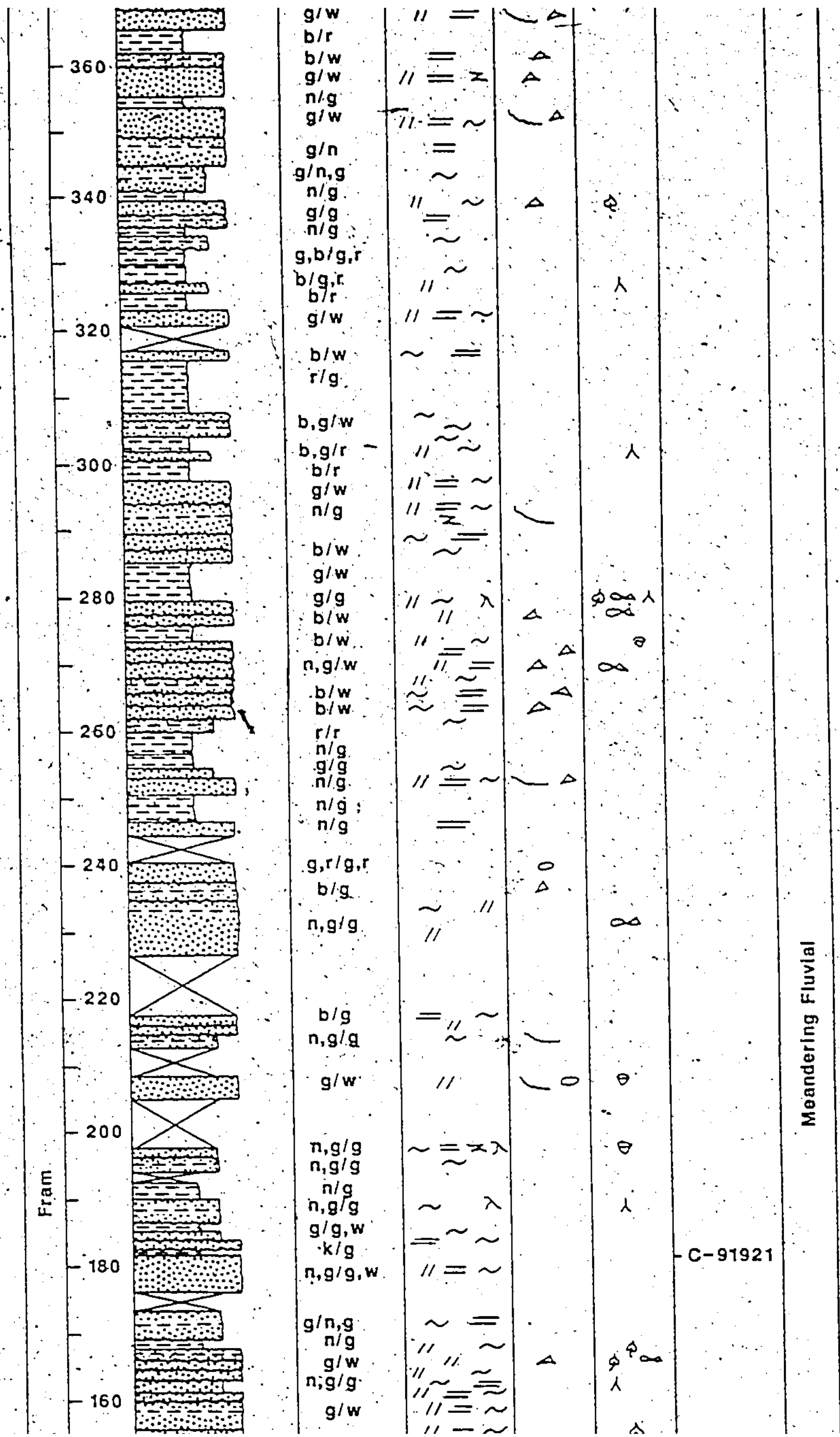
ND


HG2
F2
hg
f
hg
f
M. Frasnian
L. Eifelian - E. Givetian
f
L. G
hb
hb
sf
HB1
&
F5
15.5
8.5
hb
sf
HB3
49.3

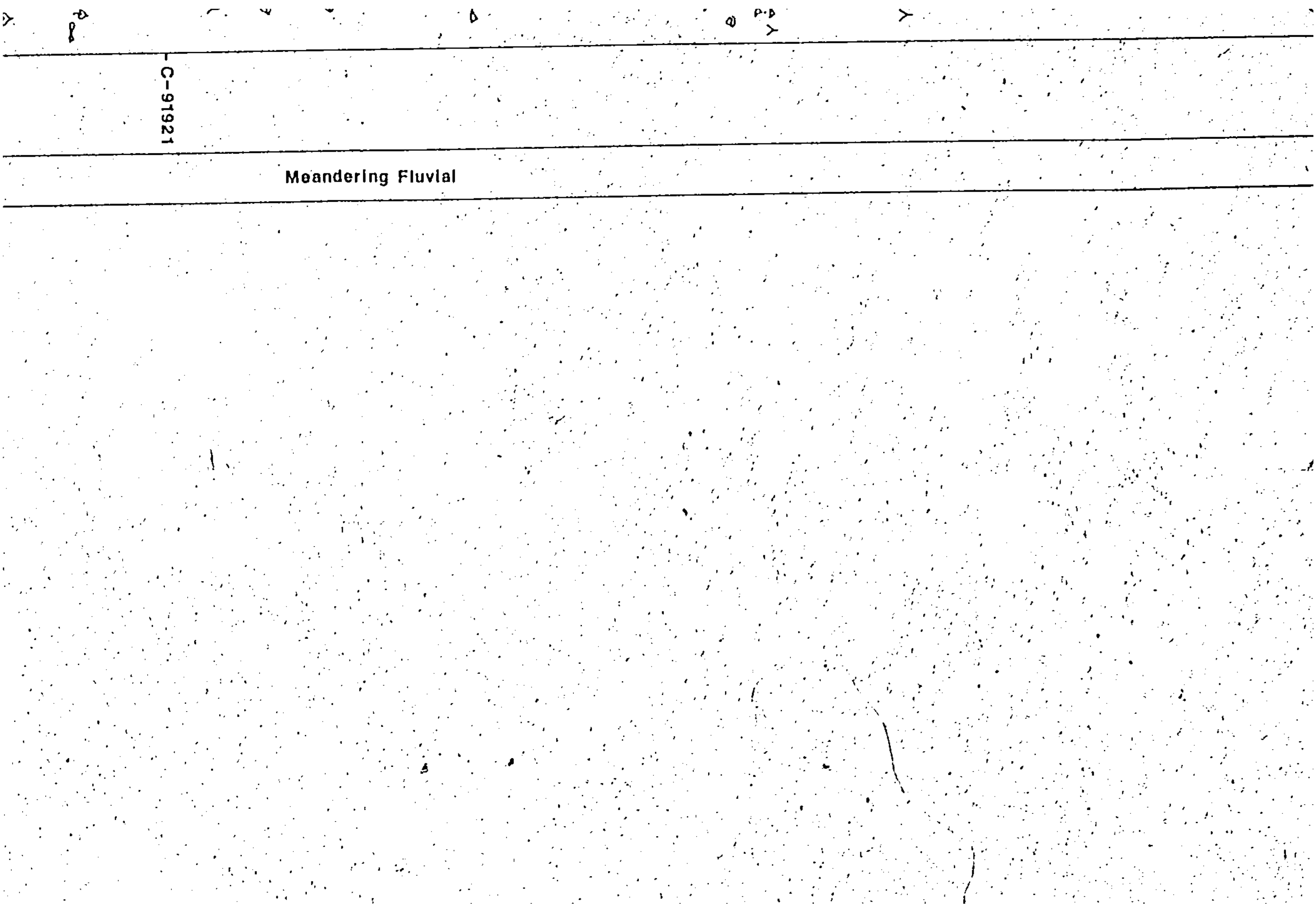


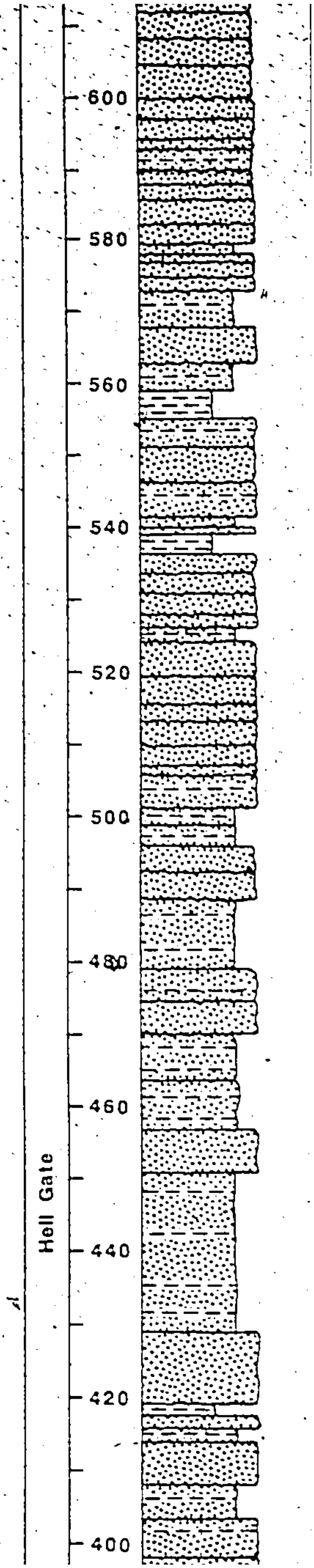
N
F1
f
L. Givetian - E. Frasnian
f
hb
L. Eifelian - E. Givetian
M. Eifelian
E. Eifelian
hb
sf
HB1
&
F5
s-f
bl
S1
20.3
30.0 km

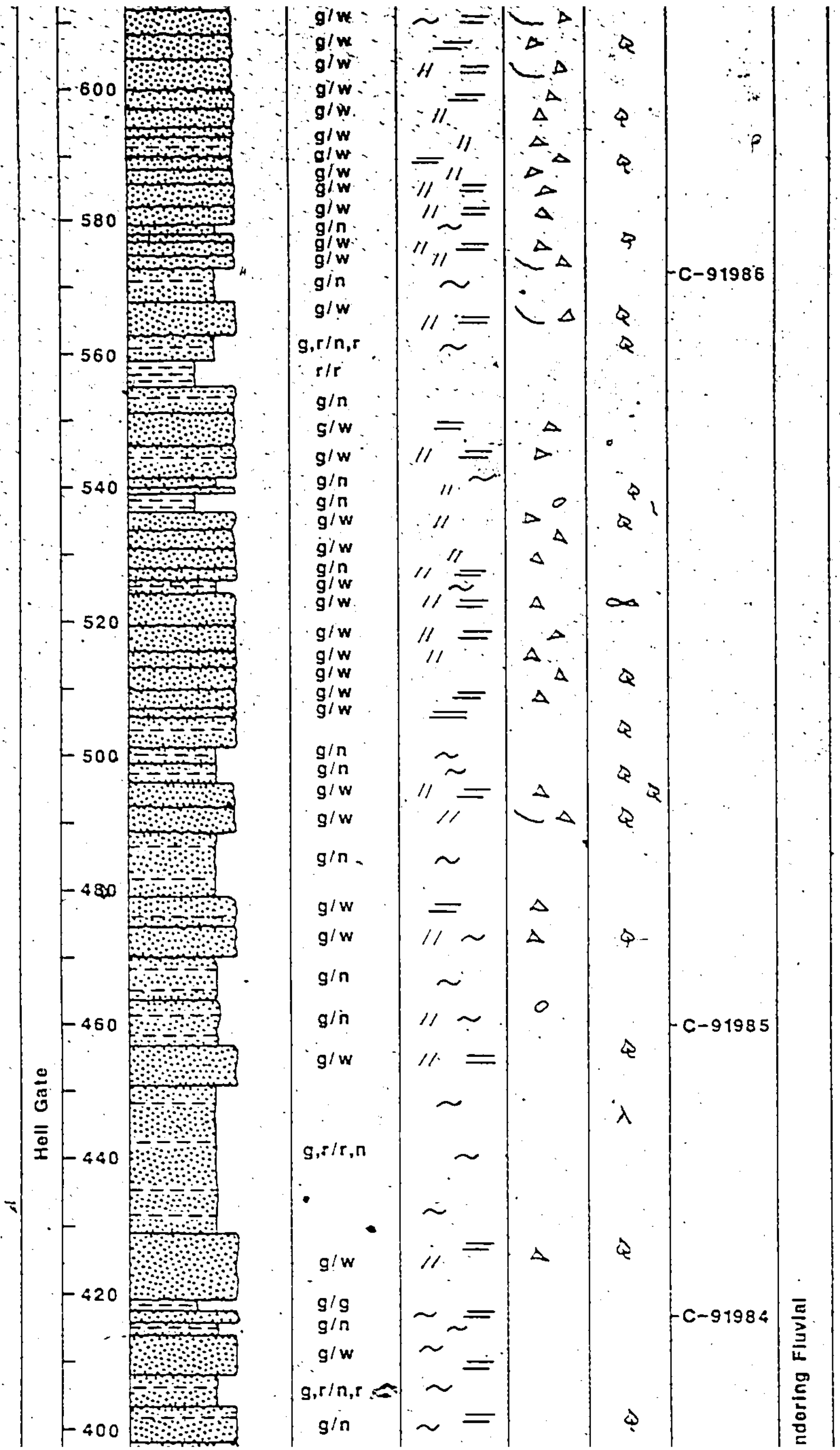

Fram
360
340
320
300
280
260
240
220
200
180
160
b/r
b/w
g/w
n/g
g/w
g/n
g/n,g
n/g
g/g
n/g
g,b/g,r
b/g,r
b/r
g/w
b/w
r/g
b,g/w
b,g/r
b/r
g/w
n/g
b/w
g/w
g/g
b/w
b/w
n,g/w
b/w
b/w
r/r
n/g
g/g
n/g
n/g
n/g
g,r/g,r
b/g
n,g/g
b/g
n,g/g
g/w
n,g/g
n,g/g
n/g
n,g/g
g/g,w
k/g
n,g/g,w
g/n,g
n/g
g/w
n,g/g
g/w
n/g



360
340
320
300
280
260
240
220
200
180
160
Fram
g/w
b/r
b/w
g/w
n/g
g/w
g/n
g/n,g
n/g
g/g
n/g
g,b/g,r
b/g,r
b/r
g/w
b/w
r/g
b,g/w
b,g/r
b/r
g/w
n/g
b/w
g/w
g/g
b/w
b/w
n,g/w
b/w
b/w
r/r
n/g
g/g
n/g
n/g
n/g
g,r/g,r
b/g
n,g/g
b/g
n,g/g
g/w
n,g/g
n,g/g
n/g
n,g/g
g/g,w
k/g
n,g/g,w
g/n,g
n/g
g/w
n,g/g
g/w
C-91921
Meandering Fluvial


C-91921
Meandering Fluvial


600
580
560
540
520
500
480
460
440
420
400
Hell Gate



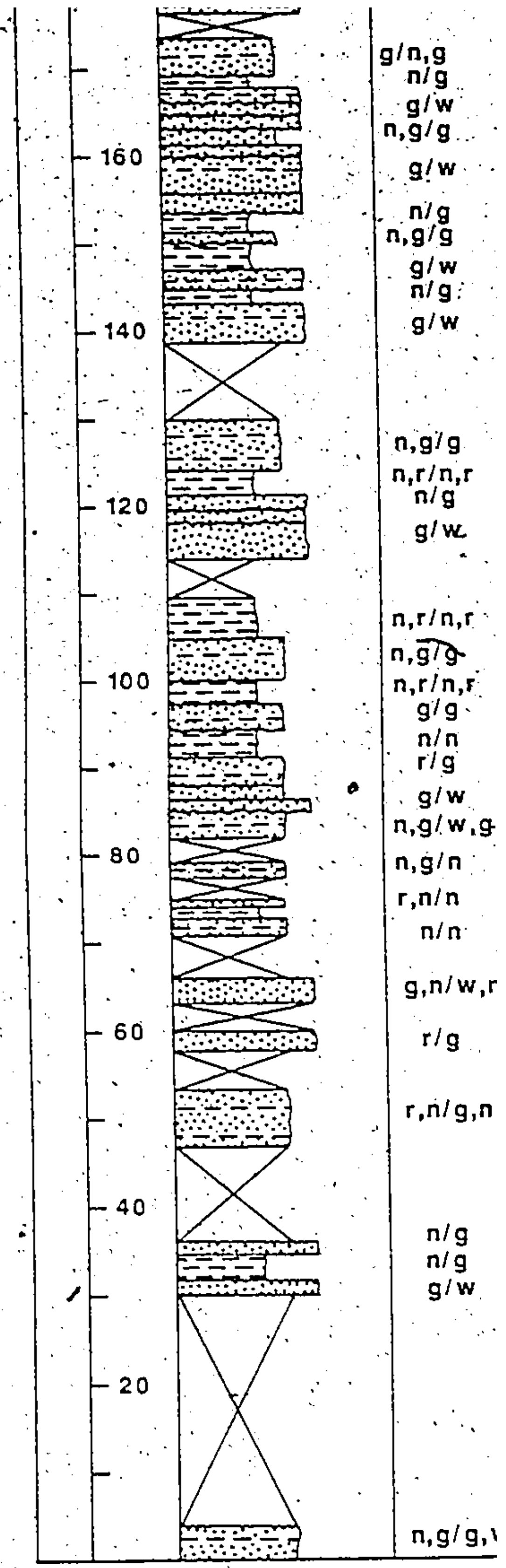
600
580
560
540
520
500
480
460
440
420
400
Hell Gate
g/w
g/n
g,r/n,r
r/r
g,r/r,n
g/g
C-91986
C-91985
C-91984
ndering Fluvial

C-91986

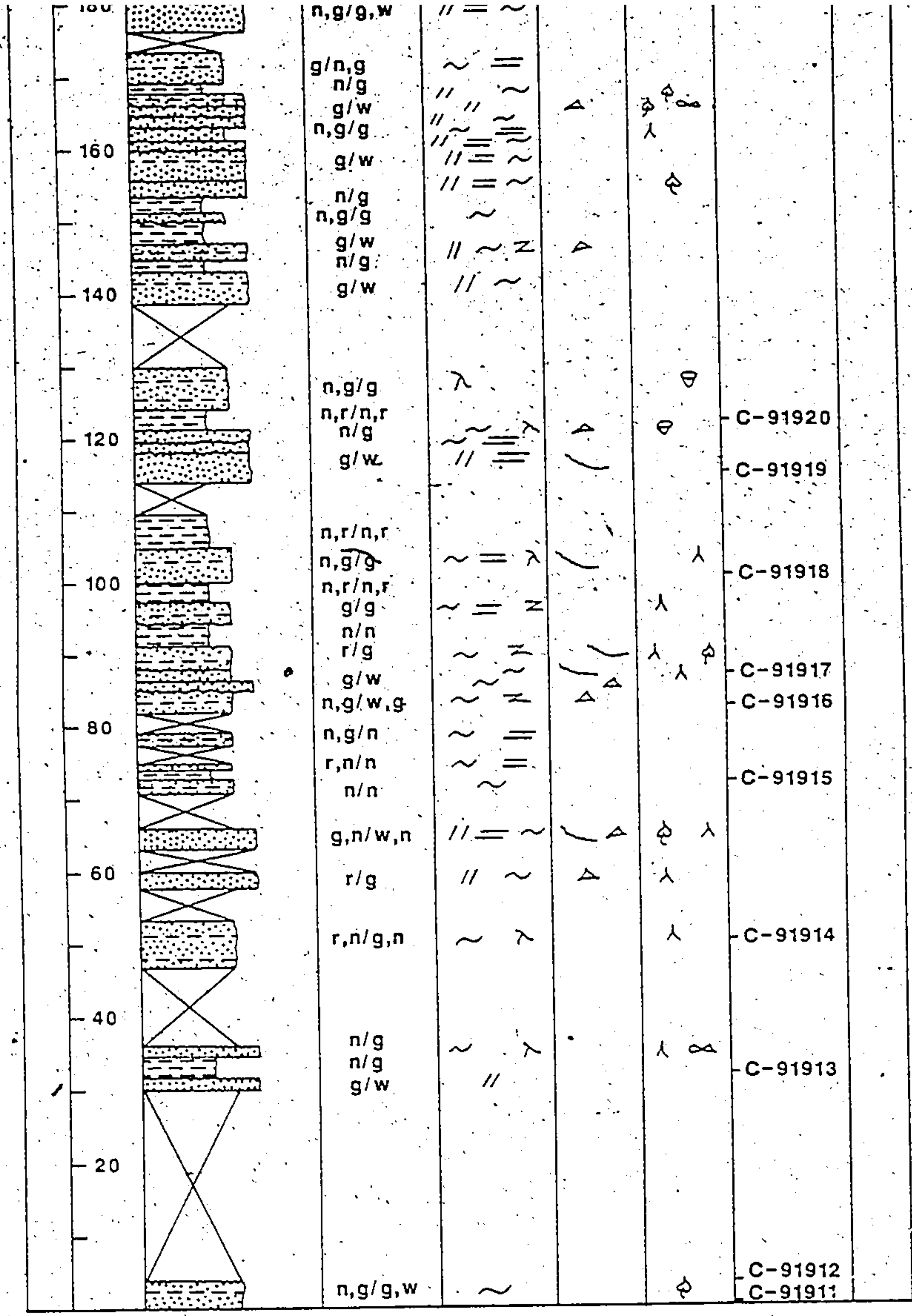
C-91985

C-91984

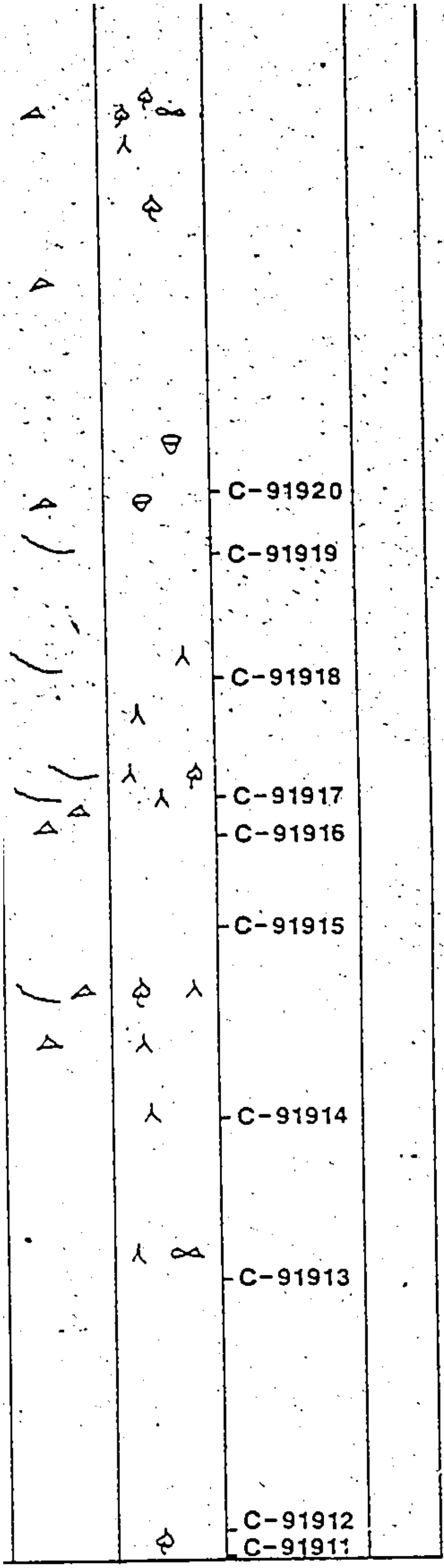
ndering Fluvial

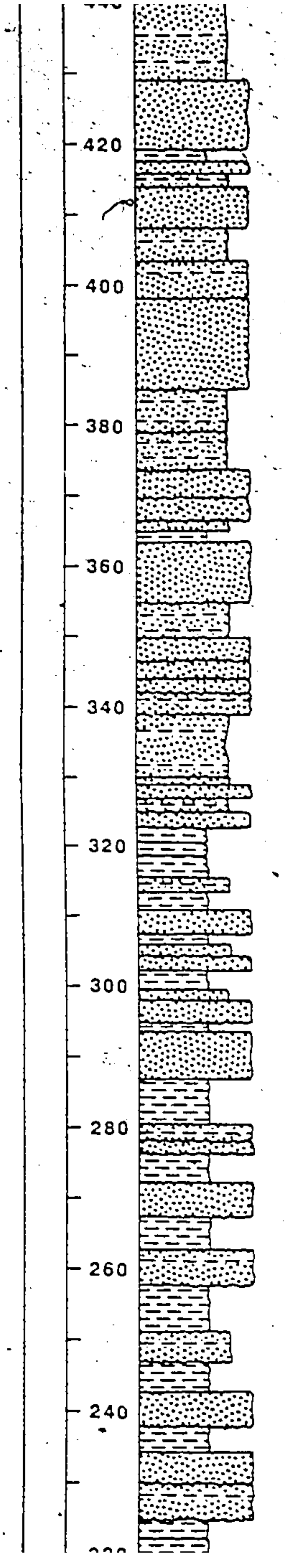


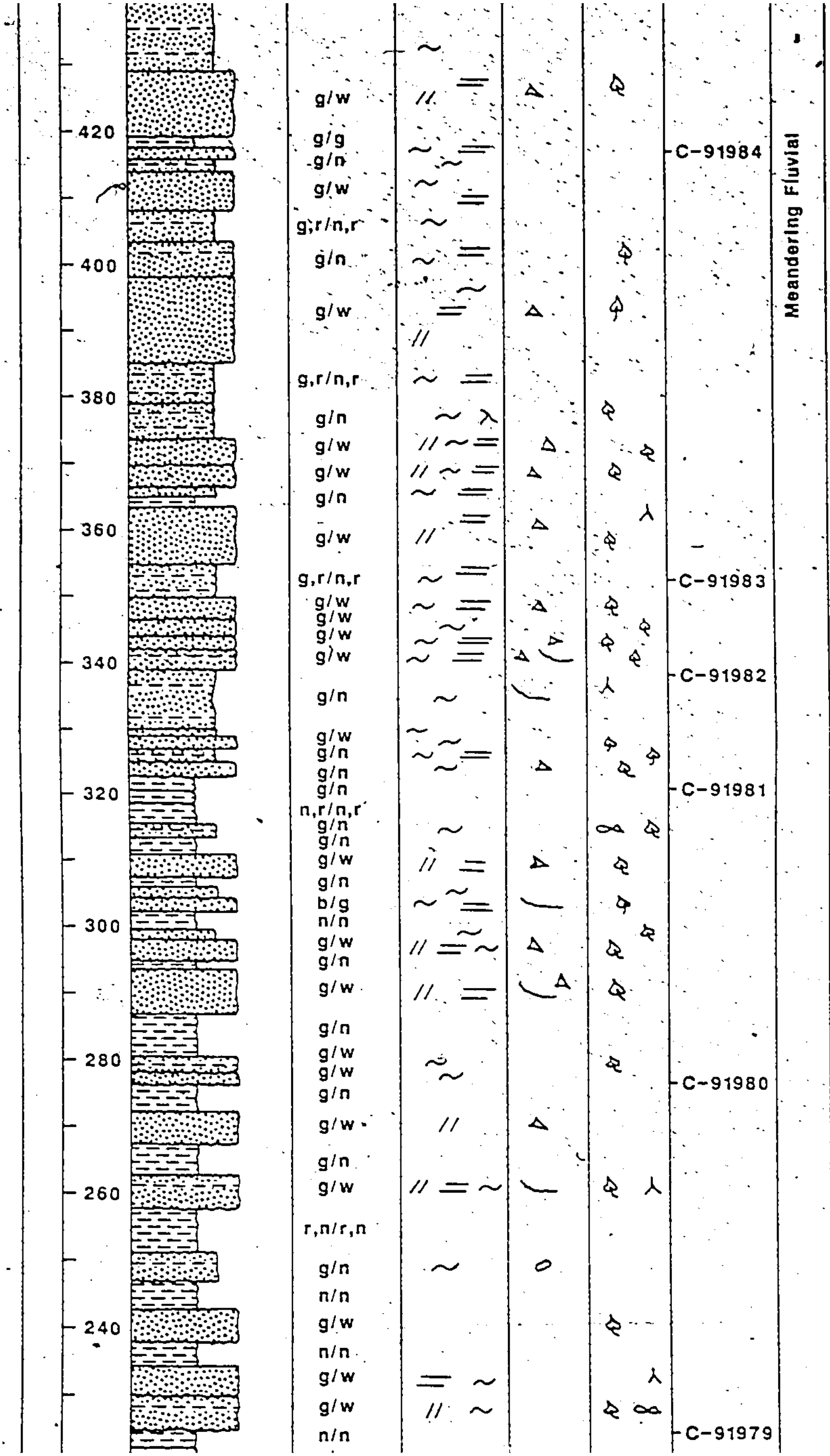
g/n,g
n/g
g/w
n,g/g
160
g/w
n/g
n,g/g
g/w
n/g
140
g/w
n,g/g
n,r/n,r
n/g
120
g/w
n,r/n,r
n,g/g
100
n,r/n,r
g/g
n/n
r/g
g/w
n,g/w,g
80
n,g/n
r,n/n
n/n
g,n/w,r
60
r/g
r,n/g,n
40
n/g
n/g
g/w
20
n,g/g,



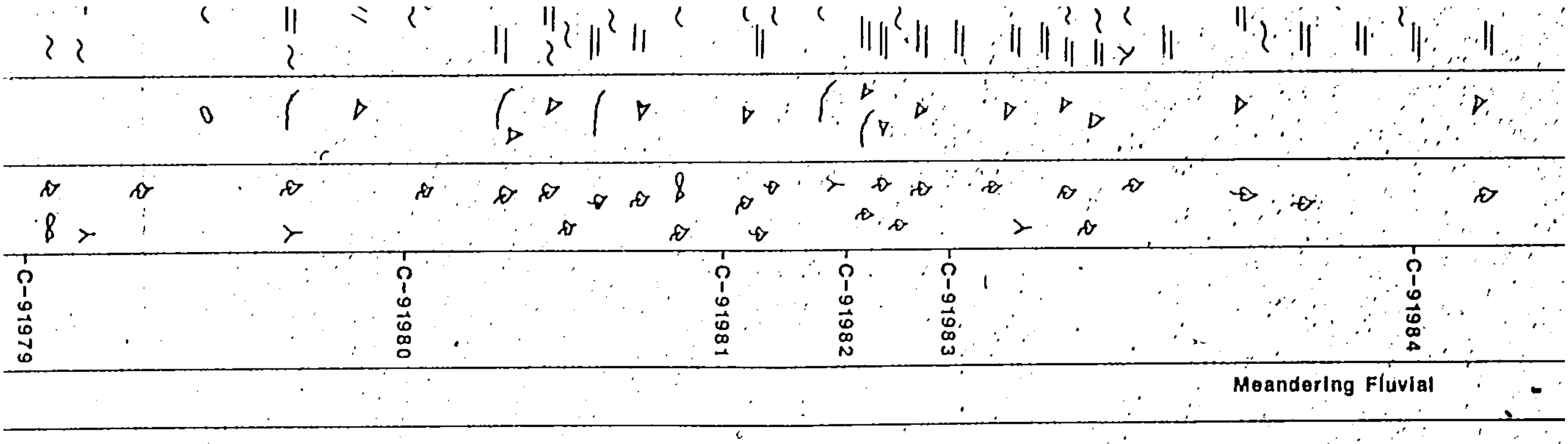
160
140
120
100
80
60
40
20
n,g/g,w
g/n,g
n/g
g/w
n,g/g
g/w
n/g
n,g/g
g/w
n/g
g/w
n,g/g
n,r/n,r
n/g
g/w
n,r/n,r
n,g/g
n,r/n,r
g/g
n/n
r/g
g/w
n,g/w,g
n,g/n
r,n/n
n/n
g,n/w,n
r/g
r,n/g,n
n/g
n/g
g/w
n,g/g,w
C-91920
C-91919
C-91918
C-91917
C-91916
C-91915
C-91914
C-91913
C-91912
C-91911


C-91920
C-91919
C-91918
C-91917
C-91916
C-91915
C-91914
C-91913
C-91912
C-91911


420
400
380
360
340
320
300
280
260
240



420
400
380
360
340
320
300
280
260
240
g/w
g/g
g/n
g/w
g,r/n,r
g/n
g/w
g,r/n,r
g/n
g/w
g/w
g/n
g/w
g,r/n,r
g/w
g/w
g/w
g/w
g/n
g/w
g/n
g/n
g/n
n,r/n,r
g/n
g/n
g/w
g/n
b/g
n/n
g/w
g/n
g/w
g/n
g/w
g/w
g/n
g/w
g/n
g/w
r,n/r,n
g/n
n/n
g/w
n/n
g/w
g/w
n/n
C-91984
C-91983
C-91982
C-91981
C-91980
C-91979
Meandering Fluvial



C-91979
C-91980
C-91981
C-91982
C-91983
C-91984
Meandering Fluvial

Base of section

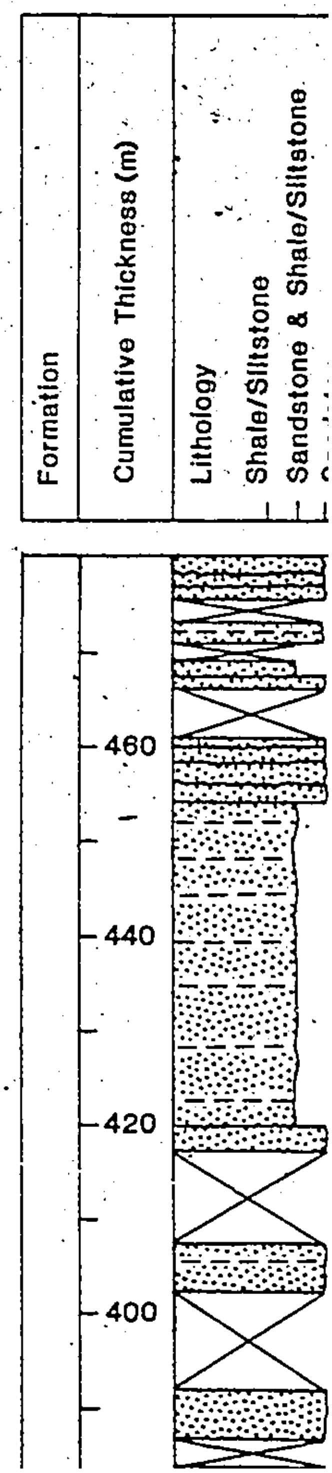


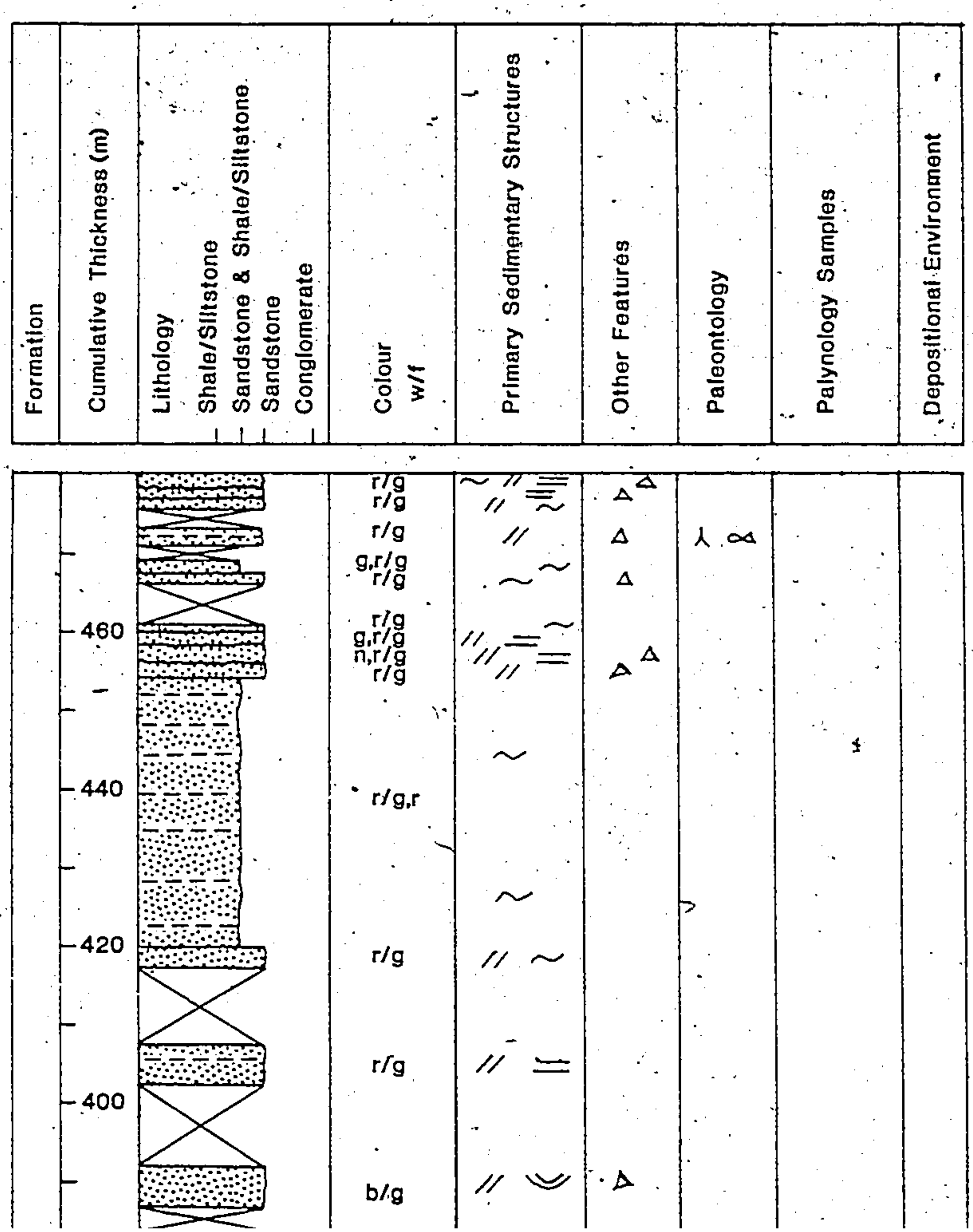
Figure 2.3.4.1-1

SECTION F5

Base of section : 559250 E., 8559375 N., UTM Zone 16x

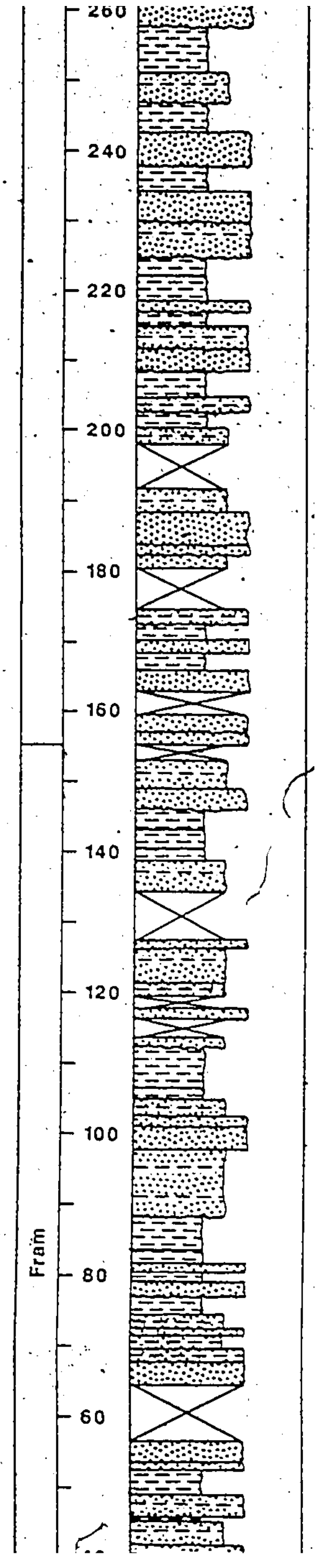
NTS 49C

Baumann Fiord Sheet

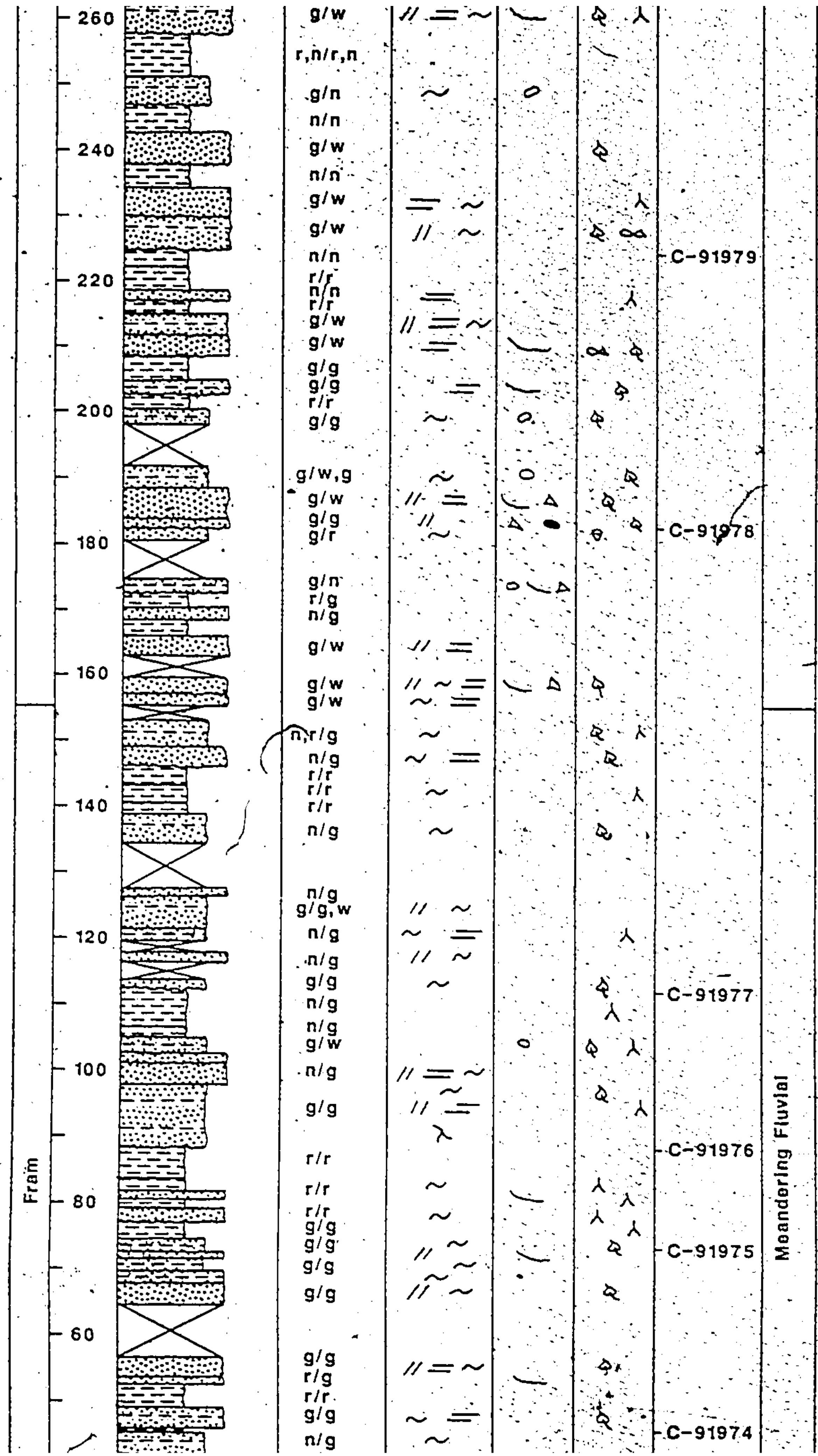


I., UTM Zone 16x

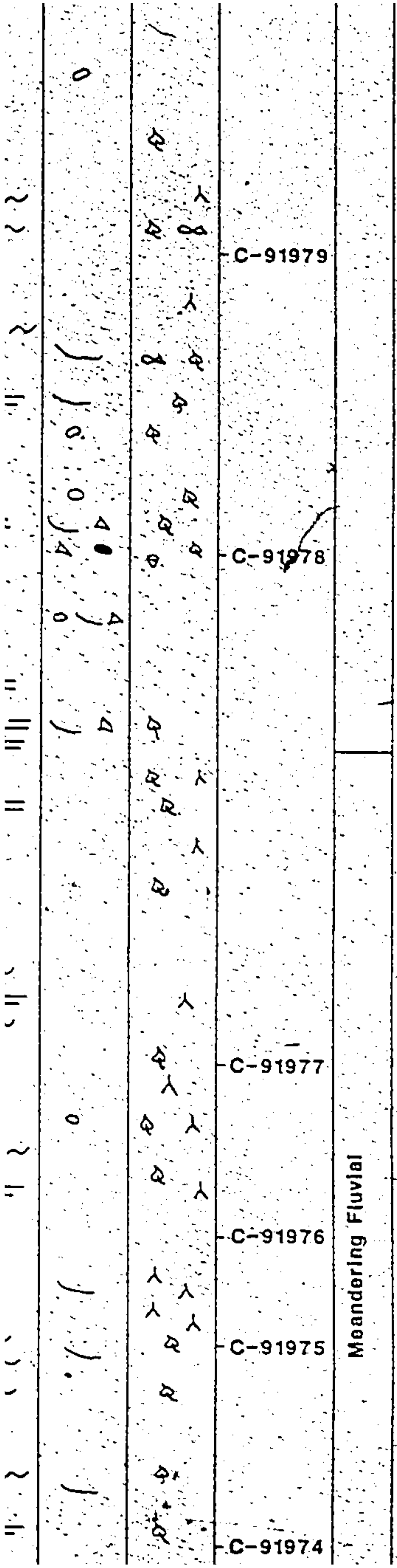
Paleontology	Palynology Samples	Depositional Environment

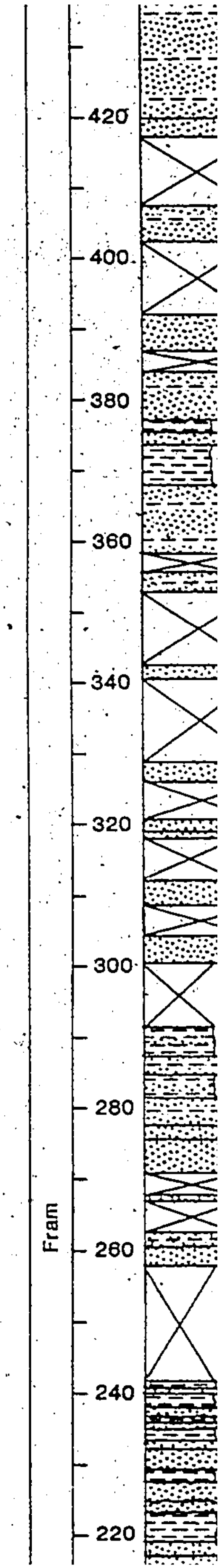


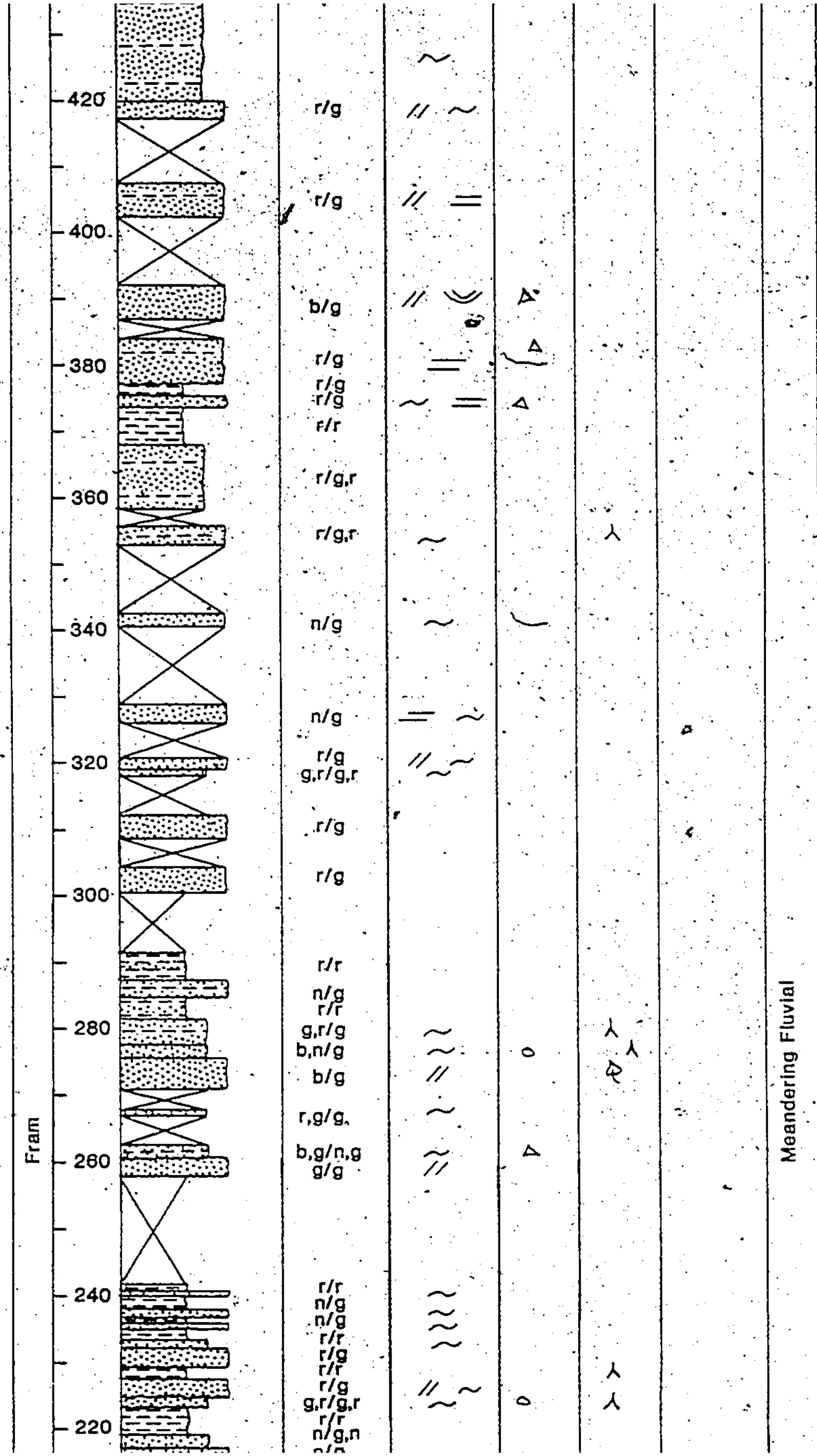
260
240
220
200
180
160
140
120
100
80
60
Fram



260
240
220
200
180
160
140
120
100
80
60
g/w
r,n/r,n
g/n
n/n
g/w
n/n
g/w
g/w
n/n
r/r
n/n
r/r
g/w
g/w
g/g
g/g
r/r
g/g
g/w,g
g/w
g/g
g/r
g/n
r/g
n/g
g/w
g/w
g/w
n,r/g
n/g
r/r
r/r
r/r
n/g
n/g
g/g,w
n/g
n/g
g/g
n/g
n/g
g/w
n/g
g/g
r/r
r/r
r/r
g/g
g/g
g/g
g/g
g/g
r/g
r/r
g/g
n/g
C-91979
C-91978
C-91977
C-91976
C-91975
C-91974
Fram
Meandering Fluvial


C-91979
C-91978
C-91977
C-91976
C-91975
C-91974
Meandering Fluvial


420
400
380
360
340
320
300
280
260
240
220
Fram



420
400
380
360
340
320
300
280
260
240
220
Fram
Meandering Fluvial
r/g
r/g
b/g
r/g
r/g
r/g
r/r
r/g,r
r/g,r
n/g
n/g
r/g
g,r/g,r
r/g
r/g
r/r
n/g
r/r
g,r/g
b,n/g
b/g
r,g/g,
b,g/n,g
g/g
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n/g
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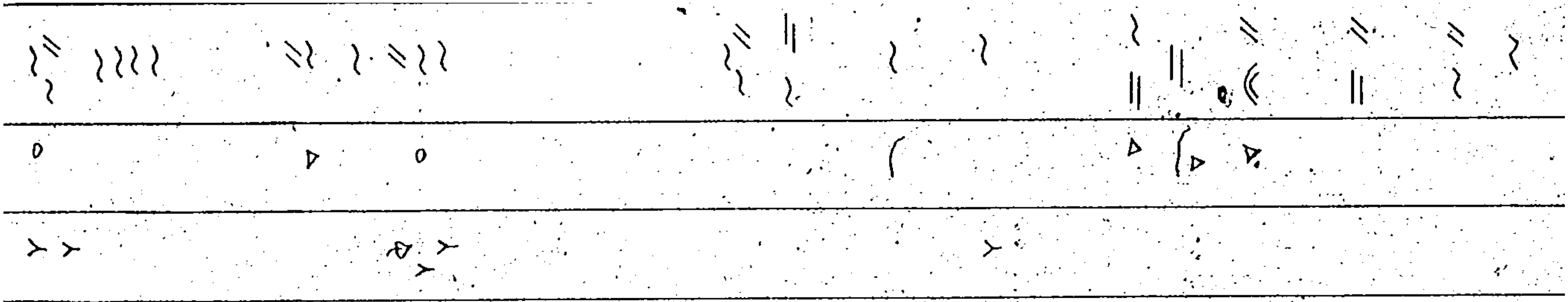
r/g
r/r
r/g
g,r/g,r
r/r
n/g,n



Meandering Fluvial

Figure 2.2.6.1-2

Base of section :

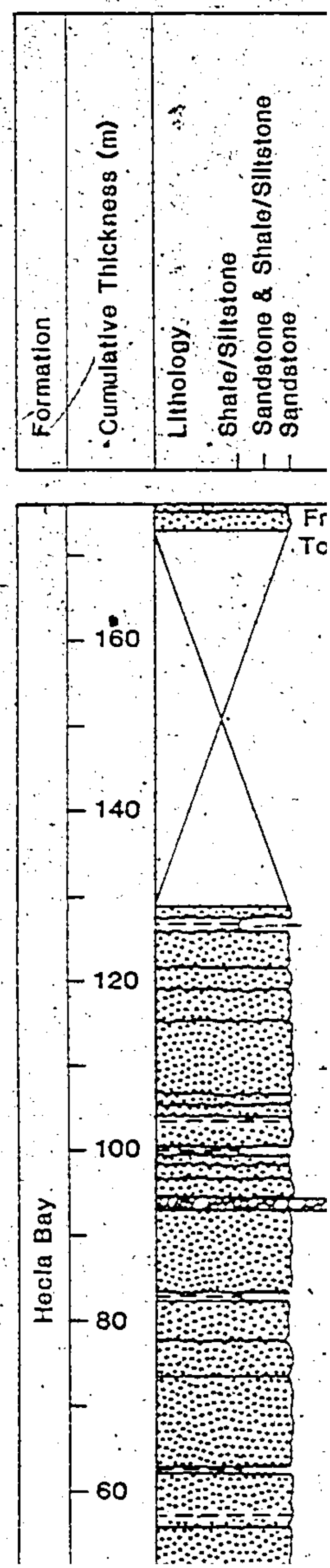
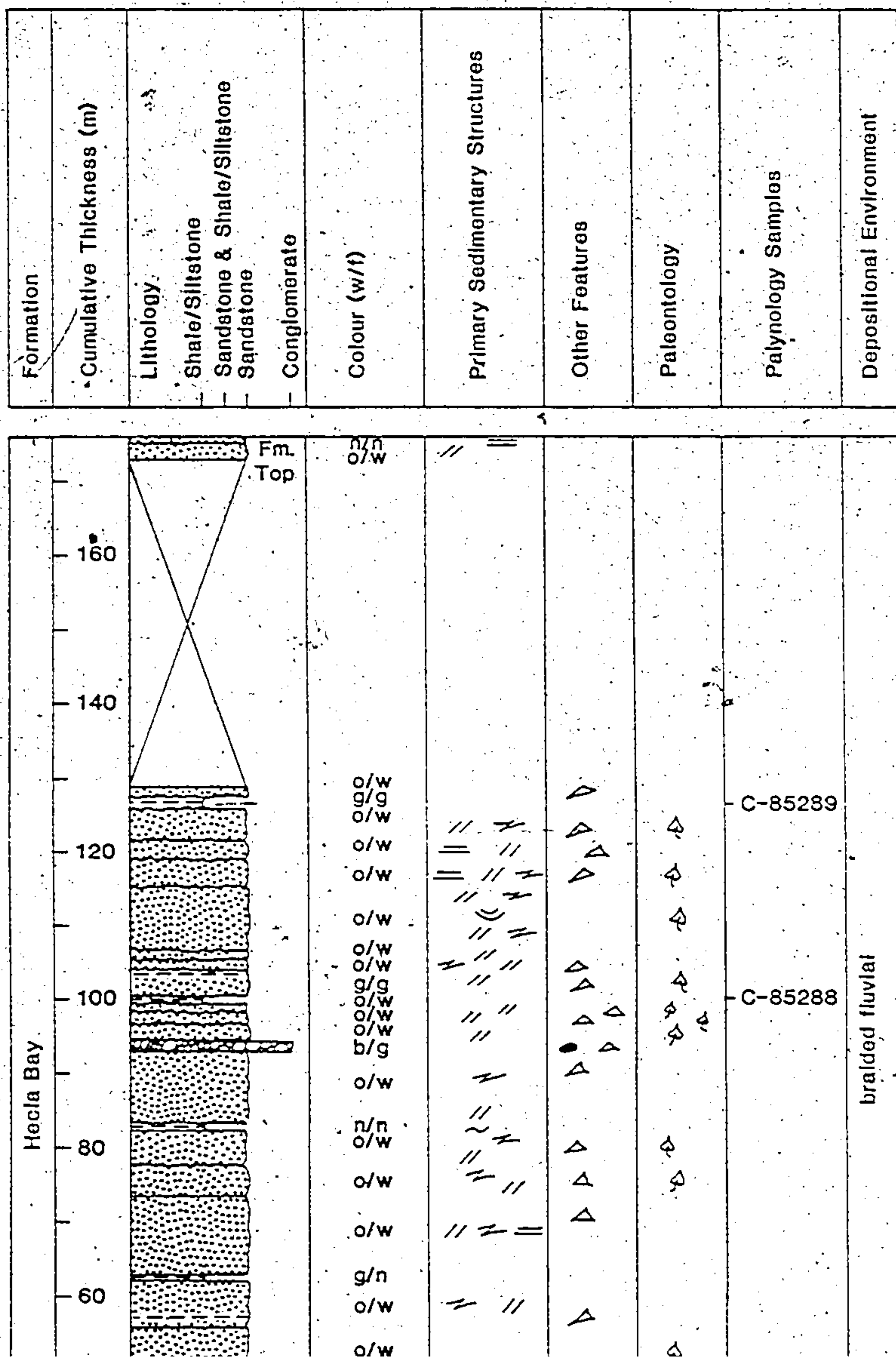


Figure 2.2.6.1-2 SECTION HB2

Base of section : 571550 E., 8507675 N., UTM Zone 15x

NTS 59A

Cardigan Strait Sheet

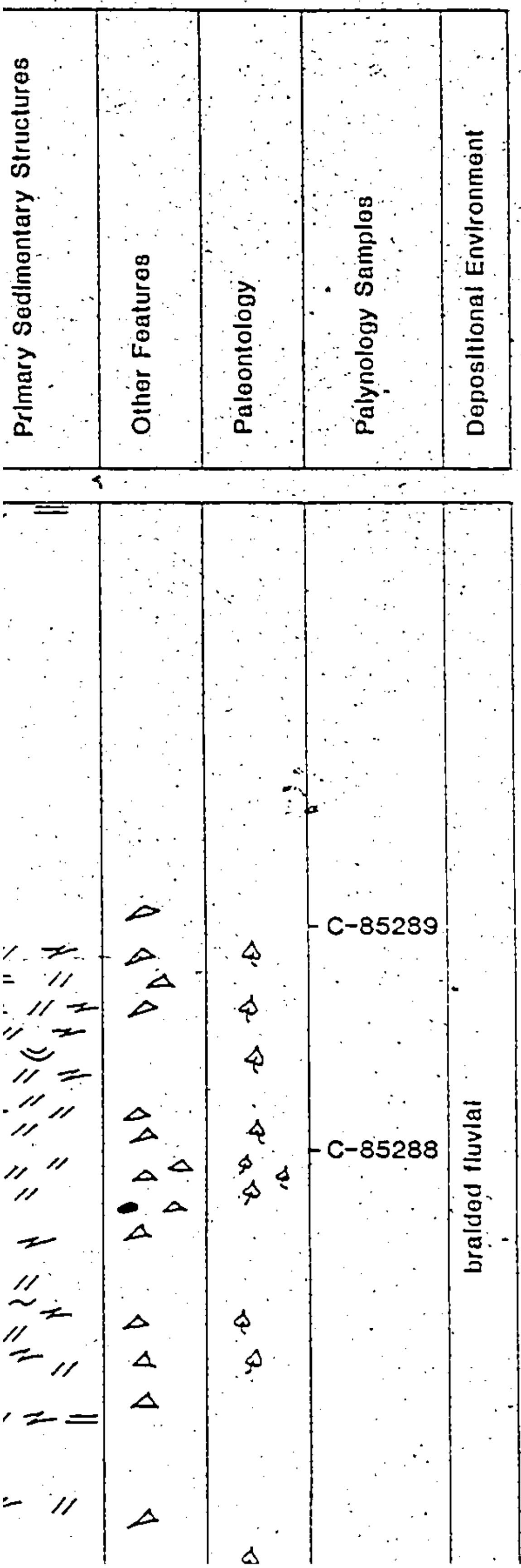


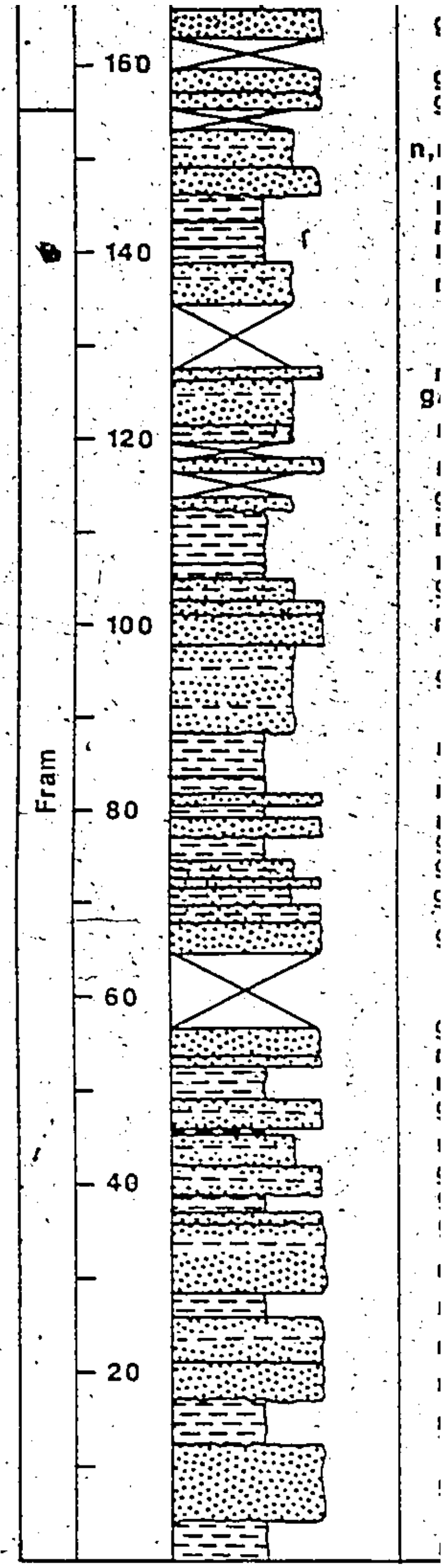
ION HB2

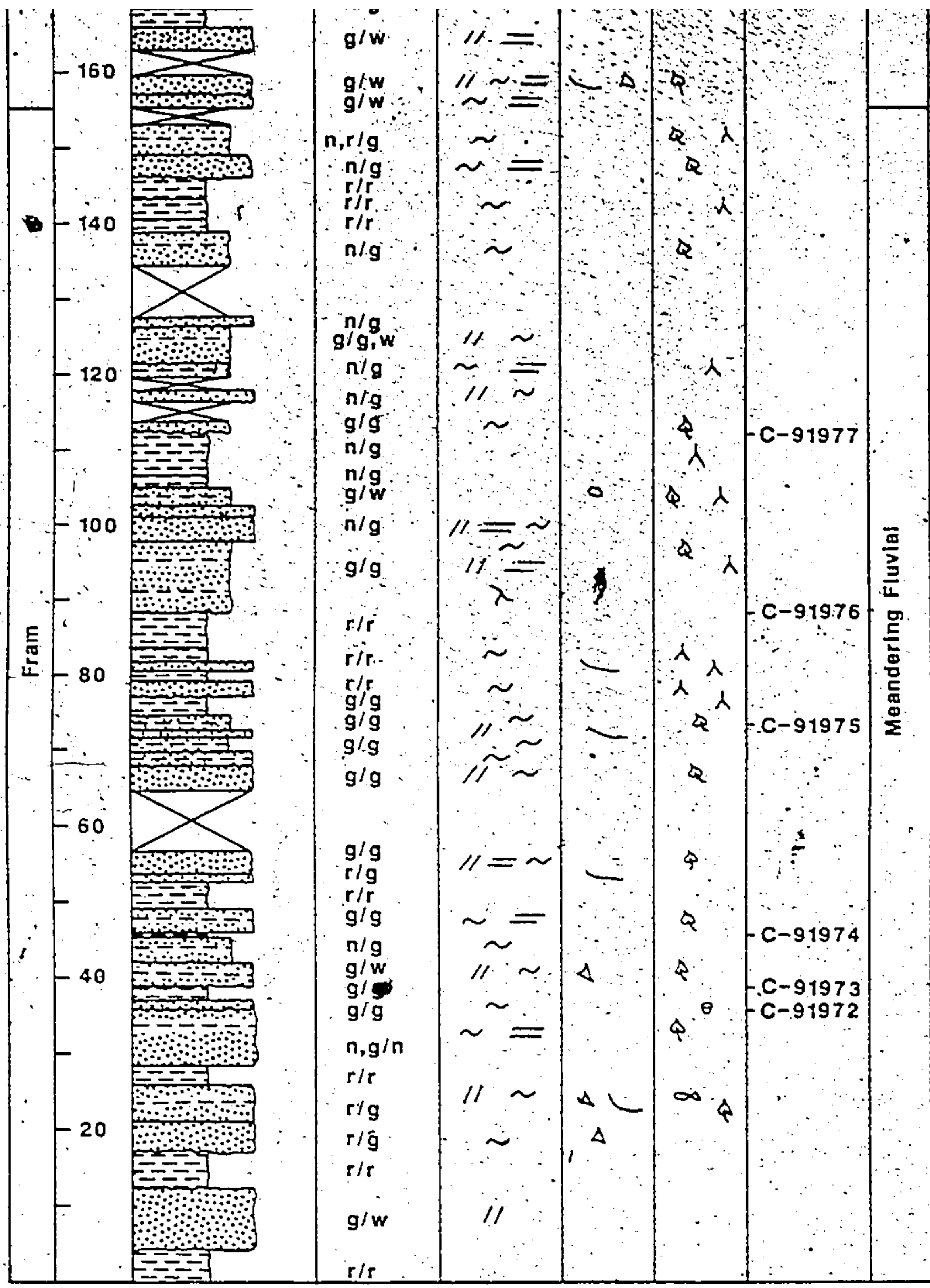
8507675 N., UTM Zone 15x

S 59A

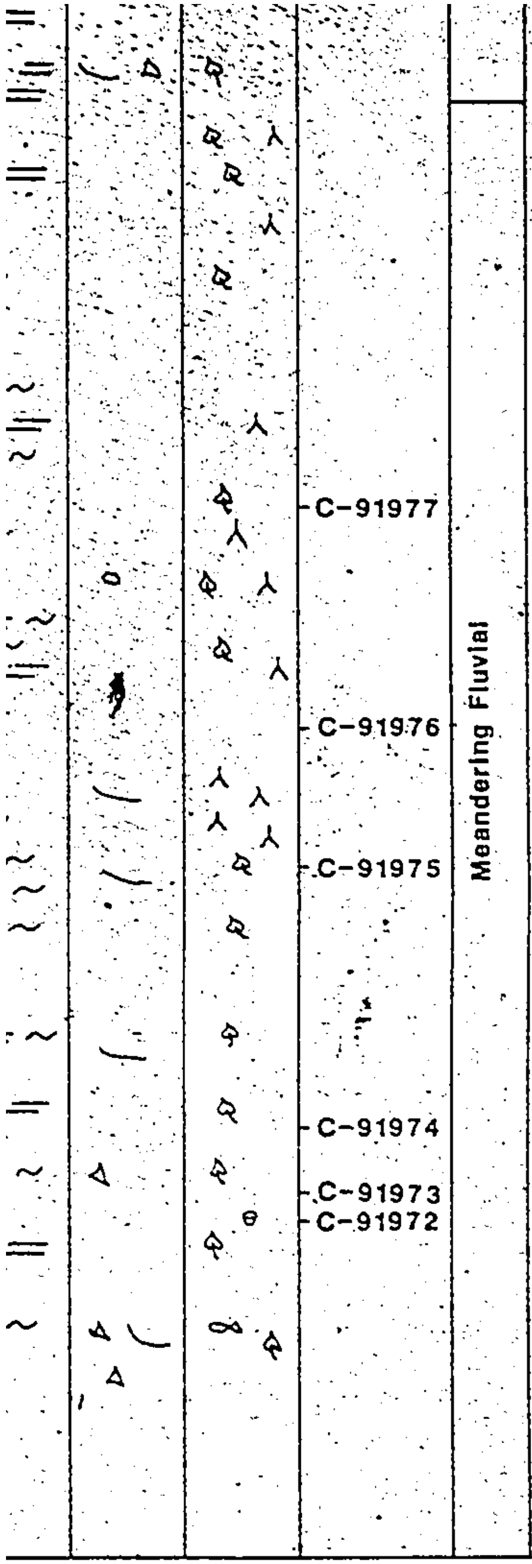
Strait Sheet

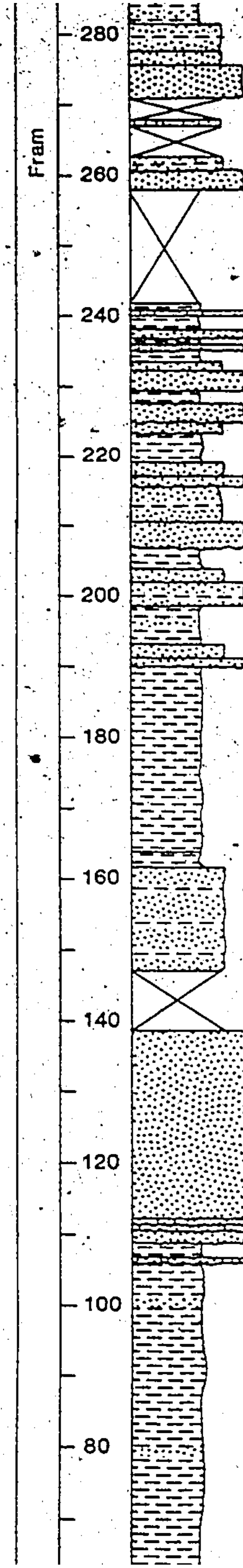


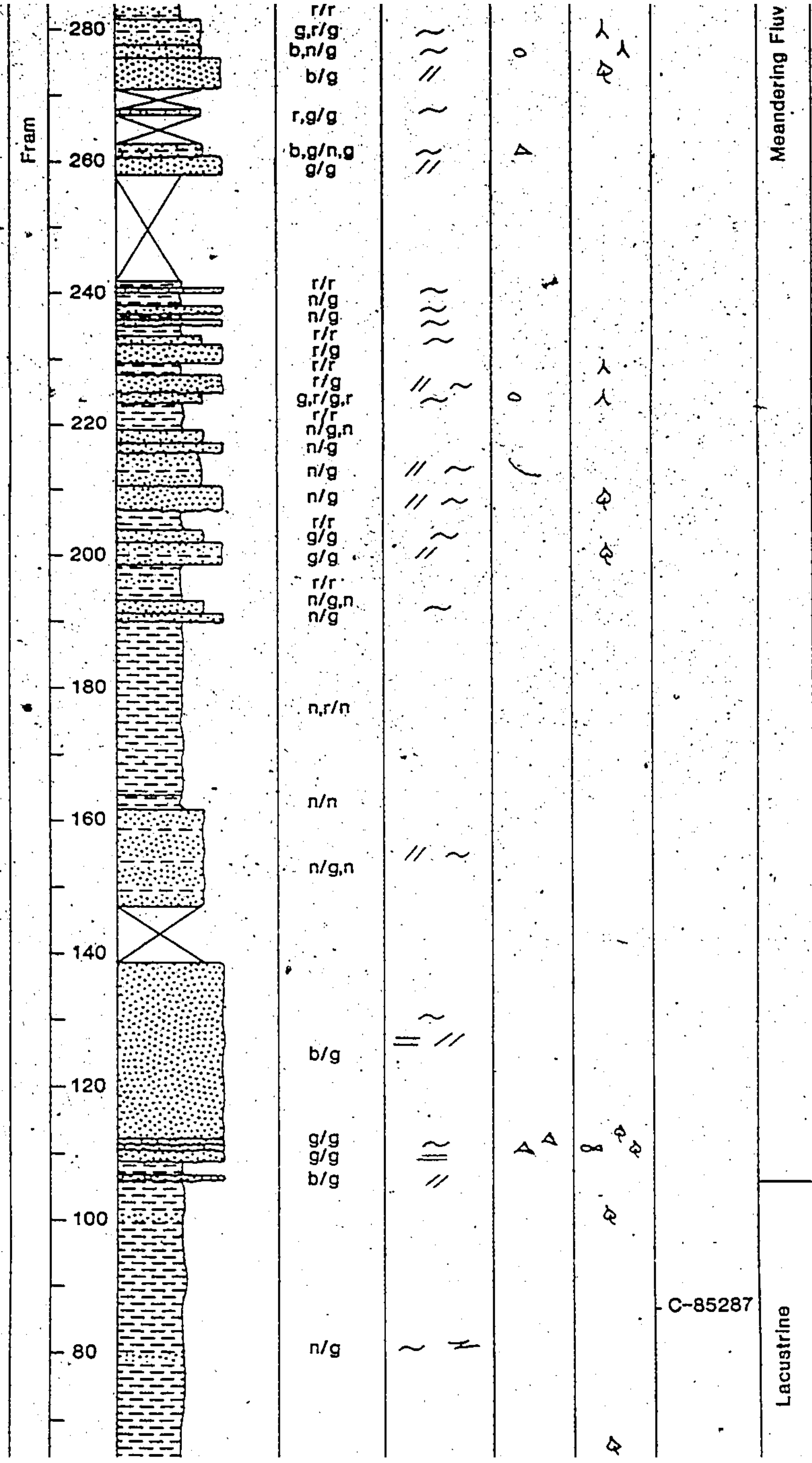

Fram
160
140
120
100
80
60
40
20



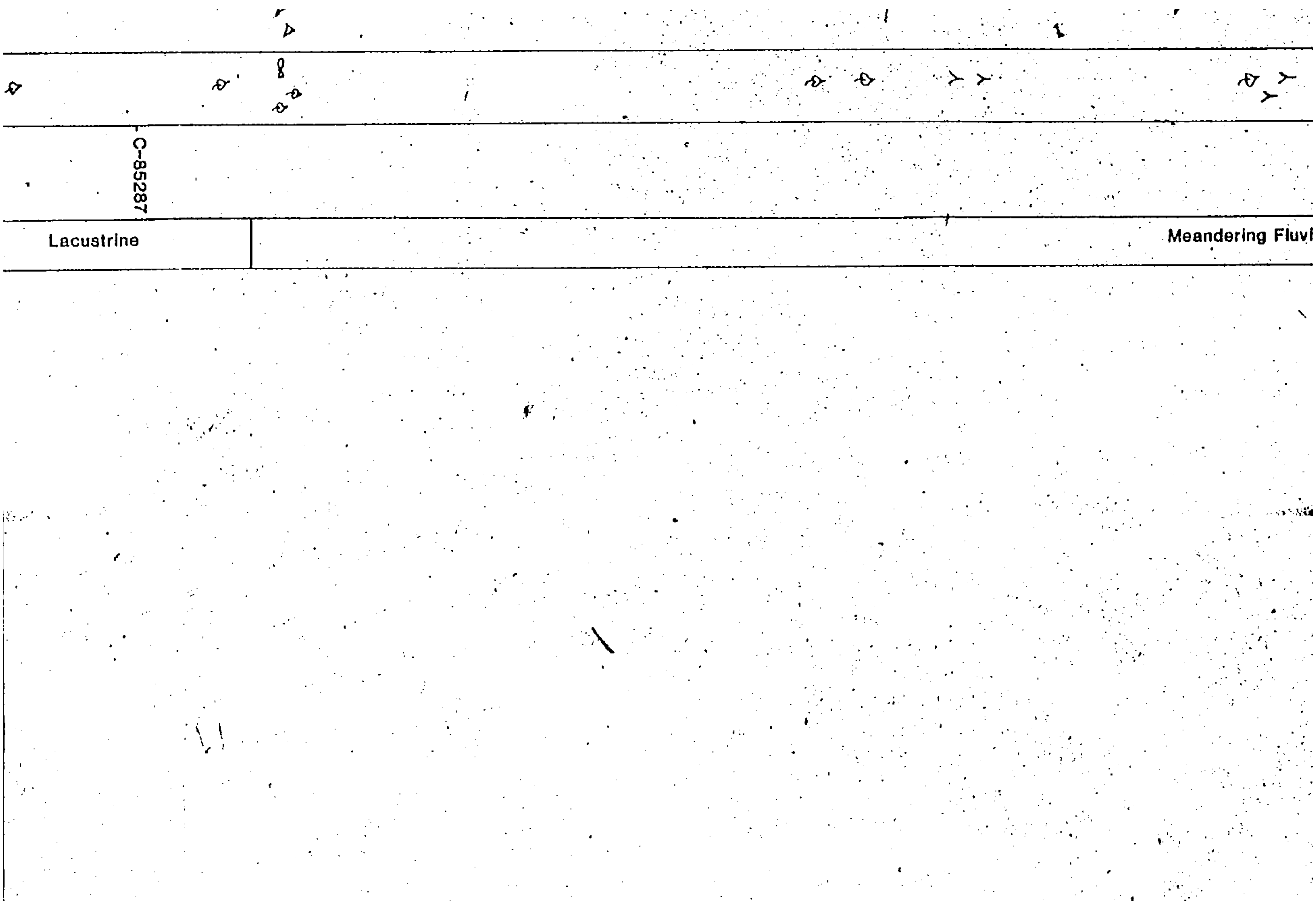
Fram
Meandering Fluvial
160
140
120
100
80
60
40
20
g/w
g/w
g/w
n,r/g
n/g
r/r
r/r
r/r
n/g
n/g
g/g,w
n/g
n/g
g/g
n/g
n/g
g/w
n/g
g/g
r/r
r/r
r/r
g/g
g/g
g/g
g/g
g/g
r/g
r/r
g/g
n/g
g/w
g/g
n,g/n
r/r
r/g
r/g
r/r
g/w
r/r
C-91977
C-91976
C-91975
C-91974
C-91973
C-91972

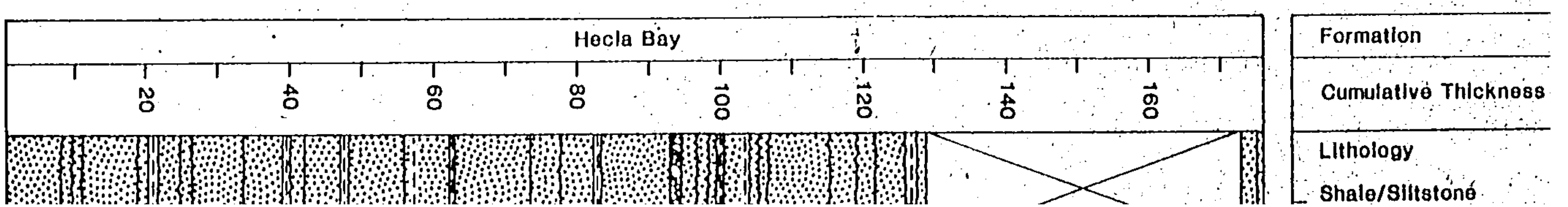

C-91977
C-91976
C-91975
C-91974
C-91973
C-91972
Meandering Fluvial


Fram
280
260
240
220
200
180
160
140
120
100
80

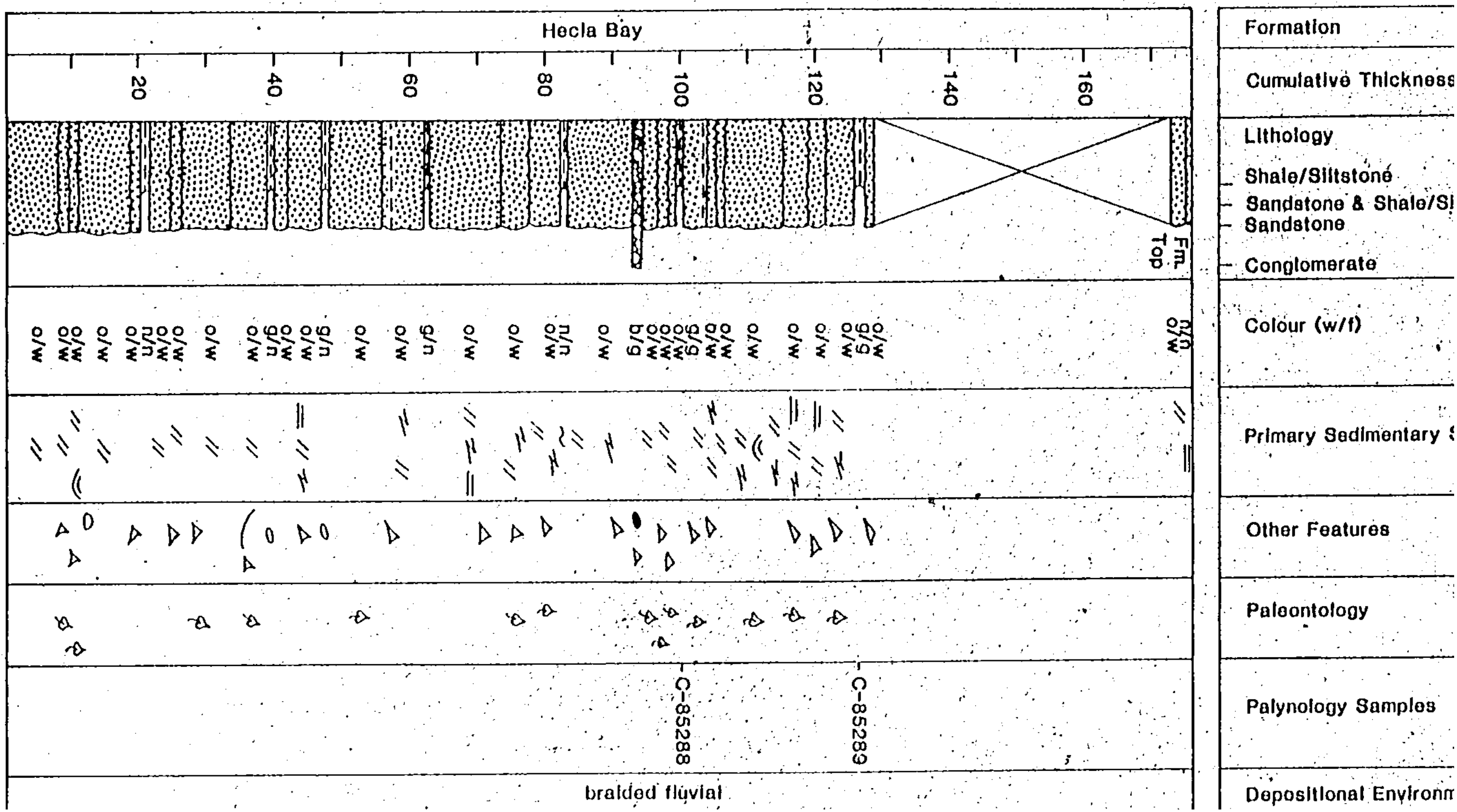


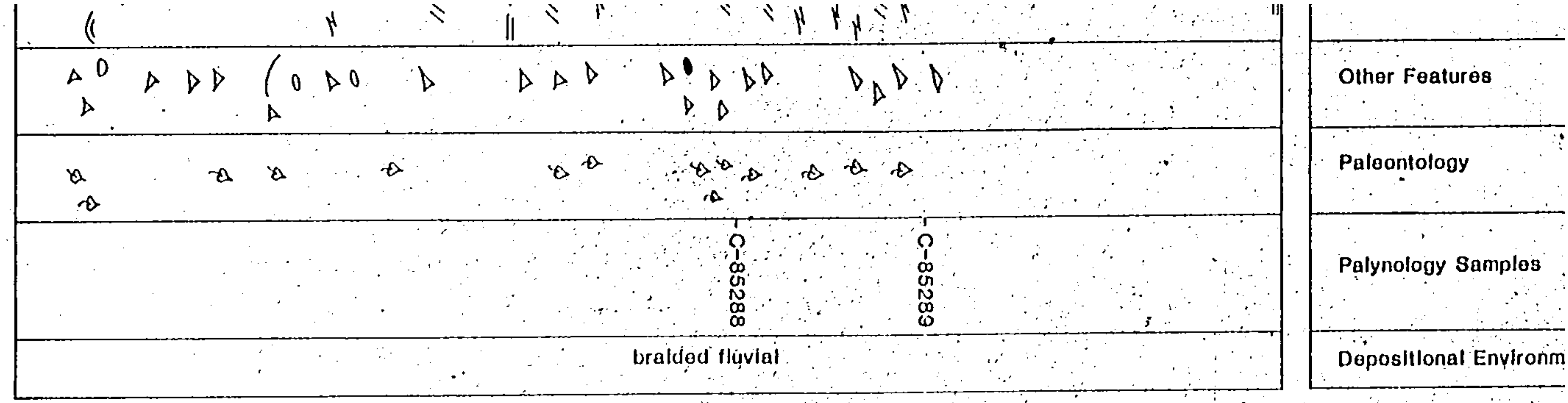
Fram
280
260
240
220
200
180
160
140
120
100
80
r/r
g,r/g
b,n/g
b/g
r,g/g
b,g/n,g
g/g
r/r
n/g
n/g
r/r
r/g
r/r
r/g
g,r/g,r
r/r
n/g,n
n/g
n/g
n/g
r/r
g/g
g/g
r/r
n/g,n
n/g
n,r/n
n/n
n/g,n
b/g
g/g
g/g
b/g
n/g
C-85287
Meandering Fluv
Lacustrine


C-85287
Lacustrine
Meandering Fluvi

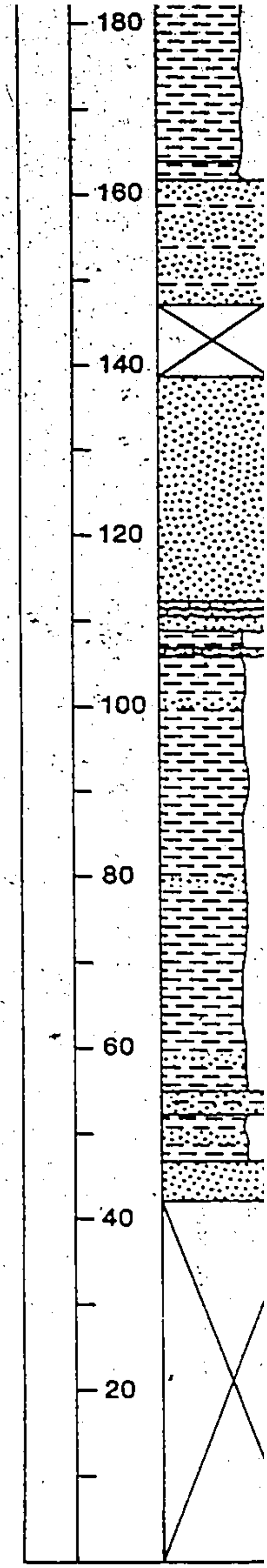


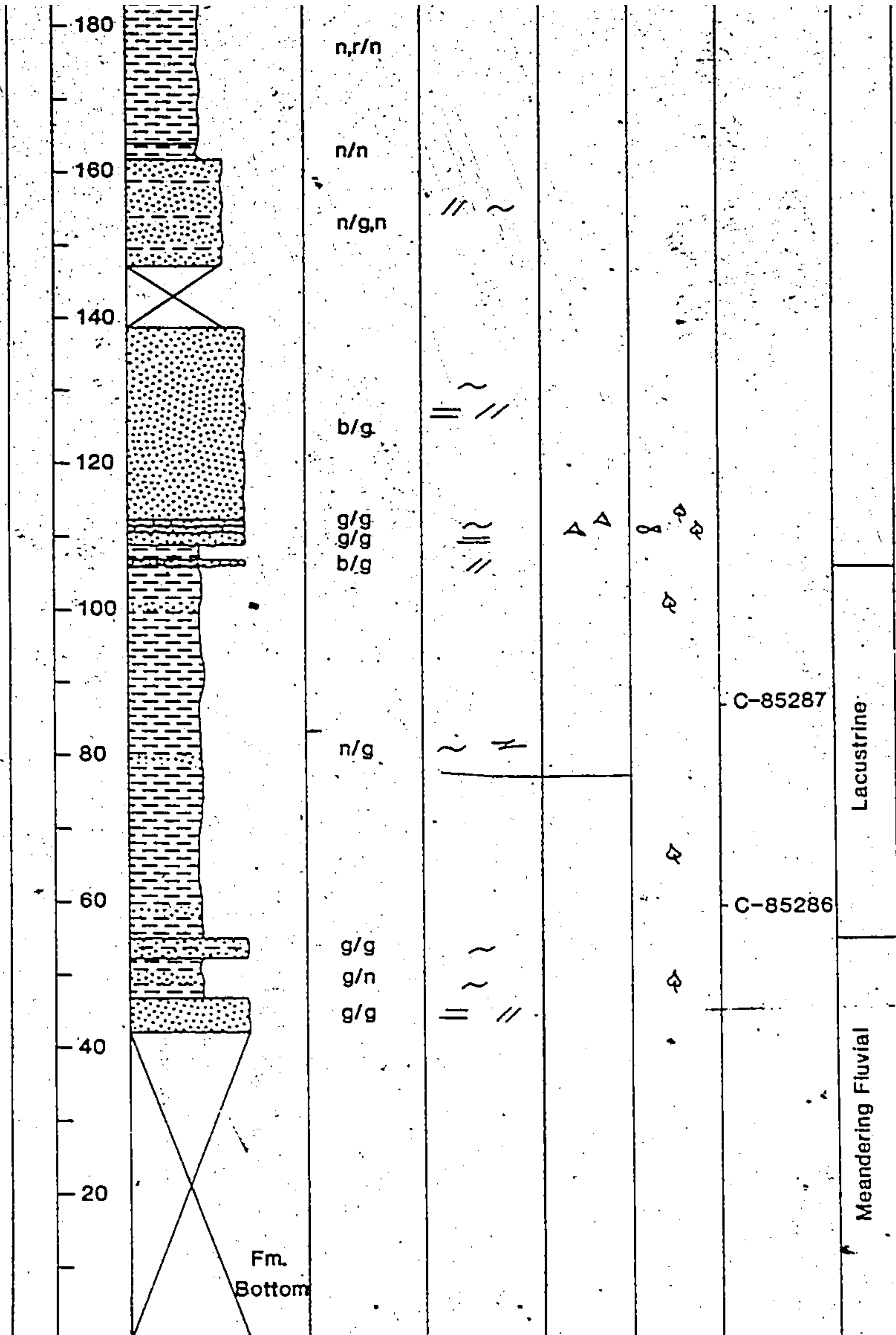
Formation
Cumulative Thickness
Lithology
Shale/Siltstone
Hecla Bay
20
40
60
80
100
120
140
160


Formation
Cumulative Thickness
Lithology
Shale/Siltstone
Sandstone & Shale/Si
Sandstone
Conglomerate
Colour (w/f)
Primary Sedimentary
Other Features
Paleontology
Palynology Samples
Depositional Environ
Hecla Bay
20
40
60
80
100
120
140
160
Fm. Top
C-85288
C-85289
braided fluvial

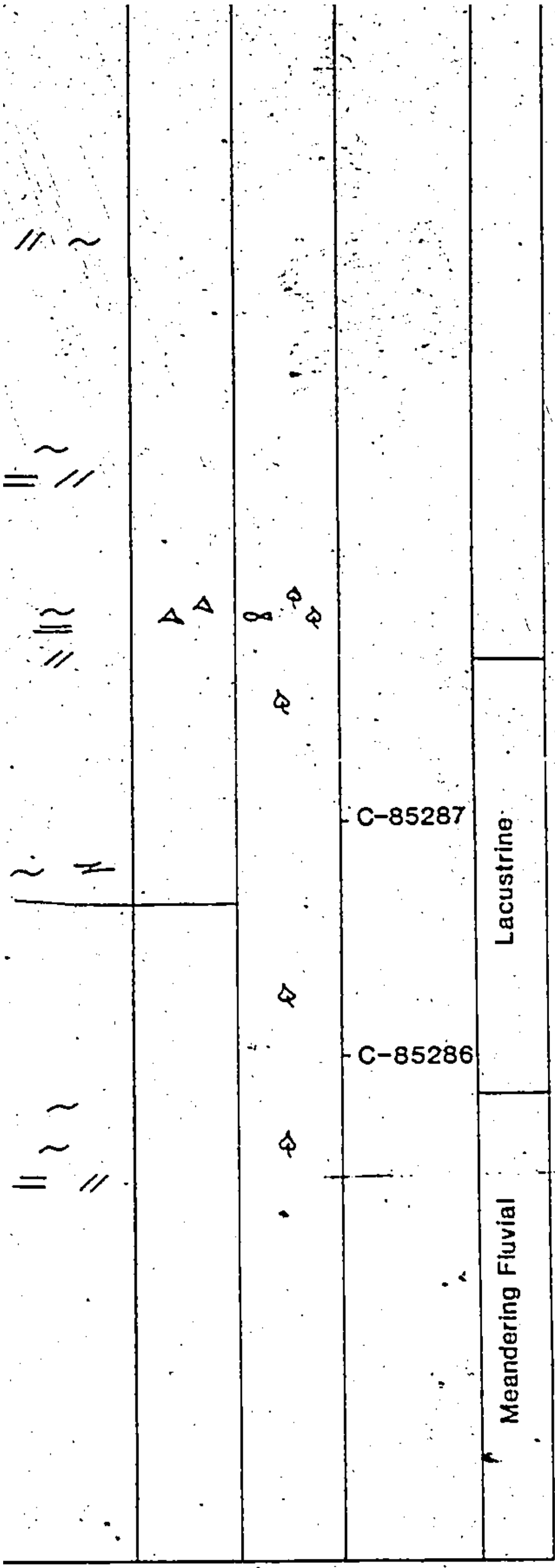


Other Features
Paleontology
Palynology Samples
Depositional Environm
C-85288
C-85289
braided fluvial


180
160
140
120
100
80
60
40
20



180
160
140
120
100
80
60
40
20
n,r/n
n/n
n/g,n
b/g
g/g
g/g
b/g
n/g
g/g
g/n
g/g
Fm. Bottom
C-85287
C-85286
Lacustrine
Meandering Fluvial



C-85287
C-85286
Lacustrine
Meandering Fluvial

F

Base of section : 456

Ca

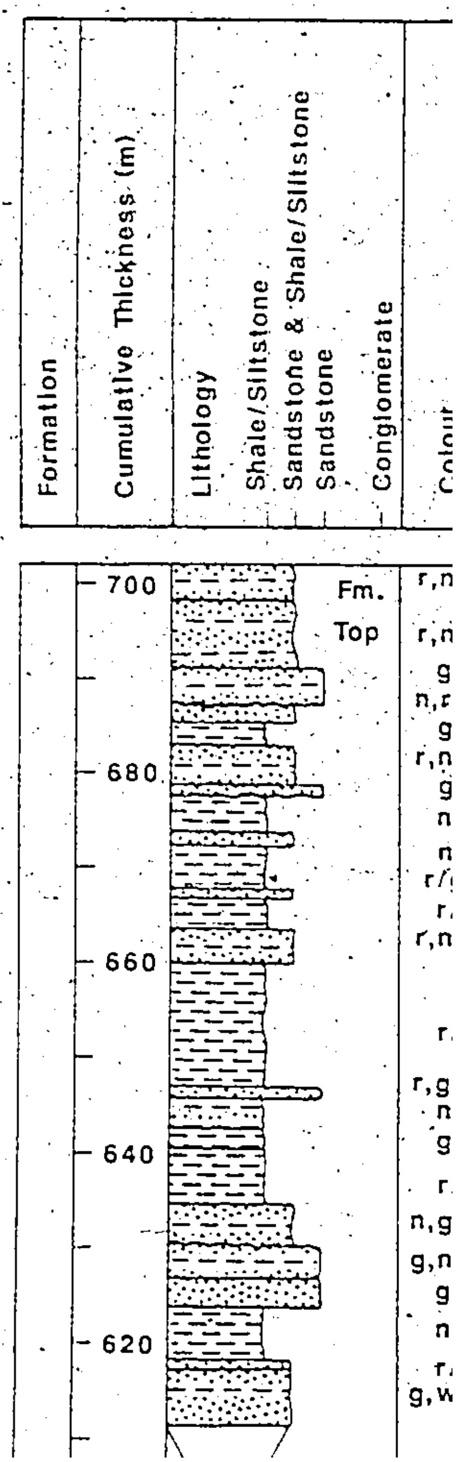


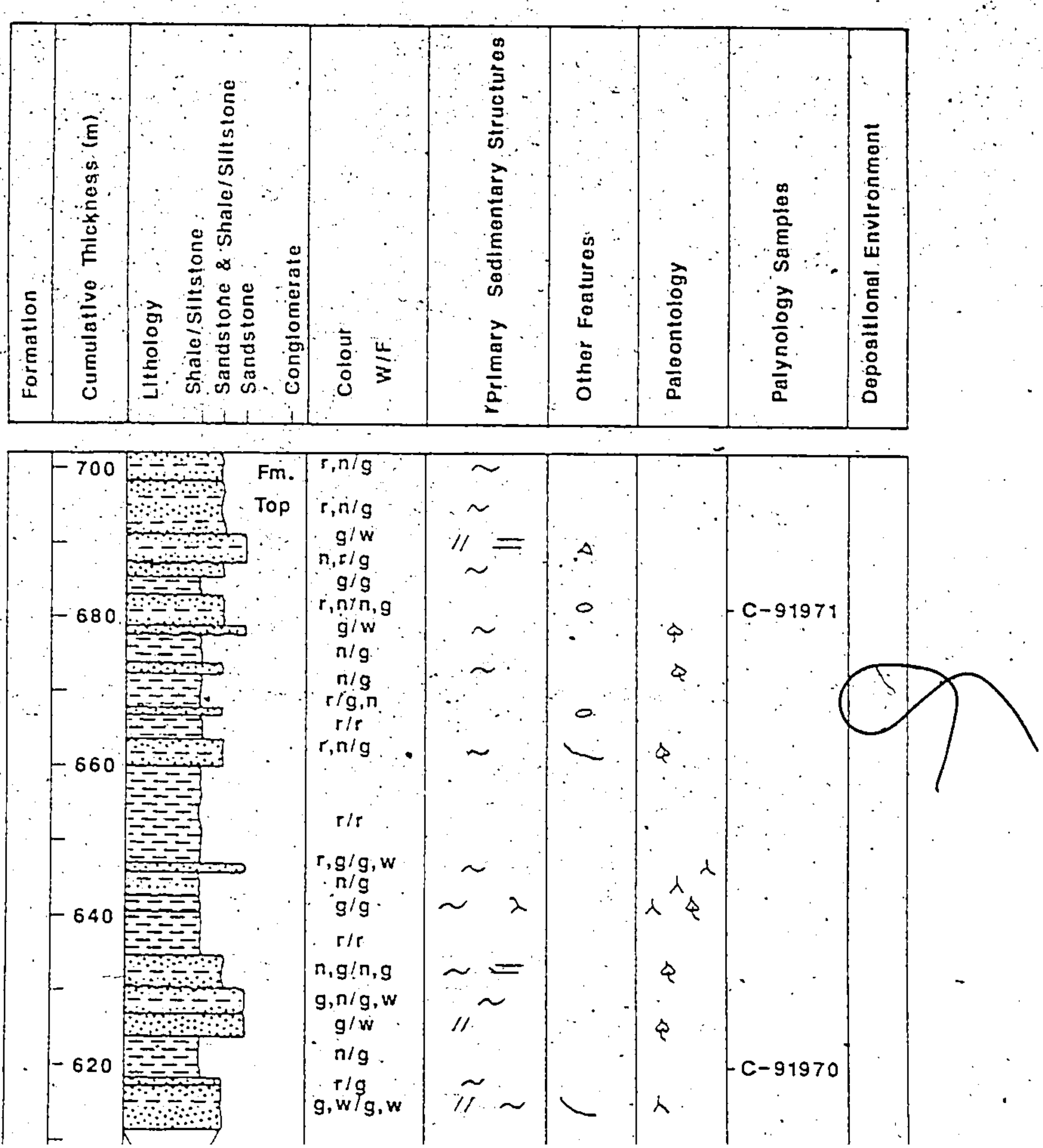
Figure 2.2.5.1-2

SECTION F4

Base of section : 456500 E., 8534000 N., UTM Zone 16x

NTS 59A

Cardigan Strait Sheet



UTM Zone 16x

Paleontology	Palynology Samples	Depositional Environment
	C-91971	
	C-91970	

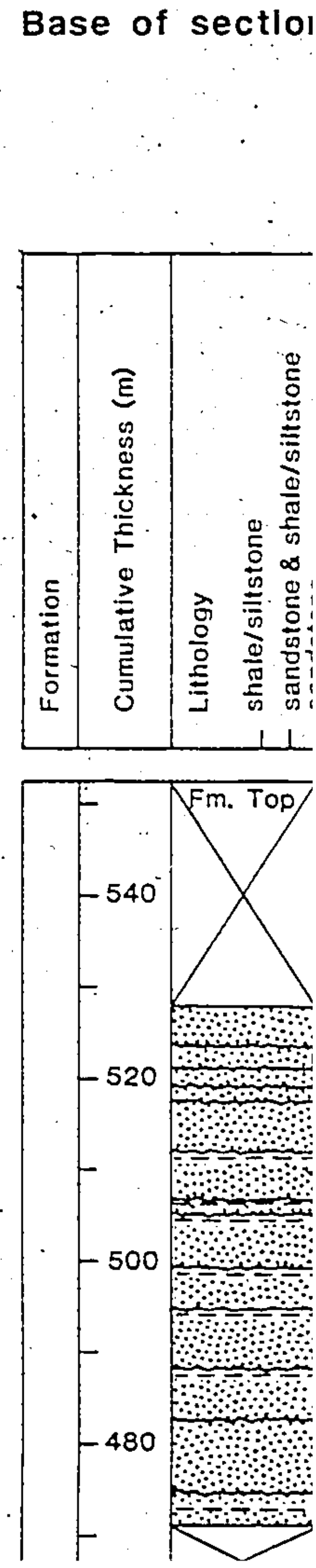

Base of sectio[n]
Formation
Cumulative Thickness (m)
Lithology
shale/siltstone
sandstone & shale/siltstone
Fm. Top
540
520
500
480

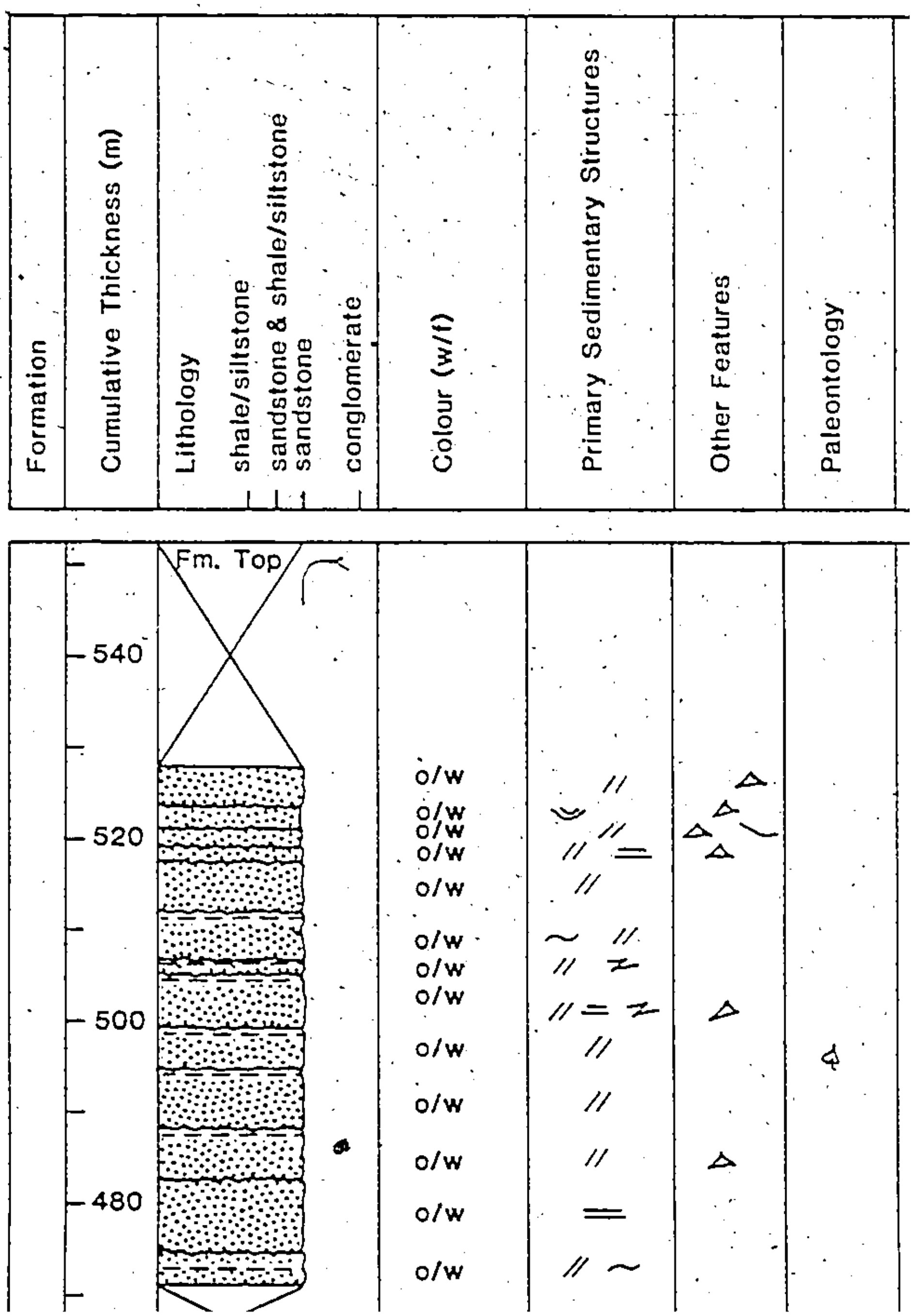
Figure 2.1.6.4-2

SECTION HB1

Base of section : 560600 E., 8556850 N., UTM

NTS 49C

Baumann Fiord Sheet



igure 2.1.6.4–2

SECTION HB1

50600 E., 8556850 N., UTM Zone 16x

NTS 49C

Baumann Fiord Sheet

Colour (w/f)	Primary Sedimentary Structures	Other Features	Paleontology	Palynology Samples	Depositional Environment
o/w	//	△			
o/w		△			
o/w	//	△			
o/w	// =	△			
o/w	//				
o/w	~ //				
o/w	// ≠				
o/w	// = ≠	△			
o/w	//				
o/w	//				
o/w	//	△			
o/w	=				
o/w	// ~				

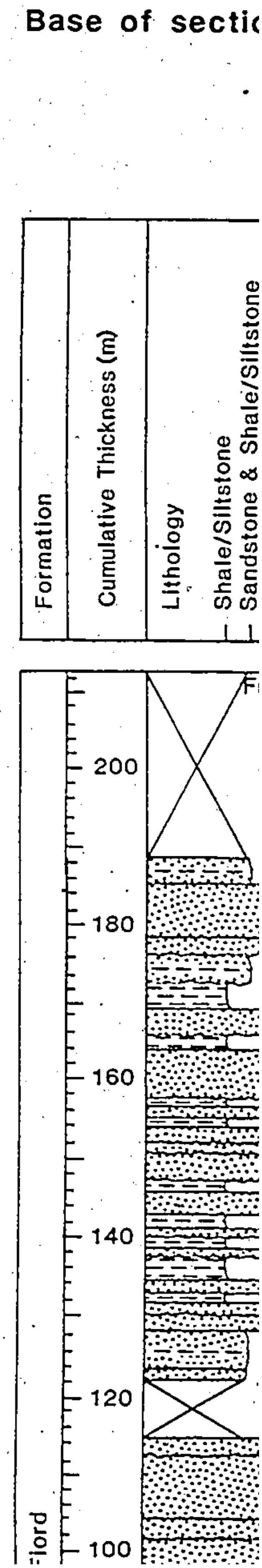

Base of secti
Formation
Cumulative Thickness (m)
Lithology
Shale/Siltstone
Sandstone & Shale/Siltstone
200
180
160
140
120
100

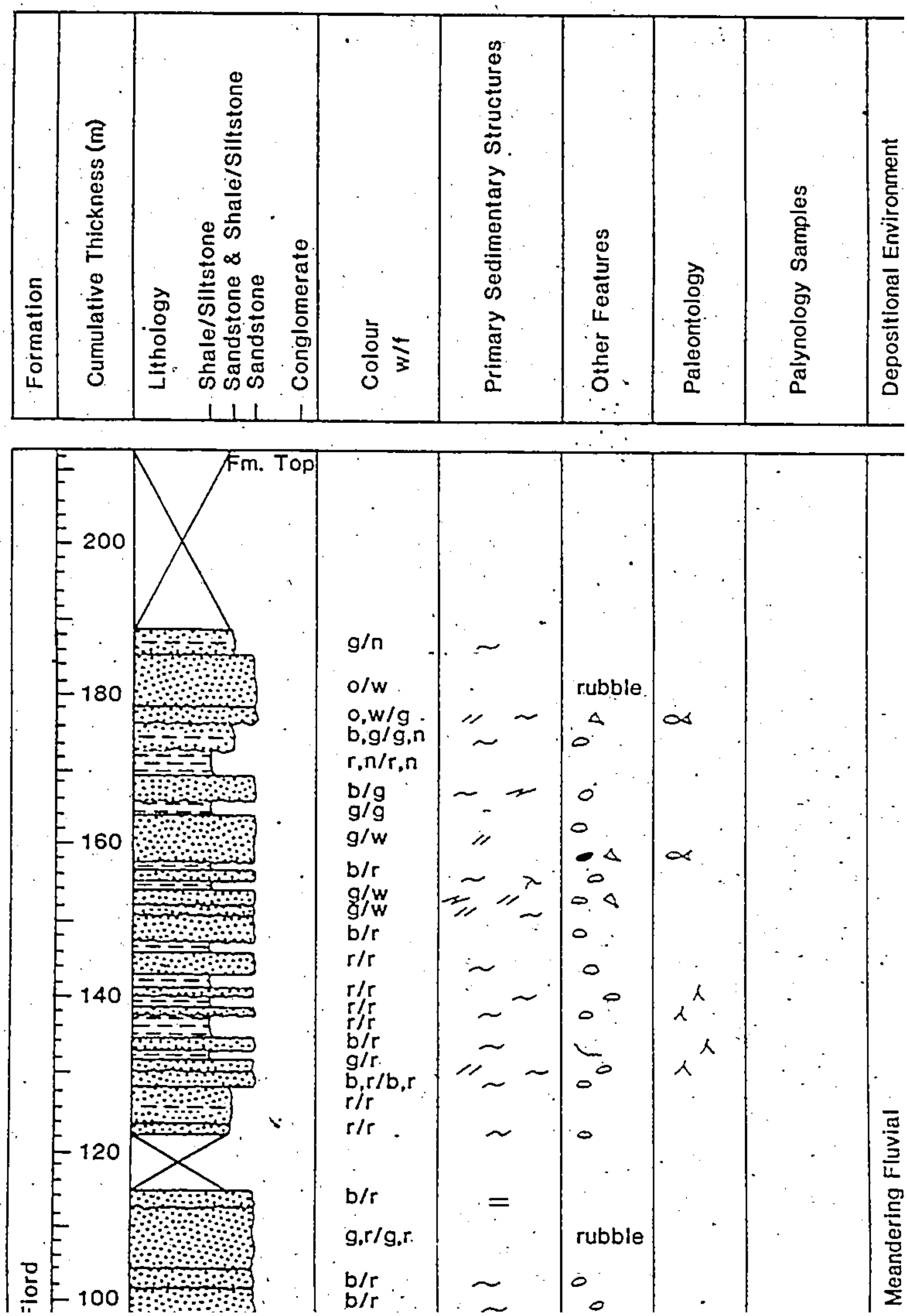
Figure 2.1.5.4-2

SECTION S2

Base of section : 489000 E., 8519000 N., UTM Zone 16

NTS 49B

Baad Fiord Sheet



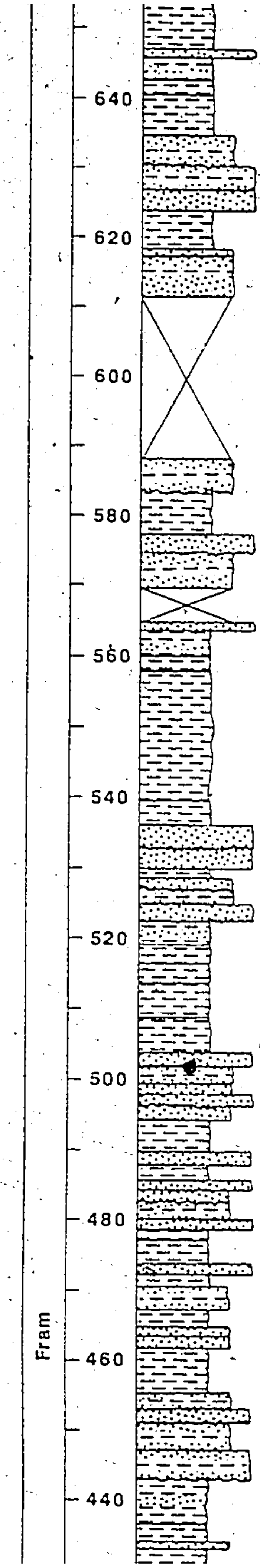
.4-2

?

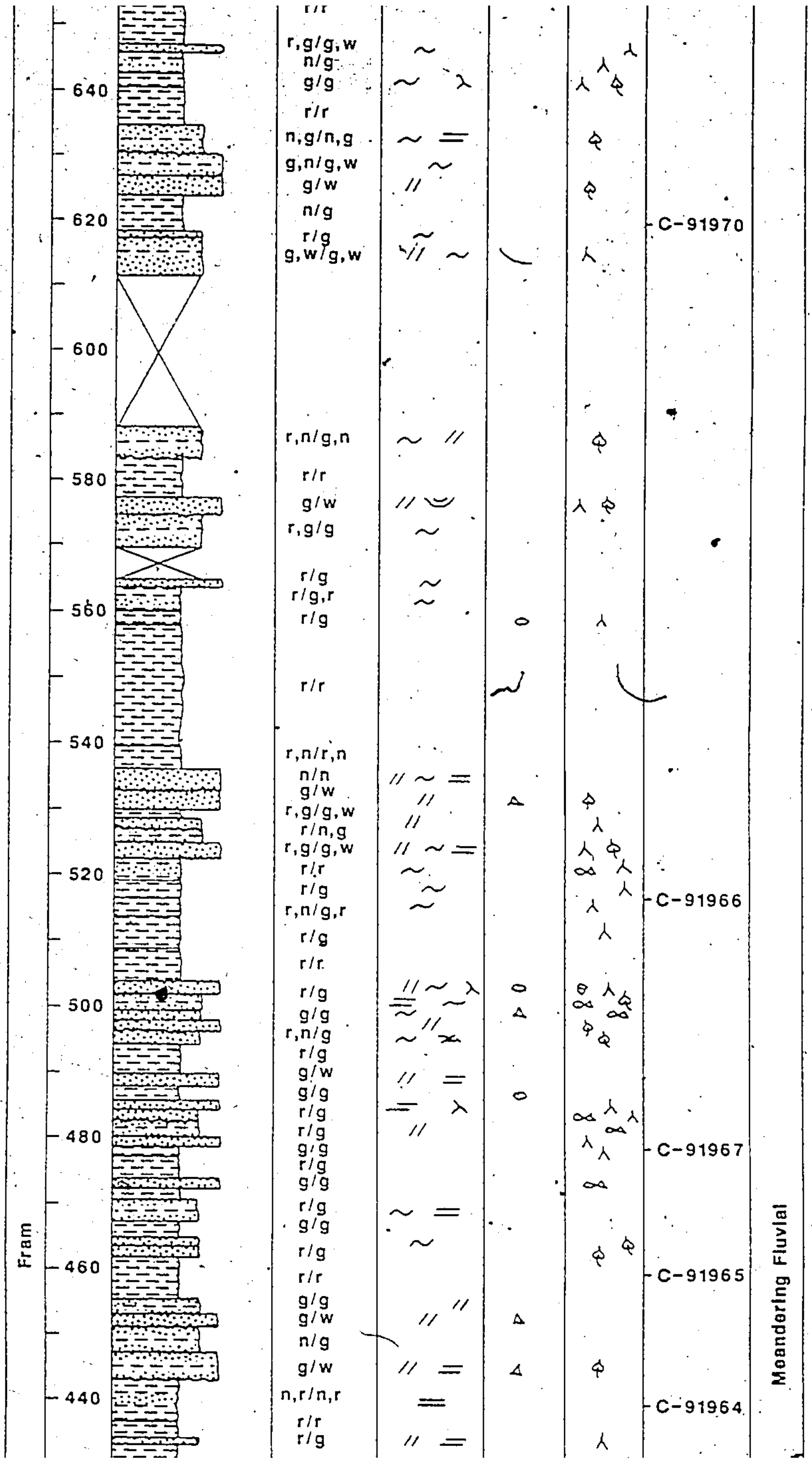
90,00 N., UTM Zone 16x

eet

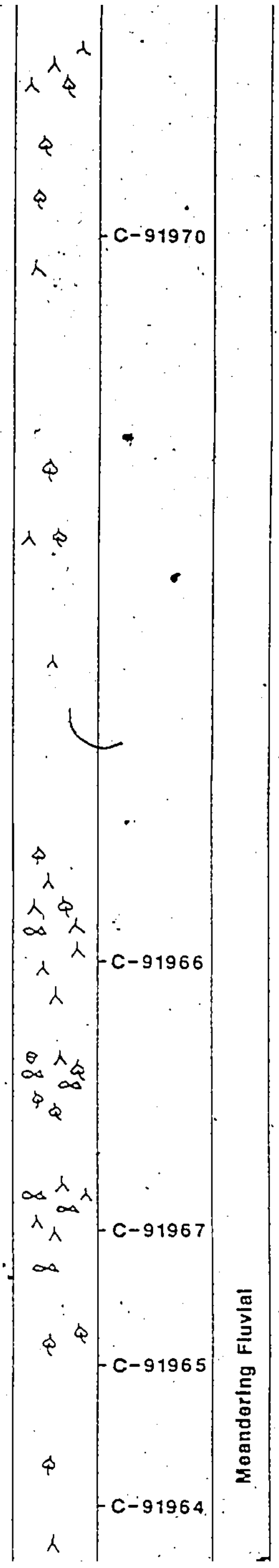
Other Features	Paleontology	Palynology Samples	Depositional Environment
rubble			
rubble			Meandering Fluvial

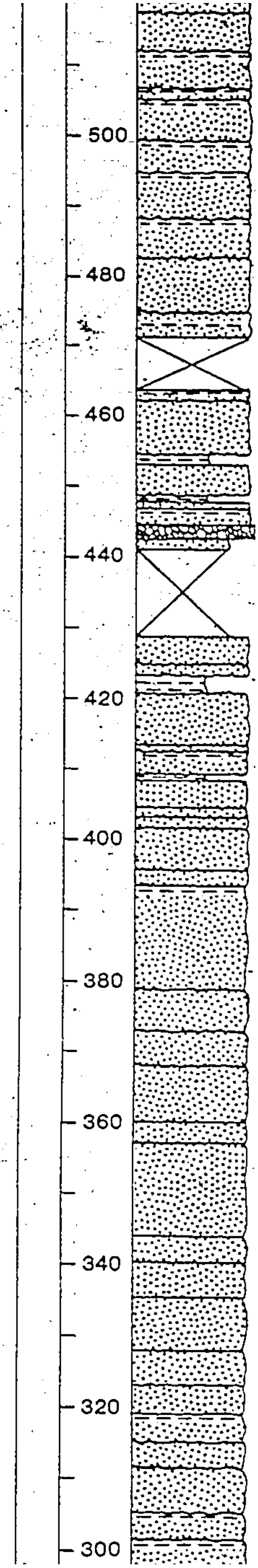


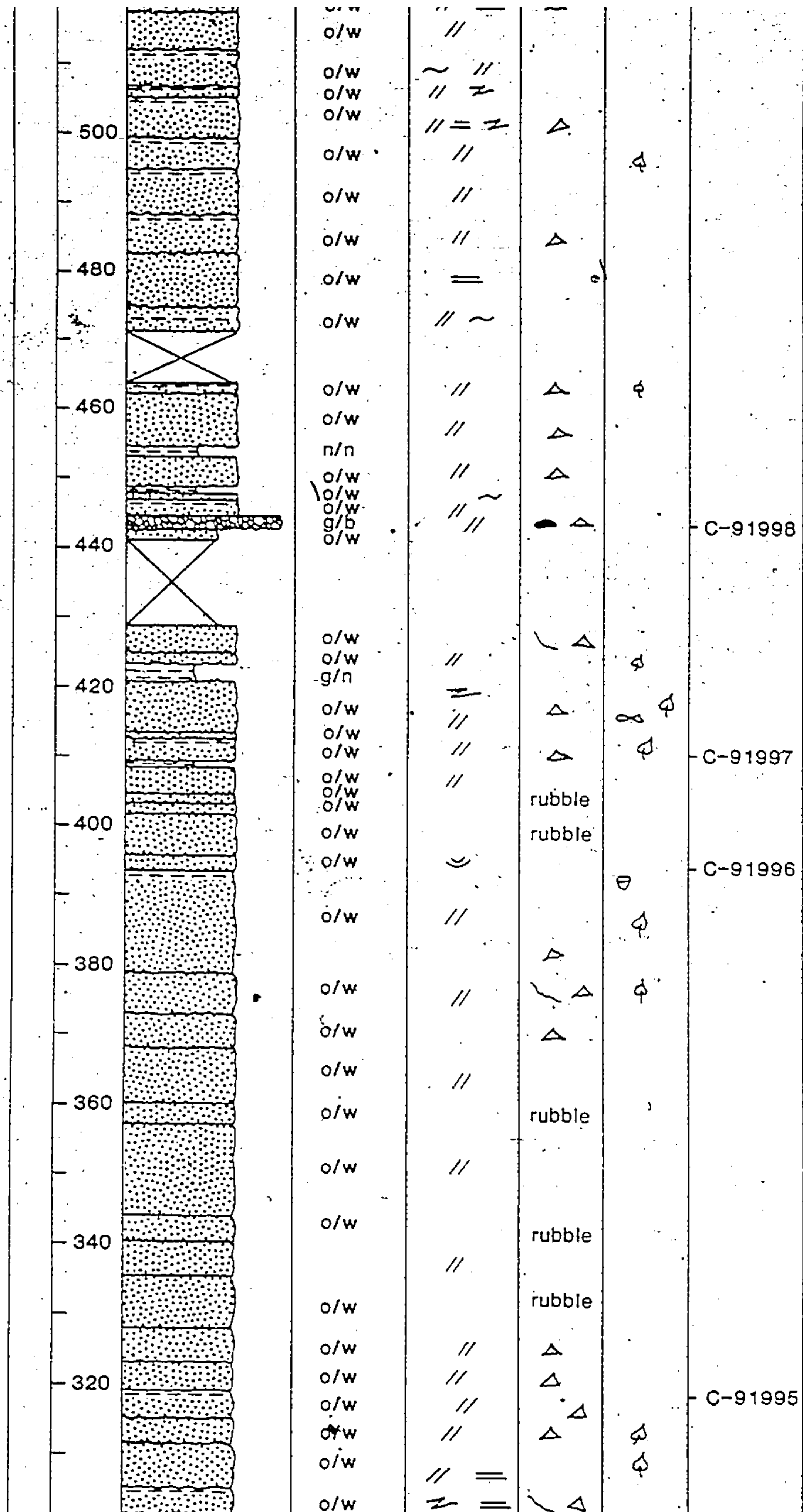
640
620
600
580
560
540
520
500
480
460
440
Fram



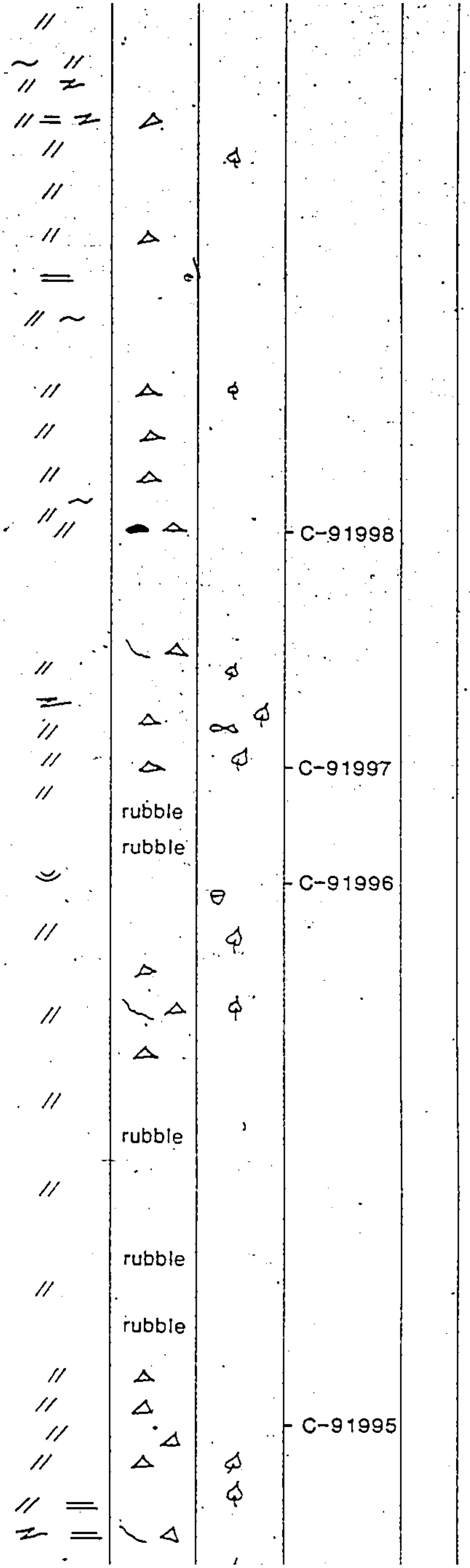
r,g/g,w
n/g
640
g/g
r/r
n,g/n,g
g,n/g,w
g/w
n/g
620
C-91970
r/g
g,w/g,w
600
r,n/g,n
580
r/r
g/w
r,g/g
r/g
r/g,r
560
r/g
r/r
540
r,n/r,n
n/n
g/w
r,g/g,w
r/n,g
r,g/g,w
520
r/r
r/g
C-91966
r,n/g,r
r/g
r/r
r/g
500
g/g
r,n/g
r/g
g/w
g/g
r/g
480
r/g
g/g
r/g
g/g
C-91967
r/g
g/g
r/g
Fram
460
r/r
C-91965
g/g
g/w
n/g
g/w
Meandering Fluvial
440
n,r/n,r
C-91964
r/r
r/g


C-91970
C-91966
C-91967
C-91965
C-91964
Meandering Fluvial

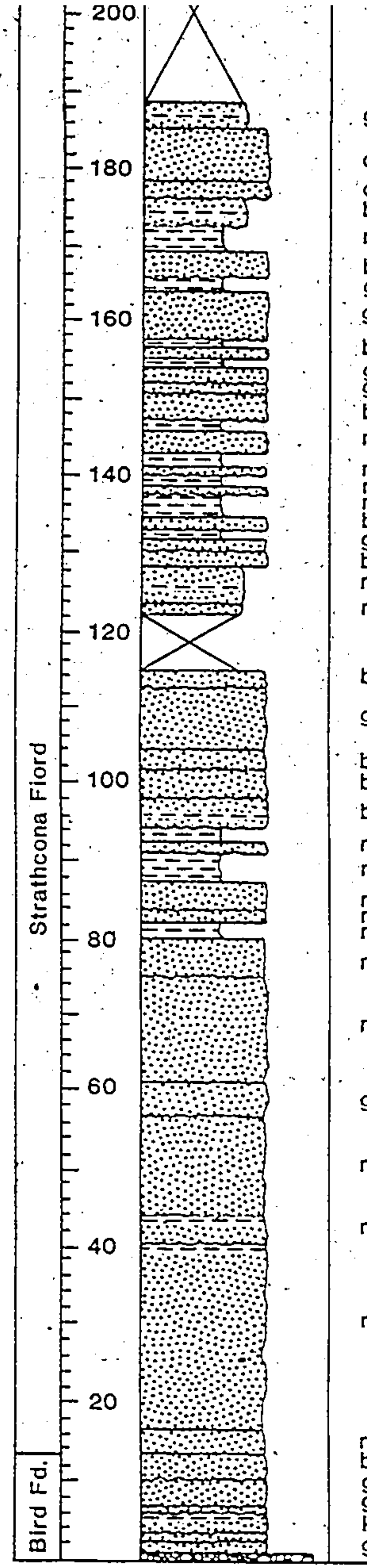

500
480
460
440
420
400
380
360
340
320
300



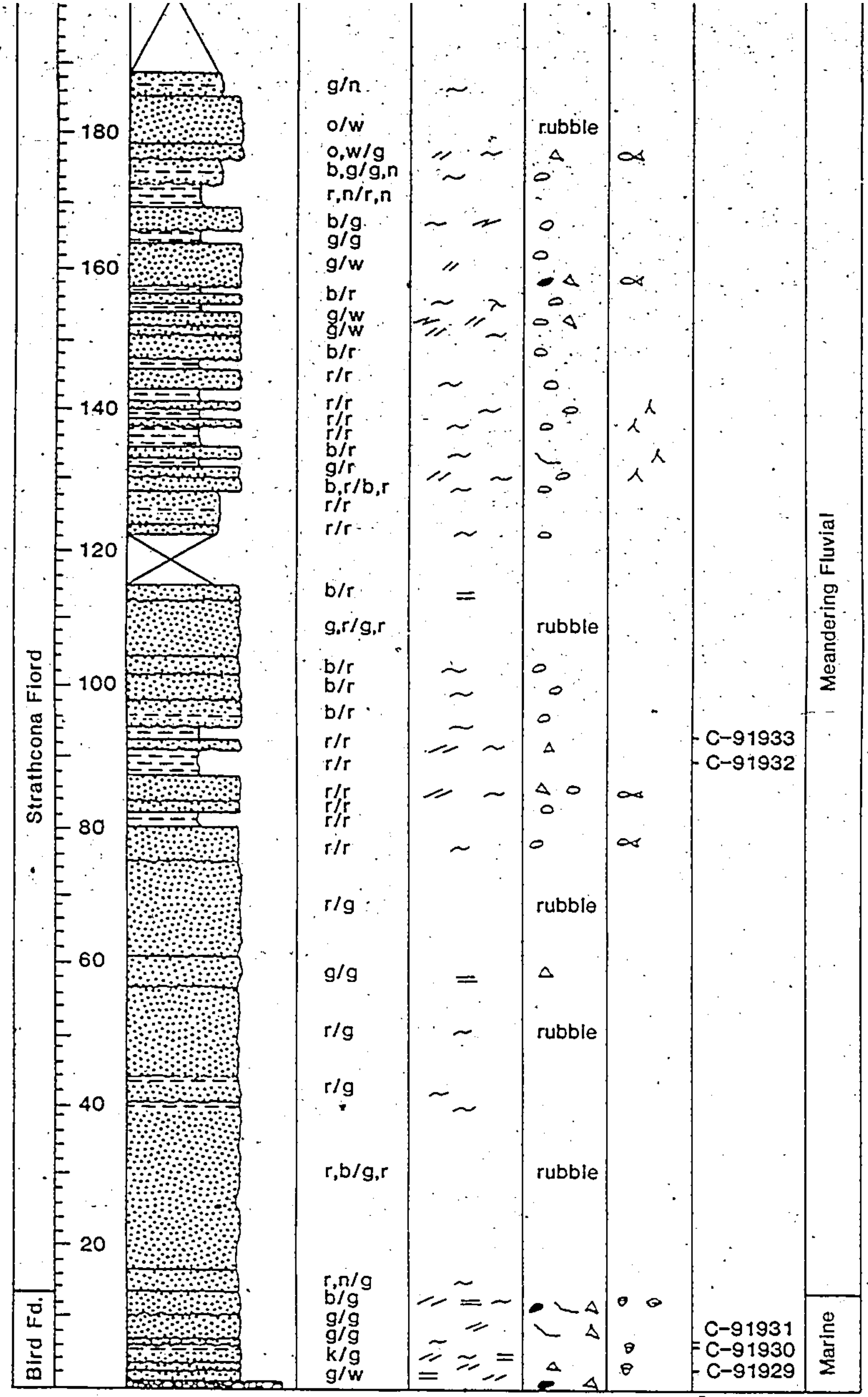
500
480
460
440
420
400
380
360
340
320
300
o/w
n/n
g/b
g/n
rubble
C-91998
C-91997
C-91996
C-91995



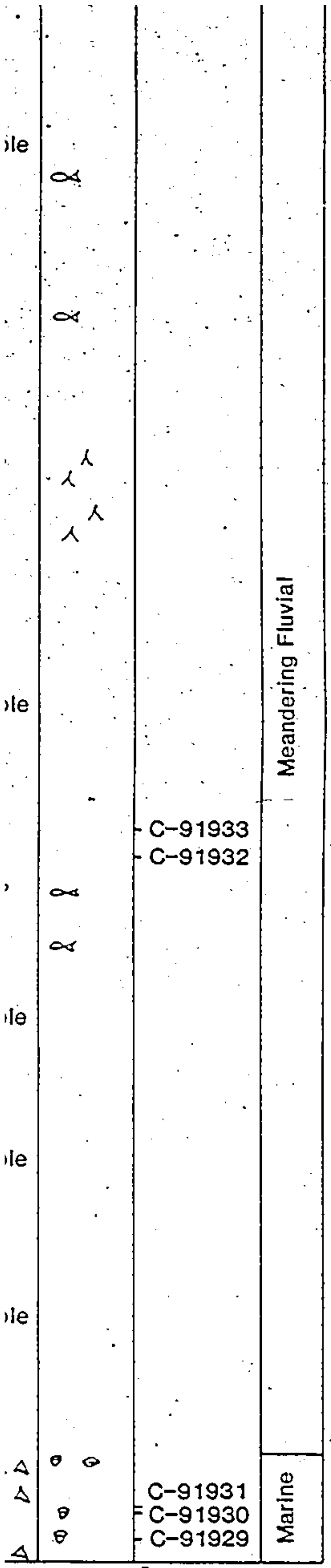
C-91998
C-91997
rubble
rubble
C-91996
rubble
rubble
rubble
C-91995

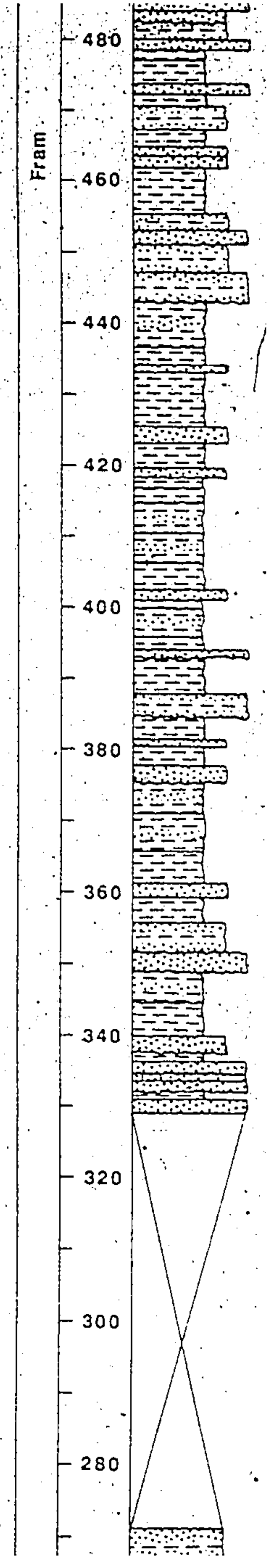


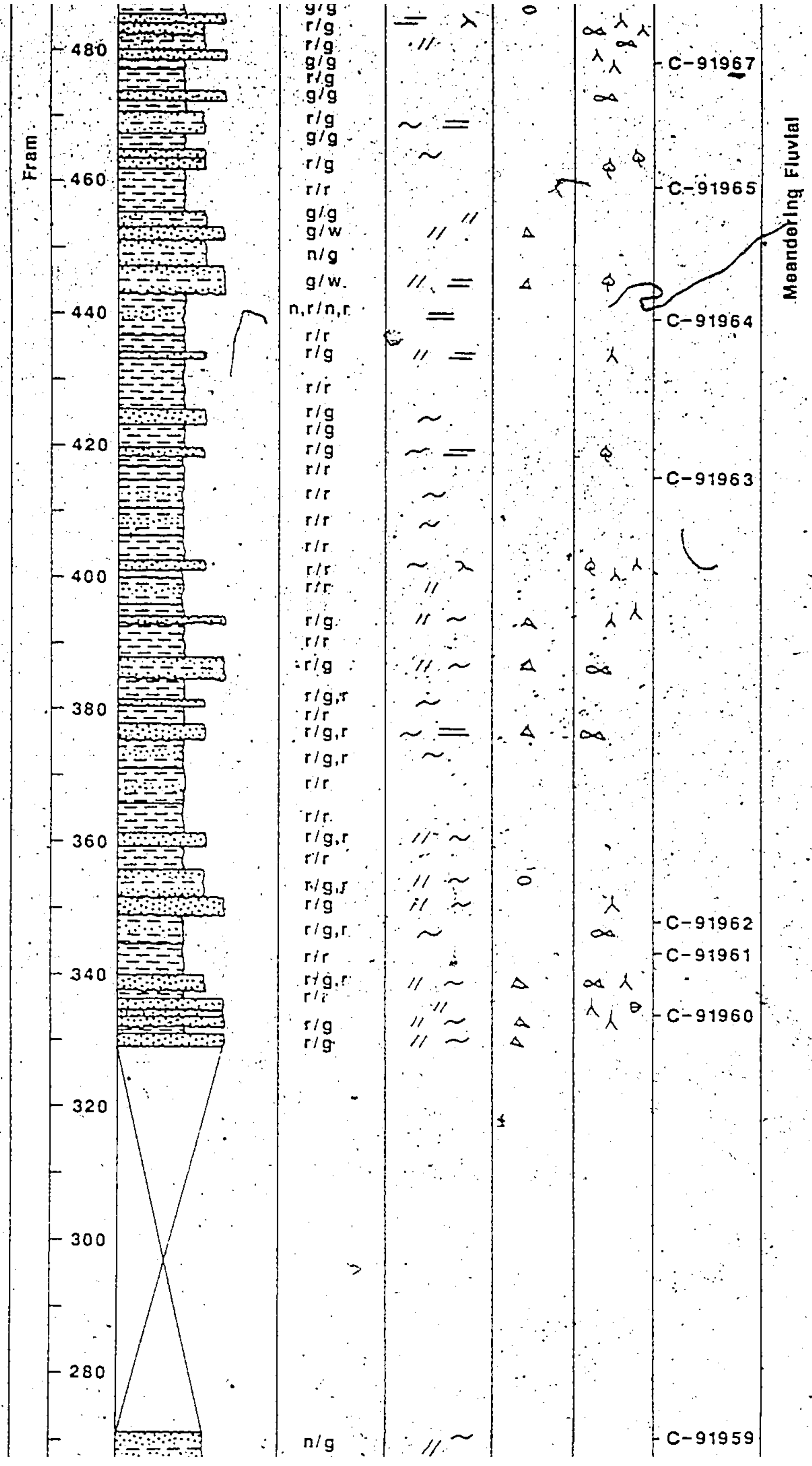
200
180
160
140
120
100
80
60
40
20
Strathcona Fiord
Bird Fd.



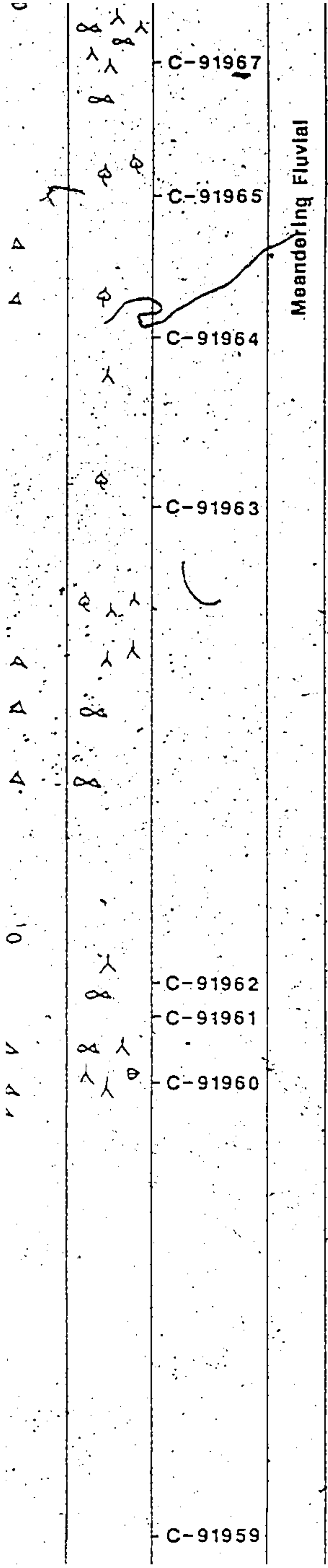
Strathcona Fiord
Bird Fd.
180
160
140
120
100
80
60
40
20
g/n
o/w
o,w/g
b,g/g,n
r,n/r,n
b/g
g/g
g/w
b/r
g/w
g/w
b/r
r/r
r/r
r/r
r/r
b/r
g/r
b,r/b,r
r/r
r/r
b/r
g,r/g,r
b/r
b/r
b/r
r/r
r/r
r/r
r/r
r/r
r/r
r/g
g/g
r/g
r/g
r,b/g,r
r,n/g
b/g
g/g
g/g
k/g
g/w
rubble
rubble
rubble
rubble
rubble
C-91933
C-91932
C-91931
C-91930
C-91929
Meandering Fluvial
Marine

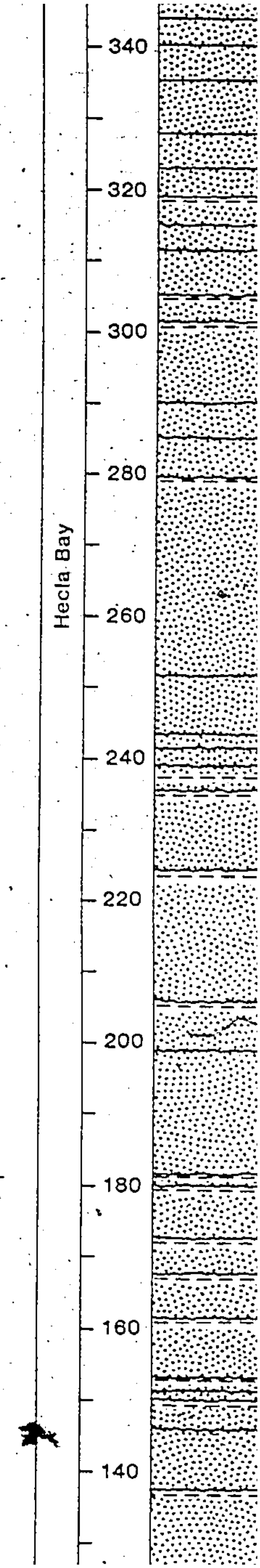

ble
ble
ble
ble
ble
C-91933
C-91932
C-91931
C-91930
C-91929
Meandering Fluvial
Marine

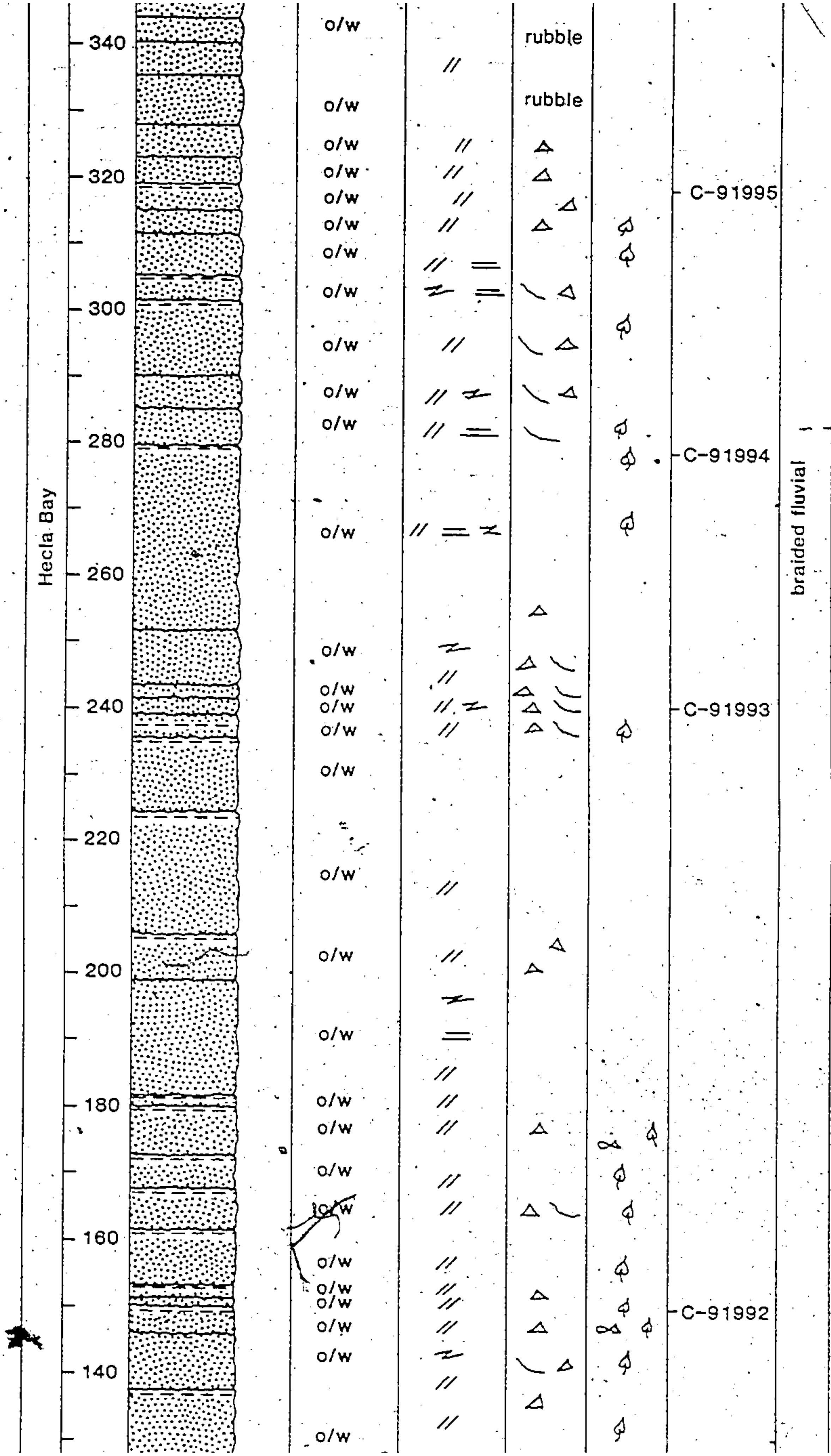

Fram
480
460
440
420
400
380
360
340
320
300
280



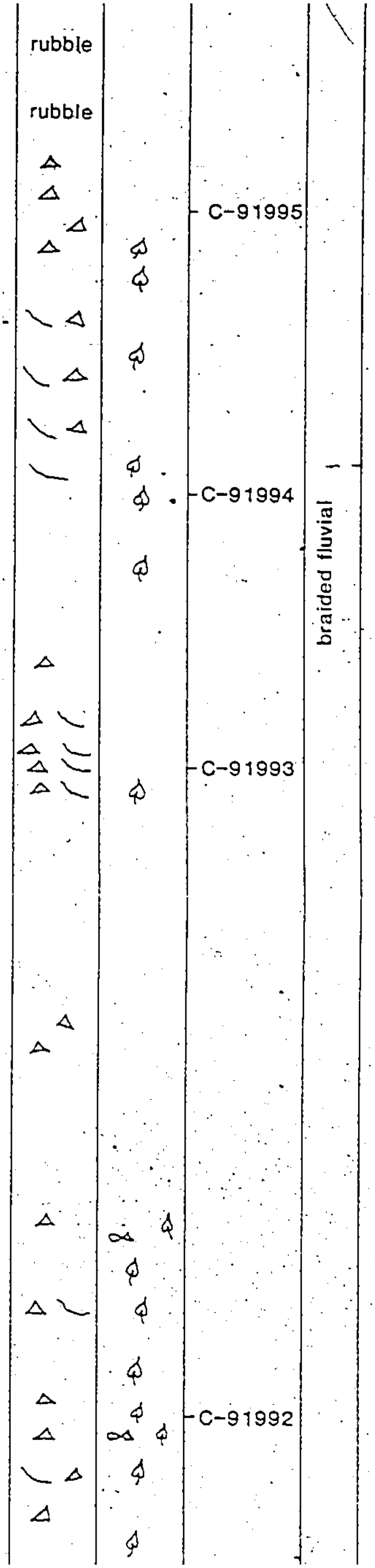
Fram
480
460
440
420
400
380
360
340
320
300
280
g/g
r/g
r/g
g/g
r/g
g/g
r/g
g/g
r/g
r/r
g/g
g/w
n/g
g/w
n,r/n,r
r/r
r/g
r/r
r/g
r/g
r/g
r/r
r/r
r/r
r/r
r/r
r/r
r/g
r/r
r/g
r/g,r
r/r
r/g,r
r/g,r
r/r
r/r
r/g,r
r/r
r/g,r
r/g
r/g,r
r/r
r/g,r
r/r
r/g
r/g
n/g
C-91967
C-91965
C-91964
C-91963
C-91962
C-91961
C-91960
C-91959
Meandering Fluvial

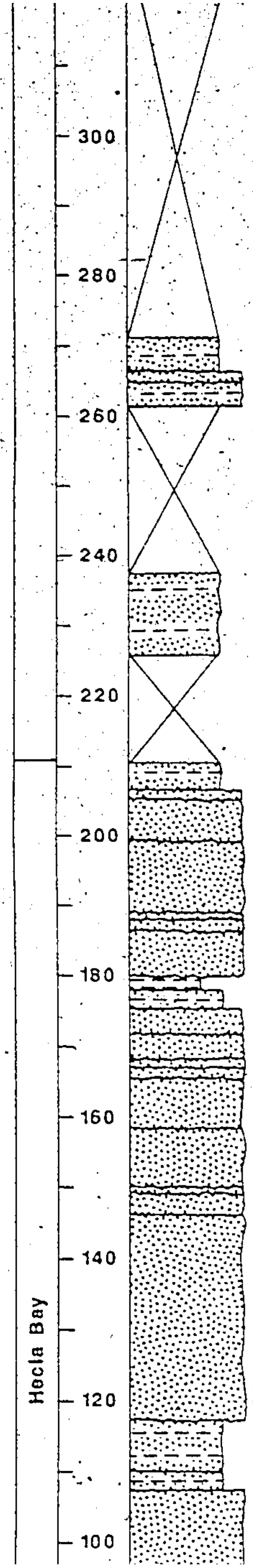

C-91967
C-91965
C-91964
C-91963
C-91962
C-91961
C-91960
C-91959
Meandering Fluvial

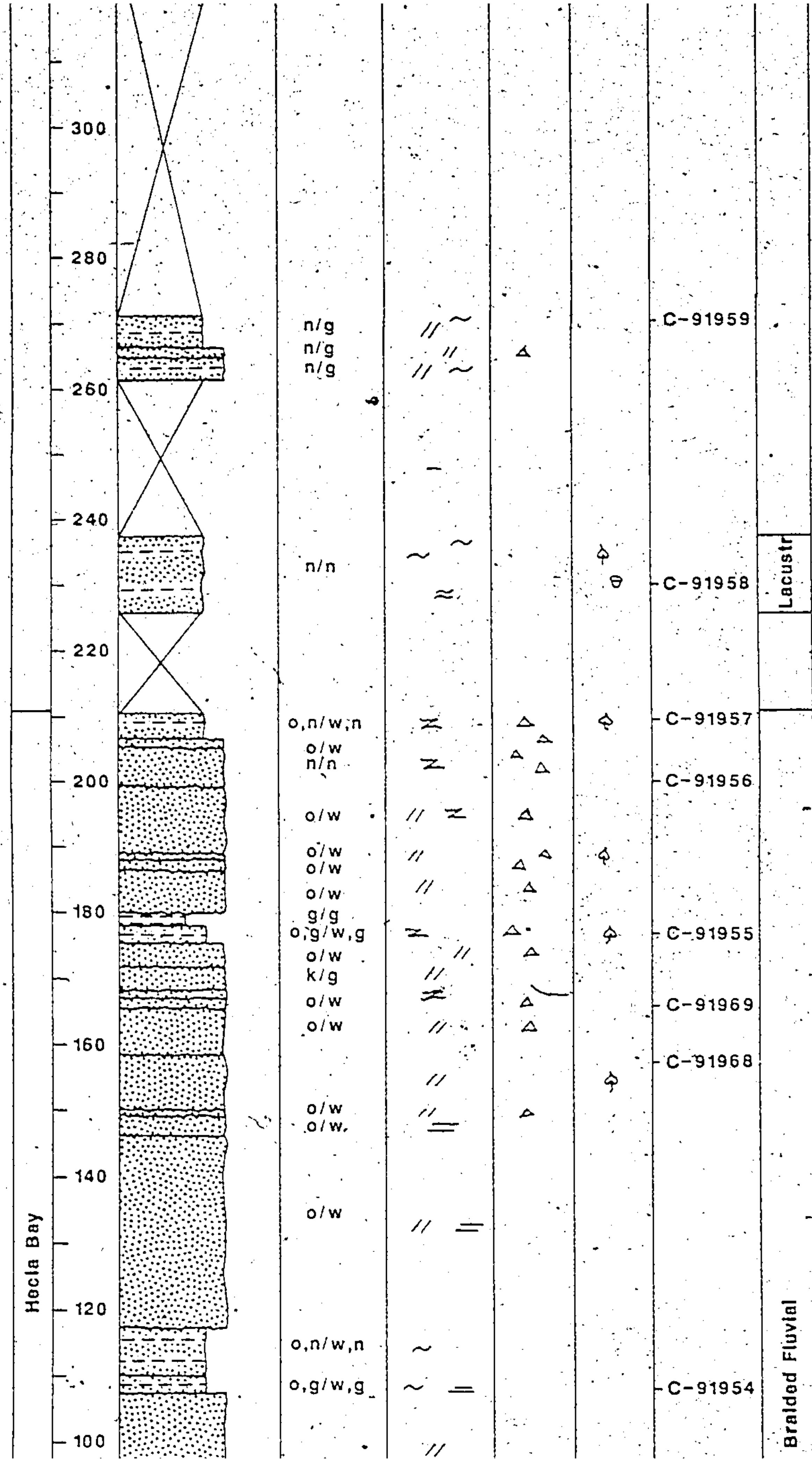

340
320
300
280
Hecla Bay
260
240
220
200
180
160
140



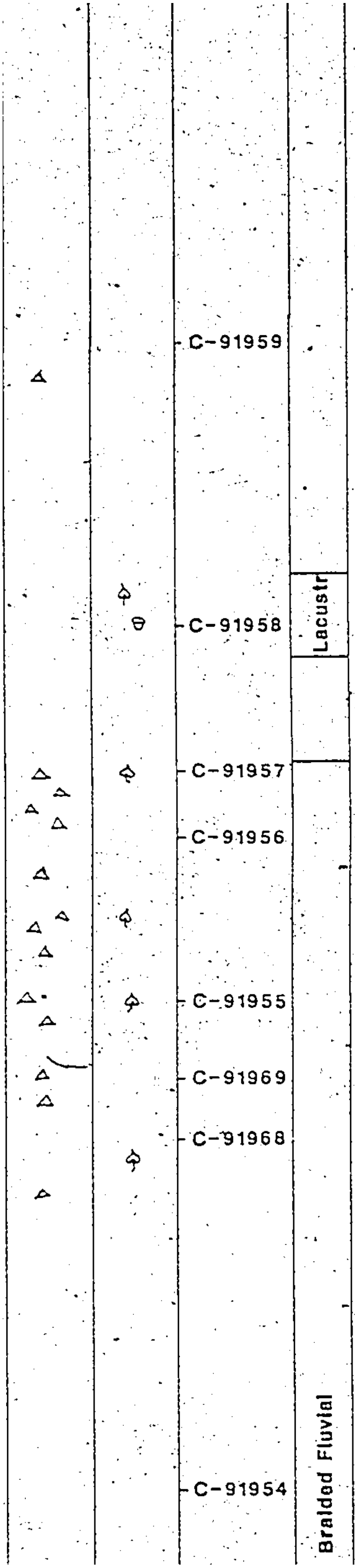
Hecla Bay
340
320
300
280
260
240
220
200
180
160
140
o/w
rubble
rubble
C-91995
C-91994
C-91993
C-91992
braided fluvial

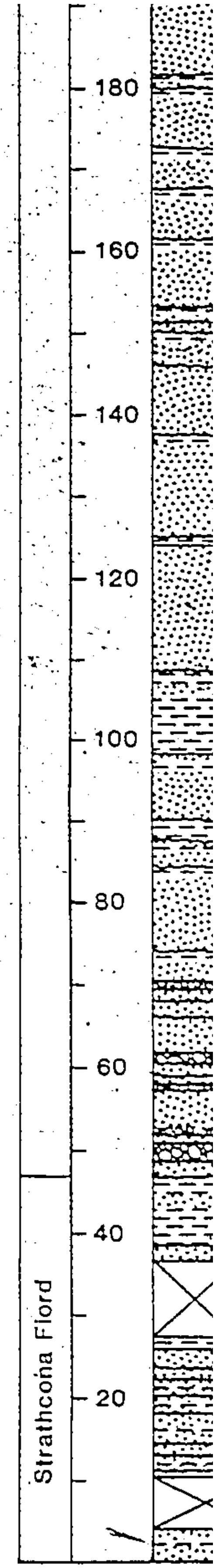

rubble
rubble
C-91995
C-91994
braided fluvial
C-91993
C-91992


300
280
260
240
220
200
180
160
140
120
100
Hecla Bay

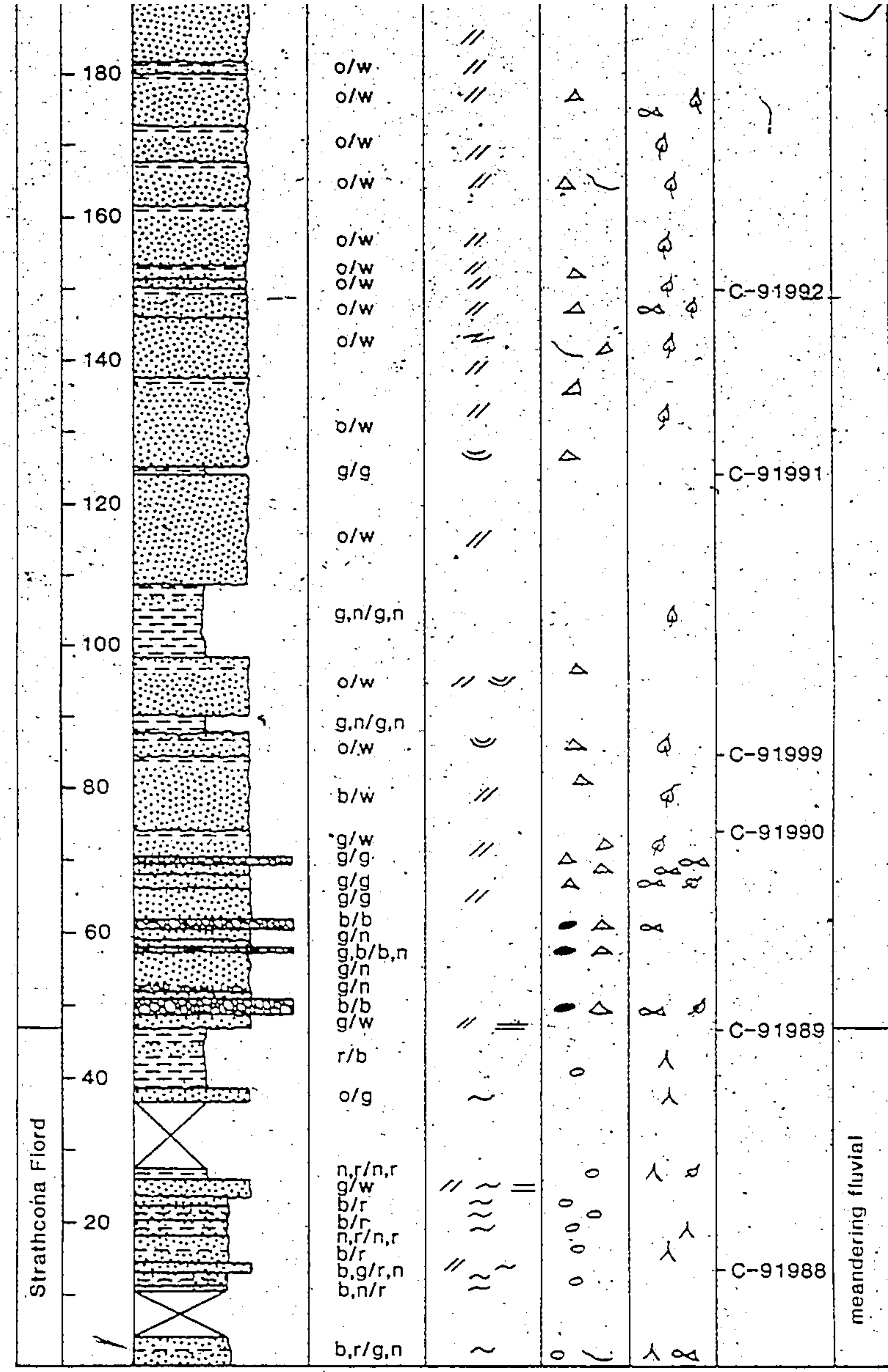


300
280
260
240
220
200
180
160
140
120
100
Hecla Bay
n/g
n/g
n/g
n/n
o,n/w,n
o/w
n/n
o/w
o/w
o/w
o/w
g/g
o,g/w,g
o/w
k/g
o/w
o/w
o/w
o/w
o/w
o,n/w,n
o,g/w,g
C-91959
C-91958
C-91957
C-91956
C-91955
C-91969
C-91968
C-91954
Lacustr
Braided Fluvial

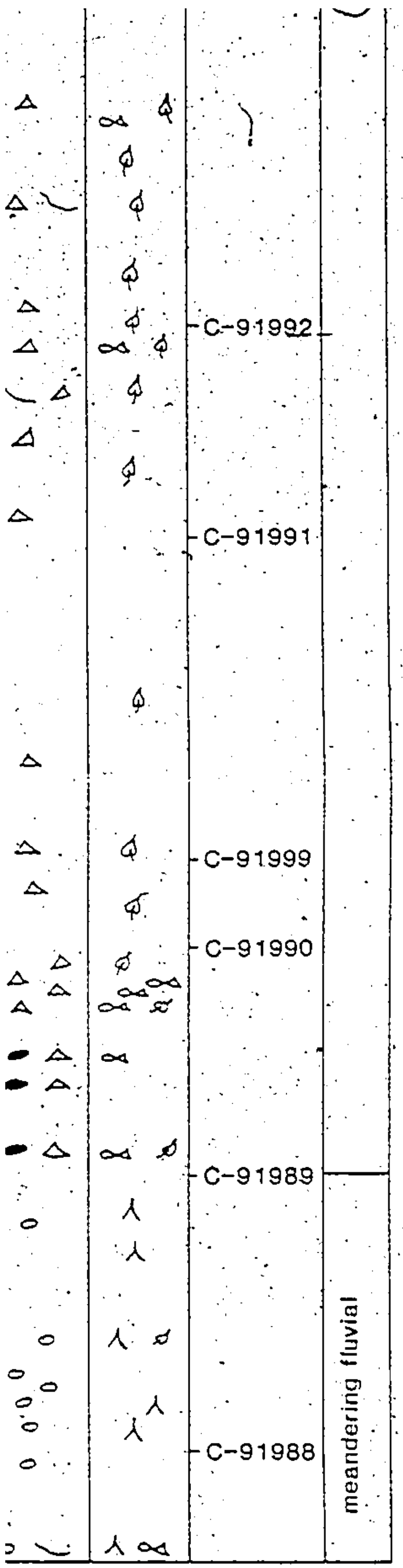

C-91959
C-91958
Lacustr
C-91957
C-91956
C-91955
C-91969
C-91968
C-91954
Braided Fluvial

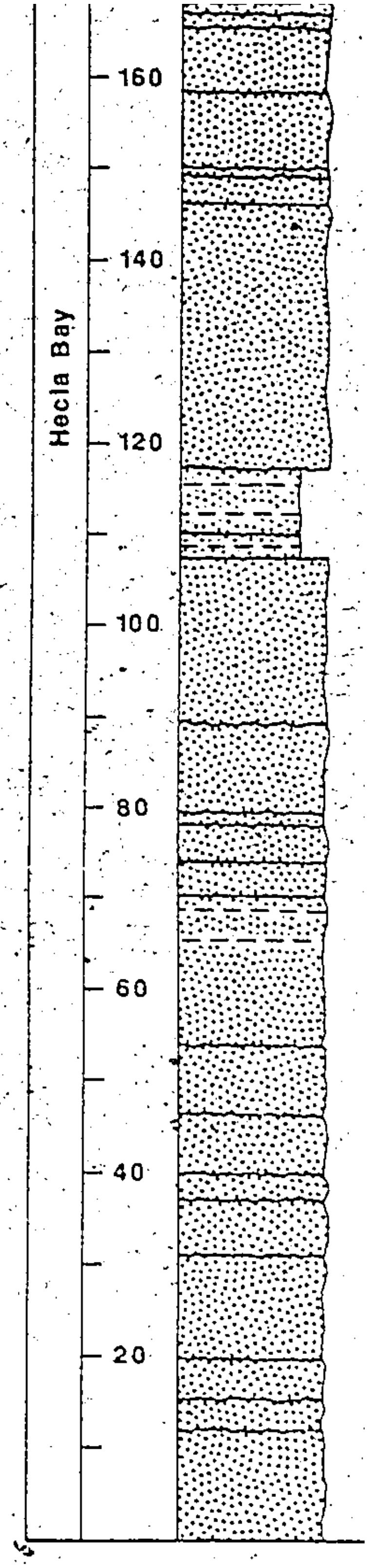


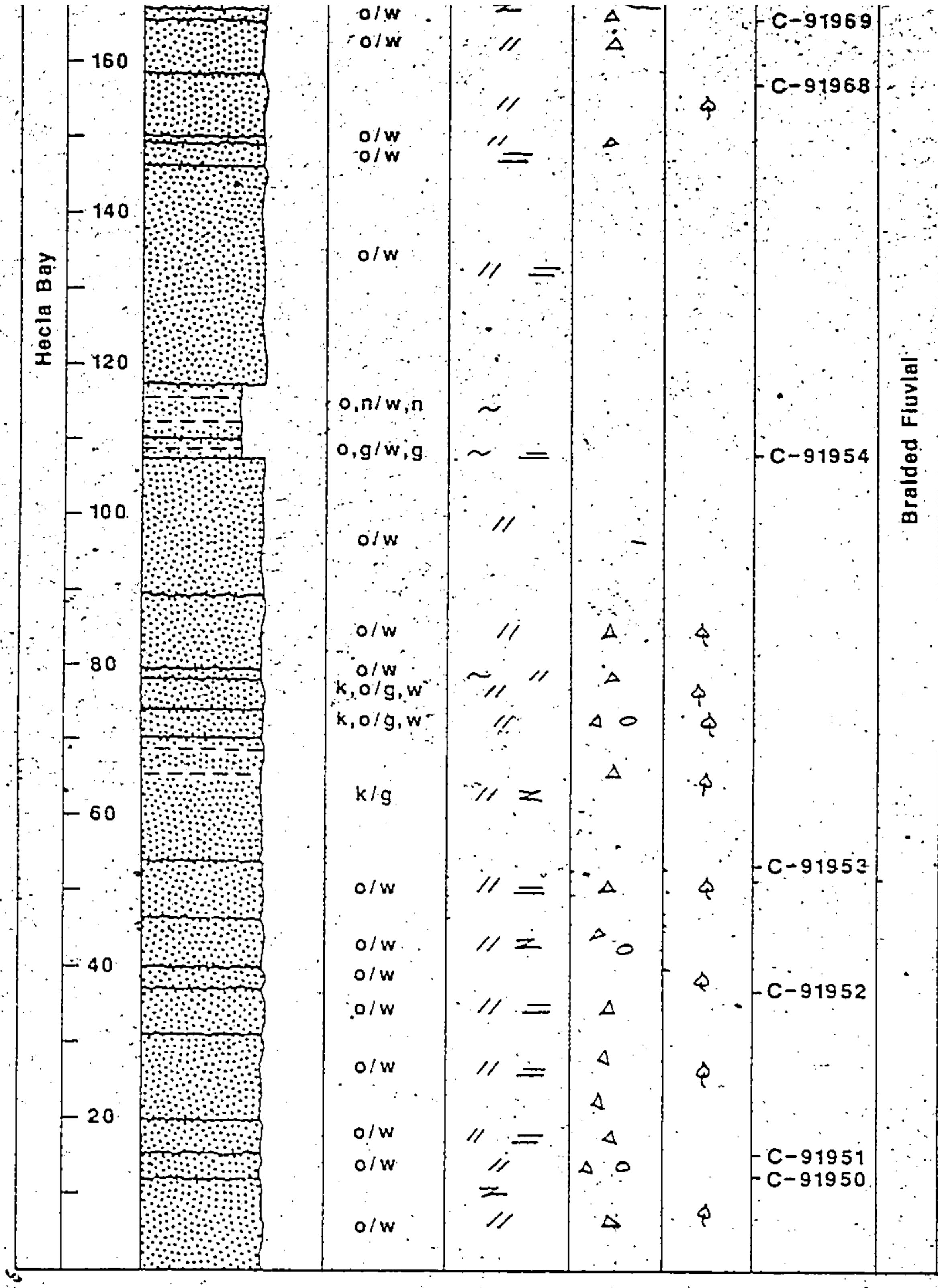
180
160
140
120
100
80
60
40
20
Strathcona Fiord



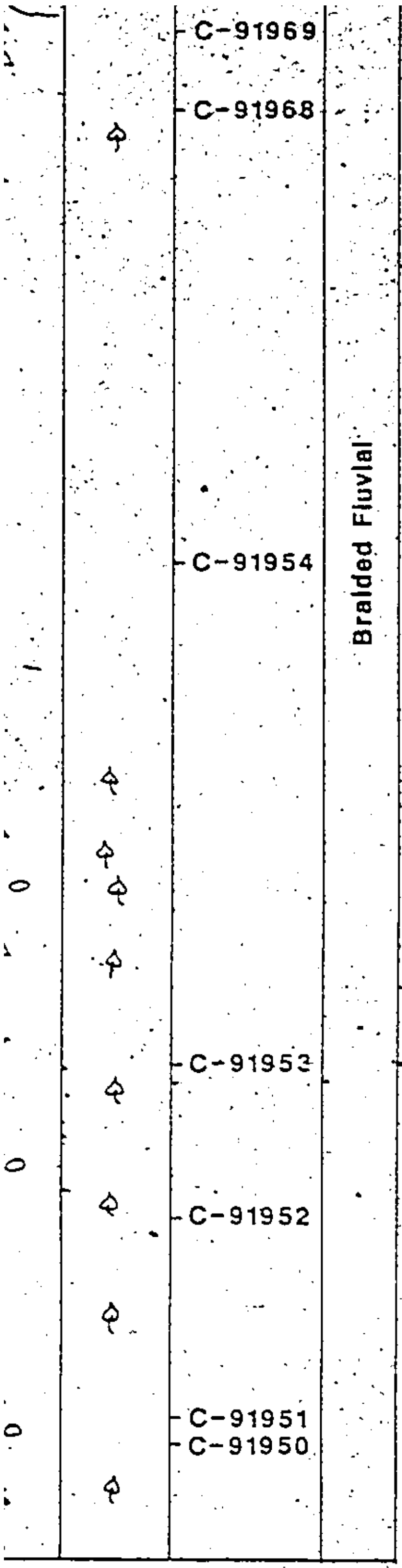
Strathcona Fiord
meandering fluvial
180
160
140
120
100
80
60
40
20
o/w
o/w
o/w
o/w
o/w
o/w
o/w
o/w
o/w
o/w
g/g
o/w
g,n/g,n
o/w
g,n/g,n
o/w
b/w
g/w
g/g
g/g
g/g
b/b
g/n
g,b/b,n
g/n
g/n
b/b
g/w
r/b
o/g
n,r/n,r
g/w
b/r
b/r
n,r/n,r
b/r
b,g/r,n
b,n/r
b,r/g,n
C-91992
C-91991
C-91999
C-91990
C-91989
C-91988


C-91992
C-91991
C-91999
C-91990
C-91989
C-91988
meandering fluvial


Hecla Bay
160
140
120
100
80
60
40
20



Hecla Bay
160
140
120
100
80
60
40
20
o/w
o/w
o/w
o/w
o/w
o,n/w,n
o,g/w,g
o/w
o/w
o/w
k,o/g,w
k,o/g,w
k/g
o/w
o/w
o/w
o/w
o/w
o/w
o/w
o/w
C-91969
C-91968
C-91954
C-91953
C-91952
C-91951
C-91950
Braided Fluvial


C-91969
C-91968
C-91954
Braided Fluvial
C-91953
C-91952
C-91951
C-91950

Base Of Sectio

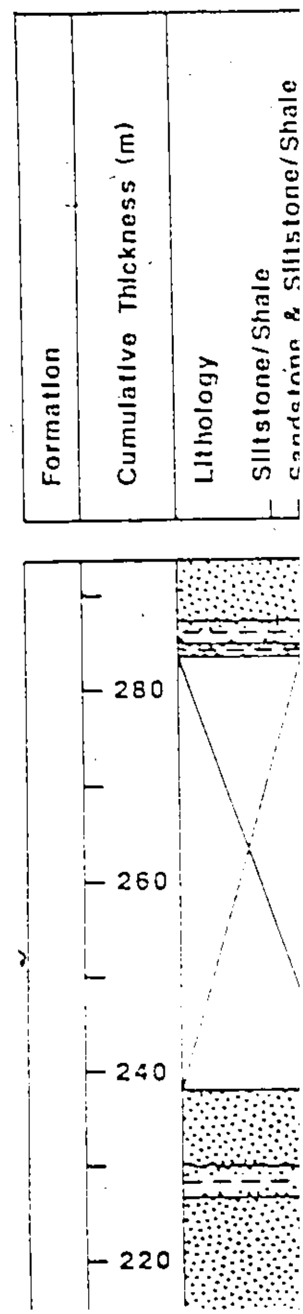


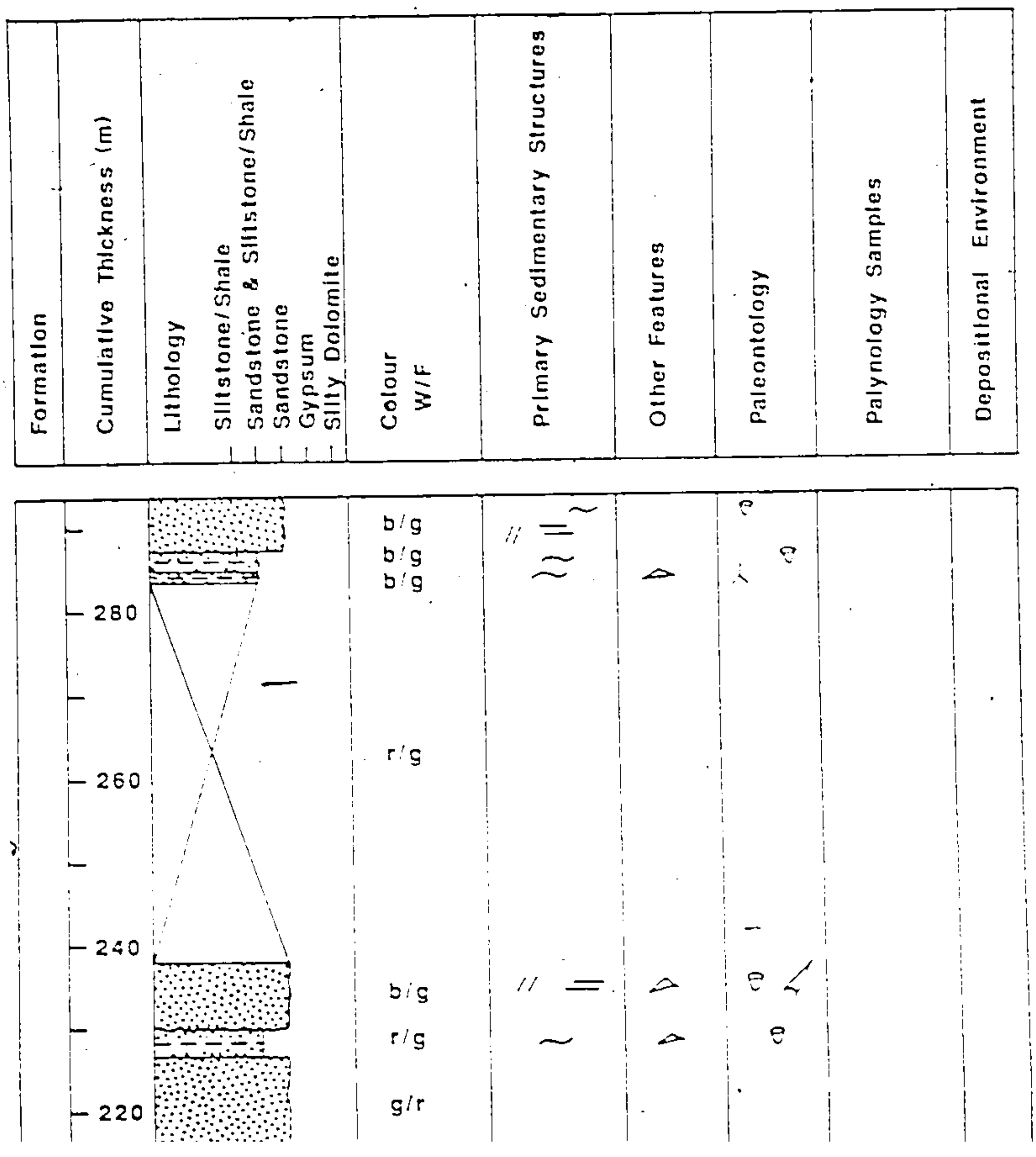
Figure 2.1.4.4-2

SECTION S1

Base Of Section : 432825 E., 8596750 N., UTM Zone 17x

NTS 49D

Vendom Fiord Sheet



4-2

S1

750 N., UTM Zone 17x

Sheet

	Other Features	Paleontology	Palynology Samples	Depositional Environment

Base of section :

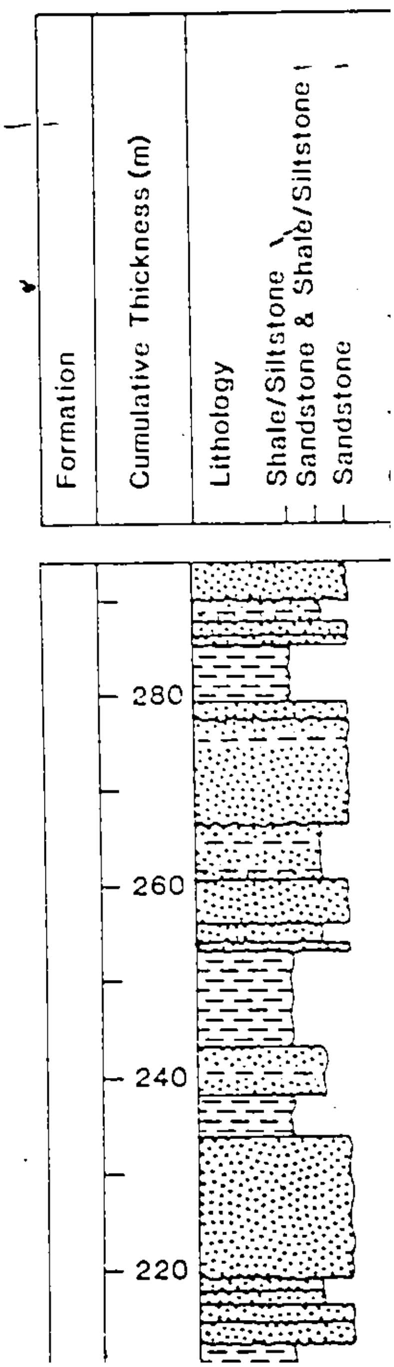


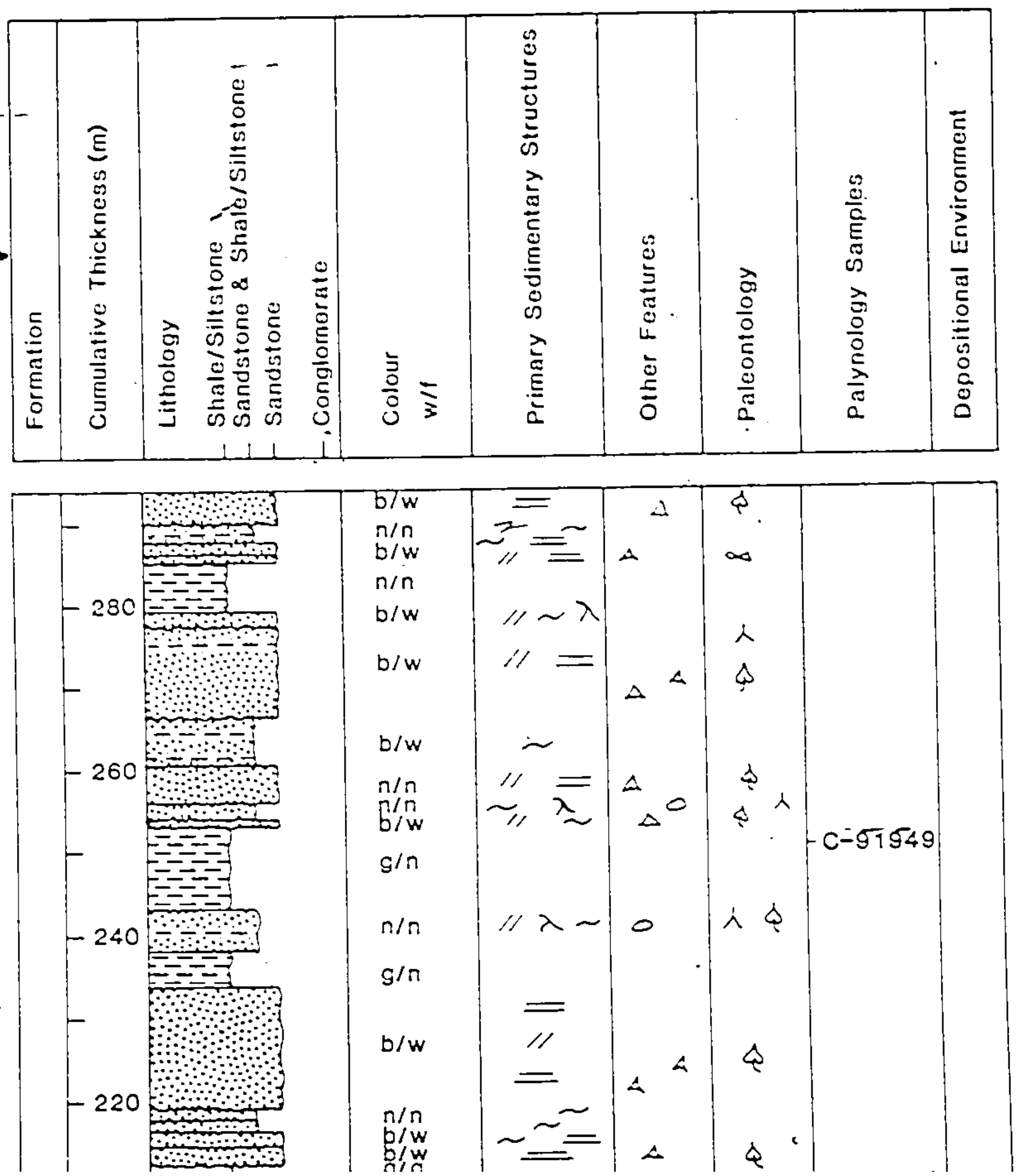
Figure 2.3.8.1-2

SECTION F3

Base of section : 438750 E., 8518250 N., UTM Zone 16x

NTS 59A

Cardigan Strait Sheet



1−2

3

250 N., UTM Zone 16x

Sheet

Other Features	Paleontology	Palynology Samples	Depositional Environment
		C-91949	

Fig

Base Of Section : 496

B

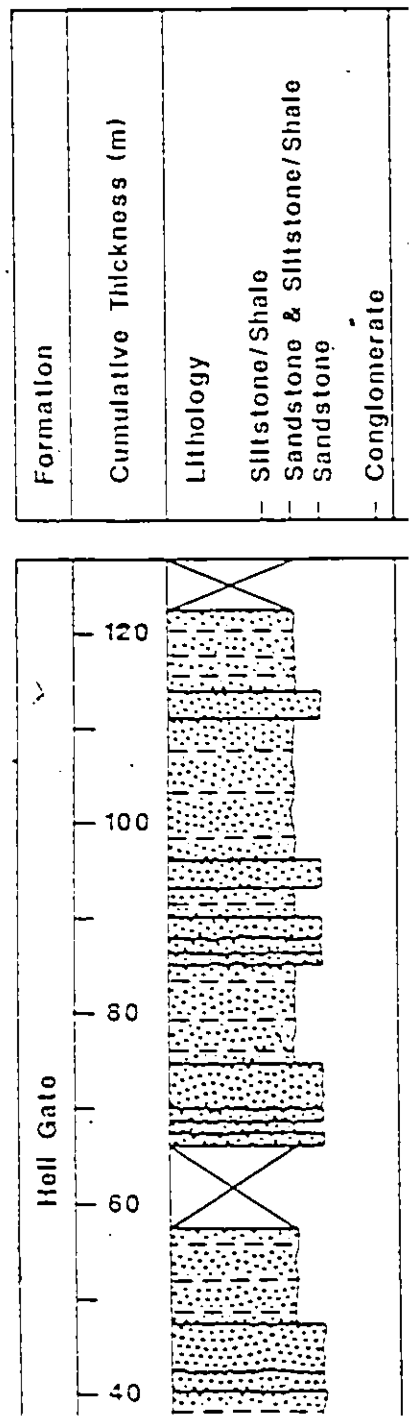


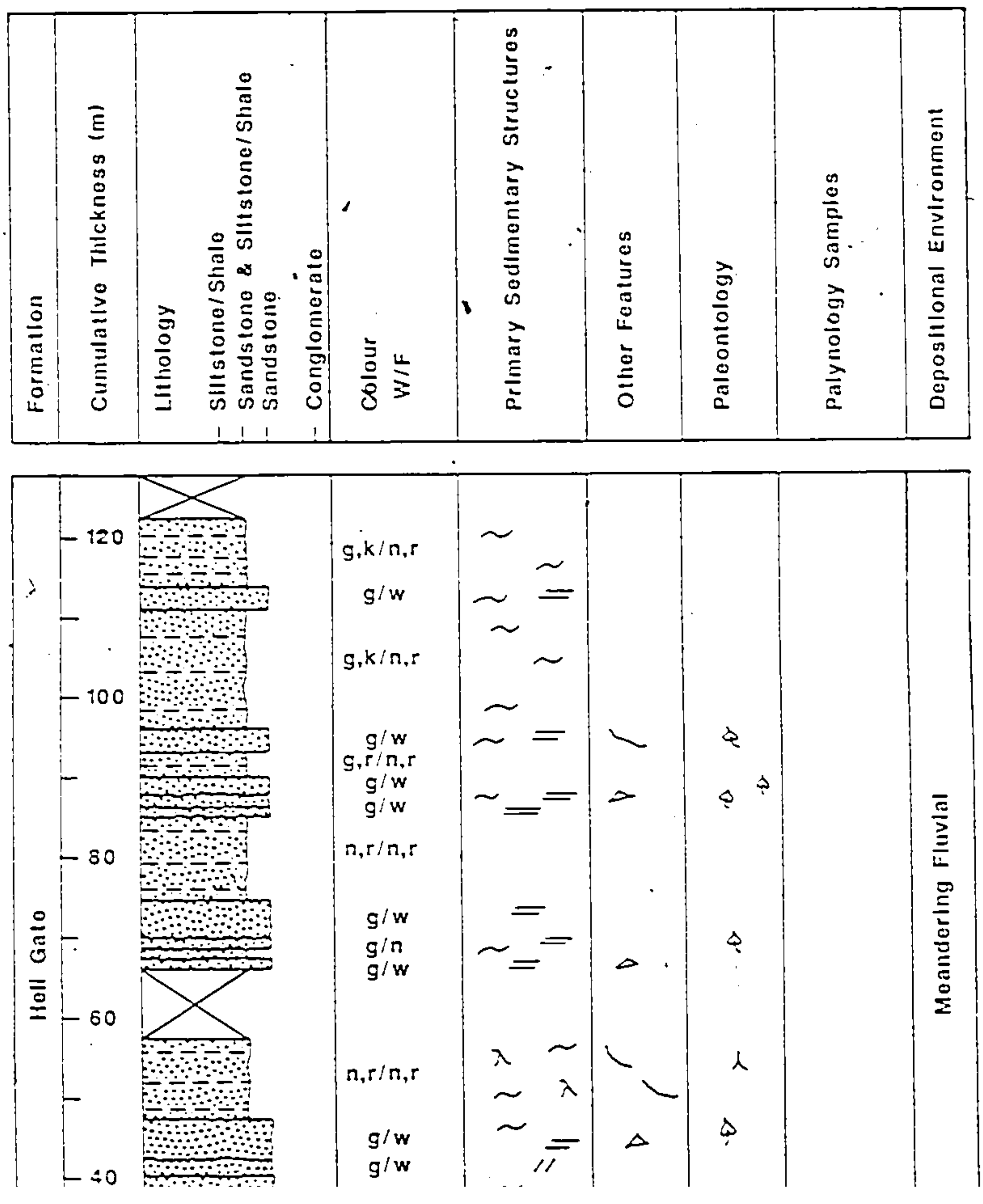
Figure 2.4.6.1-2

SECTION HG1

Base Of Section : 496825 E., 8545500 N., UTM Zone 16x

NTS 49B

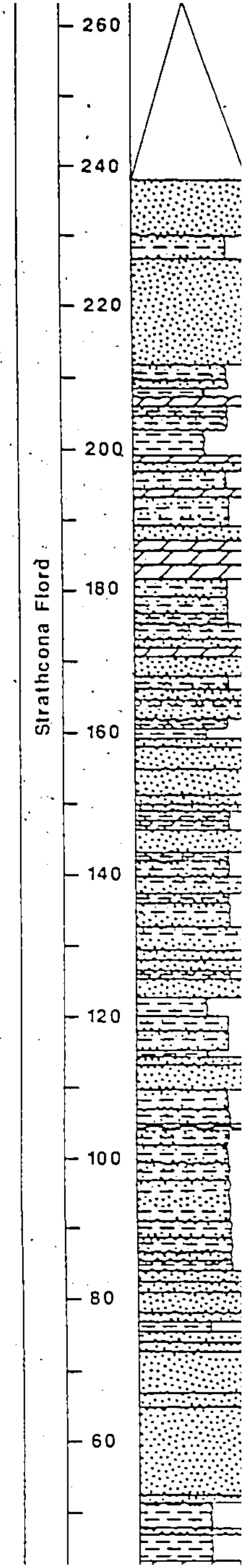
Baad Fiord Sheet

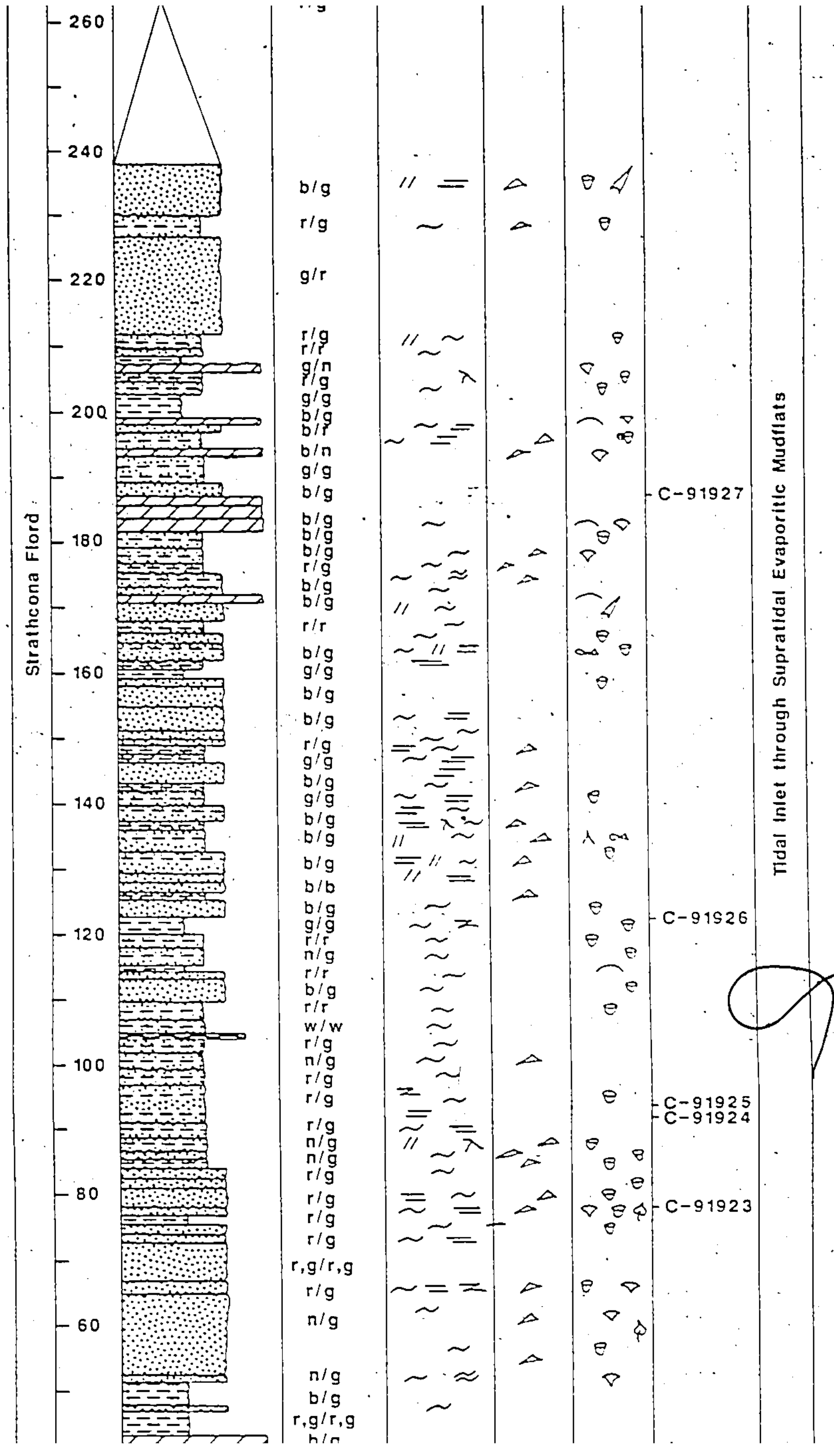


2

l., UTM Zone 16x

Other Features	Paleontology	Palynology Samples	Depositional Environment
			Meandering Fluvial


Strathcona Fiord
260
240
220
200
180
160
140
120
100
80
60



260
240
220
200
180
160
140
120
100
80
60
Strathcona Fiord
Tidal Inlet through Supratidal Evaporitic Mudflats
C-91927
C-91926
C-91925
C-91924
C-91923
b/g
r/g
g/r
r/g
r/r
g/n
r/g
g/g
b/g
b/r
b/n
g/g
b/g
b/g
b/g
b/g
r/g
b/g
b/g
r/r
b/g
g/g
b/g
b/g
r/g
g/g
b/g
g/g
b/g
b/g
b/g
b/b
b/g
g/g
r/r
n/g
r/r
b/g
r/r
w/w
r/g
n/g
r/g
r/g
r/g
n/g
n/g
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r/g
r/g
r/g
r,g/r,g
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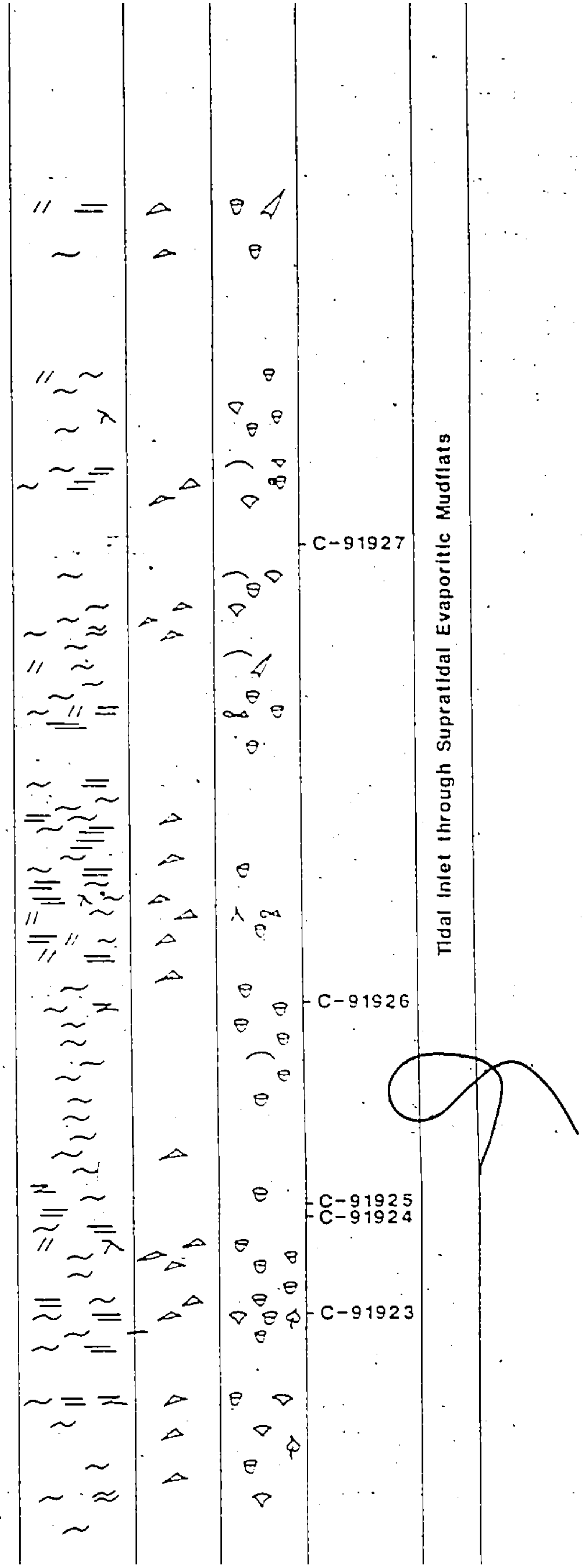
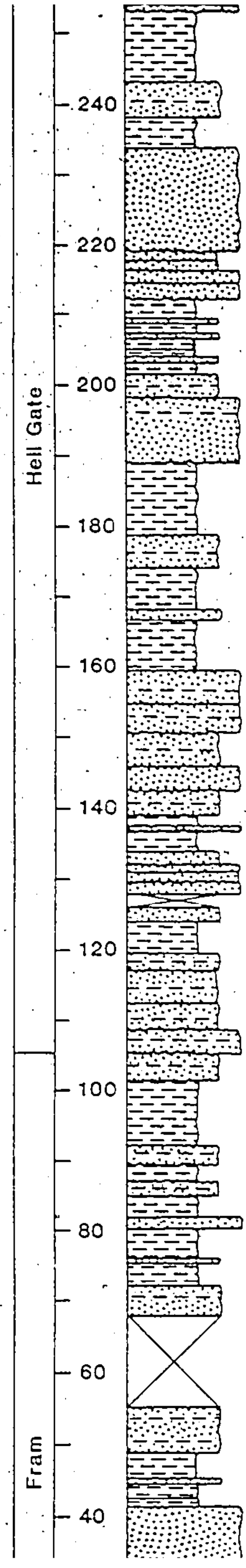
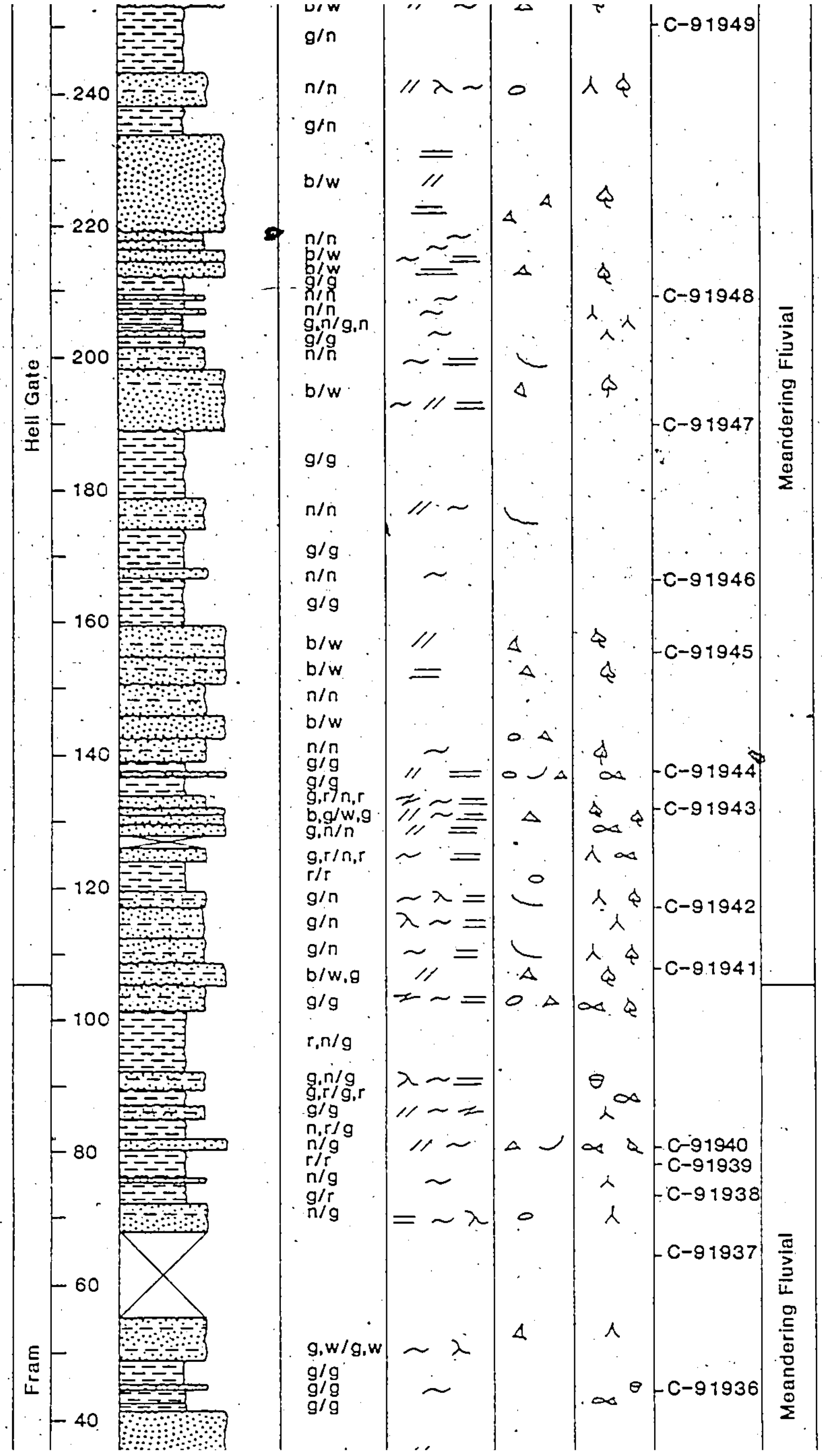
n/g
n/g
b/g
r,g/r,g



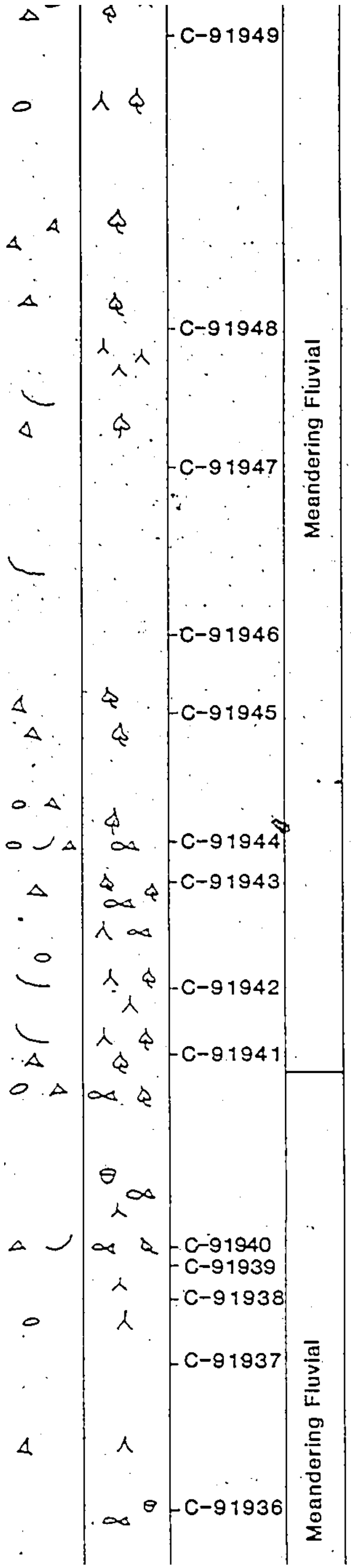
C-91927
C-91926
C-91925
C-91924
C-91923
Tidal Inlet through Supratidal Evaporitic Mudflats

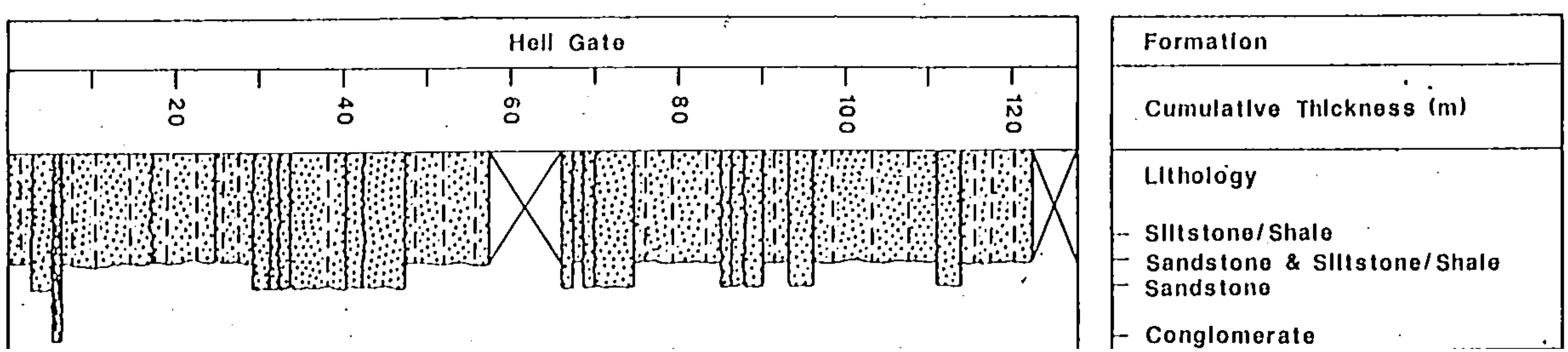


Hell Gate
Fram
240
220
200
180
160
140
120
100
80
60
40

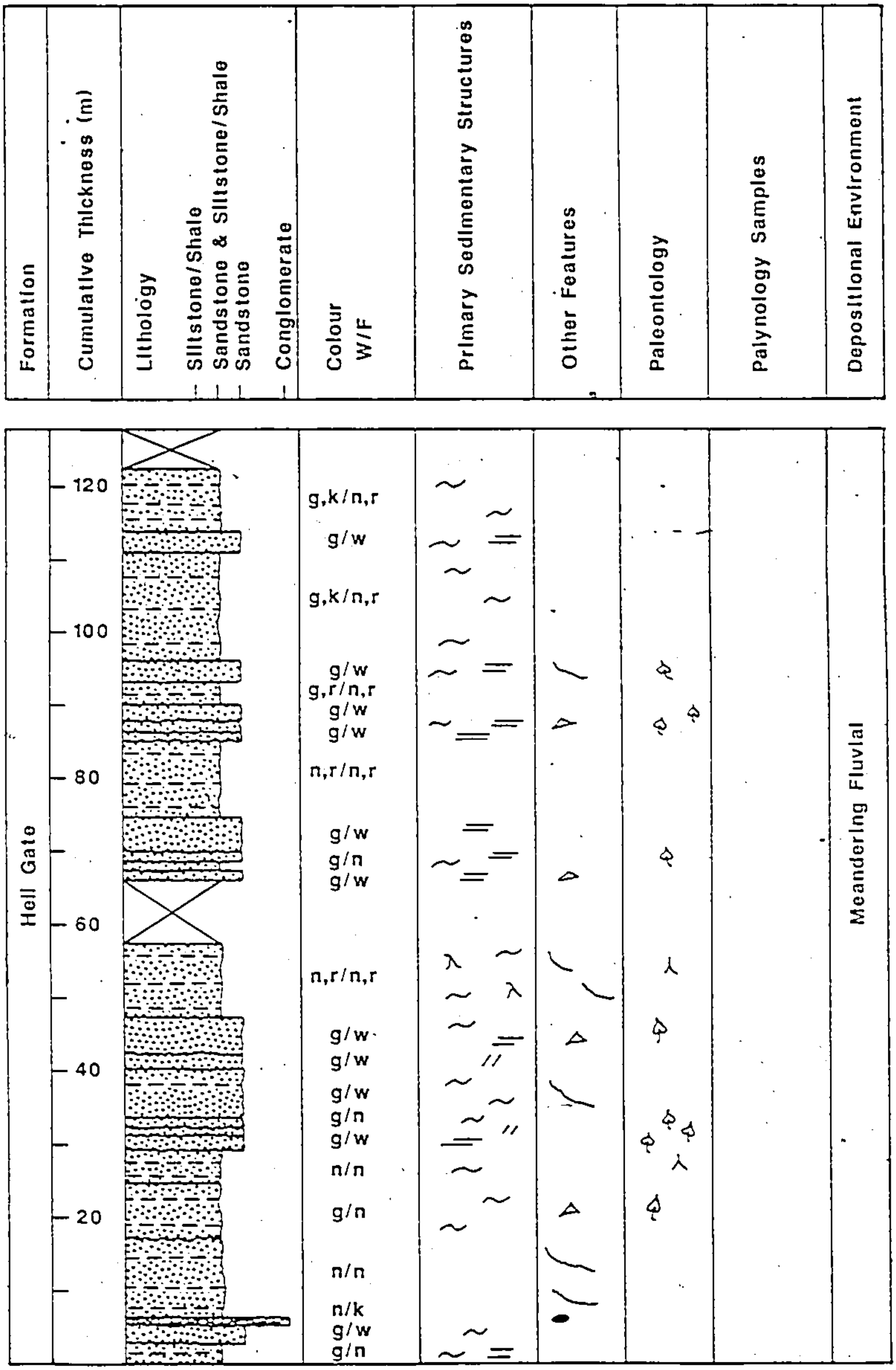


Hell Gate
Fram
Meandering Fluvial
Meandering Fluvial
240
220
200
180
160
140
120
100
80
60
40
g/n
n/n
g/n
b/w
n/n
b/w
b/w
g/g
n/n
n/n
g,n/g,n
g/g
n/n
b/w
g/g
n/n
g/g
n/n
g/g
b/w
b/w
n/n
b/w
n/n
g/g
g/g
g,r/n,r
b,g/w,g
g,n/n
g,r/n,r
r/r
g/n
g/n
g/n
b/w,g
g/g
r,n/g
g,n/g
g,r/g,r
g/g
n,r/g
n/g
r/r
n/g
g/r
n/g
g,w/g,w
g/g
g/g
g/g
C-91949
C-91948
C-91947
C-91946
C-91945
C-91944
C-91943
C-91942
C-91941
C-91940
C-91939
C-91938
C-91937
C-91936

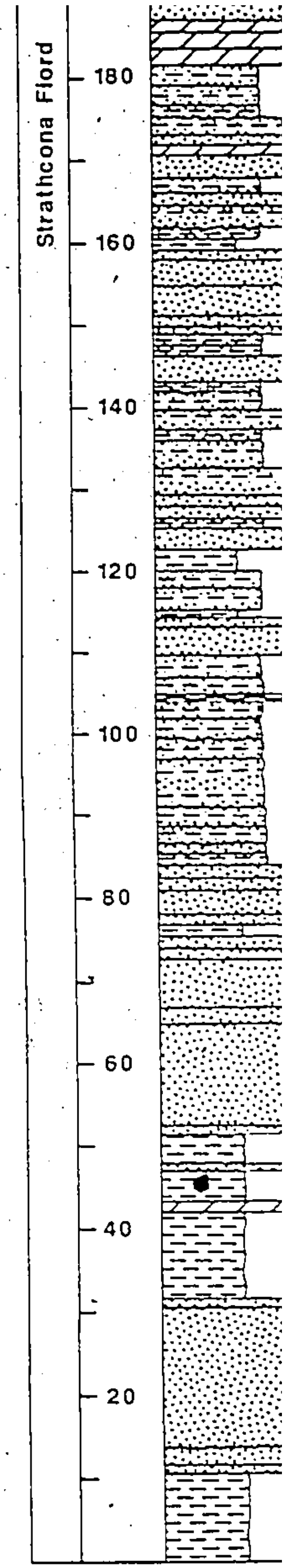

C-91949
C-91948
C-91947
C-91946
C-91945
C-91944
C-91943
C-91942
C-91941
C-91940
C-91939
C-91938
C-91937
C-91936
Meandering Fluvial
Meandering Fluvial

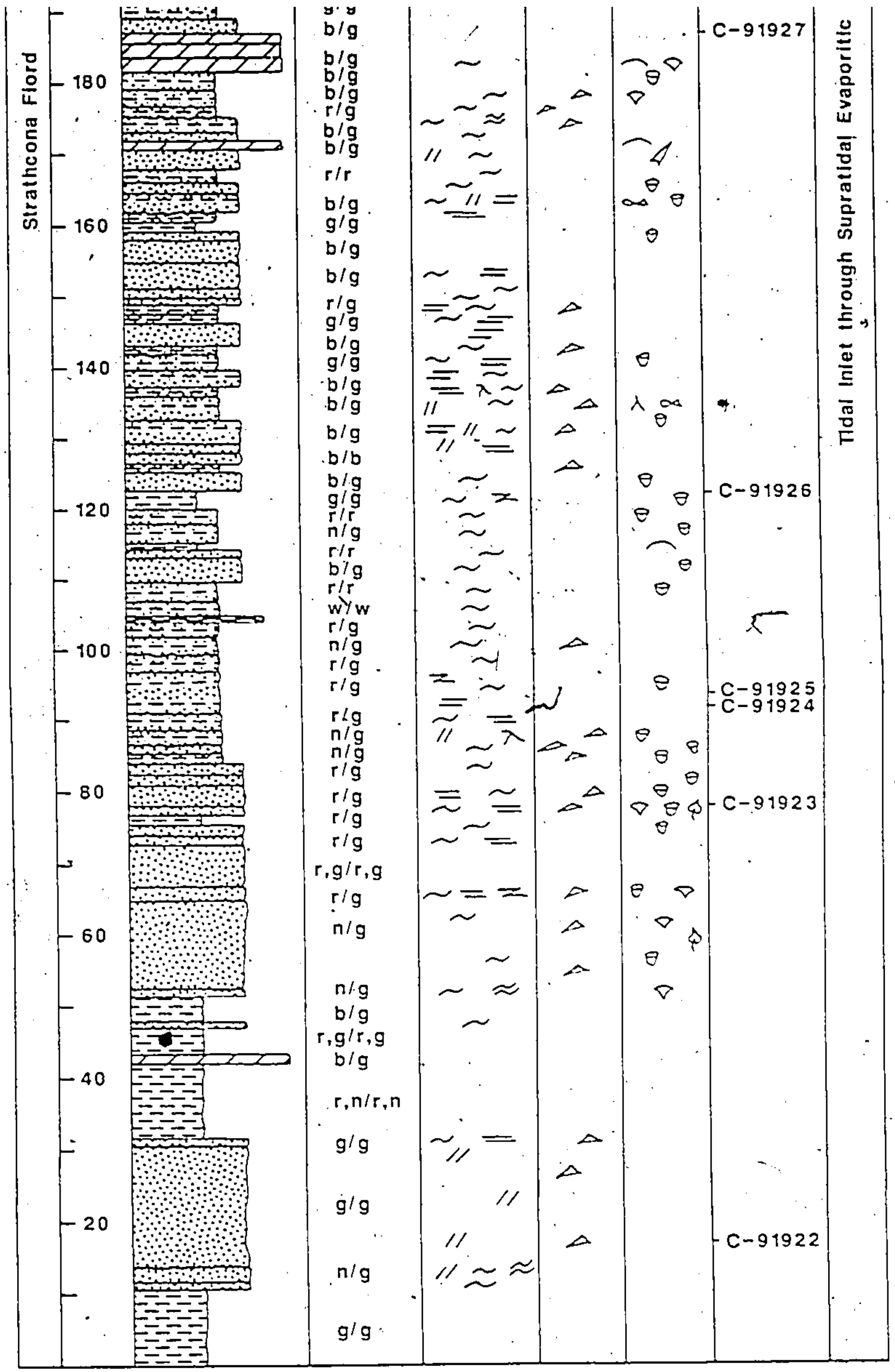

Formation
Cumulative Thickness (m)
Lithology
Siltstone/Shale
Sandstone & Siltstone/Shale
Sandstone
Conglomerate
Hell Gate
20
40
60
80
100
120

Baad Fiord Sheet

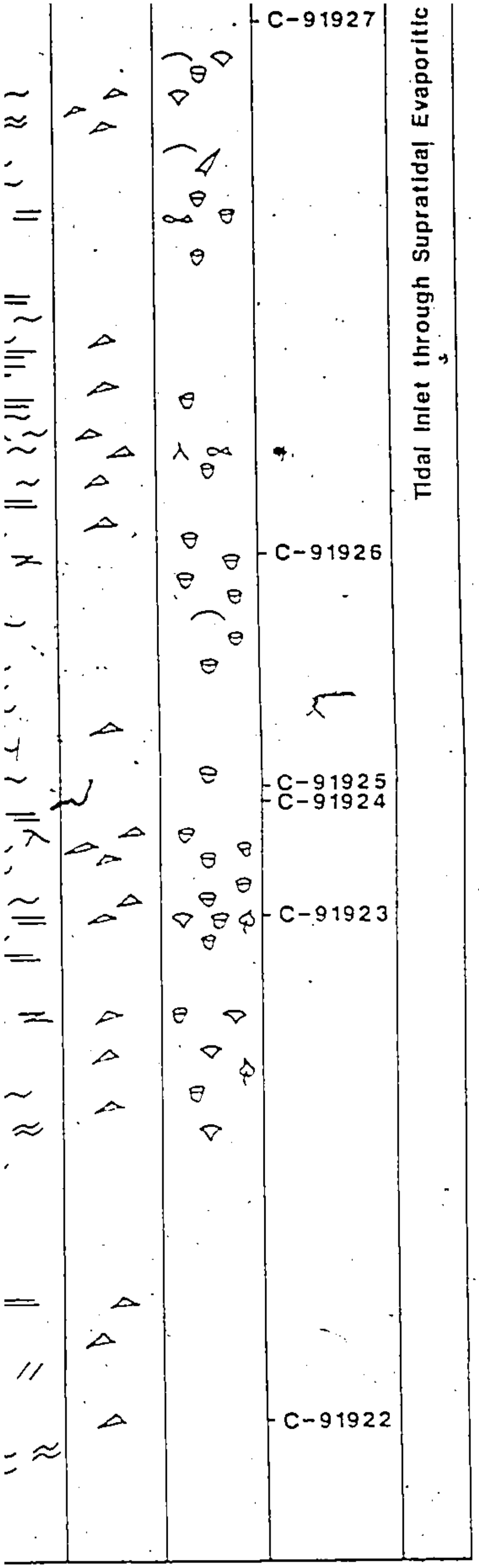


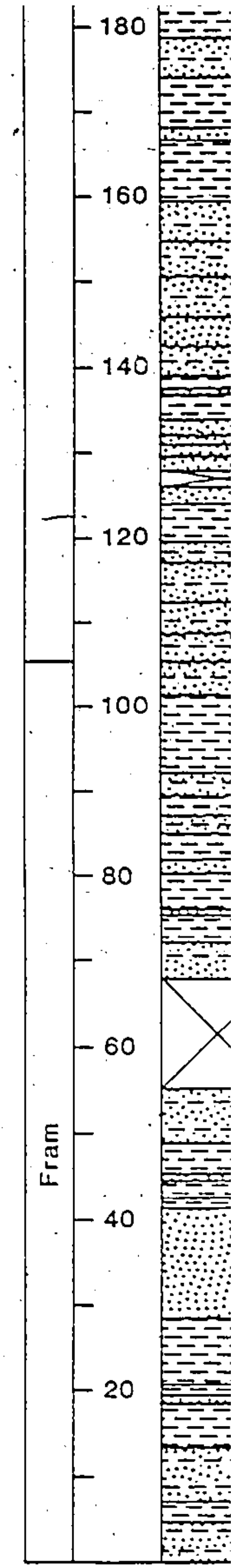
Other Features	
Paleontology	
Palynology Samples	
Depositional Environment	Meandering Fluvial

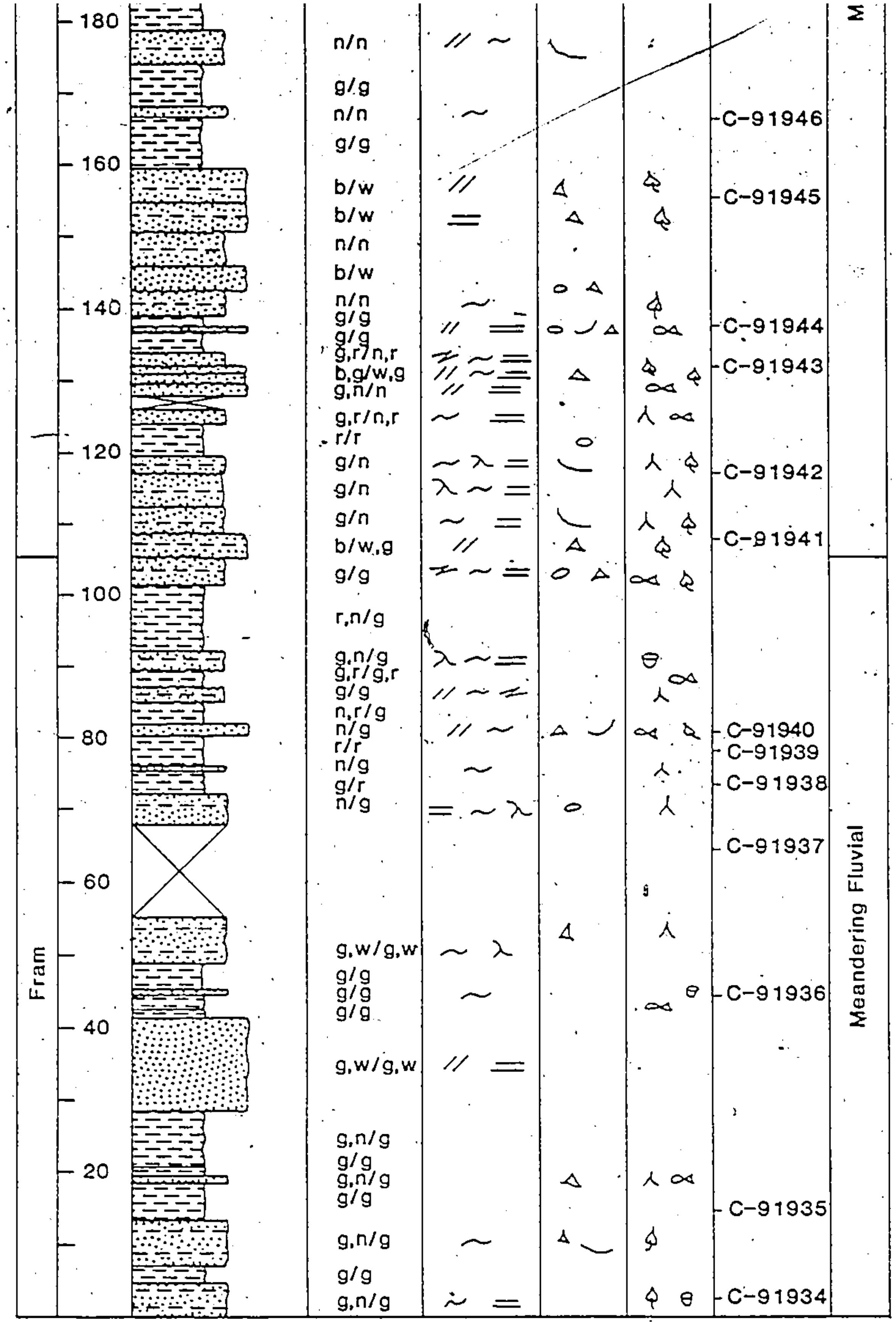

Strathcona Fiord
180
160
140
120
100
80
60
40
20



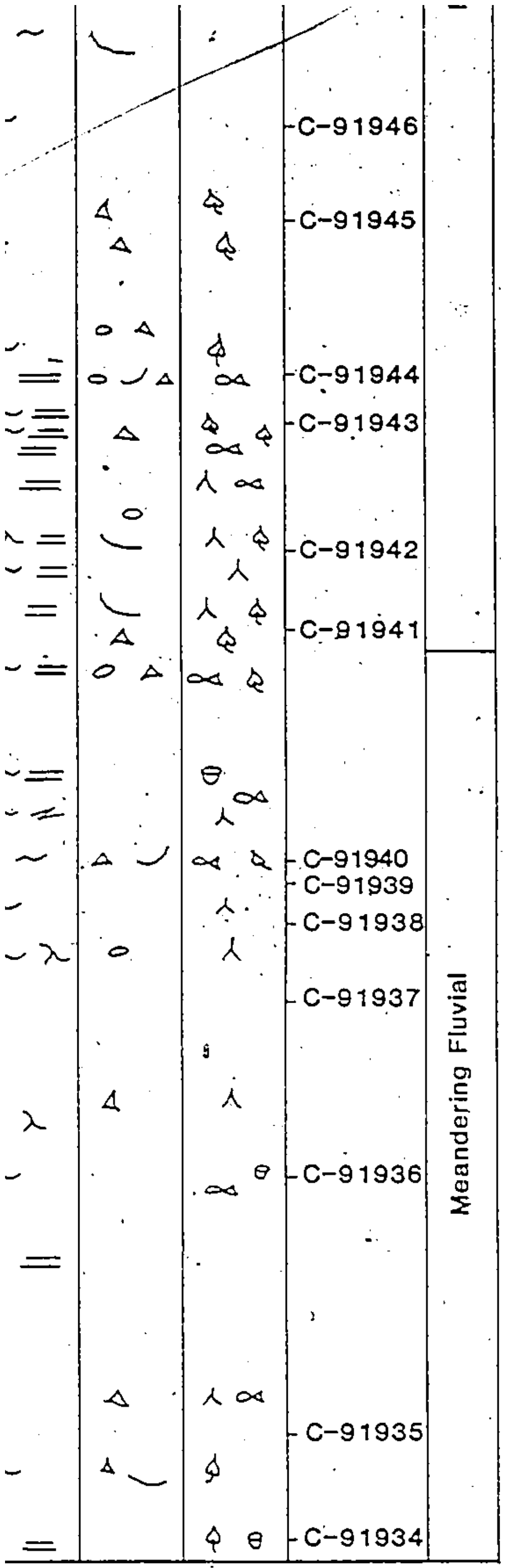
Strathcona Fiord
180
160
140
120
100
80
60
40
20
b/g
b/g
b/g
b/g
r/g
b/g
b/g
r/r
b/g
g/g
b/g
b/g
r/g
g/g
b/g
g/g
b/g
b/g
b/g
b/b
b/g
g/g
r/r
n/g
r/r
b/g
r/r
w/w
r/g
n/g
r/g
r/g
r/g
n/g
n/g
r/g
r/g
r/g
r/g
r,g/r,g
r/g
n/g
n/g
b/g
r,g/r,g
b/g
r,n/r,n
g/g
g/g
n/g
g/g
C-91927
C-91926
C-91925
C-91924
C-91923
C-91922
Tidal Inlet through Supratidal Evaporitic


C-91927
C-91926
C-91925
C-91924
C-91923
C-91922
Tidal Inlet through Supratidal Evaporitic


Fram
180
160
140
120
100
80
60
40
20



180
160
140
120
100
80
60
40
20
n/n
g/g
n/n
g/g
b/w
b/w
n/n
b/w
n/n
g/g
g/g
g,r/n,r
b,g/w,g
g,n/n
g,r/n,r
r/r
g/n
g/n
g/n
b/w,g
g/g
r,n/g
g,n/g
g,r/g,r
g/g
n,r/g
n/g
r/r
n/g
g/r
n/g
g,w/g,w
g/g
g/g
g/g
g,w/g,w
g,n/g
g/g
g,n/g
g/g
g,n/g
g/g
g,n/g
C-91946
C-91945
C-91944
C-91943
C-91942
C-91941
C-91940
C-91939
C-91938
C-91937
C-91936
C-91935
C-91934
Fram
Meandering Fluvial
M


C-91946
C-91945
C-91944
C-91943
C-91942
C-91941
C-91940
C-91939
C-91938
C-91937
C-91936
C-91935
C-91934
Meandering Fluvial

Base of secti

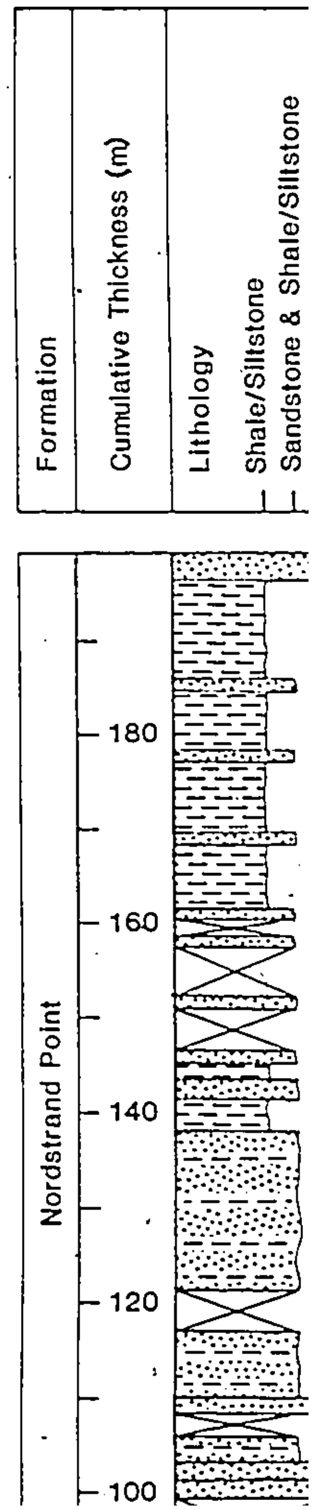


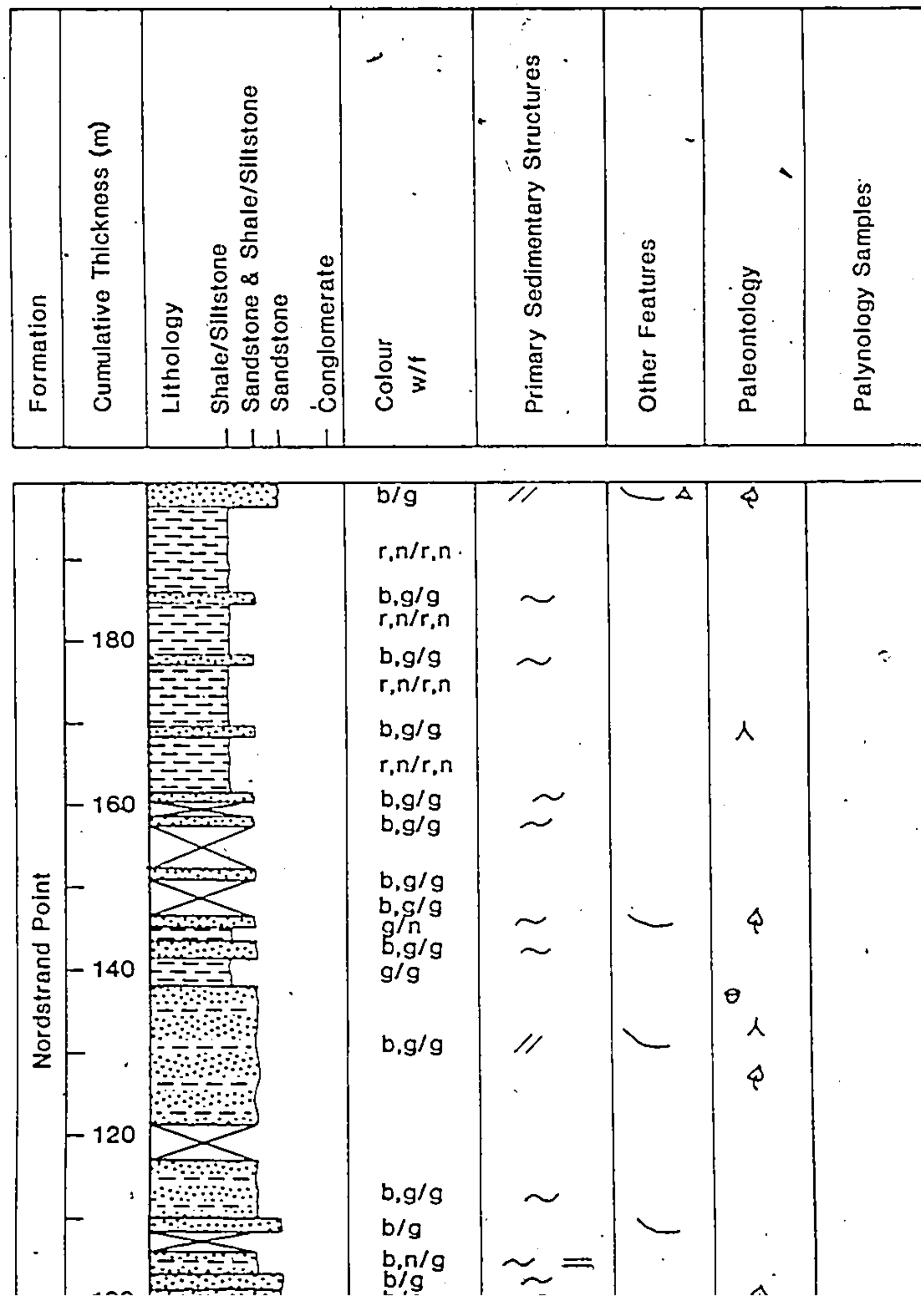
Figure 2.4.7.1-1

SECTION HG3

Base of section : 494750 E., 8551000 N., UTM Zo

NTS 49C

Baumann Fiord Sheet



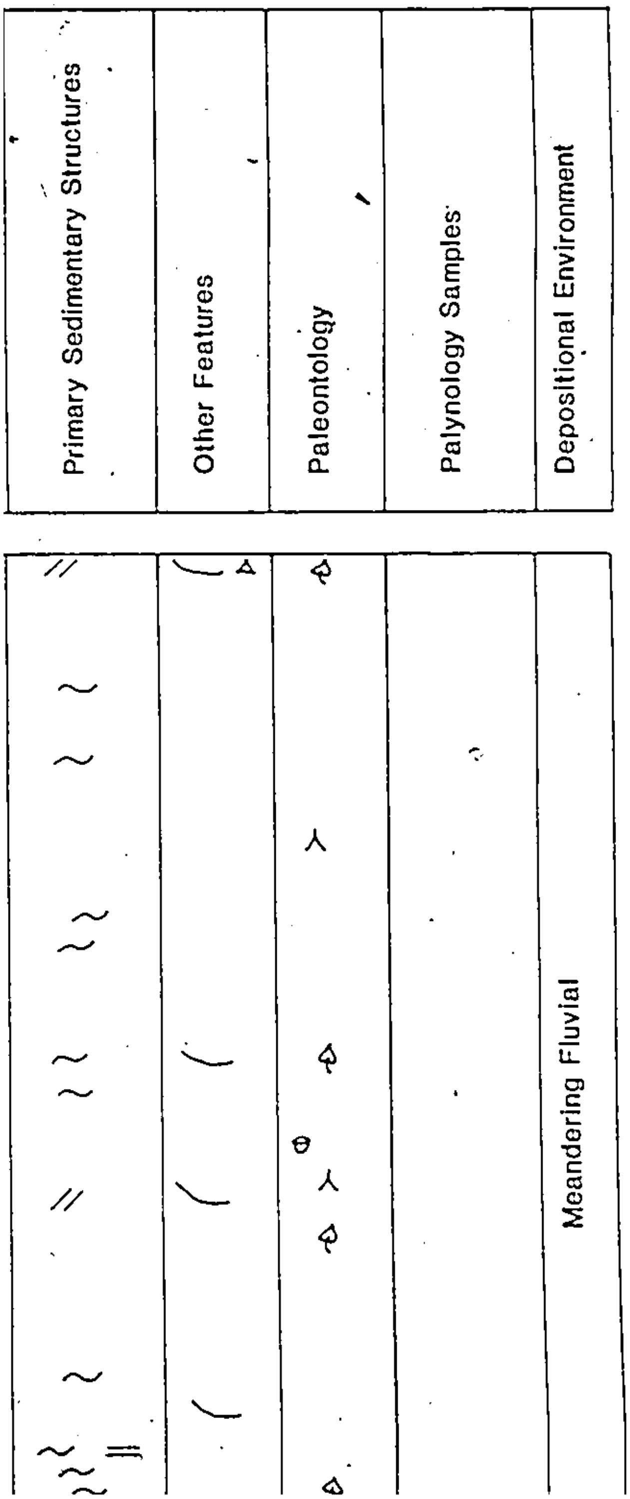
2.4.7.1-1

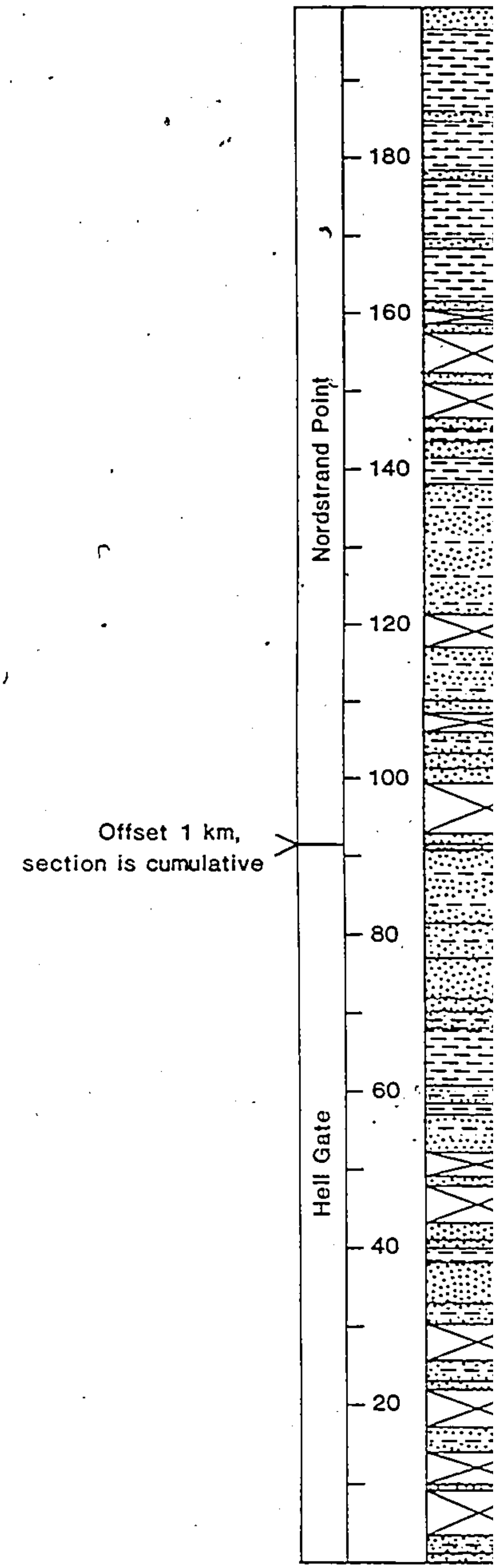
CTION HG3

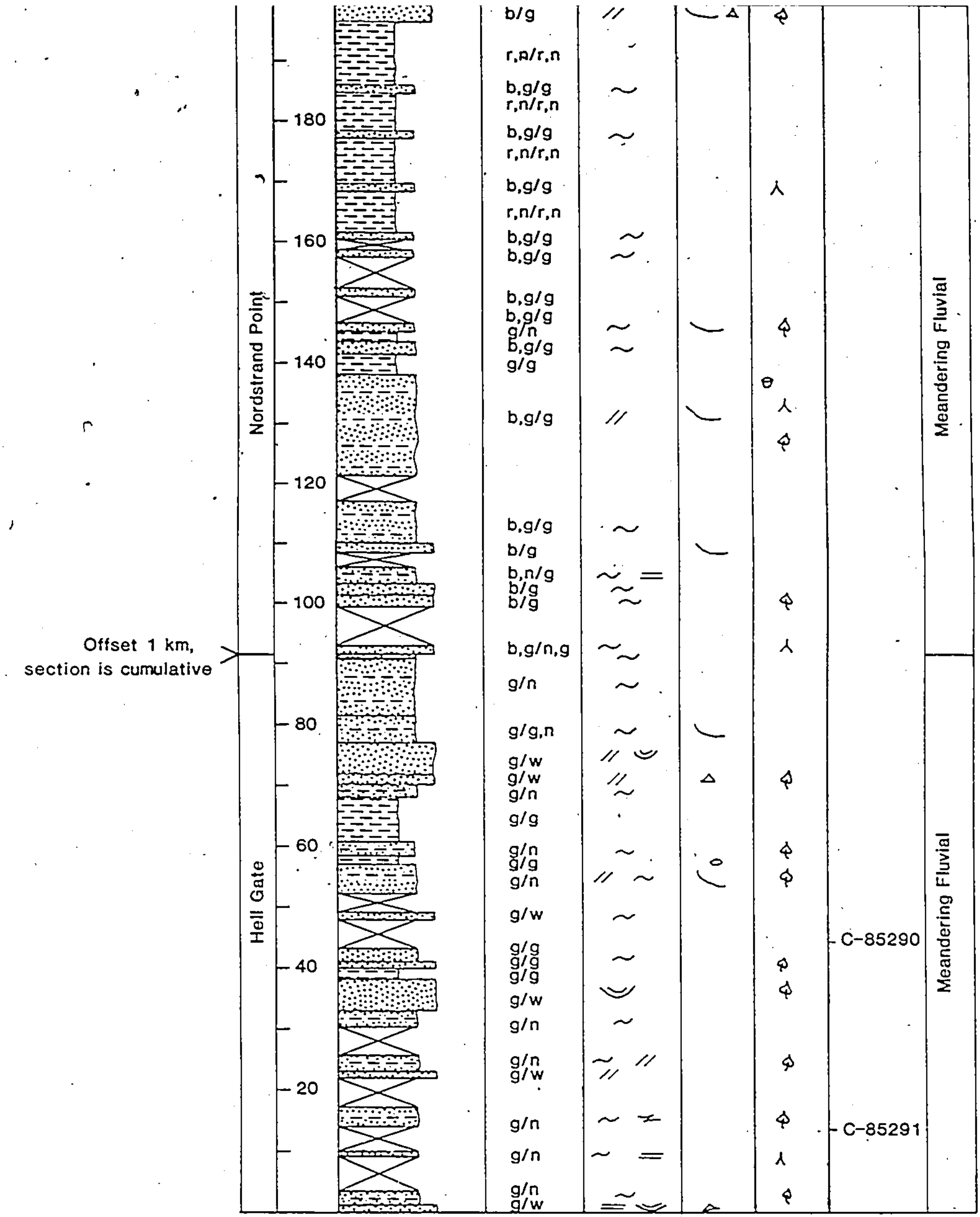
0 E., 8551000 N., UTM Zone 16x

ITS 49C

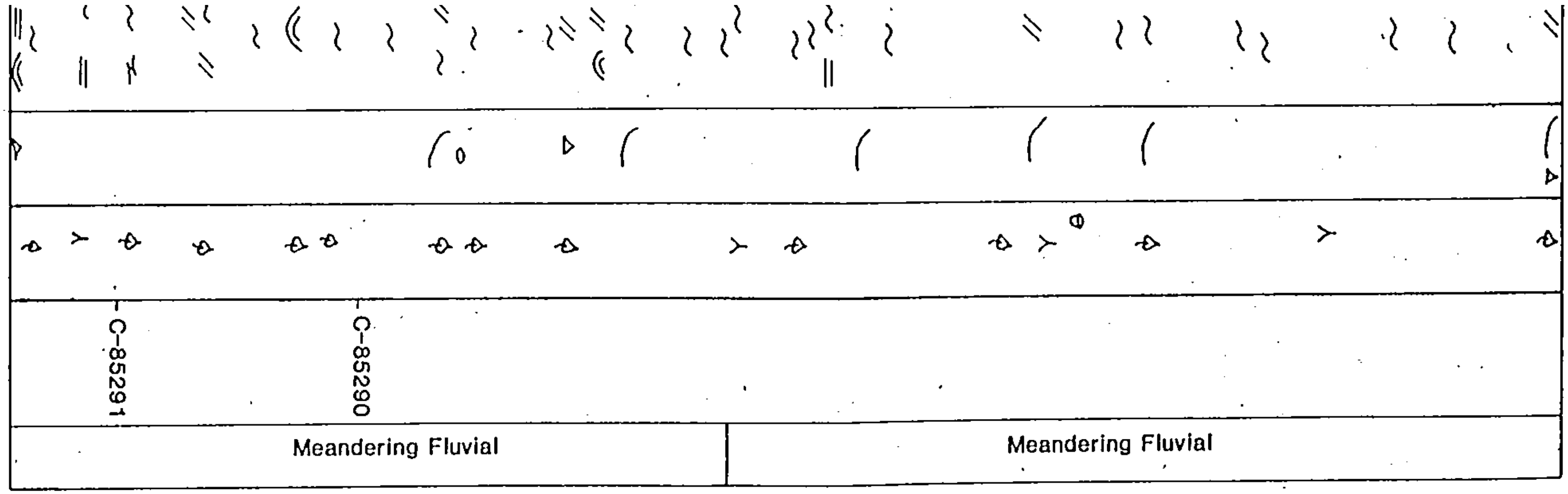
n Fiord Sheet




Nordstrand Point
Hell Gate
Offset 1 km,
section is cumulative
180
160
140
120
100
80
60
40
20



Nordstrand Point
Hell Gate
Offset 1 km,
section is cumulative
180
160
140
120
100
80
60
40
20
b/g
r,n/r,n
b,g/g
r,n/r,n
b,g/g
r,n/r,n
b,g/g
r,n/r,n
b,g/g
b,g/g
b,g/g
b,g/g
g/n
b,g/g
g/g
b,g/g
b,g/g
b/g
b,n/g
b/g
b/g
b,g/n,g
g/n
g/g,n
g/w
g/w
g/n
g/g
g/n
g/g
g/n
g/w
g/g
g/g
g/g
g/w
g/n
g/n
g/w
g/n
g/n
g/n
g/w
C-85290
C-85291
Meandering Fluvial
Meandering Fluvial


C-85291
C-85290
Meandering Fluvial
Meandering Fluvial