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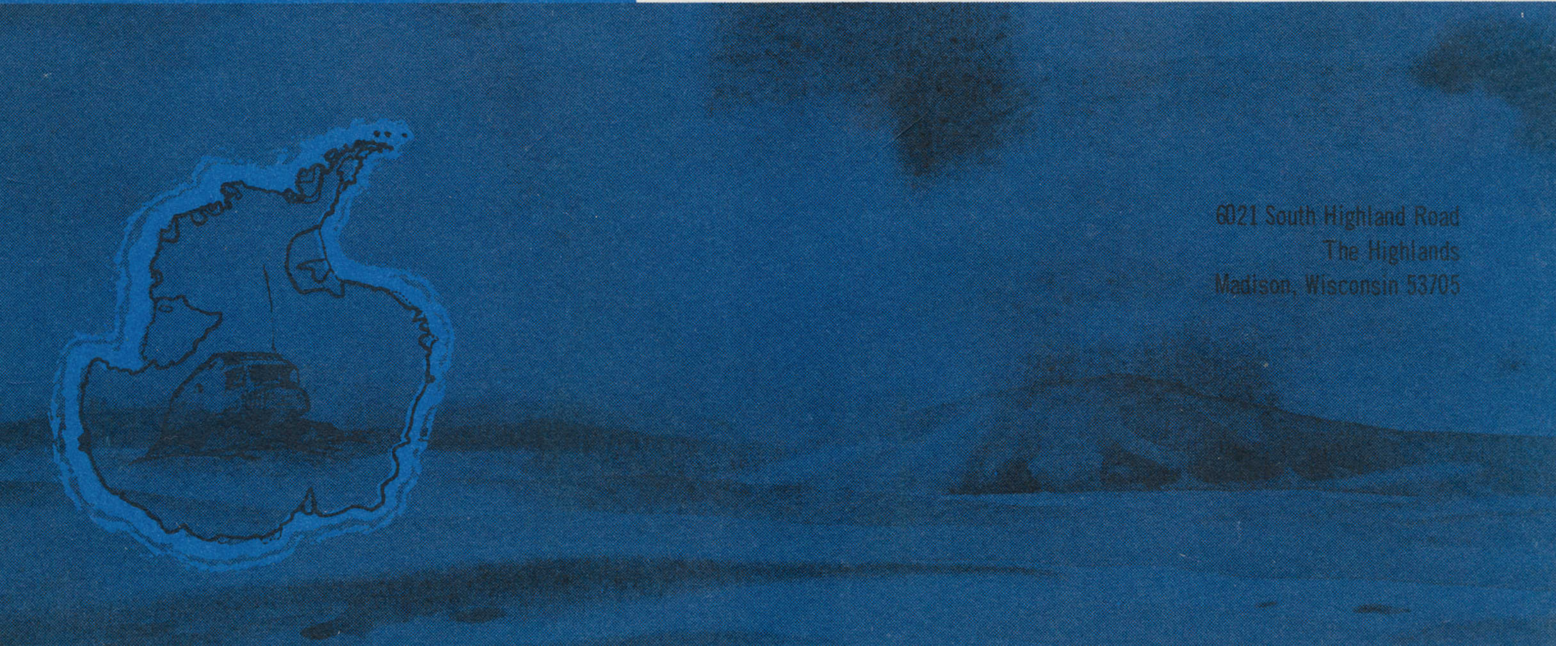
GEOPHYSICAL INVESTIGATIONS OF THE ARCTIC OCEAN BASIN

by Ned A. Ostenso

RESEARCH REPORT NO. 4–JUNE, 1962



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ABSTRACT

The history of exploration and the development of geologic thought on the Arctic Ocean Basin is briefly reviewed. A new bathymetric chart is constructed from a critical evaluation of all available data and principal geomorphic features are described. During the past two years 129 gravity stations have been established on the arctic slope and over the adjoining Arctic Ocean by ski-equipped aircraft. Free air and Bouguer iso-anomaly maps are presented and discussed. An airborne magnetic survey was completed during April and May 1961 using a Varian nuclear-precession magnetometer mounted in a P2V-5 aircraft. Flights covered nearly all of the Arctic Basin to within 350 km of the Russian coast; 56,000 km of magnetic profiles were obtained at a flight evaluation of 450 meters above sea level. Residual magnetic profiles and a regional magnetic chart are shown and discussed.

The Arctic Ocean Basin is shown to contain four oceanic deeps (Canada, Makarov, Eurasia and Fram Deeps) and is crossed by three ridge systems (Alpha Ridge, Lomonosov Ridge and a trans-Arctic Ocean continuation of the Mid-Atlantic Ridge). The deeps have exceedingly flat floors and contain large volumes of detritus. The Alpha Ridge is shown to be composed of rocks of high magnetic susceptibility and may be a horst structure. The Lomonosov Ridge appears to be formed of folded sediments as interpreted by Soviet investigators. The "Mid-Arctic" Ridge is either poorly developed or deeply buried by sediments. The magnetic character of the sub-basin on the European side of the Lomonosov Ridge, the Nansen Basin, supports the theory of an underlying thick sedimentary column. The Hyperborian platform does not extend eastward beyond about 150°W longitude nor does it connect with the Canada-Greenland platform.

Gravity data show that the Chukchi Shelf and Canada Deep are in isostatic equilibrium whereas a free air low is associated with the Beaufort Deep. A ridge of high density non-magnetic material parallels the continental shelf off northern Alaska. In the vicinity of 145°W longitude the ridge rises inshore of the 200 m isobath. Farther west its crest lies approximately under the 200 m isobath to longitude 160°W where it swings inshore into the Chukchi Shelf. Over the continental shelf at the terminus of the Brooks Range there is a +107 free air anomaly caused by a sharp rise in the basement and mantle associated with an uplifting of the north end of the range. There is a rise in the granitic basement at the Chukchi Shelf northwest of Pt. Barrow (73°N, 160°W) similar to those forming Wrangel, Herald, and the Diomede Islands elsewhere on the shelf. The genesis of two submarine valleys in the vicinity of 152°W and 158°W longitude is thought to be related to high angle faults radiating from a complex core of basement rock located approximately 16 km southwest of Barrow.

Quantative methods of evaluating magnetic data are briefly discussed and depths to the source of anomalies are calculated with remarkable consistency. The observed values of the regional magnetic gradient are much less than shown on Hydrographic Office Chart HO 1703N. The highest observed value of F is 58,750 gammas. An S-shaped flexure of the 56,000 gamma isoline over the Robeson Channel is assumed to be a local distortion possibly caused by underlying geology.

The crustal structure of the Arctic Ocean defies neat classification into either continental or oceanic categories. Rather it appears to contain elements that are salient to both. Within its boundaries are depressions of truly oceanic depth underlain by crustal sections approximately 6 km thick. Contrastingly, large volumes of sediments have collected within the basin that have subsequently undergone "continental" deformation.

TABLE OF CONTENTS

Chapter Page

LIST OF ILLUSTRATIONS

TABLES

PREFACE

In collaboration with Professor G. P. Woollard and Dr. Edward C. Thiel a program for geophysical investigations of the Arctic Ocean Basin was proposed to the Geography Branch of the Office of Naval Research in 1959. This proposal provided for a continuing and integrated research program combining the three fundamental and mutually supporting elements of geophysical investigation; gravity, magnetics and seismology. From its conception this program has received enthusiastic and generous support from the Office of Naval Research, and thanks to the personal interest and untiring efforts of Dr. Max E. Britton and LTJG Leonard LeSchack of the Geography Branch and Mr. Max C. Brewer, Director, Arctic Research Laboratory, the program has progressed successfully.

In January 1961, Dr. Thiel left the University of Wisconsin to join the faculty of the University of Minnesota but continued his responsibility as principal investigator on the seismic phase of the research program. Despite this physical separation, the entire investigation continued as a closely integrated and coordinated project.

The overall program was inaugurated in March-June 1960 with the beginning of an airlifted gravity survey off the northern coast of Alaska. This initial phase of the field program was capable carried out by Robert W. Patenaude and Robert M. Iverson. The second year's field program began in March 1961 with the continuation of the gravity survey by Robert Iverson and the writer.

Gravity stations were established on the sea ice to a distance of 540 km from shore, using ski-equipped Cessna 180 aircraft. Water depth soundings were obtained at most of the gravity stations. The very difficult job of flying the aircraft was expertly handled by the pilots from the Arctic Research Laboratory: Robert Fisher, Lloyd Zimmerman, and Robert Marsh.

During the months of May and June 1961, 49,500 km of aeromagnetic flight lines were flown over the Arctic Ocean in a P2V-5 (Neptune) patrol bomber instrumented with a Varian proton precession magnetometer. The operational support for this investigation was delegated to the Naval Air Development Unit (NADU) based at Naval Air Station, South Weymouth, Massachusetts, under the code name of PROJECT ARCTIC BASIN. A major share of the credit for the successful completion of this mission goes to the following men of the flight and support crews of NADU and Air Development Squadron 6 (VX-6) who worked long hours, often under trying conditions:

Naval Air Development Unit (NADU) flight personnel

Lt. C. W. Hall	Aircraft Commander
Lt. J. T. Jackson	Co-Pilot
Lt. R. G. Geer	Co-Pilot
LTJG E. W. Sarsfield	Navigator
LTJG A. R. Rutberg	Navigator
Carey, W. AO1	Plane Captain
Kraus, D. AD3	2nd Mechanic
Kitterman, R. J. AD2	Ground Supt. and 2nd Mechanic
LeBlanc, R. A. AE2	Electrician
Hoberg, N. J. ATCA	Radioman
Edwards, W. R. AE2	Technician
Parshall, F. T. AMH2	Metalsmith

Support

Lt.Cdr. C. F. Hallums	R4D Logistics, Search & Rescue
Lt. D. W. Player (VX-6)	Search & Rescue
Casey, C. J. AM3	Ground Support
Childs, J. J. ATR3	Ground Support
Clement, J. E. ATN3	Ground Support

Lt. C. W. Hall, the aircraft commander, took a keen personal interest in the study and on a number of occasions his spirit of aggressive cooperation prevented the program from aborting completely or being seriously abbreviated. Richard J. Wold and the writer operated the magnetometer on these flights.

In August and September 1961 the writer returned to the Arctic Research Laboratory, Barrow, Alaska to participate in an explosion seismic program in cooperation with the University of Minnesota under the direction of Dr. Edward C. Thiel. Dennis D'Andrea of the University of Minnesota is preparing a Master's thesis from the results of these first year's data.

Although the program of gravity and magnetic studies will continue for a number of years, enough data have now been collected to provide considerable insight into the structure of the continental slope off the norther coast of Alaska and of the Arctic Ocean Basin, as well as the character of the regional total magnetic field in the high northern latitudes. This report treats the data collected during the first two years of a continuing and many faceted geophysical investigation of the Arctic Ocean Basin.

A project of this magnitude is dependent upon the efforts and talents of many people. In addition to those already mentioned, it is a pleasure to acknowledge the following who have made real contributions to this study: Peter J. Wolf, Richard L. Coons and Richard J. Wold did the machine programming of the magnetic data for the Control Data Corporation 1604 computer. The herculean task of picking the magnetometer analog records and punching thousands of data cards for the computer was done by Edward Schneider, Ruth H. Mitchel and Patricia G. Thiel. The gravity data was computed by Delia M. Lavin. Valuable computer time was generously donated by the Numerical Analysis Laboratory of the University of Wisconsin. The excellent job of drafting the figures for this manuscript was done by Paul L. Dombrowski. I am deeply grateful to the entire office staff of the Geophysical and Polar Research Center who have cheerfully lent a helping hand and sympathetic ear and have deciphered my handwriting and corrected my spelling. Dr. J. L. Worzel of the Lamont Geological Observatory, Columbia University kindly made available the unpublished results from 16 submarine pendulum stations established off the northern coast of Alaska in 1949 and 1953. Dr. Charles R. Bentley and Professor L. R. Laudon of the University of Wisconsin and Mr. E. R. Hope of the Defence Research Board, Canada have critically reviewed this manuscript and offered many helpful suggestions.

Finally, it is both a pleasure and an honor to acknowledge the contribution to this study from the other two principal investigators, Professor George P. Woollard of the University of Wisconsin and the late Dr. Edward C. Thiel of the University of Minnesota. In addition to being instrumental in the conception of the program, they were a constant source of stimulation, sound advice, and constructive criticism. The tragic and untimely death of Dr. Thiel in a plane accident while conducting an aeromagnetic survey in Antarctica on 9 November 1961, is a severe loss to this research program as it is to the entire science and profession.

INTRODUCTION

The Arctic Ocean Basin is the Earth's least understood first order physiographic feature. Indeed, whether it may in the geologic sense be properly considered an ocean is an open question. Its isolation, inclement weather, and perpetual ice cover have contributed to the Arctic Ocean being largely ignored by man in his quest for geographic and scientific discovery; yet it occupies a position of unique importance to better understanding the Earth's structural framework. Because of the ocean's position between the continents of North America and Eurasia, it might be considered the keystone in the structure of northern hemisphere geology making its study fundamental to better understanding of intercontinental lithologic and tectonic relationships.

To be sure, it has been the inaccessibility and inhospitability of the region, not lack of interest, that has left the Arctic environs so long unstudied. Even now, with the powerful weapons of a modern technology, the assault on the polar sea is tenuous and the cost of observational data dear. This unhappy combination of intense scientific interest coupled with a few factual data has resulted in a disproportionate ratio of theories to observational investigation. Unfortunately, many of the papers on the subject do not clearly distinguish between the two. Therefore, one is forced into the role of a detective tracing down clues to the creditability of undocumented statements. To do this successfully, knowledge of the history of Arctic Ocean exploration becomes essential; for only when one knows where and how the data supporting a thesis were obtained, can the argument be evaluated.

To assist the reader in arriving at his own evaluation of credence, the work and routes of significant expeditions have been described in considerable detail. For convenience this discussion of the history of previous investigations is divided into three chapters. The first chapter covers the period up to the year 1949, when the Arctic Ocean Basin was generally believed to be a single, homogeneous deep. Chapter 2 covers the discovery of the Lomonosov Ridge and the realization that the ocean basin had a more complex physiography. Chapter 3 covers the period from 1956 to the present. It is during the latter period that research in the polar sea received new impetus through the advent of the International Geophysical Year. Each of these three chapters is divided into two parts; the first reports the various expeditions and the second discusses geological thoughts and concepts of that period. Generally more emphasis is given to the discussion on Soviet research, as their literature is probably less readily available to the reader.

Bottom topography is important to the study of submarine geology. Bottom features, unlike their subaerial counterparts, are not so subject to the ravages of erosion and, therefore, are more indicative of the orogenic forces that created them. Because of this significance to the geologic framework of the Arctic Basin, Chapter 4 is devoted to bathymetry and a new bathymetric chart is presented. Geomorphic features and provinces are described and a compromise on nomenclature confusion is attempted.

Chapters 5 and 6 deal with the gravity and magnetic programs respectively. Their general organization is: field program, instrumentation, data reduction, and interpretation. Conclusions are summarized in Chapter 7. For convenient reference the geographic place names mentioned in the text are located on a special map as Figure 1.

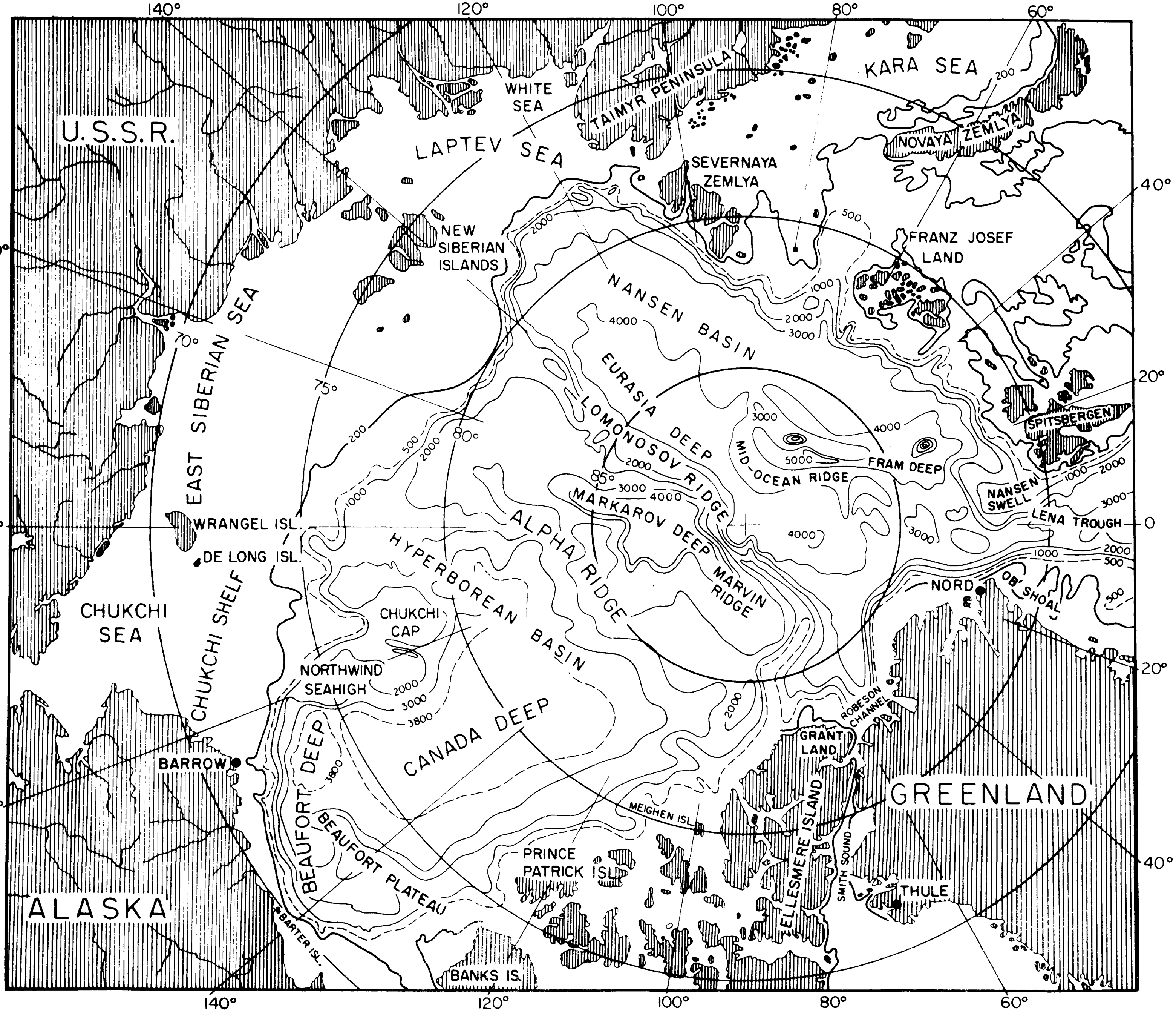

U.S.S.R.
KARA SEA
WHITE SEA
TAIMYR PENINSULA
NOVAYA ZEMLYA
LAPTEV SEA
SEVERNAYA ZEMLYA
NEW SIBERIAN ISLANDS
FRANZ JOSEF LAND
NANSEN BASIN
EAST SIBERIAN SEA
EURASIA DEEP
LOMONOSOV RIDGE
MID-OCEAN RIDGE
FRAM DEEP
SPITSBERGEN
NANSEN SWELL
LENA TROUGH
MARKAROV DEEP
ALPHA RIDGE
MARVIN RIDGE
WRANGEL ISL.
DE LONG ISL.
HYPERBOREAN BASIN
CHUKCHI SEA
CHUKCHI SHELF
CHUKCHI CAP
NORTHWIND SEAHIGH
NORD
OB' SHOAL
CANADA DEEP
ROBESON CHANNEL
GRANT LAND
BARROW
BEAUFORT DEEP
GREENLAND
MEIGHEN ISL.
ELLESMERE ISLAND
SMITH SOUND
PRINCE PATRICK ISL.
BEAUFORT PLATEAU
THULE
ALASKA
BARTER ISL.
BANKS IS.

FIGURE 1.

Chapter 1

INVESTIGATIONS OF THE ARCTIC OCEAN BASIN TO 1949 -- THE CONCEPT OF A SINGLE BASIN

1. 1. Early Expeditions

Since the earliest concepts of a spherical earth, inquiring man has speculated about the nature of the polar regions. From astronomical observations the Greeks theorized that north of the Arctic Circle there must be a midnight sun at midsummer and continual darkness at midwinter. The enlightened view was that both the northern and southern polar regions were uninhabitable frozen wastes; whereas the more popular belief was that there was a "Utopia" north of the north wind (Boreas) where the sun always shown and the Hyperboreans led a peaceful life. Such speculations provided incentives for adventurous man to risk the hazards of severe climate and fear of the unknown to further geographic knowledge and national and personal prosperity. To this day Arctic exploration remains a science, art, sport, and economic service, although military tactics and geopolitics have become new motivations for accelerated effort.

With 20 percent of their country lying north of the Arctic Circle, the Russian people were logically among the first and most active Arctic explorers. As early as the 17th and 18th centuries, privately financed trapping and trading expeditions made major discoveries in the far north. In 1733 the Great Northern Expedition was sent to the Arctic by Peter the Great where it spent more than ten years searching for a northeastern sea route for mercantile traffic between Europe and Asia. Although the venture did not succeed in its proposed mission, the explorers mapped the coastlines of northern Russia from the White Sea to the Chukchi Sea and discovered the Aleutian and Kuril Islands, as well as much of the northwestern shore of North America. The economic and tactical demand for a "Northeast Passage" has remained a strong motivating force for Soviet activities in the Arctic Ocean.

In the ensuing years many national and privately financed expeditions were sent to the Arctic. Most of these expeditions, such as those of Peary, Franklin, Ross, Scoresby, Nordenskjold, Nares, McClintock, and Markham, are now legendary monuments to man's intrepidity and insatiable quest for knowledge and adventure. However, these efforts were directed principally toward geographic exploration of coastal lands or searches for the last Franklin Expedition, and no attempt was made to penetrate into the central reaches of the polar sea.

1. 2. Voyages of the JEANNETTE and the FRAM

By the latter part of the nineteenth century most of the Arctic Ocean coast line had been fairly well charted, although the greater part of the ocean itself was still unexplored. The northward extent of Greenland and the island groups to its west were unknown, and opinions of geographers concerning the distribution of land and sea were divided. Many joined the German geographer Petermann in believing that Greenland extended across the North Pole to Wrangel Land, now Wrangel Island; whereas others believed that the unknown central polar region consisted of numerous islands separated by shallow waters.

In 1879 U. S. Navy Commander DeLong set out in the ill-fated ship JEANNETTE, in search of the possible new lands north of Siberia. The JEANNETTE became beset in the ice at 71°35'N., 175°06'W. and drifted with the ice pack for nearly two years before finally being crushed and sunk at 77°15'N., 154°59'E. This drift demonstrated that Wrangel Land was not contiguous with Greenland. The drift tracks of various expeditions and the largest known ice islands in the Arctic Ocean are given in Figure 2. The principal facts on the drifting expeditions are given in Table I.

The discovery, along the southwestern coast of Greenland, of objects from the crushed JEANNETTE, driftwood from Siberia, and implements belonging to Alaskan Eskimo led Professor H. Mohn to suggest in a Norwegian newspaper article that this material was carried by currents across the "Polar Sea" (Sverdrup, 1950). From Professor Mohn's theory Fridtjof Nansen concluded that if a ship of sufficient strength and proper design were allowed to be trapped in the ice near the vicinity where the JEANNETTE had sunk, it would drift with the currents until released off the coast of Greenland. Such an operation would permit exploration of a large part of the inaccessible central Arctic, and possibly even the North Pole could be reached. Despite the profound skepticism of most Arctic explorers, Nansen pursued his plan and in 1893-96 successfully completed the drift from the New Siberian Islands to Spitsbergen in the FRAM.

In accord with popular opinion Nansen expected to find only shallow water in the North Polar Basin. Consequently the FRAM was equipped to make soundings to only 1,900 meters. Soon after the drift had begun, depths in excess of 1,900 meters were encountered. Unraveling one of the ship's steel wire cables and joining the individual strands end to end permitted 11 successful soundings to be completed under most difficult conditions. These soundings gave depths ranging from 3,400 to 4,000 meters, showing that there was a deep basin under at least part of the North Polar Sea. These deep soundings made only 75 years ago mark the discovery of the Arctic Ocean.

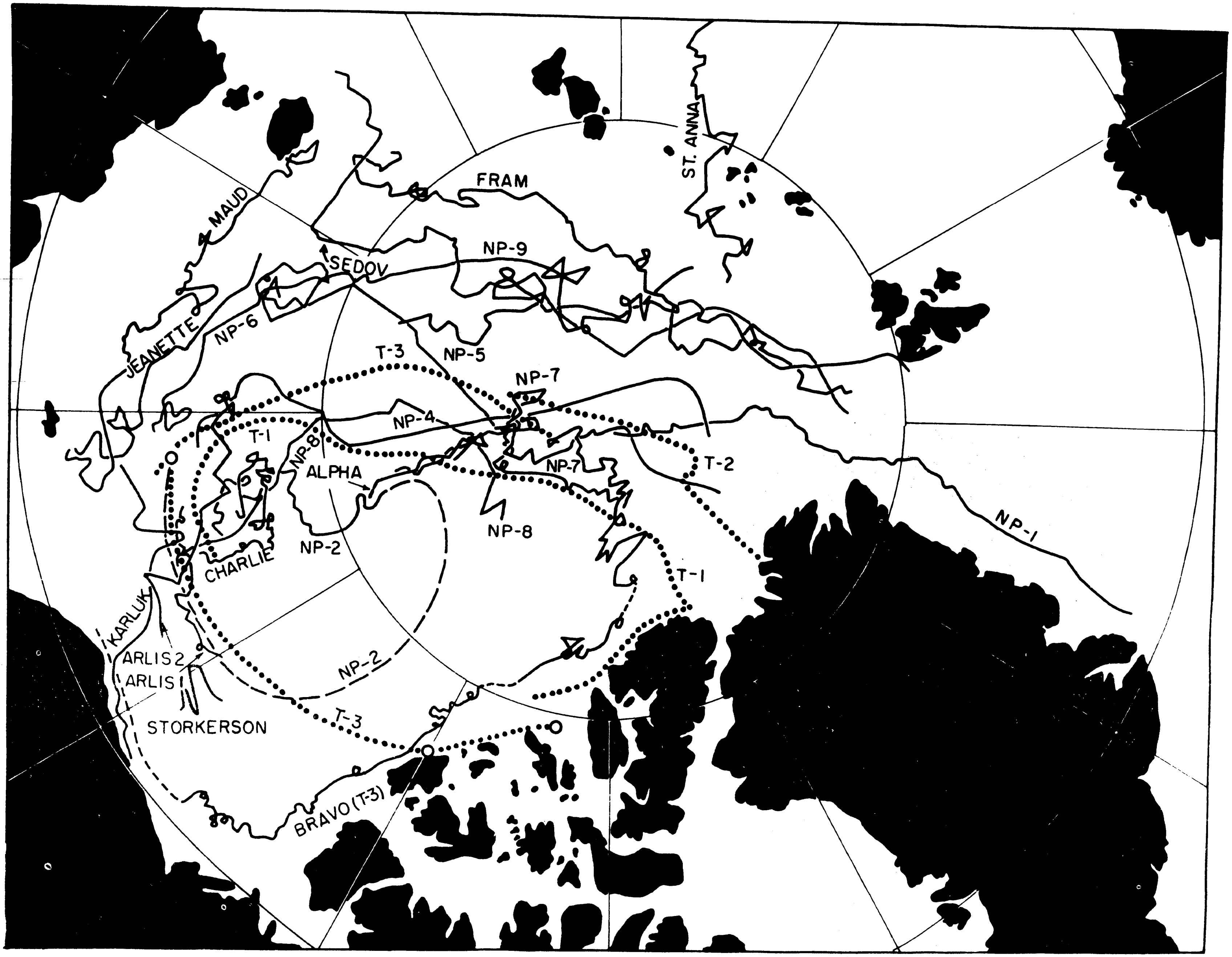


Figure 2.

THE DRIFTS OF VARIOUS EXPEDITIONS AND OF THE LARGEST KNOWN ICE ISLANDS IN THE ARCTIC OCEAN THROUGH 1961.

TABLE I

Principal Facts on Drift Expedition in the Arctic Ocean

Name of station and commander	Dates: Start	Dates: Finish	Duration of drift, days	Positions: Start		Positions: Finish	
Jeanette G. W. deLong	6/9/1879	12/6/1881	638	71°35'N	175°06'W	77°15'N	154°59'E
Fram F. Nansen	22/9/1894	13/8/1896	1055	78°40'N	132°45'E	80°00'N	11°45'E
St. Anna G. A. Brusilov	15/10/1912	23/4/1914	555	71°35'N	68°10'E	83°17'N	60°E
Karluk R. A. Bartlett	20/9/1913	11/1/1914	112	71°30'N	148°30'W	79°30'N	174°W
Maud R. Amundsen	8/8/1922	9/8/1924	731	71°10'N	175°W	76°10'N	144°E
George Sedov Badigin	23/10/1937	13/1/1940	812	75°35'N	131°10'E	76°N	2°45'E
S. T. Storkerson	8/4/1918	9/10/1918	184	72°30'N	146°W	73°45'N	145°10'W
North Pole 1 I. D. Papanin	21/5/1937	19/2/1938	274	89°25'N	78°40'W	70°40'N	19°16'W
North Pole 2 M. M. Somov	2/4/1950	11/4/1951	374	76°03'N	166°36'W	81°44'6"N	163°48'W
North Pole 3 A. F. Treshnikov	9/4/1954	20/4/1955	376	85°58'N	178°00'W	86°00'N	24°00'W
North Pole 4 Ye. I. Tolstikov	8/4/1954	17/4/1955	374	75°48'N	178°25'W	80°49'5"N	175°35'W
North Pole 4 P. A. Gordienko	17/4/1955	18/4/1956	367	80°49'5"N	175°35'W	87°24'N	177°46'W
North Pole 4 A. G. Dralkin	18/4/1956	19/4/1957	367	87°24'N	177°46'W	85°52'8"N	00°00'W
North Pole 4			1108				

TABLE I con't.

Name of station and commander	Dates: Start	Dates: Finish	Duration of drift, days	Positions: Start		Positions: Finish	
North Pole 5 N. A. Volkov	21/4/1955	20/4/1956	365	82°10'N	156°51'E	86°18'N	88°57'E
North Pole 5 A. L. Sokolov	20/4/1956	8/10/1956	171	86°18'0"N	88°57'E	84°18'N	63°20'E
North Pole 5			536				
*North Pole 6 K. A. Sychev	19/4/1956	19/4/1957	366	74°24'N	144°04'W	75°59'N	171°45'E
*North Pole 6 V. M. Driacki	19/4/1957	8/4/1958	354	75°59'N	171°45'E	80°56'N	150°15'E
*North Pole 6 S. T. Serlapov	8/4/1958	12/4/1959	370	80°56'N	150°15'E	86°18'0"N	39°37'E
*North Pole 6 V. S. Antonov	12/4/1959	14/9/1959	1156	86°18'0"N	39°37'E	82°06'0"N	03°56'E
*North Pole 6			246				
North Pole 7 V. A. Vedernikov	23/4/1957	11/4/1958	355	82°06'N	164°11'W	86°21'4"N	149°38'W
North Pole 7 N. A. Belov	11/4/1958	11/4/1959	366	86°21'4"N	149°38'W	85°14'0"N	33°03'W
North Pole 7			721				
North Pole 8 V. M. Rogachev	27/4/1959	3/4/1960	342	76°11'N	164°24'W	79°09'N	179°35'E
North Pole 8 N. A. Blinov	3/4/1960		---	79°15'N	179°10'E	---	---
North Pole 9 V. A. Shamont'yev	16/4/1960	29/3/1961	347	77°15'N	163°35'E	86°36'N	176°00'W
*T-3 J. Fletcher et al.	3/4/1952	14/5/1954	771	87°54'N	156°30'W	84°31'N	80°40'W
*T-3 A. P. Crary	1/5/1955	21/9/1955	144	83°37'N	88°W	82°19'N	98°W

TABLE I con't.

Name of station and commander	Dates: Start	Dates: Finish	Duration of drift, days	Positions: Start		Positions: Finish	
*Bravo (T-3) LeBlanc, et al.	7/3/1957	14/5/1960	1163	82°50'N	99°W	71°51'N	159°45'W
Alpha N. Untersteiner, et al.	8/6/1957	3/11/1958	512	80°51'N	160°17'W	86°11.5'N	113°08'W
Charlie (Alpha 2) K. O. Bennington, et al.	8/6/1959	7/1/1960	287	76°42"N	161°12'W	76°55'N	169°04'W
Arlis I K. O. Bennington	25/9/1960	18/3/1961	174	74°40'N	141°06'W	74°59.2'N	169°50'W
*Arlis II J. Beck, et al.	23/5/1961	---	---	73°10'N	156°05'W	---	---

*Ice Islands

1. 3. Speculations on a Divided Basin from Tidal and Water Temperature Observations

Since its discovery by Nansen, knowledge of the Arctic Ocean grew very slowly. By analyzing tidal data, R. A. Harris (1904) was the first to gain further knowledge of the structure of the basin. From this study he concluded that the basin was divided by "a tract of land, an archipelago, or an area of shallow water." Five years later Suess (1909) suggested that, because of geological similarities, the New Siberian Islands and Ellesmere Island might be connected across the Arctic by a suboceanic structure thought to be a prolongation of the Mesozoic folding of the Verkhoyan Range. To digress briefly, it is interesting to note that later investigations were to arrive at a similar conclusion from studies of ocean tides and water temperatures. Harris's theory was supported by Fjelstand (1923) using tidal observations from the MAUD expedition. However, Sverdrup (Marmer, 1928) questioned such a hypothesis and concluded that the observed tidal effects could be explained equally well by the effects of friction and the deflecting force of the earth's rotation. His skepticism was increased (Sverdrup, 1950) when Amundsen and Ellsworth flew from Spitsbergen to Alaska in 1926 in the dirigible NORGE and failed to see land. Nansen himself believed in a divided ocean basin but ultimately relinquished this point of view in favor of the concept of a single oceanic deep.

The existence of a divided oceanic basin was again predicted by I. V. Maksimov (1945) after analyzing data on tidal variations, temperature, and salinity obtained from the 1941 Soviet airborne expedition. He suggested that somewhere in the region of 81°30'N and longitude 180° there should be shallows in the order of 1,000 m. Worthington (1953) arrived at a similar conclusion from his observations that the bottom waters of the Beaufort Sea were as much as 0.50°C warmer than those on the other side of the basin. He concluded: "There is a submarine ridge running roughly from Ellesmere to the New Siberian Islands, which separates the deepest water of the Beaufort Sea from the remainder of the basin." Worthington predicted that the sill depth of the ridge did not exceed 2,300 m.

1. 4. Additional Deep Soundings

Following Nansen's deep soundings in 1893-96, additional information on the deep ocean basin was very slowly accumulated. During his dash to the North Pole in 1909, Peary completed several soundings at shallow and intermediate depths north of Grant Land. His single attempt at a deep cast near the Pole aborted when his line broke at 2,750 m. In 1913, Stefansson began explorations that carried him into the Beaufort Sea and through much of the western part of the Arctic Archipelago. One of his ships, the KARLUK, attempted 9 deep casts in open water north of Alaska before becoming imprisoned and crushed by the ice. Although none of these soundings reached bottom, they did prove the existence of deep water. During the following 2 years Stefansson, while on a sledging journey, completed 2 deep soundings to the west of Banks Island. In the summer of 1918 Storkerson, who was a member of Stefansson's expedition, drifted with the ice pack off the northern coast of Alaska and obtained four deep soundings. In 1922-24 Amundsen attempted to parallel the drift of the FRAM in his ship the MAUD. Although many scientific studies were accomplished on this expedition, the MAUD unfortunately drifted only in Siberian shelf waters, and no new information was obtained from the deep ocean. Wilkins (1928) was the first to attempt echo soundings to determine water depth. While pioneering the use of the airplane in the Arctic, he obtained a single sounding of 5455 m, 550 miles north of Point Barrow. However, subsequent Russian investigations showed this figure to be in error (Hope, 1954). As late as 1930 most of the Arctic Basin had neither been seen nor studied. The status of exploration at this time is graphically illustrated in Figure 3 taken from Joerg (1930).

1. 5. Soviet Investigations

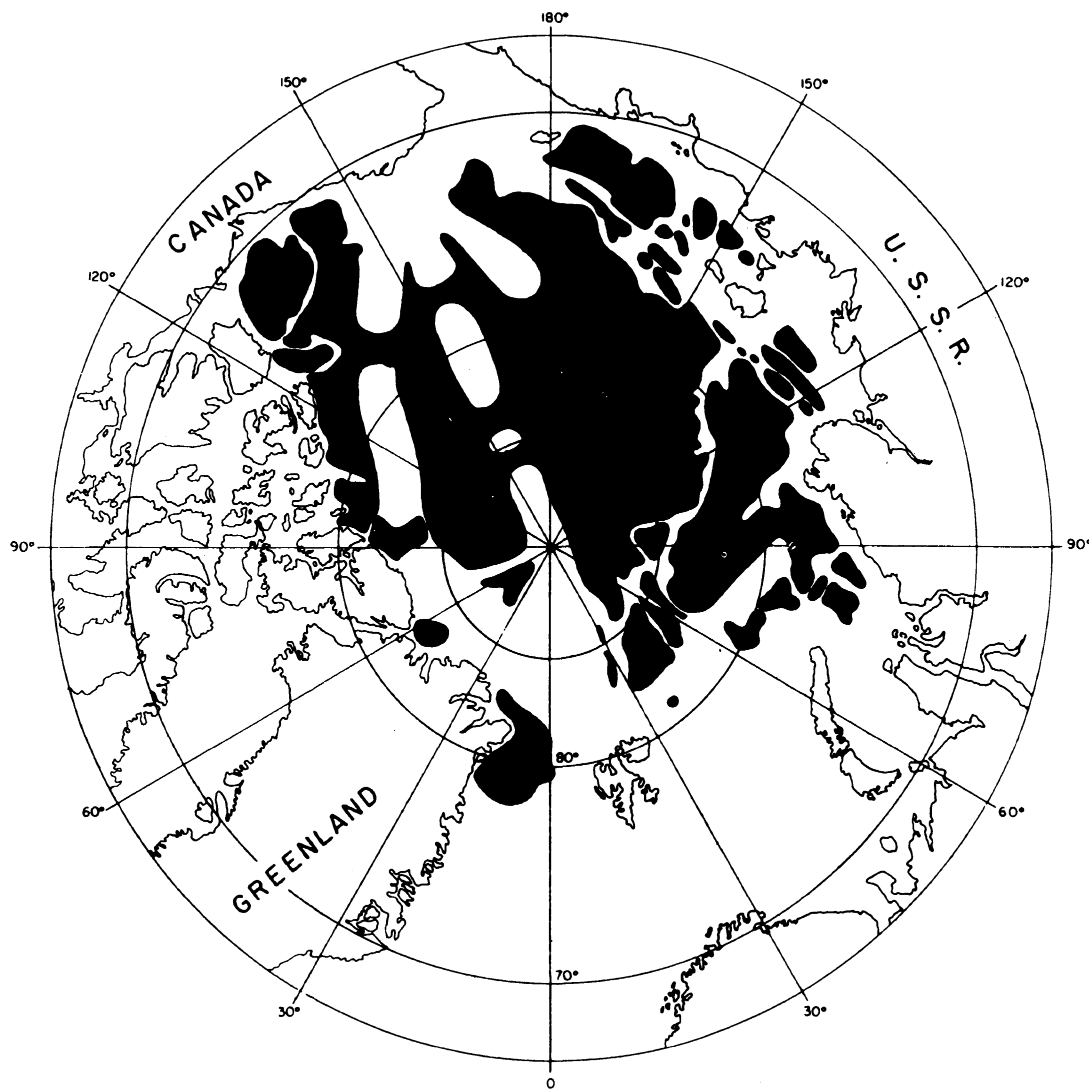
After the 1917 Revolution the Russians intensified their efforts in the Arctic with the initiation of an integrated, long-range, scientific study. Lenin himself was instrumental in formulating this program, which began with the outfitting of ice-strengthened ships capable of penetrating deep into the ice pack, followed by the establishment of a network of scientific stations on islands in the Arctic Ocean and on the adjoining coast. The first voyage into the ice pack to carry out scientific investigations was made in 1930 by the SEDOV which was followed by such now famous ships as the SIBIRYAKOV (1932-33), RUSANOV (1932), SADKO (1935) and the MALYGIN (1935).

In 1937 the Russians landed a ski-equipped, four-engined, ANT-6 airplane at the North Pole and established a drifting station on the sea ice which they occupied continuously for 9 months. In 1941 they established three airlifted scientific stations over deep water in the vicinity of the Pole of Relative Inaccessibility, i.e. in the region of 83°N, 150°E (the N-169 Expedition).

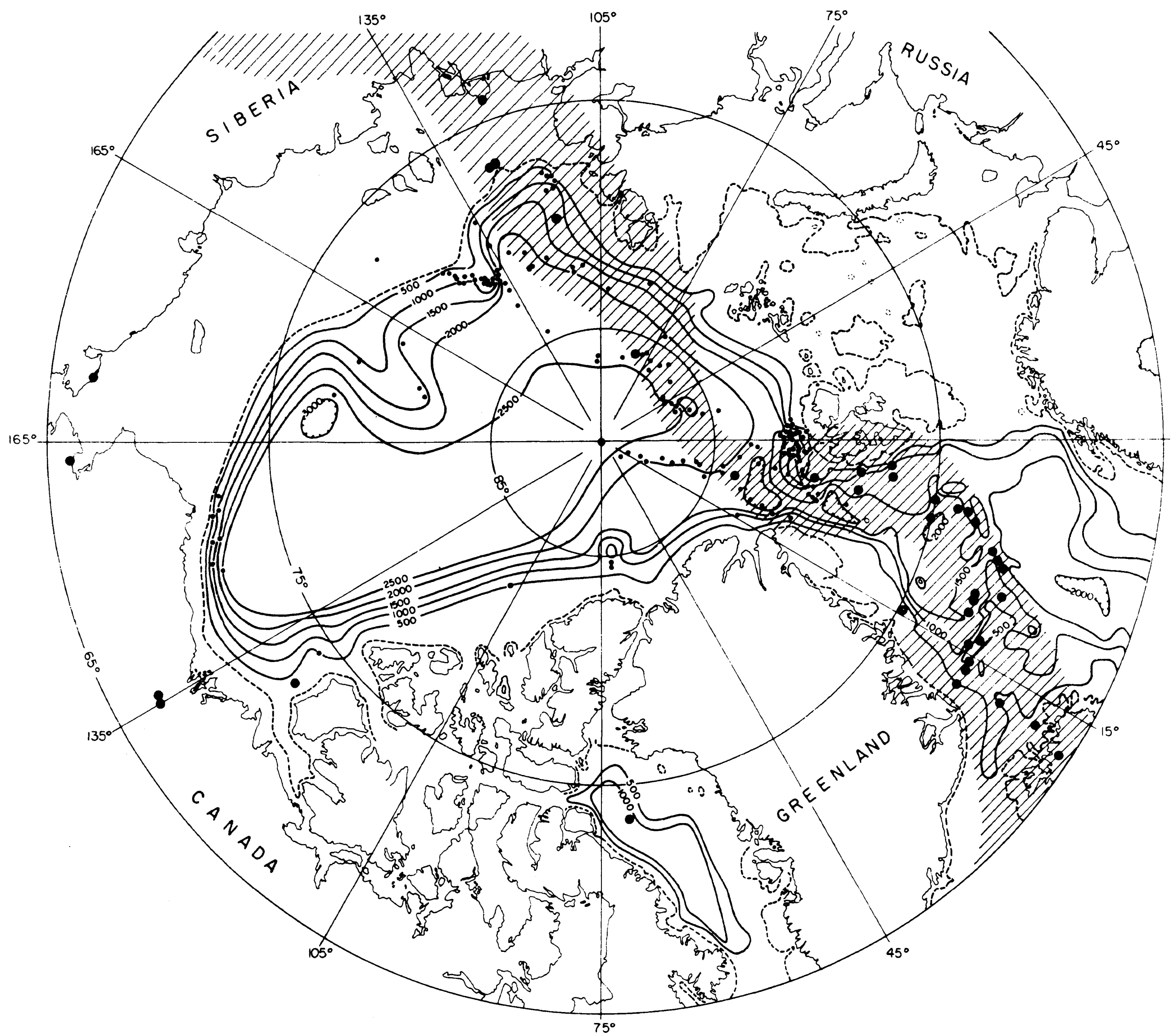
1. 6. Summary of Concepts on the Geology and Structure of the Arctic Ocean Basin

Following World War II activity in the Arctic Ocean has been greatly accelerated, particularly by the Soviets. In 1949 Emery summarized what was then known of the ocean floor in a published chart of the Arctic Basin. This chart was based on 152 soundings deeper than 915 m, or an average of one to each 12,000 square miles. His bathymetric map is shown as Figure 4 and portrays the popularly-held belief that the ocean was a single homogeneous basin. It is interesting to note that this 1949 bathymetric chart varies little from that constructed by Nansen in 1904. In a careful analysis of all the data then available, Emery arrived at the following conclusions:

Figure 3.



UNEXPLORED OR UNSEEN AREAS IN THE ARCTIC BASIN AS OF 1929
(AFTER AMERICAN GEOGRAPHICAL SOCIETY, 1929)



1949 BATHYMETRIC MAP OF THE ARCTIC OCEAN (AFTER EMERY)

——— 500 FATHOM INTERVAL
- - - - - 100 FATHOM ISOBATH
• SOUNDINGS DEEPER THAN 500 FATHOMS
//// SEISMIC
● EARTHQUAKE EPICENTERS 1921 TO 1944

Figure 4.

1. The continental shelf from the Taimyr Peninsula eastward to eastern Alaska is deep and irregular because of glacial erosion and deposition, while the rest of the shelf is shallow and flat because it was not covered by the Pleistocene glaciation.

2. The bottom topography may be irregular because of submarine faulting. This speculation was based on projection of the earthquake epicenter zone from the well defined Mid-Atlantic Ridge to the virtually unknown basin north of Europe.

3. The basin is oval-shaped, possibly being deepest near Alaska and eastern Siberia. On the basis of four relatively shallow soundings north of the East Siberian Sea, Emery speculated that the Arctic Basin might be divided by a structural ridge extending northward from a position between Wrangel Island and the New Siberian Islands.

4. The floor of the basin may be fairly irregular because of the slow rate of deposition of sediments by all agents.

Meanwhile some thought was given to the geologic structure of the Arctic Ocean Basin. The theories of continental drift that were formulated in the early years of the century served to focus attention on the basin. Taylor (1910) postulated that Eurasia and North America had once been joined over the North Polar region as one great continent. They were subsequently rent apart and drifted toward the equator leaving the Arctic Basin as a single "disjunctive" depression. Greenland was considered a fragment of the rupture between North America and Europe. The schemes of continental drifting of Koppen and Wegener (1924) show a small polar basin that was enlarged appreciably as North America, hinging in the North Polar region, drifted westward and away from Europe.

By the time of Wegener's major publications the concept of a layered crust had become accepted. The continents were believed to be made up of a silica-rich, light, upper layer (sial) resting on a mafic-rich layer (sima). When a continent broke and parted, the sial drifted over the sima, leaving behind a crust made up solely of sima which, for isostatic reasons, formed a basin. Hence, according to Koppen and Wegener, the Arctic Ocean Basin is underlain by simatic crust.

In the support of this conclusion, Gutenberg and Richter (1939) observed that the amplitudes of reflected longitudinal earthquake waves indicated the presence of bottom rock similar to that of the Pacific Ocean and not like that of continents. Unfortunately they did not have the seismic velocity measurements needed to verify the character of the basement material (Emery, 1949).

The continental drift theories of Taylor (1910) and of Koppen and Wegener (1924) implied that the Arctic basin was structurally a continuation of the Atlantic depression and that the structure of its floor had no connection with the geologic structures of the surrounding continents and islands. However, in an extensive review of the geology of the lands around the Arctic Ocean Basin, Eardly (1948) argued that the basin was a foundered continental section which had been dry land in Precambrian or perhaps even Paleozoic times. His conclusions were based upon the following evidence:

1. The occurrence of a mainland assemblage of sediments on the Arctic side of the Paleozoic Cordilleran geosyncline in Alaska required a source north of the present land area.

2. Much of the floor of the Arctic Ocean is very shallow, and the deep basin is smaller than that of any existing oceans, being more comparable to the Mediterranean and the Gulf of Mexico-Caribbean Sea.

3. The Precambrian shields of the northern hemisphere (Canadian, Greenland, Russian-Baltic and Angara) all face the Arctic Ocean and, with the exception of Alaska, surround it with a common geology; thus, it appears that the deep basin is only a foundered part of a single great continent.

4. The Precambrian shields are separated by Paleozoic orogenic belts (Ural-Novaya Zemlya, Norway and Spitzbergen, East Greenland, Canadian Arctic Archipelago, Northland and New Siberia) which project with full development to the Arctic coast, implying that they must continue for long distances into the region now covered with water.

5. Stratigraphic and structural evidence on the lands surrounding the Arctic Ocean indicate considerable tectonic unrest in Cenozoic time with great vertical movements of the crust and the development of belts of compressional orogeny.

6. The occurrence of common Paleozoic fossil fauna in North America and Eurasia bespeaks shallow sea migration routes bordering the once emergent and later subsiding lands.

Eardly's thesis that the Arctic Basin was a foundered continental block was in agreement with the prevailing Soviet concept that the geological structure of the Arctic Ocean floor is a direct continuation of the coastal structural elements, the floors of the shallow bordering seas, and the islands in these seas (Saks, et al., 1955).

Chapter 2

INVESTIGATIONS OF THE ARCTIC OCEAN BASIN 1949 to 1955--THE CONCEPT OF A DIVIDED BASIN

2. 1. Soviet Investigations

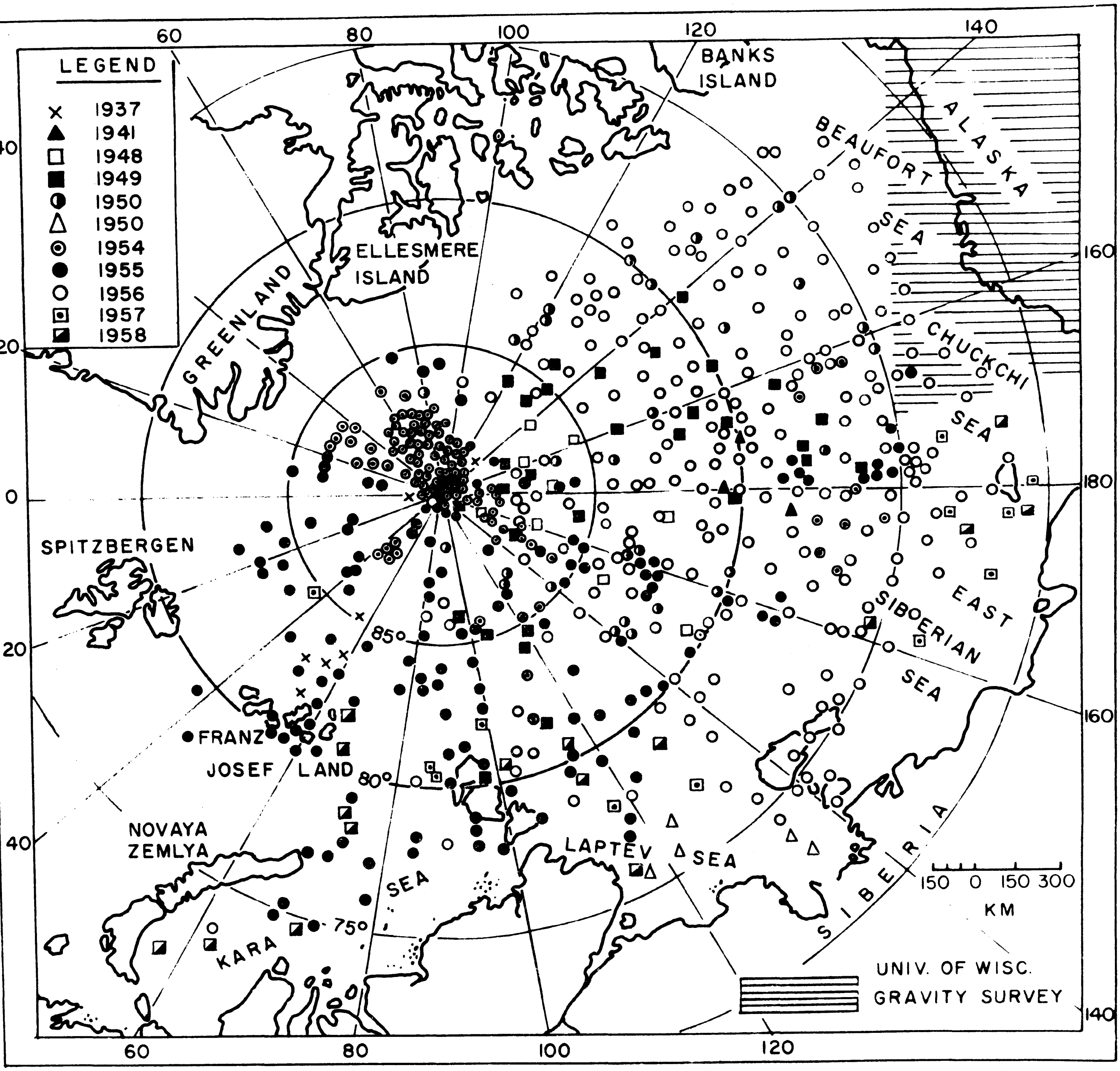
In 1948 the Russians resumed air expeditions into the Arctic Basin under the name of the "High Latitude Expedition." A "flying laboratory" method of investigation was used in which scientific parties are landed at pre-selected points upon the sea ice, where they conduct impressively complete scientific programs including oceanography, meteorology, gravity, seismology, and terrestrial magnetism. The plane and crew remain with the party for the two to four days required to complete observations. By this method several stations are established on each "flight" and the "laboratory" returns to base only as often as fueling, maintenance, weather, and personnel fatigue demand. By 1954 hundreds of these airborne stations had been occupied, and in 1955 alone a total of three quarters of a million miles were flown over the Arctic Ocean in nearly 5,500 flight hours using 22 aircraft (Laktionov and Shamontév, 1957). The locations of the Soviet airlifted stations are shown in Figure 5. Some principal facts about U.S.S.R. and U.S.A. airlifted expeditions are given in Table II, and the number of airplanes, hours aloft, and extent of aerial ice reconnaissance routes in the Arctic completed by the Soviets annually is shown in Table III.

Soundings from the High Latitude Expeditions of 1948-49 led by Professor Ya. Ya. Hakkel' confirmed the existence of a great submarine mountain range which extends across the Arctic Basin from the New Siberia Islands to Ellesmere Island. The Lomonosov Ridge, as it was subsequently named, was apparently not reported in literature until 1954.

As a result of aeromagnetic surveys conducted by the Arctic Institute over the Soviet Arctic seas in 1946-48, Russian investigators traced the seaward extension of the Mesozoic folded Verkhoyan Range into the Laptev Sea to the western part of the New Siberian Islands (Saks, et al., 1955). Although the existence of the Lomonosov Ridge had not yet been proven by soundings, the strike of the range was seen in anomalies in the vertical component of the magnetic field.

No other references have been found regarding Soviet aeromagnetic activities over the Arctic Ocean. However, Saks, et al. (1955) emphasized the importance of continuing such studies and implied the intent to re-establish the program.

Two manned ice-floe stations were established in 1954 followed by a third in 1955 (Table I). These were designated NORTH POLE 2, 3, and 4 and supported comprehensive programs in meteorology, oceanography, and geophysics (Fig. 2).



SOVIET AIRLIFTED SCIENTIFIC STATIONS

Figure 5.

TABLE II

Some Principal Facts About Airlifted Scientific Stations in the Arctic Ocean

Year	Leader	Country	Scientific Program				No. of Stations
			S	M	O	G	
1927	G. H. Wilkins	U.S.A.	X				1
1937	O. Yu. Schmidt	U.S.S.R.		X			7
1941	Ia. S. Libin	U.S.S.R.	X	X	X	X	3
1948	Ya. Ya. Hakkel'	U.S.S.R.	X	X	X	X	8
1949	Ya. Ya. Hakkel'	U.S.S.R.	X	X	X	X	33
1950	M. E. Ostrekin	U.S.S.R.	X	X	X	X	39
1951	A. P. Crary	U.S.A.	X		X	X	6
1951	L. V. Worthington	U.S.A.	X(2)		X		12
1952	L. V. Worthington	U.S.A.	X(1)		X		8
1954	V. F. Burkhanov	U.S.S.R.	X	X	X	X	103
1955	V. F. Burkhanov	U.S.S.R.	X	X	X	X	136
1956	E. I. Tolstikov	U.S.S.R.	X	X	X	X	208
1957	M. M. Nikitin	U.S.S.R.	X	X	X	X	12
1958	M. M. Nikitin	U.S.S.R.	X	X	X	X	16
1959	M. M. Nikitin	U.S.S.R.	X	X	X	X	?
1960	M. M. Nikitin	U.S.S.R.	X	X	X	X	?
1960	R. W. Patenaude	U.S.A.				X	38
1961	P. A. Gordienko	U.S.S.R.	X	X	X	X	?
1961	N. A. Ostenso	U.S.A.	X			X	71

S = Depth Soundings
M = Meteorology
O = Oceanography
G = Geophysics

TABLE III

Number of Airplanes, Hours Aloft and Extent
Aerial Ice Reconnaissance Routes in the
Arctic by the Soviets, 1933-56*

Year	1933	1934	1935	1936	1937	1938
Number of aircraft	3	6	7	10	9	19
Hours aloft	200	300	600	500	400	1,300
Extent (km x 10^3)	---	---	---	---	---	---

(cont.)

Year	1939	1940	1941	1942	1943	1944
Number of aircraft	23	24	23	11	9	9
Hours aloft	1,400	2,100	1,800	2,000	2,100	2,900
Extent (km x 10^3)	---	---	---	---	---	---

(cont.)

Year	1945	1946	1947	1948	1949	1950
Number of aircraft	15	15	21	21	27	35
Hours aloft	2,600	3,300	2,900	2,400	4,800	5,200
Extent (km x 10^3)	---	---	---	---	---	---

(cont.)

Year	1951	1952	1953	1954	1955	1956
Number of aircraft	49	48	31	27	22	59
Hours aloft	5,500	5,400	6,000	6,100	5,500	6,700
Extent (km x 10^3)	1,650	1,240	1,300	1,360	1,250	1,665

*after Laktionov and Shamont'ev (1957)

2. 2. United States Investigations

In April 1951, under the sponsorship of the U. S. Air Force Cambridge Research Center, six landings were made on the Beaufort Sea ice pack north of Alaska (Fig. 6). Although only six hours time was allowed for each station, seismic soundings, gravity measurements, and measurements of the direction of ice movement were completed. The ocean depths in this region varied between 3400 and 3800 m (Crary, et al., 1952). Another series of airlifted oceanographic stations was completed with the sponsorship of the Office of Naval Research under the code name "Project Skijump." During the spring of 1951 twelve landings were made on the sea ice, and three hydrographic stations were occupied (Fig. 6). In March 1952, eight more landings were made and five hydrographic stations completed. Although considerable oceanographic data were collected, only one shallow and two deep soundings were obtained as a result of this project (Worthington, 1953).

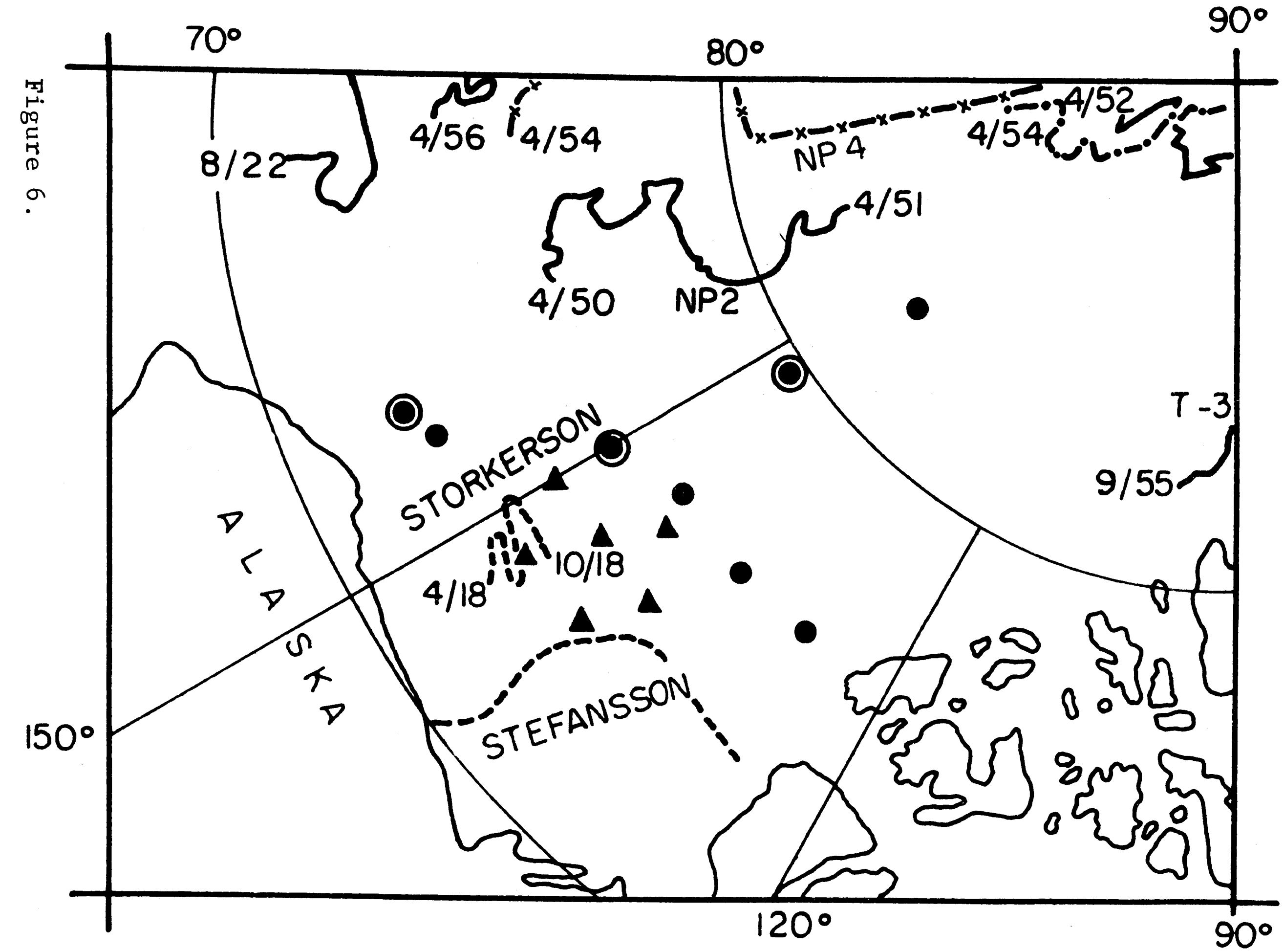
In March 1952 the Alaskan Air Command of the U. S. Air Force installed a scientific station on ice island T-3 which was then located in the center of the Arctic Ocean. Because this camp was initially under the leadership of Lt. Col. J. O. Fletcher, the island is frequently referred to as "Fletcher's Ice Island." In April 1952 a program of geophysical investigations was initiated by A. P. Crary on T-3, and in June upper air meteorological studies were added by the Air Weather Service of the U. S. Air Force. The station was occupied until May 1954 when it was abandoned due to its proximity to Ellesmere Island. T-3 was briefly re-occupied from April to September 1955, and a modest geophysical, meteorological, and marine biology program was carried out (Table 1 and Fig. 2).

One of the most significant discoveries to be made from T-3 was a prominent ridge (Marvin Ridge) paralleling the Lomonosov Ridge (Crary and Goldstein, 1957). The scientific program included reflection and refraction seismology, and sub-bottom velocities were obtained at three sites.

2. 3. Summary of Concepts on the Geology and Structure of the Arctic Ocean Basin

Despite the fact that most of the data from the recently intensified U. S. and U. S. S. R. investigations had not yet been published, considerable thought went into reinterpreting the geology and tectonics of the Arctic Basin. Several significant papers were presented on these topics in the mid-1950's by Saks, et al. (1955), Hagemeister (1955), Ostrekin (1954), Hope (1954, 1959), Panov (1955 a, b) and Oliver et al. (1955). From these studies two theories, both with strong supporting evidence, emerged concerning the basic structure of the Arctic Basin. One held that the basin was of true oceanic structure, while the other supported the concept of a foundered crustal section.

Figure 6.



▲ CRARY 1951

● PROJECT SKI JUMP, 1951, 1952, WITH SOUNDINGS ◉

UNITED STATES AIRLIFTED SCIENTIFIC STATIONS, 1951-52

2. 4. The Arctic Basin as a Foundered Continent

As previously pointed out, investigators in the U. S. S. R. and Eardley in the United States believed the geology and structure of the Arctic Basin to be a direct continuation of the structural elements of the encircling continents and islands. The basin was thought to be enclosed by three great Precambrian platforms* (Fig. 7). In Russian literature these platforms are referred to as the East European platform, the Central Siberian platform, and the Greenland-Canadian platform, whereas Eardley calls them shields, and refers to the Canadian and Greenland shields separately and names the remaining two the Russian-Baltic shield and the Angara shield respectively. These ancient parts of the earth's crust are interpreted to have determined the direction of subsequent geosynclinal depressions which accumulated massive sedimentary deposits and were later folded and uplifted to form mountain systems.

Although the floor structure of the deep basin on the North American side of the Lomonosov Ridge was not clear, certain inferences were drawn. Because of the absence of Mesozoic folding in the eastern part of the New Siberian archipelago and in northern Alaska, and because of the East-West strike of the Mesozoic folds on the coasts of the East Siberian and Chukchi Seas, on Wrangel Island, and in the Brooks Range of Alaska; an area which was bypassed and skirted by the Mesozoic folds was believed to lie north of these localities. Long ago the Soviet geologist Shatskiy (1935) had put forward the idea of a so-called Hyperborean Shield located in the region of the De Long Islands and in the northern portion of the East Siberian Sea. Saks et al. (1955) reported that aeromagnetic surveys have confirmed the existence of a "solid buttress" north of northeastern Siberia. The platform apparently extends to Northern Alaska and into the Beaufort Sea, perhaps even joining up with the Greenland-Canadian platform.

Hakkel' (1958) reported evidence of volcanic activity in the Arctic Ocean (Fig. 8). While drifting over the crest of the Lomonosov Ridge on 21 November 1954, a strong shock was felt on the drifting station North Pole 3, which was attributed to an earthquake. On 24 November four more severe shocks were felt, and soon after there was a strong smell of hydrogen sulfide and probably sulfur dioxide. With the final shock the ice floe upon which the station was built split across. When one of the camp personnel walked over to this fresh lead he was overcome by the gas. Hakkel' concluded that the station had drifted over an erupting submarine volcano.

Believing that the Lomonosov Ridge is an extension of the Mesozoic Verkhoyan folded mountain range, Hakkel' developed the following theory: In the Verkhoyan Range, strong explosive eruptions occurred during the

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*Soviet geologists use the term "platform" to mean a highly deformed basement of ancient rock overlain by relatively undislocated strata. The system represents a stable tectonic element and can possibly be considered as being most synonymous with the term "craton." Their use of the term "shield" on the other hand is more explicit, denoting the emergence of the ancient basement of a platform (Hope, 1959).

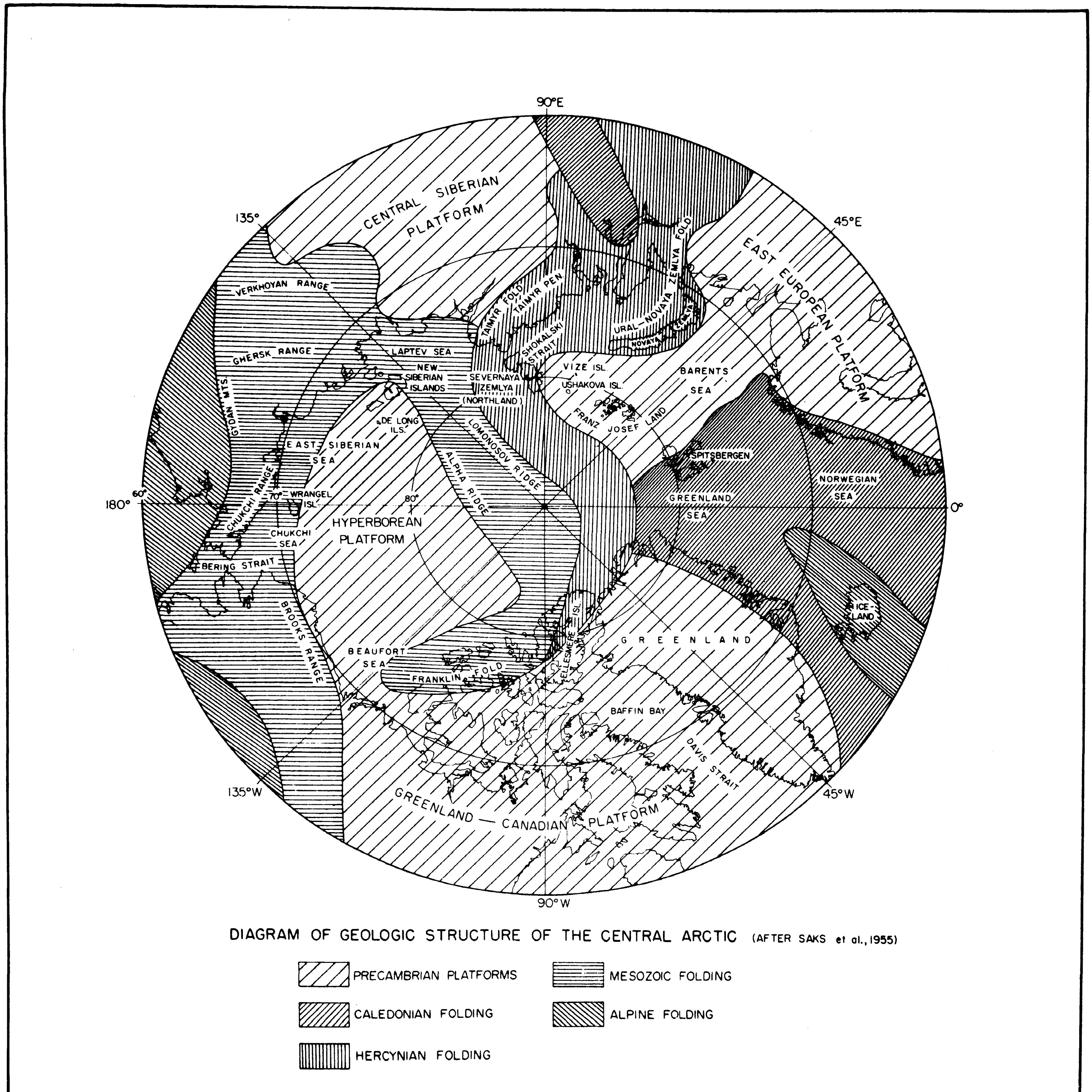
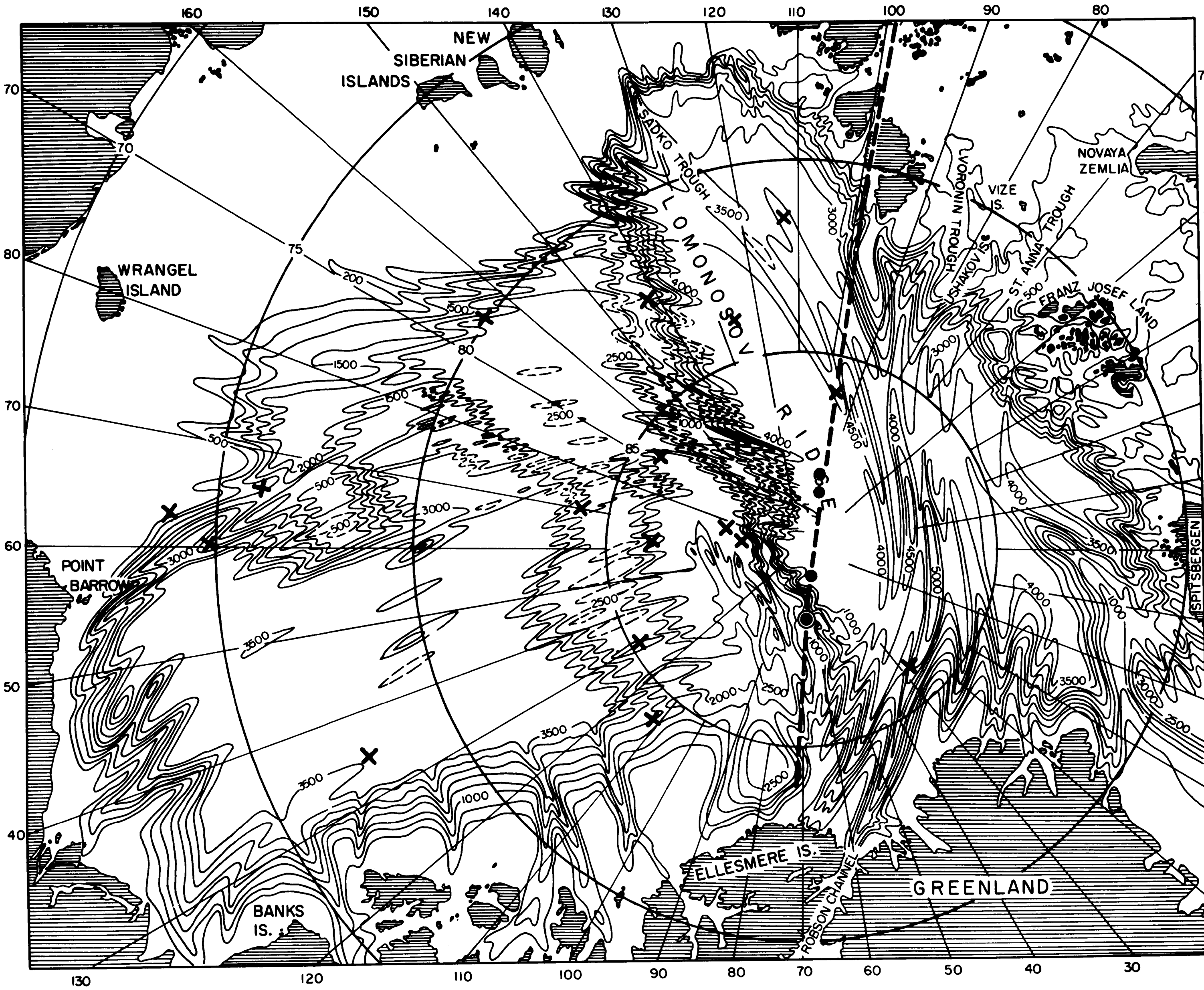

90°E
CENTRAL SIBERIAN PLATFORM
135°
45°E
EAST EUROPEAN PLATFORM
VERKHOYAN RANGE
TAIMYR FOLD
TAIMYR PEN
URAL–NOVAYA ZEMLYA FOLD
NOVAYA ZEMLYA
SHOKALSKI STRAIT
GHERSK RANGE
LAPTEV SEA
NEW SIBERIAN ISLANDS
SEVERNAYA ZEMLYA (NORTHLAND)
VIZE ISL
USHAKOVA ISL.
BARENTS SEA
FRANZ JOSEF LAND
GYDAN MTS.
DE LONG ILS.
LOMONOSOV RIDGE
ALPHA RIDGE
EAST SIBERIAN SEA
SPITSBERGEN
NORWEGIAN SEA
180°
60°
70°
80°
0°
CHUKCHI RANGE
WRANGEL ISL.
HYPERBOREAN PLATFORM
GREENLAND SEA
CHUKCHI SEA
BERING STRAIT
ICELAND
BROOKS RANGE
ELLESMERE ISL.
GREENLAND
BEAUFORT SEA
FRANKLIN FOLD
BAFFIN BAY
DAVIS STRAIT
135°W
45°W
GREENLAND — CANADIAN PLATFORM
90°W
DIAGRAM OF GEOLOGIC STRUCTURE OF THE CENTRAL ARCTIC (AFTER SAKS et al., 1955)
PRECAMBRIAN PLATFORMS
MESOZOIC FOLDING
CALEDONIAN FOLDING
ALPINE FOLDING
HERCYNIAN FOLDING

Figure 7.



DIAGRAMMATIC CHART OF SIGNS OF VULCANISM IN THE ARCTIC OCEAN BASIN (AFTER HAKKEL, 1958)

◉ ACTIVE SUBMARINE VOLCANO IN THE LOMONOSOV RANGE

● POINTS WHERE VOLCANIC GLASS WAS FOUND

✕ POINTS WHERE BASALTIC HORNBLENDE WAS FOUND

– – – SUGGESTED FRACTURE LINE

SCALE 100 0 100 200 300 KM

Figure 8.

Triassic, which were later renewed in the Upper Jurassic, gradually subsiding throughout the whole of the lower Cretaceous, and apparently terminating in the upper Tertiary. Volcanic eruptions possibly took place in the Lomonosov Ridge also during the Mesozoic and Cenozoic eras and have continued to the present time. In addition to the suspected active volcano, other evidence of recent volcanism in the Arctic Ocean Basin was observed. From bottom corings, Soviet investigators found basaltic hornblende in seventeen locations and volcanic glass in three. Hakkel' noted that the occurrence of the active volcano and locations of the volcanic glass lie on a great circle which, when extended southward, passes through Shokal'ski Strait to the Lower Taimyr River. Soviet geologists believe that these latter two features, along with Lake Taimyr, lie along a deep fracture in the earth's crust. If the great circle is extended southward from the active volcano, it follows the western slope of the Lomonosov Ridge terminating against the coast of Ellesmere Island. Thus, Hakkel' postulates the existence of an enormous fault in the earth's crust passing near the North Pole.

Panov (1955 a) described recent tectonic movements in the Arctic based upon observational evidence and speculation. His conclusions are summarized in Figure 9.

2. 5. Historical Development of the Arctic Basin

From the available evidence, Soviet geologists constructed the following picture of the development of the tectonic framework of the Arctic Ocean Basin: First, the great Arctic Precambrian consolidation broke up into the East European, Central Siberian and Greenland-Canadian platforms leaving them separated by thin crusted geosynclinal corridors. Subsequently, the geosyncline, which is now marked by the Lomonosov Ridge, began to receive an influx of detritus from the flanking regions of folding, i.e., Precambrian on the North American side and Hercynian on the Eurasian side.

During the Caledonian cycle (see Table IV), folding took place in Scandinavia, the Greenland Sea, Spitsbergen, Nansen's Sill and North-East Greenland (Fig. 7). To the east of the Caledonian orogenic belt there was a rigid block extending over the Barents Sea which included the eastern part of Spitsbergen, Franz Josef Land and the northern part of the Kara Sea including Ushakov and Vize [Wiese] Islands. This block was a northward continuation of the East European platform.

At the close of the Paleozoic era, Hercynian folding developed in the Ural-Tianshan area between the East European and Central Siberian platforms. This fold belt extended northward to Novaya Zemlya, the Taimyr Peninsula, Severnaya Zemlya, and thence, it is presumed, across the Arctic Basin, coming to the surface again on Ellesmere Island. Saks et al. (1955) stated that it is highly probable that the Hercynian fold-structures occupy the bottom of the ocean deep on the Eurasian side of the Lomonosov Ridge including the region of the North Pole. These folds closely parallel the strike of the Lomonosov Ridge.

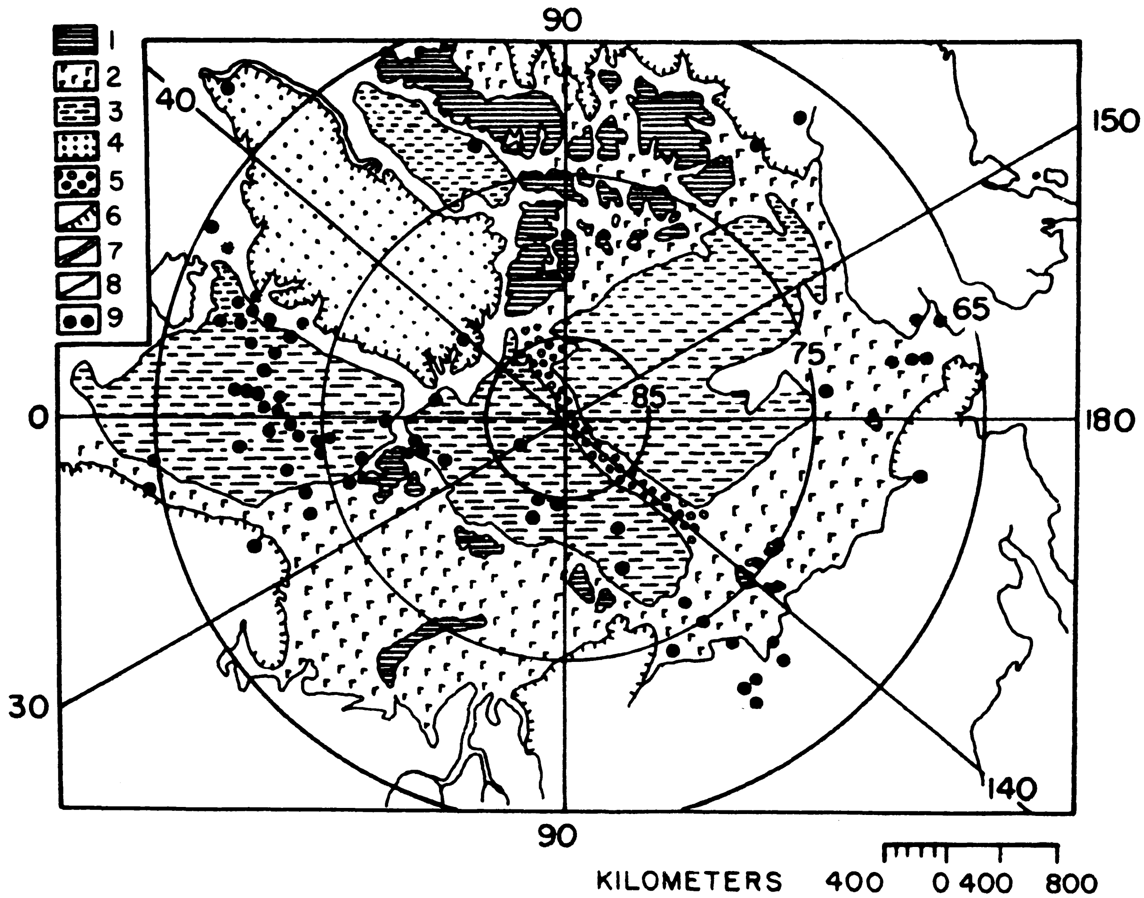


DIAGRAM OF NEOTECTONIC MOVEMENTS IN THE ARCTIC (PANOV, 1955a)

1. Block uplifts and anticlinal uplifts of Arctic islands. 2. Regions with predominant irregular subsidence of shelf in Alpine platform areas. 3. Regions with predominant subsidence of ocean basins in ancient platform areas. 4. Region of present-day continental ice with accompanying disturbance of isostatic equilibrium of the earth's crust (subglacial depression of crust). 5. The Lomonosov oceanic mountain range, a region of probably irregular subsidences. 6. Coasts with intensive postglacial uplift. 7. Coasts with intensive postglacial subsidence. 8. Coasts with relatively stable level during postglacial epoch (possible alternation of minor uplifts and subsidences). 9. Earthquake epicenters.

Figure 9.

TABLE IV

Time Relationships of Orogenic Cycles*

Orogenic cycles**	Periods of Systems	Eras	Time Since Beginning of Interval *** years x 10^6
Alpine	Quaternary	Cenozoic	1
	Tertiary		63
Mesozoic	Cretaceous		135
	Jurassic	Mesozoic	181
	Triassic		230
Hercynian	Permian		280
	Carboniferous	Upper Paleozoic	345
	Devonian		405
Caledonian	Silurian		425
	Ordovician	Lower Paleozoic	500
	Cambrian		600+

*After Hope (1959)
**These four orogenic cycles are commonly distinguished by Soviet geologists
***After Kulp (1961)

The Mesozoic era was marked by intense folding in Alaska and Northeastern Asia with the development of the Brooks Range in the former and the Verkhoyan, Chersk, Gydan and Chukchi Ranges in the latter. From structural relationships with the Verkhoyan fold belt in Siberia, the Franklin fold belt along the northern margin of the Canadian archipelago, and aeromagnetic evidence, the Lomonosov Ridge was considered to be a Mesozoic fold structure representing the continuation of a single orogenic belt stretching across the Arctic Ocean.

At the close of the Mesozoic era and concomitant with, or slightly later than, the orogenesis of the Lomonosov Ridge the portions of the Arctic Ocean now covered with deep water subsided. The Hyperborean platform sank to form the floor of the basin on the North American side of the Lomonosov Ridge while the Hercynian fold-structure formed the floor of the other sub-basin. Hakkel's bathymetric chart (Fig. 8), which will be discussed later, shows a series of parallel rises on the floor of the former basin. These rises run parallel to the North American and Siberian continental shelves and roughly perpendicular to the strike of the Lomonosov Ridge. Hakkel' first described these ridges as being folds, but later, on the basis of topographic evidence, concluded that the major ridges were due to faulting. He theorized that the Hyperborean platform, in the process of subsidence, fractured along roughly parallel lines, with the fractures forming the continental slope on the North American side and a staircase effect on the Siberian side (Hakkel', 1957). These "ancient mountain arcs," as Burkhanov calls them, extend onto the Lomonosov Ridge. Their influence on the later Mesozoic folding of the Lomonosov Ridge takes on a topographic expression in the form of parallel spurs striking at an angle of about 60° to the mountain range. These spurs are clearly shown in Hakkel's bathymetric chart.

Paleontological evidence as well as evidence of past glaciation, indicate that only the deepest basins of the ocean were water-filled during the beginning of the Tertiary period (Saks et al., 1955). The Arctic border seas and continental shelves were dry land with the exception of the Kara and Greenland Seas. These seas served as straits connecting the two deep basins with the seas in southern Eurasia and the Atlantic Ocean until the middle of the Triassic period. The straits also played a major role in creating a mild climate in the Tertiary Arctic Ocean, along the shore of which broad-leaved forests are known to have flourished. The unique character of the deep-water fauna shows that water depths of the order of several kilometers existed in the deep basins from at least the beginning of the Tertiary period.

Although no Alpine orogeny was recognized in the Arctic Basin, an active seismic zone is known to extend from the Mid-Atlantic Ridge across the Laptev Sea, then paralleling the Verkhoyan Range, and finally joining the Circum-Pacific seismic belt (Figs. 4 and 9). In contrast the deep basin on the North American side of the Lomonosov Ridge is marked by seismic quiescence. The mobility of the earth's crust in the area of the Eurasian Arctic Ocean deep, together with manifestations of recent volcanism on the periphery of the deep (Spitsbergen, Greenland, Greenland Sea, Iceland), suggested to Soviet investigators that this depression is an incipient geosyncline. Throughout the Tertiary and Quaternary periods, this geosyncline was the catch-basin for enormous quantities of detritus washed northward from the greater part of the Eurasian continent (including the Barents, Kara and Laptev Seas which were then dry land), from Greenland, and from the eastern part of Canada and the Canadian archipelago (Saks et al., 1955).

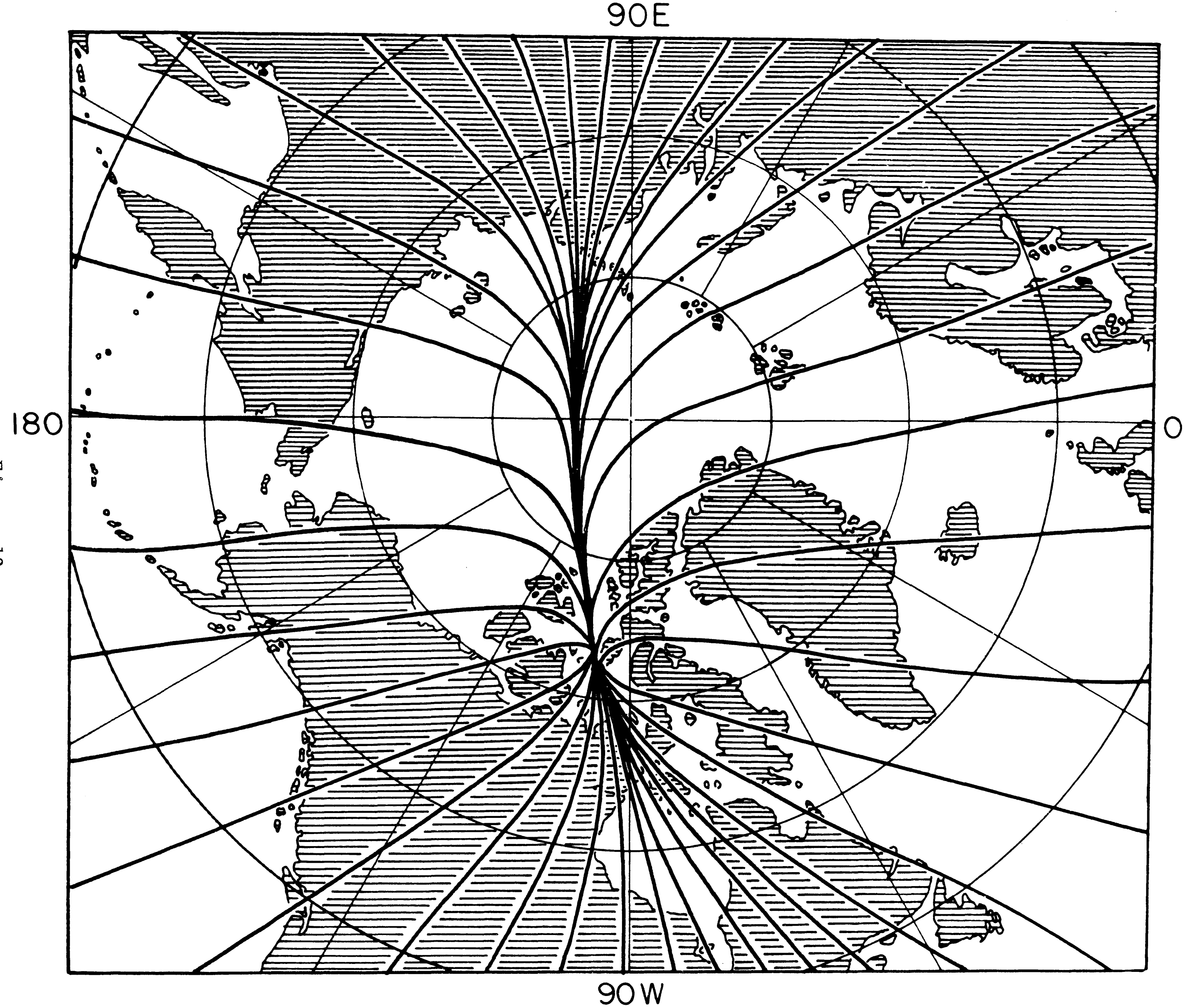
2. 6. The Arctic Basin as an Oceanic Structure

Oliver, Ewing, and Press (1955) presented strong evidence that the crustal structure of the Arctic Basin in noncontinental in character. Analyzing a number of trans-Arctic Ocean earthquake paths, they noted the absence of the Lg surface-wave in every instance. As they pointed out, there have been no cases reported where the Lg phase has been propagated for any great distance beneath water deeper than 2000 meters whereas it is transmitted freely through a continental crust. Thus it appears that water depths actually reflect changes in the crustal column. Further, there has been no geophysical evidence of a continental crustal column underlying oceanic depths.

Failing to observe the Lg phase on wave paths crossing the Arctic Ocean, the Beaufort, Greenland, and Norwegian Seas and the deep Bering Sea, they concluded these areas to be of noncontinental structure. On the other hand, the presence of the Lg phase indicated that the water-covered areas of continental structure include the Canadian archipelago, parts of Baffin Bay, the Barents Sea, and Davis and Bering Straits. In the same paper, Rayleigh-wave dispersion from three earthquakes with trans-oceanic wave paths were analyzed. This study indicated a crustal thickness intermediate between continental and oceanic. However, Oliver, Ewing, and Press state that these data were too poor to warrant a final conclusion.

2. 7. The Great Arctic Magnetic Anomaly

The magnetic observations taken during the drifts of North Pole-1 and the SEDOV substantiated the century-old theory of a possible second magnetic pole in the vicinity of 86°N, 180°E, in addition to the one near the Boothia Peninsula. However, observations conducted during the High-Latitude Expeditions showed that at this supposed second magnetic pole the inclination of the vertical component of the earth's magnetic field was only about 88.5°, not 90° (Hakkel', 1957). Thus, rather than two magnetic poles, there was a corridor along which the magnetic meridians drew together to form a long cluster of near parallel lines extending across the Arctic Basin from Taimyr Peninsula to the north magnetic pole (Fig. 10). This feature was subsequently named the Great Arctic Magnetic Anomaly by the Soviet investigators, who also pointed out the close relationship between the anomaly and the Lomonosov Ridge. Burkhanov (1956) stated that there is no doubt that the magnetic anomaly, in some degree, originates in the magnetic content of the rock formation of the Lomonosov Ridge. He also made brief reference to the discovery of local magnetic anomalies concentrated in comparatively small areas. The Great Arctic Magnetic Anomaly will be discussed further in Chapter 6.



GREAT ARCTIC MAGNETIC ANOMALY

Figure 10.

Chapter 3

INVESTIGATIONS OF THE ARCTIC OCEAN BASIN SINCE 1955

3. 1. Soviet Expeditions

Since 1955 the U.S.S.R. has continued an intense program of geophysical research in the Arctic Ocean including very active participation in the International Geophysical Year. Their drifting station activities were extended by the addition of five research stations: North Pole-5 (1955), North Pole-6 (1956), North Pole-7 (1957), North Pole-8 (1960) and North Pole-9 (1960), (Fig. 2, Table I). Presumably only North Pole-8 is still occupied. Gordienko and Laktionov (1960) report that as of 1960 the airborne and drifting station research operations had completed more than 900 episodic deep-water oceanographic stations, over a hundred 24-hour stations with continuous recording of temperature and salinity, about 300 hydrobiological stations, over 800 bottom corings and more than 20,000 depth measurements.

3. 2. United States Expeditions

The United States' program of Arctic Ocean research received new impetus during the International Geophysical Year and two drifting stations were established. One was placed on ice island T-3 which had been abandoned since 21 September 1955. The ice island was renamed station Bravo, and was abandoned in late 1961 after being grounded on the Chukchi Shelf about 150 km northwest of Point Barrow, Alaska for over a year. The magnitude of the scientific program on Bravo has varied considerably. On 19 February 1962 a skeleton party from the Arctic Research Laboratory was placed on T-3 shortly after it broke loose of its mooring and began drifting northward into deep water. A full scientific program is planned for the island.

The second station, Alpha, was constructed on pack ice and was occupied for seventeen months before breakage of the floe necessitated an emergency evacuation (Table I, Fig. 2). In addition to comprehensive oceanography and meteorology, the scientific program on Alpha included gravity measurements and reflection and refraction seismology from which a major submarine physiographic feature was discovered (Hunkins, 1960). Throughout its occupation, station Alpha drifted over a rise which was subparallel to, and on the North American side of the Lomonosov Ridge. This feature, named Alpha Ridge, is over 200 km wide and has a vertical relief of 1,600 m. On Hakkel's bathymetric chart of 1955 (Fig. 8) the pedestal of the Alpha Rise is clearly indicated but not the rise itself. Apparently the Soviet network of Arctic Ocean soundings was not sufficiently detailed in this region to detect the crest.

To continue Arctic Ocean research begun during the I.G.Y., a third station, Charlie (originally designed Alpha-2), was established on floe ice in April 1959. This joint military-civilian effort was undertaken in conjunction with the International Geophysical Co-operation. Station Charlie was occupied for 287 days during which time it drifted across the Chukchi Cap.

Under Office of Naval Research sponsorship, the Arctic Research Laboratory, Barrow, Alaska has recently established two drifting stations in the Beaufort Sea. The first of these, ARLIS-1 (Arctic Research Laboratory Ice Station - One), was set up on 25 September 1960 and was occupied for 174 days before breaking up northeast of Wrangel Island. The second station, ARLIS-2, was established on an ice island 200 km north of Point Barrow on 23 May 1961. This station is still in operation and its scientific program includes gravity and magnetic observations and depth soundings conducted by the Geophysical and Polar Research Center of the University of Wisconsin.

3. 3. Submarine Voyages

With the advances of modern technology and nuclear sources of power Sir Hubert Wilkens's dream of exploring the Arctic Ocean by submarine has become a reality. The modern nuclear submarine with its ability to move with relative impunity under the ice pack promises to be a powerful tool in studying the Arctic Basin. Unfortunately, the movement of these vessels is usually shrouded in secrecy and thus far few data obtained from their passages across the Arctic Ocean have been made available. Hopefully this imposed limitation on the scientific value of nuclear submarines is but temporary. A brief resumé of United States submarine activity in the Arctic Ocean is given in Table V.

3. 4. Current Concepts on the Structure of the Arctic Ocean Basin

Opinions as to the structure of the Arctic Ocean Basin can still be divided into two divergent camps; one maintaining that the basin is truly oceanic in character, while the other supports the theory of a foundered segment of continental crust with a continuation of structural elements from the encircling land masses into the basin. Proponents of the foundered continent theory are represented by such well-known investigators as Beloussov, Burkhanov, Hakkel', Panov, and Saks. The oceanic theory is supported by such equally well-regarded investigators as Ewing, Heezen, Oliver, Press, and also Eardley who, in his most recent paper (1961) on the subject, reversed his earlier stand.

Soviet thought has been little changed from that summarized in Chapter 2 although there are some differences of opinion regarding specific

TABLE V

United States Submarine Activity in the Arctic Ocean

Date	Vessel	Remarks
Summer, 1947	USS Boarfish (SS-327)	In the first extended under-ice dives covered about 30 miles in three dives in the Chukchi Sea.
Summer, 1948	USS Carp (SS-338)	Experimented with methods of diving and surfacing in ice in the Chukchi Sea.
Aug.-Sept., 1952	USS Redfish (SS-395)	Conducted joint explorations with Canada in the Beaufort Sea.
Aug.-Sept., 1957	USS Nautilus (SSN-571)	Conducted under-ice operations in the Greenland Sea and Arctic Ocean. In five and one-half days covered 1,383 miles under the ice pack to within 180 miles of North Pole.
	USS Trigger	Traversed under the edge of the pack.
Aug., 1958	USS Nautilus (SSN-571)	Made first under-ice crossing of Arctic Ocean from Bering Strait to Iceland passing under the North Pole.
	USS Skate	Made exploratory trip from eastern Arctic to North Pole closely paralleling the eastern track of the Nautilus.
March, 1959	USS Skate	Completed long winter cruise under pack. Proved the feasibility of surfacing through winter ice.

TABLE V cont.

Date	Vessel	Remarks
March, 1959	USS Harder USS Trout	Penetrated winter pack ice near Newfoundland and traveled 280 miles each beneath the ice, surfacing in leads to recharge batteries. This was a record distance for conventionally-powered submarines.
Feb., 1960	USS Sargo	Made first entry to and exit from the western approaches of the Arctic Ocean.
Aug., 1960	USS Seadragon	Made first east-west transit of the Arctic Basin via Northwest Passage and North Pole.

details. Hope (1959) and Saks (1958) give excellent reviews of recent explorations and theories on the geologic and tectonic framework of the Arctic Ocean Basin. A diagram of the tectonics of the Arctic shown in Saks's paper differs but little from the one given earlier by Saks, Belov, and Lapina (1955), (Fig. 7). In his 1958 version of the diagram the mid-Atlantic zone of Alpine folding is extended further northeastward towards the Barents Sea, and the Caledonian folding along the southwestern border of the Central Siberian Platform is extended northward almost to Novaya Zemlya. Also the tongue of seismicity projecting into the Chuckchi Sea from Bering Strait has been eliminated. Hope (1959) extends the Hercynian fold belt to Prince Patrick Island.

Beginning in 1955 geologic investigation of the Canadian archipelago has been greatly accelerated. The results of this intensive study were recently summarized by Thorsteinsson and Tozer (1961) who show a considerably more complex structural framework than indicated in Figure 7. According to their review, the entire northern portion of the archipelago underwent profound subsidence from the Cambrian (possibly also the late Precambrian) to the Upper Devonian, and is now the site of a complex orogenic system resulting from two phases of earth movement; the first period, apparently of limited extent, in the early Paleozoic era (Siluro-Devonian) and the second during mid-Paleozoic time (upper Devonian to middle Pennsylvanian). The term Franklin geosyncline or fold belt has been applied to this orogenic system.

Superimposed on the Franklin geosyncline, and extending from Prince Patrick Island to northern Ellesmere Island, is the Sverdrup Basin which was the site of heavy sedimentation from the middle Pennsylvanian to the early Tertiary. A pronounced angular unconformity separates the beds in this basin from those of the folded lower Paleozoic rocks. In Tertiary (probably early Tertiary) time, folding and thrust faulting took place throughout the Franklin geosyncline and Sverdrup Basin.

Whether or not the Hyperborean platform connects with the Greenland-Canadian platform as shown in Saks's diagram is open to question. Argument is made for such a connection via a narrow neck north of the Mackenzie River by Saks (1958), whereas strong evidence to the contrary is given by Panov (1955b) and Hope (1959).

The discovery of the Alpha Ridge in 1957, which was interpreted by Hunkins (1960) to be of fault block origin, is considered by Hope (1959) to have either lagged behind the late Mesozoic subsidence of the Hyperborean platform or was subsequently thrust upward as a gigantic horst. From Saks's (1958) diagram of recent Arctic tectonics, he apparently prefers the latter interpretation. Unlike the Lomonosov Ridge, there is no evidence of subaerial continuations of the Alpha Ridge on either the Canadian or Siberian sides of the ocean nor in the contours of the continental slopes.

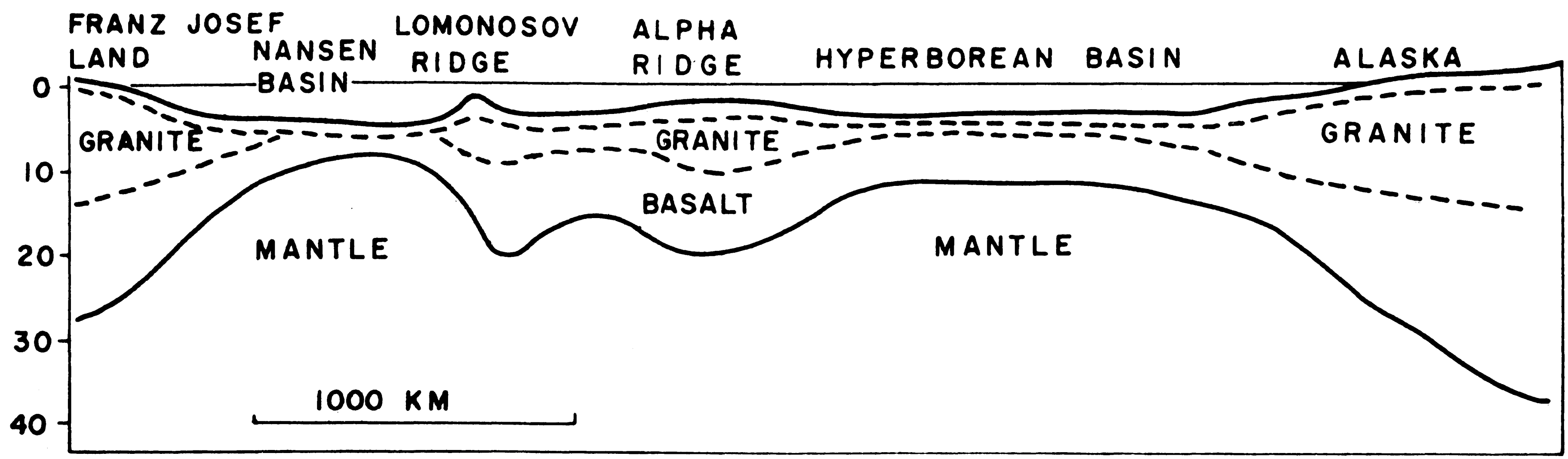
3. 5. Demenitskaya'a Crustal Section

A crustal seismic section across the Arctic Basin from Franz Josef Land to Alaska has been presented by Demenitskaya (1958), which shows a thickening of the basaltic layer under the Lomonsov Ridge and Alpha Ridge (Mendeleev Range) to 20 km and the development of a 6-km thick granite lens over the thickened basalt (Fig. 11). Unfortunately, she does not give the nature of the information upon which this diagram is drawn. This fact is particularly disturbing in that her earlier section (Hope, 1959) is somewhat different, i.e., no sediments overlying the granite, granite underlying the "Nansen Basin" (the deep on the European side of the Lomonosov Range) and a crustal thickness of 10 to 18 km under the "Nansen Basin" and Lomonosov Ridge respectively. In her paper discussing the relationship between the thickness of the earth's crust and the age of rocks (1958), Demenitskaya tabulates what are presumably all of the known seismically determined crustal thicknesses throughout the world. It is disturbing to note that this table contains no data for the Arctic Ocean. If, on the other hand, her seismic crustal section is based solely on dispersion of earthquake waves the detail shown can hardly be justified.

In Figure 11 Demenitskaya shows a typical ocean crust underlying the "Nansen Basin" where according to Saks and Hakkel' the Hercynian fold belt should be. Eardley considered the premise of this fold belt across the basin as one of the chief reasons for supporting the foundered continent theory. He now uses Demenitskaya's crustal model as evidence that the subsidence theory is improbable (Eardley, 1961). However, this apparent discrepancy can be reconciled by Hope's (1959) suggestion that, "It is possible that the roots of this ancient Hercynian mountain system have been resorbed and degranitized (Belousov, 1955), a process of which there are indications elsewhere on the globe."

3. 6. Mid-Oceanic Ridge

The existence of a seismic belt across the Arctic Ocean has long been recognized (Gutenberg, 1956; Heck, 1936; Hodgson, 1930; Raiko and Linden, 1935; Tams, 1922; and Mushketov, 1935). The seismic zone enters the Arctic Ocean from the Norwegian Sea through the Lena Trough, but it does not divide the ocean basin into two equal parts as does the Atlantic seismic belt (Fig. 9). Rather, it parallels the continental slope from Spitsbergen to Severnaya Zemlya about 450 km offshore, and finally leaves the Arctic Ocean through the Sadko Trough. This seismic belt is an extension of a network of shallow earthquakes which is associated with the global mid-oceanic ridge system. Heezen and Ewing (1961) and Heezen, Tharp, and Ewing (1959) have given evidence for extending the mid-oceanic ridge through the Arctic Basin and suggested a possible way of recontouring the Soviet bathymetric chart of the Nansen basin to be compatible with such an extension. Their arguments will be discussed in some detail in the following chapter (4.2).



CRUSTAL STRUCTURE ACROSS THE ARCTIC BASIN (AFTER DEMENITSKAYA, 1958)

Figure 11.

3. 7. Carey's Continental Drift Theory

Carey (1958) elaborated on du Toit's theory of continental drift and pictured the Americas and Eurasia separating to the north from a hinge point in south central Alaska. This hinging action would result in a bending of the western American orogenic belts and the opening of a huge triangular-shaped tension rift basin (the Arctic Ocean). The Lomonosov Ridge is believed to be a more viscous (i.e. warmer) part of the crust that was stretched out like a "thread" across the Arctic rift. However, the deeps on either side of the range will have a truly oceanic crustal structure. Carey's theory is provocative but complex.

Chapter 4

BATHYMETRIC CHART

4. 1. Hakkel's Bathymetric Chart

The most detailed bathymetric chart of the Arctic Ocean was first published by Hakkel' in 1955 (Fig. 8). According to Ostrekin (1954), the Soviets had completed more than 200 soundings at High Latitude Expedition stations by this time. The distribution of stations, however, was far from uniform (Fig. 5). Additional soundings for this chart were obtained from drift stations and ships (Fig. 2). With the possible exception of certain select localities the detail shown on Hakkel's chart is hardly justified considering the paucity of soundings. The original chart was entitled, "Bathymetric Chart of the Arctic Basin, 1955"; however, the 1958 caption for a republished copy of this same figure describes it as "diagrammatic" (Hope, 1959). However, Hakkel' may have had access to soundings made from naval and merchant vessels which have not been indicated on track maps. For instance he stated that the ridges on the Eurasian side of the Lomonosov Ridge had been traced continuously from the continental shelf off Severnaya Zemlya and Franz Josef Land to Greenland. To accomplish this more soundings would be required than are indicated from the published locations of the High Latitude Expedition sites and the tracks of drifting stations and ships. It is significant to note that a later bathymetric chart published by the highly regarded Soviet oceanographer Treshnikov (1960) and dated March 1, 1959 does not show so much detail as Hakkel's chart.

4. 2. Heezen and Ewing's Bathymetric Chart

Heezen and Ewing (1961) estimate that there are probably less than 4,000 soundings in the ice-covered portions of the Arctic Basin, excluding those from atomic submarines which are not generally available for scientific study. To date only a small number of these soundings has been published (Nansen, 1904; Buynitsky, 1940; Somov, 1954-55; Crary and Goldstein, 1957; Hunkins, 1960 b, c, d). The several bathymetric charts published by Soviet investigators have not shown the location or value of individual soundings except in the cases of Buynitsky and Somov mentioned above. As Heezen and Ewing point out, such contour charts are by themselves of limited use as it is impossible to distinguish fact from speculation. To add support to their thesis of a possible extension of the mid-oceanic ridge through the Arctic Basin, Heezen and Ewing (1961) constructed a new bathymetric chart of the deep on the European side of the Lomonosov Range. Their chart was based upon published soundings and a re-evaluation of Soviet data; i.e., by superimposing track maps of the Soviet drifting stations and High Latitude Expedition stations over bathymetric charts of similar vintage, they could, with reasonable assurance, re-establish the locations and values of observed water depth. Their revised chart clearly shows a mid-oceanic ridge extending from the Lena Trough to the Laptev Sea, dividing the "Nansen" or "European" basin into two nearly equal deeps. Heezen and Ewing qualify their interpretation with the following statement: "Scattered soundings may be contoured in an infinite number of ways but only one of these configurations is correct. Thus, there is no objective way to draw bathymetric contours from scattered soundings. The ultimately correct contour results from contouring on the basis of the correct hypothesis."

4. 3. Ostenso's Bathymetric Chart

Bearing in mind Heezen and Ewing's warning, the author has constructed a bathymetric chart of the Arctic Ocean based upon all available unclassified material. The chart is shown as Figure 12 and is based upon the following sources of information: Carsola, et al. (1961), Crary (1954), Crary and Goldstein (1957), Crary, et al. (1952), Dietz and Shumway (1961), Emery (1949), Fisher, et al. (1958), Gordienko and Laktionov (1960) Hakkel' (1958), Heezen and Ewing (1961), Hunkins (1960 b, c, d), Laktionov (1959), Somov (1955), Treshnikov (1960), Volkov (1961), Worthington (1953), Defence Research Board (Canada) Bathymetric Chart of Arctic Ocean, 1956 (approx) and all available U. S. Coast and Geodetic Survey and Hydrographic Office charts. These data were weighted according to their indicated degree of control. That is, highest credence was given to published soundings. In areas where published soundings were not available and published bathymetric charts had to be resorted to, more reliance was given to the chart or that portion of a chart where the compiler was believed to have access to the greatest number of original soundings. Necessary interpretations and interpolations were made conservatively and detailed flexures of isobaths were made only where sufficient and reliable data warranted. An irregular contour interval (200, 500, 1,000, 2,000, 3,000, 4,000 and 5,000 meters) was used to emphasize salient physiographic features. Where the floor of a deep was shallower than 4000 m, a 3800 m isobath was used to delimit the extent of the deep.

4. 4. Major Physiographic Features

In discussing the topography of the Arctic Ocean Basin one is confronted by the bewildering absence of standardization in nomenclature used by various investigators. Some attempt will be made in the following discussion to arrive at logical compromises in selecting geographic names. Priority of discovery and common usage generally receive the greatest consideration in deciding among conflicting names.

E. R. Hope (personal communication) expressed the opinion that, by virtue of its classic usage, the term "Arctic Basin" or "Arctic Ocean Basin" should be used to refer to the entire complex of basins and shelves that contain the Arctic Ocean and the deep-water sub-basins should be

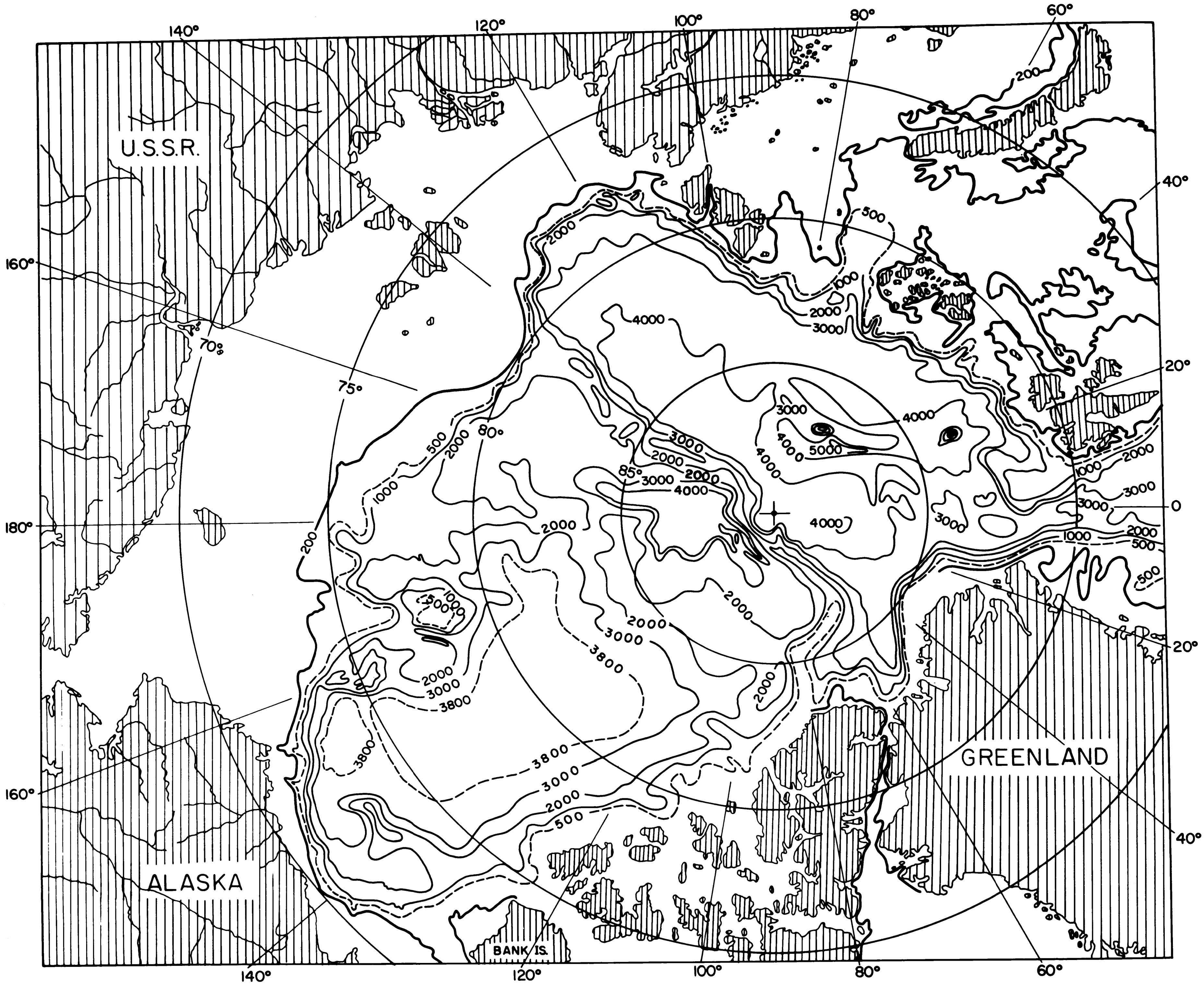


Figure 12.

BATHYMETRIC CHART OF THE ARCTIC OCEAN

COMPILED FROM SOVIET AND UNITED STATES SOURCES

BY

NED A. OSTENSO, 1961

ISOBATH INTERVAL IN METERS

called "deeps". In view of the confusing overuse of the term "basin" in literature, this seems to be a most suitable system and will be used in the following discussion. Hope (1959) suggested the name Hyperborean Basin be applied to the entire ocean area on the North American side of the Lomonosov Ridge and the region on the Eurasian side be called the Nansen Basin. Realizing the convenience of having a single term to apply to these physiographically complex regions, Hope's convention is supported by the author.

4. 5. Continental Margin

The Arctic Ocean is unique among the oceans of the world in that a major portion of it is continental shelf. The shelf is not of uniform extent, being several times wider off the Eurasian coast than off the North American coast. Off Alaska and Greenland the shelf is 100-200 km wide, which can be considered a normal shelf width, whereas the East Siberian Shelf and the Barents Sea and Kara Sea Shelves range from 500 to 1700 km in width. Soviet investigators believe that continental glaciation continued considerably farther north than indicated by Flint (1957) and suggest that probably the entire shelf region east of the Taimyr Peninsula was glaciated. Saks (1958) states that evidence of Quaternary glaciation is found not only in Franz Josef Land, Novaya Zemlya, Severnaya Zemlya, the DeLong Islands, Greenland, Ellesmere Island, and Baffin Island, where glaciers now exist, but also on Wrangel Island and in the New Siberian and Canadian archipelagos, where no glaciers now exist. He attributes the lack of reported evidence of glaciation in Peary Land to either destroyed evidence or insufficient research. Scouring by continental glaciers could account for much of the microrelief reported on the Beaufort Sea Shelf and the Chukchi Cap (Carsola, 1954; Dietz and Shumway, 1961; Cromie, 1961).

The continental slope begins at the usual depth of 200 m except off Greenland (see Volkov's chart, 1961) where the break occurs at approximately 300 m, probably reflecting isostatic depression by ice loads. North of Alaska the gradient of the continental slope ranges from 1½° to 4°, similar to the continental slopes in other oceans. However, Fisher et al. (1958) report slopes as steep as 23°. Several submarine valleys have been charted and undoubtedly more will be found. The largest of these, the St. Anna Trough, lying east of Franz Josef Land, is 180 km wide and 500 km long. Fisher et al. (1958) show a valley 45 km wide dissecting the Beaufort Sea Shelf north of Pt. Barrow, Alaska.

In cooperation with the IGY oceanographic program the Soviet vessels OB' and LENA completed a detailed sounding survey of the northern Greenland Sea. The results of this survey as shown by Laktionov (1959) and Volkov (1961) disproved the existence of Nansen's Sill which was believed to connect Greenland and Spitsbergen, impeding the flowage of water from the Atlantic into the Arctic Ocean. Rather, Nansen's Sill is pierced by a trough (Lena Trough)[1] whose depth is in excess of 3000 m; Hope (1959) and Heezen and Ewing (1961) consider the discovery of this channel as supporting evidence for the continuation of the mid-oceanic ridge system into the Arctic Ocean, the trough being the median rift valley. Their argument is attractive as the earthquake epicenter belt is superimposed upon the trough in a similar relationship to that observed along the Mid-Atlantic rift.

The name Nansen Swell is now applied to the eastern shoulder of "Nansen's Sill" and the smaller western shoulder was named Ob' Shoal[2] (Volkov, 1961). The continental shelf adjoining the northeastern coast of Greenland is dissected by numerous channels which appear to be glacially scoured valleys from a past glacial advance.

4. 6. Chukchi Cap

Projecting northward from the Chukchi Shelf is a semi-detached piece of continental shelf called the Chukchi Cap, which Heezen and Ewing (1961) consider to be analogous to the well-known Flemish Cap off the Grand Banks of Newfoundland. The cap, 200 km in diameter, rises abruptly from the floor of the ocean deep and has a truncated and dissected top, suggesting surf or glacial planation (Hunkins 1962). A smaller but similar feature, the Northwind Seahigh, is located to the southeast of the Chukchi Cap (Fisher et al., 1958).

4. 7. Canada Deep

The Canada Deep[3] extends for approximately 1100 km from the Beaufort Shelf to the Alpha Ridge. Dietz and Shumway (1961) in describing the echograms from the SSN NAUTILUS (Fig. 13) show the 3940-m deep floor[4] of the basin to be strikingly smooth, interrupted only in the northeastern portion by two sea knolls. Fisher et al. (1958) also comment upon its lack of relief. Heezen and Ewing (1961) suggest that, as the submarine canyons

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[1]Heezen and Ewing (1961) call this feature Nansen's Strait. Preference is given to the Soviet nomenclature by virtue of discovery.

[2]Gordienko and Laktionov (1960) call them the Yermak Plateau and Ob' Shelf respectively. Volkov's nomenclature is preferred.

[3]Canada Basin (Dietz and Shumway, 1961), North Canada Basin (Heezen and Ewing, 1961), Beaufort Deep (Gordienko and Laktionov, 1960; Treshnikov, 1961; Fisher, et al., 1958). The term Canada Basin and North Canada Basin commonly appears on U.S.C. & G.S. and U. S. Hydrographic Office charts.

[4]Actually Dietz and Shumway (1961) quote a depth of 3,850 m. However, they compute all of the NAUTILUS soundings assuming a velocity of 4,800 ft/sec (1,463 m/sec) for sound in water. Using the more realistic velocity of 4,915 ft/sec (1,498 m/sec) [see discussion 5.3] the depth of the abyssal floor is 3,940 m. This correction brings their value in line with that given by Fisher, et al. (1958).

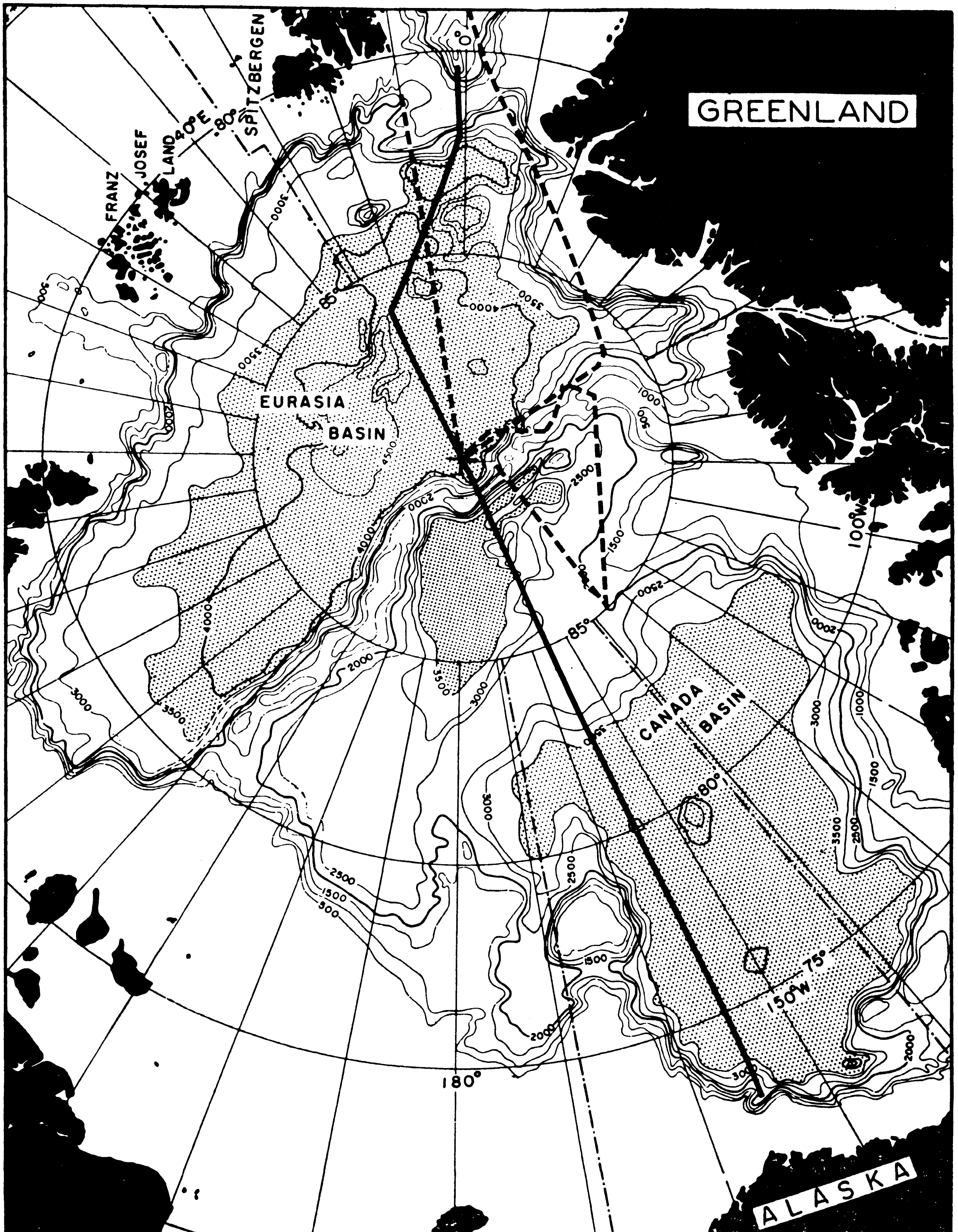

Figure 13.

Tracks of SSN (571) NAUTILUS (solid line) and SSN (578) SKATE (dashed line) in the Arctic Ocean during August 1958. Bathymetry from published Soviet soundings (Canada Defense Research Board, 1957) **After Dietz and Shumway.**

dissecting the Beaufort Shelf are probably similar in origin to submarine canyons in general, abyssal plains should be found spreading out from the edge of the continental margin. Also, abyssal cones may occur on the floor of the ocean deeps off the mouths of the major arctic rivers, analogous to those of the Mississippi, Hudson, and Ganges Rivers.

A smaller deep, the Beaufort Deep, underlies the Beaufort Sea and is separated from the main Canada Deep by a broad sill rising 350 m above the abyssal plain. Because of the shallow and still uncertain separation of the Canada and Beaufort Deeps, it is suggested that the name Canada Deep apply to both i.e., the Beaufort Deep is part of the larger Canada Deep. Heezen and Ewing (1961) refer to a peninsula-like segment of continental crust projecting from the vicinity of Banks Island westward into the Beaufort Deep, as the Beaufort Plateau.

4. 8. Alpha Ridge

The Alpha Ridge[5] lies on the North American side of and sub-parallel to the Lomonosov Ridge. It ascends to a minimum depth of about 1400 m and is approximately 900 km long and varies considerably in width. The ridge is joined to the continental shelf at either end by broad triangular plateaus. Seismic dip information and bathymetric profiles across the crest of the ridge show rugged topography which led Hunkins et al. (1961) to suggest that this is an area of fault blocks.

On either side of the Alpha Ridge the sea floor drops off gradually to the abyssal plains but does not merge smoothly into the deep ocean floor. Instead the flanks of the ridge are terminated abruptly by escarpments about 600 m high which presumably mark major faults (Dietz and Shumway, 1961). The flanks contain relatively large undulations whose relief is as much as 1000 m.

There is no evidence of seismic activity or volcanism associated with the Alpha Ridge. Heezen and Ewing (1961) point out that the physiography as well as the crustal structure of the rise is closely similar to that observed in the oceanic rises of the Atlantic.

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[5]Alpha Ridge (Heezen and Ewing, 1961), Central Arctic Rise (Dietz and Shumway, 1961), Mendeleyev Ridge (Gordienko and Laktionov, 1960; Treshnikov, 1961). Although lettering a feature of this magnitude seems singularly unimaginative, the term Alpha (Hunkins, 1960a) is given preference by virtue of discovery.....The feature was named Alpha Rise after drifting station Alpha. However, to be consistent with internationally accepted nomenclature conventions (Wiseman and Ovey, 1953) this feature should properly be called Alpha Ridge. Rise is defined as "A long and broad elevation of the deep-sea floor which rises gently and smoothly." Such a definition is hardly applicable to the Alpha Ridge. A ridge is defined as, "A long elevation of the deep-sea floor having steeper sides and less regular topography than a rise."

4. 9. Lomonosov Ridge

The Lomonosov Ridge[6] extends 1800 km from the continental shelf north of Ellesmere Island to the continental shelf north of the New Siberian Islands. The depth of the ridge summit appears to be fairly uniform between 900 and 1450 m, the maximum depth reported being about 1650 m. The shallowest recorded depth along the central part of the ridge is 954 m and the average relief of the ridge is about 3000 m above the adjacent basin floors. Its width ranges from 60 to 200 km. The NAUTILUS' traverse showed the flanks of the ridge to be slightly convex upward. The south flank slopes here at an angle of 13° whereas the north flank is less steep, with the region shallower than 3850 m being steeper than the deeper portion. The summit was 26 km wide at the traverse crossing and appeared remarkably flat with the suggestion of truncation to a depth of 1400 m below the present sea level.

Between the Lomonosov and Alpha ridges, the low Marvin Ridge extends into the Makarov Deep. The three ridges are aseismic and join in the vicinity of 88°N., 90°W., where they form a broad shelf.

The track of the NAUTILUS (Fig. 13) is shown as passing over the Marvin Ridge, yet this feature, well documented by the drift of T-3 (Crary and Goldstein, 1957), does not appear in the soundings.

4. 10. Makarov Deep

The Makarov Deep[7] is enclosed by the Lomonosov Ridge, the Alpha Ridge and the Marvin Ridge. Echograms from the NAUTILUS show its floor to be completely featureless and flat at 4030 m, or 120 m deeper than the Canada Deep[8]. Gordienko and Laktionov (1960) report depths of over 4000 m in the Makarov Deep yet their chart shows no 4000 m isobath. The extreme flatness of its floor and abrupt contact with the Lomonosov Ridge and Alpha Ridge suggest that the deep has been a catch-basin for a considerable thickness of sediment (See Dietz and Shumway, 1961, Plate 2).

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[6] Soviet investigators used the Russian term "Khrebet'" which can be translated as either ridge or range. Hope (1959) translated it as range but now prefers the term "ridge" which has come into more popular usuage (Hope, personal communication). In the interest of uniformity "ridge" is used in this paper. Lomonosov Ridge (Dietz and Shumway, 1961; Heezen and Ewing, 1961).

[7] Central Arctic Basin (Dietz and Shumway, 1961), Siberia Basin (Heezen and Ewing, 1961). Preference is given to the term Makarov Deep (Gordienko and Laktionov, 1960; Treshnikov, 1961) by virtue of prior usage.

[8] Corrected from the given depth of 3940 m. See footnote 4.

4. 11. Eurasia Deep

Soviet investigators contoured the basin on the European side of the Lomonosov Ridge as a single deep which they call the "Nansen Deep"[9]. However, Heezen and Ewing (1961) have given strong evidence for extending the mid-oceanic ridge across the Arctic Ocean, dividing this deep into two sub-basins (see discussion 4.2). They named the deep adjacent to the Lomonosov Ridge, the Eurasia Basin, and the deep adjoining the Barents and Kara Shelves, the Fram Basin. In constructing the bathymetric chart shown in Figure 12, it was possible to preserve Heezen and Ewing's division of the "Nansen Deep" without violating known soundings. In view of the strong arguments favoring such a division by the global ridge system, this pattern of contouring was elected.

The North Pole is located close to the contact of the Eurasia Deep[10] and Lomonosov Ridge. Dietz and Shumway (1961) report water depth at the pole to be 4200 m. From T-3 Crary (1954) obtained a sounding of 4300 m at the pole and Papanin (1947) reported a depth of 4290 m at 88°54'N., 20°W. from the Soviet station NP-1. Correcting the NAUTILUS' sounding to Crary's sound transmission velocity gives a depth of 4290 which brings the three values into agreement.

The NAUTILUS' sounding profile shows the floor of the Eurasia Deep to be, like the other abyssal plains, strikingly flat and featureless. However, the floor of the deep appears to slope gently southward, being 410 m deeper at the mid-oceanic ridge than along its contact with the Lomonosov Ridge. Dietz and Shumway suggest that this depression of the floor may be the result of crustal flexure in response to the loading effect of the mid-oceanic ridge, similar to that observed with the Hawaiian Ridge.

4. 12. Mid-Ocean Ridge

The mid-ocean ridge in the Arctic Basin is too poorly defined by soundings to permit any certainty regarding its topographic character. Indeed, as has been pointed out, its very existence is speculative. Heezen and Ewing (1961) give a detailed description of the Mid-Atlantic Ridge; and if the "Mid-Arctic Ridge" is a continuation of the same system, as it is supposed to be, then their topographic character should be similar. The most salient feature of the Mid-Atlantic Ridge is the rift valley which forms a deep cleft along the axis of the ridge. Rift mountains rise to an elevation of 900-2700 m above the valley floor. The rift mountains, in turn, are flanked by high, fractured plateaus. The rift valley and mountain system is generally less than 200 km in width with the valley itself varying in width from 40 km to 150 km.

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[9] European Basin (Hope, 1959).

[10] Eurasia Basin (Heezen and Ewing, 1961).

Both the SKATE and NAUTILUS traversed across the mid-oceanic ridge province. Their echograms show the region to be one of jagged topography containing continuous strings of peaks of various size and having a maximum relief of about 1000 m. Dietz and Shumway (1961) refer to this physiographic province as the "Region of Seamounts". From the sounding profiles one cannot tell if the peaks are conical seamounts or cross sections of ridges. Dietz and Shumway point out the similarity of the echo profile in this region to those obtained when passing over the Mid-Atlantic Ridge. They conclude that the "Region of Seamounts" is a continuation of the Mid-Atlantic Ridge and thus at least some of the peaks shown in the echograms are undoubtedly cross sections of ridges.

4. 13. Fram Deep

It was not possible to contour the Fram Deep[11] as the large lecticular basin shown by Heezen and Ewing (1961) without violating credible data. Rather, the Fram Deep appears to have an irregular outline and is the smallest of the four deeps, being 950 km in length and 350 km wide. It is also the deepest of the abyssal basins, extending to 5180 m. Adjacent to the deepest part of the depression a suboceanic mountain rises to within 730 m of the sea surface. In a distance of 80 km there is a 4450 m change in bottom elevation. Another seamount, 400 km north of Spitsbergen, rises over 3000 m above the 4000 m deep abyssal floor. Little is known about the Fram Deep; the scant information available suggests that its character may be complex.

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[11] Fram Basin (Heezen and Ewing, 1961).

Chapter 5

GRAVITY SURVEY

5. 1. Field Program

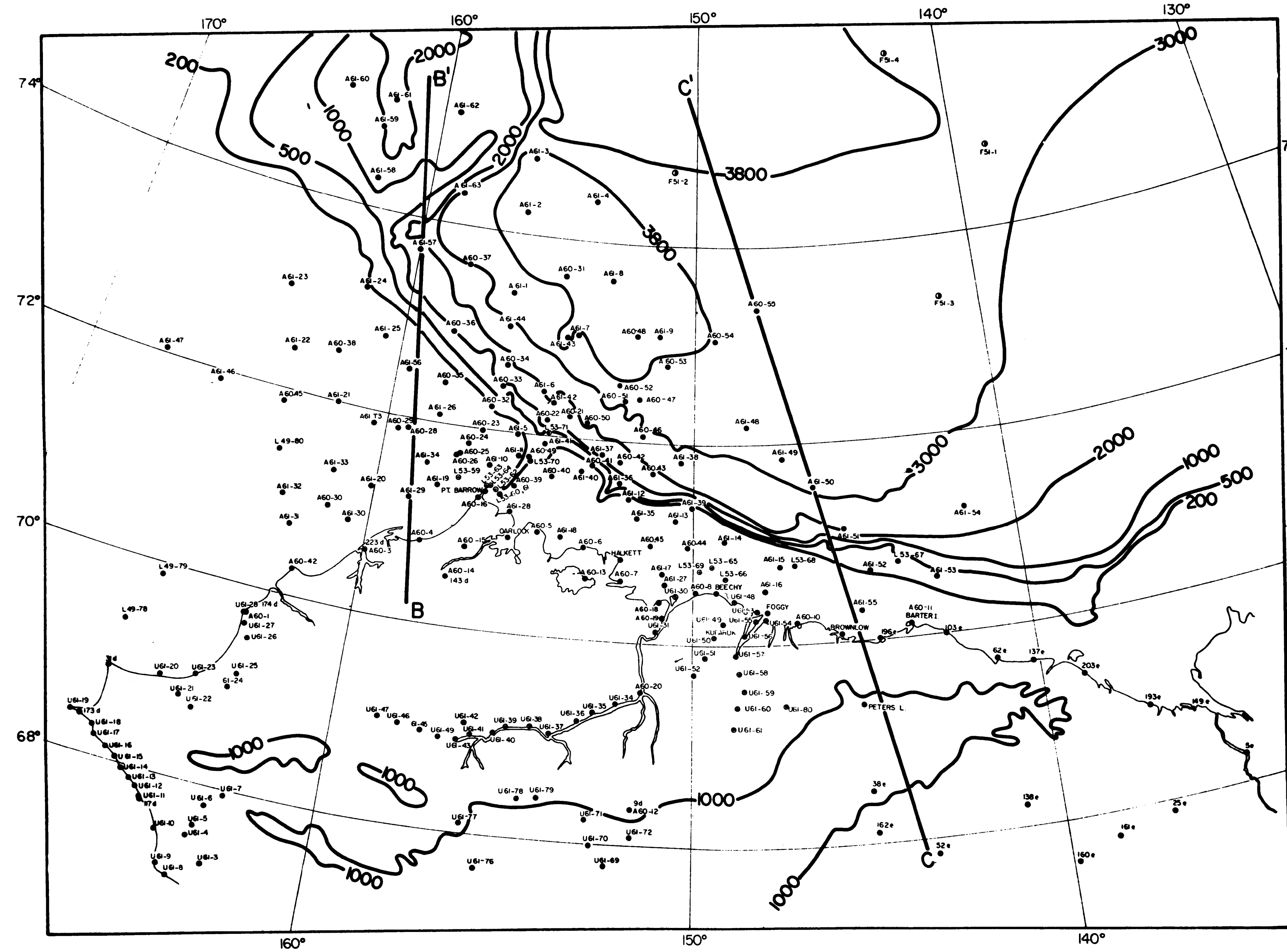
The gravity field program was conducted in the spring of 1960 and 1961. The normal operating procedure was to use two ski-equipped Cessna 180 aircraft to establish gravity stations on the sea ice. The flights originated from Barrow and Barter Island, Alaska and ranged out to 350 km from shore. Landings were made at preselected intervals and up to eight stations were occupied on a single flight. The observations made at each station required about 20 minutes and included a gravimeter reading, seismic water depth sounding, and sun line of position to assist in navigation. Two planes were used for safety considerations and to increase flight range by carrying reserve fuel.

The optimum time of the year for conducting an airlifted gravity survey is in the late spring and early summer. By mid-March there is sufficient daylight and the temperature has risen to the point where operations are feasible and relatively comfortable. In temperatures much below -30°F, the aircraft engines cool off so fast that they cannot be shut down long enough to complete the observations. By mid-May increasing areas of open water cause frequent fog and cloud cover, and by mid-June surface melting of the pack ice has made ski landings hazardous.

During the two field seasons, 120 gravity stations were established on the sea ice and ten stations on the Alaskan coast, (Fig. 14). Twenty additional stations over the Arctic Ocean are available from Lamont Geological Observatory (unpublished) and Crary, Cotell, and Oliver (1951). One-hundred and three gravity observations in Alaska, the northern Yukon, and the Northwest Territories were made by Thiel, Ostenso, Bonini, and Woollard (1958) and Barnes and Allen (1961). The principal facts on all of these gravity stations are listed in Table VI. Stations off the sea ice which can be identified by more than latitude and longitude coordinates are described in Table VII. Descriptions and elevations for the U. S. Geological Survey stations in northern Alaska (U61 Series) are not available.

5. 2. Gravimetry

La Coste and Romberg thermostatically controlled geodetic gravity meters were used for the gravity survey. Large La Coste and Romberg meter No. 1 was used the first season and small meter No. G-12 was used for the 1961 field program. These gravimeters were calibrated over the University of Wisconsin Gulf pendulum calibration line from Mexico, D.F. to Barrow, Alaska, which enabled both their calibration and "screw error" to be accurately determined. The drift rates were monitored by a minimum of twice daily base station readings at the Arctic Research Laboratory (A.R.L.), Barrow, Alaska plus readings at the beginning and termination of each flight. Meter drift was never a problem as the time away from the base station never exceeded eight hours.



GRAVITY STATIONS OVER THE ARCTIC OCEAN

0 100 200
KILOMETERS

● A–UNIV. WIS.
● U–U. S. G. S.
◉ L–LAMONT GEOLOGICAL OBSERVATORY
◐ F–AIR FORCE CAMBRIDGE RESEARCH CENTER

Figure 14.

TABLE VI

Principal Facts on Gravity Stations

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
A60-1	69°45'	162°55'	Quad. map	3	0	--	--	982.5992	982.5955	- 2.8	- 3.1
-2	70°17'	161°53'	Quad. map	0	0	--	--	.6302	.6073	-22.9	-22.9
-3	70°36'	159°51'	Quad. map	24	0	--	--	.6483	.6374	- 2.6	- 5.6
-4	70°48'	158°14'	Quad. map	28	0	--	--	.6596	.6543	+ 3.4	+ 0.2
-5	71°03'	154°43'	Quad. map	4	0	--	--	.6735	.6683	- 4.2	- 4.6
A60-6	70°54'	153°14'	Quad. map	9	0	--	--	982.6653	982.6596	- 3.0	- 4.0
-7	70°35'	152°14'	Quad. map	9	0	--	--	.6473	.6354	- 9.3	-10.3
-8	70°30'	149°53'	Quad. map	5	0	--	--	.6427	.6304	-10.8	-11.3
-9	70°25'	148°41'	Quad. map	5	0	--	--	.6380	.6193	-17.3	-17.8
-10	70°10'	146°50'	Quad. map	7	0	--	--	.6235	.6052	-16.1	-16.9
A60-11	70°08'	143°36'	Quad. map	3	0	--	--	982.6216	982.5958	-25.0	-25.3
-12	68°20'	151°39'	Quad. map	747	30	--	--	.5135	.2822	-10.3	-90.6
-13	70°37'	153°11'	Quad. map	3	0	--	--	.6493	.6369	-11.5	-11.8
-14	70°28'	157°25'	Quad. map	30	4	--	--	.6408	.6216	-19.8	-23.2
-15	70°21'	156°57'	Quad. map	15	0	--	--	.6331	.6497	+21.3	+19.6
A60-16	71°20'	156°46'	Quad. map	4	0	--	--	982.6893	982.6997	+11.4	+11.0
-17	69°23'	152°09'	Quad. map	176	5	--	--	.5725	.5444	0	-12.0
-18	70°24'	151°13'	Quad. map	0	0	--	--	.6370	.6321	- 4.9	- 4.9
-19	70°12'	151°02'	Quad. map	3	1	--	--	.6255	.6249	+ 0.3	0
-20	69°36'	151°30'	Quad. map	61	5	--	--	.5904	.5688	- 2.8	- 9.6
A60-21	72°12'	154°02'	D.R.& Sun fix	0	0	1490	500	982.7360	982.7265	- 9.5	+111.7
-22	72°09'	154°44'	D.R.& Sun fix	0	0	1190	30	.7333	.7316	- 1.7	+79.9
-23	71°58'	156°50'	D.R.& Sun fix	0	0	117	9	.7237	.7246	+ 0.9	+ 8.9
-24	71°43'	157°13'	D.R.& Sun fix	0	0	73	9	.7165	.7293	+12.8	+17.8
-25	71°43'	157°27'	D.R.& Sun fix	0	0	64	9	.7102	.7204	+ 9.8	+14.2

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bougue: Anomaly mgal
A60-26	71°42'	157°31'	D.R.& Sun fix	0	0	64	9	982.7093	982.7194	+10.1	+14.5
-27	71°42'	157°31'	D.R.& Sun fix	0	0	64	9	.7093	.7194	+10.1	+14.5
-28	71°54'	159°17'	D.R.& Sun fix	0	0	51	4	.7200	.7605	+40.5	+44.0
-29	71°52'	159°33'	D.R.& Sun fix	0	0	51	4	.7183	.7469	+28.6	+32.1
-30	70°58'	161°19'	D.R.& Radar	0	0	46	4	.6690	.6778	+ 8.8	+12.0
A60-31	73°37'	154°35'	D.R.& Sun line	0	0	3840	30	982.8081	982.8370	-49.7	+213.7
-32	72°14'	156°37'	D.R.& Radar	0	0	229	4	.7593	.7593	+21.5	+37.2
-33	72°27'	156°21'	D.R.& Radar	0	0	737	90	.7680	.7680	+19.1	+69.7
-34	72°40'	156°15'	D.R.& Sun line	0	0	1810	9	.7613	.7613	+ 1.0	+125.2
-35	72°24'	158°15'	D.R.& Sun line	0	0	64	9	.7836	.7836	+37.1	+41.5
A60-36	72°55'	158°15'	D.R.& Sun line	0	0	915	90	982.7731	982.7742	+ 1.1	+63.9
-37	73°35'	158°00'	D.R.& Sun line	0	0	3020	200	.8075	.7886	-18.9	+188.3
-38	72°30'	162°00'	D.R.& Sun line	0	0	55	3	.7517	.7651	+13.4	+17.2
-39	71°28'	155°35'	D.R.& Radar	0	0	18	2	.6966	.7081	+11.6	+12.8
-40	71°36'	154°25'	D.R.& Radar	0	0	51	10	.7039	.7161	+12.2	+15.7
A60-41	71°44'	153°13'	D.R.& Radar	0	0	146	30	982.7111	982.7493	+38.2	+49.2
-42	71°47'	152°18'	D.R.& Radar	0	0	1300	400	.7137	.7348	+21.1	+110.3
-43	71°41'	151°15'	D.R.& Radar	0	0	1740	200	.7084	.6858	-22.6	+96.8
-44	70°57'	150°07'	D.R.& Radar	0	0	22	4	.6681	.6711	+ 3.0	+ 4.5
-45	70°56'	151°18'	D.R.& Radar	0	0	16	2	.6671	.6810	+13.9	+15.0
A60-46	72°03'	151°38'	D.R.& Radar	0	0	2743	400	982.7281	982.7280	- 0.1	+188.1
-47	72°26'	151°50'	D.R.& Sun line	0	0	3621	8	.7134	.7134	-34.8	+213.8
-48	73°04'	151°55'	D.R.& Sun line	0	0	3840	90	.7807	.7316	-49.1	+214.3
-49	71°47'	155°13'	D.R.& Radar	0	0	220	30	.7137	.7110	- 2.6	+12.5
-50	72°10'	153°25'	D.R.& Sun line	0	0	2085	200	.7342	.7588	+24.6	+167.6
A60-51	72°25'	152°15'	D.R.& Sun line	0	0	3419	8	982.7474	982.7271	-20.3	+214.5
-52	72°34'	152°35'	D.R.& Sun line	0	0	3749	8	.7517	.7104	-41.3	+216.1
-53	72°46'	150°40'	D.R.	0	0	3750	90	.7654	.7159	-49.5	+207.8
-54	73°02'	149°15'	D.R.	0	0	3750	200	.7790	.7315	-47.5	+209.8
-55	73°20'	147°45'	D.R.	0	0	3750	200	.7941	.7466	-47.5	+209.8

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
A61-1	73°23'	156°23'	D.R.& Radar	0	0	3640	90	982.7969	982.7661	-30.8	+219.1
-2	74°14'	156°15'	D.R.	0	0	3845	10	.8375	.7854	-52.1	+211.7
-3	74°46'	156°10'	D.R.& Sun line	0	0	3845	100	.8627	.7913	-71.4	+192.4
-4	74°24'	153°40'	D.R.& Sun line	0	0	3845	100	.8458	.7907	-55.1	+208.7
-5	71°59'	156°40'	D.R.,Radar & Sun line	0	0	124	10	.7245	.7666	+42.1	+50.6
A61-6	72°27'	155°00'	D.R.	0	0	2235	200	982.7488	982.7357	-13.1	+140.2
-7	73°02'	154°00'	D.R.	0	0	3750	80	.7790	.7366	-42.4	+214.9
-8	73°38'	152°52'	D.R.	0	0	3845	90	.8089	.7521	-56.8	+207.0
-9	73°04'	151°13'	D.R.	0	0	3750	100	.7807	.7280	-52.7	+204.6
-10	71°39'	156°28'	D.R.,Radar & Sun line	0	0	155	10	.7066	.7094	+ 2.8	+13.4
A61-11	71°44'	155°31'	D.R.& Radar	0	0	130	20	982.7109	982.7047	- 6.2	+ 2.7
-12	71°24'	152°04'	D.R.	0	0	68	9	.6928	.7119	+19.1	+23.8
-13	71°14'	150°32'	D.R.	0	0	51	9	.6835	.7124	+28.9	+32.4
-14	71°00'	149°00'	D.R.	0	0	35	5	.6709	.6664	- 4.5	- 2.1
-15	70°46'	147°25'	D.R.	0	0	44	4	.6578	.7132	+55.4	+58.4
A61-16	70°29'0	147°49'5	Quad. map	0	0	2	1	982.6417	982.6305	-11.2	-11.1
-17	70°41'	150°52'	D.R.& Radar	0	0	15	2	.6529	.6436	- 9.3	- 8.3
-18	71°01'	154°01'	D.R.& Radar	0	0	5	1	.6720	.6770	+ 5.0	+ 5.3
-19	71°23'	158°00'	D.R.,Radar & Sun line	0	0	55	5	.6917	.6983	+ 6.6	+10.4
-20	71°15'	160°04'	D.R.,Radar & Sun line	0	0	60	9	.6849	.6733	-11.6	+ 7.5
A61-21	72°00'	161°35'	D.R.& Sun line	0	0	37	5	982.7254	982.7713	+45.9	+48.4
-22	72°25'	163°25'	D.R.& Sun line	0	0	48	4	.7476	.7640	+16.4	+19.7
-23	73°03'	164°05'	D.R.& Sun line	0	0	73	9	.7795	.7713	- 8.2	- 3.2
-24	73°12'	161°31'	D.R.& Sun line	0	0	92	20	.7872	.8095	+22.3	+28.6
-25	72°45'	160°33'	D.R.& Sun line	0	0	55	9	.7645	.8010	+36.5	+40.3
A61-26	72°04'	158°15'	D.R.& Sun line	0	0	76	9	982.7289	982.7529	+24.0	+29.2
-27	70°35'	150°49'	D.R.& Radar	0	0	4		.6472	.6354	-18.8	-11.5
-28	71°12'2	155°42'0	Quad. map	0	0	1	1	.6822	.6880	+ 5.8	+ 5.9
-29	71°13'	158°53'	D.R.& Sun line	0	0	64	9	.6829	.6835	+ 0.6	+ 5.0
-30	70°53'	160°32'	D.R.& Sun line	0	0	55	5	.6639	.6587	- 5.2	- 1.4

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
A61-31	70°42'	162°21'	D.R.& Sun line	0	0	38	5	982.6544	982.6671	+12.7	+15.3
-32	70°59'	162°42'	D.R.& Sun line	0	0	44	4	.6699	.6860	+16.1	+19.1
-33	71°19'	161°17'	D.R.& Sun line	0	0	49	5	.6888	.6822	- 6.6	- 3.2
-34	71°35'	158°28'	D.R.& Sun line	0	0	64	9	.7030	.7448	+41.8	+46.2
-35	71°15'	151°43'	D.R.,Radar & Sun line	0	0	46		.6844	.6896	+ 5.2	+ 8.4
A61-36	71°38'	152°17'	D.R.& Sun line	0	0	597	10	982.7055	982.7518	+46.3	+87.3
-37	71°52'	152°53'	D.R.& Sun line	0	0	1592	10	.7179	.7564	+38.5	+147.7
-38	71°47'	150°22'	D.R.& Sun line	0	0	2770	10	.7136	.6895	-24.1	+165.9
-39	71°21'4	150°00'	D.R.& Sun line	0	0	640	5	.6906	.6534	-37.2	+ 6.7
-40	71°41'	153°31'	D.R.,Radar & Sun line	0	0	73	9	.7084	.6977	-10.7	- 5.7
A61-41	71°55'	154°45'	D.R.,Radar & Sun line	0	0	283	200	982.7207	982.7363	+15.6	+35.0
-42	72°20'	154°38'	D.R.,Radar & Sun line	0	0	1970	9	.7428	.7525	+ 9.7	+144.8
-43	73°03'	154°22'	D.R.,Radar & Sun line	0	0	3650	100	.7797	.7554	-24.3	+226.2
-44	73°06'	156°25'	D.R.,Radar & Sun line	0	0	2853	20	.7820	.8048	+22.8	+218.5
-45	71°54'	163°20'	D.R.,Radar & Sun line	0	0	38	4	.7199	.7581	+38.2	+40.8
A61-46	71°53'	165°31'	D.R.,Radar & Sun line	0	0	42	2	982.7193	982.7171	- 2.2	+ 0.7
-47	72°04'	167°27'	D.R.,Radar & Sun line	0	0	42	2	.7287	.7177	-11.0	- 8.1
-48	72°10'	148°15'	D.R.,Radar & Sun line	0	0	3658	20	.7338	.7065	-27.3	+223.6
-49	71°50'	147°09'	D.R.& Sun line	0	0	3438	200	.7165	.6841	-32.4	+203.4
-50	71°33'	146°12'	D.R.& Sun line	0	0	3189	9	.7012	.6753	-25.9	+192.4

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bougue Anomal mgal
A61-51	71°07'	145°19'	D.R.& Sun line	0	0	2359	60	982.6774	982.6956	+18.2	+180.0
-52	70°41'	144°41'	D.R.& Sun line	0	0	206	4	.6531	.7605	+107.4	+121.5
-53	70°35'	142°39'	D.R.,Radar & Sun line	0	0	320	10	.6474	.7021	+54.7	+76.7
-54	71°14'	141°30'	D.R.& Sun line	0	0	2100	200	.6838	.6506	-33.2	+112.9
-55	70°18'	144°56'	D.R.,Radar & Sun line	0	0	33	2	.6314	.5937	-37.7	-35.4
A61-56	72°28'	159°38'	D.R.& Sun line	0	0	60	9	982.7500	982.8419	+91.9	+96.0
-57	73°41'	159°56'	D.R.& Sun line	0	0	1620	10	.8114	.8062	- 5.2	+105.9
-58	74°18'	162°00'	D.R.& Sun line	0	0	1412	10	.8410	.8366	- 4.4	+92.5
-59	74°50'	162°22'	D.R.& Sun line	0	0	1829	10	.8658	.8482	-17.6	+107.9
-60	75°08'	163°44'	D.R.& Sun line	0	0	1533	10	.8794	.8779	- 1.5	+103.7
A61-61	75°07'	162°00'	D.R.& Sun line	0	0	2152	10	982.8786	982.8490	-29.6	+118.0
-62	75°07'	159°19'	D.R.& Sun line	0	0	1384	10	.8786	.8517	-26.9	+68.0
-63	74°19'	158°40'	D.R.& Sun line	0	0	3213	10	.8418	.7399	-101.9	+118.5
ARLIS I	75°00'	171°28'	D.R.	0	0	317*	10	982.8734	982.9361	+62.7	+84.4
A61-T3	71°51'7	160°20'	Sun fix	3	0.5	39	1	.7180	.7309	+13.7	+16.6
Beechy Pt.	70°29'3	149°08'8	Quad. map	1.5	0	--	--	.6422	.6253	-16.8	-16.8
Foggy Isl.	70°17'2	147°45'4	Quad. map	2	0	--	--	.6305	.6088	-21.5	-21.6
Kuparuk R.	70°03'1'	149°19'9	Quad. map	10	5	--	--	.5697	.6169	-46.3	-46.6
Point Barrow	71°24'4	156°28'6	Quad. map	0.7	0	--	--	.6925	.6996	+ 7.1	+ 7.0
Cape Halkett	70°48'7	152°17'5	Quad. map	0	0	1	0.5	982.6603	982.6549	- 5.4	- 5.3
Oarlock Isl.	70°57'1	155°39'0	Quad. map	0	0	1	0.5	.6682	.6701	+ 1.9	+ 2.0
Peter's Lake	69°20'9	145°04'2	Quad. map	852	10			.5754	.3262	+13.7	-80.4
Barrow Pendulum Site	71°19'7	156°40'5	Quad. map	3.5	0.5	--	--	982.6890	982.6996	+11.4	+11.1
A.R.L. Greenhouse	71°19'7	156°40'5	Quad. map	3	0.5	--	--	.6890	.6997	+11.5	+11.2
Barter Isl.	70°08'1	143°36'8	Quad. map	1.5	0	--	--	.6217	.5963	-25.0	-25.2
Brownlow Pt.	70°09'6'	145°49'8	Quad. map	1	0	--	--	.6231	.5907	-32.1	-32.2
5e	68°13'4	135°00'	Quad. map	29	0	--	--	.5067	.4882	-15.8	-16.8

*Grounded ice island

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
6e	68°13'2	135°00'	Quad. map	9	5	--	--	982.5065	982.4894	-16.3	-16.6
9d	68°10'2	151°44'9	Quad. map	670	30	--	--	.5034	.2804	-16.1	-91.1
25e	67°50'8	137°16'0	Quad. map	612	5	--	--	.4830	.3183	+24.0	-44.4
31d	68°52'7	166°09'4	Quad. map	2	1	--	--	.5471	.5296	-16.9	-17.1
38e	68°30'3	145°05'7	Quad. map	646	5	--	--	.5242	.3225	- 2.5	-74.7
52e	67°44'3	142°24'5	Quad. map	352	5	--	--	982.4762	982.3838	+16.2	-23.1
62e	69°39'4	141°13'2	Quad. map	0.3	0	--	--	.5938	.5664	-27.3	-27.3
103e	69°59'0	142°32'5	Quad. map	2	1	--	--	.6129	.5694	+ 0.2	- 6.6
117d	67°44'1	164°33'9	Quad. map	2	1	--	--	.4759	.4614	-13.9	-14.1
137e	69°36'3	140°07'1	Quad. map	1	0	--	--	.5907	.5862	- 4.1	- 4.3
138e	68°11'5	141°02'6	Quad. map	340	5	--	--	982.5047	982.4365	+36.9	- 1.2
143d	70°28'5	157°24'0	Quad. map	6	5	--	--	.6413	.6203	-19.1	-19.8
149e	68°43'0	136°21'1	Quad. map	2.5	5	--	--	.5372	.4903	-46.1	-46.4
160e	67°34'1	139°49'1	Quad. map	274	5	--	--	.4654	.4108	+30.1	- 0.6
161e	67°42'1	138°46'2	Quad. map	373	5	--	--	.4739	.3997	+40.9	- 0.8
162e	68°05'3	145°07'0	Quad. map	657	5	--	--	.4982	.3140	+18.5	-54.9
173d	68°20'8	166°44'5	Quad. map	6	8	--	--	982.5144	982.5214	+ 8.9	+ 8.2
174d	69°45'6	163°03'5	Quad. map	3.3	1	--	--	.5998	.5965	- 2.3	- 2.7
193e	68°59'9	137°26'0	Quad. map	0	1	--	--	.5544	.5215	-32.9	-32.9
196e	69°58'7	144°19'5	Quad. map	5	1	--	--	.6126	.5603	-50.9	-51.4
203e	69°20'0	138°43'0	Quad. map	0	1	--	--	.5745	.5694	- 5.1	- 5.1
223d	70°37'9	159°59'1	Quad. map	0.6	1	--	--	982.6502	982.6443	- 5.7	- 5.8
L49-78	69°22'	166°14'	?	0	0	37	?	982.577	982.579	+ 2	+ 4
-79	69°52'	165°30'	?	0	0	41	?	.606	.602	- 4	- 1
-80	71°24'	163°14'	?	0	0	44	?	.693	.719	+26	+29

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
L53-59	71°28'	157°21'	?	0	0	132	?	982.697	982.693	- 4	+ 5
-60	71°21'	156°04'	?	0	0	5	?	.690	.701	+11	+11
-61	71°21'	156°04'	?	0	0	5	?	.690	.703	+13	+13
-62	71°23'	156°11'	?	0	0	7	?	.692	.702	+10	+10
-63	71°25'	156°24'	?	0	0	7	?	.694	.696	+ 2	+ 2
-64	71°25'	156°20'	?	0	0	7	?	.694	.695	+ 1	+ 1
L53-65	70°46'	149°21'	?	0	0	15	?	982.658	982.642	-16	-15
-66	70°39'	149°00'	?	0	0	5	?	.951	.640	-11	-11
-67	70°45'	143°45'	?	0	0	452	?	.657	.720	+63	+94
-68	70°46'	146°55'	?	0	0	35	?	.658	.633	-25	-23
-69	70°43'	149°49'	?	0	0	15	?	.655	.645	-10	- 9
L53-70	71°42'	155°12'	?	0	0	197	?	982.709	982.730	+21	+35
-71	72°00'	154°41'	?	0	0	469	?	.725	.743	+18	+50
U61-1	66°55'	162°45'	Quad. map	?	?	?	?	?	?	?	-10
-2	67°01'	162°20'	Quad. map	?	?	?	?	?	?	?	-13
-3	67°14'	162°35'	Quad. map	?	?	?	?	?	?	?	+ 4
-4	67°28'	163°05'	Quad. map	?	?	?	?	?	?	?	-51
-5	67°37'	162°55'	Quad. map	?	?	?	?	?	?	?	- 4
U61-6	67°51'	162°45'	Quad. map	?	?	?	?	?	?	?	- 7
-7	67°57'	162°23'	Quad. map	?	?	?	?	?	?	?	-38
-8	67°04'	163°30'	Quad. map	?	?	?	?	?	?	?	+11
-9	67°10	163°47'	Quad. map	?	?	?	?	?	?	?	+18
-10	67°26'	163°53'	Quad. map	?	?	?	?	?	?	?	- 6
U61-11	67°39'	164°15'	Quad. map	?	?	?	?	?	?	?	-16
-12	67°44'	164°35'	Quad. map	?	?	?	?	?	?	?	-14
-13	67°52'	164°54'	Quad. map	?	?	?	?	?	?	?	- 6
-14	67°58'	165°10'	Quad. map	?	?	?	?	?	?	?	-15
-15	68°03'	165°22'	Quad. map	?	?	?	?	?	?	?	- 8

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
U61-16	68°07'	165°48'	Quad. map	?	?	--	--	?	?	?	+ 4
-17	68°12'	166°05'	Quad. map	?	?	--	--	?	?	?	+ 5
-18	68°18'	166°15'	Quad. map	?	?	--	--	?	?	?	+ 9
-19	68°23'	166°48'	Quad. map	?	?	--	--	?	?	?	+ 8
-20	68°55'	164°41'	Quad. map	?	?	--	--	?	?	?	-21
U61-21	68°48'	164°12'	Quad. map	?	?	--	--	?	?	?	-29
-22	68°43'	163°45'	Quad. map	?	?	--	--	?	?	?	-25
-23	69°05'	163°50'	Quad. map	?	?	--	--	?	?	?	-20
-24	68°59'	162°55'	Quad. map	?	?	--	--	?	?	?	-22
-25	69°08'	162°45'	Quad. map	?	?	--	--	?	?	?	-10
U61-26	69°25'	162°40'	Quad. map	?	?	--	--	?	?	?	- 3
-27	69°34'	162°51'	Quad. map	?	?	--	--	?	?	?	- 1
-28	69°46'	162°58'	Quad. map	?	?	--	--	?	?	?	- 5
-29	71°22'	156°56'	Quad. map	?	?	--	--	?	?	?	+10
-30	70°30'	151°13'	Quad. map	?	?	--	--	?	?	?	- 7
U61-31	70°07'	151°52'	Quad. map	?	?	--	--	?	?	?	-16
-32	69°51'	150°55'	Quad. map	?	?	--	--	?	?	?	-25
-33	69°46'	151°00'	Quad. map	?	?	--	--	?	?	?	-29
-34	69°25'	152°11'	Quad. map	?	?	--	--	?	?	?	-13
-35	69°17'	152°48'	Quad. map	?	?	--	--	?	?	?	-19
U61-36	69°12'	153°15'	Quad. map	?	?	--	--	?	?	?	-18
-37	69°02'	153°55'	Quad. map	?	?	--	--	?	?	?	-28
-38	69°08'	154°35'	Quad. map	?	?	--	--	?	?	?	-31
-39	69°06'	155°10	Quad. map	?	?	--	--	?	?	?	-32
-40	69°58'	155°40'	Quad. map	?	?	--	--	?	?	?	-37
U61-41	69°57'	156°05'	Quad. map	?	?	--	--	?	?	?	-34
-42	70°06'	156°23'	Quad. map	?	?	--	--	?	?	?	-31
-43	69°55'	156°30'	Quad. map	?	?	--	--	?	?	?	-30
-44	69°54'	156°57'	Quad. map	?	?	--	--	?	?	?	-28
-45	69°57'	157°35'	Quad. map	?	?	--	--	?	?	?	-23

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
U61-46	70°00'	158°10'	Quad. map	?	?	--	--	?	?	?	-17
-47	70°02'	158°40'	Quad. map	?	?	--	--	?	?	?	-13
-48	70°27'	148°45'	Quad. map	?	?	--	--	?	?	?	-22
-49	70°13'	149°05'	Quad. map	?	?	--	--	?	?	?	-33
-50	70°02'	150°28'	Quad. map	?	?	--	--	?	?	?	-39
U61-51	69°53'	150°39'	Quad. map	?	?	--	--	?	?	?	-38
-52	69°42'	150°55'	Quad. map	?	?	--	--	?	?	?	-36
-53	70°21'	148°00'	Quad. map	?	?	--	--	?	?	?	-22
-54	70°16'	147°45'	Quad. map	?	?	--	--	?	?	?	-22
-55	70°13'	148°05'	Quad. map	?	?	--	--	?	?	?	-26
U61-56	70°04'	148°35'	Quad. map	?	?	--	--	?	?	?	-38
-57	69°53'	148°45'	Quad. map	?	?	--	--	?	?	?	-44
-58	69°41'	148°38'	Quad. map	?	?	--	--	?	?	?	-45
-59	69°29'	148°32'	Quad. map	?	?	--	--	?	?	?	-42
-60	69°20'	148°44'	Quad. map	?	?	--	--	?	?	?	-38
U61-61	69°08'	148°46'	Quad. map	?	?	--	--	?	?	?	-32
-62	69°23'	145°01	Quad. map	?	?	--	--	?	?	?	-56
-63	66°34'	152°38'	Quad. map	?	?	--	--	?	?	?	-18
-64	66°35'	151°42'	Quad. map	?	?	--	--	?	?	?	- 9
-65	66°55'	151°33'	Quad. map	?	?	--	--	?	?	?	- 2
U61-66	67°07'	151°01'	Quad. map	?	?	--	--	?	?	?	-32
-67	67°28'	150°58'	Quad. map	?	?	--	--	?	?	?	-50
-68	67°21'	152°02'	Quad. map	?	?	--	--	?	?	?	-49
-69	67°46'	152°17'	Quad. map	?	?	--	--	?	?	?	-39
-70	67°58'	152°39'	Quad. map	?	?	--	--	?	?	?	-95
U61-71	68°13'	152°45'	Quad. map	?	?	--	--	?	?	?	-75
-72	68°10'	151°40'	Quad. map	?	?	--	--	?	?	?	-93
-73	66°55'	153°23'	Quad. map	?	?	--	--	?	?	?	0
-74	67°09'	154°23'	Quad. map	?	?	--	--	?	?	?	-40
-75	66°49'	154°18'	Quad. map	?	?	--	--	?	?	?	-18

TABLE VI con't.

Station No.	Latitude N	Longitude W	Position determined by:	Elev M	± M	Water Depth M	± M	Theoretical Sea Level Gravity/gal	Observed Gravity/gal	Free Air Anomaly mgal	Bouguer Anomaly mgal
U61-76	67°41'	155°40'	Quad. map	?	?	--	--	?	?	?	-82
-77	68°09'	156°12'	Quad. map	?	?	--	--	?	?	?	-57
-78	68°23'	154°44'	Quad. map	?	?	--	--	?	?	?	-41
-79	68°25'	154°10	Quad. map	?	?	--	--	?	?	?	-44
-80	69°22'	147°22'	Quad. map	?	?	--	--	?	?	?	-32
F51-1	74°47'	138°40'	Sun fix	0	0	3520	5	982.863	982.857	- 6	+235
-2	74°45'	150°55'	Sun fix	0	0	3838	5	.862	.845	-17	+178
-3	73°22'	141°20'	Sun fix	0	0	3457	5	.796	.781	-15	+222
-4	75°53'	142°10'	Sun fix	0	0	3739	5	.912	.901	-11	+245

Source of Data

A60-series; University of Wisconsin (1960) Patenaude and Iverson

A61-series; University of Wisconsin (1961) Ostenso and Iverson

#d,e-series; University of Wisconsin (1958) Thiel, Ostenso, Bonini and Woollard

U61-series; U. S. Geological Survey (1961) Barnes and Allen

L49-series; Lamont Geological Observatory (1949) unpublished

L53-series; Lamont Geological Observatory (1953) unpublished

F51-series; Air Force Cambridge Research Center (1951) Crary, Cotell, and Oliver

TABLE VII

Gravity Station Descriptions

Station	Description
Beechy Pt.	Abandoned trading post, on wooden floor of front porch of main building facing and 15 m from ocean.
Foggy Isl.	Northern tip of island at abandoned Eskimo village at entrance to westernmost sod hut.
Point Barrow	Approximately 15 km northwest of the Arctic Research Laboratory on northernmost point of land on spit and 400 m north of Eskimo whale lookout shack.
Cape Halkett	On sea ice 30 m west of coast and ½ km south of survey marker.
Oarlock Isl.	On sea ice 20 m North of North shore.
Peter's Lake	At research camp to right of main entrance of main living quarters of ground level.
Barrow Pendulum Site	At Arctic Research Laboratory over gravity marker site desk set in concrete floor by the U. S. Coast and Geodetic Survey in Butler Building machine shop (Bldg. 353). This building burned in Feb. 1961 but foundation and marker are still intact and identifiable.
ARL Greenhouse	Arctic Research Laboratory in center of greenhouse gravel floor. This is about 50 m from and 0.3 m lower than pendulum site.
Barter Isl.	In corner of airplane hanger on corner of concrete platform for the winch which opens the hanger doors.
Brownlow Point	On floor of garage at abandoned radar station.

TABLE VII con't.

Station	Description
Aklavik A, N.W.T.	Army Signal House, on the boardwalk 5 feet from the meteorological instrument shelter in front of the building.
Aklavik B, N.W.T.	At the ski plane terminal on the Mackenzie River at the extreme south end of town.
Anaktuvuk Pass	Southwest bank of Summit Lake, 15 feet from edge of lake, 1 foot above lake level.
Bell River, Y.T.	On the ice in the center of a lake in a steep mountain valley.
Cape Lisburne	Center of the apron at south end of runway.
Chandalar River	Approximately 30 miles north of Old John Lake, on the ice in the center of the small lake on the east side of the east channel of Chandalar River.
Coleen River	Approximately 50 miles southwest of Mallard Springs, on the ice in the center of a small lake beside a "cat" trail.
Demarcation Point	DEW line radar station, in the center of the runway at its west end.
Humphrey Point	DEW line radar station, at the east end of the runway.
Kivalina	Extreme south end of landing strip.
Malcolm River, Y.T.	DEW line radar station 15 miles northwest along the coast from the mouth of Malcolm River, in the center of the runway.
Mallard Springs	On the southwest corner of the landing strip which parallels a "cat" trail.
Meade River	Seaplane landing, 50 feet north of a small tributary stream, 8 feet from river's edge.

TABLE VII con't.

Station	Description
Moose Channel, N.W.T.	On the ice in the center of a small lake on the Machenzie River delta, 1 mile south of Moose Channel and 1 mile east of the Yukon-Machenzie District border.
Old Crow, Y.T.	Off the south end of the north-south runway, on the ice in the center of the Porcupine River, 1 mile east of its junction with the Old Crow River.
Old Crow Flats, Y.T.	About 25 miles northwest of Old Crow, in the center of a lake in Old Crow Flats.
Old Joh Lake	On the ice at the northwest corner of the lake.
Point Hope	Eight feet south of building at west end of landing strip.
Point Lay	Foot of steps to door at southwest corner of school.
Shingle Point, Y.T.	DEW line radar station, in the center of the temporary runway built out onto the sea ice.
Simpson Cove	DEW line radar station, at the west end of the runway.
Stokes Point, Y.T.	DEW line radar station, in the center of the runway.
Wainwright	Seaplane landing on shore of a small lagoon 1 mile inland from village. Lagoon is separated from river by a bay bar. Reading taken on land just behind the bar, at a corner of the lagoon and on its downstream side.

The gravity survey was placed on an absolute datum via ties to the University of Wisconsin pendulum station in the machine shop at the Arctic Research Laboratory. The value of gravity at this site is 982.6996 gal. In February 1961, the machine shop burned down and a new gravity base was established in the middle of the gravel floor of the laboratory greenhouse. The new base station is 50 m from and 0.3 m lower than the pendulum site. The machine shop's concrete foundation was undamaged by the fire and the pendulum station marker could be easily located. Several closed loop ties were made between the pendulum and new base station. The value of gravity at the A.R.L. greenhouse was determined to be 982.6997 gal.

Some difficulty was experienced in reading the gravimeters on oscillating sea ice. However, the damping of the meters was sufficiently great that with care and patience reading with an accuracy of better than $\pm$ 0.5 mgal could be obtained.

5. 3. Seismic Water Depth Soundings

Water depths were obtained with a two-channel seismograph which recorded on a Century model 444 Ultragraph. This seismic camera utilized Kodak linograph recording paper which is self-developing in sunlight. Thus it was possible to determine immediately the water depth without delaying for a liquid developing process. The seismograms were later fixed chemically for permanency. The third channel of the ultragraph was used to record the shot instant and a 100-cycle timing signal from a thermostatically controlled tuning fork was put on the fourth and final trace. Two S.I.E. GA-11 amplifiers were used along with S.I.E. 20-cycle geophones to detect the reflected acoustic energy. The explosive charge size varied from a cap to one pound (500 g) of dynamite, depending upon the water depth. There was not enough time available at the stations to permit the charges to be placed beneath the ice, so abnormally large shots were needed. In general, good bottom reflections were obtained and the overall accuracy of water depths determined by seismic sounding is considered to be $\pm$ 5 m.

The travel time of reflected energy was related to water depth by use of Crary and Goldstein's formulas (1959) based upon the Kauwahara Charts (Kauwahra, 1938) and using known Arctic Ocean salinities and temperatures. The latter are extremely stable throughout most of the Central Arctic Basin and can be considered constant throughout the year. For convenient field use Crary's relationship of travel time to water depth and mean compressional wave velocity was plotted graphically (Fig. 15).

In the first year's program, plans made to borrow a small seismograph failed to materialize at the last minute, so no depth soundings were obtained with the gravity readings. Thus the water depths under these stations had to be picked off bathymetric charts. Fortunately, most of these gravity sites were over the shallow and featureless Chukchi Shelf and continental shelf.

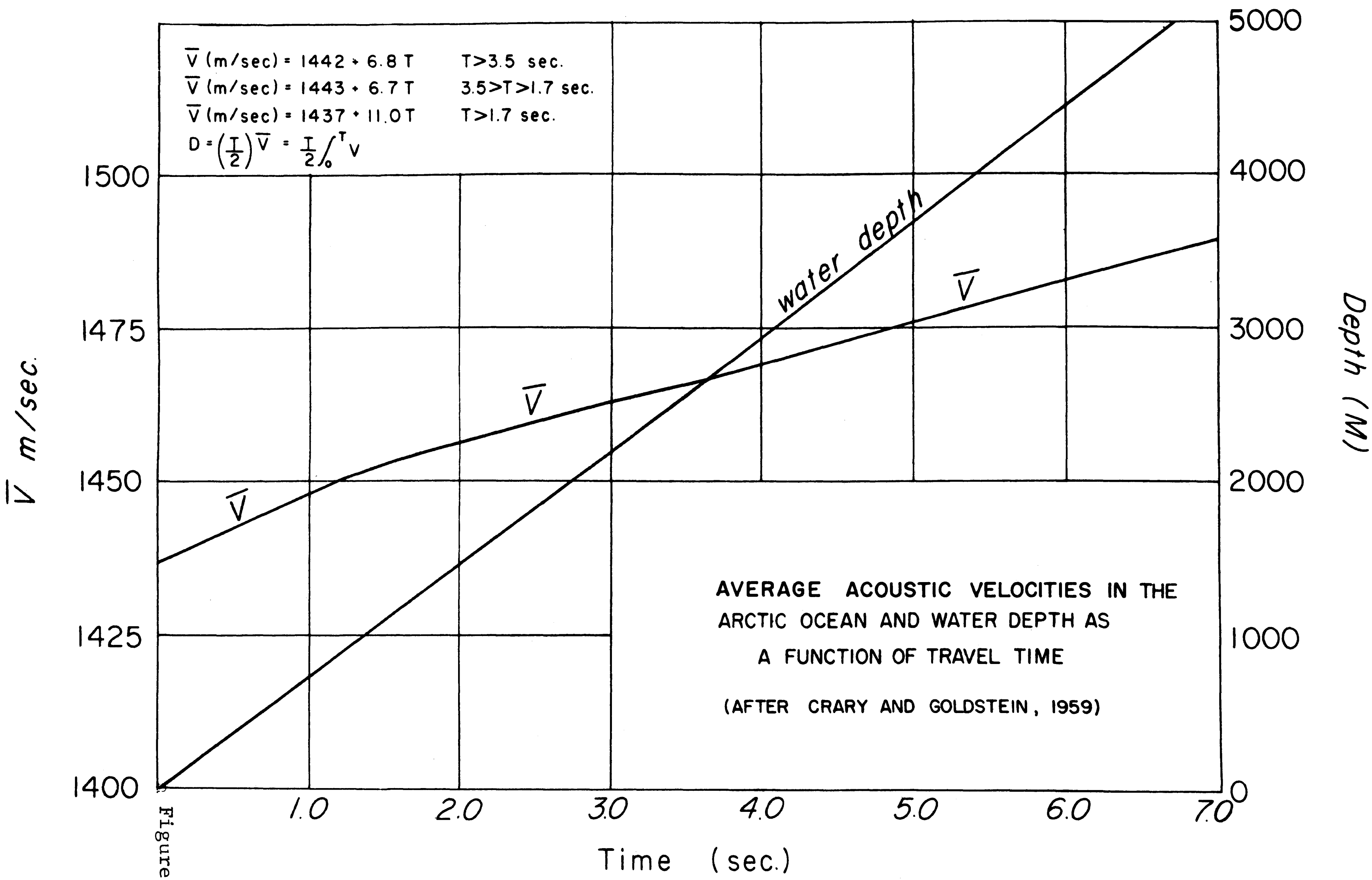


Figure 15.

MEAN WAVE VELOCITIES AS A FUNCTION OF DEPTH

The water depths under the ocean gravity stations and the elevations of the land stations are listed in Table VI along with their estimated accuracy. At the stations where seismic soundings were not available, an estimation of the accuracy of water depth obtained from bathymetric charts was obtained by enscribing a circle around the stations, whose radius was a function of navigational reliability, and noting the variations of water depth within this circle. The maximum variation of ocean bottom elevation within a circle was used as the estimated accuracy of the assumed water depth at that station. The accuracy of the bathymetric charts themselves, based on ship soundings, is presumably high as the coverage was generally quite detailed in the areas in question and each sounding was plotted on large scale charts used.

5. 4. Navigation

Accurate navigation over the Arctic Ocean was the most difficult problem encountered in the survey. Several methods of determining position were used which included dead reckoning, radio compass, radar positioning from DEW line sites, and sunlines of position from sextant observations. Usually, several of these methods were used simultaneously; in general, the farther from shore, the poorer the position accuracy. The distant stations are located to no better than an estimated $\pm$ 5 km. The navigational methods used in locating each of the gravity stations are included in Table VI.

5. 5. Free Air Iso-Anomaly Map

A free air iso-anomaly map of northern Alaska and the adjoining Arctic Ocean is shown in Figure 16. The low anomaly values over the Chukchi Shelf and Canada Deep show that these major features are in isostatic equilibrium. In contrast, a free air anomaly of approximately -50 mgals is superimposed over northeasterly trending end of the Brooks Range east of the Colville River, indicating that it is slightly over-compensated. Also, there is a broad negative anomaly over the Beaufort Deep of -55 mgls culminating in an oval-shaped anomaly of -100 mgals at the northwestern junction of the deep with the Northwind Seahigh (75°N., 158°W). The Bouguer anomaly over the Beaufort Deep is +225 mgals vs. +245 mgals over the Canada Deep (Fig. 19).

A possible explanation of the -50 mgal regional free air gravity low over the Beaufort Deep is that the basaltic crust (ρ = 2.86 gm/cc) is depressed by 2.6 km into the mantle (ρ = 3.32 gm/cc). A second possible explanation would be the presence of an uncompensated layer of lower density material overlaying the crustal basalt. For instance, assuming a density differential of 0.3 gm/cc such a layer would have to be 4 km thick. Of course, there could be any variety of a combination of these two effects, and any unique solution is contingent upon seismic evidence. A Bouguer gravity low is located over the Chukchi Shelf just to the northwest of the -100 mgal oval-shaped free air anomaly. A granitic section is known to exist in other parts of the shelf, where it protrudes above sea level in places forming Wrangel, Herald, and the Diomede Islands. Furthermore, seismic refraction studies south of Barrow conducted during the Naval Petroleum Reserve No. 4 exploration program showed basement compressional wave velocities of 5.18 km/sec overlying 6.4 km/sec (Payne et al., 1952). The lower velocity was associated with argillite and slate, possibly of Precambrian age, whereas the higher velocity was suggested to be related to granite. Thus, it seems reasonable to assume that the Chukchi Shelf is capped by material of normal crustal density; and that a probable explanation, then, for the Bouguer low is the presence of an abnormal thickness of this material. However, it could also be the result of a thinner lens of uncompensated lower density sediments. The -100 mgal free air anomaly could be caused by an extension of the relatively low density material under the northwestern portion of the Beaufort Deep.

There is a +92 mgal free air anomaly and +96 Bouguer anomaly northwest of Barrow in the vicinity of 73°N., 160°W. These anomalies are probably caused by a rise in the granitic (ρ = 2.8 gm/cc) basement similar to the granitic rises forming Wrangel, Herald, and the Diomede Islands elsewhere on the Chukchi Shelf. This rather high density for granite was obtained by applying Payne's velocity of 6.4 to Woollard's (1959) relationship between rock density and velocity of compressional wave transmission. A model that would satisfy these anomalies is shown in Figure 17. The gravimetric effect of this and following models was computed by Hubbert's (1948) line-integral method. Naturally these models represent only one of many possible crustal structures.

A large elliptical +107 mgal free air anomaly is located over the continental shelf off the northeast coast of Alaska at the termination of the Brooks Range. Payne (1951) states: "East of the 149th (W.) meridian the Brooks Range province bulges northward to within about 25 miles of the Arctic Coast. In as much as folds and thrust faults in the area of the bulge maintain the general east strike characteristic of the province, the bulge seems to have been caused by greater uplift of the area east of the 149th meridian rather than by a northward swing at the structural axis." From this geological evidence the free air high is attributed to a sharp rise in the basement and mantle. This interpretation is consistent with the Bouguer anomaly which has a very steep positive gradient in this same area. A possible crustal model which would satisfy the observed gravity along the profile A-A' is shown in Figure 18. Although this model does not represent a unique solution (assuming different densities and adding additional crustal elements would alter the section somewhat), it does point out the obvious fact that the strong positive Bouguer gradient occurs over the continental shelf and not over the continental slope. The most reasonable explanation of this gradient is an abrupt crustal thinning of the order of magnitude shown in the model.

A relative free air high extends northwestward from the +107 mgal anomaly to the +92 mgal anomaly centered at 73°N., 160°W. This high is broad and irregular. It has a maximum amplitude of 70 mgals and its crest parallels the 200 m isobath. The steep positive Bouguer gradient in this region lies over the continental slope. The free air anomaly, then, could be accounted for by a ridge of relatively high density material such as granite within the crust, and projecting into less dense overlying material.

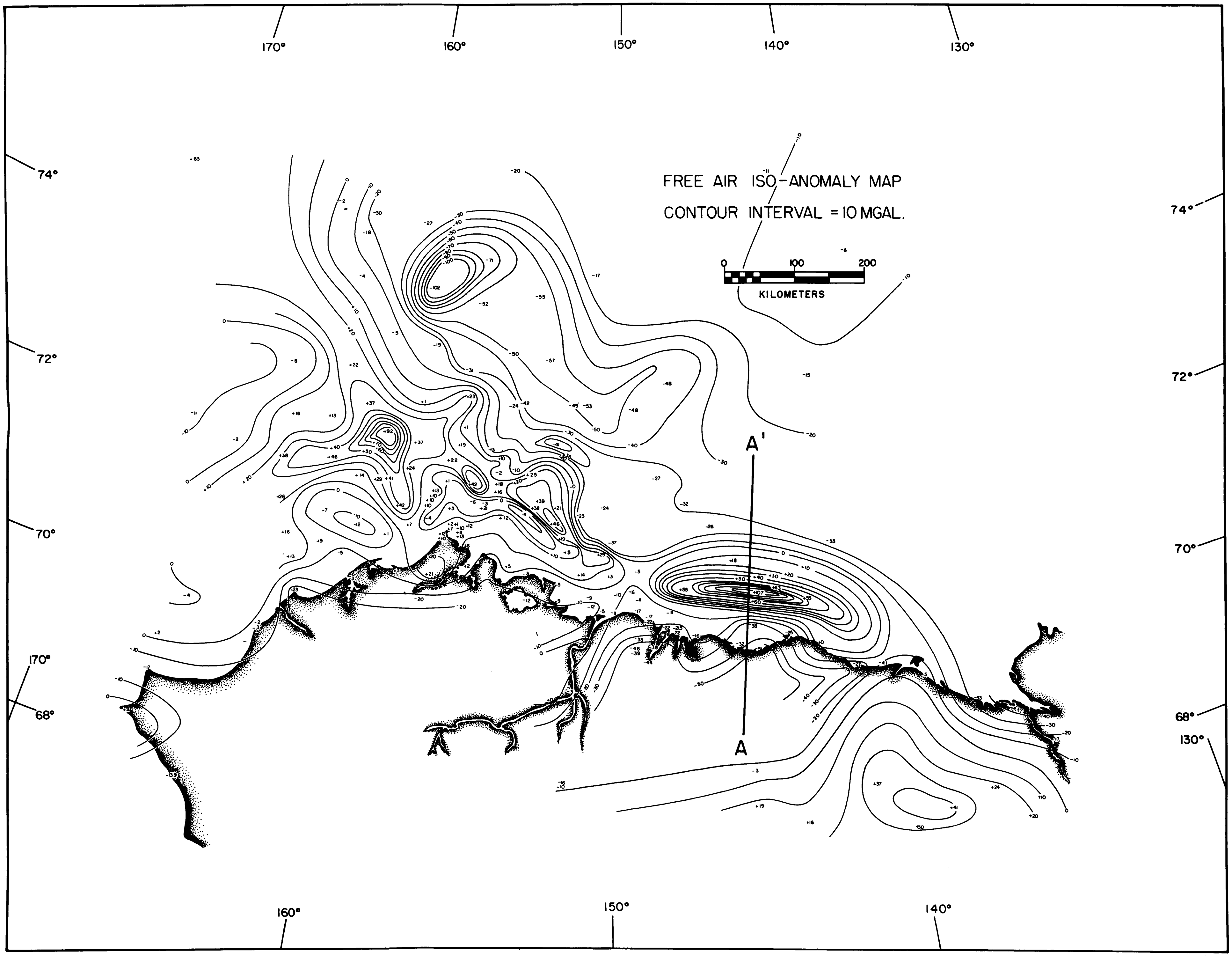

FREE AIR ISO-ANOMALY MAP
CONTOUR INTERVAL = 10 MGAL.
0
100
200
KILOMETERS
A'
A
170°
160°
150°
140°
130°
74°
72°
70°
68°

Figure 1?.

POSSIBLE CRUSTAL SECTION UNDER ANOMALY CENTERED AT 73°N, 160°W

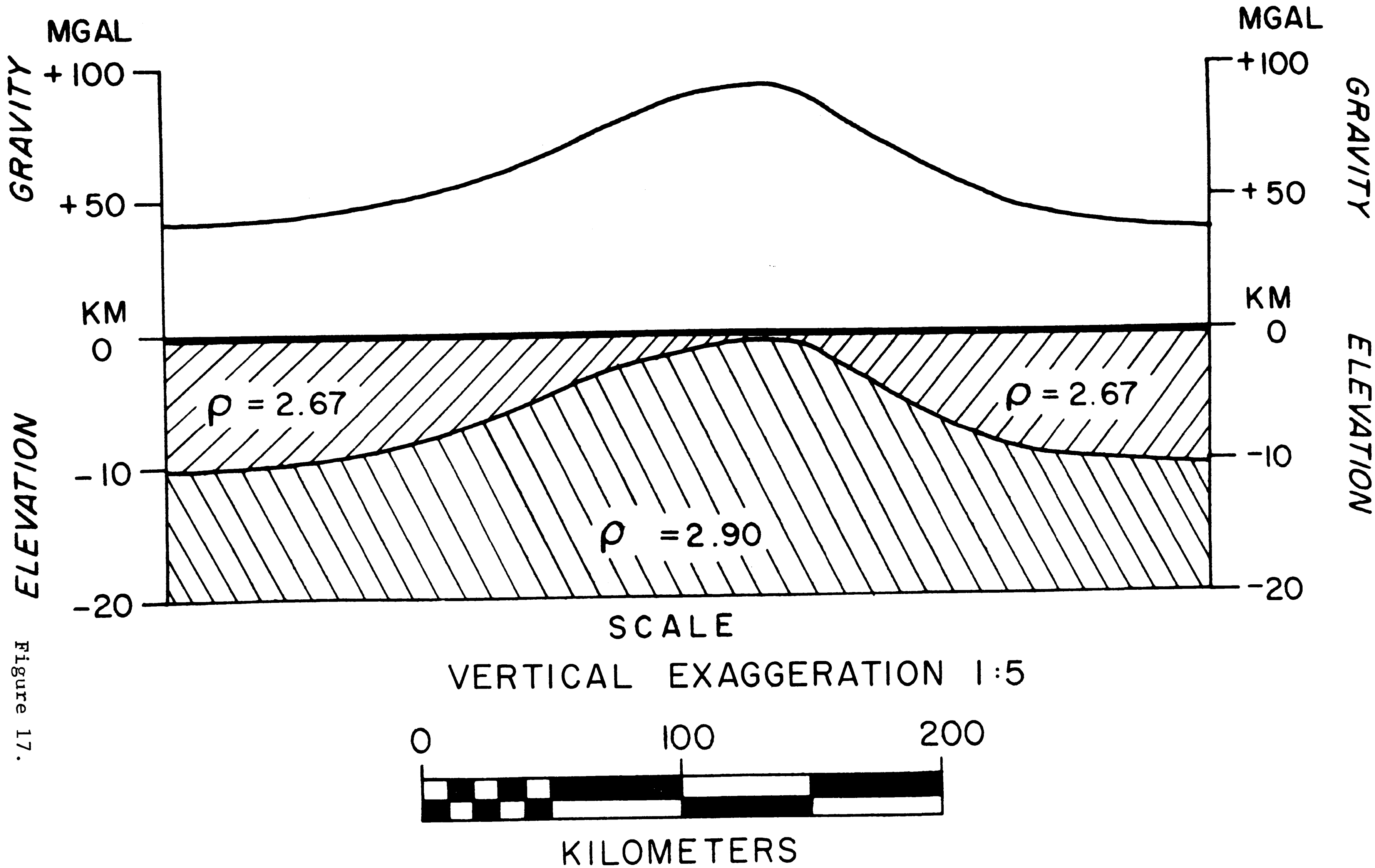


Figure 17.

POSSIBLE CRUSTAL SECTION A - A'

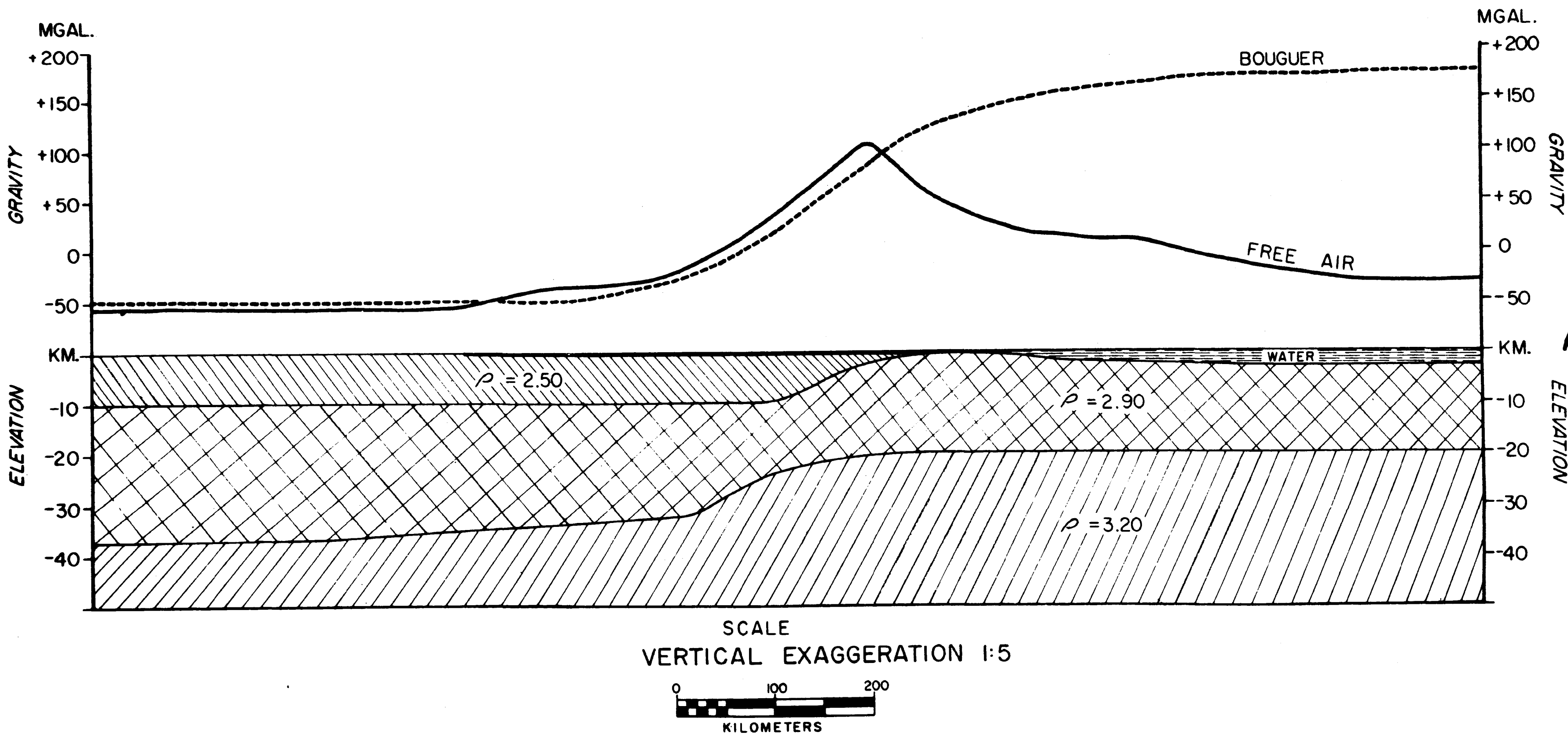


Figure 18.

A possible interpretation of the general structural framework of the continental shelf off northern Alaska is as follows: There is a ridge of high density material, probably granite, paralleling the continental shelf. In the vicinity of 145°W. longitude the ridge rises inshore of the 200 m isobath. Farther west the crest of the ridge lies approximately under the 200 m isobath to latitude 160°W. where it swings inshore into the Chukchi Shelf. Centered on 145°W. longitude there is an abrupt rise in elevation of M under the continental shelf.

The +40 mgal anomaly centered in the area 68°N., 140°W. is associated with a broad Bouguer high which Woollard et al. (1960) attributed to an intrusive basic rock mass within an ancient crystalline cratonic complex.

5. 6. Bouguer Iso-Anomaly Map

A Bouguer iso-anomaly map of northern Alaska and the adjacent Arctic Ocean is shown in Figure 19. A geologic correction has been applied to the Bouguer anomalies over the ocean i.e. the water column has been substituted by material with a density of 2.67 gm/cc. The most prominent feature of this map is the steep positive gravity gradient over the continental slope reflecting the abrupt deepening of the ocean. The highest Bouguer values are located over the Beaufort and Canada Deeps.

The Bouguer low centered at 75°N., 160°W. and the high in the vicinity of 73°N., 160°W., have been discussed in the previous section (see Fig. 17). Along the continental slope there are a series of four highs that more or less point inwards towards the region south of Barrow. The northwesternmost of these anomalies joins the +96 mgal anomaly at 73°N., 160°W. and is probably related to the same cause, a rise in the granitic basement. The two anomalies occurring between longitudes 152°W. and 158°W. are located over submarine valleys that cut into the continental shelf. These Bouguer highs reflect the increased water depths. The fourth and easternmost anomaly probably reflects a rise in basement rock.

Payne et al. (1951) state that approximately 16 km southwest of Barrow a complex core of basement rock has been delimited by seismic studies. This core, which extends to within approximately 400 m of the surface, is roughly circular with a diameter of about 8 km. It is bounded by a peripheral fault or faults with additional high-angle faults radiating from it. The Bouguer highs are in line with the high angle normal faults shown by Payne et al. (1951) suggesting that the genesis of the submarine valleys and rises in basement rock might be influenced by, if not directly attributable, to these fractures.

The Bouguer high in the vicinity of Barrow has been described by Woollard et al. (1960) as being associated with the basement ridge which rises to within 750 m of the surface (Payne et al. 1951). This feature lies on the north side of a cretaceous sedimentary basin which is outlined by a gravity low. A depth of nearly 5 km of sediment was conservatively calculated for this basin (Woollard et al., 1961).

The marked negative anomaly of nearly 100 mgal associated with crustal thickening beneath the Brooks Range does not faithfully follow the topography. In the area south of Barter Island a negative anomaly in excess of -50 mgal swings northward toward the Arctic Ocean. This swing coincides with a change in the geologic pattern of the surface formations caused by two periods of orogeny in this area. Structurally the Brooks Range is an elevated geanticline which underwent folding during both the Cretaceous and Tertiary periods. The east-west oriented structural and gravity anomaly pattern is associated with the earlier Cretaceous folding, which exposed a great section of Paleozoic sediments, metamorphics, and associated intrusive masses that are predominantly granitic. The north-trending gravity anomaly pattern is associated with the later Tertiary orogeny which exposed both Upper Paleozoic and Cretaceous sediments. The later, softer sediments have subsequently been eroded, forming the northern foothills of the Brooks Range, and the older, more indurated Paleozoic sediments stand in bold relief to form the Romanzof Mountains, which contain the highest peaks of the range. In view of the history of orogenic folding and the parallelism of structural and gravity anomaly patterns, it is probable that the gravity anomalies are related to crustal roots developed at the time of orogeny.

Woollard (1959) and the Soviet investigator Demenitskaya (1959) have demonstrated the feasibility of using Bouguer gravity anomalies to obtain a first approximation to the elevation of the Mohorovicic discontinuity. Both investigators have given plots of seismically determined crustal thickness from continents and oceans against Bouguer anomalies and have fitted these data with the best possible curve. Their curves are compared in Figure 20. Demenitskaya's curve for continental crustal thicknesses is biased with a preponderence of data from Eurasia, whereas Woollard uses mainly North American data for this section of his curve. The oceanic section of Demenitskaya's curves is based predominantly on Pacific data, in contrast to Woollard who used mostly Atlantic information. Although these two relationships agree well in the -25 km to -35 km elevation range and meet again at -67 km, they diverge considerably elsewhere. This divergence could be the result of either a fundamental difference in crustal structure of the regions sampled or a basic difference in interpretation of seismic data (see Steinhart and Meyer, 1961).

In Figure 21, two generalized crustal models are given based upon Bouguer anomalies. Section B-B' (see Fig. 13) extends from east of Barrow into the Chukchi Shelf. Here Woollard's and Demenitskaya's elevations of M are seen to be in good agreement. Woollard's relationship gives an elevation for M of -32 km under the arctic slope to -27 km under the Chukchi Shelf. Demenitskaya's curve gives a 3 km thicker crust at the continental end and a 3/4 km thinner crust under the shelf. Regardless of whose relationship is used, this entire crustal section must be regarded as truly continental in character. The second profile C-C' extends from approximately the United States-Canada border south of the Brooks Range northwestward into the Canada Deep. Here considerable difference is seen between the two sections. Where Woollard's relationship gives an elevation of -36 km for M under the continent and -19 km under the Canada Deep Demenitskaya's curve gives -41 km and -14 km respectively. Whereas the former relationship would indicate an intermediate crustal thickness under the deep ocean, the latter implies a

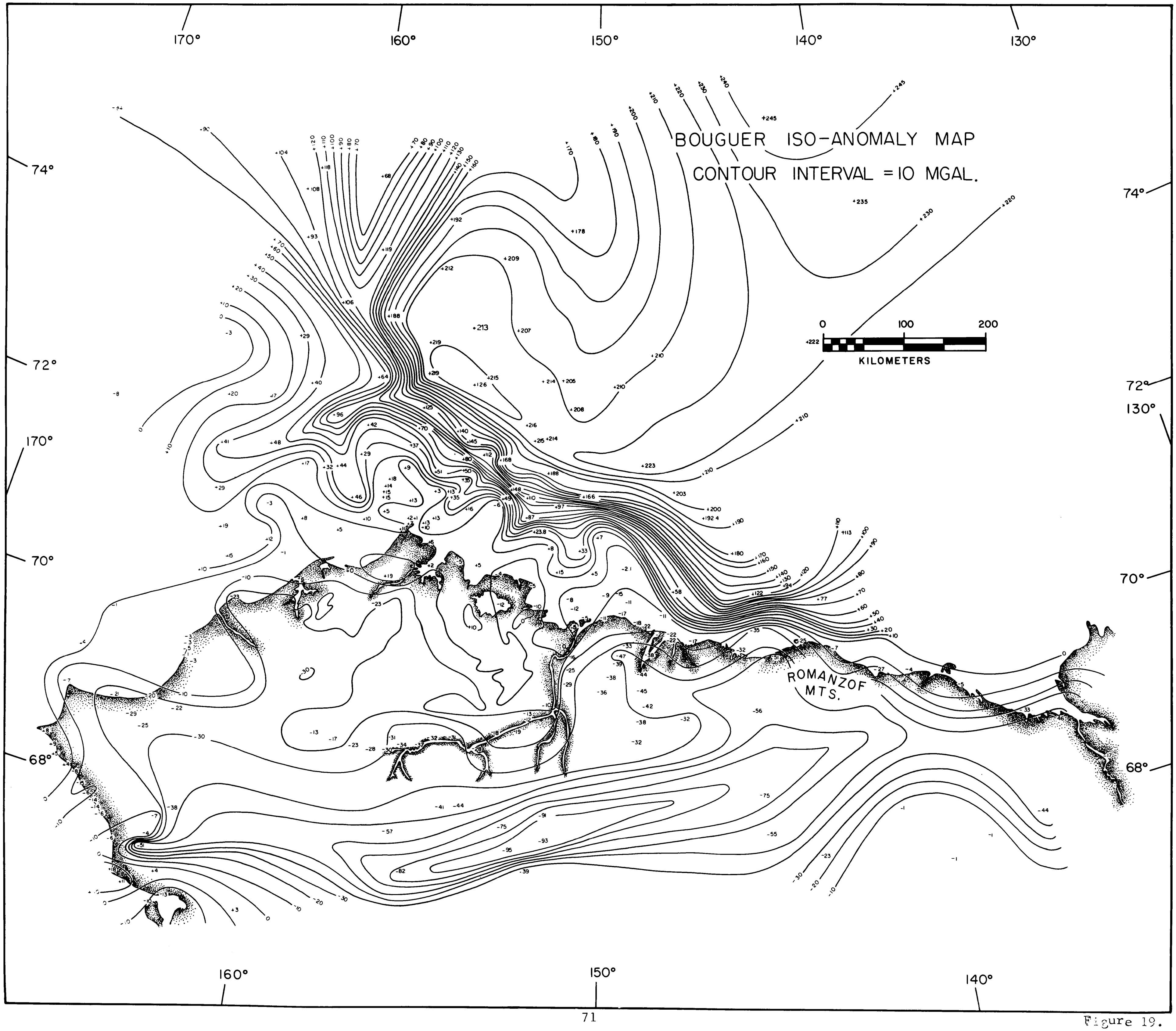
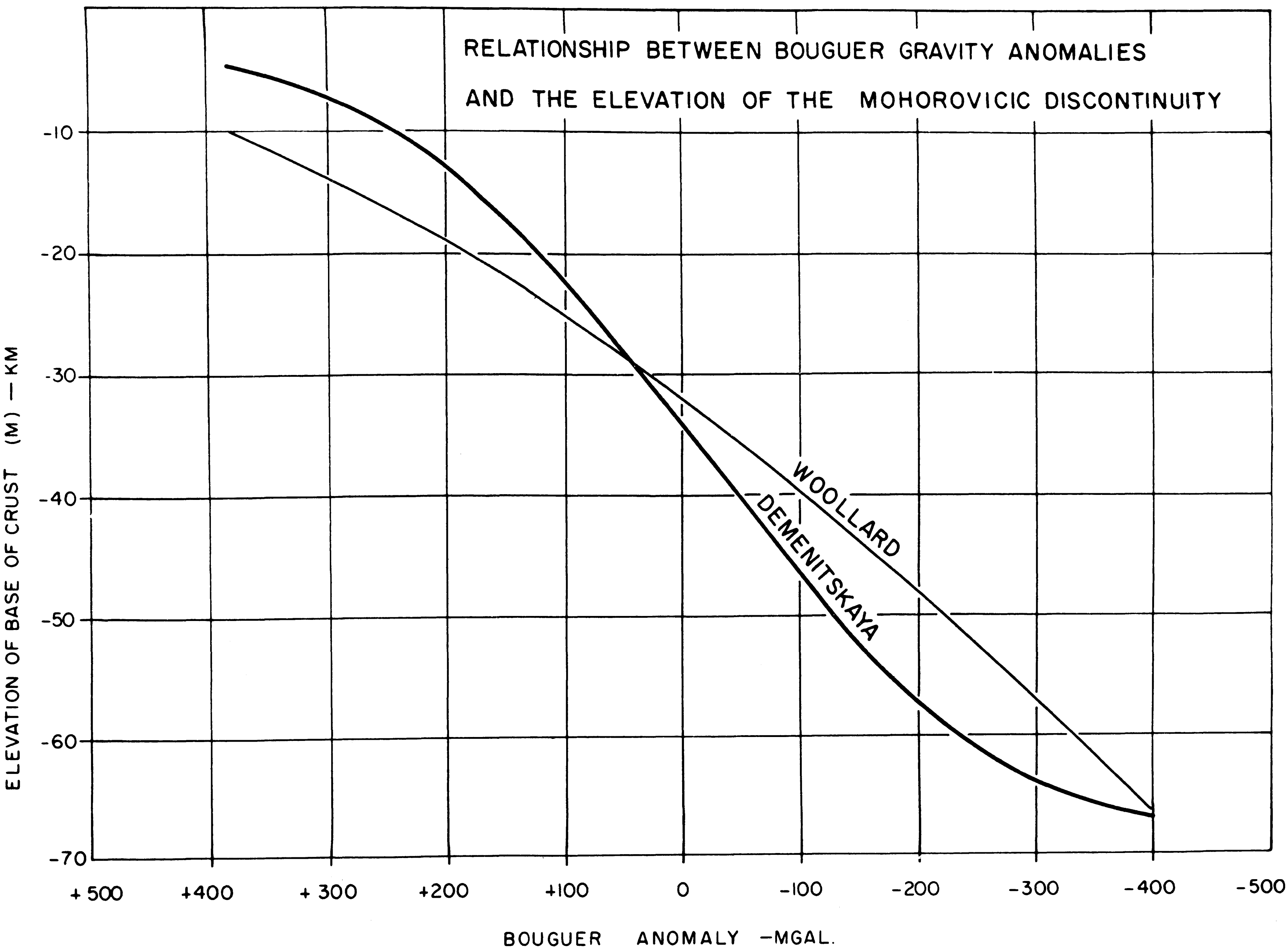

BOUGUER ISO-ANOMALY MAP
CONTOUR INTERVAL = 10 MGAL.
0 100 200
KILOMETERS
ROMANZOF MTS.
170°
160°
150°
140°
130°
74°
72°
70°
68°

Figure 19.

Figure 20.



RELATIONSHIP BETWEEN BOUGUER GRAVITY ANOMALIES
AND THE ELEVATION OF THE MOHOROVICIC DISCONTINUITY
ELEVATION OF BASE OF CRUST (M) — KM
-10
-20
-30
-40
-50
-60
-70
WOOLLARD
DEMENITSKAYA
+500
+400
+300
+200
+100
0
-100
-200
-300
-400
-500
BOUGUER ANOMALY -MGAL.

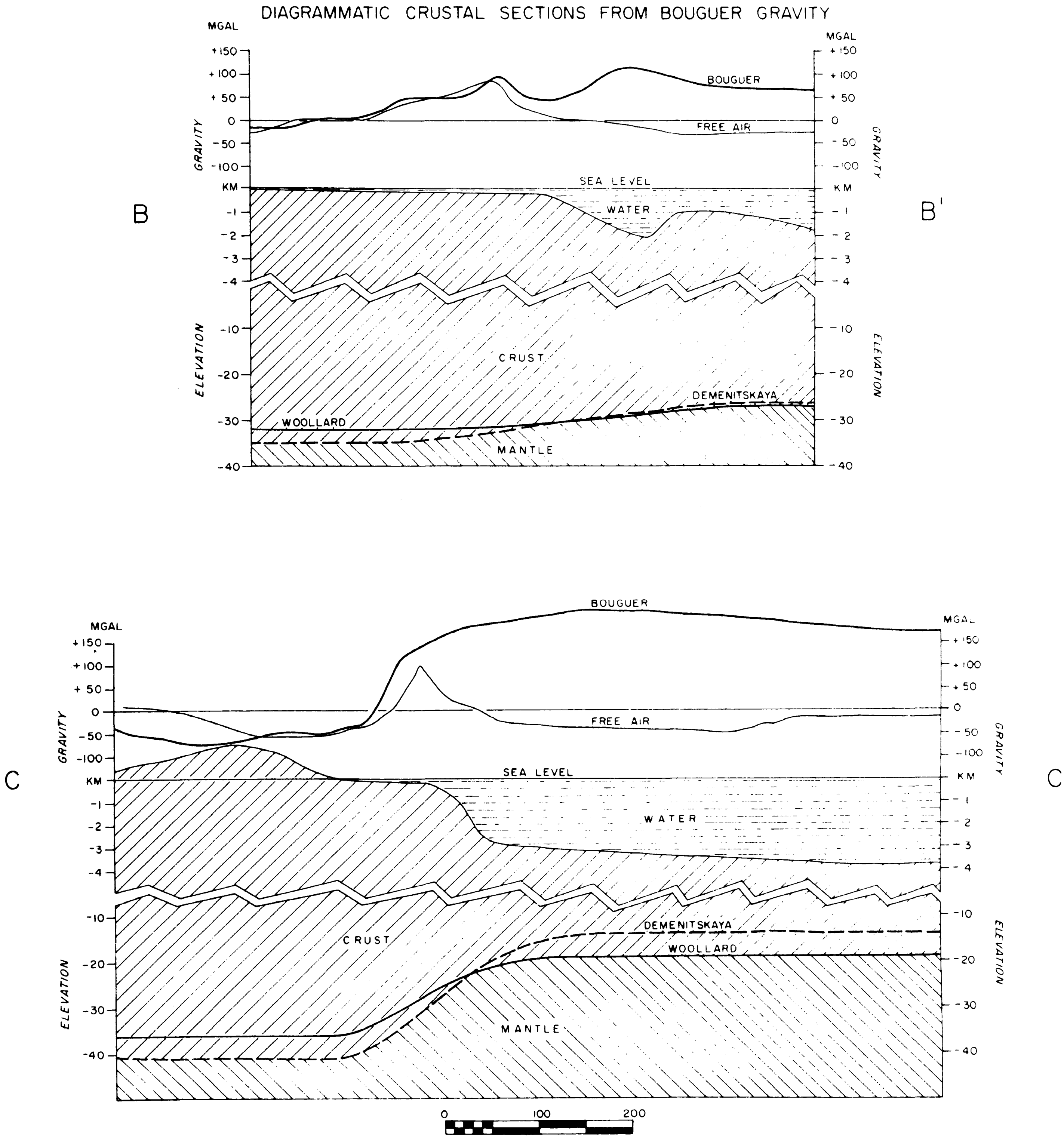

DIAGRAMMATIC CRUSTAL SECTIONS FROM BOUGUER GRAVITY
B
B'
MGAL
GRAVITY
BOUGUER
FREE AIR
SEA LEVEL
KM
WATER
ELEVATION
CRUST
DEMENITSKAYA
WOOLLARD
MANTLE
C
C'
0
100
200
KILOMETERS

Figure 21.

more nearly oceanic crust. Which of these two models is more correct depends upon whether the crustal structure of the Arctic Ocean is more nearly like the Atlantic or Pacific Ocean in character (discounting the possibility that the divergence of Woollard's and Demenitskaya's curves is caused mainly by differences in seismic interpretation). It should also be borne in mind that both of the curves were constructed with very little data for the range of intermediate crustal thicknesses.

Crary and Goldstein (1957) and Hunkins (1960) have published a total of six refraction profiles over the Alpha Rise (Fig. 22). These un-reversed profiles show a velocity structure indicative of a continental rather than an oceanic crust.

A chart of crustal thickness inferred from gravitational information for the entire Arctic Basin is shown in Figure 23. This figure is from a small insert map appearing in a paper by Demenitskaya (1959). The crustal thicknesses were computed from her Bouguer gravity relationship, and presumably the gravity data are from all or nearly all of the drift stations and High Latitude Expedition Landings. As all of these data are under security classification by the Soviets, there is no certainty as to their quantity or quality. This map shows the crustal structure of the Arctic Basin to be considerably variable, as might be expected from its topographic irregularities. Had Woollard's curve been used to calculate crustal thicknesses appreciably greater values would have been obtained. For comparison a conversion key has been added to Figure 23.

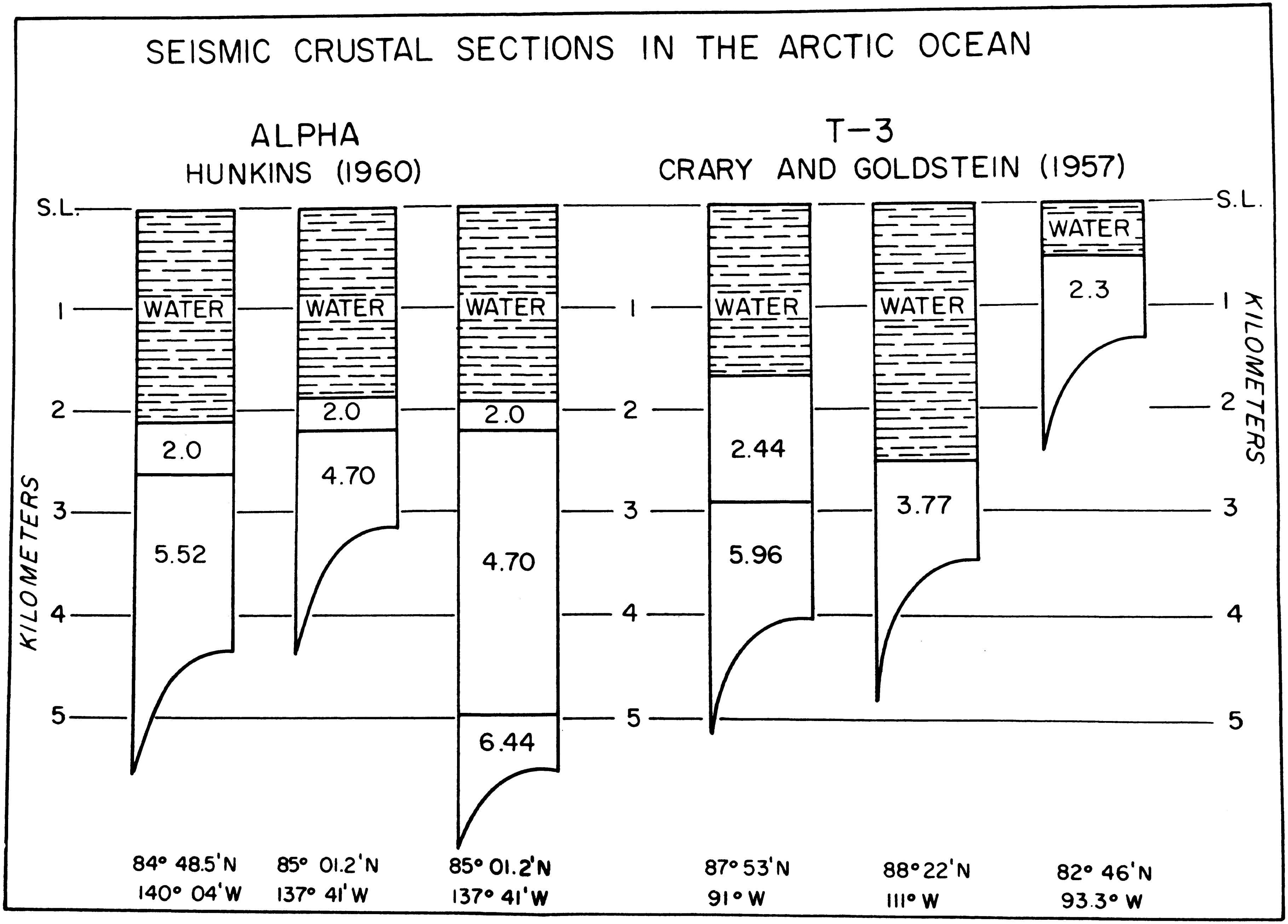
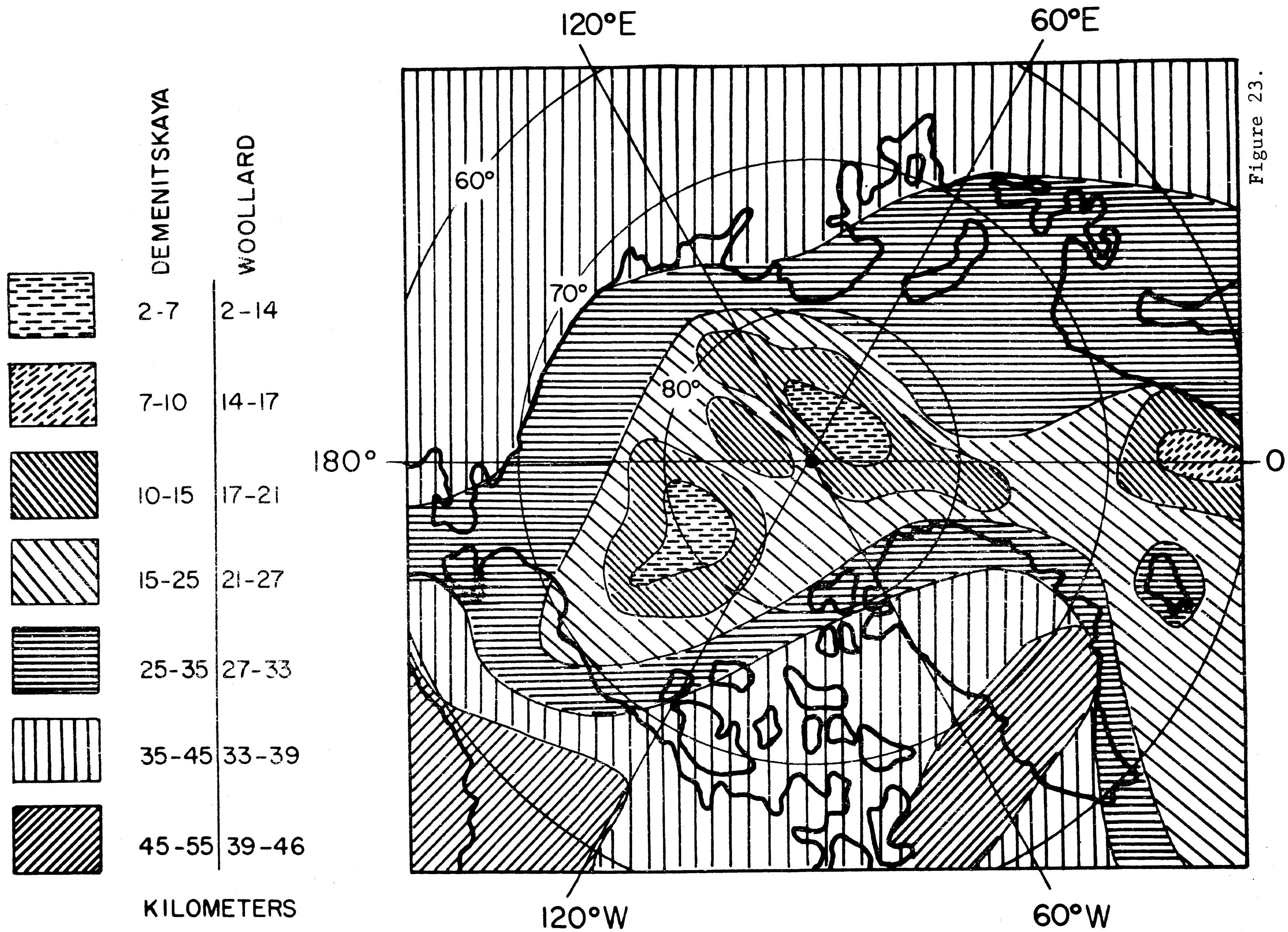

SEISMIC CRUSTAL SECTIONS IN THE ARCTIC OCEAN
ALPHA
HUNKINS (1960)
T-3
CRARY AND GOLDSTEIN (1957)
S.L.
KILOMETERS
WATER
2.0
5.52
4.70
6.44
2.44
5.96
3.77
2.3
84° 48.5'N
140° 04'W
85° 01.2'N
137° 41'W
85° 01.2'N
137° 41'W
87° 53'N
91° W
88° 22'N
111° W
82° 46'N
93.3° W

Figure 22.

Figure 23.



DEMENITSKAYA'S MAP OF CRUSTAL THICKNESS FROM BOUGUER GRAVITY

Chapter 6

MAGNETIC SURVEY

6. 1. Field Program

The aeromagnetic survey was conducted during the months of May and June, 1961. Flights originated out of Thule, Greenland, and Barrow and Eielson Air Force Bases, Alaska. In 200 hours of flying time approximately 66,000 km of aeromagnetic flight lines were completed. Of this total, 49,500 km were over the Arctic Ocean and the adjoining Canadian Archipelago and 16,500 km were over land and the Atlantic Ocean in transit to and from the Arctic Ocean (Fig. 24).

The responsibility for operational support of this project was delegated to the Naval Air Development Unit based at South Weymouth, Massachusetts. A P2V-5 (Neptune) aircraft was instrumented with a Varian proton precession magnetometer (Model 4910) capable of recording the absolute value of the earth's total magnetic field to a sensitivity of $\pm$ 4 gammas. The cycling time of the magnetometer was 0.7 sec; thus at an average ground speed of 330 km/hr readings were obtained approximately every 65 m. The normal flight elevation was 450 m above the ice pack and was closely controlled by a radio altimeter.

Flying conditions throughout the project were generally good. In early June the cloud cover rose, and the weather at Thule and Barrow deteriorated as the ice pack began to break up. However, even under the worst weather conditions encountered, the sun was sufficiently visible at least half the time for navigational purposes. An APN-122 doppler navigator was used to obtain true ground speed and drift. Although the aircraft was equipped with a LORAN-C navigator, it never worked properly and was ultimately removed from the plane to reduce weight. Navigational accuracy is estimated to be $\pm$ 15 km. Further details of the flight operations have been given by Hall and Ostenso (in press).

The greatest navigational problem was the uncertainty concerning winds aloft. Although pre-flight planning was based on the best information available, winds were frequently encountered 180° from the predicted direction. This factor, coupled with severe icing conditions, proved to be a great handicap, and many flight plans had to be changed en route to compensate for the lost ground speed.

6. 2. Data Reduction

Over one million measurements of the earth's total magnetic field were obtained from this aerial survey. This vast amount of data was reduced and analyzed with the assistance of the Control Data Corporation 1604 high speed computer of the Numerical Analysis Laboratory, University of Wisconsin. The computer was programmed to perform the following operations: 1) to compute

AEROMAGNETIC FLIGHT LINES OVER ARCTIC OCEAN 1961

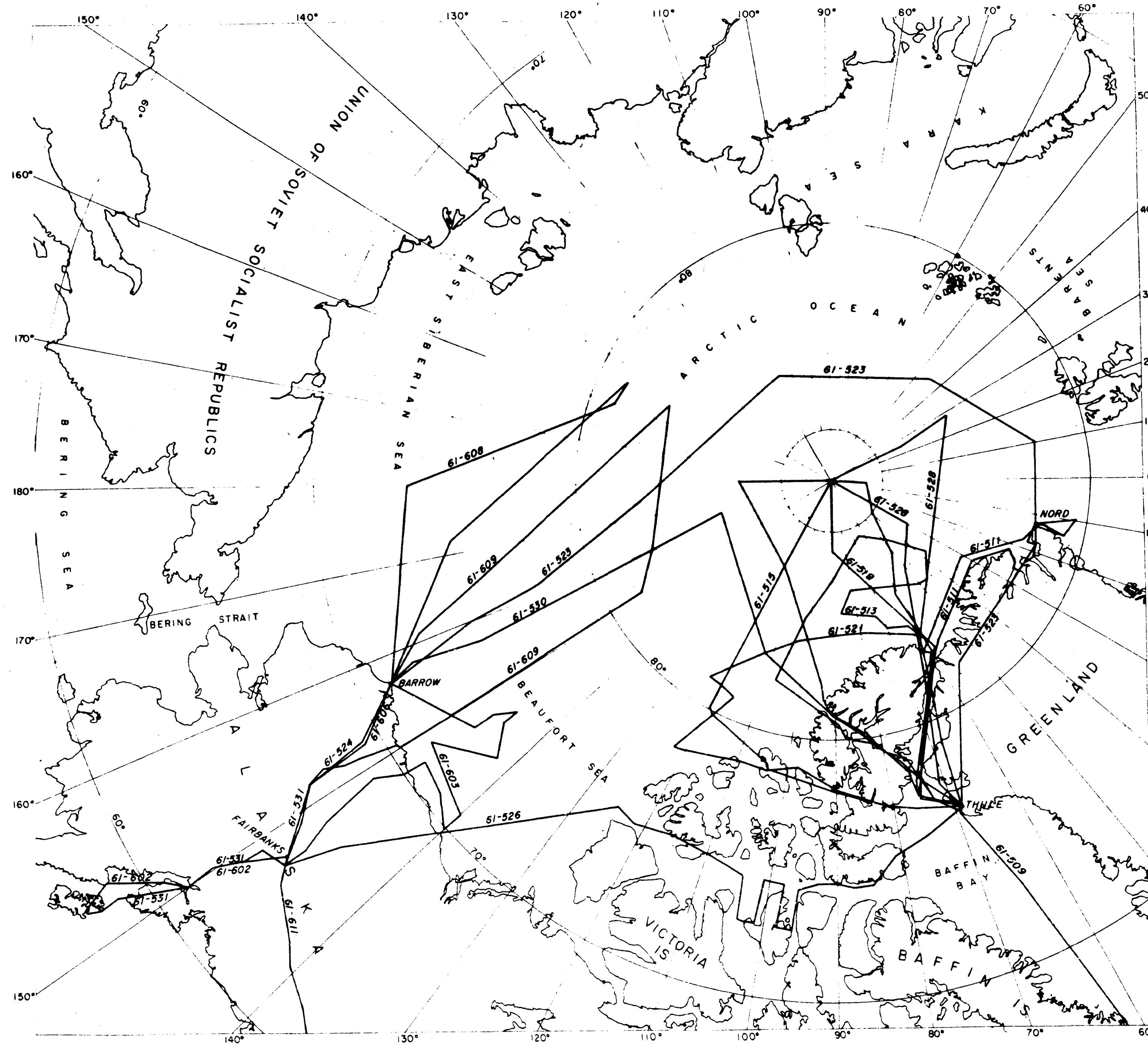


Figure 24.

the absolute value of the earth's total magnetic field from the magnetometer's analog recordings, 2) to compute first and second derivatives of the field, 3) to perform upward and downward continuations of the total field and its derivatives, and 4) to compute two dimensional least square fits. This program has been discussed in detail by Wolf (in preparation).

To compute upward and downward continuations and second derivatives by Henderson's (1960) formulas, which were designed for a three-dimensional data distribution, it was necessary to adopt his coefficients to a two-dimensional distribution by using the following formula (Henderson, personal communication):

$$
\begin{aligned}
\Delta T_i\ (m) = {} & a_i\ D\ (o,m) + 1/4\ (a_{i-1} + 2a_i + a_{i+1})\ D\ (1,m) \\
& + 1/2\ (a_{i-1} + a_{i+1})\ D\ (\sqrt{2},m) + 1/4\ (a_{i-2} + a_{i-1} + a_{i+1} + a_{i+2})\ D\ (\sqrt{5},m) \\
& + 1/2\ (a_{i-2} + a_{i+2})\ D\ (\sqrt{8},m) + 1/4\ (a_{i-3} + a_{i-2} + a_{i+2} + a_{i+3})\ D\ (\sqrt{13},m) \\
& + 1/12\ (a_{i-3} + 2a_{i-4} + 2a_{i-3} + 2a_i + 2a_{i+3} + 2a_{i+4} + a_{i+5})\ D\ (\sqrt{25},m) \\
& + 1/6\ (a_{i-7} + a_{i-5} + a_{i-1} + a_{i+1} + a_{i+5} + a_{i+7})\ D\ (\sqrt{50},m) \\
& + 1/4\ (a_{i-10} + a_{i-6} + a_{i+6} + a_{i+10})\ D\ (\sqrt{136},m) \\
& + 1/4\ (a_{i-15} + a_{i-7} + a_{i+7} + a_{i+15})\ D\ (\sqrt{274},m) \\
& + 1/12\ (a_{i-25} + 2a_{i-20} + 2a_{i-15} + 2a_i + 2a_{i+15} + 2a_{i+20} + a_{i+25})\ D\ (25,m)
\end{aligned}
$$

For easier computation this equation was algebraically rearranged:

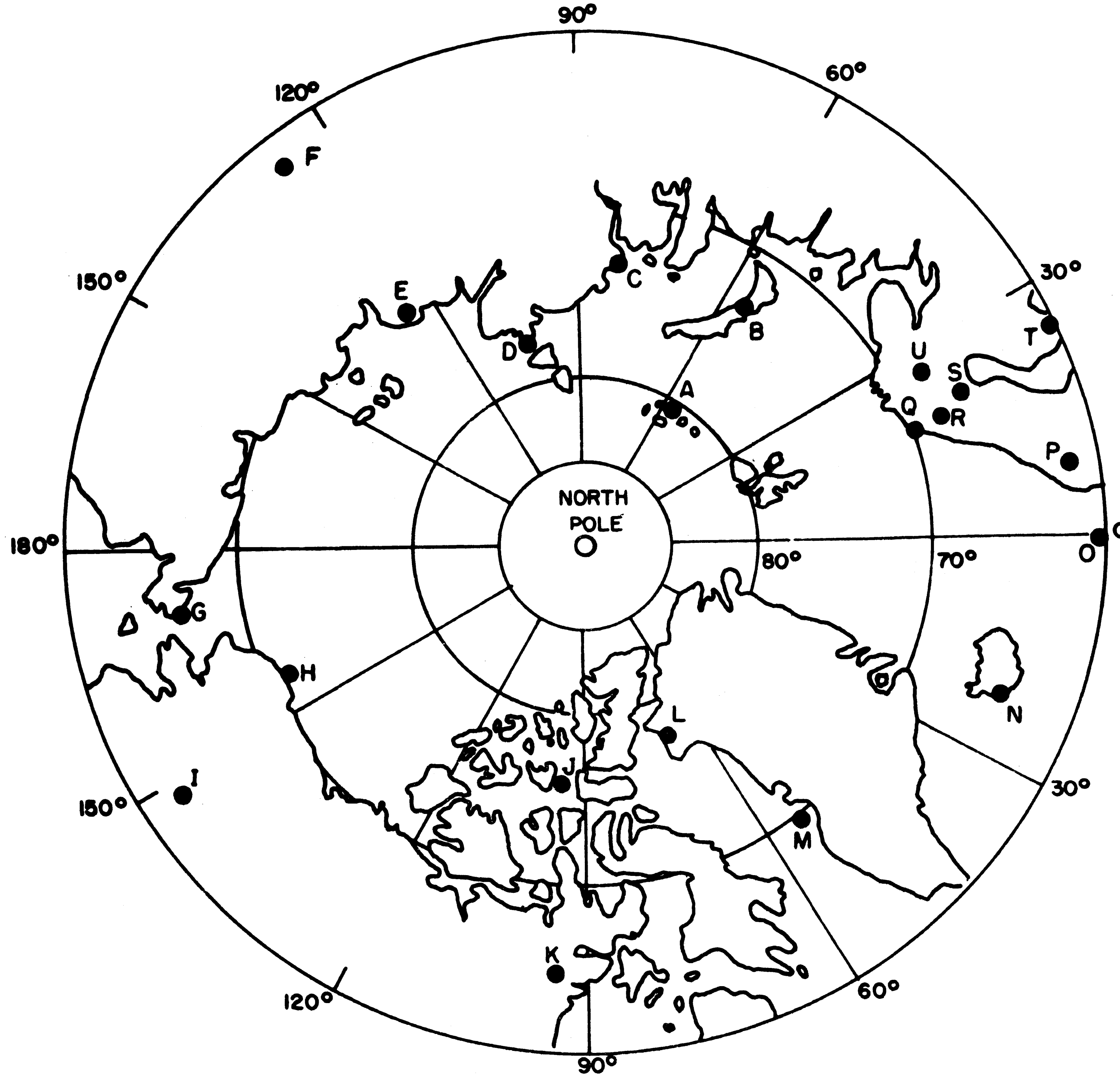
$$\begin{aligned}
\Delta T_i\ (m) = {} & a_i\ (D(o,m) + 1/2\ D\ (1,m) + 1/6\ D\ (\sqrt{25},m) + 1/6\ D(25,m)) \\
& + (a_{i-1} + a_{i+1})\ (1/4\ D\ (1,m) + D(\sqrt{2},m) + 1/4\ D\ (\sqrt{5},m) + 1/6\ D\ (\sqrt{50},m)) \\
& + (a_{i-2} + a_{i+2})\ (1/4\ D\ (\sqrt{5},m) + 1/2\ D\ (\sqrt{8},m) + 1/4\ D\ (\sqrt{13},m)) \\
& + (a_{i-3} + a_{i+3})\ (1/4\ D\ (\sqrt{13},m) + 1/6\ D\ (\sqrt{25},m)) \\
& + (a_{i-4} + a_{i+4})\ (1/6\ D\ (\sqrt{25},m)) \\
& + (a_{i-5} + a_{i+5})\ (1/12\ D\ (\sqrt{25},m) + 1/6\ D\ (\sqrt{50},m)) \\
& + (a_{i-6} + a_{i+6})\ (1/4\ D\ (\sqrt{136},m)) \\
& + (a_{i-7} + a_{i+7})\ (1/6\ D\ (\sqrt{50},m) + 1/4\ D\ (\sqrt{274},m)) \\
& + (a_{i-10} + a_{i+10})\ (1/4\ D\ (\sqrt{136},m)) \\
& + (a_{i-15} + a_{i+15})\ (1/4\ D\ (\sqrt{274},m) + 1/6\ D\ (25,m)) \\
& + (a_{i-20} + a_{i+20})\ (1/6\ D\ (25,m)) \\
& + (a_{i-25} + a_{i+25})\ (1/12\ D\ (25,m))
\end{aligned}$$

For these aeromagnetic data from the Arctic Ocean, the output of the computer was programmed to print in profile form the following information: 1) total intensity, 2) second derivatives, 3) downward continuation to 5,000 ft. (1,525 m) below flight level, 4) downward continuation to 10,000 ft. (3,050 m) below flight level, and 6 & 7) two-dimensional least square fits to polynomials of orders varying between 10 to 60. Two least square fits were profiled simultaneously with the number of allowable inflections determined by the length of an unbroken flight line, the purpose being to accentuate the longer wave length anomalies originating at depth, i.e. anomalies with half-wave lengths in the range of 20 to 40 km. These anomalies tend to be obscured by short wave length, high amplitude anomalies originating from near-surface geologic variations. The program was designed to allow for approximately one and two inflection points per 40 km of continuous flight line. Therefore, the computer would scan ahead and select the orders of polynomials to be used according to the length of unbroken flight track. The normal combinations were 10 and 20, 20 and 40, and 30 and 60 degrees of freedom. In addition to profiling, the computer tabulated: 1) total intensity, 2) second derivative, 3) 5,000 ft. (1,525 m) downward continuation, 4) 10,000 ft. (3,050 m) downward continuation, and 5) the highest order of least square fit. With this system of machine printout, one has displayed on a continuous strip of paper a variety of mathematical tools, in addition to the original data, to assist in evaluating and interpreting the aeromagnetic profiles. An extensive review and evaluation of various quantitative methods of magnetic interpretation has been given by Sanker Narayan (1961). This paper also gives a detailed description of the proton precession magnetometer.

No corrections have been applied to the aeromagnetic data for temporal changes in the earth's magnetic field. An attempt to correlate such changes over the great distances involved might introduce more ambiguities than it would eliminate. However, a "degree of credence" for the anomalies along any profile can be obtained if one knows the intensity of magnetic disturbance of the region being surveyed at the time of the survey. Fortunately, the Arctic Ocean is surrounded by an international network of magnetic observatories (Fig. 25). There are 22 observatories north of latitude 60° N. (Table VIII). By tabulating and comparing the K-indices and whole day magnetic character figures from these observatories for the time of each flight (Table IX), it is possible to obtain a qualitative estimate of temporal disturbance that might be expected on each magnetic profile. Unfortunately, at the time of writing the K-indices and whole day characters from three of the stations had not yet been received; as a result Table IX is not complete. However, the tabulated indices from 18 observatories show that, in general, the aeromagnetic flights were made during periods of magnetic quiet and that no flight was made during a magnetic storm. In addition, weekly radio propagation forecasts from the North Pacific Radio Warning Service, National Bureau of Standards, Anchorage, Alaska, and the North Atlantic Radio Warning Service, N.B.S., Fort Belvoir, Virginia were received by teletype at Thule and Barrow and, in so far as was possible, flights were scheduled for days when ionospheric disturbances were predicted to be at a minimum.

6. 3. Quantitative Interpretation

Since the development of recording high precision magnetometers just prior to World War II, considerable attention has been given to mathematical methods of quantitatively evaluating magnetic data. The various mathematical treatments have progressed along two basic theoretical concepts: 1) The Pole and Line Theory expresses observed magnetic fields in terms of the effects of a magnetic pole, or poles, or line of poles within the disturbing body without any assumption regarding the origin of the poles themselves. This theory is valid for any strength and direction of magnetization regardless of origin, only the position of the poles must be known. 2) The Induction Theory explicitly assumes that anomalies are caused by induction of a body in the present field of the earth and are expressed in terms of the strength and direction of that inducing field, magnetic susceptibility contrasts of the body with respect to its surroundings, and the dimensions and attitude of the body.



LOCATION OF MAGNETIC OBSERVATORIES

Figure 25.

Table VIII

Magnetic Observatories in the Arctic Regions

	Observatory	Country	Latitude	Longitude
A	Tikhaya Bay	U.S.S.R.	80°20 'N	52°48 'E
B	Vykhodnoi (Motochkin Shar)	U.S.S.U.	73 14.1 N	56 43.8 E
C	Dikson	U.S.S.R.	73 32.6 N	80 33.7 E
D	Chelyuskin	U.S.S.R.	77 43 N	104 17 E
E	Tiksi (Tixie)	U.S.S.R.	71 35 N	129 00 E
F	Yakutsk	U.S.S.R.	62 01.0 N	129 43.0 E
G	Uelen (Welen)	U.S.S.R.	66 09.8 N	169 50.1 W
H	Barrow	U.S.A.	71 18.2 N	156 44.9 W
I	College	U.S.A.	64 51.6 N	147 50.2 W
J	Resolute Bay	Canada	74 41.2 N	94 49.9 W
K	Baker Lake	Canada	64 20 N	96 02 W
L	Thule (Greenland)	Denmark	77 29 N	69 10 W
M	Godhaven (Greenland)	Denmark	69 14.4 N	53 31.3 W
N	Leirvogur	Iceland	64 11 N	21 41 W
O	Larwick	U.K.	60 08 N	01 11 W
P	Dombas	Norway	62 04 N	09 07 E
Q	Tromso	Norway	69 40 N	18 57 E
R	Abisko	Sweden	68 21 N	18 49 E
S	Kiruna	Sweden	67 50 N	20 25 E
T	Nurmijarvi	Finland	60 30 N	24 39 E
U	Sodankyla	Finland	67 22 N	26 39 E

Table IX

K-indices and Whole-Day Characters for Periods of Aeromagnetic Flights

Flight #61-528 Date: 11-12 May '61 Time: 1312-0206Z

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	5		5	3	5	3	4	5	5	2	3	6	6	4	3	4	4			4	4	4
15-18	4		5	3	5	2	3	4	4	5	7	6	6	4	3	4	4			4	3	4
18-21	6		7	5	7	2	3	5	2	3	6	3	5	4	3	4	5			4	5	4
21-24	5		5	4	4	3	3	4	3	2	3	5	4	4	2	2	4			2	4	3
00-03	6		5	5	4	2	3	4	4	2	4	5	4	6	3	3	5			3	5	4
Whole-day char.	1		1	1	1	0	1	1	1	0	1	1	1	1	0	1	1			0	1	1

Observatories*

Flight #61-513 Date: 13-14 May '61 Time: 1310-0156Z

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	5		4	4	4	3	3	5	4	1	6	6	5	3	3	3	3			3	3	4
15-18	4		6	3	5	1	3	4	3	2	4	6	5	3	2	2	3			3	3	3
18-21	5		6	3	5	2	3	3	2	3	3	5	3	3	2	3	4			3	3	3
21-24	4		5	3	2	1	2	3	2	2	2	4	3	3	2	1	4			2	1	2
00-03	5		4	3	3	1	3	3	3	2	6	4	4	4	3	3	4			2	3	3
Whole-day char.	1		1	1	1	0	0	1	0	0	1	1	1		0	0	1			0	0	1

Observatories*

Flight #61-515 Date: 15-16 May '61 Time: 1315-0245Z

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	3		3	3	2	0	1	2	1	0	2	5	4	1	1	1	2			2	1	2
15-18	4		3	3	2	1	2	4	2	0	3	4	4	1	2	1	2			2	1	2
18-21	4		6	5	5	1	2	3	2	1	2	4	4	2	2	2	5			2	3	3
21-24	5		6	4	5	1	2	3	2	1	3	4	3	3	3	3	4			2	5	3
00-03	6		7	5	4	4	3	4	3	3	3	5	4	6	4	5	6			4	6	4
Whole-day char.	1		1	1	1	0	0	1	0	0	0	1	1		0	0	1			0	1	1

Observatories*

Table IX cont.

Flight #61-519 Date: 19-20 May '61 Time: 1315-0150Z

Time	Observatories*																				
	A	B	C	D	E	F	H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	3		3	2	2	1	2	2	1	1	2	5	5	1	2	2	2			2	2	2
15-18	3		4	3	4	2	2	4	2	2	1	5	4	1	2	2	3			2	2	3
18-21	5		4	3	3	2	2	3	2	2	2	4	3	2	1	2	3			2	4	3
21-24	5		5	4	4	2	3	3	2	2	1	5	4	5	4	5	4			3	6	4
00-03	5		5	4	4	3	3	4	3	2	2	4	3	5	4	4	5			3	5	4
Whole-day char.	1		1	1	1	0	0	1	0	0	0	1	1	0	0	0	1			0	1	1

Flight #61-521 Date: 21-22 May '61 Time: 1250-0025Z

Time	Observatories*																				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	3		3	2	3	2	3	4	4	0	1	4	2	0	1	0	1			1	0	2
15-18	3		4	2	3	0	1	3	1	0	1	4	3	1	2	0	2			2	1	2
18-21	5		6	5	6	2	3	4	2	1	2	4	3	3	2	2	3			2	2	3
21-24	3		3	3	4	1	2	2	1	1	2	4	3	3	2	0	2			1	2	2
00-03	5		3	3	3	1	2	3	3	2	1	3	2	4	2	2	4			2	3	3
Whole-day char.	1		1	1	1	0	0	1	0	0	0	1	0		0	0	0			0	0	0

Flight #61-523 Date: 23-24 May '61 Time: 1212-0615Z

Time	Observatories*																				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
12-15	5		5	3	5	2	3	4	4	1	2	5	6	3	3	4	4			4	4	4
15-18	4		5	3	4	0	3	4	4	3	6	6	6	3	3	4	3			4	3	4
18-21	4		5	3	3	2	2	3	2	4	3	5	4	2	2	1	4			2	2	3
21-24	4		4	3	4	1	2	3	2	2	2	5	3	2	1	0	2			1	1	2
00-03	5		4	4	3	1	2	4	3	2	4	4	5	6	3	3	5			3	4	4
03-06	5		3	3	3	1	3	4	3	1	2	4	3	-	3	2	4			2	2	3
Whole-day char.	1		1	1	1	0	0	1	0	0	1	1	1		0	0	1			0	0	1

Table IX cont.

Flight #61-526 Date: 26-27 May '61 Time: 2110-0852Z

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
	Observatories*																					
21-24	3		3	3	2	1	2	2	1	0	1	3	2	2	1	3	4			1	4	2
00-03	5		4	4	3	1	2	3	2	0	0	4	3	5	1	3	5			2	2	3
03-06	5		2	2	3	1	2	3	2	0	1	3	2	2	0	0	2			1	2	2
06-09	4		2	3	3	1	3	3	2	0	1	3	3	1	1	0	1			1	0	2
Whole-day char.	1		0	1	0	0	0	0	0	0	0	1	0		0	0	1			0	0	0

Flight #61-528 Date: 28-29 May '61 Time: 1320-0158Z

Time	A	b	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
	Observatories*																					
12-15	5		4	3	4	1	3	4	3	1	3	5	4	1	3	4	3			4	3	3
15-18	4		7	5	7	3	4	4	3	1	5	4	4	2	3	3	4			3	4	4
18-21	4		5	5	6	3	4	5	3	3	3	4	3	4	3	3	4			3	4	4
21-24	5		5	5	4	2	3	4	3	1	3	5	3	4	3	3	4			3	5	4
00-03	4		3	2	3	1	2	3	2	0	0	3	2	1	1	0	1			1	1	2
Whole-day char.	1		1	1	1	0	1	1	0	0	0	1	1		0	0	1			1	1	1

Flight #61-530 Date: 30-31 May '61 Time: 1308-0048Z

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
	Observatories*																					
12-15	4		3	2	3	0	2	3	2	1	2	5	4	1	3	3	3			3	3	3
15-18	4		4	3	2	0	3	4	2	4	5	6	5	1	3	3	3			3	2	3
18-21	4		4	3	2	1	1	2	1	5	1	4	3	1	1	1	2			2	1	2
21-24	4		3	3	2	1	2	3	1	2	3	4	3	1	2	2	3			2	1	2
00-03	5		4	4	4	3	3	3	3	1	1	4	3	2	3	3	2			3	2	3
Whole-day char.	1		1	1	0	0	0	0	0	0	0	1	1		0	0	0			0	0	0

Table IX cont.

Flight #61-603   Date: 3-4 June '61   Time: 1943-0703Z

Observatories*

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
18-21	5		4	3	3	0	1	2	1	4	1	4	3	0	1	0	2			1	1	2
21-24	4		3	3	3	0	2	2	1	1	2	4	3	0	1	2	3			1	2	2
00-03	4		2	2	1	0	2	4	3	1	1	4	3	2	1	0	3			2	1	2
03-06	4		3	4	2	2	3	4	3	1	7	4	3	3	1	1	1			2	2	3
06-09	4		3	3	2	0	2	5	3	1	2	4	4	3	2	1	2			2	1	2
Whole-day char.	1		1	1	0	0	0	1	0	0	0	1	1		0	0	0			0	0	0

Flight #61-608   Date: 8 June '61   Time: 1040-2240Z

Observatories*

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
09-12	6		5	4	4	3	5	6	5	2	2	6	5	3	3	3	4			3	3	4
12-15	4		4	5	5	2	4	4	4	2	2	6	5	2	3	4	3			4	3	4
15-18	5		6	6	4	2	4	4	4	3	3	5	5	3	3	4	3			4	4	4
18-21	4		6	4	4	2	3	4	2	4	4	5	4	3	3	3	5			3	3	4
21-24	5		5	5	4	1	3	5	3	2	3	5	4	4	2	2	4			3	3	3
Whole-day char.	1		1	1	1	0	1	1	1	0	0	1	1		0	1	1				1	1

Flight #61-609   Date: 9-10 June '61   Time: 2314-1414Z

Observatories*

Time	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	Av.
21-24	3		4	3	3	1	2	2	1	1	2	4	3	3	2	2	4			2	2	2
00-03	4		3	4	2	0	1	2	1	0	1	3	3	2	1	1	2			1	1	2
03-06	4		2	2	2	0	2	2	2	0	1	3	2	3	1	0	1			1	0	1
06-09	4		3	3	3	0	3	3	2	0	2	3	3	1	1	1	2			2	2	2
09-12	3		4	3	3	1	3	5	3	0	2	4	4	0	1	1	3			2	3	3
12-15	4		4	3	3	2	2	3	3	1	3	6	4	0	2	2	3			2	2	3
Whole-day char.	1		1	1	0	0	0	0	0	0	0	1	1		0	0	0			0	0	0

Sanker Narayan (1961) presents a detailed theoretical and empirical evaluation of the most common methods of computing depths to the surfaces of anomaly causing bodies. Of the various methods available the half-slope method described by Peters (1947) is of the greatest interest as it provides a simple method of depth analysis that can be used on a routine basis for all magnetic interpretation work. Peter's method is basically a solution of the inverse potential problem where, by starting with the actual observed field, a distribution of magnetization is derived which would account for it. As with all methods of interpretating potential fields, no solution is unique. With certain reasonable assumptions, however, ambiguities in interpretation can be minimized though they always exist in a rigorous theoretical sense.

Peter's method rests on the following basic assumption: 1) The magnetic anomaly is caused by a body having a uniform susceptibility which differs from the susceptibility of the surrounding rocks. 2) The contact between the body and the surrounding rock is vertical. If the sides of the anomalous rock mass slope downward and outward the depth obtained by this method is too great. If the sides slope inward the calculated depth is too shallow. The sides can deviate from vertical by 10 degrees without introducing serious error in the depth determinations (Gardner, 1962). 3) The body is polarized only by induction in the earth's field and that this field has a negligible horizontal component. In high magnetic latitudes the total field vector is steep enough to justify an assumption that the change in inclination angle would be negligible and that anomalies would be symmetrical. Also, if the anomalies are small compared to the total field intensity causing little change in the magnetic vector, airborne data in which the total field is measured can be considered equivalent to measurements of changes in only the vertical component of the total field. 4) The anomaly-producing body extends downward to infinite depth. 5) The body is of infinite length. Gardner (1962) reports that the length-to-width ratio can be as little as 3 without appreciable error being introduced. 6) The top surface of the anomalous body is such that it expresses no topographic relief (an example would be a dyke or plug of basaltic material intruded into granitic rock that comes up to the basement surface). If the rock mass extends above the adjacent surface into non-magnetic sediments, it is equivalent to a double-layer problem, and the calculated depths will be too shallow.

According to Peters, 90% of the depth estimates evaluated by the Gulf Oil Company were accurate to better than ± 20% and about 75% were probably accurate to within ± 10%. Sanker Narayan (1961), in comparing this method with other methods of depth determination in the United States using the total field, found that on the average the depth of basement can be estimated to within ± 15 to 20%.

It is important to realize that the proper selection of anomalies and the choice of the position and attitude of profiles across them are the most important factors which govern the success of any method of depth determination. The anomalies must not be influenced by the effects of neighboring anomalies or regional gradients. The latter must be removed before analysis. The best results are obtained with an anomaly of elliptical form whose major axis is at least three times longer than the minor axis. Further, the profiles to be analyzed should run at right angles to the major axes and pass through the apex of the anomalies, preferably going through a section where the contour spacings are fairly uniform. These requirements for the "sampling" of anomalies impose the greatest limitation upon determining depth estimates from magnetic profiles where data are not sufficient to construct isogonic maps. A marked deviation from an ideal sampling of an anomaly will usually result in a depth estimation that is too great.

With this serious limitation in mind depth determinations were made from the residual magnetic profiles over the Arctic Ocean. "Contamination" of a given anomaly by neighboring anomalies, if not apparent in the anomaly itself, could be detected by referring to the various levels of downward continuation plotted by the CDC 1604 computer. Many of the anomalies were eliminated from quantitative consideration by this method. However, there is no way of knowing the areal shape of an anomaly or how it is traversed by the flight profiles. However, some protection is afforded by using only anomalies with classical bell-shaped profiles.

The frequency of occurrence of depths to sources of magnetic anomalies in 1/4 km intervals as determined by Peters' half-slope method is graphically illustrated in Figure 26. Here it is seen that the bulk of the depth estimations occur between 1 and 5 km indicating that most of the anomalies suitable for quantitative analysis are the result of surface or near-surface causes. Between 6 and 7½ km there is a distinct break in the curve, implying a vertical hiatus between sources of surface and near surface anomalies and those caused by deep basement effects.

The depth determinations from anomalies of shallow origin (1/2 to 5 3/4 km) are plotted in Figure 27 and the deeper depth estimates (6 1/4 to 32 km) are shown in Figure 28.

These figures provide the best indication of the validity of attempting depth determinations from magnetic profiles. Referring to Figure 27 it is seen that the depth estimations do not occur as a random scatter, but show some orderly grouping along the flight lines. Where flight tracks cross at or near points of depth determinations the independently determined values are equal or nearly so. The appearance of order is less obvious in Figure 28 because there are fewer anomalies to analyze and areal separation between them is greater. These anomalies originating from deep sources will be discussed in detail in section 6.15.

The possibility of magnetic anomalies originating from sources deeper than 20 km has been debated. From a statistical analysis of a number of typical anomalies Vacquier and Affleck (1941) were able to find no anomalies that originated from sources deeper than 20 km and concluded that this was the level of the Curie Point Geotherm. However, Birch (1955) pointed out that anomalies of deeper origin may have been excluded by the choice of data used in their analysis. He went on to show that the 578°C Curie temperature of magnetite would be reached at approximately 25 km at the shallowest and in all probability would occur considerably deeper.

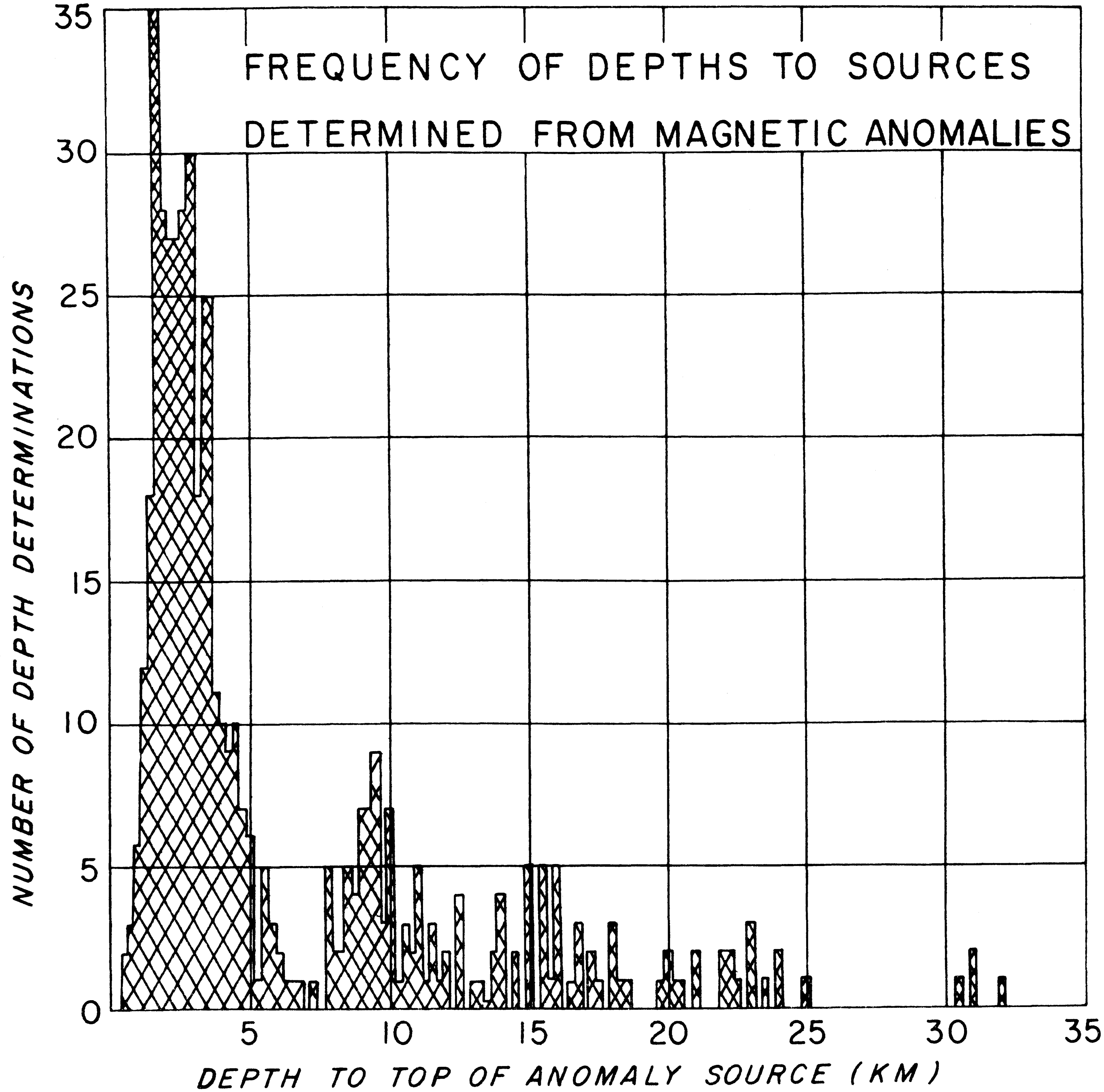

FREQUENCY OF DEPTHS TO SOURCES
DETERMINED FROM MAGNETIC ANOMALIES
NUMBER OF DEPTH DETERMINATIONS
0
5
10
15
20
25
30
35
5
10
15
20
25
30
35
DEPTH TO TOP OF ANOMALY SOURCE (KM)

Figure 26.

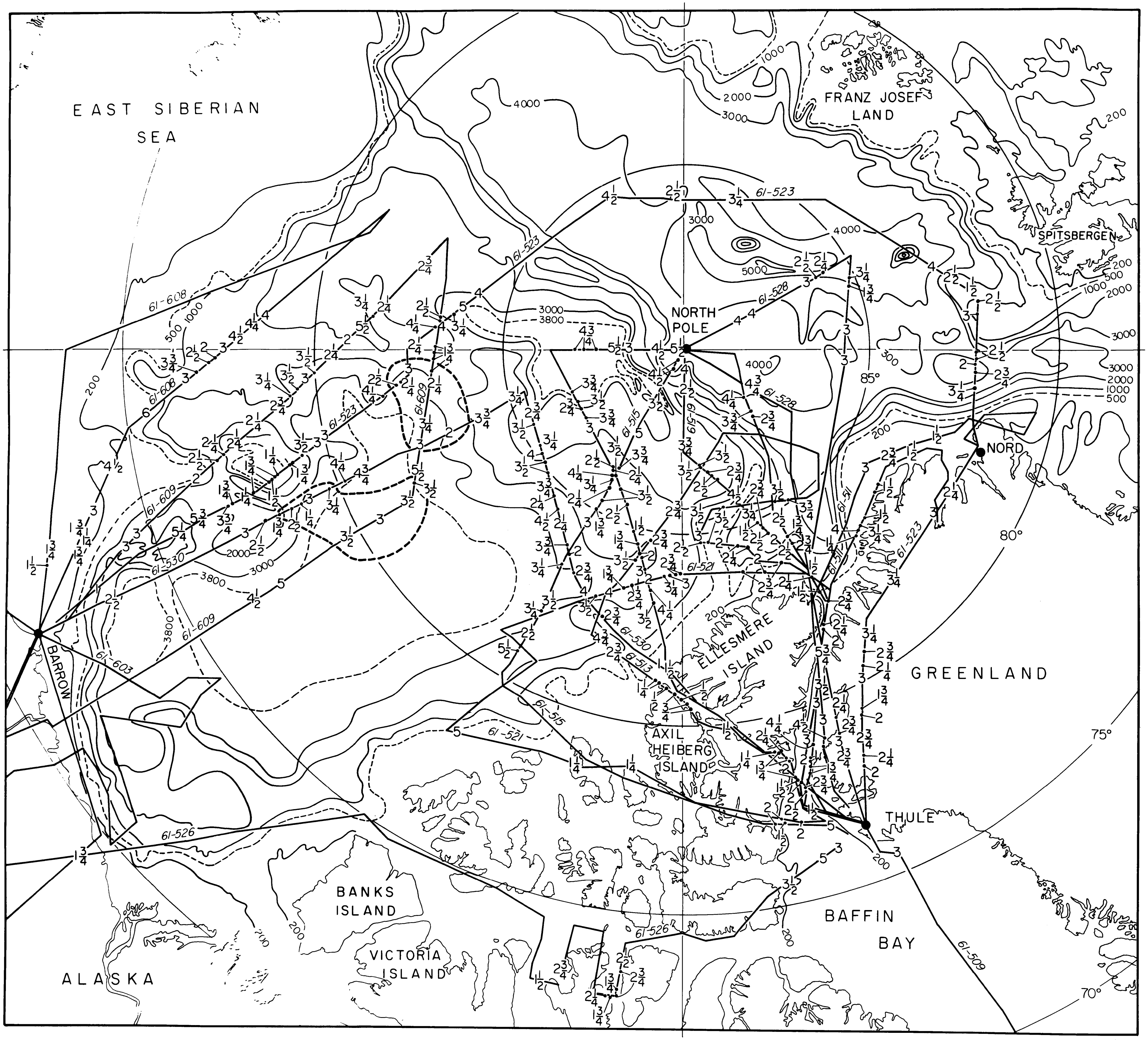


Figure 27.

DEPTH DETERMINATIONS FROM MAGNETIC ANOMALIES ORIGINATING FROM SHALLOW SOURCES

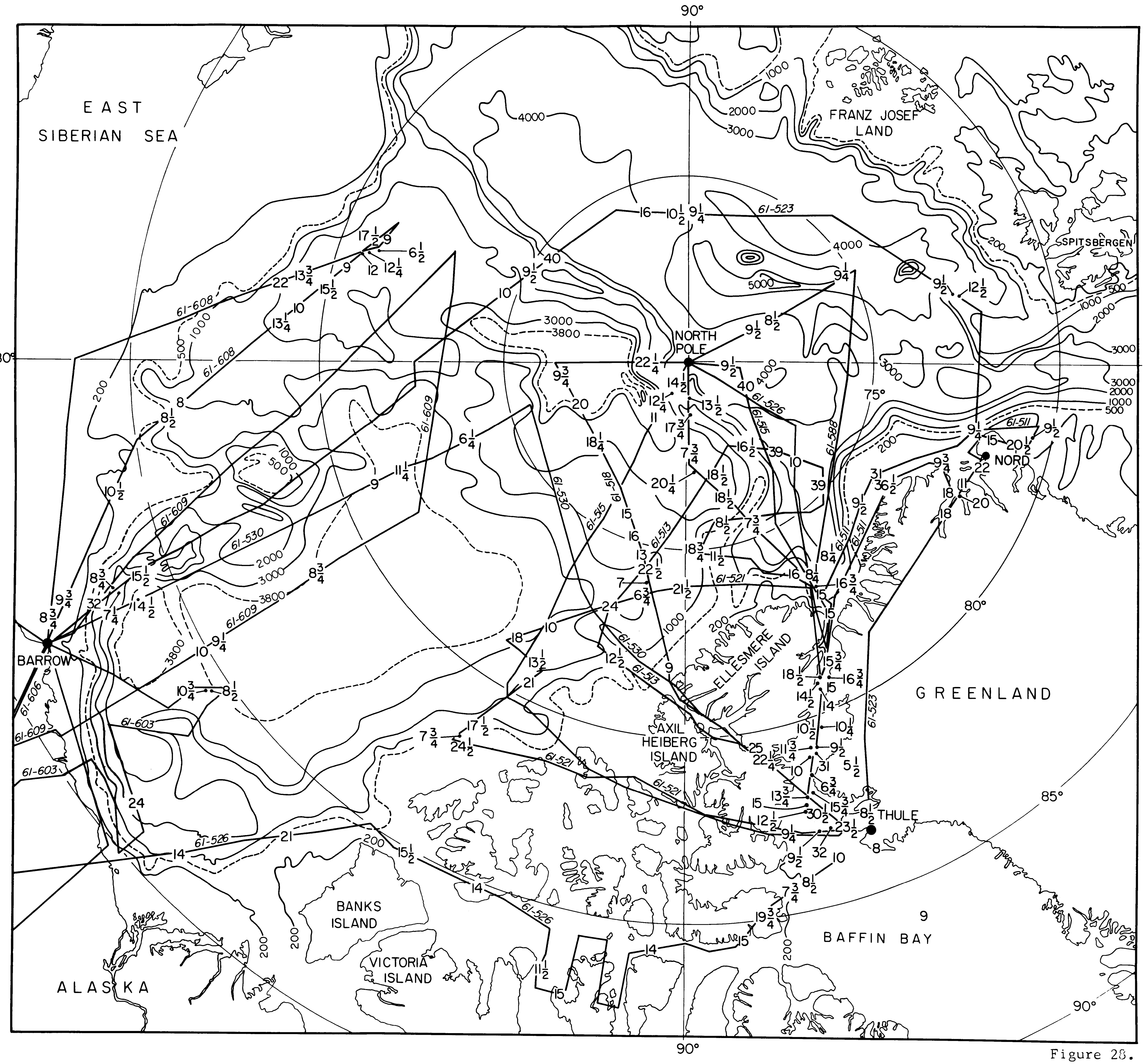


Figure 28.

DEPTH DETERMINATIONS FROM MAGNETIC ANOMALIES ORIGINATING FROM DEEP SOURCES

Serson and Hannaford (1957) give the depth of the Curie isotherm to range from 20 to 100 km. Sanker Narayan (1961) analyzed anomalies in Kansas which originated from depths as great as 36 km and demonstrated the ability to interpret with a high degree of accuracy two superimposed magnetic anomalies of different lengths and depths of origin.

6. 4. Residual Magnetic Profiles

The residual magnetic profiles along the various flight tracks over the Arctic Ocean are shown in Figure 29. The magnetic profiles over the Canadian Archipelago correlate well with those completed by Canadian investigators. (Fortier and Morley, 1956; Gregory, Bower and Morley, 1960, 1961). The aeromagnetic profiles after Fortier and Morley (1956) are shown as Figure 30. From these profiles and the depth determinations shown in Figure 27 and 28, certain conclusions can be drawn or inferred.

In general the Lomonosov Ridge appears to divide the Arctic Ocean Basin into two sub-basins with distinctly different magnetic characters. The portion of the ocean floor on the European side of the ridge is generally quiescent, except off the coasts of Greenland and Spitsbergen. Conversely, on the North American and Siberian side of the Lomonosov Ridge magnetic activity is very intense with anomalies in excess of 1000 gammas being common.

6. 5. Franklin Geosyncline

An exception to the intense magnetic activity over this sub-basin is seen in the large area off the Canadian Archipelago west of Axel Heiberg Island and including the Arctic coastal plain and continental shelf north of eastern Alaska. The magnetic character of this region, which includes nearly all of the Beaufort and Canada Deeps, is suggestive of the magnetic profiles over the Gulf of Mexico (Affleck, 1948; Miller and Ewing, 1956) where the sediment thickness is estimated to be on the order of 30 km. The implication is, then, that most of the Beaufort and Canada Deeps are underlain by a great volume of sediment.

Referring to Figure 27 it can be seen there are no anomalies that can be related to shallow causes on profile 61-603 or on the western part of profile 61-526. The shallow anomalies to the north of the archipelago and west of Axel Heiberg Island lie on the edge of the Canada Deep and are related to near surface causes with the exception of the two at 5 and 5½ km. The anomalies on the leg of profile 61-609 that passes over the Beaufort and Canada Deeps are caused by surface or near surface effects. Four of the anomalies show sources that are even slightly shallower than the indicated bottom elevation, suggesting that there is somewhat more relief to the floor of the deep than the limited soundings have revealed. The calculated depths to deep sources are consistently shallower along the western edge of the Canada Deep than under the continental shelf to the east.

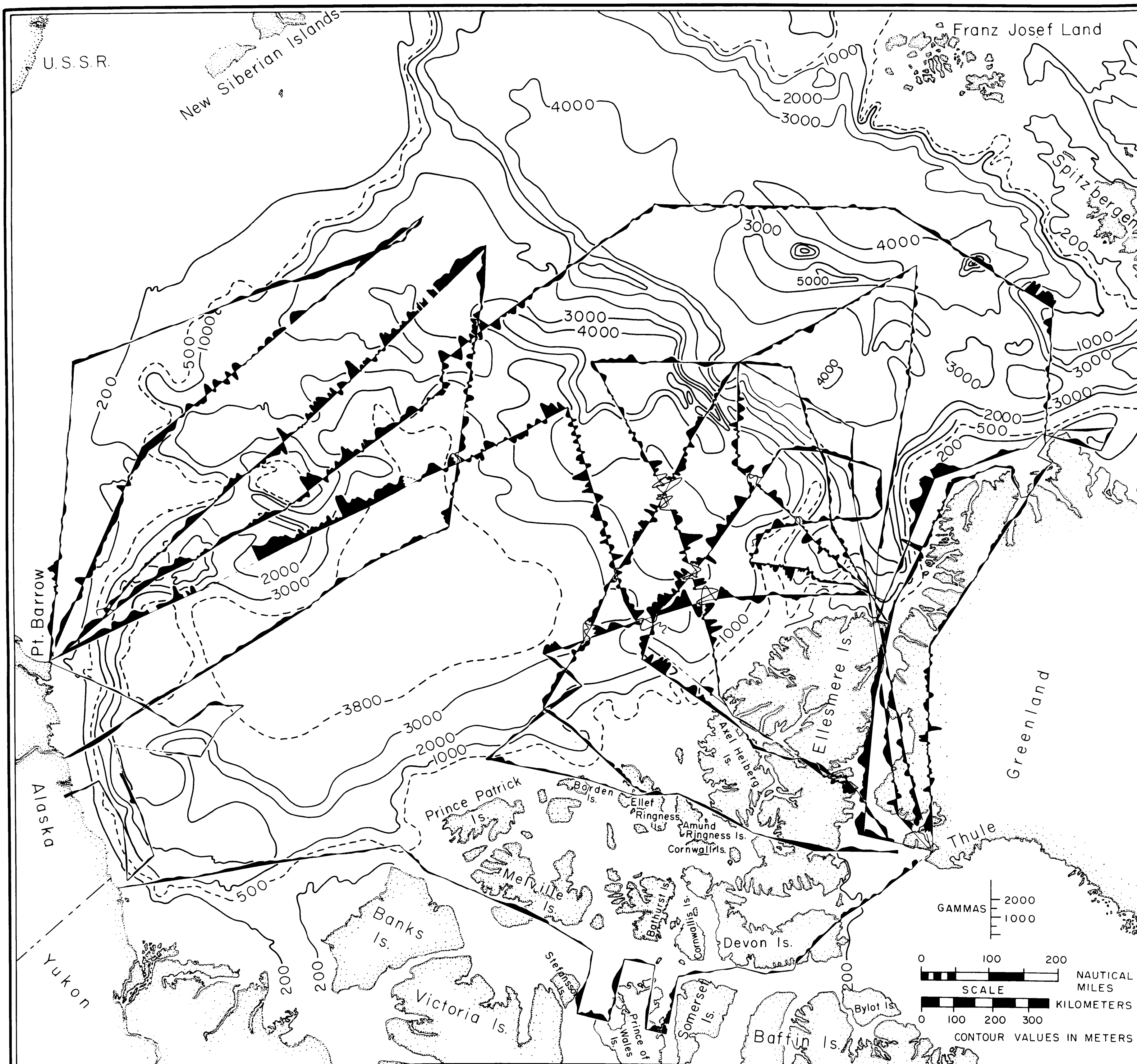
This sedimentary basin appears to be a northwestward continuation of the Franklin geosyncline (Fig. 31). Thorsteinsson and Tozer (1961) give the following representative thicknesses of the stratigraphic column in various parts of the geosyncline:

1) Western Melville Island; Lower Ordovician to Upper Devonian, about 16,000 ft. (5 km).
2) Cornwallis Island: Middle Ordovician to Upper Silurian, more than 20,000 ft. (6 km).
3) Okse Bay area, southern Ellesmere Island; Devonian (probably only Middle and Upper Devonian), 17,000 ft. (5¼ km).
4) North Axel Heiberg and northwestern Ellesmere Islands; about 60,000 ft. (18¼ km) of altered sedimentary rocks and lavas occur; the only fossils present are Silurian.

One can see that the total thickness of the sedimentary column in the geosyncline is indeed great and appears to increase northward. Further west, in the vicinity of the Mackenzie River, Martin (1961) shows a crustal cross-section of the mainland Arctic coastal plain in which the sedimentary column thickens rapidly to undetermined depths under the Arctic Ocean. In his review of the tectonic framework of northern Canada, Martin indicates that the northern mainland and most of the Arctic Archipelago were positive tectonic elements since Lower Devonian time. Therefore, it seems reasonable to find a thick clastic wedge on the oceanward side of this region as the sediments derived from such a long period of erosion must be deposited somewhere. To concede the existence of a sedimentary column of such magnitude, one must either consider the crust to be continental or intermediate or assume that, as in the Gulf of Mexico, (Ewing and Landisman, 1961) a thick column of sediments is spread over an oceanic crust which was depressed due to the loading but has preserved its original oceanic character.

Referring to the wave paths analyzed by Oliver et al. (1955) for Lg propagation (Figs. 32 and 33), it is seen that a continental type crustal structure can be assumed for this region of the Beaufort and Canada Deeps without violating their data. All of the wave paths studied that traversed this region could have had the Lg phase filtered out elsewhere in the Arctic Ocean or in the Pacific or Atlantic Oceans. As this area is aseismic, it was not possible to analyze a wave path that originated within its confines and was propagated along an unbroken continental path. However, to find a continental crustal structure under water 3800 m deep would indeed be unusual and such an occurrence has never been reported in the literature. The Gulf of Mexico, which has a quiescent magnetic character, is underlain by a truly oceanic crust which will not transmit Lg waves. Referring to Figure 23, Demenitskaya shows a zone of crustal thickness ranging from 25 to 35 km (Woollard's equivalents: 27-33 km) along the northwestern margin of the Canadian Arctic Archipelago and northern Alaska which is bounded to the north by crustal thicknesses of 15 to 25 km (Woollard's equivalents, 21-27 km).

Saks and his colleagues indicate the Hyperborean Platform extending eastward almost to the Canadian Arctic Archipelago and joining the Greenland Canadian Platform via a narrow neck north of the Alaskan-Canadian border (Fig. 7). The magnetic evidence precludes such an eastward extension and an aeromagnetic flight line 61-526 which passes directly across



RESIDUAL MAGNETIC PROFILES

Figure 29.

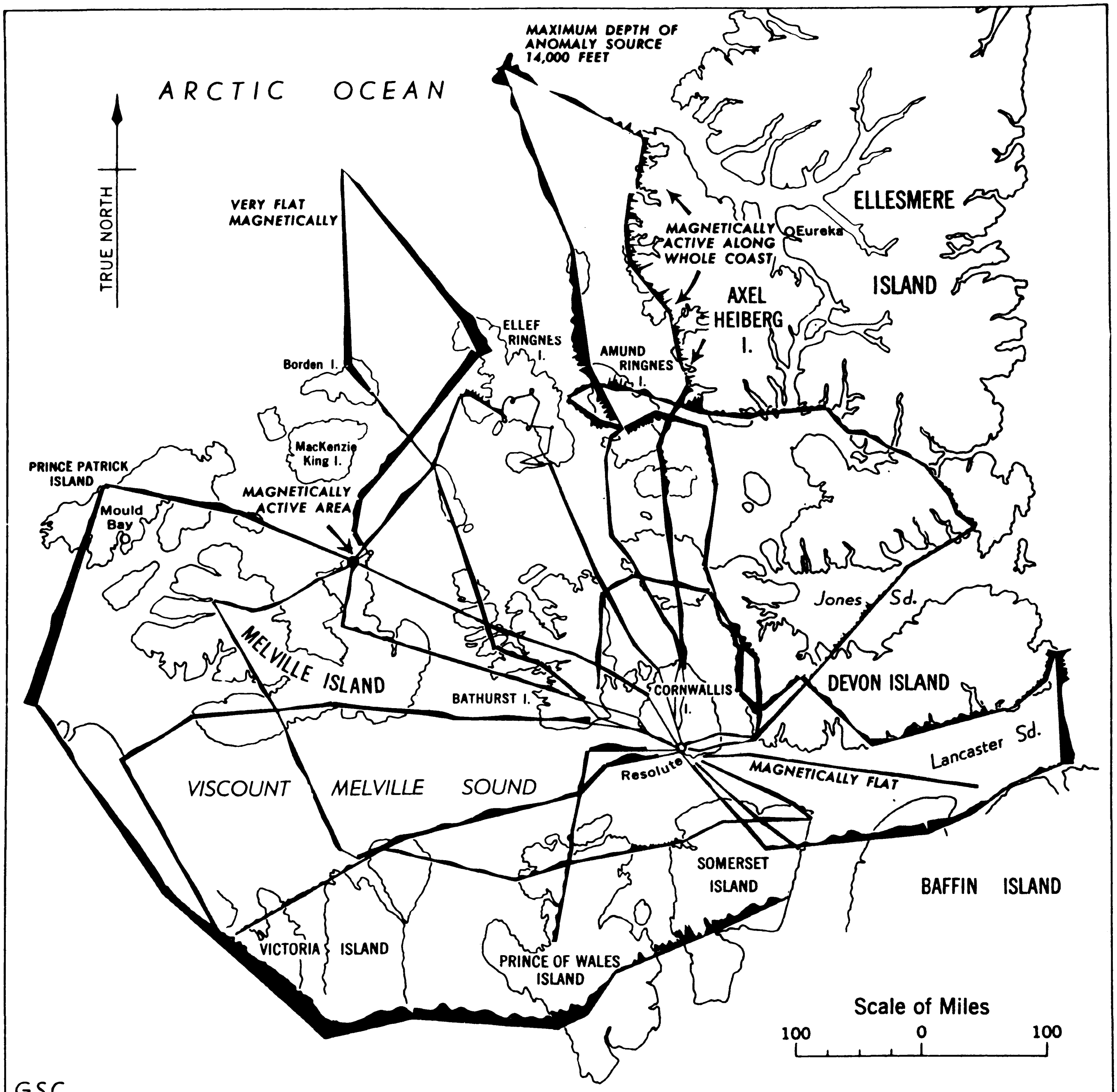


Figure 30.

Location and general character of the aeromagnetic profiles (after Fortier and Morley, 1956). Magnetic intensities should not be quantitively compared as they are relative to arbitrary bases for each segment of the profile

STRUCTURAL HISTORY OF THE CANADIAN ARCTIC ARCHIPELAGO SINCE PRECAMBRIAN TIME

(AFTER THORSTEINSSON AND TOZER, 1961)

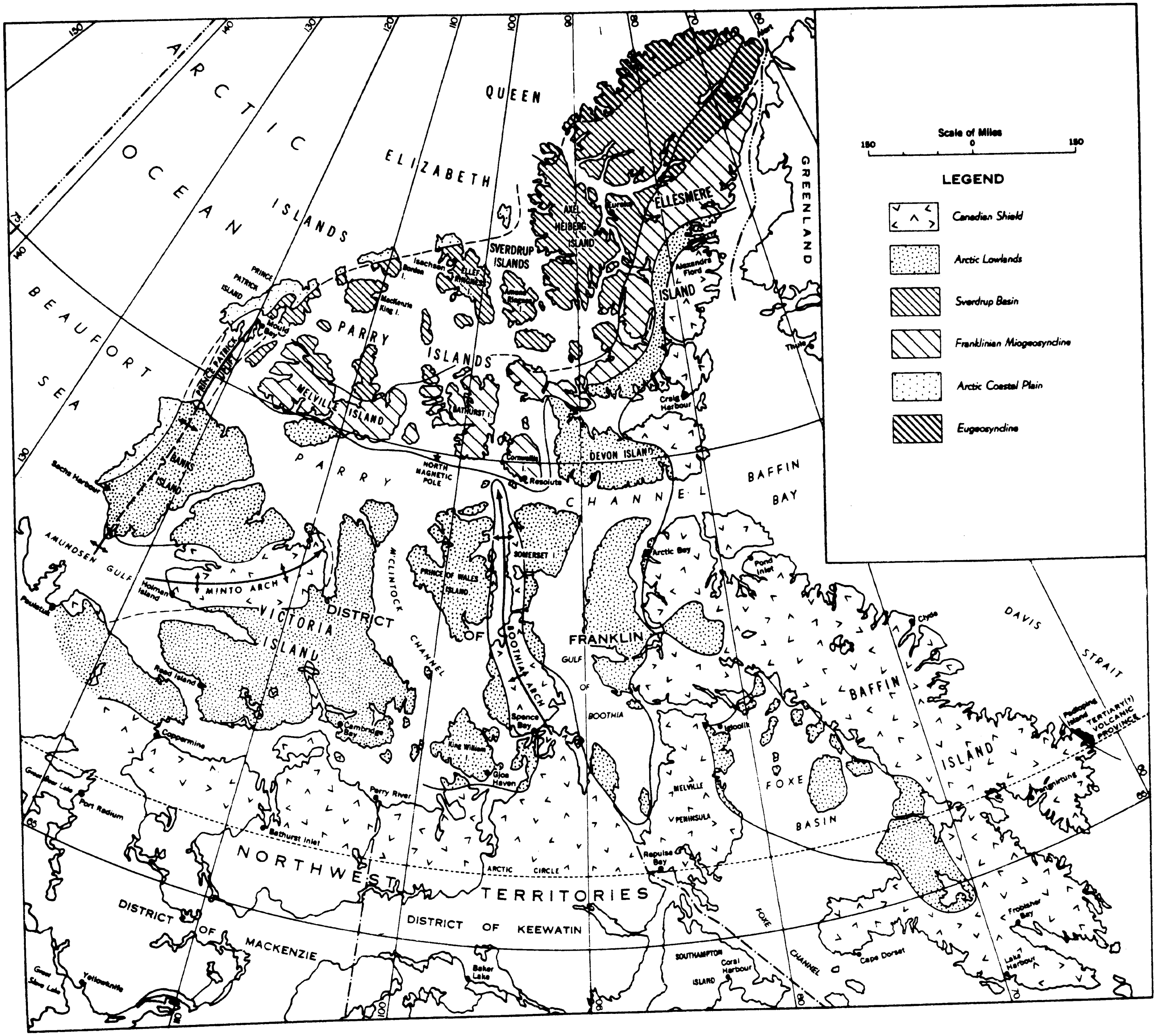
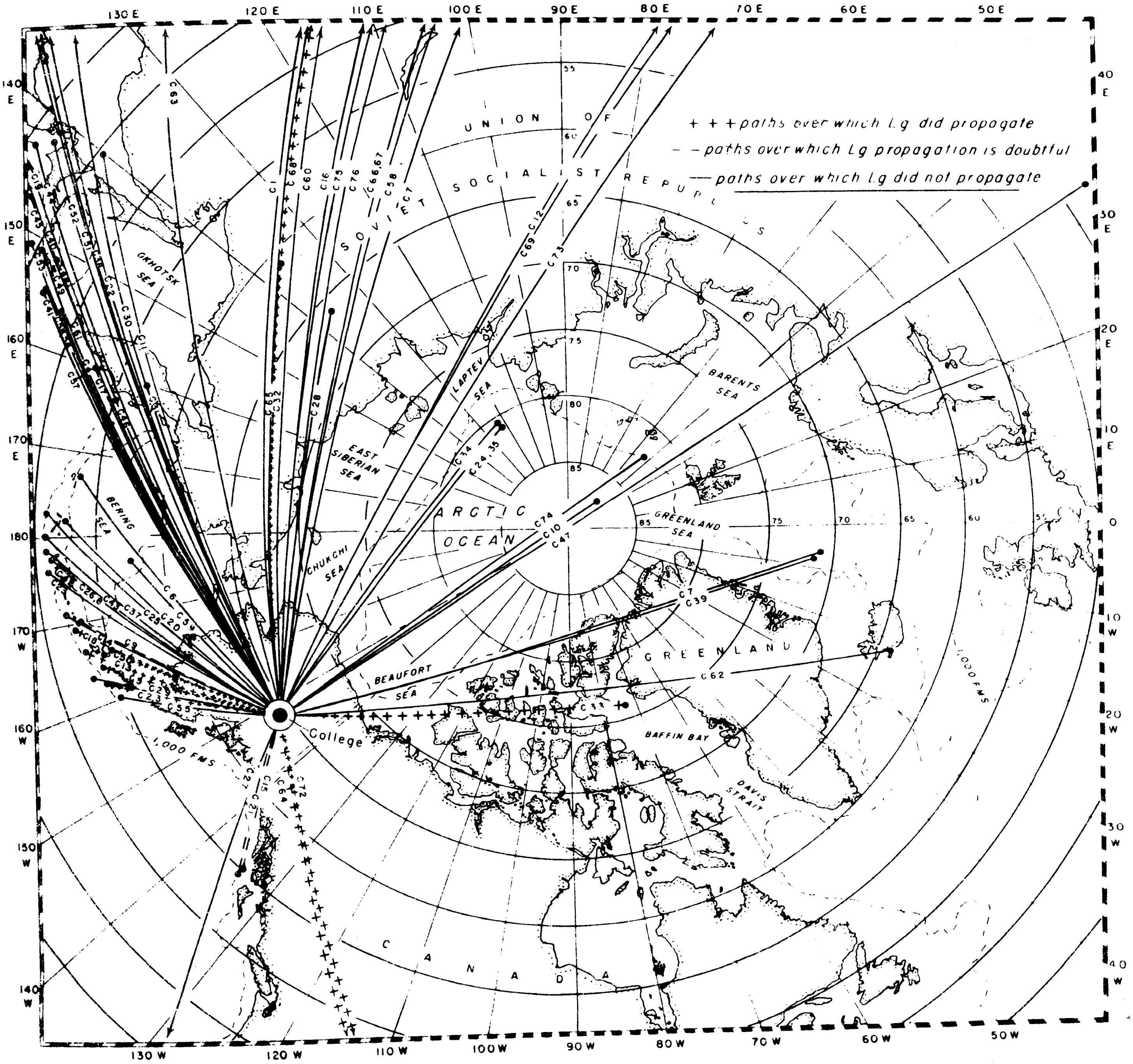
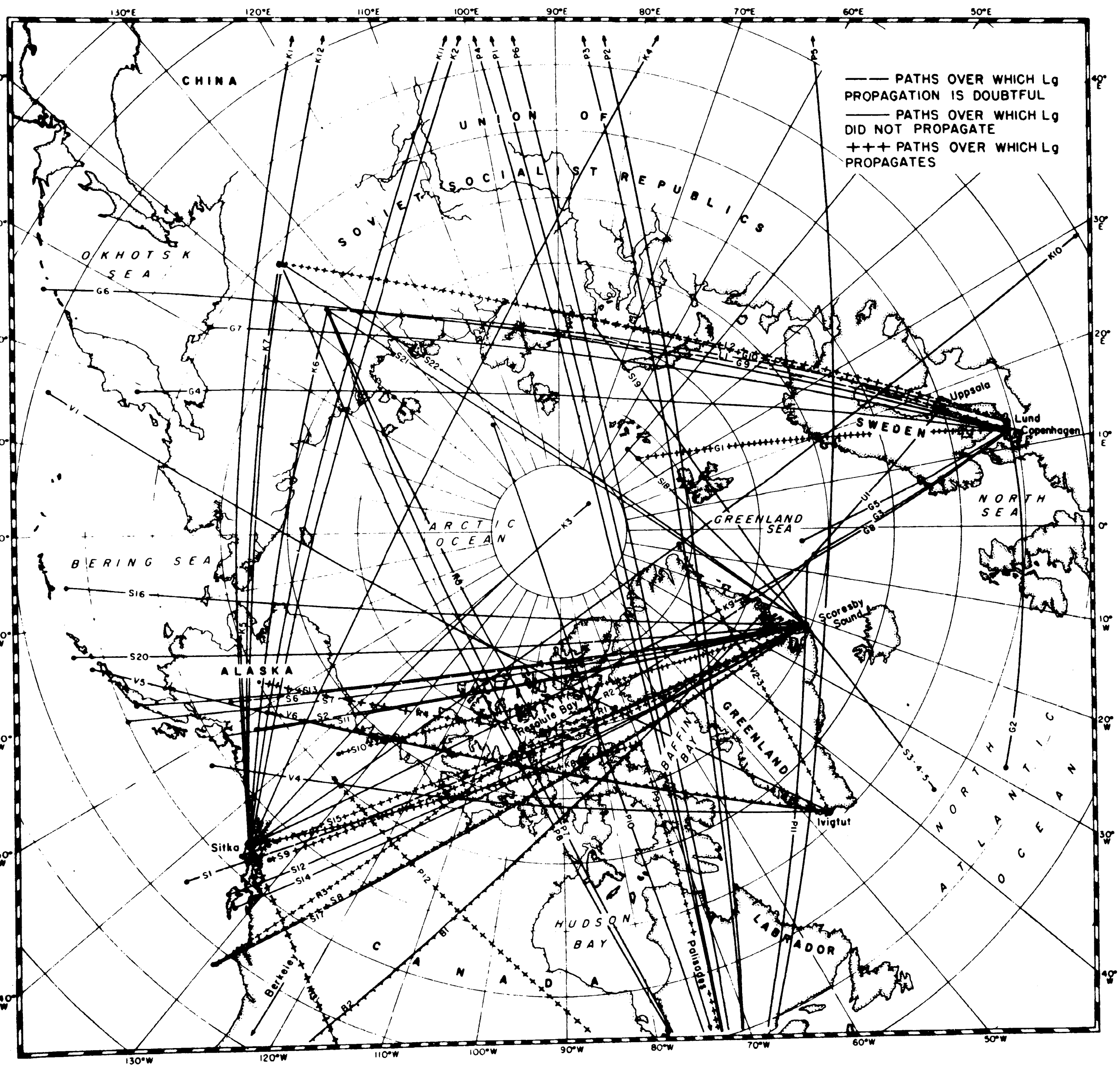


Figure 31.



A. Paths across Arctic Regions to College, Alaska

Figure 32.



B. PATHS ACROSS ARCTIC REGIONS TO ALL STATIONS EXCEPT COLLEGE, ALASKA

Figure 33.

the proposed neck joining the Hyperborean and Greenland-Canadian Platforms is not indicative of the types of magnetic profile that might be expected over ancient basement rocks.

It is unfortunate that logistic limitations prevented further study of this most interesting region. However, it is being given priority for further investigation in the near future.

6. 6. Sverdrup Basin

Situated west and north of the exposed part of the Franklin geosyncline is the Sverdrup Basin which was the site of heavy sedimentation from the Middle Pennsylvanian to the early Tertiary. The beds in this basin are separated from the underlying folded lower Paleozoic rocks by a profound angular unconformity. Thorsteinnsson and Tozer (1961) suggest that the beds in the basin become thinner towards the northwest, and the regional dip in this northwestern part is apparently to the southeast. Thus, they conclude that the basin may be regarded as a major synclinorium striking northeast. Gregory et al. (1961) point out that on their aeromagnetic profiles across the Sverdrup basin there is no evidence that the basement occurs along the northwestern rim of the basin at depths of the order of 10,000 ft (3 km) or less. However, they state that a noncrystalline fold complex may underlie the arctic coastal plain and attribute two positive dyke-like anomalies observed over these sediments on Prince Patrick Island to small plutons in a fold belt buried under a thin veneer of sediments. The anomalies indicating sources originating at depths of 5 and 7 3/4 km north of the island (see Figs. 29 and 30) could be related to similar features.

It is interesting to note that the basement ridge suggested by the gravity survey (chapter 5) under the continental shelf off northern Alaska is not reflected in the magnetic profiles east of Barrow despite the fact that a special pattern was flown over the +107 mgal free air anomaly north of Barter Island. It appears that there may be a nonmagnetic ridge extending from off the northern coast of Alaska eastward under the continental shelf possibly to the vicinity of Axel Heiberg Island.

6. 7. Canadian Arctic Archipelago

In their papers on the airborne geophysical reconnaissance over the Canadian Arctic Archipelago, Gregory et al. (1960, 1961) interpretated their aeromagnetic data in relation to geologic structure. Following is a brief review of some of their significant conclusions.

Local anomalies of 20 to 100 gammas over Proterozoic rocks in the eastern part of the Sverdrup Basin were attributed to dykes and disturbed sheets of basic rock. Also in the eastern part of the basin there is a regional cluster of anomalies which range from -600 to +2400 gammas in intensity. These anomalies were attributed to gabbroic dykes and sills and to basic flows which have been deformed by folding, faulting, or intrusion of gypsum piercement structures. This region of magnetic anomalies probably defines the extent of the Eureka Sound Fold Belt within the eastern half of the Sverdrup Basin, which appears to extend no further west than Ellef Ringnes Island (see Fig. 30). Contrastingly, the western part of the basin is marked by very flat profiles with the exception of a few local anomalies that suggest the presence of thin sheets of basic rock in slightly deformed strata.

As on Prince Patrick Island, small dyke-like anomalies of 20 to 30 gammas were recorded over the Paleozoic fold belts on Bathurst Island. Only a few such plutons have been observed. Rather, the otherwise flatness of the aeromagnetic profiles over these fold belts indicate that basic material is not generally involved in the associated deformation.

Positive anomalies near the northern tip of Axel Heiberg Island and further northwest at the edge of the continental shelf were tentatively interpreted as indicating westward extensions of the basement rocks of northern Ellesmere Island. However, these anomalies may represent separate basement complex or submarine volcanic features (see Fig. 27). It is interesting to note their figure for the maximum depth of 4½ km for the northernmost anomaly compares well with the 4 3/4 km depth determined by this independent survey. Gregory et al. point out that similar anomalies have been observed over the continental slope along the eastern coast of North America (Drake, et al., 1959) which were correlated with a relatively shallow basement ridge separating two deep sedimentary troughs. These troughs were suggested to be an inner miogeosyncline under the continental shelf and an outer eugeosyncline that merges into the ocean basin. Gregory et al. speculate on the possibility of an analogous structure under the edge of the polar continental shelf but state that due to the few aeromagnetic profiles across the shelf no conclusion can be drawn.

Hunkins et al. (1962) also comment on the similarity in magnetic anomalies observed over the 2000 m isobath along the margin of the Chukchi Cap to that reported by Drake, et al. (1959) off the northeastern coast of the United States. They further point out that the anomaly has been found to extend as a positive belt from 29° N. to 42° N. latitude (Heirtzler et al., in preparation). The magnetic anomaly of Drake and colleagues was attributed to induced magnetization in the basement rocks with the sediments apparently playing no part in creating the anomaly because the observed anomaly is in reasonable agreement with the magnetic anomaly calculated for the basement topography defined by seismic refraction methods. Hunkins et al. conclude that because of the similarities of form and location between the eastern North American and Chukchi anomalies, they probably have similar origins, and that it is likely that the Chukchi Cap anomaly is also to a ridge in the basement rocks.

Gregory et al. (1961) give magnetic topographic and bathymetric evidence of a regional basement fault along the Parry Channel (M'Clure Strait, Viscount Melville Sound, Barrow Strait and Lancaster Sound) which may continue westward to offset the Boothia Arch. The abrupt change in character along profile 61-526 from northwest of Somerset Island to Devon Island (Fig. 29) supports this conclusion.

Two Precambrian arches are prominent geological structures in the Arctic Archipelago (Fig. 31). The Minto arch, which is covered by 3 km of Proterozoic sediments, has little effect on the profiles of Fortier and Morley (Fig. 30). The Boothia arch, on the other hand, is partially exposed at the surface and has a marked expression on the aeromagnetic profiles. From their magnetic data Gregory et al. estimate that the Boothia arch rises about 3 km above the general basement level. They interpret the western side of the arch to be a fault scarp, whereas the eastern flank appears to be a homocline which may be steeper and possibly faulted farther south. In gross structure they picture the Boothia arch as an incompletely developed horst which probably extends as far north as the southeastern corner of Bathurst Island where it terminates or plunges northward. Figure 28 shows deep anomaly sources of 11½ and 15 km on the west and 14 km on the east sides of the arch.

One leg of aeromagnetic profile 61-526 parallels the crest of the Boothia arch between Prince of Wales and Somerset Islands. The profiles (Figs. 27 and 30) pass onto the arch from the west, just north of Fortier and Morley's traverse across the structure (Fig. 30) and turn eastward off the arch in the Parry Channel. The steep magnetic gradient on the western flank of the arch supports the conclusion of faulting reached by Gregory et al. However, in passing over the eastern flank of the arch in the Parry Channel, an even steeper gradient is seen suggesting that here also the structure is bounded by a fault. This evidence adds support to the inferred horst structure of the Boothia arch.

Finally, Gregory et al. describe large magnetic anomalies associated with gypsum piercement domes and diapirs which intrude the Paleozoic and younger rocks but are found primarily within the Sverdrup basin.

6. 8. Hakkel's Staircase Region

In contrast to the general magnetic quiescence over the region north of eastern Alaska, the remainder of the Arctic Ocean sub-basin is magnetically active. From the limited magnetic profiles and maps that have recently become available over the deep oceans (Alldredge and Keller, 1949; Heezen, Ewing and Miller, 1953; Keller, Meuschke and Alldredge, 1954; Mason, 1958; Ewing, Antoine and Ewing, 1960; Raff, 1961; Adams and Christoffel, 1962), a general pattern of intense magnetic activity seems to be emerging as characteristic for the deep oceans. This same character describes the residual magnetic field of much of this Arctic Ocean sub-basin. However, one notes the incongruity of the relatively quiescent Beaufort, Canada and Makarov Deeps contrasted with intense magnetic activity in the shallower water region north and west of the Chukchi Shelf. The magnetic character of this region is similar to that found over any crystalline shield and the interpretation of an underlying Precambrian shield (Hyperborean platform) therefore seems reasonable. This area is the same as Hakkel's "staircase region" (Fig. 8) which he interprets as a series of fault-terraces or benches in the platform. Hope (1959) suggested that the parallel ridges shown in Hakkel's map might just as well be caused by deformation of surface layers during subsidence of the basin or by the folded basement pattern of the Hyperborean platform which has been protected from erosion by its submergence and shows through the sedimentary super-structure. The more recent and conservative bathymetric charts do not preserve Hakkel's staircase structure.

Several interesting features can be seen from the shallow depth determination plotted in Figure 27. With the exception of the profile over the eastern edge of the Chukchi Cap there is no obvious correlation between anomaly source depth and ocean bottom topography. Although there is no discernable pattern to the variation in depths, there is a strong tendency toward grouping, resulting in the overall appearance of an irregularly undulating basement surface.

The two areas delineated by heavy dashed lines enclose depth determinations that are everywhere shallower than the ocean bottom topography shown on the bathymetric chart compiled by Ostenso. Within the northernmost of the two areas, which is defined by three flight profiles, no sounding data were available and the indicated isobaths were interpolated. Scientific station ALPHA was established just north of this region. The abnormally shallow, estimated depth of 6¼ km shown in Figure 28 also falls within this area. The southernmost region, defined by two profiles, was traversed by the NAUTILUS in 1958 (Fig. 13). In describing the soundings from this cruise Dietz and Shumway (1961) state that the profile across the southern portion of the Canada Deep shows no topographic interruptions, but two sea knolls were crossed in the northern portion. Unfortunately they did not describe the location, elevation, or areal extent of these features. Presumably they lie within the southern anomalous area which includes most of the northern section of the Canada Deep as transited by the NAUTILUS. A bathymetric chart compiled in 1956 by the Defence Research Board of Canada from Soviet sources also shows two rises in the floor of the deep within this area. One rise is defined by a 2000 m isobath and the second includes a 1500 m isobath. It is curious to note that the most recently available Soviet bathymetric chart (Treshnikov, 1960) omits these features. Because of this omission in what is considered the most authoritative and recently revised chart, these features were not included on the bathymetric chart shown in Figure 12. It is concluded that the dashed lines indicate the approximate boundaries of two areas of somewhat shallower water depth and greater bottom irregularities than is shown in Figure 12.

None of the flight profiles passes directly over the anomalies associated with the western margin of Chukchi Cap described by Hunkins et al. (1962). However, the western leg of flight 61-609 passes just east of these anomalies. One depth estimate of 2½ km and three of 2¼ km were obtained along this portion of the profile. These values compare well with the 2 km deep crest of the basement ridge postulated by Hunkins and his colleagues.

6. 9. Chukchi Shelf

The magnetic profiles north of Barrow are shown in detail in Figure 34. The strong suggestion of lineation of the anomalies and the depth determinations plotted in Figure 27 suggests the existence of a near surface dyke or magnetic basement ridge complex striking at an angle of approximately 45° to the margin of the continental shelf. It would appear that this structure should form a topographic ridge extending from the edge of the shelf in the vicinity of 73° N., 157° W. The strike and location of this ridge is in perfect agreement with a spur shown on the 1956 bathymetric map compiled by the Defence Research Board, however, it does not appear in the detail soundings of the region reported by Fisher et al. (1958). These magnetic anomalies are located just north of and parallel to the gravity high shown in Figure 19. The broad magnetic anomalies on the Barrow side of the large amplitude anomalies occur over the gravity high but, unfortunately, they are not suitable for quantitative evaluation. The gravity anomaly is attributed to a rise in granitic basement. This basement uplifting may have been accompanied by basaltic intrusions along its northwestern margin causing steep magnetic anomalies. Matthews (1961) analysis of 43 specimens of basaltic lavas dredged from the Atlantic Ocean floor showed a range in magnetic susceptibility from 2 to 28 x 10^{-3} emu whereas the compressional wave velocities measured on 45 specimens ranged from approximately 1.5 to 4.8 km/sec. These velocities represent a range in density from approximately 1.7 to 2.6 gm/cc according to Woollard's (1959) relationship. Thus, even the denser basalts are near the lower limit for the density range of granite and one might not be surprised at finding magnetic anomalies over sub-oceanic basalt without associated gravity anomalies.

The southernmost leg of profile 61-608 which passes over the Chukchi Shelf shows very little magnetic activity except for the anomalies just noted in the vicinity of Barrow. Such magnetic quiescence supports the belief that granitic material composes the shallow shelf.

6. 10. Alpha Ridge

High amplitude magnetic anomalies over the Alpha Ridge indicate that, whatever its orogenesis may have been, the result was an uplifting of "magnetic" basement material. Seismic refractions over the rise show compressional wave velocities typical of crystalline rock complex overlain by a veneer of unconsolidated sediments (Fig. 22). The section of the ridge lying approximately between 80° and 84° N. latitude appears to be essentially free of sedimentary cover (see Fig. 27). Elsewhere on the ridge the sedimentary cover varies from about ¼ to 4¼ km in thickness. Crary and Goldstein's (1957) data from the Marvin Ridge and the deep shelf to the south show considerably thicker sedimentary columns overlying basement which would account for the reduced amplitudes of the anomalies in this region (Fig. 29).

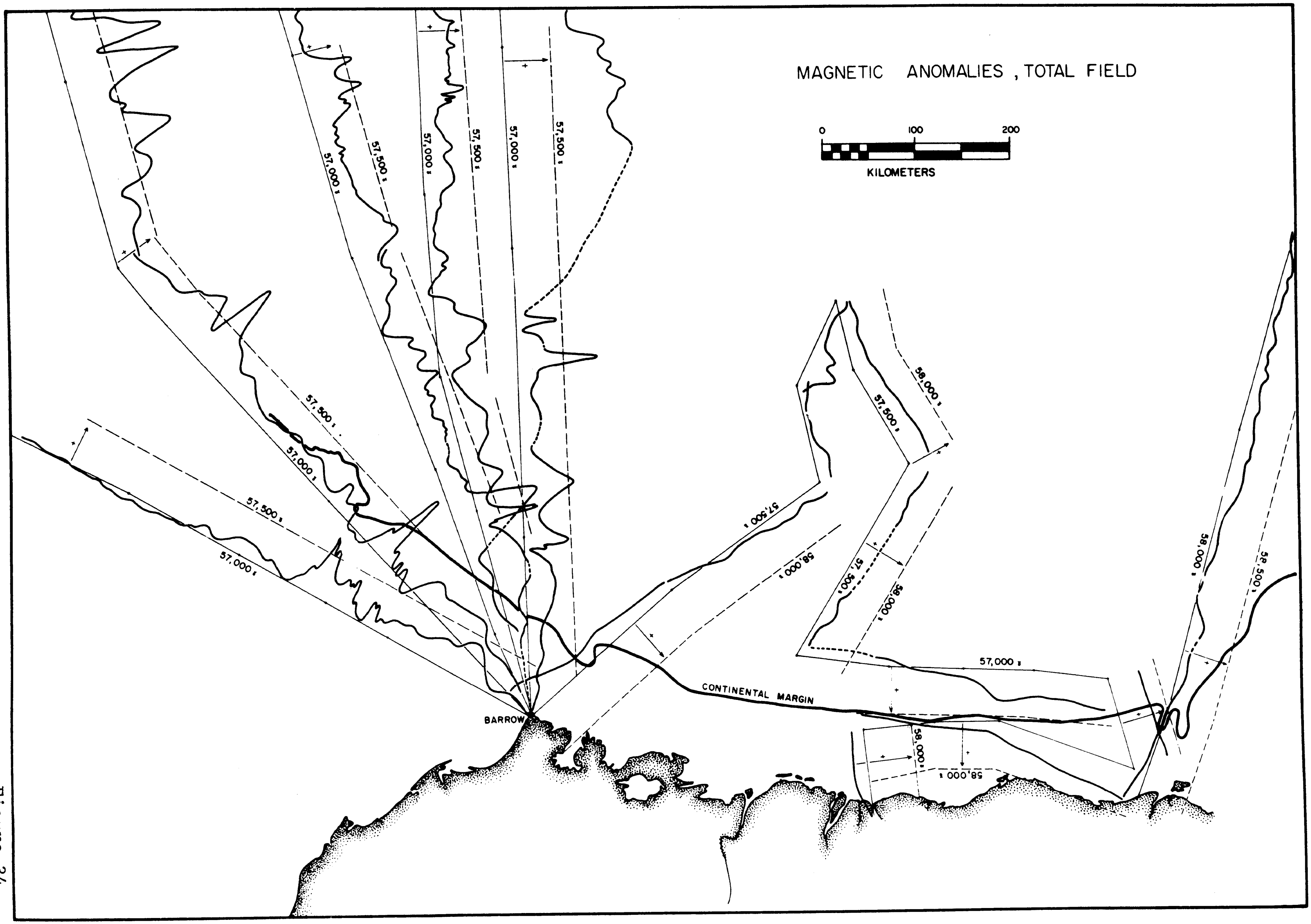

MAGNETIC ANOMALIES, TOTAL FIELD
0
100
200
KILOMETERS
BARROW
CONTINENTAL MARGIN
57,000
57,500
58,000

Figure 34.

6. 11. Makarov Deep

Four depth determinations over the Makarov Deep show remarkable agreement, averaging 5 km. The floor of the deep lies at 4030 m so a sedimentary column on the order of 1 km appears to overlie basement. These sediments could easily account for the featureless and flat nature of the deep floor noted by Deitz and Shumway (1961).

6. 12. Lomonosov Ridge

In contrast to the Alpha Ridge, the Lomonosov Ridge is practically devoid of shallow anomalies along its entire length. On nine crossings of the ridge only one near surface (2½ km) anomaly was observed with the exception of a few on the North American extremity of the ridge near Ellesmere Island. This marked difference in magnetic characters graphically illustrates the contrasting nature of the two features. Whereas the Alpha Ridge is obviously of crystalline composition, the Lomonosov Ridge must be comprised of folded sediments with few mafic crystalline elements. These conclusions support the Soviet concept of structural relationships outlined in Chapter 2.

6. 13. Nansen Basin

The entire Nansen Basin on the European side of the Lomonosov Ridge shows very little magnetic activity except off the coasts of Greenland and Spitsbergen. The few anomalies seen do not appear to be influenced by bottom topography; in fact the character of this residual magnetic field is what would be expected if the depression had been the catch-basin for enormous quantities of Tertiary and Quaternary detritus derived from Eurasia, Greenland, eastern Canada, its archipelago, and the adjoining continental shelves as suggested by Saks et al. (1955).

From a Transatlantic magnetic profile Heezen et al. (1953) report considerable magnetic disturbance over the Mid-Atlantic Ridge. The absence of such disturbances is conspicuous on three of the aeromagnetic profiles crossing the projected extension of the ridge into the Arctic Basin. However, anomalies on a fourth profile east of Greenland give five depth estimates ranging from 2 to 3¼ km in the northern end of the Lena Trough. Heezen and Ewing believe the Lena Trough is a northern extension of the mid-ocean rift. Excluding those within the Eurasia Deep, most of the depth determinations in the central reaches of the sub-basin shown in Figure 26 are approximately along the projected strike of the ridge. The absence of more intense magnetic activity over the hypothesized ridge extension suggests that it is either poorly developed or is devoid of the magnetic elements observed in the Atlantic Ocean.

Within the Eurasia deep there are ten depth determinations from four separate flights, omitting three additional depths on the southern margin of the deep which may be related to the mid-oceanic ridge. Despite wide areal distribution, these values are remarkably consistent and are about equal to the floor elevation i.e. three at 4 km, four at 4½ km, and one each at 4½, 4 3/4, and 5½ km. These magnetic anomalies may be caused by surface lava flows associated with the Hercynian folding advocated by Soviet investigators or other tectonic activity. However, these must be of limited extent or the magnetic field would show more disturbance. The lava flows are probably the source of the basaltic hornblend and volcanic glass dredged from the ocean floor reported by Hakkel' (1958).

North of Spitsbergen on the northeastern corner of the Nansen Swell there is a cluster of prominent anomalies from which it was possible to obtain four depth estimations ranging from 1½ km in the center to 3 and 4 km on either side. These anomalies are located in the approximate vicinity of two earthquake epicenters reported by Linden (1959).

Surprisingly, there is no magnetic anomaly associated with the seamount reported by Treshnikov (1960) to rise over 3000 m above the floor of the southern end of the Fram Deep. Profile 61-523 passes directly over this seamount which, from its striking relief and apparent isolation, would suggest a volcanic origin. However, because of the indicated limited areal extent of this feature and possible errors in flight navigation, the profile may not pass over the seamount as shown in Figure 29.

6. 14. North Greenland and Environs

The northern coasts of Greenland are bordered by Precambrian geosynclines; on the north and west by the Northwest Greenland geosyncline and on the east by the Northeast Greenland geosyncline. The latter is thought to be older and contains over 6 km of sediments which underwent folding in Precambrian time. These mountains were then eroded to supply more than 4 km of Precambrian sediments (Koch, 1961). Lying unconformably over the Precambrian sediments is a thick lower Paleozoic section composed mostly of limestone and dolomite with some sandstone and shale. This stratigraphic sequence, with many unconformities and stratigraphic breaks, thins to the west from 3¼ km in Kronprins Christians Land to somewhat over ½ km in Peary Land (Cowie, 1961). Mild tertiary folding and faulting occurred across the northeastern tip of Greenland. A northwestern extrapolation of the orogenic axis marks the change in character of the magnetic profile on flight 61-511 west of Nord. Eastward from this point the profile is relatively quiet reflecting the underlying thick stratigraphic column.

The Northwest Greenland geosyncline is considered by Koch to be a northeastern extension of the Innuitian geosyncline from the Canadian shield. The fault zone in the Thule district (Cenozoic) may be associated with the downwarping of Baffin Bay. The geosyncline probably contains about 3 km of Precambrian sediments (Upper Thulean) which were intruded by numberous sills and dykes of basalt including many basic eruptives. The Precambrian sediments are capped by over 5 km of Ordovician and Silurian sediments which form a large plateau extending from the Kane Basin in the west to the central part of Peary Land. No Devonian sediments are found north of 76° N. latitude. The Paleozoics thin to the east upon the Greenland shield where their contact is buried under the ice cap. The Archean shield is exposed in the Thule district and Inglefield Land.

In Figure 27, shallow anomaly sources of the order of 1 to 3 km, are seen over the intruded Caledonian folds of Peary Land and the exposed Archean shield of Inglefield Land. The shield appears to extend across Smith Sound to Ellesmere Island. Within the sound, north and south of Inglefield Land, the anomalies indicate slightly deeper sources as the Paleozoic sediments thicken.

6. 15. Anomalies Originating from Deep Sources

The frequency of occurrence of estimated deep anomaly sources are plotted according to geomorphic provinces in Figure 35. In this histogram all depths over high land elevations have been omitted. Over the ocean deeps there is a very close grouping of depth determinations. The depths of 14½, 16 and 18 km are located on the extreme southern edges of the Beaufort and Eurasia Deeps and the far western side of the Canada Deep respectively. The overall average of the determinations is 10 3/4 km. Omitting the three deepest values, the average is 9 3/4 km. These figures are representative of normal crustal thicknesses under the deep ocean. It is possible that these anomalies originated at the Mohorovicic discontinuity (M), in which case the deeps would be considered oceanic in character. On the other hand the anomalies may originate from effects within the crust, such as the lower crustal layer reported in the Atlantic Ocean (Ewing and Landisman, 1961). In the case of the Canada Deep the distribution of anomalies (i.e. deeper on the margin adjoining the continental shelves) and the general magnetic character discussed earlier, coupled with geological evidence, strongly suggest landward crustal depression, presumably due to sedimentary loading.

A fairly broad and uniform distribution of depth determinations is associated with the Lomonosov and Alpha Ridges and the area they enclose, excluding the Makarov Deep. The depths range from 6¼ to 24 km and average 14 km. There can be no doubt of a greater crustal thickness in this region than is found under the adjoining (and enclosed) oceanic deeps.

An approximately equal range, but spottier distribution of estimated depth is associated with the continental slopes. This irregular distribution might well be expected considering the abrupt change in topography. The depths average 14¼ km, essentially the same as the average for the Lomonosov-Alpha ridge physiographic province.

There is considerable scatter in the depth estimates over the continental shelf with values ranging from 8 3/4 to 31 km. The latter, apparently anomalous figure, occurs just off the northern coast of Greenland. Unfortunately, few broad anomalies suitable for quantitative analysis were found over the continental shelves.

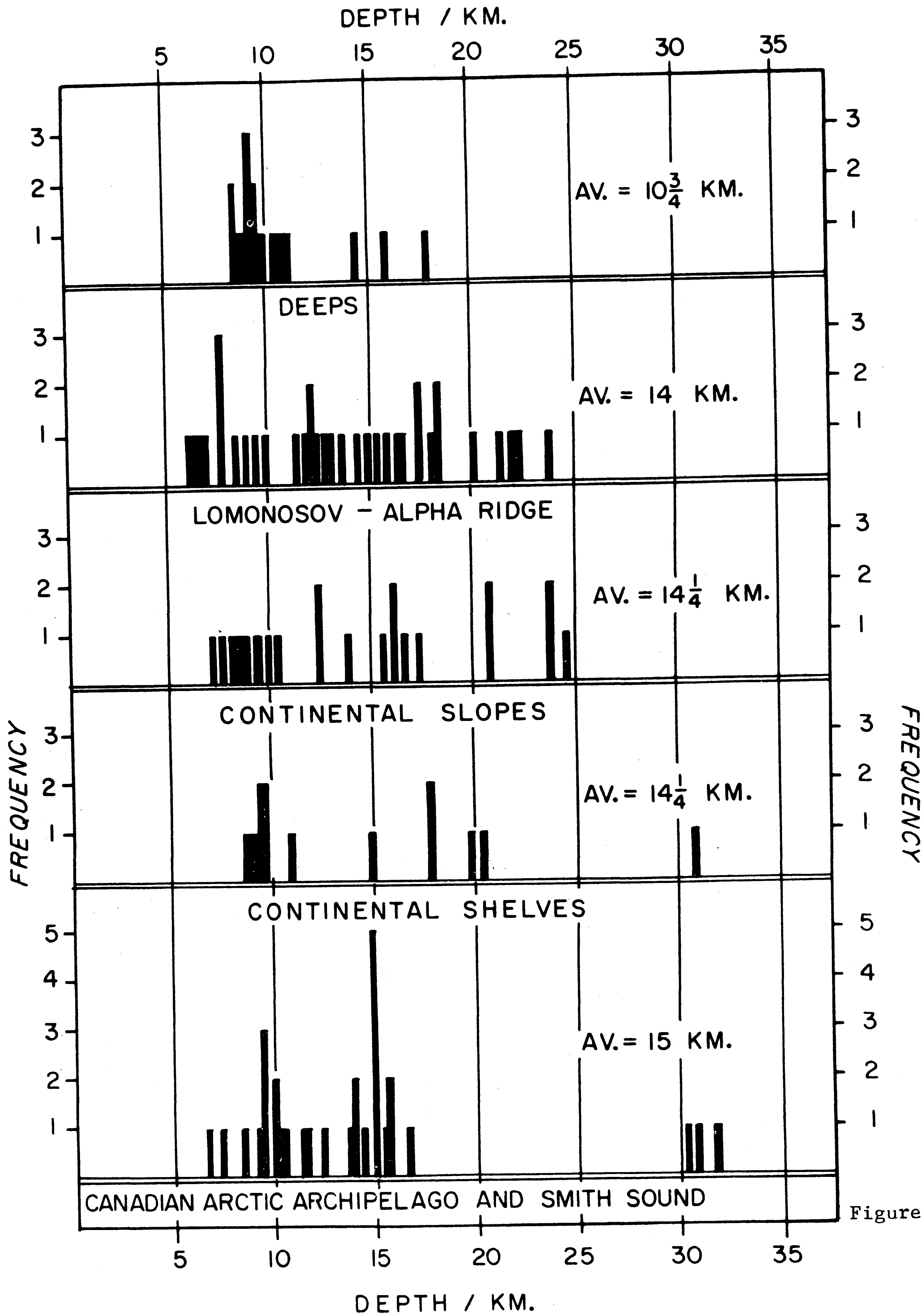


Figure 35.

DEEP SOURCE DETERMINATIONS VS. GEOMORPHIC PROVINCES

Over the Canadian Arctic Archipelago and Smith Sound, separating Greenland and Ellesmere Island, the depth determinations fall within two groupings, 6 3/4 to 16 3/4 km and 30½ to 32 km. The latter group is located entirely within Smith Sound suggesting that the anomalies originate from an intermediate crystalline basement as well as a deeper source, possibly M. All of the depth estimates in the archipelago fall along Parry Channel and are found to be strikingly consistent, averaging 14¼ km.

It is interesting to compare Figures 28 and 35 with the map of crustal thickness determined from Bouguer gravity anomalies shown in Figure 23. Over the central Arctic Basin the average magnetic depth determinations are in reasonably good agreement with the crustal thickness given by gravity. However, over the continental shelves and slopes, the Canadian Arctic Archipelago, and Smith Sound, the average magnetic depth estimates are too shallow by a factor of two, with the exception of the four deep anomalies in Smith Sound which are in excellent agreement with the gravity results. From this relationship one might suppose that the analyzed deep source anomalies over the central Arctic Basin and Smith Sound originated at M, whereas the remainder were caused by intracrustal sources.

The 9 3/4-km average anomaly source depth for the deeps agrees best with Woollard's crustal depth in Figure 22 and the deepest anomaly sources in the Lomonosov-Alpha province fall within the ranges given by both investigators. The deep anomalies in Smith Sound agree best with Woollard's values. Thus it appears that if the deep anomaly sources are related to the M as they appear to be, then they tend to give a better fit to Woollard's relationship of crustal thickness to Bouguer anomalies than to that of Demenitskaya. But it must be remembered that such a conclusion is contingent upon the quantity and quality of the gravity data upon which the map shown in Figure 23 was constructed. Unfortunately this is an unknown factor.

6. 16. Great Arctic Magnetic Anomaly

Possibly the most distinctive geophysical phenomena in the arctic region is the Great Arctic Magnetic Anomaly (see Chapter 2.7). This anomaly is expressed in the horizontal field component by a long cluster of magnetic meridians extending across the Arctic Basin from the Taimyr Peninsula to the north magnetic pole (Fig. 10). In the vertical component of the magnetic field the anomaly is seen as two maxima of nearly equal intensities centered over Siberia (about 67° N., 105-115° E.) and over Canada, just west of Hudson Bay (about 58° N., 97° W.). The anomaly is unique to the Arctic Basin; similar features are unknown elsewhere on the earth.

There have been several theories proposed to explain the Great Arctic Magnetic Anomaly. Alldredge and Van Voorhis (1962) show that the anomaly can be reproduced by magnetic sources at the core-mantle interface. Hope (1957, 1959) ascribes the anomaly to geologic sources deep within the earth's crust but above the Curie-point level and intimately associated with trans-Arctic Ocean Mesozoic folding. In a later paper Hope (1962, in preparation) suggests that "crustal or near-crustal (mantle-top) macroanomalies" caused by convection cells in the mantle play a fundamental role in shaping the arctic anomaly. The Soviet investigator Hakkel' (Hope, 1959) believed the anomaly to be due to a concentration of the geomagnetic field in the crustal rocks of two ancient centers of consolidation located in the Greenland-Canadian shield and the Central Siberian platform. He pictures the earth's magnetic field being preferentially channeled through these great crustal shields giving two, rather than one, maximum concentrations of geomagnetic lines of force. However, this theory is developed on the basis of the vertical component only, and Hope points out that the pattern of the horizontal component around each of these nearly equal vertical maxima would be symmetrical with the dip-pole lying about halfway between them. This is obviously not the case as can be seen from Figure 10. Currently available data are not sufficient to decide conclusively the origin of the Great Arctic Magnetic Anomaly.

6. 17. Regional Magnetic Chart

Figure 36 shows the observed regional isodynamic contours of the total field (F) obtained from the 1961 aeromagnetic survey superimposed upon the isodynamic lines taken from Hydrographic Office Chart No. 1703 N, "The Total Intensity of the Earth's Magnetic Force for the Year 1955." For this comparison HO 1703 N was adjusted to the year 1961 by using the isogam contours for the annual change in total field. The observed regional network was tied to the magnetic observatories Barrow, Alaska and Thule, Greenland for datum control, taking mean values for F of 57,200 gammas at Barrow and 56,800 gammas at Thule. As no aeromagnetic tracks were flown during magnetic storms, and most of the traverse lines intersect each other several times, reliable comparisons and adjustments could be made. The overall accuracy of the observed regional chart is believed to be better than $\pm$ 200 gammas.

The most striking feature of Figure 36 is that the observed regional gradient is much less than that shown on the Hydrographic Office Chart. The highest value observed over the region of the north magnetic pole is 58,750 gammas, whereas HO 1703 N shows F in excess of 61,000 gammas. A S-shaped flexure of the 56,000 gamma contour is seen over the Robeson Channel. This deflection occurs over the proposed continuation of Caledonian folding and associated basaltic intrusions, from northern Greenland to northern Ellesmere Island. This local distortion of the total field may be caused by underlying geology.

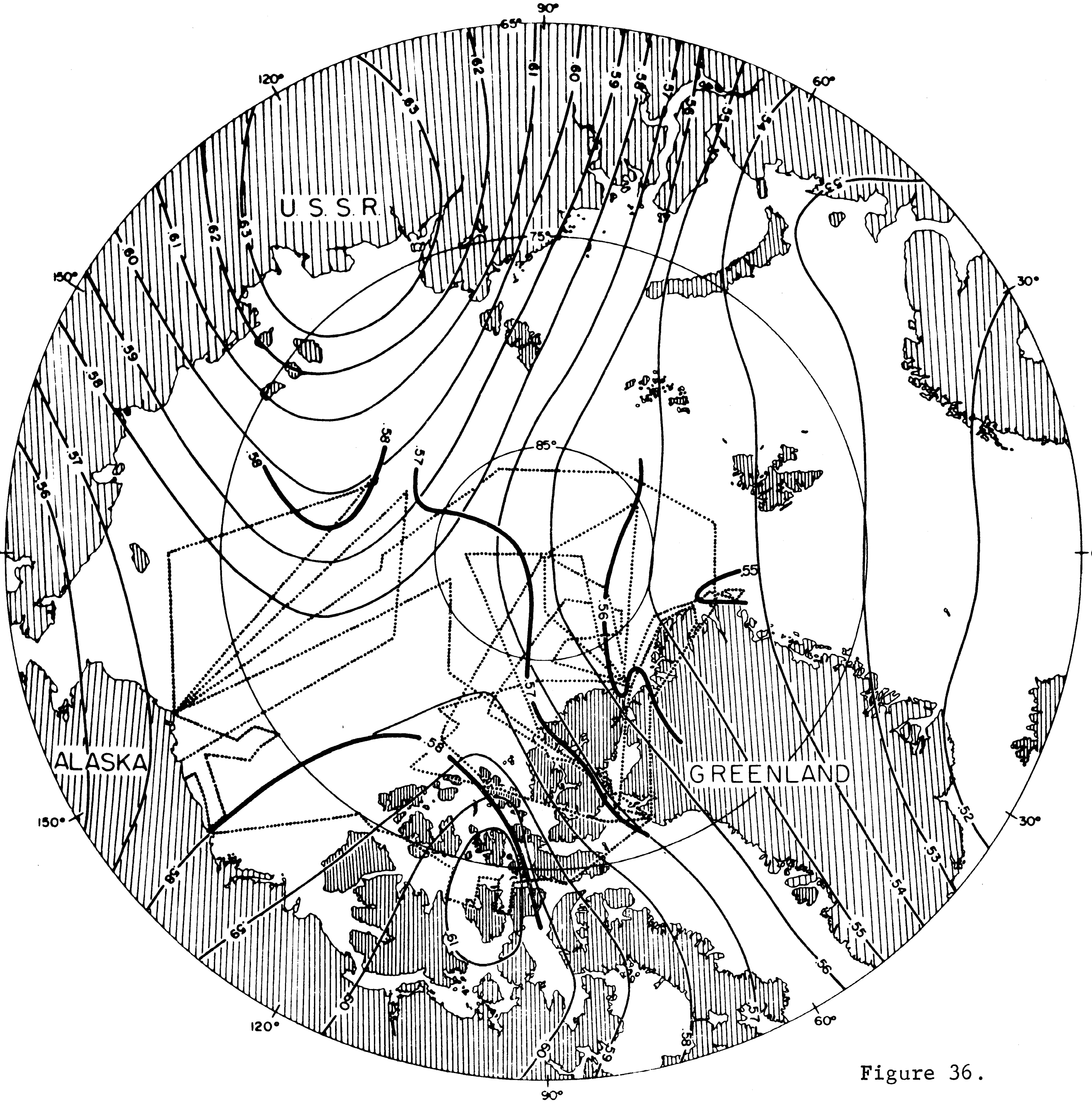


Figure 36.

THE TOTAL INTENSITY OF THE EARTH'S MAGNETIC FORCE

CONTOUR INTERVAL = .01 OERSTED

——— ISODYNAMIC LINES FROM H.O. CHART NO.1703N ADJUSTED TO 1961

━━━ OBSERVED ISODYNAMIC LINES, 1961

········ FLIGHT TRACKS OF AEROMAGNETIC SURVEY, 1961

Chapter 7

SUMMARY

7. 1. Bathymetry

A new bathymetric chart of the Arctic Basin was constructed by a critical evaluation of all available and inferred data. The principal geomorphic provinces are described and an attempt is made to arbitrate nomenclature confusion. From this chart the following conclusions are summarized.

1) The Arctic Basin is comprised of four deeps; Fram, Eurasia, Makarov and Canada. The southern end of the Canada Deep is divided by a broad low sill, which forms the Beaufort Deep. The separation of the Fram and Eurasia Deeps by a mid-oceanic ridge is speculative.
2) It is possible to project the Mid-Atlantic Ridge across the Arctic Basin (as suggested by Heezen and Ewing; 1961) without violating known sounding data.
3) The continental shelf off northeastern Greenland terminates at a depth of 300 m rather than the normal 200 m because of isostatic depression by the Greenland ice cap.

7. 2. Gravity

From a gravity survey of 250 stations over the Arctic Ocean and northern Alaska and Canada, free air and Bouguer iso-anomaly maps were constructed. Possible explanations of various anomalies were discussed and probable crustal models presented. Demenitskaya's map of crustal thickness under the Arctic Basin, based upon classified Soviet gravity data, is presented and discussed. Listed below is a summary of specific conclusions:

1) The Chukchi Shelf and Canada Deep are in isostatic equilibrium.
2) A -50 mgal free air anomaly is associated with the Brooks Range indicating slight overcompensation.
3) There is a rise in the granitic basement of the Chukchi Shelf northwest of Pt. Barrow (centered on 73°N., 160°W.) similar to those forming Wrangel, Herald, and the Diomede Islands elsewhere on the shelf.
4) An elliptical +107 mgal free air anomaly over the continental shelf at the terminus of the Brooks Range is due to a sharp rise in the basement and mantle associated with an uplifting of the north end of the Brooks Range.
5) A possible interpretation of the general structural framework of the continental shelf off northern Alaska is: A ridge of high density nonmagnetic material, probably granite, parallels the continental shelf. In the vicinity of 145°W. longitude the ridge rises inshore of the 200 m isobath. Farther west its crest lies approximately under the 200 m isobath to longitude 160°W. where it swings inshore into the Chukchi Shelf.
6) The genesis of two submarine valleys in the vicinity of longitudes 152°W. and 158°W. is thought to be related to high angle faults radiating from a complex core of basement rock located approximately 16 km southwest of Barrow.

7) A -100 mgal Bouguer anomaly is associated with crustal thickening beneath the Brooks Range, but does not faithfully follow the topography at the northern end of the range where the north-trending anomaly pattern is associated with later tertiary orogeny which exposed Upper Paleozoic and Cretaceous sediments.
8) Two crustal profiles across the continental shelf north of Alaska were constructed using Woollard's (1959) and Demenitskaya's (1959) relationships between Bouguer anomalies and crustal thickness. Both curves give a continental crustal thickness under the Chukchi Shelf and an intermediate thickness under the southern end of the Canada Deep.

7. 3. Magnetics

From a regional aeromagnetic survey over the Arctic Ocean Basin the following conclusions are summarized:

1) The Beaufort and Canada Deeps are underlain by a great volume of sediments and the crystalline basement appears to slope to the east. Geological evidence supports this conclusion. The character of the magnetic profiles over these deeps is similar to that observed over the Gulf of Mexico.
2) The seismic wave paths analyzed by Oliver et al. (1955) do not prove conclusively that the Lg phase is not transmitted across the Beaufort and Canada Deeps.
3) The Hyperborean platform does not underlie the Beaufort and Canada Deeps nor does it connect with the Canada-Greenland platform.
4) Geologic evidence suggests that the nonmagnetic basement ridge off the northern coast of Alaska extends eastward possibly as far as Axel Heiberg Island.
5) The portion of the aeromagnetic survey over the Canadian Arctic Archipelago compares well with the survey reported by Fortier and Morley (1956) and interpreted by Gregory et al. (1961).
6) The proposed fault along the Parry Channel is supported by these data.
7) The Boothia arch is a horst structure as suggested by Gregory et al. (1960, 1961).
8) Intense magnetic activity was observed over Hakkel's "staircase" region which is probably due to an ancient crystalline shield or platform (craton) complex i.e. the Hyperborean platform.
9) In the vicinity of the northwestern corner of the Canada Deep areas of slightly higher than anticipated bottom elevations were delineated by aeromagnetic methods.
10) Magnetic evidence indicates the presence of a near surface dyke or magnetic basement ridge complex (probably basaltic intrusion) to the northwest of Barrow, Alaska and striking at an angle of approximately 45° to the margin of the continental shelf. This feature is along the northwestern edge of and probably orogenically related to the rise in granitic basement defined by the gravity survey. Furthermore, it appears to continue beyond the edge of the continental shelf forming a short ridge as shown on earlier Soviet bathymetric charts.

11) The Alpha Rise is probably a horst block composed of crystalline rock covered by a sedimentary layer of variable thickness.
12) The Makarov Deep contains sediments, probably on the order of 1 km in thickness, which could account for its flat and featureless floor.
13) In contrast to the Alpha Rise, the Lomonosov Range is composed of folded and undoubtedly metamorphosed sediments but is devoid of mafic crystalline elements.
14) There is limited magnetic evidence for a continuation of the Mid-Atlantic Ridge across the Arctic Basin. However, if it does exist it is either poorly developed or is devoid of the magnetic elements observed in the Atlantic Ocean.
15) There may be lava flows of limited extent on the floor of the Eurasia Deep.
16) No magnetic anomaly was observed over the seamount reported by Treshnikov (1960) to rise over 300 m above the floor of the southern end of the Fram Deep.
17) The magnetic profiles over Greenland and Smith Sound are consistant with the known geology. The exposed Archean shield of Inglefield Land appear to extend across Smith Sound to Ellesmere Island. Within the sound north and south of Inglefield Land the anomalies indicate thickening of the Paleozoic sediments.
18) The broad anomalies over the central Arctic Basin and Smith Sound appear to originate at M, whereas the remainder are caused by intracrustal sources.
19) The average elevation of M under the deeps, exclusive of the Beaufort Deep, is believed to be -9 3/4 km.
20) A regional magnetic chart is presented for the Arctic Basin. The observed values and regional gradient are much less than shown on Hydrographic Office Chart HO 1703N. The highest observed value of F is 58,750 gammas. The S-shaped flexure of the 56,000 gamma isoline over the Robeson Channel is assumed to be a local distortion possibly caused by underlying geology.

7. 4. Crustal Structure

Just where in the earth's tectonic framework the Arctic Ocean Basin fits is still open to speculation. The evidence presented in the preceding chapters indicate that this ocean defies neat classification into any distinct category. Rather it appears to contain elements that are salient to both oceans and continents. Within its boundaries are depressions of truly oceanic depth underlain by crustal sections approximately 6 km thick. In addition, large volumes of sediments have collected within the basin that have subsequently undergone "continental" deformation. Perhaps the Arctic "Ocean" should be considered four "oceans"; the Canada, Makarov, Eurasia and Fram Oceans? Or does the basin represent a transitional phase from ocean to continent? Such questions can be answered with certainty only when more data become available and when the physical and chemical factors governing geologic processes are better understood.

REFERENCES

Adams, R. D. and D. A. Christoffel (1962) Total magnetic field surveys between New Zealand and the Ross Sea, Jour. Geophy. Res., vol. 67, no. 2, pp. 805-813.

Affleck, J. (1948) Aeromagnetic profile from Venezuela to Texas, World Oil, vol. 128, pp. 223-228.

Alldredge, L. R. and F. J. Keller, Jr. (1949) Preliminary report on magnetic anomalies between Adak, Alaska, and Kwajalein, Marshall Islands, Trans.. Amer. Geophys. Union, vol. 30, pp. 494-500.

________ and G. D. Van Voorhis (1961) Dept to sources of magnetic anomalies, J. Geophys. Res., vol. 66, no. 11 pp. 3793-3800.

________ and G. D. Van Voorhis (1962) Source of the Great Arctic Magnetic Anomaly, J. Geophys. Res., vol. 67, no. 4, pp. 1573-78.

Armstrong, T. (1958) The Russians in the Arctic, Methuen, London.

Barns, D. F. and R. V. Allen (1961) Preliminary results of gravity measurements between Kotzebue and Point Hipe, Alaska, Trace elements investigation Report 779, U. S. Dept. of the Interior, Geological Survey, pp. 80-86.

Belousov, V. V. (1955) The geological structure and evolution of the oceanic depressions, Izvest. Akad. Nauk. SSSR, Ser. Geol., no. 3, pp. 3-18, (DRB Translation T 284R by Hope, July 1958).

________ (1958) Tectonophysics: A promising new orientation in geology, Vestnik Akad. Nauk SSSR, vol. 28, no. 9, pp. 3-10 (DRB Translation T 310R by Hope, Nov. 1958.

Birch, F. (1955) Physics of the Crust, Crust of the Earth, Geol. Soc. Amer. Special Paper 62, pp. 101-118.

Burkhanov, V. (1956) New Soviet discoveries in the Arctic, Foreign Languages Publishing House, Moscow, 60 pp.

________ (1957a), Soviet Arctic research, Privoda, no. 5, pp. 21-30 (DRB Translation T 265R by Hope).

________ (1957b), Achievements of Soviet geographic exploration and research in the Arctic, Geografgiz, Moscow (DRB Translation T 253R by Hope, July 1957).

Bushnell, V. C. (1959) Scientific studies at Fletcher's ice island, T-3, vol. 1, pp. 1-6.

Buynitzky, V. H. (1940) Scientific work during the drift of the Sedov, All Union Geog. Soc. Bull. vol 77, no. 3, pp. 301-5.

Carey, S. W. (1958) The tectonic approach to continental drift, Continental drift: A Symposium, Univ. of Tasmania, pp. 177-355.

Carsola, A. J. (1954) Microrelief on the Arctic sea floor, Bull. Amer. Assn. Petrol. Geol., vol. 38, no. 7, pp. 1587-1601.

________, R. L. Fisher, C. J. Shipek, and G. Shumway (1961) Bathymetry of the Beaufort Sea, Geology of the Arctic, Univ. of Toronto Press, vol. 1, pp. 678-689.

Cowie, J. W. (1961) The lower Paleozoic geology of Greenland, Geology of the Arctic, Univ. of Toronto Press, vol. 2, pp. 161-169.

Crary, A. P., R. D. Cotell, and Jack Oliver (1952) Geophysical studies in the Beaufort Sea, 1951, Trans. Amer. Geophys. Union. vol. 33, pp. 211-216.

________ (1954) Bathymetric chart of the Arctic Ocean along the route of T-3, April 1952 to October 1953, Bull. Geol. Soc. Amer., vol. 65, pp. 709-12.

________, N. Goldstein (1957) Geophysical studies in the Arctic Ocean, Deep-Sea Research, vol. 4, pp. 185-201.

________ and N. Goldstein (1959) Geophysical Studies in the Arctic Ocean, A.F.C.R.C. Geophysical Research Papers No. 63, A.F.C.R.C.-TR-59-232 (1), vol. 1, pp. 7-30.

Cromie, W. J. (1961) Preliminary results of investigations on arctic drift station Charlie, Geology in the Arctic, Univ. of Toronto Press, vol. 1, pp. 691-708.

Demenitskaya, R. M. (1958) Structure of the earth's crust in the Arctic; Bull. Inst. Geol. Arctic, no. 7, p. 46.

________ (1958) The thickness of the earth's crust depending on the age of rocks, Soviet Geology, no. 6, Moscow. (ACIC translation TC-405 by Synenko, Philips and Tomas, Nov. 1961).

________ (1959) The method of research of the geological structure of the crystalline mantle of the Earth, Sovetskaya Geologiya, no. 1, pp. 90-109, (ACIC translation TC-345 by Tomas, 1962).

Dietz, R. S., and G. Shumway (1961) Arctic Basin geomorphology, Bull. Geol. Soc. of Amer., vol 72, pp. 1319-1330.

Drake, C. L., M. Ewing and G. H. Sutton (1959) Continental margins and geosynclines: The east coast of North America north of Cape Hatteras, Physics and Chemistry of the Earth, Pergamon Press, London, vol. 3, pp. 110-198.

Eardley, A. J. (1948) Ancient Arctica, Jour. Geology, vol. 56, pp. 409-36.

________ (1961) History of geologic thought on the origin of the Arctic Basin, Geology of the Arctic, Univ. of Toronto Press, vol. 1, pp. 607-621.

Emery, K. O. (1949) Topography and sediments of the Arctic basin, Jour. Geology, vol. 57, pp. 512-521.

Ewing, J. and M. Ewing (1959) Seismic refraction measurements in the Atlantic Ocean Basins, in the Mediterranean Sea, on the Mid-Atlantic Ridge, and in the Norwegian Sea, Bull. Geol. Soc. Amer., v. 70, pp. 291-318.

________, J. Antoine and M. Ewing (1960) Geophysical measurements in the western Caribbean Sea and in the Gulf of Mexico, J. Geophy. Res., vol. 65, no. 12, pp. 4087-4126.

Ewing, M. and F. Press (1952) Magnetic anomalies over oceanic structures, Trans. Amer. Geophys. Union, vol. 33, pp. 349-355.

________ and M. Landisman (1961) Shape and Structure of Ocean Basins, Oceanography, AAAS pub. no. 67, pp. 3-38.

Fisher, R. L., A. J. Carsola and G. Shumway (1958) Deep-sea bathymetry north of Point Barrow, Deep-Sea Res., vol. 5, pp. 1-6.

Fjeldstad, J. E. (1923) Litt om Tidevanneti Nordishavet, Naturen, vol. 47, p. 161.

Flint, R. F. (1957) Glacial and Pleistocene geology, John Wiley and Sons, New York, Plate 3.

Fortier, Y. O. and L. W. Morley (1956), Geological unity of the Arctic Islands; Trans. Roy. Soc. Canada, vol. 50, Ser. III, pp. 3-12.

Gardner, L. W. (1962) Personnel communication, Gulf Research and Development Lab., Pittsburgh 30, Pa.

Gordienko., P. A., and A. F. Laktionov (1960) Principal results of the latest oceanographic research in the Arctic Basin, Izvestiya Akad. Nauk SSSR, Geographic Series, vol. 5, pp. 22-33, (DRB trans T350R, by Hope, Feb., 1961).

Gregory, A. F., L. W. Morley and M. E. Bowers (1960) Geological Interpretatations of Aeromagnetic profiles from the Canadian Arctic Archipelago, Geol. Survey of Can., Paper 60-6.

________ (1961) Airborne geophysical reconnaissance in the Canadian Arctic Archipelago, Geophysics, vol. 26, no. 6, pp. 727-737.

Gutenberg, B., and C. F. Richter (1939) Structure of the crust. Continents and ocean basins: Nat. Res. Council Physics of the Earth, vol. 8: Internal composition of the earth, pp. 301-23.

Gutenberg, B. (1956) Earthquakes in the Arctic area, The Dynamics of the North, book 1, Bur. Naval Ops., Washington, D. C.

Hall, C. W. and N. A. Ostenso (in press) Project Arctic Basin, Proceedings of the U. S. Naval Institute.

Hakkel', Ya. Ya. (1957) Nauka i Osvoyeniye Arktiki (Science and the conquest of the Arctic), Morskoi Transport Press, Leningrad.

________ (1958) Signs of recent submarine volcanic activity in the Lomonosov Range, Priroda, vol. 4, pp. 87-90, (DRB Translation T296R by Hope, June, 1958).

Harris, R. A. (1904) Some indications of land in the vicinity of the North Pole, Natl. Geogr. Mag., vol. 15, pp. 255, 261.

Heck, N. H. (1938) The role of earthquakes and the seismic method in submarine geology; Proc. Am. Philos Soc. vol. 79, pp. 97-108.

Heezen, B. C., M. Ewing and E. T. Miller (1953) Trans-Atlantic profile of total magnetic intensity and topography, Dakar to Barbados, Deep-Sea Res., vol. 1, no. 1, pp. 25-33.

________, M. Tharp and M. Ewing (1959) The floors of the ocean; I, The North Atlantic, Geol. Soc. Amer., Special Paper 65.

________ and M. Ewing (1961) The mid-oceanic ridge and its extension through the Arctic Basin, Geology in the Arctic, Univ. of Toronto Press, vol. 1, pp. 622-642.

Henderson, R. G. (1960) A comprehensive system of automatic computation in magnetic and gravity interpretation, Geophysics, vol. 25, no. 3, pp. 569-585.

Hodgson, E. A. (1930) The seismicity of the Arctic, J. Roy. Astro. Soc., Canada, vol. 24, pp. 201-10.

Hope, E. R. (1954) Translation and comments from an anonymous article in Izv. Akad. Nauk. Ser. Geog. 1954, vol. 5, pp. 3-16, (DRB translation T165R).

________ (1957) Linear secular oscillations of the northern magnetic pole, J. Geophys. Res., vol. 62, pp. 19-27.

________ (1959) Geotectonics of the Arctic Ocean on the Great Arctic Magnetic Anomaly, J. Geophys. Res., vol. 64, pp. 407-427.

Hubbert, M. K. (1948) A line-integral method of computing the gravimetric effects of two-dimensional masses, Geophysics, vol. 13, pp. 215-225.

Hunkins, Kenneth (1960) Seismic studies of the Arctic Ocean floor, Air Force Cambridge Res. Lab., AF 19 (604) 2030, pp. 15.

Hunkins, Kenneth (1960b) Geophysical and oceanographic research in the Arctic Ocean, Lamont Geol. Obs. of Columbia Univ. final report AF 19 (604) -2030, ASTIA 253807, (mimeographed).

________ (1960c) Results of depth soundings taken from drifting station Charlie in the Arctic Ocean, Lamont Geol. Obs. of Columbia Univ. (mimeographed).

________ (1960d) Result of depth soundings taken at drifting station Bravo (T-3) in the Arctic Ocean, Lamont Geological Observatory, Columbia Univ. (mimeograph).

________, T. Herron, H. Kutschale, and G. Peter (1962) Geophysical studies of the Chukchi Cap, Arctic Ocean, J. Geophys. Res., vol. 67, no. 1, pp. 235-247.

Joerg, W. L. G. (1930) Brief history of polar exploration since the introduction of flying, Amer. Geogr. Soc., Spec. Pub. 11, p. 25.

Keller, F., Jr., J. L. Meuschke and L. R. Alldredge (1954) Aeromagnetic surveys in the Aleution, Marshall and Bermuda Islands, Trans. Amer. Geophys. Union, vol. 35, pp. 633-657.

Koch, L. (1961) Precambrian and early Paleozoic structural elements and sedimentation: north and east Greenland, Geology of the Arctic, Univ. of Toronto Press, vol. 2, pp. 148-154.

Koppen, W. P., and A. Wegener (1924) Die Klimate der Geologischen Vorzeit, Gebrueder Borntraegger, pp. 1-255.

Kulp, J. Laurence (1961) Geologic Time Scale, Science, vol. 133, No. 3459, p. 1111.

Kuwahara, S. (1938) Velocity of sound in sea-water and calculation of the velocity for use in sonic sounding, Hydrographic Dept., Imp. Japanese Navy, Tokyo, pp. 124-140.

Laktionov, A. F. and V. A. Shamontev (1957) The use of aviation in oceanographic investigations in the Arctic, Problemy Arktiki, no. 2: pp. 19-31 (ASTIA Trans. 245761 by Holden, Oct. 1959).

________ (1959) Bottom topography of the Greenland Sea in the region of Nansen's Sill, Priroda, vol. 10, pp. 95-97 (DRB translation T 333R by Hope, Nov. 1959).

Linden, N. A. (1959) Seismic chart of the Arctic 1959 seismology and seismological researches during the IGY, no. 2, Academy of Science, Moscow, pp. 7-17.

Maksimov, I. V. (1945) Kizucheniya prilivnykh yavlenic central'nois chasti Severnogo Ledovitogo Okeana (Contribution to the study of tidal phenomena in the central part of the Arctic Ocean), Problemy Arktiki, No. 3.

Marmer, H. A. (1928) Arctic tides; problems of polar research, Amer. Geogr. Soc. Spec. Pub. 7, pp. 22-3.

Martin, L. J. (1961) Tectonic framework of Northern Canada, Geology of the Arctic, Univ. of Toronto Press, pp. 443-457.

Mason, R. G. (1958) A magnetic survey of the west coast of the United States between lat. 32° and 36°N., long. 121° and 128°W., Geophy. J., vol. 1, no. 4, pp. 320-329.

Matthews, D. H. (1961) Lavas from an abyssal hill on the floor of the North Atlantic Ocean, Nature, vol. 190, no. 4771, pp. 158-159.

Miller, E. T. and M. Ewing (1956) Geomagnetic measurements in the Gulf of Mexico and in the vicinity of Caryn Peak, Geophysics, vol. 21, no. 2, pp. 406-432.

Mushketov, D. (1935) Seismicity of the Arctic, Trans. Seis. Inst. Acad. Sci. USSR, no. 61, pp. 9-15.

Nansen, R. (1904) The bathymetrical features of the north polar season with a discussion of the continental shelves and previous oscillations of the shore-line; Norwegian North Polar Expedition, 1893-96, vol. 4, no. 13, pp. 1-231.

Oliver, J., A. Ewing, and F. Press (1955) Crustal structure of the Arctic regions from Lg phases Bull. Geol. Soc. Amer., vol. 66, pp. 1063-74.

Ostrekin, M. Ye (1954) Recent study and exploration of the central Arctic, Priroda, vol. 12, pp. 3-12, (DRB trans. T 172R by Hope, Sept. 1955).

Panov, D. G. (1955a) Neotectonic movements in the Arctic region, Dok. Akad. Nauk., vol. 104, pp. 462-465, (DRB trans. T204R by Hope, Oct., 1955).

________ (1955b) Tectonics of the central Arctic, Dok. Akad. Nauk., vol. 105, pp. 339-342 (DRB trans. T207R by Hope, June, 1956).

Papanin, Ivan (1947) Life on an ice floe, Hutchinson and Co., London, p. 240.

Payne, T. G. editor (1951) Geology of the Arctic Slope of Alaska, Oil and Gas Investigations Map OM 126 (in 3 sheets), U. S. Geol. Survey.

Peters, L. J. (1949) Direct approach to magnetic interpretation and its applications, Geophysics, vol. 14, pp. 290-320.

Raff, A. D. (1961) The magnetism of the ocean floor, Scientific Amer., Oct. pp. 146-156.

Raiko, N. V. and N. A. Linden (1935) The earthquake of November 20, 1933, in Baffin Bay and the distribution of seismic foci in the Arctic, Trans. Seis. Inst., Acad. Sci. USSR, no. 61, pp. 1-8.

Saks, V. N., N. A. Belov, N. N. Lapina (1955) Our present concepts of the Central Arctic, Priroda, vol. 7, pp. 13-22, (DRB Translation T196R by Hope, Oct. 4, 1955).

________ (1958) Some considerations on the geological history of the Arctic, Problems of the North, no. 1, pp. 70-90 (translated version by Natl. Res. Council, Canada by Hope, Dec. 1960).

Sanker Narayan, P. V. (1961) Mathematical methods in the interpretation of magnetic data, Univ. of Wis. unpublished Ph.D. thesis.

Serson, P. H. and W. L. W. Hannaford (1957) A statistical analysis of magnetic profiles, J. Geophys. Res., vol. 62, pp. 1-18.

Shatskiy, N. S. (1935) On the tectonics of the Arctic, The geology and the minerals of the northern USSR Trudy 1-oy geol.-razved. Konf. Glavsevmorputi, No. 1, Leningrad.

Somov, M. M. (1955) Observational data of the scientific-research drifting station of 1950-51, Morskoi Transport Press, vol. 1, art. 2., (translation by Amer. Met. Soc., Boston, by Hope).

Steinhardt, J. S. and R. P. Meyer (1961) Explosion studies of continental structure, Carnegie Inst. of Wash. Pub. 622, pp. 375.

Süss, E. (1909) Das Antlitz der Erde, vol. 3, part 2, pp. 283-84 and p. 730, F. Tempski, Vienna.

Sverdrup, H. V. (1950) (1950) Physical oceanography of the North Polar Sea, Arctic, vol. 3, pp. 178-86.

Tams, E. (1922) Die Seismischen Verhaltnisse des. europaischen Nordmeeres; Centralblatt f. Mineralogie, Geologie u. Paleontologie Jahrg., no. 13, pp. 385-97.

Taylor, F. B. (1910) Bearing of the tertiary mountain belt on the origin of the earth's plan, Bull. Geol. Soc. Amer. vol. 21, pp. 179-226.

Thiel, E. C., N. A. Ostenso, W. E. Benini and G. P. Woollard (1958) Gravity measurements in Alaska, Woods Hole Oceanographic Inst. Report No. 58-54, AFCRC-TN-59-206, pp. 104.

Thorsteinsson, R. and E. T. Tozer (1961) Structural history of the Canadian Arctic Archipelago since Precambrian time, Geology of the Arctic, Univ. of Toronto Press, vol. 1, pp. 339-360.

Treshnikov, A. F. (1960) The Arctic discloses its secrets: New data on the bottom topography and the waters of the Arctic Basin, Priroda, vol. 2, pp. 25-32 (DRB translation T357R, by Hope, Aug. 1961).

Vacquier, V. and J. Affleck (1941) A computation of the average depth to the bottom of the earth's magnetic crust, based on a statistical study of local magnetic anomalies, Trans. Amer. Geophys. Union, Vol. 22, pp. 446-450.

Volkov, P. (1961) New explorations of the bottom topography in the Greenland Sea, Morskoi Flat, vol. 3, pp. 35-37 (DRB translation T356R by Hope, July, 1961).

Webster, C. J. (1954) The Soviet expedition to the Central Arctic, 1954, Arctic, v. 7, pp. 59-80.

Wilkins, G. H. (1928) Problems of polar research, Am. Geog. Soc. Sp. Pub. no. 7, pp. 397-410.

Wiseman, J. D. H. and C. D. Ovey (1953) Definitions of features on the deep-sea floor, Deep-Sea Research, vol. 1, pp. 11-16.

Woollard, G. P. (1959) Crustal structure from gravity and seismic measurements, J. Geophys. Res. vol. 64, no. 10, pp. 1521-1544.

________, N. A. Ostenso, E. Thiel and W. E. Bonini (1960) Gravity anomalies crustal structure, and geology in Alaska, Geophys. Res., vol. 65, no. 3, pp. 1021-1037.

Worthington, L. V. (1953) Oceanographic results of Project Skijump I and Skijump II in the Polar Sea, 1951-1952, Trans. Amer. Geophys. Un., vol. 34, pp. 543-51.

Worzel, J. L. and M. Ewing (1952) Gravity measurements at sea, 1948 and 1949, Trans. Am. Geophys. Union, vol. 33, no. 3, pp. 453-460.

________, G. L. Shurbert and M. Ewing (1955) Gravity measurements at sea, 1952 and 1953, Trans. Am. Geophys. Union, vol. 36, no. 2, pp. 326-334.