Thomas Frisch

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

MEMOIR 331

GEOLOGICAL RECONNAISSANCE OF NORTHEASTERN ELLESMERE ISLAND, DISTRICT OF FRANKLIN

(120, 340, parts of)

R. L. Christie

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PLATE I. View west towards Lake Hazen and the United States Range. Ruggles River, the outlet of Lake Hazen, is visible in the left middle distance. The upturned, northeast-trending Cape Rawson beds are evident in the foreground.

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By

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PREFACE

Exactly 75 years after British explorers under Captain Nares made the first geological studies in northeastern Ellesmere Island, systematic mapping was started by the Geological Survey of Canada.

Five years of this study, aided by observations of other scientists active in the region, has resulted in reasonably complete reconnaissance mapping of the northeast quarter of Ellesmere Island. The data obtained, and conclusions drawn from them, are presented in this report.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, June 27, 1962

Memoir 331—Die geologische Erkundung der nordwestlichen
Ellesmere-Insel (Bezirk Franklin).
Von R. L. Christie.

Das Gebiet umfasst einen Gürtel metamorpher, möglicherweise präkambrischer Gesteine an der Nordküste, einen breiten zur Geosynclinale gehörenden Gürtel gefalteter paläozoischer Schichten und die Ostspitze der Sverdrup-Mulde aus offenen gefalteten spätpaläozoischen und jüngeren Sedimenten.

Мемуар 331 — Р. Л. Кристи. Предварительное обследование северо-восточной части о. Эллесмир, район Франклина.

Площадь эта включает в себя северную береговую полосу метаморфических (возможно докембрийских) пород, широкий геосинклинальный пояс интенсивно-складчатых палеозойских отложений, а также восточную оконечность бассейна Свердрупа, состоящую из слабоскладчатых, палеозойских и более молодых осадков.

CONTENTS

CHAPTER I

Illustrations

GEOLOGICAL RECONNAISSANCE OF NORTHEASTERN ELLESMERE ISLAND, DISTRICT OF FRANKLIN

Abstract

Northeastern Ellesmere Island embraces three tectonic provinces: a coastal belt of metamorphic, possibly Precambrian rocks; a broad geosynclinal belt of tightly folded early and middle Palaeozoic bedded rocks; and a less folded 'basin' of late Palaeozoic, Mesozoic, and Cenozoic sedimentary rocks.

The metamorphic belt, composed of gneisses, schists, and granitic rocks, underlies the north coastal region. The geosynclinal belt forms the greater part of the area. In the north, this belt consists of volcanic and related sedimentary rocks, sandstones, and Ordovician fossiliferous limestone. A mountain and plateau region to the south is underlain by a generally unfossiliferous, tightly folded greywacke-sandstone formation that includes Silurian beds. Variably folded Ordovician and probably other quartzites and limestones form the southeastern part of the geosynclinal belt. Less severely folded sandstones, conglomerates, and limestones of Carboniferous, Permian and possibly Cenozoic ages form an eastward extension of the Sverdrup Basin, and overlie the geosynclinal rocks to form much of the prominent United States Range. Lake Hazen lies in a deep trough excavated from a down-faulted wedge of the younger rocks. Permian, Triassic, Jura-Cretaceous, and Cenozoic ages are indicated for sandstone and shale in the Lake Hazen vicinity.

Résumé

La portion nord-est de l'île Ellesmere comprend trois provinces tectoniques: une bande côtière de roches métamorphiques qui remontent peut-être au Précambrien; une large aire géosynclinale de roches stratifiées et très plissées du début et du milieu du Paléozoïque; et un «bassin» moins plissé de roches sédimentaires qui remontent à la fin du Paléozoïque, au Mésozoique et au Cénozoïque.

La bande métamorphique est composée de gneiss, de schistes cristallins et de roches granitiques et forme le sous-sol de la région côtière du nord. L'aire géosynclinale couvre la majeure partie de la région étudiée. La partie nord de cette aire se compose de roches volcaniques et de roches sédimentaires connexes, de grès et de calcaire fossilifère ordovicien. Au sud de cette partie nord il y a une région de montagnes et de plateaux composée d'une formation généralement non fossilifère et très plissée de grauwacke et de grès dans laquelle on a reconnu des couches siluriennes. Des quartzites et des calcaires plus ou moins plissés qui remontent à l'Ordovicien et probablement à d'autres périodes composent la portion sud-est de l'aire géozynclinale. Une succession moins plissée de grès, de conglomérats et de calcaires d'âge carbonifère, permien et peut-être même cénozoïque forme un prolongement vers l'est du bassin Sverdrup et recouvre les roches de l'aire géosynclinale, tout en formant une grande partie de l'importante chaîne de montagnes appelée «United States». Le lac Hazen occupe une dépression profonde excavée d'un tronçon de roches plus récentes en forme de coin et affaissé le long de failles. Le calcaire et le schiste argileux des environs du lac Hazen remontent au Permien, au Trias, au Jura-Crétacé et au Cénozoïque.

Chapter I

INTRODUCTION

Location

Ellesmere Island is the largest and most northerly of the Queen Elizabeth Islands, District of Franklin. This report describes the northeasternmost part of the island: the area north of latitude 80°30′N and east of longitude 79°W, including the area around Lake Hazen.

Present Investigation and Acknowledgments

Incorporated in this report are the results of field work conducted by V. K. Prest in 1950, by R. G. Blackadar in 1953, and by the author in 1954, 1957, and 1958. The results of the reconnaissance of the north coast of Ellesmere Island carried out in 1950, 1953, and 1954 have been published previously (Prest, 1952[1]; Blackadar, 1954; Christie, 1957) and are presented here in summary form.

Field work in 1957 and 1958 was based at Lake Hazen and extended north to Clements Markham Inlet, northeast to Alert, and southeast to Judge Daly Promontory. A permanent camp was established at Lake Hazen in 1957 as a base for the Defence Research Board's "Operation Hazen", which was part of the Canadian program of scientific work for the International Geophysical Year. The author was attached to, and participated in, the I.G.Y. program at Lake Hazen.

The author is indebted to the other members of Operation Hazen for considerable geological information and for other cooperation and assistance. Dr. G. Hattersley-Smith, the leader of the expedition, was particularly generous in providing data collected on two extended sledging journeys along the ice-cap of the United States Range.

B. P. Walker of Ingersoll, Ontario, was geological assistant in 1958, and carried out his duties with ability and resourcefulness.

Dr. Terris Moore, of Waterville, Maine, generously flew the author on an aerial reconnaissance in August 1958 in a Piper Super-Cub aircraft that he had flown from the United States.

History of Discovery

The conditions for travel northward along the channels separating Ellesmere Island from Greenland are among the most severe in the Arctic Archipelago;

[1] Names and dates in parentheses are those of references cited in the Bibliography.

winds, ice movement, and cliff-lined shores make the region most difficult of access without well-powered ships or long-range aircraft.

The first explorers nearing northern Ellesmere Island were Dr. Elisha Kane in 1853-55 and Dr. I. I. Hayes in 1860-61. These expeditions voyaged with great difficulty along the west coast of Greenland, and wintered in the vicinity of Etah, in about latitude 79°. Both parties suffered considerably from scurvy and loss of men. Kane's party abandoned their ship and retreated southward in small boats.

It is somewhat paradoxical that although Kane and Hayes almost certainly did not reach or even see northern Ellesmere Island, a good many of the geographical features bear names provided by them. The early journeys were made under arduous circumstances by explorers, some of whom were not, apparently, aware of the limitations of their navigation and map-making. In 1854 Morton, of the Kane expedition, reached Cape Constitution on the Greenland coast; he made notes on an "open Polar sea" and Kane gave names that have since been applied to features 80 to 100 miles farther north. Hayes, in 1861, claimed to have reached latitude 81°35′, and gave the name Lady Franklin Bay. However, a careful comparison of his account with a modern map will show that his northernmost point probably was Cape Joseph Good, about 140 miles to the south. This has been noted by Greely (1886, vol. II, p. 95), and by others (Taylor, 1955, pp. 62, 63). The names now applied to most of the capes and bays along the western shores of Kennedy and Robeson Channels are attributable to Kane and Hayes, though it is unlikely that they could have seen and identified these features.

The expedition of Charles Frances Hall in 1871-73 reached Thank God Harbour in Greenland, opposite the mouth of Lady Franklin Bay. From this vicinity the glacier-laden peaks of the United States Range were seen and named.

A Royal Navy expedition to Lady Franklin Bay in 1875-76, commanded by Captain Sir George Nares, first set foot on northern Ellesmere Island. The ship *Discovery* wintered at Discovery Harbour, and the *Alert* near Cape Sheridan. The men of this expedition made lengthy journeys along the coasts of Greenland and Ellesmere Island, although suffering considerably from scurvy. Lieutenant Pelham Aldrich reached Alert Point with man-hauled sledges, and Lieutenant Robert H. Archer reached the head of Archer Fiord in a small launch. Sub-Lieutenant G. I. C. Egerton journeyed some distance up the valley of Wood River. Captain H. W. Feilden, naturalist on the Nares expedition, and others made extensive collections of rocks and fossils in the region between Discovery Harbour and Feilden Peninsula. The outlines of the coasts as shown by these excellent British navigators have formed the bases for atlases until recently, and compare not unfavourably with modern maps. The first geological map of the region was published in 1878 by Feilden and De Rance.

An expedition led by Lieutenant Adolphus W. Greely of the United States Army established 'Fort Conger' in Discovery Harbour in 1881, and engaged primarily in scientific work in connection with the first international 'Polar Year'. Parties from Fort Conger travelled widely, and Greely himself discovered Lake Hazen in April of 1882, naming it after General W. B. Hazen who was then commanding a similar expedition in Alaska. Lieutenant Lockwood and Sergeant Brainard travelled up Archer Fiord, crossed to the head of Greely Fiord, and travelled some miles down Greely Fiord before returning.

The Fort Conger party retreated southward according to plan in August of 1883, no relief ship having reached them. All but seven died of starvation the following winter at Cape Sabine in Smith Sound. So near the end were the rescued that another died during the journey south by ship.

Greely and his men collected geological and archaeological specimens and made copious notes. The expedition ended in tragedy, but contributed greatly to knowledge of the high Arctic.

Commander R. E. Peary or members of his parties visited Lake Hazen on hunting trips from Fort Conger and Cape Sheridan between 1898 and 1909. In 1900, some 140 muskoxen were shot in the vicinity of Black Rock Vale, Lake Hazen, and Very River. The party spent the following winter in igloos built near the carcasses of the game killed. In 1905, Peary sent his Eskimos overland to Lake Hazen from Cape Sheridan, where the *Roosevelt* was frozen in. The Eskimo families established three winter 'settlements' on and near Lake Hazen to fish and to hunt muskoxen and caribou, and sledge loads of meat were taken overland to the ship by the light of the full moon each month. Matt Henson, Captain Bob Bartlett, and Ross Marvin sledged overland to Lake Hazen at various times.

Peary was concerned, however, almost wholly with the attainment of the pole. His travels were confined mainly to the east and north coasts of Ellesmere Island, and usually he noted only game and conditions of travel. In 1906 Peary traversed the entire northern coast and crossed to Axel Heiberg Island. Sledge journeys from Cape Sheridan to Cape Columbia, Ward Hunt Island, and Cape FanshaweMartin were made in 1909 to establish caches in support of Peary's final attempt for the north pole.

W. Elmer Ekblaw, geologist and botanist of D. B. MacMillan's Crocker Land expedition of 1913-17, viewed the Lake Hazen region from above the head of Tanquary Fiord in 1917. He returned to Greely Fiord, travelled to its head, crossed the plateau to Lake Hazen, and descended Ruggles River to Lady Franklin Bay. Ekblaw collected Permian fusulinids from limestone at the mouth of Tanquary Fiord (Troelsen, 1950, p. 69).

Commander Godfred Hansen, of the Royal Danish Navy, sledged by dog in 1920 from Thule to Cape Aldrich, laying depots in support of Roald Amundsen's north polar drift in the *Maud*.

In 1935, A. W. Moore and Sergeant H. W. Stallworthy, RCMP, both of the Oxford University Ellesmere Land expedition, travelled to Lake Hazen from Etah, Greenland, with two Eskimos, Nukapinguak and Inuatuk. Stallworthy and Inuatuk fished to obtain dog-food while Moore and Nukapinguak ascended the ice-cap north of Lake Hazen. They climbed a peak which they named Mount Oxford, and from it they viewed and photographed the high peaks of the United Stages Range.

Dr. J. C. Troelsen, geologist on the 1939-40 Van Hauen expedition, crossed the plateau between Greely and Archer fiords. Fossils were collected at Cape Baird.

Alert weather station was established in 1950 after reconnaissance to Cape Belknap in 1948 by U.S. Navy and U.S. Coast Guard icebreakers. V. K. Prest, Geological Survey of Canada, made brief visits to shore during a passage up Kennedy and Robeson Channels.

Various scientific surveys have used Alert as a base. P. F. Bruggeman and S. D. MacDonald, on a biological survey in 1951, travelled up Wood River almost to the ice-cap, and G. Hattersley-Smith, Defence Research Board, and R. G. Blackadar, Geological Survey of Canada, carried out a glaciological and geological reconnaissance of the north coast between Cape Rawson and Cape Columbia in 1953. Hattersley-Smith and Blackadar travelled up Wood River to the ice-cap, and southwestward to a point about 35 miles from Lake Hazen.

A research expedition was led by Hattersley-Smith in 1954 to the ice-shelf on the north coast of Ellesmere Island. Various trips were made along the coast and inland from a base-camp near Ward Hunt Island. Geological reconnaissance was extended by the present author westward to Lands Lokk.

The geology of Johns Island was reported on briefly in 1956 by D. F. Barnes, U.S. Air Force Cambridge Research Center, who accompanied the first aircraft landing on Lake Hazen.

Accessibility and Methods of Travel

Northern Ellesmere Island is accessible by air or by icebreaker. Journey by dog team along the fiords and channels from more southerly points is lengthy, arduous, and more or less hazardous.

Modern icebreakers have little difficulty in reaching Lady Franklin Bay and Chandler Fiord during August, but only in some seasons have they been able to reach Alert weather station.

Colonel J. Fletcher, U.S. Air Force, landed his aircraft at Cape Aldrich in 1950 and aircraft have been used since then to bring in entire expeditions and to land small parties at the sites of their scientific work. Wheel-equipped aircraft can land during most of the year on the airfield at Alert weather station, and during the winter and early part of the melt season on Lake Hazen. Light snowfall and relative windlessness during the winter make Lake Hazen a good landing-field for large aircraft. A minimum ice thickness of 59 inches and a maximum snow depth of 12 inches were recorded in 1957 and 1958. Large aircraft of the RCAF have used the ice as late as June 11 (1958). Ski-wheel equipped Dakota aircraft have landed at Lake Hazen, Ward Hunt Island, on the ice-cap of the United States Range, and on the fiords. Float and hull-equipped aircraft have landed on the fiords, on Lake Hazen, and on various small lakes during the month of August.

A light aircraft was first used in 1956 by W. W. Phipps, of Ottawa, who has since then made numerous landings in the region. Terris Moore used a light aircraft with pontoons in 1958.

Travel during the spring has been by dog team, snowmobile, and by ski. Conditions for sledging are good along the rivers, lakes, and fiords. The lake and fiord ice may be used without much inconvenience until about early July, when the shore leads become wide and continuous, and the ice begins to move.

Motorized vehicles proved to be well adapted to spring travel on the ice-cap and the lake region in 1957 and 1958. The Eliason Motor Toboggan is a most versatile tractor and compares favourably, in performance and fuel consumption, with dog teams. Heavy vehicles such as the Bombardier snowmobile (muskeg tractor) must be used with caution on river channels, where the ice over drained pools may be thin.

The melt period begins about the first week in June. The snow cover quickly disappears and travel by foot on land is generally easy but caution should be exercised in crossing streams during the first weeks of the melt season. Dogs with packs are a useful aid on extended overland trips.

Canoes and boats are most useful on Lake Hazen when the lake ice nearly or entirely disappears. In 1958, however, lake travel was hindered throughout the season by drifting ice.

Physiography

Northeastern Ellesmere Island lies within a mountain belt of folded rocks that trends northeasterly across Axel Heiberg and Ellesmere Islands and northern Greenland. The area described here may be divided into three physiographic regions. From north to south they are: the Grant Land Mountains[1], the Hazen Plateau, and the northeast continuation of the Victoria and Albert Mountains.

Various names for these divisions have appeared. Taylor (1956, III, IV), who described the region fully from airphoto studies, used the names Grant Land highlands, Greely-Hazen plateau, and Victoria and Albert Mountains. Fortier (1957, p. 402)used the term Hazen Lake upland. The terms 'mountains' and 'plateau' used in the present report follow the terminology used by Bostock (1948) for the western Cordillera.

The Grant Land Mountains comprise the United States Range and several lesser flanking and outlying ranges and mountain groups (*see* Frontispiece). The physiographic separation between the United States Range and certain adjacent ranges is not distinct. The United States Range was named in 1871 by Hall[2], whose grave lies on the west shore of Greenland within sight of the ice-capped mountains. The range, though broken by two deep passes, forms the backbone of the Grant Land Mountains. A nearly continuous snowfield obscures all but scattered nunataks and supports numerous glaciers that flow into and through the flanking ranges.

The eastern pass transecting the United States Range trends south from the head of Clements Markham Inlet. This feature, named Piper Pass, is a strikingly deep, narrow trench containing several ice-dammed lakes. It is an interesting

[1] Grant Land is a now unused name for the northernmost part of Ellesmere Island.

[2] Taylor (1956, vol. III, p. 21) notes that the name is not mentioned in the account of Hall's expedition, but it is acknowledged by the Nares expedition of 1875-76.

PLATE II. View west showing the Hazen Plateau and the deeply cut fiord valleys. Lake Hazen, at the foot of the Grant Land Mountains, is visible in the right distance. *(RCAF T397L-178)*

anomaly that several streams on the southeast side of the United States Range drain northward through the pass.

The Hazen Plateau is some 50 miles wide and 200 miles long and separates the Grant Land Mountains from the Victoria and Albert Mountains (*see* Pls. I and II). The Grant Land Mountains rise abruptly along the northern edge of the Hazen Plateau, and are separated from the plateau over a considerable distance by a major fault zone. The plateau has a relatively uniform, rolling surface that is dissected by many deep transverse valleys. The surface lies at about 3,000 feet elevation at its southern edge, and at about 1,000 feet along the northern edge. As suggested by Taylor (1956, III, p. 45) the gentle northerly slope may be due to tilting.

The underlying bedrock of uniformly and tightly folded slates and impure sandstones of the Cape Rawson Group is well exposed. The northeast grain of the strata controls the minor drainage, and persists with remarkable uniformity of direction for more than 160 miles. The trends swing to easterly near the head of Greely Fiord.

Lake Hazen occupies a trough near the foot of the Grant Land Mountains. The trough appears to be, in a large part, an excavated part of a basin or depression filled with weakly consolidated sedimentary rocks. The lake, its axis about 10 degrees off the regional structural trend, lies along one edge of the basin.

R. E. Deane, University of Toronto, who has sounded and sampled the bottom of Lake Hazen (Deane, 1959, pp. 61-63), described the trough as "a shallow, asymmetrical, U-shaped depression". Certain bottom profiles indicate an irregular floor such as would result from glacial scouring. The deepest sounding, 864 feet (lake elevation about 520 feet), indicates considerable overdeepening. From the foregoing evidence it seems probable that the trough owes much of its present shape and depth to glacial action.

The Victoria and Albert Mountains of folded sedimentary rocks extend northeastward into Judge Daly Promontory (*see* Pl. III). A large snowfield to the west obscures the junction between the mountains and the Hazen Plateau[1].

[1] Taylor (1956, III, p. 44) defined the southeastern limit of the plateau as lying along a line joining the head of Greely Fiord and Ella Bay. However, it is evident from improved maps that the border lies to the southeast, perhaps along a scarp-like lineament of nunataks about at the ice divide.

PLATE III. Air view of Judge Daly Promontory from the west. The northeast-trending fold mountains of the Archer Fiord Terrane in the foreground contrast with the more jumbled peaks of the Daly River Terrane in the distance. Greenland is visible in the far distance. *(RCAF T401L-128)*

The fiords and some large valleys are generally straight-walled for many miles; their directions variously parallel and diverge from the regional structural trend. The location and trends of these features may be due to faulting. Evidence for this is found on Judge Daly Promontory, where some larger streams follow lineaments that are known fault-lines.

Glacial Deposits and Glaciation

The following notes are a résumé of a fuller description (*in prep'n.*) of the glaciation and related deposits and features of northeastern Ellesmere Island.

Large ice-caps and valley glaciers are now active in the Lake Hazen region. Former, more extensive glaciation is indicated by the presence, everywhere, of glacial erratics and by glacial grooves and *roches moutonnées*. Certain gravels, sands, and silts such as those at the east end of Lake Hazen, presumably were deposited by and in meltwater during the recession of the ice. The abundant small canyons, and perhaps some canyon-like valleys, of the Hazen Plateau probably were incised by numerous large meltwater streams. Marine silts, now at elevations up to about 250 feet, also were deposited during the ice-recessional period.

Granite and gneiss erratics are found in large numbers at elevations up to about 2,500 feet on Judge Daly Promontory and possibly are present along the eastern edge of the plateau east of Lake Hazen, but are not found inland, to the west or northwest. It seems probable that the erratics were derived from Greenland, and that their westward limit marks the maximum extent of Greenland ice in northern Ellesmere Island.

Two groups of hills of coarse, boulder-bearing gravel lie northeast of Lake Hazen and rise about 1,500 feet above the surrounding plateau surface. There are almost no obviously related landforms or surficial deposits, and the origin of the hills is uncertain. Possibly the debris was transported by meltwater from high parts of the United States Range and deposited in 'wells' or 'moulins' in a stagnant ice-sheet which, on ablation, left the deposits as isolated hills.

Light grey-white marine silts form conspicuous banks or benches in the lowermost parts of the major river valleys. The silts pass upstream into coarser silts and sand of fluvioglacial origin. Marine shells lie scattered in the silts, and a minimum height for the post-glacial marine inundation may be estimated as about 250 feet.

Climate

The climate of northern Ellesmere Island varies considerably from place to place, though in general it shares the characteristics of all Arctic weather. It is cold or cool and continental in nature during much of the year when the water is covered by ice, and cool modified by the maritime influence of open water during the summer.

The following notes on climate are taken in a large part from reports by C. I. Jackson (1959), J. R. Lotz (1959), and R. B. Sagar (1960), McGill University, who maintained meteorological stations at Lake Hazen and on the Gilman Glacier during the International Geophysical Year.

Lake Hazen, being some distance from the large salt-water channels to the east and west, and protected by the high United States Range to the north, has a continental climate all year; Alert weather station, on the other hand, on the shore of the Lincoln Sea, has warmer winter temperatures, cooler summer temperatures, greater precipitation, and stronger and more frequent winds than Lake Hazen.

The ice-caps present special climatological situations, so that data from them are not easily compared with those from land stations. The following table gives data on inland and coastal climates for the year 1957-58 from Lake Hazen and Alert weather station.

	Lake Hazen	Alert
Winter cold month (February) mean temperature	−41.0°F	−30°F
Temperature below −50°F	73 days	1 day
Summer warm month (July) mean temperature	43.8°F	39.4°F
Temperature above 32°F	61 days	35 days
Total measurable precipitation	0.98 inch	4.5 inches
Precipitation more than 'trace' (snow and rain)	39 days	95 days
Precipitation more than 'trace' (rain)	3 days	10 days
Snow depths and month of deepest snow	13 inches May	16 inches Nov. & Dec.
Proportion of observations where winds over 20 mph	1.1%	11.2%

The melt season in the Lake Hazen and Lady Franklin Bay region began in 1957-58 in the second week in June. In 1954, on the ice-shelf at Ward Hunt Island, the melt began on July 2. Break-up of both Lake Hazen and the fiord ice began in the last week of July or early August. Freezing temperatures commenced at Lake Hazen late in August. Lake Hazen, lying in a large shallow basin, or 'frost-hollow' in the shadow of a high mountain range, experiences prolonged periods of calm and low temperatures during the winter. The minimum recorded (January 1958) was −68.5°F. Over one year, the wind was calm on 35 per cent of the observations; in the winter, two out of three observations were calm.

The prevailing winds are northeast and southwest, in that order of predominance.

The amounts of cloud cover at Lake Hazen and at the coastal stations are similar, but the low-lying clouds (below 2,500 feet) with attendant fog, rain, and sleet which so frequently envelop the coasts are conspicuously rare inland. The climate at Lake Hazen is, by Arctic standards, generally pleasant and favourable to human comfort.

Soil temperatures at various depths were measured during the summer of 1958 by J. M. Powell[1], now of the Research Branch, Department of Agriculture. A thermometer lightly covered with soil showed surface temperatures consistently above 31°F during the entire period of measurement, from early May to mid-August. These temperatures prevailed despite some air temperatures considerably below freezing or the presence of permafrost a few inches down. The high temperatures recorded (not necessarily the maximum temperatures) ranged from about 50° to 80°F. The soil temperature depended mainly upon the sunshine and cloud cover; on clear days the range between highest and lowest soil temperatures observed was generally about 30°F.

Frost polygons, stone nets, soil stripes, ground ice, and other features characteristic of cold or periglacial climates are abundant in northeastern Ellesmere Island, and are apparently compatible with the present climate.

Vegetation and Wildlife

Botanical studies were carried out in the Lake Hazen region in 1958 by J. H. Soper, University of Toronto, and a wildlife reconnaissance was made by J. S. Tener, Canadian Wildlife Service. The following notes are, for the most part, a summary of their reports (Soper, 1959[2]; Tener, 1959). Certain contributions by the author are appropriate because his travels during three summers cover a considerable area.

The greater part of northeastern Ellesmere Island is essentially an Arctic desert. The low annual precipitation, the rapid ablation of snow cover and surface moisture in the spring, and the scanty rainfall during the growing season result in a generally sparse plant cover. Widely exposed bedrock and coarse surficial debris also inhibit most plant life, although the bedrock formations are more or less favourable for plant growth. The weak, shaly rocks north and east of Lake Hazen provide abundant fine material which can form a more or less stable sandy loam; the greywackes and impure limestones of the Cape Rawson beds have produced a stony, mucky glacial till that dries into a hard surface on which poppy (*Papaver radicatum*) and saxifrage (*Saxifraga oppositifolia*) are thinly but widely scattered; the limestone and quartzite terrane of Judge Daly Promontory is the most barren of all, presumably because of the disinclination of these rocks to weather or break down into fine deposits that will hold water and roots.

On the other hand, limited areas of more or less continuous plant cover develop where gentle slopes are well watered throughout the summer. The water is derived from glaciers and snowbanks, or is collected from thawing ground.

Soper describes, in the Lake Hazen region, two common situations where a continuous cover is developed: hummocky tundra and wet meadow. The tundra

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[1] This summary of soil temperatures is from Jackson (1959, p. 79). Details of the climate at Lake Hazen have since been described fully by Powell (1961).

[2] Vegetation and micro-climate have since been treated more fully by Powell (1961).

is grey-green and is dominated by *Dryas integrifolia,* willow (*Salix arctica*), and the sedge-like *Kobresia myosuroides.* In snow-patch depressions the evergreen Arctic white heather (*Cassiope tetragona*) becomes a primary species and colours these areas a darker green. The wet meadows are a luxuriant sedge-cottongrass (*Carex-Eriophorum*) association. The sedge *Carex stans,* and the cotton grasses *Eriophorum Scheuchzeri* and *E. triste* are dominant, with the grass *Arctagrostis latifolia* and foxtail (*Alopecurus alpinus*) often conspicuous. The latter association is obviously an important feeding ground for muskoxen.

An unsuccessful attempt was made by Powell (1959, p. 85) to grow vegetables in watered but otherwise natural soil at the Lake Hazen base-camp. Apparently the plants were unable to obtain nutrient from the soil. That soil conditions may be peculiar might be deduced from the widespread presence of white soluble salts at the surface. Water movement is apparently mainly upward at dry locations and the uppermost layer of soil may become impregnated by at least one soluble salt. X-ray and spectroscopic analyses by Joan C. Climo and W. H. Champ of the Geological Survey of Canada show the white mineral to be thenardite (Na_2SO_4).

The wildlife of northeastern Ellesmere Island is varied but, except for birds, rather sparse. Tener recorded eighteen bird species, of which the knot, turnstone, snow bunting, jaeger, gull, and tern are the most abundant. The red-throated loon, ptarmigan, snowy owl, and old-squaw duck are fairly common; the eider duck is rarely seen. The snow goose nests in the innumerable ponds and lakes northeast of Lake Hazen.

Mammals are not particularly abundant, except for the periodic lemming population 'explosion'. In 1957 lemmings (*Dicrostonyx* sp.) seemed numberless; in 1958 the author saw only three during the 4-month season, and intensive trapping by Tener for 10 days yielded only twenty-two specimens. Live lemmings were not seen in 1954 on the north coast.

Arctic hares apparently diminished from 1957, when they were numerous, to 1958. The predators, snowy owl, fox, wolf, and weasel are not numerous and their populations seem not to have changed greatly despite the decrease in number of lemmings and hares.

Muskoxen may be seen in herds and singly throughout the season in the plateau country and in the wide valleys on the north coast. Tener estimates a total population of about 200 for the Lake Hazen region. Caribou are very sparse; two were seen on the north coast in 1954, and ten in the Lake Hazen-Lady Franklin Bay region in 1958.

The tracks of a polar bear were observed in Clements Markham Inlet.

Seals are not plentiful in the fiords of Lady Franklin Bay, and are decidedly scarce along the north coast. Only forty-nine were seen in 1958 (with the help of binoculars), and on the most rewarding seal count only nineteen were observed.

Archaeology

Remains of ancient Eskimo encampments are widely but thinly scattered in the region south of the Grant Land Mountains. M. S. Maxwell, Michigan State University, carried out archaeological investigations for the National Museum of Canada in the Lake Hazen region in 1958. His conclusions (1960, p. 87) may be summarized as follows: hunters from the south—perhaps from settlements peripheral to the main cultural centres around Thule—visited the Lake Hazen region sporadically in the interval between about 1,000 years ago and the mid-fifteenth century. Relatively few winter dwellings are found near Lake Hazen, and there is no sign of prolonged habitation. Hunting was restricted mainly to summer visits for fish and inland animals.

The cultural periods indicated are: middle to late Dorset, early twelfth century Thule, and an unidentified culture transitional from Thule to Inugsuk. The earliest known peoples appear not to have crossed to or from Polaris Promontory in Greenland, where very old (pre-Dorset) remains have been found, and no evidence was found to support a long-standing postulation that the Lake Hazen region was an early route of Eskimo migration.

Chapter II

GENERAL GEOLOGY

Formations of a wide range of ages are found on northern Ellesmere Island: a gneiss and schist terrane, probably of early Palaeozoic age or older, is extensively exposed on the north coast; tightly folded, slightly metamorphosed sedimentary formations that underlie the Hazen Plateau and Judge Daly Promontory are of early to middle Palaeozoic age; open folded, well-bedded Permo-Carboniferous sandstones and limestones underlie much of the United States Range; and sedimentary rocks containing fossils ranging from Permo-Carboniferous to Cenozoic underlie a narrow belt along the north shore of Lake Hazen and to the northeast.

Orogenic deformation probably occurred during three different periods: early Palaeozoic or earlier; post-Silurian, pre-Pennsylvanian; and in late Cretaceous or early Cenozoic time.

Granitic rocks intrude the metamorphic formation of the north coast of Ellesmere Island. The age of intrusion is not known. Dyke-rocks intrude all but the youngest strata.

Glacial ice apparently has not receded appreciably in recent years, and may be at a state of advance not exceeded for some time. Widespread glacial debris indicates that ice formerly extended over most or all of the land.

Table of Formations

Period or Epoch	Group or Formation	Locality	Lithology
Pleistocene and Recent			Stream deposits, talus, soil
		North Coast	Ice shelf
			Glacio-fluvial deposits; sand, gravel, boulder deposits
			Alpine glacier ice; till
		Unconformity	
Paleocene to Miocene		'Watercourse Valley', Lake Hazen	Shale, sandstone, coal

	Unconformity on Jura-Cretaceous beds?		
Cretaceous or Cenozoic	Brainard's "petrified forest" beds Beds exposed on Daly River	Judge Daly Promontory	Sandstone, shale
Cretaceous?		Lake Hazen	Basalt sills and dykes; diabase, gabbro
	Intrusive contacts		
Probably Jurassic		Lake Hazen	Sandstone, shale
Probably Triassic			Sandstone, shale, coal
Lower Permian			Sandstone, shale, limestone
Permian	Feilden Group	Feilden Peninsula	Limestone, sandstone, conglomerate
	Guide Hill Group		Sandstone, conglomerate, shale, limestone
	Angular unconformity?		
	Dana Bay Group	Feilden Peninsula	Limestone, shaly limestone
Carboniferous and Permian		United States Range	Limestone, sandstone, arkosic sandstone, chert-pebble conglomerate, gypsum
	Angular unconformity on Cape Rawson and Cape Columbia Groups		
Permian or earlier	View Creek Group	Feilden Peninsula	Sandstone, quartzite, greywacke, slate, conglomerate, limestone
	Relations not known		
	Sail Harbour Group	Parry Peninsula to Clements Markham Inlet	Shale, slate, shaly limestone
	Relations not known		
Silurian and probably Silurian	Archer Fiord Terrane	Judge Daly Promontory	Argillite, slate, limestone, quartzite, chert
	Cape Rawson Group	Hazen Plateau	Greywacke, impure sandstone, sandstone, slate, phyllite, impure limestone, gypsum

	Relations not known		
Ordovician	Challenger Group	M'Clintock Inlet	Limestone, sandstone, conglomerate, slate, basic volcanic rock
	Angular unconformity on Cape Columbia Group?		
	Daly River Terrane	Judge Daly Promontory	Limestone, sandstone, quartzite
	Relations not known		
Probably Ordovician or earlier	M'Clintock Group	M'Clintock Inlet and Disraeli Fiord	Andesitic and basaltic flows, breccias, tuffs, greywacke, arkosic sandstone, slate
	Relations not known		
Probably Ordovician or earlier	Mount Disraeli Group	Markham Bay to Clements Markham Inlet	Calcareous slate, phyllite, limestone, shaly limestone, calcarenite, granule conglomerate, quartzite, marble
	Relations not known		
Syenite, and granitic and pegmatitic dykes intrude Cape Columbia Group rocks; relationship to all other groups unknown			
	Intrusive contact		
Pre-Middle Ordovician	Cape Columbia Group	Cape Aldrich to Cape Nares; Ward Hunt I.; M'Clintock Inlet	Biotite gneiss, garnet-biotite gneiss, augen gneiss, chlorite-feldspar schist, amphibole-mica-feldspar gneiss, quartzite, syenite gneiss?

Probably Pre-Middle Ordovician

Cape Columbia Group

The Cape Columbia Group (1)[1] of metamorphic rocks was named by R. G. Blackadar (1954, p. 8) and described from exposures at Capes Aldrich and Columbia. Similar rocks extensively exposed between Cape Aldrich and Phillips Inlet were included in the Cape Columbia Group by the present author (1957, p. 10). Metamorphic rocks of medium or high grade, between Capes Aldrich and Albert Edward, on Ward Hunt Island, and at the head of M'Clintock Inlet are considered here.

[1] Numbers in brackets following rock group names refer to the number of the map-unit.

Lithology, Structure, and Correlation

The Cape Columbia Group comprises gneiss, schist, quartzite, crystalline limestone, and gneissic granite or granite-gneiss. The group, as it now stands, includes rocks of a wide range of metamorphic grade, and more than one formation or group, of different ages and history, may be present.

The gneisses near Cape Columbia were described by Blackadar (1954) as follows: biotite-feldspar gneiss, with biotite forming 50 to 80 per cent (by volume) of the rock; garnetiferous biotite gneiss, with garnet forming up to 15 per cent of the rock; narrow bands of spectacular augen gneiss, in which large white and pink feldspar crystals lie in a matrix of biotite, sericite, garnet, and fine-grained feldspar; and banded biotite and granitic gneisses, in which biotite-rich bands alternate with biotite-poor quartz-feldspar bands. Dykes of both granitic and pegmatitic character cut the gneisses. The granitic type is leucocratic and medium grained. The pegmatites are coarse grained and variable in composition; some contain pink feldspar and quartz, others white feldspar and minor amounts of garnet and pale brown muscovite.

Rocks of high metamorphic grade apparently pass more or less gradually and conformably into rocks of lower grade on the west side of Markham Bay. There mica-feldspar schist, exposed at the base of Cape Nares, passes southward into phyllite within about 5 miles; the southernmost metamorphosed rocks exposed are altered impure limestone similar to the calcareous rocks exposed at Wood Point and to the east. It is possible that a zone of granitic intrusion and high-grade metamorphism extends along the coast from Cape Aldrich to Ward Hunt Island, and that the metasedimentary rocks of the Cape Columbia Group are equivalent to the phyllites, altered limestones, and schists of the Mount Disraeli Group to the east. It may be significant that the two groups have somewhat similar trends. Dips are moderate to steep and the structural trend is easterly.

Age

The Cape Columbia Group is assumed to be older than the other rock-units of the region because of its higher metamorphic grade. Metamorphic rocks at the head of M'Clintock Inlet are unconformably overlain by Permo-Carboniferous strata, and it is certain, therefore, that the Cape Columbia Group is pre-Permian.

A conglomerate on the east shore of Disraeli Fiord and presumably part of the M'Clintock Group contains pebbles of crystalline limestone and quartzite that may be derived from the Cape Columbia Group. The latter group may, therefore, be pre-Ordovician (?).

A potassium-argon age of 545 million years was determined in the laboratories of the Geological Survey of Canada from a specimen of biotite gneiss from the vicinity of Cape Aldrich submitted by Blackadar. As Blackadar (1960) has pointed out, this age is of the latest Precambrian or earliest Palaeozoic, depending on the time-scale chosen. In a recent time-scale published by Kulp

(1960) the beginning of Middle Cambrian time was 540 million years ago; this would make the northern Ellesmere specimen of probably earliest Palaeozoic age.

The age given by isotope methods is that of the latest metamorphism undergone by the rocks, but the rocks themselves may be much older.

Mount Disraeli Group

This name was applied by Blackadar (1954, p. 10) to slightly metamorphosed, folded sedimentary strata (2) west of Clements Markham Inlet. The group includes a calcareous black slate and phyllite assemblage and a limestone and shaly limestone assemblage. The extent of the Mount Disraeli Group and its relationships with other groups have not been determined, but exposures as far west as the west side of Markham Bay may be included.

The age of the Mount Disraeli Group is not known. It was placed by Blackadar in the Precambrian or Palaeozoic; the beds are slightly metamorphosed and no fossils were found. The easterly and east-southeasterly trends of the group conform approximately with the trend of banding in the Cape Columbia Group to the west, which suggests that the latter is the metamorphic equivalent of the former. On the other hand, folded Permo-Carboniferous beds also with easterly trends are present in the region, and at least part of the Mount Disraeli Group may be of this age.

Ordovician (?)

M'Clintock Group

The M'Clintock Group (3) of closely folded volcanic flows, breccias, and associated sedimentary rocks in the M'Clintock Inlet and Disraeli Fiord region was described and named earlier (Christie, 1957). The sedimentary rocks of the group include tuffaceous greywacke, slate, sandstone, chert, and limestone. The thickness is unknown, but is probably at least 10,000 feet.

Greenish grey, fine- to medium-grained tuffs and tuffaceous rocks predominate, and these are interbedded with andesitic to basaltic flows and breccias. Under the microscope, the greenish grey greywacke-tuff rocks are seen to consist of crystals and fragments of feldspar and a few fragments of quartz in a chlorite-epidote-feldspar matrix. The more mafic-rich varieties are commonly chloritic and schistose.

The beds are closely folded, with dips moderate to steep. Trends vary from northeast to southeast.

The age of the M'Clintock Group is uncertain, but an Ordovician or near-Ordovician age seems probable from the following evidence: fossils identified as imperfect orthid (?) brachiopods found in greywacke talus near land on the Ward Hunt Ice Shelf are taken by Lyons and Leavitt (1961, p. 2) as supporting evidence for an Ordovician age for the M'Clintock Group; a pre-Middle Ordovician age is inferred from the presence of volcanic rocks similar to those of the M'Clintock Group in the fossiliferous Challenger Group; and the degree of induration and the severity of folding of the M'Clintock rocks are at least as great as in the adjacent Challenger Group.

Ordovician

Daly River Terrane

Limestones and quartzites (4) with Ordovician fossil-bearing beds underlie the eastern part of Judge Daly Promontory, through which flows Daly River. The lithology and structure differ from those beds exposed along Archer Fiord (*see* Pl. III). The structural and stratigraphic history of this region is not well understood, and in this report the provisional term 'Daly River Terrane' will be used for the eastern lithological-structural province. Fossils were collected near Cape Baird by Greely's party, and by Troelsen, who named the fossiliferous beds the 'Cape Baird limestone'. The writer collected fossils near Cape Baird and in the upper parts of Daly River.

Lithology

The Daly River Terrane consists of grey and brown limestone, arenaceous limestone, calcareous sandstone, and quartzite. Fossils are widespread. The rocks weather various shades of grey, light brown, and red-brown.

The limestone strata are variously thick bedded and thin bedded; the latter being mainly silty and of various colours. The thick-bedded strata are more richly fossiliferous and weather dark grey or grey-brown.

The carbonate rocks include some recognizable rocks, but others are so extensively recrystallized that their origin is uncertain.

Feldspathic, arenaceous limestone containing detrital muscovite and lithic fragments forms conspicuous dark beds high in certain sections. Dark, micaceous calcareous sandstone (near subgreywacke) outcrops as a dark, quartzitic rock near Cape Baird. Other quartzites are relatively pure quartz-arenites containing minor amounts of detrital muscovite.

In general, carbonate is dominant, and quartz, plagioclase, and detrital mica are widespread constituents in variable but minor amounts. Fine-grained matrix is notably absent, in contrast to rocks of Archer Fiord or the Cape Rawson Group.

Structure

The structure in the vicinity of Daly River is extremely varied and complex: areas of flat-lying or little-folded strata lie adjacent to upturned beds and tight folds. The folds trend easterly to northeasterly and faults of various trends but unknown displacement are numerous.

A belt of little-folded strata lies along the central part of Judge Daly Promontory. The nearly flat-lying beds are generally separated from adjacent folded rocks by steep fault planes, but in places appear unconformably to overlie them. The central belt may be a down-faulted block, but the scale of faulting cannot be determined until the ages and stratigraphy of the bedded rocks are more certainly known. Associated, weakly lithified beds, probably of Mesozoic or Cenozoic age, almost certainly are down-faulted.

Southeast of the central, little-folded belt the strata are again steeply upended, although the degree of folding and the trends vary. West of Cape Cracroft, a decided swing in trend from northeast to nearly east is evident in airphotos.

Faulting is a most conspicuous structural feature in this part of Judge Daly Promontory. Faults are evident from the juxtaposition of beds of different composition and attitudes, and from the strong lineaments which in some cases are followed by major streams. The faults trend northeast to easterly; all appear to be steep-dipping, but the nature of the movement is generally unknown. A particularly strong lineament nearly parallels the coast from Cape Baird to Cape De Fosse, and perhaps it, or another, continues toward Cape Back. This lineament, shown on the map by Prest (1952), is due to faulting that has juxtaposed weakly lithified, probably Mesozoic or Cenozoic strata against steeply dipping Ordovician limestone near Cape Baird. The movement probably had an important horizontal component, but also appears to have raised the eastern block relative to the western.

The abundant more-or-less-moderate dips and somewhat-rounded topography of the Daly River Terrane contrast with the tight folding and more rugged mountains in the vicinity of Archer Fiord, to the west and north. Conspicuous fold structures southeast of Archer Fiord disappear abruptly northeastward along their strike, where they are apparently overlain by younger rocks or are truncated by the structures of the Daly River Terrane. The possibility that the Daly River Terrane is a thrust sheet might be considered, but again, the stratigraphic relations are too little understood to be certain.

Age and Correlation

The first fossils were collected near Cape Cracroft by men of Greely's party who were searching for their relief ship. Sergeant H. S. Gardiner made a collection that included many large fossil forms and he and Greely (1886, II, p. 421) concluded, by comparing them with the fossils illustrated in Dana's *Manual of Geology*, that the "Upper and Lower Silurian" periods (now Silurian and Ordovician, respectively) were represented.

Troelsen (1950, p. 59) regarded the limestone near Cape Baird as "evidently of Ordovician age, ... not older than the Trenton" (late Middle Ordovician).

Collections obtained by the writer in 1958 have been identified by G. Winston Sinclair of the Geological Survey of Canada, who reports as follows:

(1)[1] Cape Baird (GSC 36962)[2]:

Catenipora sp.
Armenoceras cf. *A. richardsoni*
Foerstephyllum sp.
Streptelasma sp.
?*Plectorthis* sp.
Zygospira sp.
Indicated age: probably Ordovician, and if so, late Ordovician.

[1] Numbers in brackets adjacent to fossil localities and faunal or floral lists refer to localities shown on the accompanying geological map.

[2] Locality catalogue number, Geological Survey of Canada.

(2) Pavy River, near Cape Baird (GSC 36966):
Catenipora sp.
Streptelasma aff. *S. trilobatum*
?*Bighornia* sp.
Cheirocrinus sp.
Indicated age: late Ordovician

(3) Pavy River, near Cape Baird (GSC 36959):
Receptaculites cf. *R. arcticus*
Streptelasma aff. *S. trilobatum*
S. cf. *S. rusticum*
Indicated age: late Ordovician

(4) Daly River (GSC 36963):
Stromatocerium sp.
Streptelasma sp.
S. aff. *S. trilobatum*
Foerstephyllum sp.
Labyrinthites sp.
Catenipora sp.
?*Bighornia* sp.
Protaraea sp.
cf. *Batostoma* sp.
Austinella sp.
Lepidocyclus sp.
Parastrophina sp.
Rhynchotrema sp.
Plectorthis sp.
Trochonema sp.
Lophospira sp.
Gyronema sp.
Ctenodonta cf. *C. nasuta*
Orthoceras sp.
Indicated age: late Ordovician

(5) Upper Daly River (GSC 36967):
Ceratopea n. sp.
Ectomaria? sp.

Age: Middle or Late Canadian. As Troelsen has found *Ceratopea* to be common in beds in Peary Land, a possible correlation is suggested.

The Daly River strata probably are correlative with Ordovician strata in Washington and Hall lands in northwest Greenland, for Koch (1925, p. 277) has shown that Ordovician strata are exposed in a belt extending from Kennedy Channel to Independence Fiord in northern Greenland. It is significant that the trend of folded strata south of Cape Baird is easterly, or toward the mouth of

Petermann Fiord in Greenland, where the Ordovician strata are exposed. However, there are structural differences: the Ordovician strata of Petermann Fiord are part of Koch's unfolded 'great Sediment Plain'; the Ordovician beds of Judge Daly Promontory, however, are probably structurally equivalent to conspicuously bedded folded strata evident in the northern part of Polaris Promontory.

A reasonably accurate estimate of the thickness of the Ordovician beds of Judge Daly Promontory cannot at present be made. Koch (1925, p. 28) reports a thickness of about 2,600 feet for the Ordovician beds of northern Greenland.

Middle and Upper Ordovician

Challenger Group

The Challenger Group (5), underlying an area round upper M'Clintock Inlet, was named and described by the author in 1957 (1957, p. 13). The group comprises grey limestone and reddish sandstones, with minor conglomerate, feldspathic sandstone, and mudstone, and some altered basic volcanic rocks. The rocks are hematitic and weather brilliant red in places. The total thickness of these beds is unknown, but certainly exceeds 5,000 feet and may be two or three times this thickness.

Impure sandstone and the green-grey matrix of a conglomerate are seen under a microscope to be calcareous sandstones with a subgreywacke aspect. The rocks contain mainly angular quartz and chert grains, with fragments of plagioclase, perthite, muscovite, and carbonate in minor amounts. The matrix of these rocks comprises carbonate, clay minerals, and hematite.

A fossiliferous conglomerate of Middle Ordovician age, exposed on a headland west of M'Clintock Inlet, contains pebbles of volcanic flow or tuffaceous rocks and altered granitic rock.

The Challenger Group has been moderately to tightly folded, with dips generally about 30 to 60 degrees. Most fold axes trend eastward. A complex drag-fold or overthrust fold on the west wall of M'Clintock Inlet indicates, it may be suggested, an overturned fold due to an upriding thrust from the south.

Fauna

Fossils collected from the Challenger Group were provisionally identified by G. Winston Sinclair of the Geological Survey of Canada. Sinclair's report (also published earlier: Christie, 1957, p. 14) follows:

(6) From a headland west of M'Clintock Inlet (GSC 24720):

crinoid fragments
Anthozoa, genus indeterminate
Sowerbyella sp.
Liospira sp.
Illaenus sp.
Gonioceras sp.
Richardsonoceras sp.
Lophospira sp.

These fossils are of Middle Ordovician age (Wilderness stage[1]), and the beds are probably correlative with the Gonioceras Bay Formation (and thus with the lower part of the Cape Calhoun Formation —*see* Troelsen, 1950, p. 53) of Greenland as described by Koch, Troedsson, and Troelsen.

(7) From the west wall of upper M'Clintock Inlet (GSC 24721):

Plasmopora lambei Schuchert
Columnaria n. sp. aff. *C. halysitoides* Troedsson
Palaeofavosites sp.
Calapoecia canadensis Billings
Halysites sp. aff. *H. feildeni* Etheridge
Syringopora n. sp.
Batostoma n. sp.
Rhinidictya sp.
Cyclospira cf. *C. vokesi* Roy
Hormotoma gracilis (Hall)
Lophospira spp.
Umbospira sp.
Holopea sp.
trilobite fragments
Leperditia sp.
Aparchites sp.
Krausella sp.
Conchoprimites sp.
scolecodonts

The age of these fossils is Upper Ordovician (Richmondian), and the beds probably correspond to the upper part of the Cape Calhoun Formation of Greenland as described by Koch and Troedsson[2].

The Challenger Group apparently lies in fault contact with observed adjacent formations. However, the fossiliferous conglomerate beds, which possibly lie near the base of the group, contain detritus that appears to be derived from nearby volcanic and metamorphic-plutonic terrane. The Challenger Group may thus unconformably overlie both the Cape Columbia and the M'Clintock Groups.

Silurian

Cape Rawson Group

The Cape Rawson Group (6) was named by Feilden and De Rance (1878, p. 556), who described tightly folded dark slates and grits conspicuously displayed at Cape Rawson, on the northeast extremity of Ellesmere Island.

[1] This stage, defined by G. A. Cooper (1956, p. 8) in his revision of the Black River-Trenton relationships, includes beds of the Black River Formations and the Rockland Formation.

[2] Troelsen (1950, p. 53) has shown that the Cape Calhoun Formation of Koch (1929a, p. 28; 1929b, p. 236) should be divided into two parts, the lower indistinguishable from the Gonioceras Bay Formation and of Mohawkian (specifically, Wilderness) age, the upper of Richmondian age.

Feilden and De Rance placed the southern boundary of the group at Scoresby Bay on Kennedy Channel and the northern boundary at Cape Cresswell. Troelsen (1950, p. 63) limited the southern extent to Archer Fiord and located the western extension of the northern boundary at the head of Greely Fiord. Blackadar (1954) placed the northern boundary at Porter Bay on Feilden Peninsula.

Tightly folded, unfossiliferous strata of the Cape Rawson Group extend in a broad, northeasterly trending belt that underlies the Hazen Plateau and parts of United States Range and Victoria and Albert Mountains (*see* Pls. I, II, III). The northern limit of exposure extends from Porter Bay to the heads of Tanquary and Greely Fiords. The southern boundary is not easily defined. Folded strata are widely exposed on Judge Daly Promontory, and the type and degree of folding are similar to those of the Cape Rawson Group to the north. However, the lithological characters differ, and it is convenient to map the two separately for purposes of description. An abrupt change in lithology takes places just north of Keppel Head on Archer Fiord, and this is taken to mark the southern boundary of the Cape Rawson Group. The boundary is presumed to follow more or less along the north shore of Archer Fiord.

Lithology

The Cape Rawson Group comprises mainly dark coloured greywacke, subgreywacke or impure sandstone, sandstone, micaceous gritty slate, phyllite, impure limestone, and minor gypsum. The grade of metamorphism is low; original textures and sedimentary structures, such as ripple-marks (Pls. IV, V), are preserved, and very little new mineral growth has taken place. Bedding is distinct and variations in grain size and texture are fairly wide. Beds of coarser grained greywacke, subgreywacke, and calcareous greywacke or sandstone alternate with finer grained strata of phyllite, greywacke, gritty calcareous phyllite, or slaty impure limestone. The general character of the group is one of monotony of colour and composition.

A bed of gypsum some tens of feet thick was found near the snout of Clements Markham Glacier. A conspicuous bed of fine-grained, grey limestone about 500 feet thick outcrops in the same vicinity, and the only fossil collection from the Cape Rawson Group, made some miles up the valley, is probably from this horizon.

A weak cleavage is generally present and is due in part to the abundance of detrital mica. The mica flakes, lying parallel with the bedding, impart a weak fissility to even the coarser rocks. Small amounts of secondary interstitial chlorite and sericite also generally lie parallel with the bedding and contribute to the fissility. Well-developed schistosity was observed in the mountains adjacent to upper Gilman Glacier, and more or less slaty cleavage and schistosity in various other areas.

The arenaceous rocks of the Cape Rawson Group contain, typically, from 30 to 80 per cent quartz detritus, up to about 30 per cent feldspar, and small amounts of detrital muscovite and biotite. A chlorite-sericite-quartz cement

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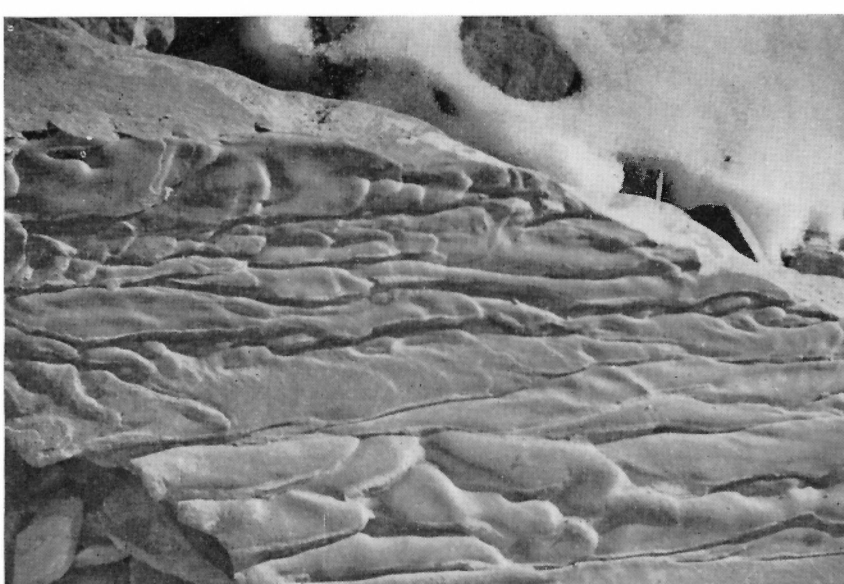
R.L.C., 11-4-57

PLATE IV

Ripple-marks, Cape Rawson Group, at the head of Ruggles River.



R.L.C., 4-6-57

PLATE V

Bedding plane (mud-flow?) structures in Cape Rawson Group beds of Conybeare Bay.

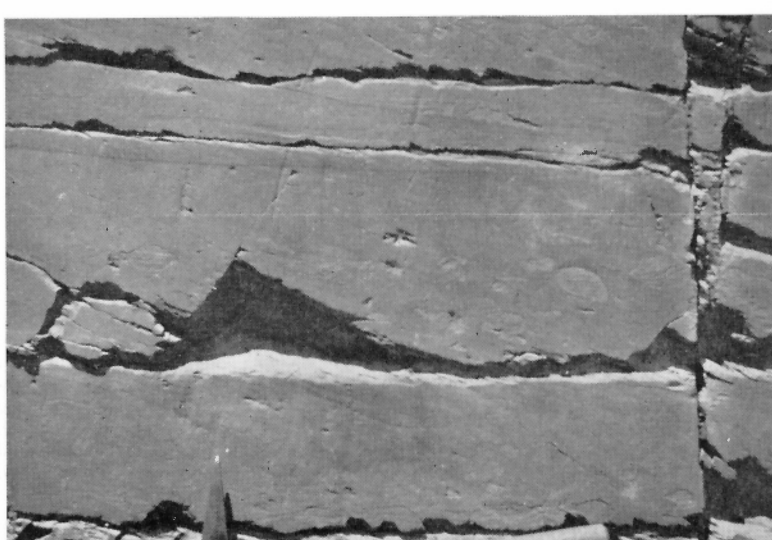
mostly shows only slight preferred orientation. Biotite is present to a minor extent but is particularly noticeable in the region north of Lake Hazen. Carbonate is widespread in small amounts, and among the finer grained rocks tends to dominate. In hand specimen, the resulting impure limestones are almost indistinguishable from the finer greywackes and subgreywackes.

The quartz detritus is angular to subangular, and fresh-appearing. Evidence of addition of secondary quartz to the original grains is rare. Widespread but slight corrosion of quartz grains by the micaceous matrix results in beard-like growths of chlorite along quartz boundaries.

Angular plagioclase and potash feldspar detritus is present in all but the finest grained rocks. Plagioclase is widespread, and is generally the only feldspar evident in thin sections. The composition of the plagioclase apparently ranges from albite to about oligoclase-andesine. Potash feldspar, less widespread than plagioclase, equals or exceeds the proportion of plagioclase in the region north of the west end of Lake Hazen. The feldspars generally appear unaltered in thin section, though secondary sericite, and more rarely carbonate, is found at scattered localities. Where sericite is abundant in the matrix, the feldspars are more sericitized.

Detrital mica is widespread, and forms about 5 per cent or less of the rock, regardless, to a great extent, of grain size and composition. Even in the impure carbonate rocks, where quartz is a minor constituent, detrital muscovite is present in about its usual proportions. The detrital mica is generally all muscovite, but biotite, more or less altered to chlorite, is not uncommon.

Lithic fragments, such as chert and quartzite, are rare. Intraformational conglomerate (Pl. VI) is present but not abundant.



R.L.C., 9-7-57

PLATE VI

Intraformational conglomerate and bedding structures exposed on a glacially polished surface, lower Ruggles River valley. The rock is a fine-grained phyllitic sandstone of the Cape Rawson Group.

Certain lithological differences are apparent in the Cape Rawson Group from southeast and east to northwest, although the general characteristics persist across the entire belt. Southeast of Lake Hazen the strata are predominantly fine grained, relatively poor in quartz, and rich in carbonate. Lithological variations include slaty micaceous arenaceous limestone, slaty calcareous feldspathic sandstone or arenaceous limestone, and greywacke-limestone or calcareous greywacke and subgreywacke.

Fine-grained impure limestone, calcareous sandstone and greywacke, and thick beds of black chert predominate south and west of Alert. Northwest of Lake Hazen, on the other hand, the group includes distinctly coarser beds than to the east and southeast, and finer grained rocks assume minor proportions. The rocks are relatively rich in quartz and feldspars and typically dark greywacke, subgreywacke, and feldspathic sandstone are predominant.

Structure

Cape Rawson strata lie in tight, isoclinal and chevron folds of various sizes, and excellent sections of fold structures are exposed in deep, steep-walled valleys, such as that of Chandler Fiord, that dissect the plateau (*see* Pl. VII). Many of the smaller folds (Pl. VIII) are probably drag-folds related to larger structures. The largest folds observed cross Chandler Fiord near its mouth; anticlinal axes adjacent to a syncline there, for example, are spread about 6,000 or 7,000 feet apart. A suspected larger fold, perhaps 3 or 4 miles wide, crosses Henrietta Nesmith Glacier about 7 miles north of Lake Hazen. For the greater part, however, the folding is tight, with closely spaced, steeply dipping axial planes. The axial planes generally dip between 70°NW and vertical, but dips of 50° to 70°NW are not uncommon.

R.L.C., 12-5-57

PLATE VII

A view east across Chandler Fiord. Cape Rawson beds are here irregularly folded into a flat-topped, steep-sided anticline and tight chevron folds. (June, 1957.)

PLATE VIII

A small chevron fold in Cape Rawson beds exposed in a bank of upper Gilman River. The bank is about 15 feet high.

R.L.C., 6-4-57

Moderate to steep dips obtain over an area of several thousand square miles, and the up-ended, resistant strata produce the marked northeast lineation of the plateau and adjacent mountains (*see* Pl. I). Thickness of the Cape Rawson beds is difficult to determine due to the extreme distortion and the general absence of horizon markers.

An interesting feature of the Hazen Plateau is the marked change in structural trend east of Tanquary Fiord and south of Lake Hazen. The trends swing from easterly in a smooth arc through about 45 degrees to about northeast. To the west, the Cape Rawson beds are buried by younger strata.

A virgation or divergence of structure may be present east of Clements Markham Inlet, where both northeasterly and easterly trends are apparent. The grouping and relative ages of the rocks of this region are not certain, however, and the significance of the contrasting trends is therefore not clear.

More or less slaty cleavage, as described above, has developed in the Cape Rawson rocks, but is mostly parallel with the bedding and not distinguishable from bedding-plane cleavage. Occasionally, however, cleavage may be observed to crossbedding.

Quartz and quartz-carbonate veins cut the beds here and there. These were observed to be more abundant north than south of Lake Hazen.

Age and Correlation

The Cape Rawson Group is unconformably overlain by the Permo-Carboniferous rocks of the Lake Hazen and Tanquary Fiord regions. On the south, Cape Rawson beds lie in fault contact against strata of unknown age, which are described in a later section as beds of the 'Archer Fiord Terrane'.

Fossils from an impure limestone bed on the north side of Clements Markham Glacier (GSC 36957) were examined by T. E. Bolton, of the Geological Survey of Canada, who remarks as follows:

(8) *Atrypella phoca*
coarse ribbed spirifer (*Delthyris*?)
rugose and phacelloid corals
These all strongly suggest an early Upper Silurian age (the Arctic *Atrypella phoca* fauna) for this part of the Cape Rawson Group.

A collection of fossils (GSC 23091) was obtained by Blackadar from argillaceous limestone at the entrance to Colan Bay, near Alert. Bolton has described the collection as follows:

(9) *Favosites* spp.; in some specimens a suggestion of pores, in walls and corners, of *Palaeofavosites* type
Heliolites sp.
rugose coral
Conchidium sp.; between *C. arcticum* Holtedahl and *C. alaskense* Kirk and Amsden; convexity of these forms is suggestive of *Conchidium* rather than of *Virgiana*
cephalopod fragments
This fauna is common to Upper Silurian[1] strata throughout much of the Arctic

Blackadar considered the limestone to be apparently unconformable on, and younger than, the adjacent Cape Rawson beds. It seems probable now, however, that the limestone should be included in the Cape Rawson Group.

Thorsteinsson (pers. com.) has suggested, from certain lithological similarities, a correlation with graptolitic rocks in Canyon Fiord, southwest of the map-area, and thus an Ordovician or Silurian age.

The Sail Harbour Group described by Blackadar (1954, p. 12) appears to pass along strike into Cape Rawson beds. As suggested in a later section, the two groups are similar in certain respects and may be equivalent.

Probably Silurian or Later

Archer Fiord Terrane

The lithology of a highly folded assemblage of strata (7) that underlies both sides of Archer Fiord and much of Judge Daly Promontory is distinct, although to some extent it is similar to the Cape Rawson Group to the north. The Archer Fiord assemblage is lithologically and structurally distinct from that

[1] A Middle Silurian age was originally suggested (Blackadar, 1954, p. 11) from a preliminary examination of the collection.

of the adjacent Daly River Terrane, to the east. The stratigraphic and structural history of the region is uncertain, and in this report the provisional name 'Archer Fiord Terrane' will be used for the western lithological-structural province.

Well-bedded rocks are thrown into folds that are strikingly evident in airphotos of Judge Daly Promontory south of the head of Archer Fiord (Pl. III). This region has not been traversed and is tentatively included in the Archer Fiord Terrane.

Lithology

Rocks of the Archer Fiord Terrane include limy argillite, slate, limestone, micaceous feldspathic quartzite, and black chert. A striking light grey limestone intraformational breccia is widespread. The rocks weather variously dark grey, light grey, black, and buff-brown, so that the bedding is evident from a great distance. Efflorescent salts that coat certain argillaceous beds are described in a later section.

The above characters distinguish the Archer Fiord rocks from the monotonous grey rocks of the Cape Rawson Group to the north. However, the more impure rocks of Archer Fiord are similar to the rocks of the Cape Rawson Group. Under the microscope detrital quartz, plagioclase, and muscovite are seen to be tightly compacted and cemented by newly developed chlorite and sericite.

Grey and buff limestones on the northern part of Judge Daly Promontory contain quartz, plagioclase, and muscovite as minor constituents.

Structure

Strata of the Archer Fiord Terrane are thrown into tight, uniform folds with steep to vertical limbs. The northeast structural trend conforms to that of the Cape Rawson Group, and the folds, too, are similar but more open than those on Hazen Plateau. Some large folds are strikingly evident because of the colourful weathering; indeed some folds may be traced in airphotos about 40 miles.

Visible faults are rare, but a fault separates Archer Fiord beds from Cape Rawson beds north of Keppel Head, and much of the southern boundary, on Judge Daly Promontory, lies along lineaments probably of fault origin.

Age and Correlation

The similarities of the Archer Fiord Terrane with the adjacent Cape Rawson Group suggest that the two are related. Beds of the Archer Fiord Terrane may be merely part of the Cape Rawson Group, but the structural and palaeontological data are insufficient to determine the relative ages with certainty.

The Archer Fiord beds appear to be overlain unconformably by Ordovician limestone in the interior of Judge Daly Promontory, but as remarked earlier, it is uncertain whether or not this is a stratigraphic unconformity.

Permian or Earlier

Sail Harbour Group

Folded black shale, slate, and argillaceous limestone (8) east of Clements Markham Inlet were described by Blackadar (1954, p. 12) who named them the Sail Harbour Group. Folds are variously open and tight. A single fossil was found. The Sail Harbour beds appeared not to be folded and metamorphosed to the extent of Cape Rawson beds. They apparently underlie a Permo-Carboniferous formation, and were assigned a Permian or earlier age.

Field work in this critical area has been limited, and additional remarks are therefore speculative.

Beds of the Sail Harbour Group south of Parker Bay appear, in airphotos, to pass into Cape Rawson beds, but a divergence of trends in that region makes correlation uncertain. The Sail Harbour Group also appears possibly continuous with the Permo-Carboniferous folded beds at the head of Clements Markham Inlet.

View Creek Group

This group (9) of slightly metamorphosed beds on Feilden Peninsula was described by Blackadar in 1954 (p. 12) as a diversity of prevailingly clastic rocks outcropping over an area about 1 mile by 4 miles. The rocks include light buff sandstone with numerous interbeds of granule and pebble conglomerate, red sandstone and conglomerate, black and green slate and phyllite, quartzite, grey and dark grey limestone, and greywacke. Along their projected strike, the View Creek strata give place to argillaceous limestone and calcareous sandstone of the Cape Rawson Group. No evidence of gradation between the two groups was observed, and the View Creek beds were thought to be the same age as, or older than, nearby fossiliferous Permian Dana Bay beds, with which they are structurally conformable.

No further field work has been done in this area, but it is appropriate to add that, to the writer, the rocks collected by Blackadar appear similar to certain suites of the Cape Rawson Group, and it is possible that the View Creek Group is Cape Rawson Group faulted into the Permo-Carboniferous terrane.

Carboniferous and Permian

Late Carboniferous and Permian rocks (10) are widespread. They underlie much of the United States Range (*see* Pl. IX) and extensions and outliers lie along the north coast. Permian beds are also present along Tanquary and Greely Fiords, and are exposed at Lake Hazen. Certain elevated, little folded strata in the Victoria and Albert Mountains and on Judge Daly Promontory may also be of Permo-Carboniferous age.

The Permo-Carboniferous beds of Feilden Peninsula have been described by Blackadar (1954, pp. 12-16) and those to the west by Christie (1957, pp. 18-22).

PLATE IX. An air view of gently dipping beds of the United States Range. These beds unconformably overlie steep-dipping beds of the Cape Rawson Group, visible in the right foreground. Lake Hazen lies in the left distance. The valley in the foreground is tributary to Tanquary Fiord.
(RCAF T409R-185)

Lower Permian beds lie at the base of a series of weakly consolidated sedimentary rocks at Lake Hazen. The Lake Hazen beds are described in a later section.

Permo-Carboniferous Beds (10A) of the United States Range

Lithology

Bright red, weakly indurated arkosic conglomerate and arkose outcropping on the east side of Henrietta Nesmith Glacier are presumed to be down-faulted basal Permo-Carboniferous beds, and the unconformity below these is strikingly exposed on the west side of the glacier. Most of the fragments in the conglomerate are of sandstone and greywacke similar to rocks in the nearby Cape Rawson Group. Dark chert and phyllite pebbles also are important constituents.

The basal conglomerates are overlain by red arkose and greyish red arkosic sandstone. The thickness of fragmental beds has not been measured, but is estimated to be at least 1,000 feet.

The high peaks of the United States Range comprise several thousand feet of sandstones, chert-pebble conglomerates, and fossiliferous limestones. The order of these beds is unknown.

The limestones are thick bedded, fine grained, white, grey, or buff-brown weathering, and fossiliferous. Certain fossiliferous beds are vuggy or cavernous, and others comprise fossils in a breccia matrix.

R.C.L., 1954-14-2

PLATE X

Bedding plane grooved structures in Permo-Carboniferous sandstone above the head of M'Clintock Inlet.

The arenaceous rocks comprise mainly compact, well-sorted sandstones, reddish, greenish, or yellow. Impure rocks, such as green-grey and red-grey subgreywacke, are rare in the areas examined. Many of the high peaks of the United States Range consist of these well-bedded rocks, which include red arkose, red and grey-green sandstone, grey-green conglomeratic quartzite, red and green chert-pebble (jasper) conglomerate, calcareous sandstone, and hematitic calcareous sandstone. These arenaceous beds, which must total 1,000 feet or more in thickness, appear to overlie the thick, fossiliferous limestones described above.

A uniform sequence of grey, green, and red sandstone beds estimated to be at least 2,000 feet thick occurs in the mountains at the head of M'Clintock Inlet, and is presumed from the structural and lithological nature of the beds to be of Permo-Carboniferous age. About 800 feet of the section was examined, and a few poorly preserved plant impressions found.

The basal beds include fine- to coarse-grained, green, grey, brown, and red impure sandstone and interbedded coarse to fine conglomerate. The red sandstones are arkosic, and contain abundant detrital mica. The conglomerate at the base of the section unconformably overlies calcareous and quartzose mica schists and comprises mainly rounded to subangular boulders of grey, micaceous quartzite and lesser amounts of blue-grey marble. Most of the section above the basal beds is medium- to fine-grained, impure red sandstone and compact, greenish, quartzitic sandstone. High in the section is a bed of argillaceous limestone with chert spines or nodules.

The sandstones are well bedded. A few bedding-plane features such as ripple-marks, minor mud-flows, and fluted structures, presumably groove casts, were observed (*see* Pl. X).

In thin section the arenaceous rocks are found to comprise angular to subangular fragments of quartz and chert in a matrix of authigenic quartz. The tough silica cement gives the sandstones a quartzitic nature. Hematite is abundant in the red varieties.

Fauna

Fossils have been collected from widely scattered localities in the United States Range. The collections were examined by P. Harker of the Geological Survey of Canada, who reports as follows:

(10) Ice-fields 25 miles due north of head of Tanquary Fiord: GSC 37247

Caninia sp.
Syringopora sp.
Linoproductus sp. *L. cora* group
Buxtonia sp.
Stenoscisma sp. aff. *S. crumena* (Martin)
Choristites cf. *C. fritschi* (Schellwien)

This is a typical '*Choristites*' fauna of Pennsylvanian age, similar to that of the Canyon Fiord Formation.

Nunataks at the head of M'Clintock Glacier; collected by G. Hattersley-Smith:

(11) *Caninia*? GSC 37014
coral fragments
. . . almost certainly Pennsylvanian or Permian

(12) '*Productus*' sp. GSC 37013
crinoid stems
Pennsylvanian or Permian

(13) *Spirifer*? GSC 36970
Possibly Pennsylvanian or Permian

(14) *Syringopora* sp. GSC 36969
Possibly Pennsylvanian or Permian, but could be older

(15) Head of Abbé Glacier; collected by G. Hattersley-Smith: GSC 36974
Caninia sp.
Clisiophyllum sp.
Syringopora sp.
Permian or Pennsylvanian; most likely Permian

(16) Head of M'Clintock Inlet; in greenish grey sandstone: GSC 24722
unidentifiable plant impressions

Permo-Carboniferous Beds (10B) of Clements Markham Inlet

Lithology

Permo-Carboniferous beds are widely exposed near the head of Clements Markham Inlet. They are predominantly fossiliferous, dark grey limestone, phyllitic limestone, and coarsely crystalline, vuggy, yellowish buff limestone with important amounts of white and orange carbonate breccia, black quartzite, and gypsum or anhydrite. These beds, of which several thousand feet must be present, are moderately to tightly folded. The stratigraphic sequence is not known.

The carbonate breccia is a peculiar rock of uncertain origin. It is typically brown-orange weathering, and consists of unsorted angular and subangular limestone fragments mostly ¼ inch to 4 inches, but up to about 3 feet in diameter in a rather weak limy cement. A minor proportion of the fragments is 'foreign' rock such as darker limestone, white marble, and limy slate. The breccia lies with sharp contacts against a cavernous, white weathering, somewhat similar breccia that contains whole brachiopod fossils. In places, apophyses or 'dykes' of a sorted, sand-grade phase of the orange breccia intrudes a few feet into the white breccia.

The carbonate breccias are apparently associated with the gypsum beds. From this, and the presence of crystal-lined cavities in the white breccia, it may be suggested that the breccias are the result of solution and collapse phenomena.

The basal beds of the Permo-Carboniferous formations of Clements Markham Inlet and the United States Range may be exposed on a nunatak about 8 miles northwest of the terminus of Clements Markham Glacier. This locality was discovered by Hattersley-Smith, and a collection of plant fossils made by him is reported on below. The fossiliferous rock appears to be a black, fine-grained, shaly greywacke, and nearby beds, judging from Hattersley-Smith's collection, are referable to the Cape Rawson Group.

Fauna

Several fossil collections obtained in the vicinity of Clements Markham Inlet have been examined by Harker, who reports as follows:

(17) Gypsum River, west of Clements Markham Inlet: GSC 36958

Spirifer striato-paradoxus Toula
Spiriferella sp.
Waagenoconcha? sp.
Lower Permian

(18) Left bank of Clements Markham River, 2 miles from head of Clements Markham Inlet: GSC 36975

Dictyoclostus sp.
Linoproductus sp.
Pennsylvanian or Permian; most likely Pennsylvanian

The collection of fossil plants (GSC 5806) made by Hattersley-Smith, referred to above, has been examined by F. M. Hueber of the Geological Survey of Canada, who reports as follows:

(19) *Lepidodendropsis* sp., ? *L. corrugatum* (Dawson)
Asterocalamites scrobiculatus Schlotheim
Rhodea tenuis Gothan
Rhacopteris sp.
Lepidodendron volkmannianum Sternberg
Sphenopteris new species?
This florule contains elements that indicate a Lower Carboniferous (Mississippian) age

The significance of this important dating is discussed in a following section.

Permo-Carboniferous Beds of Feilden Peninsula
(Dana Bay 10C, Guide Hill 10D, and Feilden 10E Groups)

Beds containing Permian fossils were mapped by Blackadar (1954) in the vicinity of Feilden Peninsula, and divided into three groups, two of which appeared to be conformable and to overlie a third. The name 'Dana-Bay beds' was applied by Feilden and De Rance (1878, p. 559) to fossiliferous beds exposed along the north shore of Porter Bay and apparently underlying other fossiliferous beds described as 'Carboniferous Limestone'. The 'Carboniferous Limestone' of Feilden and De Rance was more accurately mapped by Blackadar, and was divided by him into two units: the Guide Hill Group of red-beds, and the Feilden Group, dominantly of limestone. Fossil collections from the three groups, formerly tentatively dated as Lower Permian, are now definitely considered to be of Permian age.

Lithology and Fauna

Blackadar (1954, p. 13) described the Dana Bay Group (10C) as grey limestone and black, argillaceous limestone folded to produce moderate and steep dips. Beds of this group outcrop for less than a mile across their strike.

Fossils collected in 1953 from Dana Bay beds (GSC 23093, 23094) were identified by Harker[1] as follows:

(20) *'Fenestella'* sp.
Linoproductus sp. cf. *L. duplex* Wiman
Neospirifer sp. cf. *N. cameratus* (Morton)
Productus pseudohorridus? Wiman
Productus sp. cf. *payeri* Toula
Productus sp. ex gp. *P. uralicus* Tschernyschew
Productus uralicus Tschernyschew
Spiriferella sp. cf. *S. parryana* Toula
Spiriferella sp.
Tabulipora? sp.

The name Guide Hill Group (10D) was applied by Blackadar (1954, p. 14) to unmetamorphosed, deep red strata exposed on Guide Hill, on Parry and Feilden Peninsulas, and on the mountains east of Clements Markham Inlet. The group is described by Blackadar as chocolate-red, calcareous sandstone and conglomerate, brick-red sandstone, black and purple shale, and grey limestone. The conglomerate contains fragments of quartz, jasper, limestone, quartzite, shale, and granitic rocks. Guide Hill beds are folded, and dips are variously moderate, gentle, and steep. Fossils collected by Blackadar were identified by Harker as late Carboniferous or Lower Permian age and include caniniid corals.

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[1] Also reported earlier: Blackadar, 1954, p. 14.

The limestone beds (10E) of Feilden Peninsula, probably the same as most of the formation called 'Carboniferous Limestone' by Feilden and De Rance, were named the Feilden Group by Blackadar (1954, p. 15). The Feilden Group is dominantly of buff weathering, grey to dark grey limestone, but includes also fossiliferous, argillaceous limestone, sandstone, and conglomerate. Dark grey chert nodules occur locally in the limestone. Beds of the Feilden Group lie in broad, open folds.

West of Dana Bay, Feilden Group strata appear to overlie conformably Guide Hill rocks, which in turn, but unconformably, appear to rest upon Cape Rawson beds. On the southeast side of Feilden Peninsula, however, exposures of Feilden Group beds apparently are remnants of a former cover laid unconformably over Dana Bay Group and other beds.

Fossils from the Feilden Group, collected by Blackadar, were identified by Harker[1] as follows: (GSC 23092, 23095, 23096, 23097, 23098)

(21) caniniid corals
Fenestella
Lithostrotion sp.
Linoproductus
Marginifera sp. cf. *M. involuta* Tschernyschew
Productus uralicus Tschernyschew
'Productus' orientalis? Tschernyschew
Productus cf. *P. uralicus* Tschernyschew
Tabulipora? sp.
Spiriferella sp.
Syringopora sp.
Martinia sp.
These fossils are of Permian age

Permo-Carboniferous Beds (10F) of the North Coast

Outliers of fossiliferous Permo-Carboniferous beds, mainly limestone, form Cape Nares, the coastal hills to the west, and the north half of Ward Hunt Island. An outlier is also exposed a few miles inland south of Ward Hunt Island. Permo-Carboniferous beds on the west shore of Markham Bay may be an outlier or part of the United States Range-Clements Markham Inlet Permo-Carboniferous terrane.

Lithology

Permo-Carboniferous beds of the north coast include buff weathering, grey limestone, conglomerate, cherty limestone, and sandstone. The basal beds, well exposed at Cape Nares and in a creek valley east of Cape Albert Edward, comprise up to 50 feet of arkosic conglomerate containing a large proportion of pebbles

[1] Also reported earlier: Blackadar, 1954, p. 15.

and fragments of the Cape Columbia gneisses, which lie below the unconformity, and about 100 feet of red weathering arkosic conglomerate and conglomeratic, arkosic sandstone. Overlying the basal beds, and capping Cape Nares, is at least 500 feet of light brown weathering, sandy limestone and grey limestone. The limestone beds are abundantly fossiliferous.

The total thickness of Permo-Carboniferous strata exposed along the north coast is estimated to be at least 2,500 feet. The contact with the underlying gneisses is in part faulted, and a greater stratigraphic thickness may be represented. Dips of bedding vary from moderate to vertical, apparently due to folding and block faulting. The limestone beds are particularly well exposed on the western headland of Ward Hunt Island, where they dip moderately northward. They are generally light grey, with variations to dark grey and greenish grey, and weather buff-brown. Red coloration is due to hematite coating on fracture surfaces. Beds are 4 inches to several feet thick and bedding is evident mainly as variations in weathering characteristics. Some sandy, bright red- to buff-brown weathering limestone and quartz-pebble conglomeratic limestone beds must lie near the base of the exposed section, but are evident only as float[1]. Secondary flint-formation is widespread, and locally beds are nearly completely silica-rock. The silica forms concentric-banded concretions up to 10 inches in diameter and occurs also as nodules or irregular 'tuber'-like bodies. Undisturbed fossils are commonly enclosed in the flint.

The outlier exposed a few miles inland south of Ward Hunt Island apparently is much disturbed and undoubtedly is in part down-faulted. The basal beds are exposed at the northern edge of the outlier, and comprise there a great variety of fragmental rocks including limestone breccia with sandy limestone matrix, conglomeratic to sandy limestone, sandstone, and red weathering arkosic conglomerate. Fossils were collected from the overlying beds, which are mainly light brown weathering, sandy limestone and grey weathering limestone with chert nodules. Lyons and Leavitt (1961, p. 4) studied the stratigraphic section and reported a thickness of at least 1,100 metres, which includes, from the base upward, 30 metres of conglomerate, 50 metres of red weathering limestone, 330 metres of fossiliferous grey, tan, and black limestone, and overlying more fossiliferous limestones.

The Permo-Carboniferous beds of Markham Bay, examined briefly, include rock types as described on Ward Hunt Island, and in addition bedded black chert and limy black fossiliferous shale. The beds of chert and shale appear to lie more or less in the middle of the exposed section of many hundreds of feet of limestone.

[1] Lyons and Leavitt (1961, p. 4) have noted that the basal beds as exposed on the 'mainland' of Ellesmere Island, to the south, are not apparent on Ward Hunt Island, and that the contact may be a fault.

68546-1—4

Fauna

Fossil collections, obtained in 1954 and 1958 from several localities were reported by Harker as follows:

(22) Ward Hunt Island[1] (outcrop, talus, and float): GSC 24716

Echinoconchus sp. cf. *E. punctatus* (Martin)
Echinoconchus sp. cf. *E. longispinus* (Sowerby)
Productus irginae Stuckenberg (*sensu lato*)
Productus sp. possibly *P. orientalis* Tschernyschew
Productus cora-planus Miloradovich
'*Productus cora*' large flat form cf. Tschernyschew, 1902, Pl. LIV, fig. 5
Productus uralicus Tschernyschew
Martinia sp. cf. *M. subradiata* McCoy
Spiriferina cristata? Schlotheim
Choristites fritschi Schellwien
Spiriferella saranae arctica (Haughton)
Euomphalus sp.
Dictyoclostus sp. ex gp. *D. semireticulatus*
Chaetetes sp.
fenestellid bryozoa
'*Cyathophyllum*' sp.
Syringopora sp.
colonial corals

This collection contains fossils of both Upper Carboniferous and Permian age

(23) Ward Hunt Island (collected in 1958 from talus apparently from brown weathering, sandy limestone beds near the base of the section exposed on the west end of the island): GSC 36964

Marginifera? sp.
Dictyoclostus sp.
brachiopod fragments
Pennsylvanian or Permian

(24) Cape Nares[1]: GSC 24717

Streptorhynchus? sp. small form
Productus lineatus? Waagen
Dictyoclostus sp. ex gp. *D. semireticulatus*
Aulopora sp.
solitary coral fragments
Tentatively dated as Upper Carboniferous

[1] Also reported earlier: Christie, 1957, p. 19.

(25) Along creek transecting the inlier south of Ward Hunt Island[1]: GSC 24723

Syringopora sp.
rugose coral fragments
'*Cyathophyllum*' large species
Euomphalus sp.
This collection is of late Palaeozoic age

(26) West shore of Markham Bay[1]: GSC 24725

Michelinia sp.
large rugose coral
Neospirifer cameratus? Morton
Linoproductus svalbardensis Frebold
Spirifer indet.
Lower Permian

A list of fossil identifications from material collected in 1960 on Ward Hunt Island and 'Camp Creek' (the Creek of locality 25) has been published by Lyons and Leavitt (1961, p. 5) of Dartmouth College (for the United States Air Force Cambridge Research Laboratories).

Several species other than those listed above are identified or suggested and include bryozoans, brachiopods, corals, gastropods, and trilobites.

Fusulinids were collected by the author in 1954 at Cape Nares, Ward Hunt Island, the inlier south of Ward Hunt Island, and at other localities to the west of the map-area. The fusulinids, not listed with Harker's identifications, are now being studied by R. Thorsteinsson of the Geological Survey of Canada. A few fusulinids have already been described and figured, however, by M. L. Thompson (1961), Illinois State Geological Survey, from rock samples obtained from Ward Hunt Island. Thompson's dating and the correlation of these beds is discussed below.

Correlation of the Permo-Carboniferous Strata of Northern Ellesmere Island

The Permo-Carboniferous stratigraphy of the Arctic Archipelago was described in general terms by Fortier (1957, pp. 430-433) and by Thorsteinsson and Tozer (1960, pp. 11-13). The Permo-Carboniferous beds of the United States Range are probably continuous with, and may be correlated with, Permian and Carboniferous formations of the Sverdrup Basin, exposures of which have been studied by Schei (1903, 1904), by Troelsen (1950), and by members of the Geological Survey of Canada whose work is noted in part below.

Troelsen (1950, p. 67) identified Permian fossils collected by himself, and earlier by Ekblaw, from weakly disturbed beds of reddish weathering limestone, arenaceous limestone, and shale on Greely and Tanquary Fiords. Troelsen's fossil locality on Greely Fiord lies near the edge of the present map-area. He suggested an early Permian age for the beds that he named the Greely Fiord

[1] Also reported earlier: Christie, 1957, pp. 19-21.

Group. Grey, impure fossiliferous limestone and grey sandstone of Middle Pennsylvanian age on Canyon Fiord were named the Canyon Fiord Formation (Troelsen, 1950, p. 65).

Permian and Carboniferous limestone, sandstone, and volcanic beds are known on the north tip of Axel Heiberg Island and on the western extremity of Ellesmere Island (discovered by Schei, and presently under study by J. W. Kerr and H. P. Trettin of the Geological Survey of Canada and by P. Fricker of McGill University). Permian limestone is reported by Thorsteinsson (pers. com.) in the vicinity of Otto and Emma Fiords.

The presence of Upper Carboniferous beds on Ward Hunt Island was established by Harker (*in* Christie, 1957, p. 19). At least some of the fusulinid-bearing beds on the island were correlated by Thompson (1961) with the middle part of the Desmoinesian Series (late Middle Pennsylvanian) of the central United States. The presence of Middle Pennsylvanian strata (limestones with *Profusulinella*) on the northern tip of Axel Heiberg Island was noted earlier by Thorsteinsson (Thorsteinsson and Tozer, 1960, p. 12). Mississippian beds are now known on the northern tip of Axel Heiberg Island from a collection of plant fossils obtained in 1961 during Geological Survey field work.

The identification of Pennsylvanian and Mississippian strata is most significant in understanding the early history of the Sverdrup Basin. As described by Thorsteinsson and Tozer (1960, p. 11), the oldest beds of the basin rest with profound angular unconformity upon folded rocks of an older eugeosyncline. Until recently, rocks of Mississippian and Lower Pennsylvanian ages were unknown in the region; it now appears that sedimentation in at least some parts of the basin began in Mississippian time, and is represented by a non-marine formation that constitutes the basal unit of the Sverdrup Basin in the northernmost regions of the Arctic Archipelago (Kerr and Trettin, 1962). Thorsteinsson and Tozer (1960, p. 13) have suggested that on the margins, unlike the axis, sedimentation was not continuous from its beginning in late Palaeozoic time to Tertiary time; an angular unconformity between Pennsylvanian and Permian beds is known at two, and probably three localities (the uncertain one on Feilden Peninsula is summarized in this report).

P. Harker, in his report on the fossil collections obtained in 1954 from Permo-Carboniferous beds of the north coast, remarks on a particularly striking similarity with the succession in Northeast Greenland and comments as follows on the stratigraphy and correlation of these beds:

> The collections contain representatives of two distinct late Palaeozoic faunas that occur elsewhere in the Arctic regions—notably Northeast Greenland (*see* Frebold, 1950) and Spitzbergen. In general terms the older of the two faunas is characterized by *Choristites fritschi* and the younger by spiriferoids of the *Spiriferella saranae* group. The north-coastal species reported may be distributed in these faunas as follows:
>
> *Choristites fritschi* fauna
>
> *Echinoconchus punctatus*
> *Productus cora-planus*
> *Dictyoclostus* (*semireticulatus* group)

Productus cora
Euomphalus
some large rugose corals
Spiriferella saranae fauna
Echinoconchus longispinus?
Martinia subradiata
Productus irginae
Productus uralicus
Productus orientalis
Linoproductus svalbardensis

Each of these faunal groups represents a considerable thickness of strata and in the following remarks are considered in a stratigraphic sense.

The *Choristites* fauna is Carboniferous in age, and appears in the Lower Marine Group (*of* Grönwall, 1917, p. 549) of Northeast Greenland. The *Choristites* fauna also occurs in the upper part of the Cyathophyllum limestone of Spitzbergen, which is believed to be correlative with the Lower Marine Group. The greater part of the Cyathophyllum limestone is now regarded as Upper Carboniferous and equivalent to the Triticites zone and to the Gshelian stage of the Moscow Basin.

The upper part of the Lower Marine Group or its equivalents almost invariably appears to include some red sandstone beds, often associated with gypsum. In Northeast Greenland, gypsum and red and greenish grey sandstones with plant remains all occur in a sequence that contains *Choristites fritschi* in its lower beds. Although no gypsum beds are reported from north-coastal Ellesmere Island, fauna equivalent to that in the Lower Marine Group are represented, and the red and greenish sandstones with plant remains from M'Clintock Inlet could well be from the red beds so often found in the lower part of this sequence elsewhere.

The *Spiriferella* fauna is Permian and appears to be more widespread than the older, Upper Carboniferous faunas (*see* Harker and Thorsteinsson, 1960, p. 15). It occurs in the Upper Marine Group of Northeast Greenland, in the so-called Spirifer limestone of Spitzbergen, and is represented by collections from Feilden Peninsula. Frebold (1950, p. 72) described the Upper Marine Group as containing three main facies types: The Posidonomya shales, the brachiopod limestone, and the Martinia beds. The three types interfinger, but the Martinia beds are believed to be in part younger than the brachiopod limestones. Fauna from north-coastal Ellesmere Island indicates the presence of equivalents of the Upper Marine Group, including possibly an equivalent of the Martinia beds on Ward Hunt Island, where some of the limestone consists almost entirely of species of *Martinia*.

Permo-Carboniferous to Miocene Beds of Lake Hazen

White and yellow weathering sandstone, limy sandstone, impure limestone, and shale beds (10-13, 15), all weakly indurated, outcrop along the north shore of Lake Hazen (*see* Pl. I). Fossils from these beds have been assigned with varying degrees of certainty to the Permian, Triassic, Jurassic, and Cenozoic. The structural relations between the various stratigraphic units are not everywhere clear; the similarity of the strata of different ages, the complexity of the structures, and the poor exposures of weakly lithified beds contribute to uncertainty in separating beds where fossils are not available. The units are described below in order of their inferred ages.

Permo-Carboniferous beds lie in a narrow band along the front ranges of the Grant Land Mountains; Mesozoic beds lie to the southeast apparently in the form of an open syncline; and Cenozoic beds underlie a large area north and northeast of the east end of Lake Hazen, east of the Mesozoic exposures. Diabase and basalt dykes and sills are widespread in the Jura-Cretaceous and older formations.

The age of extensive sandstone and shale beds with diabasic intrusions at the south end of Piper Pass is not known, but is presumably Permo-Carboniferous or Jura-Cretaceous.

Permo-Carboniferous Beds (10G)

Beds yielding Permian fossils outcrop in a narrow zone along the foot of the mountains north of Lake Hazen (*see* Pl. XI). The lithological characters are similar to those of younger beds and the Palaeozoic beds are recognized principally by their contained fossils.

Lithology

The Permo-Carboniferous beds include brown weathering, crumbling sandstones, grey and grey-brown shales, sandy shales, and thin fossiliferous calcareous beds. The sandstones are fine-grained, well-sorted rocks, grey or grey-brown on the fresh surface. The shales or mudstones are sandy and very weakly lithified. The weaker rocks generally are poorly exposed. The thickness of Permo-Carboniferous rocks at Lake Hazen is not known, but is estimated to be about 1,000 feet.

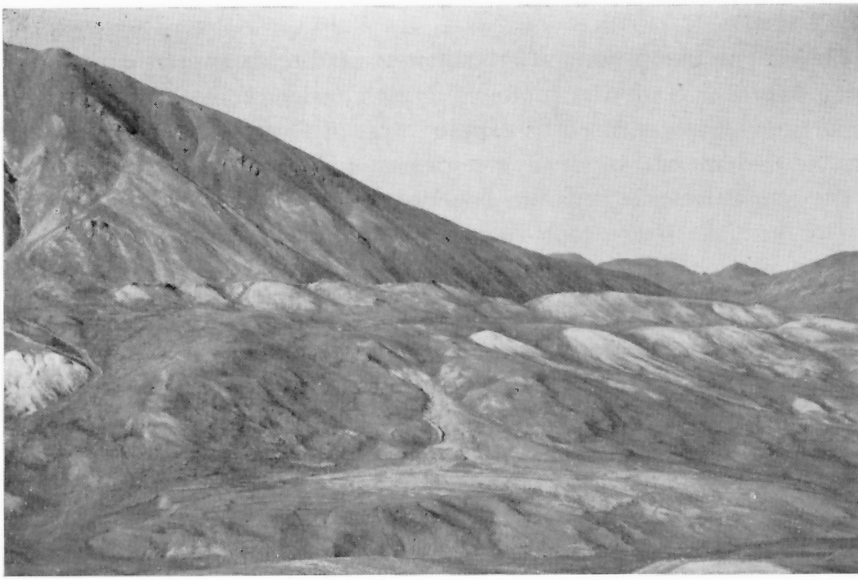
Fossiliferous beds 1 foot to 4 feet thick are variously pure and impure carbonate-rocks. At Greely's cairn, near the snout of Henrietta Nesmith Glacier, fossils occur in light grey limestone, and about a mile to the east in limy black shale. At fossil localities north of Johns Island, and to the east, the fossiliferous rock is sandy limestone and sandstone with a carbonate matrix.

Medium- and coarse-grained sandstone containing conglomeratic lenses and thin beds is present. A pebble-conglomerate bed, the thickest observed, is about 5 feet thick. The pebbles in the conglomerates are well rounded to subangular, mainly fine, black and greenish chert. About 10 per cent of the pebbles are white quartz or quartzite, and at one locality pebbles of silty limestone and greywacke also are present. The matrix is greenish or greyish sandstone.

Scarlet-coloured breccia lies between the Permian beds and the underlying Cape Rawson Group east of the snout of Henrietta Nesmith Glacier, and may be the basal member of the Permo-Carboniferous sequence there.

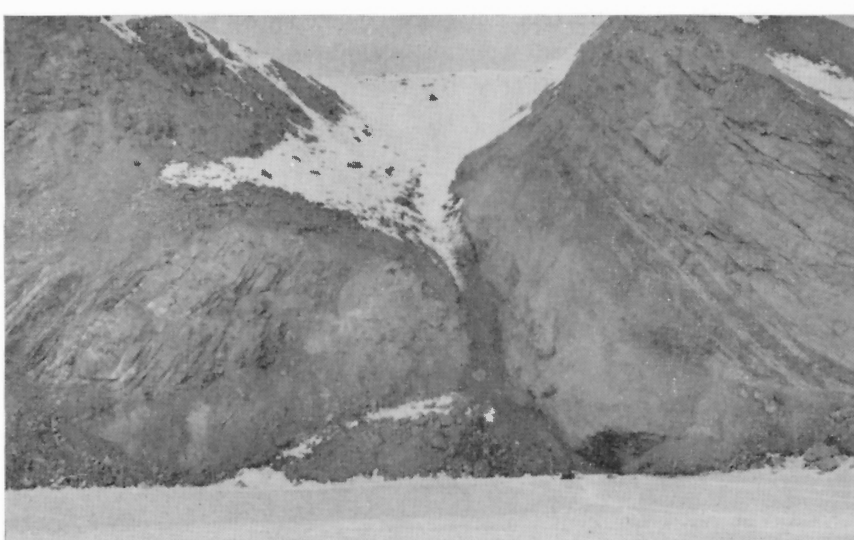
Fragments in the breccia are rounded to angular, up to 8 inches in diameter, and consist mainly of quartzite-greywacke and green phyllite. The matrix is green arkose. The breccia is faulted and slickensided.

The sandstones are seen under the microscope to be well sorted, nearly pure quartz-rocks, generally with a carbonate matrix. Carbonate crystals up to 3 mm in diameter enclose the quartz detritus in some specimens. Red sandstone beds owe their colour to a hematite-carbonate matrix. Chert detritus in minor amounts is evident.



R.L.C., 15-7-57

PLATE XI. Looking north to the front of the Grant Land Mountains in the vicinity of Johns Island. Note the scarps of the Lake Hazen fault zone, where light weathering Permo-Carboniferous and younger beds are juxtaposed against the dark Cape Rawson beds. A frost-cracked gravel bench is evident in the foreground. (July, 1957.)



R.L.C., 3-7-57

PLATE XII. The Lake Hazen fault zone exposed on Gilman River. Steep-dipping Cape Rawson beds lie to the left, and moderate-dipping Permo-Carboniferous (?) beds lie to the right of the fault.

Structure

The light coloured Permo-Carboniferous sandstones overlie dark green and grey Cape Rawson beds with profound angular unconformity. The unconformity, moderately to steeply inclined, is exposed west of Cuesta Creek, east of Gilman River, and perhaps east of Greely's cairn near Lake Hazen.

The late Palaeozoic beds are bounded on the north over considerable distances by the Lake Hazen fault zone (Pls. XI, XII). Lineaments that mark the fault zone are apparently in part expressions of the faults and in part due to upturned, relatively resistant sandstone beds and basalt sills. Dips of bedding along the fault zone are moderate to steep.

The Permo-Carboniferous rocks are bounded on the south by strata containing fossils of Triassic (?) age and younger. The late Palaeozoic and the younger beds may be, but are not certainly, conformable.

The following interpretations of the structural relations of the Permo-Carboniferous beds may be considered: The beds lie unconformably upon folded Cape Rawson strata, and (a) are the lowest beds of the northwestern limb of a synclinal structure that lies north of, and nearly parallel with, Lake Hazen; or (b) are preserved in part as fault-slices in a major fault zone, with Mesozoic formations post-dating the earliest faulting. Possibility (a) is inviting because Triassic beds in the fault zone look as if they may be conformable with Permian beds for a few miles along the zone. Permian and Triassic beds are conformable on Fosheim Peninsula and on Otto Fiord, 200 miles to the southwest (Thorsteinsson and Tozer, 1957, p. 20 and Thorsteinsson, pers. com.). It is possible that the Permo-Carboniferous and Mesozoic beds were deposited in a restricted basin, the northern edge of which was a zone of crustal weakness now marked by the fault zone.

Age

Collections of Permian fossils have been obtained from the Lake Hazen region and examined by P. Harker of the Geological Survey of Canada, who reports as follows:

(27) Greely's cairn, near Henrietta Nesmith Glacier: GSC 37016

Waagenoconcha sp.
Waagenoconcha cf. *W. payeri* (Toula)
Dictyoclostus cf. *D. neoinflatus* Licharew
Caninia? possibly talus
Lower Permian

(28) About 1½ miles north of Hazen Camp: GSC 31462

Waagenoconcha cf. *W. payeri* (Toula)
Dictyoclostus cf. *D. neoinflatus* Licharew
Almost certainly Permian, probably equivalent to the Assistance Formation of Grinnell Peninsula, Devon Island.

(29) Hills 4 miles north of Johns Island (collected by J. Tener and D. Smith): GSC 36968

Waagenoconcha sp.
Dictyoclostus cf. *D. neoinflatus*? Licharew
Cancrinella sp.
Caninia sp.
Lower Permian

No ages other than Lower Permian are reported for the Lake Hazen beds. The stratigraphic positions of the fossiliferous horizons at Lake Hazen are uncertain, and a greater range of ages may be present. The relationship to the thick Permo-Carboniferous formations of the United States Range is unknown.

Permo-Carboniferous (?) Beds

Light weathering, gently dipping sandstone strata with conspicuous diabase intrusions rest unconformably upon the tightly folded Cape Rawson Group over a large area about 20 miles north of the east end of Lake Hazen. The gently dipping strata have not been dated, but appear from their lithology to be related to the Permo-Carboniferous beds of Lake Hazen.

The sandstone beds are characteristically 20 to 40 feet thick, and consist of fine-grained, very pure quartz sand, weakly cemented. A few limy sandstone beds are present. The sandstone weathers greyish white to light brown.

Some bedding-plane structures or poorly preserved fossils were observed: one type, about 2 inches across the base, is possibly a cone-in-cone structure; another, looking much like a jelly-mould, is also conical, about 4 inches across the base and 2 inches high, and is marked on its upper surface by raised spiral convolutions.

Triassic (?) Beds (11)

Fossil collections from three widely separated localities adjacent to Lake Hazen have been identified as almost certainly of Triassic age. The extent and thickness of the enclosing beds appear to be limited, but are not known with certainty. Beds with a total thickness of about 350 feet below the fossiliferous horizon are tentatively included.

Lithology

The strata include light sandstone, grey shaly sand, thin coal seams, and thin fossiliferous limy beds. All except the fossiliferous rocks are weakly lithified. The sandstones are variously white, grey, light yellow-brown, and greenish grey.

The presumed Triassic beds are exposed in three separate areas: along the shore of Lake Hazen west of Henrietta Nesmith Glacier; along the foot of the mountains north of Lake Hazen; and near the north shore of Lake Hazen east of Johns Island.

Poorly consolidated yellowish sandstone and brown shale beds, weathering rapidly to sand and mud, underlie a narrow shoreline strip at the western extremity of Lake Hazen. The beds dip gently northwest, toward the nearby mountains. From the gentle dip and weak induration of the Triassic beds it is certain that they overlie the nearby Cape Rawson beds unconformably. The contact there, though not exposed, is probably a fault.

About 100 feet of sandstone and shale is exposed at the lake shore. One or perhaps two thin beds of limestone breccia containing fossil pelecypods occur in about the middle of this section. The fossils from these beds, which total about 2 feet in thickness, are reported in a following section.

Triassic and presumed Triassic beds are exposed along a narrow zone extending northeast from the north shore of Lake Hazen. The beds are much contorted and faulted by the Lake Hazen fault zone, and dips vary from gentle to steep or vertical.

Beds of the Triassic zone form bluffs at the lake shore about 5 miles west of Johns Island. The beds there include white and light brown sandstone, dark, carbonaceous sandstone, and fossiliferous, black argillaceous siltstone.

On Abbé River, about 3 miles from its mouth, the presumed Triassic beds consist of white weathering sandstone and a one-foot-thick bed of fossiliferous, calcareous sandstone. The beds there stand more or less vertically, and are juxtaposed against the Cape Rawson Group by the Lake Hazen fault zone.

The Triassic zone is bounded on the north mainly by beds, described earlier, that yield Permian fossils. Beds of both ages trend northeastward, and an extension in that direction for both the Triassic and Permo-Carboniferous formations is presumed and shown on the accompanying geological map. The boundaries between the beds of various ages are assumed rather than recognizable lithological contacts—as remarked earlier, the beds of several ages in the Lake Hazen region are much alike.

A fossil collection dated as possibly Triassic has been obtained from the top of a series of shaly sandstone, coaly shale, and thin coal beds east of Johns Island, near the mouth of Cuesta Creek. Some miles to the east, the fossiliferous bed is overlain conformably by sandstone beds that have yielded spores tentatively assigned a Jura-Cretaceous age. It should be noted that the coal beds near Cuesta Creek are included in the Triassic formation from a structural interpretation made in the field. Coal beds are not associated with Triassic strata elsewhere in the region and those of Cuesta Creek may be juxtaposed against the Triassic rocks by faulting or other undetermined structural relationships.

The presumed Triassic beds of Cuesta Creek make up a section about 350 feet thick, and include yellowish white and rusty brown sandstone, brown shaly sandstone, black carbonaceous shale, shaly coal, and concretionary (ironstone) siltstone. The fossils occur in a pale brown limestone breccia bed about 3 feet thick. The coal beds, the thickest of which is 1½ feet, occur in a carbonaceous member about 75 feet thick.

Age and Correlation

Fossil collections from the various localities have been identified by E. T. Tozer of the Geological Survey of Canada as follows:

(30) Near the delta of Turnstone River (GSC 31448, collected by R. E. Deane):
Myophoria cf. *M. laevigata* Ziethen

(31) Lower Abbé River: GSC 31465
Myophoria cf. *M. laevigata* Ziethen

(32) North shore of Lake Hazen, ½ mile west of mouth of Cuesta Creek: GSC 31464
Pelecypod coquina containing indeterminable form; possibly *Myophoria* sp.

Of the collections as a whole, Tozer comments:

> The specimens resemble *M. laevigata* very closely and may be identical with this species. They are almost certainly of Triassic age. It should be noted, however, that rather similar pelecypods occur in the Permian. The possibility of a Permian age for these collections, although slight, cannot be discounted completely.

A collection (33) from the north shore of Lake Hazen, about 5 miles west of Johns Island, has been studied by M. A. Fritz, University of Toronto, and T. E. Bolton, Geological Survey of Canada. The bryozoan *Arcticopora christiei* Fritz was described from the collection and was assigned a Triassic age by extrapolation from material, similar to and dated as Triassic, from Van Hauen Pass, in the Nansen Sound region (Fritz, 1961, and Bolton, 1961).

The presumed Triassic strata at Lake Hazen contain marine (shelly) beds and may include non-marine (coal) beds. They are similar to Triassic beds in the Eureka Sound and Greely Fiord regions (about 200 miles to the southwest), which Tozer (1961, pp. 9, 13) has named the Bjorne and the Schei Point Formations. Tozer (1961, p. 6) has suggested that these formations represent near-shore deposits of the Sverdrup Basin, and it seems probable that this also applies to the Triassic (?) beds of Lake Hazen.

The Triassic (?) beds of Lake Hazen, however, do not contrast lithologically with the underlying Permian beds and in this relationship the Lake Hazen area differs from parts of the Sverdrup Basin to the southwest. There, an abrupt change in lithology is taken by Tozer (1961, p. 9) to mark an interval of non-deposition and marine regression.

Jurassic and (?) Cretaceous Beds (12)

Certain beds of the weakly lithified sedimentary rocks of Lake Hazen are tentatively assigned a Jurassic or Cretaceous age from spore analyses. The spores were obtained from specimens from three localities extending over about 16 miles. The extent and thickness of these beds are uncertain; from present data it seems probable that they are about 2,000 feet thick, perhaps more.

Lithology

The Jura-Cretaceous beds include yellow, greenish, and white sandstones, grey and brown sandy shales, and black shale (*see* Pls. XIII, XIV). All the strata are weakly lithified and in general resemble the other (Permo-Carboniferous to Cenozoic) rocks of the Lake Hazen region.

Brown and grey shaly sandstones and sandy shales are the most abundant rock types. They break down rapidly into sandy mud that is not easily distinguished from some of the surficial deposits of other origins. The lighter coloured shales contain more material of sand grade, and this variety commonly passes into impure shaly, carbonaceous sandstone. Fine black shale is present as a few thin carbonaceous-appearing beds up to 5 feet thick.

The sandstones are generally fine grained and in shades of brown, yellow, green, or grey, but some are pure white, and a few are red. The sandstone beds are more resistant to erosion than the shales, and certain beds stand out as prominent hogsbacks.

Relatively pure, grey, yellowish, brown, or white sandstone is fairly abundant, forming beds about 40 to 150 feet thick. Some of the grey sandstones contain dark streaks of carbonaceous material, and are cemented by carbonate. Spheroidal concretions, 2 to 4 inches in diameter and with carbonate cement, are present in other beds. An unusually large concretion—about 6 feet in diameter—rests on the beach at the southwest extremity of Johns Island (Pl. XIV).

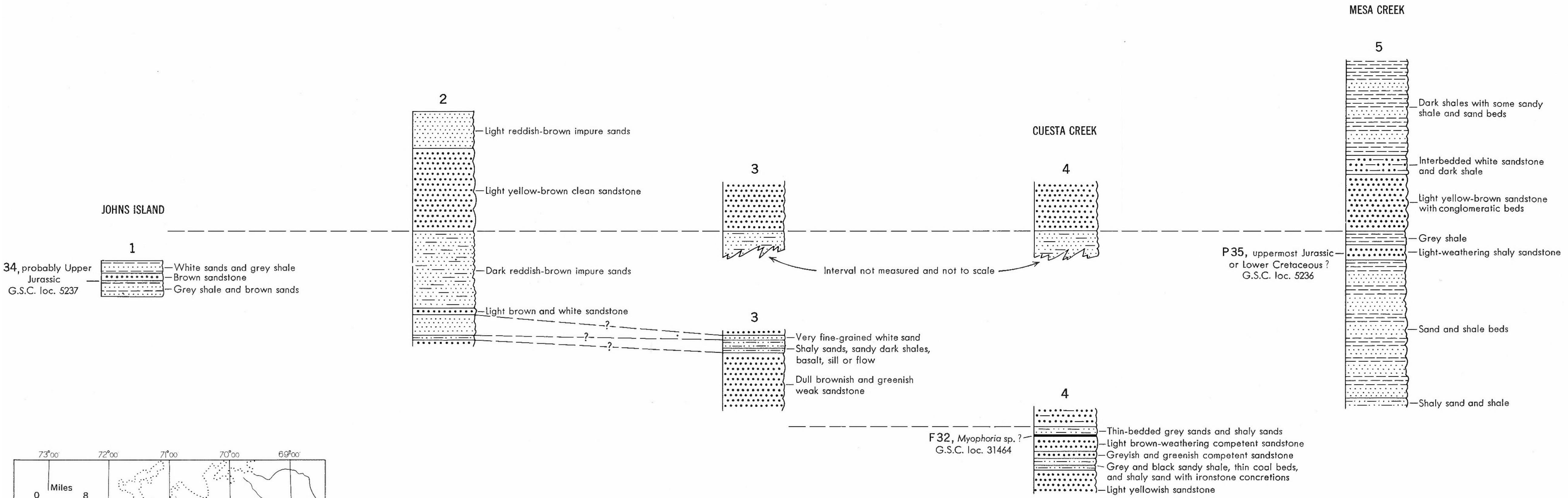
No evidence has been obtained to suggest that the conspicuous basaltic layers in the Jura-Cretacous beds are lava flows, but some, of course, may be.

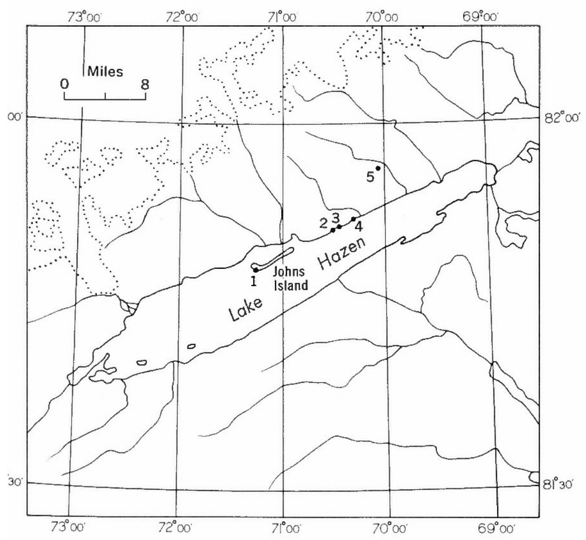
The Mesozoic beds are well exposed between Johns Island and Mesa Creek. Sections diagrammed in Figure 1 show the proposed relationship between beds and the horizons at which fossil material was collected.

Structure

The Jura-Cretaceous beds appear to lie in an open syncline with its axis lying north of, and nearly parallel with, Lake Hazen. The south limb of the syncline dips northwesterly about 20 to 30 degrees. The north limb is presumably truncated or modified by the major fault zone that follows the mountain foot north of the lake. The trends of strata in the south limb swing abruptly towards the mountains at the west end of Johns Island, and the dips steepen to 45 and 60 degrees.

The existence of a syncline in the Jura-Cretaceous rocks is not certain, but seems probable from the following evidence: (a) beds on upper Gilman River dip southeast, and are presumed to be of Jura-Cretaceous age from their proximity and similarity to dated, spore-bearing beds; (b) Permo-Carboniferous and Triassic strata along the mountain foot dip vertically to steeply southeast; and (c) the Jura-Cretaceous and Triassic beds are conformable at the one locality (Cuesta Creek) where both are known to be present.





INDEX MAP SHOWING LOCATIONS OF COLUMNAR SECTIONS

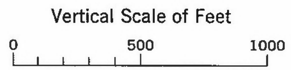
Figure 1

Measured sections of Triassic (?) and Jura-Cretaceous beds, Lake Hazen area, northeastern Ellesmere Island, District of Franklin

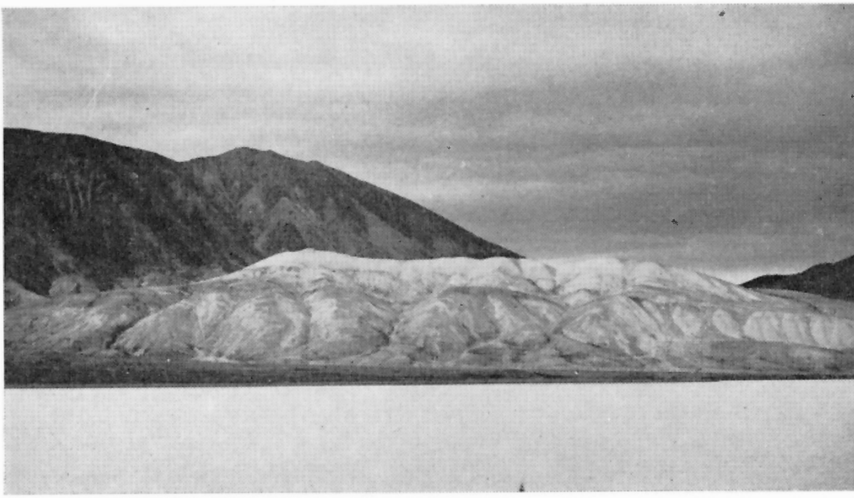
LEGEND

Pelecypods (numbers referred to in text). F32
Pollen, spores (numbers referred to in text). . . . P35

Compiled by R. L. Christie, 1961

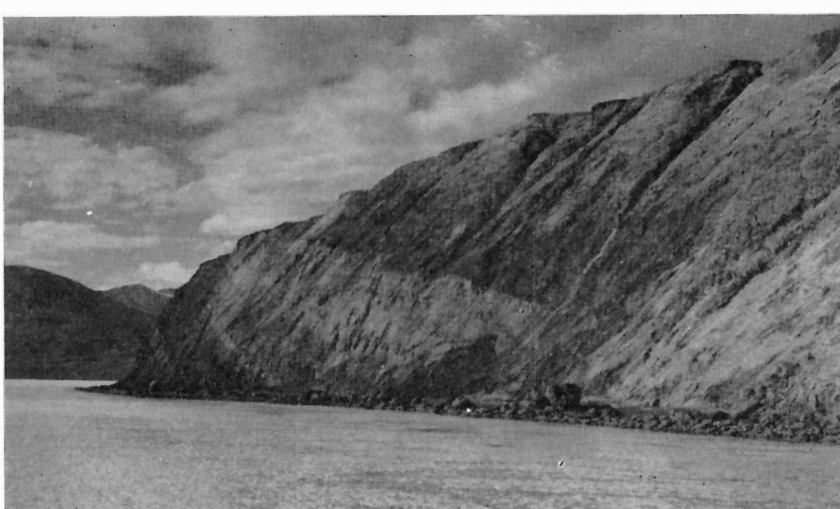


GSC



R.L.C., 14-8-57

PLATE XIII. Foreground: probably Jura-Cretaceous beds on the north shore of Lake Hazen, opposite Johns Island. Cape Rawson beds form the dark mountains in the background. (June, 1957.)



R.L.C., 15-1-57

PLATE XIV. A view looking north of the southwest end of Johns Island, where the sands and shales of Jura-Cretaceous age are well exposed. The larger boulder on the beach in the distance is a concretion about 6 feet in diameter. (July, 1957.)

Flora and Age

Microfossils from shale and sandy shale specimens from three localities have been identified by D. C. McGregor of the Geological Survey as follows:

(34) Johns Island: GSC 5237

Coniferous pollen:

Pinus haploxylon-typus Rudolph
Abietineaepollenites R. Pot.
Parvisaccites Couper (*Dacrydium*?)
cf. *Podocarpus*

Spores:

Gleicheniidites sp.
Lygodioisporites cf. *L. perverrucatus* Couper
Osmundacidites sp.
cf. *Pilosisporites tricholpapillosus* (Thier.) Del. & Sprum.
Lycopodium papillaesporites Rouse
Lycopodiumsporites cf. *L. clavatoides* Couper
Sphagnumsporites sp.
cf. *Coniopteris hymenophylloides* (Bron.) Couper
?*Cyathidites* or *Coniopteris*
Granulatisporites sp.
Leiotriletes sp.
Perotrilites sp.

(35) Mesa Creek: GSC 5236

Coniferous pollen:

Pinus haploxylon-typus Rudolph
Tsugaepollenites Pot. & Ven. (cf. *Cerebropollenites mesozoicus* (Couper) Nilsson)
Parvisaccites Couper (*Dacrydium*?)
cf. *Podocarpus*
cf. *Caytonipollenites* Couper

Spores, probably ferns:

Gleicheniidites Ross
Alsophilidites (Cookson) R. Pot.
polypodiaceae
Leiotriletes sp.
Several unassigned spores, thick-walled, trilete, probably representing species of ferns.

Others:

Perotrilites sp.
"cf. *Cyclogranisporites leopoldi* (Kremp) Pot. & Kr." (Rouse, 1957)
Several types of pollen, not similar to known recent or fossil types.

McGregor comments as follows:

> An Uppermost Jurassic or Lower Cretaceous age is suggested for these assemblages; the Jurassic age is perhaps more probable considering the absence of certain typical Cretaceous genera. The age assignment must however be regarded as tentative.

(36) Gilman River, about 6 miles above its mouth: GSC 5238

Coniferous pollen:

Alisporites sp.
"cf. typ. Walchiapites Bolch." in Rogalska, 1956
cf. *Pteruchipollenites thomasii* Couper
cf. *Podocarpus* sp.

Spores:

Deltoidospora (cf. *Coniopteris, Cyathidites*)
Densosporites
Gleicheniidites
Granulatisporites
Leiotriletes
Rugulatisporites
Striatriletes
cf. *Aneimia*
cf. *Cingulatisporites foveolatus* Couper
cf. *Cirratriradites*
cf. *Perotrilites rugulatus* Couper
cf. *Sphagnumsporites psilatus* (Ross) Couper
cf. *Sporites adriennis* f. *mesazoicus* Thier., in Rogalska, 1956
Probably Jurassic

Jurassic and Cretaceous sandstone, shale, and coal formations of marine and non-marine origin are exposed on Axel Heiberg Island and in the Eureka Sound region, 250 and 200 miles to the southwest of Lake Hazen. These beds have been described briefly by Thorsteinsson and Tozer (1957, p. 22), and are shown on GSC Map 36-1959 as the Savik, Awingak, and Deer Bay Formations.

Cenozoic Beds (15)

Very weakly indurated sandstone and shale beds of Cenozoic age with coal seams and plant remains (15A) underlie an extensive area of rolling plateau northeast of Lake Hazen (*see* Pl. I). The similarity of these beds to the Mesozoic formations of Lake Hazen makes their separation difficult.

Lithology

The Cenozoic beds include weakly lithified shale, sandy shale, and sandstone with coal beds. The shales weather grey or brown, and break down readily to mud-flows or solifluction debris.

The sandstones are white, brown, or grey, weakly cemented, and in places exhibit abundant crossbedding and some minor disconformities.

The coal beds are mostly about 6 inches to 2 feet thick. Five beds are exposed in Gilman River (Pl. XV), and a seam 8 feet or more thick is exposed along the lake shore west of Gilman River (Pl. XVI). The coal is compact, shining black to brownish, and moderately friable. Cracking and decrepitation take place after prolonged exposure to air. Proximate analyses of the coal (included in a later section) indicate a rank of sub-bituminous B.

Small, spheroidal nodules of brittle, lemon-yellow amber occur scattered and in concentrations along bedding planes in the coal. The nodules are generally about 1 to 3 mm in diameter, but many are elongate or kidney-shaped, and about 5 to 10 mm long. 'Swarms' of amber nodules, about 4 inches thick and several feet wide, consist almost entirely of amber. The amber is clear to translucent in freshly broken specimens, but becomes opaque and crumbly upon exposure.

A few thin beds of friable carbonized woody and leafy material outcrop northeast of Lake Hazen (Pl. XVII). These coaly beds, up to about 2 feet thick, are interbedded with weakly lithified grey shaly sand, white sand, and light brown sand or sandstone. About a dozen shaly coal seams 2 to 6 inches thick and interbedded with crossbedded sand are exposed in a bank on Turnabout River (*see* Pl. XVIII).

A coarse white sand bed exposed near the base of the Cenozoic rocks possesses some interesting characters: the grains are about 1 mm in diameter and the sand comprises a few grey chert fragments, about 50 per cent or more frosted quartz grains, and about 50 per cent clear quartz grains with both conchoidal and crystal surfaces. Many of the crystals are doubly terminated in hexagonal dipyramidal form. The more acute edges are slightly rounded, but the crystals otherwise appear fresh.

A thin section of a grey-brown sandstone with carbonaceous partings showed that this rock is a calcareous immature sandstone. The detrital minerals, besides quartz, include potash feldspar, magnetite, biotite, and assorted dark minerals. The composition is that of a feldspathic sandstone, very nearly a greywacke.

Basalt-pebble conglomerate forms caps on a few hills east of the main area of Cenozoic beds, and is tentatively included with them, although no similar conglomerate is known to the west. The caps are remnants of a bed that was at least 100 feet thick. The conglomerate weathers dark brown and comprises well-rounded pebbles of fine-grained basalt in a matrix of medium-grained, impure sandstone. The pebbles are up to 6 inches in diameter.

Structure

The Cenozoic beds are flat lying or gently dipping, with only occasional dips as steep as 30 degrees. The structure seems to be one of open and irregular undulations.

R.L.C., 20-2-57

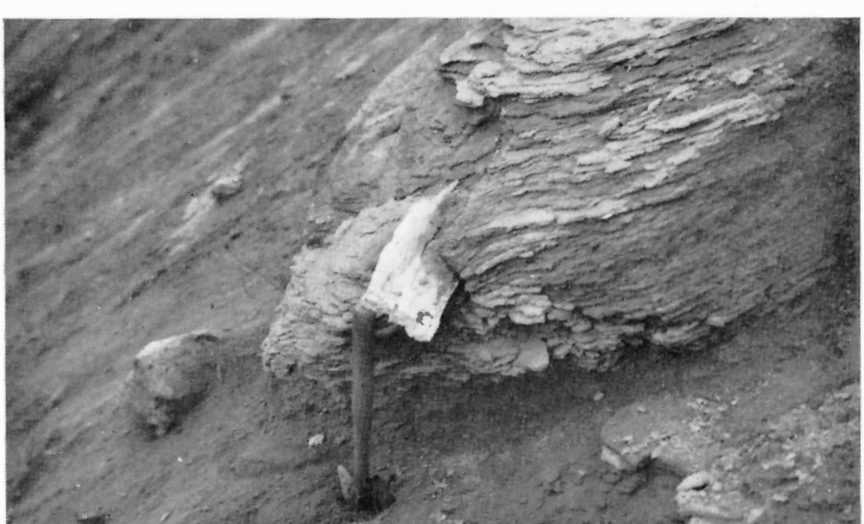
PLATE XV

Complexly folded Cenozoic coal and shale exposed in a bank of Gilman River, near Lake Hazen. The coal seams are up to 18 inches thick.

R.L.C., 19-6-57

PLATE XVI

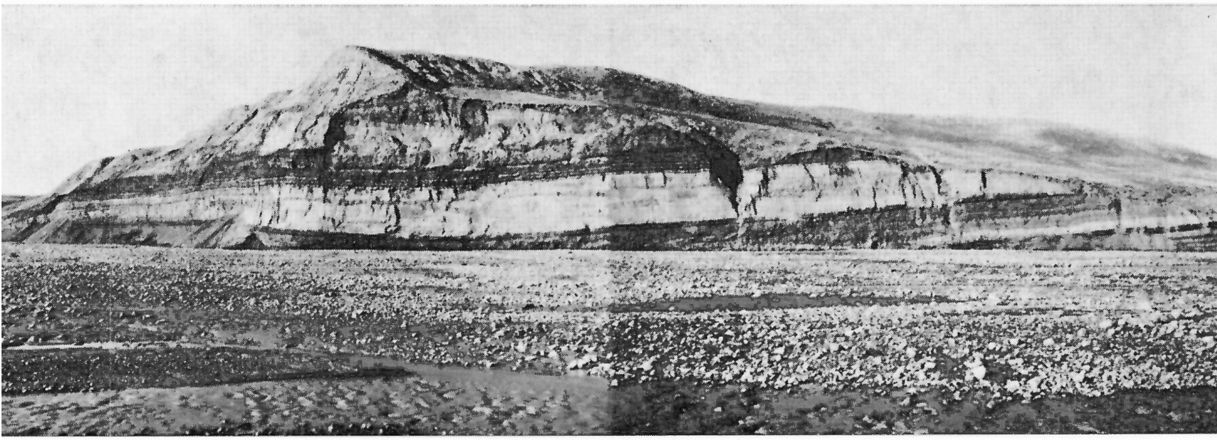
The coal seam near the mouth of Cuesta Creek. Note the blocky nature of the coal and the variable bedding in the sands. These beds are probably of Cenozoic age. (August, 1957.)



R.L.C., 18-7-57

PLATE XVII

Petrified wood fragment in Cenozoic sand northeast of Lake Hazen.



R.L.C., 21-5-58

PLATE XVIII. A section of Cenozoic beds about 100 feet high on upper Turnabout River. The black beds are coal and coaly shale, 1 foot to 3 feet thick. The grey beds are interbedded sandy shale and shaly sand. Note that the thick grey-white sand bed becomes shaly upstream (to the left). (July, 1958.)

Extreme folding in the soft rocks was observed only in the coal measures along Gilman River (Pl. XV), and appears to be restricted to this narrow zone for within a mile or so to the east or west the strata dip moderately or are flat lying. The tightest and most spectacular folds in Gilman River are of chevron type, and exhibit much rupturing and slipping along bedding planes. Some folds have ruptured at the crests to form axial plane faults.

The reasons for the severity and limited area of folding are not readily apparent. Movement in a thinly covered, more competent basement-rock might be proposed to explain the folding but no such fault-structures were seen in the Cape Rawson Group nearby.

The thickness of Cenozoic beds is unknown, but at least 500 feet is exposed locally.

The Cenozoic beds obviously overlie the folded Cape Rawson beds with great angular unconformity.

The contact relations between the Cenozoic and Mesozoic formations were not observed, but it seems probable, from the following evidence, that the Cenozoic strata overlie the older beds with angular unconformity: (a) Cenozoic beds are mostly less severely and more irregularly folded than are the Mesozoic; (b) the Cenozoic beds underlie relatively low land near the mouth of Gilman River, whereas Mesozoic beds, dipping away from the Cenozoic, form higher hills to the northwest; (c) the distribution of Cenozoic rocks does not appear to conform in any way with the structure of the Mesozoic and Permo-Carboniferous rocks; (d) basalt dykes and sills are known in the Jura-Cretaceous and older beds, but have not been found in known Cenozoic beds.

Nearly flat Cenozoic beds resting with angular unconformity upon open folded and truncated Mesozoic beds contrast with relationships of the Eureka Sound Group to the southwest. There, according to Thorsteinsson and Tozer (1957,

p. 23), that group overlies Mesozoic rocks with apparent conformity. An unconformity to the east was anticipated by Thorsteinsson and Tozer, however, who deduced the presence there of a "gentle angular discordance" between the upper Palaeozoic-Mesozoic section and the Cenozoic Eureka Sound Group.

Age and Correlation

A specimen of coal from a shoreline exposure 1.2 miles west of Gilman River (GSC 5239) was examined by D. C. McGregor of the Geological Survey of Canada, and the following microfossils were identified:

(37) Coniferous pollen:
Abietineaepollenites
Pinus haploxylon-typus Rudolph
P. diploxylon-typus Rudolph
Angiosperm pollen is abundant; types recognized resemble:
Alnus, Carya, Pterocarya, Castanea
Other pored and colpate angiosperms of unknown affinity also observed
Other microfossils:
Helicosporium sp. Pot. & Ven.
Phragmothyrites cf. *eocaenicus* Edw.
Septonema? sp. (Potonie, 1934)
Numerous branched septate fungal hyphae
Other fungal remains

McGregor remarks:

> The most probable age is in the range Paleocene to Oligocene. On comparison with present-day angiosperms, the pollens in this assemblage point to a temperate climate, similar to that in southern Ontario today.

A coniferous cone from locality 38 (GSC 3773) at the eastern extremity of the present area of soft beds was assigned by W. L. Fry (*in* Blackadar, 1954, p. 19) to either *Picea* sp. or *Larix* sp., and suggested to be not older than Miocene and possibly more recent. The extent of these beds (15C) is not known.

The Cenozoic beds of Lake Hazen are similar to those of the Eureka Sound Group, which underlies parts of Axel Heiberg and western Ellesmere Islands (Schei, 1903; Troelsen, 1950, p. 78; Thorsteinsson and Tozer, 1957, p. 16). The nearest exposures of this group are on Fosheim Peninsula, about 200 miles southwest of Lake Hazen. There, non-marine sand beds with coal seams have yielded fossil plants that were considered by Fry (*in* Thorsteinsson and Tozer, 1957, p. 17) to be probably Paleocene or Eocene.

Cenozoic (?) Beds of the United States Range

Airphotos reveal a belt of severely folded strata extending in an arc easterly from the region of M'Clintock Glacier and lying between areas of unfolded or little folded Permo-Carboniferous strata to the north and south. This fold-belt appears to be continuous with the fold-structures in the Permo-Carboniferous rocks of Clements Markham Inlet. Although otherwise unexplored, the M'Clintock Glacier region was visited in 1961 by G. Hattersley-Smith, who made geological notes and collections that later were generously submitted to the Geological Survey. The exposures visited by Hattersley-Smith comprise soft-weathering beds that include limestone-pebble conglomerate and a wood-bearing silt bed 18 inches thick.

The conglomerate from which the collection was obtained consists of fossiliferous limestone pebbles (including abraded, but intact, whole fossils) and boulders up to about 6 inches in diameter. A few boulders are fossiliferous fragmental limestone. Harker has identified the fossils as follows: GSC 48359

(39) *Dictyoclostus* cf. *D. neoinflatus* Licharew
Stenoscisma sp. (aff. *S. Kochi* Dunbar)

and tentatively refers them to beds probably correlative with the Assistance Formation (Permian) of Grinnell Peninsula, Devon Island. A provenant terrane comprising such Permian rocks could, of course, be expected in Tertiary times in the United States Range.

The silt, which contains fragments of slightly fossilized wood, was analyzed for spores by G. E. Rouse of the University of British Columbia, who identified the following plant microfossils: GSC 5851

Selaginella selaginoides (L.) Link
Betula sp.
Pinus sp. (including spruce and pine type)
Larix sp.
Alnus sp.
Sphagnum sp.
Selaginella is reported to be extremely abundant.

Lack of palynological control in the relatively unexplored region of Ellesmere Island renders a precise dating of the florule difficult. However, the following comments by J. Terasmae, Geological Survey of Canada, are relevant and help in estimating the age of the beds:

> *Selaginella* is not reported to be present in the recent vegetation of the region, and pollen of Pinaceae in the silt does not match that of modern species of pine and spruce. Birch and alder, also, are now absent in the region. On the other hand, pollen of herbaceous plants such as grass and sedge are normally present in post-glacial deposits, but are absent in the silt.
>
> Two possible ages may be suggested for the silt beds: (a) an interglacial stage of the Pleistocene, assuming that *S.* was growing nearby and that pollen of other species was derived from nearby Tertiary beds; (b) Tertiary, in which case all the plants supplying pollen grew in the region. (b) Is considered the more likely alternative.

The above data and interpretations support the contention by Thorsteinsson and Tozer (1957, p. 26; 1960, p. 14) that the mountains of Grant Land were affected by a Tertiary orogeny, and that the Tertiary structures follow earlier

('Mid-Palaeozoic') structural trends[1]. The deformed probably Tertiary beds of M'Clintock Glacier may be both correlative with, and structural equivalents of, the presumed Tertiary beds of Alert Point, about 100 miles to the west (*see* Christie, 1957, p. 22).

Cretaceous or Tertiary Beds of Judge Daly Promontory

Weakly consolidated sandstone and shale beds (14) underlie a small area straddling Daly River and a larger area near Cape Baird on Judge Daly Promontory. Other small areas of similar formations, preserved by down-faulting, probably remain to be discovered.

Beds Exposed on Daly River (14A)

Sandstone and shale beds underlie a triangular depression through which passes Daly River. The slightly lithified beds are poorly exposed, and lithological and structural data are, therefore, incomplete.

Lithology and Age

Dark greenish grey shale, dark brown sandstone, and grey-brown sandy limestone were observed. A specimen (40) (GSC 5417) of sandy limestone with carbonaceous partings was examined by D. C. McGregor of the Geological Survey of Canada, who reported that it yielded a few spores and pollen grains that indicate a post-Aptian (late Lower Cretaceous) age.

External Structural Relations

The sandstone and shale beds of Daly River are bounded on two sides by prominent lineaments that are almost certainly faults because:

(a) The soft weathering, presumably young beds are juxtaposed against probably early Palaeozoic strata.

(b) One of the lineaments is marked by occasional bright red patches due to a coating of hematite, which may be due to movement of mineralizing solutions along a break.

To the south of the soft beds lie gently dipping beds of dark green-grey impure (feldspathic, arenaceous) limestone. The relationship between the two groups of rocks is not known, but the undistorted nature and proximity of the limestones suggest that they pass upward stratigraphically into the sandstones and shales, perhaps conformably, or with only slight angular discordance. It is

[1] The possibility that the United States Range ('United States Mountains'—perhaps signifying the mountain belt as a whole) might have been affected by a younger orogeny was suggested by Troelsen (1950, p. 32), although his 'younger deformation' was referred to the Jurassic, Cretaceous, or possibly Cenozoic, or at any rate, pre-Eureka Sound (Schei's 'Miocene') beds. The simultaneous folding of Tertiary, Mesozoic, and Palaeozoic beds was recognized later by Thorsteinsson and Tozer (1957) from exposures on the west side of Ellesmere Island. The 'intensely disturbed sediments' of the United States Range observed by W. Elmer Ekblaw (*in* Troelsen, 1950, p. 32) probably were steep-dipping Cape Rawson beds at the head of Tanquary Fiord rather than folded Permo-Carboniferous or younger beds.

interesting to observe, moreover, that the weakly consolidated beds of Pavy River (Brainard's beds) appear, in airphotos, to pass conformably into more competent beds to the southwest.

Brainard's "Petrified Forest" Beds (14B)

Impure sandstone and weak shale beds with petrified trees underlie a narrow, downfaulted belt on Judge Daly Promontory. Sergeant D. L. Brainard of Greely's expedition discovered the fossil trees about 3 miles west of Cape Baird, and a report by Brainard on the "Petrified Forest", is appended to Greely's account (Greely, 1886, II, appendix).

Lithology

The sandstone is dark greenish brown, medium to coarse grained, and is cemented by a clayey greenish matrix. The shale is green-brown and crumbling. A few conglomerate beds are present; the pebbles of which are rounded and generally about 2 to 4 inches in size. A few coarse, rounded blocks 12 to 18 inches in diameter also are present. The pebbles and cobbles are almost entirely fine, grey and brown limestone and black chert.

The petrified wood is embedded as fragments or slabs in medium-coarse, dark greenish brown, crossbedded sandstone with some shale. As noted by Brainard, the trees apparently were about 10 inches in diameter.

Structure

The beds lie horizontally or dip at low angles; minor folds and contortions probably are related to the faults that bound the formation on two sides. The base of the formation may lie to the southwest, where soft weathering rocks appear to overlie carbonate-rocks.

Age and Correlation

Brainard's beds are similar in lithology and structural position to those of Daly River, where a late Lower Cretaceous or Tertiary age is indicated. No direct dating has, however, been obtained.

Paleocene or Eocene Beds of the Southeast Part of the Hazen Plateau

Small areas in the lower parts of certain valleys along the southeast edge of the Hazen Plateau are underlain by poorly consolidated sand and shale beds with coal and plant remains, all of which are tentatively correlated and mapped as unit 15B. (Map-units 15A and 15C were described in an earlier section.) An inland depression joining Lincoln and Wrangel Bays also appears, in airphotos, to be underlain by weakly lithified beds similar to those of Watercourse Valley, a contention supported by Greely's (1886, I, p. 99) mention of fragments of coal similar to that of Watercourse Valley at Lincoln Bay.

Finally, beds similar to those of Watercourse Valley may lie near the head of Discovery Harbour, where relatively coarse coal debris occurs as fragmental beds and scattered fragments in the gravels. It seems more probable, however, that the debris is derived from coal exposed at Lake Hazen and was carried to its present position by glacial meltwater.

Beds Exposed in Watercourse Valley

The coal seam in Watercourse Valley was discovered by members of the Nares expedition, and a small tonnage was mined and used. Subsequent parties also have burned some of the coal.

Lithology

The beds in Watercourse Valley are weakly lithified brown to grey sandstone, sandy shale, and shale. Beds are moderately distinct, and from 6 inches to 3 feet thick. Carbonaceous markings are numerous and thin coaly partings exhibit leaf imprints.

The coal seam, the base of which is not exposed, is at least 20 feet thick. The coal is brittle, fractured, and well banded. The seam is nearly free of sand layers which aggregate only about 10 inches in thickness.

About 300 feet of shale and shaly sandstone containing abundant carbonaceous plant remains overlies at least 40 feet of coarse presumably basal breccia in the small valley east of Watercourse Valley, but no coal seam has been found. The breccia consists of angular fragments of green-grey greywacke in a maroon and green matrix. The fragments and matrix are obviously derived from the Cape Rawson beds.

Structure

The two small patches of weak beds lie in depressions eroded into the surface of the Cape Rawson Group. There is no evidence of later faulting, and apparently the beds were deposited on a surface that at least approximately corresponds to the present one.

The strata in Watercourse Valley are bowed into a broad anticline with dips less than 5 degrees. The coal seam is the lowest bed exposed.

Age and Correlation

Plant remains obtained during a brief visit to Watercourse Valley in 1958 have been examined by D. C. McGregor of the Geological Survey of Canada, who reports the following: GSC 5231

(41) *Corylus* sp. cf. *C. macquarrii* (Forbes) Heer, *in* Heer, 1878, Pl. VI, figs. 5, 6

Feildenia rigida Herr

cf. *Arundo goeppertii* (Münst.) Heer

cf. *Phragmites oeningensis* Alex. Br.

Several impressions of coniferous shoots; one fragment is fairly well preserved and is probably *Metasequoia occidentalis* (Newberry) Chaney (=*Taxodium distichum miocenicum* (Heer)).

Several fragments have basal venation similar to *Corylus*, but are too fragmentary for precise identification.

Collections from this locality were obtained by Captain Feilden, naturalist, and Mr. Moss, surgeon, of the Nares expedition. Thirty species were identified by Professor O. Heer (1878), who assigned a Miocene age to the beds. McGregor refers to Heer, but comments that the age is now regarded as Paleocene or possibly Eocene.

From the fossils present, it is apparent that the beds of Watercourse Valley may be correlated with the larger deposits of shale, sandstone, and coal of Lake Hazen. Although the beds may not have been continuous, it is probable that early Cenozoic deposits, represented by the existing remnants, covered a much larger area in the past. The weakly lithified beds would easily be removed by stream and glacial erosion.

Intrusive Rocks

Intrusive rocks of granitic aspect are known, in northeast Ellesmere Island, only in the metamorphic terrane herein called the Cape Columbia Group. Dioritic or basaltic dyke and sill rocks, on the other hand, are widespread, and are found in all but the youngest, Cenozoic formations. Intrusive rocks of all types form but a very small proportion of the bedrock.

Intrusive Rocks of Granitic Aspect (B)

This group comprises gneissic brown syenite on Ward Hunt Island (Christie, 1957), and the intrusive rocks of Cape Columbia (Blackadar, 1954).

The syenite of Ward Hunt Island is a medium- to coarse-grained, microcline-rich rock, in part gneissose. Quartz is present in minor amounts. The rock appears in thin section to possess a crush-texture, which, with the patches of biotite or other mafic minerals, contributes to the foliated structure. Contacts between the syenite and the enclosing metamorphic rocks of the Cape Columbia Group were not observed, and an intrusive relationship is presumed from the commonly massive, equigranular character of the syenite. Lyons and Leavitt (1961, p. 3), in their geological map of Ward Hunt Island[1] and vicinity, show a somewhat interfingering distribution of syenite and metamorphic rock. This structure may be taken to suggest either a *lit-par-lit* replacement or a complex sill-like injection, or perhaps, assuming several periods of tectonic activity, a combination of intrusion, replacement, and flowage.

As described by Blackadar (1954, p. 9), granitic and pegmatitic dyke-rocks are included in the Cape Columbia Group between Cape Aldrich and Markham Bay. The granitic dykes, mostly less than 10 feet wide, are medium grained and contain less than 5 per cent biotite. The pegmatites are variously coarse, quartz-pink feldspar rocks and white-feldspar rocks with minor muscovite and garnet.

The age or ages of the leucocratic intrusions are not known precisely, but at least some are early Ordovician or pre-Ordovician because of the presence of

[1] The distribution of syenite on the map accompanying the present report is taken from Lyons and Leavitt.

granitic detritus in the Middle and Upper Ordovician Challenger Group. The most recent metamorphism of the Cape Columbia Group may have been due to, or contemporaneous with, a period of granitic intrusion. The potassium-argon age of 545 million years for a specimen of Cape Columbia rock (Blackadar, 1960) may be considered provisionally as the age of some of the intrusions.

Granitic rocks are widespread and abundant on the north coast west of the present map-area (Christie, 1957), and are exposed on northernmost Axel Heiberg Island (Trettin, pers. com.). A potassium-argon age of 360 million years has been obtained for a small pluton intruding Silurian beds of Axel Heiberg Island, and a tentative, though somewhat speculative, extrapolation may be suggested. It is not certain whether the determination dates the age of emplacement or a later period of metamorphism (Kerr and Trettin, 1962), but it may represent the former, and the pluton is possibly representative of at least some other intrusive rocks of the eugeosynclinal belt.

Dykes and Sills (A)

Dykes and sills of dioritic, diabasic, and basaltic rock occur in fair abundance throughout the area. Sills and dykes between Alert and Cape Columbia were described in some detail by Blackadar (1954) but were not mapped. West of Cape Columbia, they were described briefly by Christie (1957) but were not mapped. Many of the dykes and sills noted during field work in the Lake Hazen region, however, are shown on the accompanying map. This difference in mapping should be kept in mind in assessing the distribution of these bodies.

Blackadar (1954) found sills and dykes of dark green intrusive rocks, some diabasic, to cut the Mount Disraeli, Cape Rawson, View Creek, and Feilden Groups. Only one dyke, a porphyry lying halfway between Good Point and Cape Colan, was observed in the Mount Disraeli Group. Sills of diabase containing inclusions of black slate lie in the Cape Rawson beds northwest of Knot Bay. Diabasic intrusive bodies were found in the View Creek Group, and sills of diabase in the Feilden Group.

Sills and dykes of andesitic, dacitic, diabasic, and gabbroic rock occur in the M'Clintock Group of volcanic and sedimentary rocks. The amount of intrusive rock present is difficult to assess, however, because much of it is of a grain size and texture similar to that of the extrusive, country rock. Most dykes are small—that is, a few feet or a few tens of feet across—but some are 100 or 200 feet wide, coarse grained, and gabbroic.

Dykes and sills of basic aspect are widespread in the Lake Hazen region, and are unusually conspicuous because of the contrast in colour and resistance to erosion between the intrusive rocks and the enclosing, crumbling sedimentary rocks. Thick sills and large dykes stand out as resistant knolls, ridges, mesas, and cuestas. The intrusive rocks include fine- to medium-grained, dark blue-grey, green-grey, or grey basalt and diabase. These dark rocks generally weather brown.

The exceptional abundance and size of basaltic and diabasic intrusions northeast of Lake Hazen may be more apparent than real, as noted above, but further mapping may indeed show that the basin-structure at Lake Hazen was a locus of igneous activity. It would be reasonable to suppose, in this case, that access to a source of basaltic magma was provided by the Lake Hazen fault zone.

A prominent sill northeast of Johns Island is at least 30 feet thick, and columnar sills and dykes several hundreds of feet thick are evident in the sandstone terrane about 20 miles north of the east end of Lake Hazen. Both sills and dykes vary in thickness, and can be seen to thin and terminate in a few hundreds or thousands of feet. Dykes are continuous with sills 1 foot or 2 feet thick that intrude short distances between sandstone beds on Gilman River. The borders of a dyke that measures at least 300 feet along Gilman River are characterized by small, irregular apophyses that intrude the Cape Rawson beds. Light weathering beds about 15 miles up the Henrietta Nesmith Glacier are slashed by steeply dipping, black dykes that appear to be several hundred feet thick.

The possibility that at least some of the basaltic or diabasic rocks near Lake Hazen are flows must be considered, but seems unlikely for the following reasons: (a) associated phenomena such as beds of breccia or basalt with vesicular structure apparently are lacking; (b) the igneous bodies are scattered indiscriminately throughout the formations of Mesozoic or older age; (c) the thicknesses of the larger bodies are much greater than would be expected for basaltic flows, and there is a general similarity in structure and texture among all the bodies; (d) small and large sills integral with dykes are observable.

The dyke rocks in the Lake Hazen region are typically basaltic or diabasic in texture with lath-shaped plagioclase crystals and interstitial, granulose clinopyroxene. Subophitic textures are present where the pyroxene has formed larger grains. The rocks are mostly about 30 to 60 per cent plagioclase and 30 to 50 per cent pyroxene. Brown biotite is commonly present in small amounts (less than 10 per cent), and the oxide magnetite (and ilmenite?) is everywhere present in appreciable amounts (approaching 10 per cent). The plagioclase, which is in places more or less sericitized, seems generally to be about the composition of andesine-labradorite (about An_{50}). Much of the pyroxene is more or less altered to amphibole and the biotite and amphibole to chlorite.

Blackadar (1954) described, from thin section study, several specimens of dyke and sill rock from the region between Alert and Cape Columbia. In these he found phenocrysts of plagioclase and clinopyroxene in a groundmass generally of white mica, biotite and uralite, and in one case chlorite. Accessory minerals include titaniferous magnetite, pyrite, leucoxene, and red iron oxide, the metallic minerals in places with a texture suggesting late formation. The clinopyroxene and plagioclase of the groundmass is altered in large part, or completely, to micas and uralite, while phenocrysts of plagioclase and clinopyroxene are variously altered or nearly fresh. Plagioclase with compositions of An_{48}, An_{55}, and An_{57} were determined.

Some of the diabasic sills and dykes intrude beds tentatively dated as of uppermost Jurassic or Lower Cretaceous age but none was found in beds of probably Paleocene to Oligocene age, or in younger beds.

It seems improbable that all the hypabyssal intrusions were contemporaneous. Some intrusions in older formations, such as the Cape Rawson Group, may have been emplaced in an earlier magmatic period. The relatively altered state of some intrusive rocks in older formations suggests a wide range of ages, but at present no data prove this possibility.

Intrusive activity of a relatively recent age is known to centre around Eureka Sound (Troelsen, 1950, p. 80), where Permian and Mesozoic rocks are intruded by gabbroic or diabasic ('quartz-dolerite, dolerite') sills. The sills are thickest and most abundant in the Triassic beds (Thorsteinsson and Tozer, 1957, p. 20). Troelsen observed no sills in the Cretaceous and/or Cenozoic Eureka Sound Group.

Chapter III

STRUCTURAL GEOLOGY

Folds

All the sedimentary formations of northeastern Ellesmere Island are deformed to a greater or lesser degree. Fold axes generally trend east or northeast.

The dominant structural feature is the very uniform and persistent northeast trend of the Cape Rawson beds, which underlie the Hazen Plateau and adjacent terrain. The upturned beds change direction in a broad sweep southwest of Lake Hazen to trend easterly where they disappear beneath the overlying Permo-Carboniferous limestones. The Cape Rawson Group is thrown into large and small folds of chevron and isoclinal form. The axial planes of the folds dip steeply to moderately northwest.

Bedding in the Archer Fiord Terrane likewise is tightly folded, and the trends conform to those of the Cape Rawson Group. The scale, or size, of folds south of Archer Fiord is perhaps larger than that general in the Cape Rawson Group. Particularly striking folds are evident in airphotos of the southwestern part of Judge Daly Promontory.

Certain areas of flat-lying strata and others of folded strata with discordant trends (described earlier in this report as the Daly River Terrane) occur on Judge Daly Promontory. Trends vary but are predominantly easterly, in contrast with the uniformly northeast direction of the adjacent Archer Fiord Terrane. The origin of this anomalous trend is not known. The possibility of the Daly River Terrane being a thrust sheet, mentioned earlier, might be considered for the following reasons: (a) Well-developed folds in the Archer Fiord Terrane, which may comprise or include beds of Silurian age as does the similar Cape Rawson Group, appear to be truncated or overlain by structures or beds of the Daly River Terrane; if so, then younger (Silurian) beds are overlain by older (Ordovician), and transport or inversion of beds has occurred. (b) The marked contrast in the structure and lithology of the two 'terranes' can reasonably be explained by the tectonic juxtaposition of formations of two different sedimentary and tectonic environments; in this case formations of shelf-like character (Daly River Terrane) appear to be juxtaposed against formations of miogeosynclinal character (Archer Fiord Terrane), the former presumably having moved northwestward relative to the latter.

Trends of folding on the north coast of Ellesmere Island are predominantly eastward, but many variations also occur. The Cape Columbia gneisses trend roughly east to southeast, and these trends are followed by the Ordovician and associated, presumed early Palaeozoic, formations. An area of southeast and south trends lies west of M'Clintock Inlet.

The trend, evident in airphotos, of beds west of Clements Markham Inlet is predominantly eastward. East of the inlet, however, trends are northeast, and faulting along Clements Markham Inlet was suggested by Blackadar to explain this and other phenomena (*see below*).

Trends in northeasternmost Ellesmere Island diverge somewhat; Cape Rawson beds trend slightly north of east south of Porter Bay, whereas strata of the Sail Harbour Group between Porter Bay and Clements Markham Inlet trend northeasterly.

Beds of the Sail Harbour Group are overturned along the east shore of Clements Markham Inlet, with axial planes of the folds dipping northwest (Blackadar, 1954, p. 20). In describing these structures Blackadar suggested the likelihood of thrust faulting, which may also account for the site of Clements Markham Inlet and, as described above, the contrast in trends on either side of the inlet.

The degree of folding of the Permo-Carboniferous beds varies from nearly unfolded to moderate. Flat-lying strata overlie Cape Rawson beds along Greely Fiord, and overlie gneisses of the Cape Columbia Group on M'Clintock Inlet. Limited areas of horizontal bedding are also evident in parts of the United States Range. A belt of moderate to steeply dipping strata in the northern part of the United States Range swings northeasterly to the head of Clements Markham Inlet, where steeply dipping beds contain Permo-Carboniferous fossils. This belt and Clements Markham Inlet may be the main locus of the tectonic disturbance in which the Permo-Carboniferous and perhaps younger rocks were folded. The steep-dipping beds southwest of Clements Markham Inlet may also be in part an older, Pre-Carboniferous formation.

Open folding in the Permo-Carboniferous to Jura-Cretaceous sedimentary rocks north of Lake Hazen conforms with the northeast regional trend. The Cenozoic beds, however, are only gently undulating, except for the anomalous and spectacular fold structures of Gilman River, described earlier.

The Cenozoic and presumed Cenozoic beds of Judge Daly Promontory and the southeast edge of the Hazen Plateau are gently dipping to flat lying.

Faults

Several important faults, including the Lake Hazen fault, are known or inferred from the juxtaposition of rocks of different ages or from their expression as strong lineaments.

The Lake Hazen fault zone separates the soft rocks north of Lake Hazen from the Cape Rawson Group in the foothills of the United States Range, and can be traced for about 60 miles from the west end of Lake Hazen northeast along the mountain front. The zone is easily identified by scarps and troughs, and is well exposed where major streams cross it. The fault zone, 40 to 150 feet wide, comprises gouge, shattered rock, and mixed material derived from

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both walls. It is evident from the stratigraphic displacement of the Permo-Carboniferous beds that the south side of the fault moved down. The vertical component of movement must be considerable, and presumably is at least equal to the local relief of about 3,000 feet because the older rocks now stand as mountains above lowlands of the younger rocks. Taking into account the thickness of the Permo-Carboniferous to Jura-Cretaceous beds at Lake Hazen and ignoring the upturned and presumably dragged beds adjacent to the fault, the displacement of the erosion surface beneath the basal beds is estimated to be about 6,000 feet.

Presumed late Palaeozoic beds lie on both sides of the fault zone to the northeast, and the amount of vertical displacement, though still considerable, is apparently less. Movement on the fault may have taken place repeatedly and during periods of earth stress widely separated in time and differing in intensity and direction of stress. If so, then the net movement could be expected to vary at different places along the fault.

The Permo-Carboniferous and Mesozoic beds are of uniform character and are apparently conformable, which suggest that little or no movement took place along the Lake Hazen fault zone during their deposition. Significant movement presumably post-dates the deposition and consolidation of the Jura-Cretaceous beds. Basaltic sills near the fault zone are dislocated, and similar sills intrude beds as young as uppermost Jurassic or Lower Cretaceous, suggesting at least some movement of this or more recent age. Latest movement along the Lake Hazen fault zone may be correlated, tentatively, with the Cenozoic period of folding and faulting that Thorsteinsson and Tozer (1957) have shown to have affected western and northern Ellesmere Island.

Several prominent faults on Judge Daly Promontory are evident from the juxtaposition of rocks of different ages and from their expression as strong lineaments. One of these, trending north-northeast from the vicinity of Cape De Fosse and followed by Pavy River, displaces probable Cretaceous or Cenozoic beds. This fault is represented by an unusually well developed, straight lineament that suggests a major component of transcurrent movement. A long, arc-shaped lineament trending north from Carl Ritter Bay and followed by the upper parts of both Daly and Pavy Rivers probably marks a fault. Evidence suggesting thrust faulting was mentioned earlier.

Two long scarps, presumed to be faults, at least one of which apparently juxtaposes Permo-Carboniferous against Cape Rawson beds, are evident in the region west of Porter Bay. Strong lineaments are also evident in airphotos of the unexplored region south of Markham Bay. Another lineament is formed where mountains drop abruptly to a coastal lowland between the mouths of Disraeli Fiord and M'Clintock Inlet, and the presence of a Permo-Carboniferous outlier on the lowland side suggests block faulting, with the north side down-thrown.

A fault west of Tanquary Fiord is deduced from airphotos to separate presumed Permo-Carboniferous and younger beds on the south from beds probably of the Cape Rawson Group on the north.

Regional Structural Provinces and Tectonic History

The structure and history of the Canadian Arctic Archipelago was summarized by Thorsteinsson and Tozer (1960) and earlier by Fortier, McNair, and Thorsteinsson (1954). The belt of highly folded Palaeozoic, and slightly folded Palaeozoic and younger rocks, extending from north Greenland across the Queen Elizabeth Islands to the Beaufort Sea, was named the Innuitian Orogenic System by Fortier, McNair, and Thorsteinsson (1954, p. 2087), and the system was subdivided into various fold belts. Thorsteinsson and Tozer (1960, p. 3) used Schuchert's 1923 term, the Franklinian geosyncline, for the belt of tightly folded early and middle Palaeozoic rocks that has been the locus of Palaeozoic (Caledonian, Variscan) orogeny, and referred to the body of younger, folded and non-folded beds of late Palaeozoic, Mesozoic, and Cenozoic age as the Sverdrup Basin. The rocks of the Sverdrup Basin overlie and largely conceal the structures of the earlier Franklinian geosyncline.

The orogenic system in northern Ellesmere Island comprises three tectonic provinces: a coastal belt of metamorphic rocks, the Franklinian geosyncline of tightly folded early and middle Palaeozoic rocks, and the Sverdrup Basin of late Palaeozoic, Mesozoic, and Cenozoic rocks. The Franklinian geosyncline in northern Ellesmere Island may be further divided into a eugeosyncline to the northwest and a miogeosyncline to the southeast.

The gneisses, migmatites, and perhaps some granites of the coastal orogenic region are considered from geological and laboratory evidence to be of pre-Ordovician, probably Precambrian age. Distinct banding and beds of carbonate-rock and quartzite indicate a sedimentary origin for most of the gneisses and schists, which evidently represent an ancient body of sediments that has been metamorphosed and incorporated into the continental structure. Assuming a Precambrian age, the rocks are, as suggested by Thorsteinsson and Tozer, the basement of the Franklinian geosyncline.

A change from near-shelf or miogeosynclinal character in the southeast to eugeosynclinal in the northwest in the Franklinian geosyncline is evident from a brief description of the formations: Ordovician carbonate rocks, calcareous sandstones, and quartzites of the Daly River Terrane give way northward to the Archer Fiord Terrane, in which limy argillite, slate, and micaceous feldspathic quartzite are conspicuous; the (Silurian?) Cape Rawson beds, to the north again, comprise mainly dark greywacke, subgreywacke, micaceous gritty slate, and impure limestone; and finally volcanic flows, breccias, tuffs, and related sedimentary rocks of the M'Clintock Group, thought to be Ordovician or older, are exposed on the north side of the United States Range. The boundary between the eugeosyncline and the miogeosyncline (the edge of the volcanic deposits, following the criterion of Stille, as does Kay, 1951, pp. 4, 11) is obscured by superposed Permo-Carboniferous beds.

Both Ordovician and Silurian beds are tightly folded, and are unconformably overlain by much less folded Pennsylvanian (and almost certainly Mississippian) and younger rocks on northern Ellesmere Island. More precise data on the age of the unconformity and the date of the mid-Palaeozoic orogeny that deformed the Franklinian geosyncline have recently been obtained from northernmost Axel Heiberg Island by Kerr and Trettin (1962). Plants and spores from the lowest beds of the Sverdrup Basin have been assigned to the Mississippian, and the youngest fossils obtained in the underlying eugeosynclinal strata are considered probably early Devonian in age[1]. Kerr and Trettin (*op. cit.*) consider that the evidence strongly indicates a post-Late Devonian (Frasnian or later) age for the folding of the Franklinian geosyncline. Two periods of tectonic activity, one Caledonian and one Variscan, have been detected elsewhere in the Archipelago, and Thorsteinsson and Tozer (1960, pp. 8, 11) offered stratigraphic evidence of tectonic activity in the northern part of the geosyncline starting in Middle Devonian time.

The Pennsylvanian and Permian beds of the United States Range are an eastern extension of the Sverdrup Basin of Thorsteinsson and Tozer (1960, p. 11). The Sverdrup Basin is thought to contain, in its axial parts, a conformable sequence of sediments ranging in age from Mississippian to early Cenozoic, and is known, everywhere, to rest with profound angular unconformity upon the folded geosynclinal rocks. The younger beds may not be widely exposed on northern Ellesmere Island, where post-Palaeozoic beds attributable to the Sverdrup Basin have been found only in the down-faulted Lake Hazen region, and a break in sedimentation appears probable on Feilden Peninsula, where Blackadar (1954) found evidence of angular discordance between Pennsylvanian and Permian beds.

The moderate to gently folded eastern part of the Sverdrup Basin was described by Fortier, McNair, and Thorsteinsson (1954, p. 2094) as the Eureka Sound Fold Belt, and the folding was dated as post-Lower Cretaceous-pre-late Cretaceous or Cenozoic. Recent work by Thorsteinsson and Tozer (1957) has shown that the late Palaeozoic, Mesozoic, and early Cenozoic (Eureka Sound) beds were folded and faulted together, that the Cenozoic folding was superimposed upon Palaeozoic structures, and that in certain places Cenozoic movement affected areas that had escaped Palaeozoic tectonism. The trends of Cenozoic folds on Ellesmere Island follow the older, Palaeozoic grain.

The Cenozoic structures mapped by Thorsteinsson and Tozer north of Greely Fiord and Nansen Sound swing northeastward into the United States Range and, as has been suggested by them, it seems certain that the folding in the mountains is of Cenozoic age.

The presence of relatively little-folded but much-faulted Permo-Carboniferous and younger beds on the Hazen Plateau and southward suggests that the Cenozoic

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[1] It was generally known that Middle Pennsylvanian beds rest unconformably upon tightly folded Ordovician and Silurian rocks at Canyon Fiord (Troelsen, 1952), and this is also true at Trold Fiord (Tozer, 1963) to the southwest. Recent work by Thorsteinsson and Kerr (pers. com.) has now revealed that beds as young as early Late Devonian may be present. Furthermore, in southwestern Ellesmere Island, a late Devonian formation was found by D. J. McLaren (1963) to be folded and overlain unconformably by Middle Pennsylvanian beds.

earth movements resulted there in faulting rather than folding, as has already been recognized for the Hazen Plateau by Thorsteinsson and Tozer (1957, p. 26).

Judge Daly Promontory probably was affected by faulting rather than folding during the younger periods of tectonic activity. Reasons for this supposition are:

(a) The degree and type of folding of Palaeozoic formations does not differ markedly from that of the Hazen Plateau, where the folding is known to be of Palaeozoic age.

(b) There is no evidence of the late Palaeozoic or younger depositional trough that might be expected along a mobile folding zone of these ages. On the contrary, the young sedimentary rocks on Judge Daly Promontory are continental in character and probably represent limited basins of deposition.

(c) Faults are conspicuous. The slight deformation evident in the probably Mesozoic or Cenozoic beds may well merely be due to, and associated with, the faults that cut them. On the other hand, Tertiary folding of Palaeozoic, Mesozoic, and Tertiary beds is known in southwest Ellesmere Island, and Thorsteinsson and Tozer (1957, p. 26, and fig. 1) suggest an extension of this fold belt to Judge Daly Promontory, which is perfectly on strike.

Structural Features of Northern Ellesmere Island and the Arctic Ocean Basin

The discovery of the Lomonosov Range, the great sub-oceanic ridge that divides the Arctic Ocean basin, has revived an early hypothesis that orogenic structures of northern Ellesmere Island cross the ocean to join those of the Verkhoyansk Range in Siberia. E. R. Hope (1959) has outlined and discussed recent Soviet hypotheses and has given a brief historical account of the prophecies that preceded the discovery of the Lomonosov Range in 1948.

The earliest suggestion of a geological connection across the Arctic Ocean (noted by Hope) was made in 1909 by E. Süss, who based his proposal on similarities in the geology of Ellesmere Island, the New Siberian Islands, and the Verkhoyansk Range.

Modern Soviet geotectonic theory is based on bathymetric, magnetic, and seismic data and on ocean-bottom samples. The following is an outline of theories that are relevant to northern Ellesmere Island.

V. M. Saks, N. A. Belov, and N. N. Lapina (1955) have suggested that a belt of Mesozoic folding should appear in northern Ellesmere Island. This prediction is based on the presumed extension of folds of the Verkhoyansk Range along the Lomonosov Range, which the Soviet charts show to be continuous with the continental shelf of Ellesmere Island. A bathymetric chart published by

Soviet scientists (USSR, 1954, fig. 8) shows the Lomonosov Range swinging southwestward on its approach to North America, so the predicted fold belt should strike Ellesmere Island in the vicinity of Ward Hunt Island. D. G. Panov (1955) believed that the Lomonosov Range was probably formed by a combination of folding and large-scale faulting, the indication for this being fault-troughs filled with Mesozoic sediments in the New Siberian and Ellesmere Islands. Significant structures of this type are unknown on northern Ellesmere Island, and it is not certain to what Panov referred. The Lake Hazen structure might fit his description, but was unknown until 1957. Ya. Ya. Hakkel' (1958) believed the linear distribution of sites where volcanic glass has been dredged from the ocean floor marks a deep fault that crosses the Arctic Ocean, passes through a strait in Severnaya Zemlia, crosses the Lomonosov Range, and follows the west side of the range towards Ellesmere Island. Soviet geologists are reported by Hakkel' to believe that a deep fracture underlies the island strait, the lower Taimyr River, and Lake Taimyr on the Siberian mainland, all of which features lie on Hakkel's proposed fault.

V. F. Burkhanov (1957) reported tracing sub-oceanic 'mountain ranges' over almost the full distance from Ellesmere Island and Greenland to the Kara Sea and Severnaya Zemlia. These features, he wrote, are taken by Soviet scientists to have developed in the Caledonian and Hercynian epochs of folding.

Some geological evidence for the proposed structural features was obtained on the Asian side of the Arctic Ocean. For example, the folds of the Verkhoyansk Range do, in part, trend into the ocean, and we are assured by Saks, Belov, and Lapina (1955) that the folds can be traced by anomalies in the earth's magnetic field. In contrast, trends in northern Ellesmere Island do not conform to the proposed Mesozoic or Lomonosov fold zone. The evidence for or against Ellesmere structures passing into the proposed Caledonian-Hercynian fold zone reported by Burkhanov is less certain, however.

The trend of structures in northern Ellesmere Island is generally northeast or east along the coast, with no strongly developed structural belt passing north, or seaward, in the indicated vicinity of the Lomonosov Range. Known Mesozoic beds are absent along the north coast, and it is therefore impossible to be certain of the ages of local structures. The Permo-Carboniferous beds, which would record Mesozoic orogeny, trend consistently east.

The presumed late Mesozoic or Cenozoic folds of the United States Range, which pass seaward in the vicinity of Feilden and Parry Peninsulas (east of the Lomonosov Range as it is shown on Soviet charts), may continue into some oceanic structure. A northeast-trending sub-oceanic ridge is shown, for instance, on Soviet charts extending northeast from this vicinity. There is no direct evidence yet available, however, to suggest that continental fold structures follow this topographic feature.

The strongly developed, northeast-trending folds of the Hazen Plateau do indeed disappear seaward. However, their trends are easily accommodated to those of northernmost Greenland, and here again there is no evidence, other than the reported sub-oceanic topography, to suggest that they swing poleward.

No structural feature of northern Ellesmere Island conforms in trend or location to the deep fracture proposed by Hakkel' (1958, chart), although the suggested major fault zone of Clements Markham Inlet appears to be a structure of about the right order of magnitude.

In conclusion, it appears that the Ellesmere-Greenland structures do not, in general, invite correlation with the proposed oceanic tectonic features.

Chapter IV

MINERAL DEPOSITS

The coal seam of Watercourse Valley is the only mineral deposit so far exploited in modern times. The small tonnage available and the lignitic nature of this bed and similar beds at Lake Hazen make these deposits potentially valuable only as fuel for local use.

The coal at both localities is easily accessible, and an initial few tons could be obtained with little difficulty. The enclosing beds are weak, but openings presumably could be maintained by keeping the ground frozen. At least 100 feet of bedded overburden overlies the thick coal seam at both localities.

Specimens of coal have been analyzed by W. J. Montgomery, of the Mines Branch, who reports as follows:

	Lake Hazen 1.4 miles west of Gilman River		Watercourse Valley	
Proximate analysis:	As rec'd	Dry	As rec'd	Dry
Moisture ... %	23.5	0.0	1.8	0.0
Ash ... %	5.5	7.2	5.1	5.1
Volatile matter ... %	38.3	50.0	39.6	40.3
Fixed carbon ... % (by difference)	32.7	42.8	53.5	54.6
Ultimate analysis:				
Sulphur ... %	0.3	0.4	1.3	1.3
Calorific value BTU/lb, gross ...	9,097	11,884	14,030	14,280
Equilibrium moisture (97% relative humidity)	21.65		2.95	
Moist mineral-matter free BTU ...	9933		—	
Rank (ASTM) ...	Subbituminous B		High volatile A Bituminous	

The coal breaks with a platy fracture parallel with the bedding and has a conchoidal fracture in other directions. It is shiny black, becoming dull and decrepitated on weathering or desiccation. The high water content and occasional brownish cast of the coal indicate a general lignitic character.

Amber nodules and finely broken coal are concentrated in bands along the beach at the east end of Lake Hazen. The yellow, red, and brown lumps of amber are up to an inch in diameter, and are conspicuous in the black coal debris. This beach almost certainly is the source of drilled amber beads (*see* Maxwell, 1960, p. 63) found in ancient Eskimo habitations in this region.

Pale yellow amber is abundant as scattered nodules and 'swarms' of nodules in the coal seams near Lake Hazen. The 'swarms', or concentrations of nodules, may be more than 50 per cent amber, and up to 4 inches thick and several feet wide along the bedding plane. The amber is limited to certain horizons, but occurs indiscriminately with either thick or thin coal seams. This is undoubtedly the mineral described by Eskimos to Troelsen, who suggested it might be ozocerite (reported by Fortier, McNair and Thorsteinsson, 1954, p. 2094).

Nodules of pale yellow chalcedony, or ~~celadonite~~ carnelian, were observed scattered on the surface of basalt conglomerate about 35 miles northeast of Lake Hazen. The conglomerate, which is probably of Mesozoic or Tertiary age, occurs as a small, isolated group of remnant caps on hills. The chalcedony is banded, and the surface of the pebbles is parallel with the banding. The pebbles originally may have been cavity fillings in volcanic rock, and now are residual debris on and in the conglomerate.

A gypsum body outcrops on the east shore of M'Clintock Inlet, about 12 miles from the mouth (Christie, 1957, p. 34). The exposure apparently is a lens-shaped bed up to about 400 feet thick and 1,000 feet long. The adjacent rocks are andesitic volcanic flow-rocks and breccias of the M'Clintock group.

Thick beds of anhydrite and gypsum are widely exposed at the head of Clements Markham Inlet. A coarsely crystalline selenite vein cuts the gypsiferous rocks at the sharp bend in Gypsum River. In this, crystal plates generally up to 6 inches wide, and some 12 inches wide, were observed.

BIBLIOGRAPHY

Blackadar, R. G.
1954: Geological Reconnaissance, North Coast of Ellesmere Island, Arctic Archipelago, NWT; *Geol. Surv., Canada,* Paper 53-10.
1960: The Age of the Metamorphic Complex of Northernmost Ellesmere Island; *Arctic,* vol. 13, p. 51.

Bolton, T. E.
1961: Additional Arcticopora from the Triassic of Northwestern Ellesmere Island (Addendum to Fritz, 1961); *Proc. Geol. Assoc., Canada,* vol. 13, pp. 55, 56.

Bostock, H. S.
1948: Physiography of the Canadian Cordillera, with Special Reference to the Area North of the 55th Parallel; *Geol. Surv., Canada,* Mem. 247.

Burkhanov, V. F.
1957: Soviet Arctic Research; transl. from *Priroda,* 1957, vol. 5, pp. 21-30, by E. R. Hope; *Def. Res. Board, Canada,* T 265 R.

Christie, R. L.
1957: Geological Reconnaissance of the North Coast of Ellesmere Island, District of Franklin, NWT; *Geol. Surv., Canada,* Paper 56-9.

Cooper, G. A.
1956: Chazyan and Related Brachiopods; *Smithsonian Misc. Collections,* vol. 127.

Deane, R. E.
1959: Pleistocene Geology and Limnology; *in* Operation Hazen, Narrative and Preliminary Reports, 1957-58, *Def. Res. Board, Canada,* pp. 61-63.

Feilden, H. W., and De Rance, C. E.
1878: Geology of the Coasts of the Arctic Lands Visited by the Late British Expedition under Captain Sir George Nares, R.N., K.C.B., F.R.S.; *Quart., J. Geol. Soc.,* vol. 34, pp. 556-567.

Fortier, Y. O.
1957: The Arctic Archipelago: Chapt. VII in Geology and Economic Minerals of Canada; *Geol. Surv., Canada,* Econ. Geol. Ser. No. 1, 4th ed.

Fortier, Y. O., McNair, A. H., and Thorsteinsson, R.
1954: Geology and Petroleum Possibilities in Canadian Arctic Islands; *Bull. Am. Assoc. Petrol. Geol.,* vol. 38, pp. 2075-2109.

Frebold, Hans
1950: Stratigraphie und Brachiopodenfauna des Marinen Jungpalaeozoikums von Holms und Amdrups Land (Nordostgrönland); *Med. om Grønland,* vol. 126, No. 3.

Fritz, M. A.
1961: A New Bryozoan Genus from Lake Hazen, Northeastern Ellesmere Island; *Proc. Geol. Assoc., Canada,* vol. 13, pp. 53-55.

Greely, A. W.
1886: Three Years of Arctic Service, vols. I and II; New York, Charles Scribner's Sons.

Grönwall, K. A.
1917: The Marine Carboniferous of Northeast Greenland and its Brachiopod Fauna; *Med. om Grønland,* vol. 43, No. 20, pp. 509-618.

Geol. Survey, Canada
1959: Map 36-1959: Geology, Axel Heiberg and Stor Islands, NWT, scale 1 in. to 8 miles; *Geol. Surv., Canada.*

Hakkel', Ya. Ya.
1958: Signs of Recent Submarine Volcanic Activity in the Lomonosov Range; transl. from *Priroda*, 1958, vol. 4, p. 87, by E. R. Hope; *Def. Res. Board, Canada*, T 296 R.

Harker, P., and Thorsteinsson, R.
1960: Permian Rocks and Faunas of Grinnell Peninsula, Arctic Archipelago; *Geol. Surv., Canada*, Mem. 309.

Heer, O.
1878: Notes on Fossil Plants Discovered in Grinnell Land by Captain H. W. Feilden; *Quart. J. Geol. Soc.*, vol. 34, pp. 66-72.

Hope, E. R.
1959: Geotectonics of the Arctic Ocean and the Great Arctic Magnetic Anomaly; *J. Geophys. Res.*, vol. 64, No. 4, pp. 407-427.

Jackson, C. I.
1959: The Meteorology of Lake Hazen, NWT, pt. I: Analysis of Observations; *Def. Res. Board, Canada*, Rept. No. 8, Operation Hazen.

Kay, Marshal
1951: North American Geosynclines; *Geol. Soc. Amer.*, Mem. 48.

Kerr, J. W., and Trettin, H. P.
1962: Mississippian Rocks and the Mid-Palaeozoic Earth-Movements in the Canadian Arctic Archipelago; *J. Alta. Soc. Petrol. Geol.*, vol. 10, No. 5, pp. 247-256.

Koch, Lauge
1925: The Geology of North Greenland; *Am. J. Sci.*, 5th ser., vol. 9, pp. 271-285.
1929a: The Geology of the South Coast of Washington Land; *Med. om Grønland*, vol. 73, pt. 1, No. 1.
1929b: Stratigraphy of Greenland; *Med. om Grønland*, vol. 73, pt. 2, No. 2.

Kulp, J. L.
1960: The Geological Time Scale; *21st Int. Geol. Cong.*, Pt. III, p. 18.

Lyons, J. B., and Leavitt, F. G.
1961: Structural-Stratigraphic Studies on the Ward Hunt Ice Shelf; Geophys. Res. Dir., *USAF Cambridge Res. Labs.*, AFCRL-442, 37 pp.

Maxwell, M. S.
1960: An Archeological Analysis of Eastern Grant Land, Ellesmere Island, NWT; *Nat. Mus., Canada*, Bull. 170 (Anthropological Series 49).

McLaren, D. J.
1963: pp. 310-338 *in* Geology of the North-Central part of the Arctic Archipelago (Operation Franklin); *Geol. Surv., Canada*, Mem. 320.

Panov, D. G.
1955: Tectonics of the Central Arctic; transl. from *Dok. Akad. Nauk*, vol. 105, No. 2, pp. 339-342, by E. R. Hope; *Def. Res. Board, Canada*, T 207 R.

Powell, J. M.
1959: Plant Ecology and Microclimate; *in* Operation Hazen, Narrative and Preliminary Reports, 1957-58, pp. 83-85, *Def. Res. Board, Canada*, Hazen 4.
1961: The Vegetation and Micro-Climate of the Lake Hazen Area, Northern Ellesmere Island, NWT; *Def. Res. Board, Canada*, Rept. No. 14, Operation Hazen.

Prest, V. K.
1952: Notes on the Geology of Parts of Ellesmere and Devon Islands, NWT; *Geol. Surv., Canada*, Paper 52-32 (notes and map).

Sagar, R. B.
1960: Glacial-Meteorological Observations in Northern Ellesmere Island during Phase III, "Operation Hazen", May-August, 1958; *Def. Res. Board, Canada*, Rept. No. 13, Operation Hazen.

Saks, V. N., Belov, N. A., and Lapina, N. N.
1955: Our Present Concepts of the Geology of the Central Arctic; transl. from *Priroda*, 1955, vol. 44, No. 7, pp. 13-22; RT 3338 (translator not known).

Schei, Per
1903: Summary of Geological Results, the Second Norwegian Polar Expedition in the 'Fram'; *Geogr. J.*, vol. 22, p. 56.
1904: Preliminary Account of the Geological Investigations made during the Second Norwegian Polar Expedition in the 'Fram'; App. I in New Land, vol. II, by Otto Sverdrup, 1904; London, Longman, Green & Co.

Soper, J. H.
1959: Botany; *in* Operation Hazen, Narrative and Preliminary Reports, 1957-58, *Def. Res. Board, Canada,* Hazen 4.

Taylor, Andrew
1955: Geographical Discovery and Exploration in the Queen Elizabeth Islands; *Geogr. Branch, Dept. Mines Tech. Surv., Canada,* Mem. 3.
1956: Physical Geography of the Queen Elizabeth Islands, Canada, vols. I to XII; *Amer. Geogr. Soc.*, New York.

Tener, J. S.
1959: Wildlife Studies; *in* Operation Hazen Narrative and Preliminary Reports, 1957-58, *Def. Res. Board, Canada,* Hazen 4.

Thompson, M. L.
1961: Pennsylvanian Fusulinids from Ward Hunt Island; *J. Pal.*, vol. 35, No. 6, pp. 1130-36, Pls. 135,136.

Thorsteinsson, R., and Tozer, E. T.
1957: Geological Investigations in Ellesmere and Axel Heiberg Islands, 1956; *Arctic,* vol. 10, pp. 3-31.
1960: Summary Account of Structural History of the Canadian Arctic Archipelago since Precambrian Time; *Geol. Surv., Canada,* Paper 60-7.

Tozer, E. T.
1961: Triassic Stratigraphy and Faunas, Queen Elizabeth Islands, Arctic Archipelago; *Geol. Surv., Canada,* Mem. 316.
1963: pp. 370-380 in Geology of the North-Central part of the Arctic Archipelago (Operation Franklin); *Geol. Surv., Canada,* Mem. 320.

Troelsen, J. C.
1950: Contributions to the Geology of Northwest Greenland, Ellesmere Island, and Axel Heiberg Island; *Med. om Grønland,* vol. 149, No. 7.
1952: Geological Investigations in Ellesmere Island, 1952; *Arctic,* vol. 5, pp. 199-210.

U.S.S.R. (anonymous)
1954: New Soviet Researches, Explorations, and Discoveries in the Central Arctic; transl. from *Izv. Akad. Nauk,* Ser. Geog. 1954, vol. 5, pp. 3-16, by E. R. Hope; *Def. Res. Board, Canada,* T 165 R.

INDEX