Arctic Geophysics

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The earliest geophysical studies at Point Barrow were conducted during the First International Polar Year, 1882-1883. Lieut. Ray of the U.S. Army Signal Corps established a station near the present Browerville primarily for the investigation of geomagnetic and auroral phenomena. Even at that early date, Point Barrow was the natural site for research in arctic geophysics by the United States. However, it was not until after the Second World War that geophysics became an important part of the research program at Barrow. The large-scale geophysical exploration of Naval Petroleum Reserve No. 4 focused interest on the area and was an important factor in the establishment of the Naval Arctic Research Laboratory. Barrow was the centre for exploration by gravity, magnetic and seismic methods which extended from the foothills of the Brooks Range to the shores of the Arctic Ocean (Woolson *et al.* 1962). An asymmetric sedimentary basin was found beneath the Arctic Coastal Plain. The axis of the basin strikes east-west, parallel to the Brooks Range and the coast. The deepest part of the basin is near its southern boundary where it abuts the thrust-block mountains of the Brooks Range. Cretaceous sedimentary rocks fill the basin to a depth of 5 to 7 km. along its axis. They thin northward and are only 500 m. thick at Point Barrow.

In the years following the exploration of Naval Petroleum Reserve 4, other geophysical studies were begun at NARL. Heat flow through the earth and the problems of permafrost received considerable attention through the fifties. A regional gravity survey of Alaska was made, revealing a large negative Bouguer anomaly over the Brooks Range (Woollard *et al.* 1960). This survey was later extended seaward to cover much of the Chukchi Sea (Ostenso 1968b). The data indicate that an extension of the Brooks Range continues beneath the Chukchi Sea and joins with the Chukchi-Anadyr fold belt of Siberia. NARL serves as a magnetic and seismological observatory as well as a base for field operations. The U.S. Coast and Geodetic Survey continuously monitors the earth's magnetic field there and an earthquake seismograph station has recently been installed.

At Barrow, one looks northward across the Arctic Ocean stretching, without interruption, to Europe and the Atlantic Ocean. It was natural to consider research programs in marine geophysics as a goal for NARL. This goal began to be realized in 1960 when Arctic Research Laboratory Ice Station I (ARLIS I) was established. Although there was no geophysical program on ARLIS I the experience gained led to ARLIS II in 1961 on which was established a program in marine geology and geophysics.

ARLIS II was in operation for four years, drifting the length of the Arctic Ocean before leaving in the East Greenland Current. It was finally evacuated in Denmark

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Strait in 1965 shortly before it disintegrated and melted. Precision depth, magnetic, seismic reflection and navigation data were collected by a Lamont-Doherty Geological Observatory party during the first two years of the drift. A University of Wisconsin group made gravity observations throughout the four years and operated a seismic profiler during the last three years.

During 1961 and 1962, ARLIS II drifted over the basin between the Lomonosov Ridge and the Alpha Cordillera. The results have been reported by Kutschale (1966). The Wrangel Abyssal Plain was particularly well studied and found to be underlain by at least 3.5 km. of nearly horizontal, stratified sediments. A bedrock dam trapped sediments in this basin until it was filled to the sill depth. They then flowed over the top into a deeper part of the basin floored with the Siberia Abyssal Plain. The present surface of the Wrangel Abyssal Plain is cut by channels which funnel sediments through the Arlis Gap which joins the two abyssal plains. Crustal models based on gravity, magnetic and seismic reflection measurements indicate a crustal thickness of 15 km. beneath the Wrangel Abyssal Plain and 22 km. beneath the buried basement ridge (Figs. 1 and 2).

About 2,400 km. of sub-bottom reflection profiles off the east coast of Greenland were obtained from ARLIS II by the University of Wisconsin team with a sonar boomer system (Ostenso 1968a). Three widely separated faults were discovered on the Greenland shelf. These features were correlated with known faults on land, extending knowledge of Caledonian tectonics into the ocean. The Jan Mayen fracture zone of the Mid-Atlantic Ridge was also shown to extend onto the continental shelf.

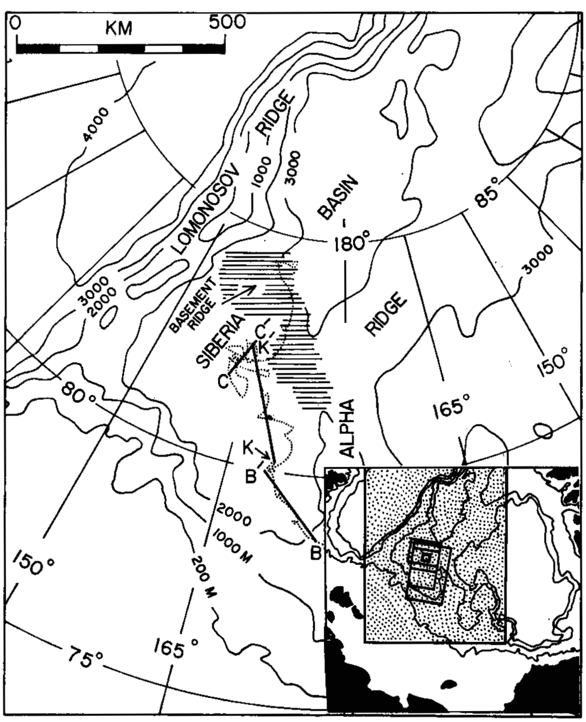

FIG. 1. Bathymetric map of portion of the Arctic Ocean investigated during ARLIS II drift of 1962 (Kutschale 1966).

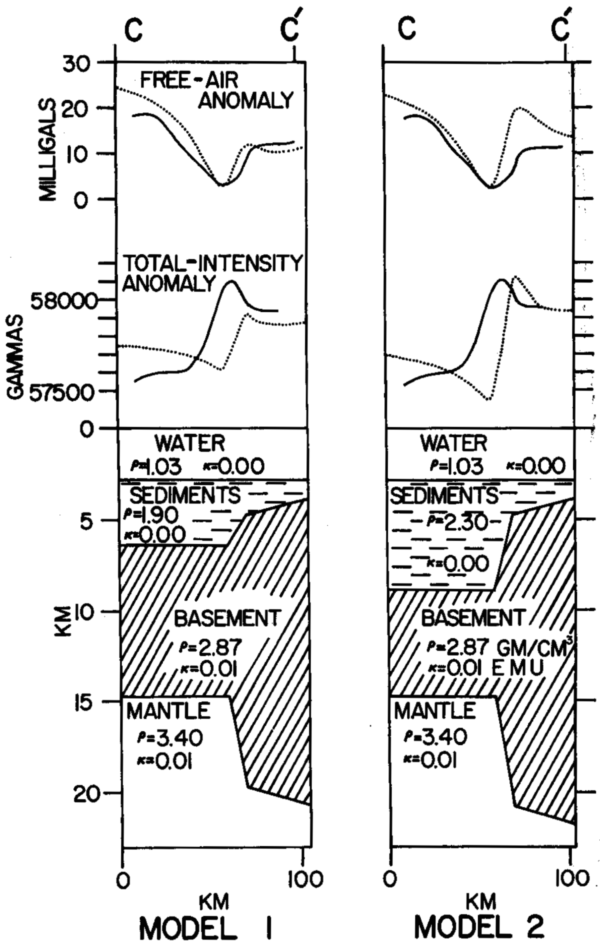

FIG. 2. Comparison of measured (solid curve) and computed (dotted curve) free-air gravity anomalies and total-intensity magnetic anomalies along section C-C′ of Fig. 1. Vertical exaggeration 10:1 (Kutschale 1966).

In addition to this type of continuous geophysical profiling which is conducted at drifting stations, special geophysical experiments are often run. The first measurements of seismic noise on the Arctic Ocean floor were made from ARLIS II in 1962 (Prentiss and Ewing 1963; Prentiss *et al.* 1965). A seismometer was successfully operated on the ocean floor for short periods. The data were telemetered to the surface by means of an acoustic link. Acoustic noise measurements in the 0.1 to 100 hz. band were also made on the ice surface at the same time.

Lower frequency waves, essentially modified gravity waves rather than acoustic waves, were also studied at ARLIS II (Hunkins 1962; LeSchack and Haubrich 1964). These long waves are interpreted as ocean swell modified by the influence of the pack ice. Observations were made primarily with gravity meters. Simultaneous measurements with two instruments at different locations showed the waves to be progressive. Wave amplitudes are on the order of a millimeter at periods of 10 to 100 seconds and are imperceptible except with instruments. Amplitudes generally increase with period throughout the observed range.

Seismic studies of ice island ARLIS II itself were made in 1961 to determine its thickness and elastic properties (Kutschale 1968). The ice island was roughly rectangular in shape, measuring about 6½ by 3 km. The ice island, presumably a remnant of a broken ice shelf, was composed of two ice types: a debris-rich gray glacial ice and a stratified blue sea ice. Seismic measurements, levelling and coring all showed the gray glacial ice to be about 25 m. thick whereas the blue sea ice varied from 6 to 14 m. in thickness.

Fletcher's Ice Island, T-3, has been occupied as a NARL drifting research station since 1962. T-3 had previously been used as a drifting research station by the U.S. Air Force. In April 1960 the ice island became grounded on the continental shelf 80 miles northwest of Barrow. A stationary base so close to Barrow held little interest for researchers and it was abandoned in September 1961. Sometime during the following winter T-3 drifted free and was spotted on 16 February, 1962 from an ARL airplane on a routine supply flight to ARLIS II. The station was occupied a few days later and by May of that year a geophysical program was being conducted by Lamont. Navigation, depth, magnetic and gravity fields were monitored. This basic program, with many improvements, is still in operation.

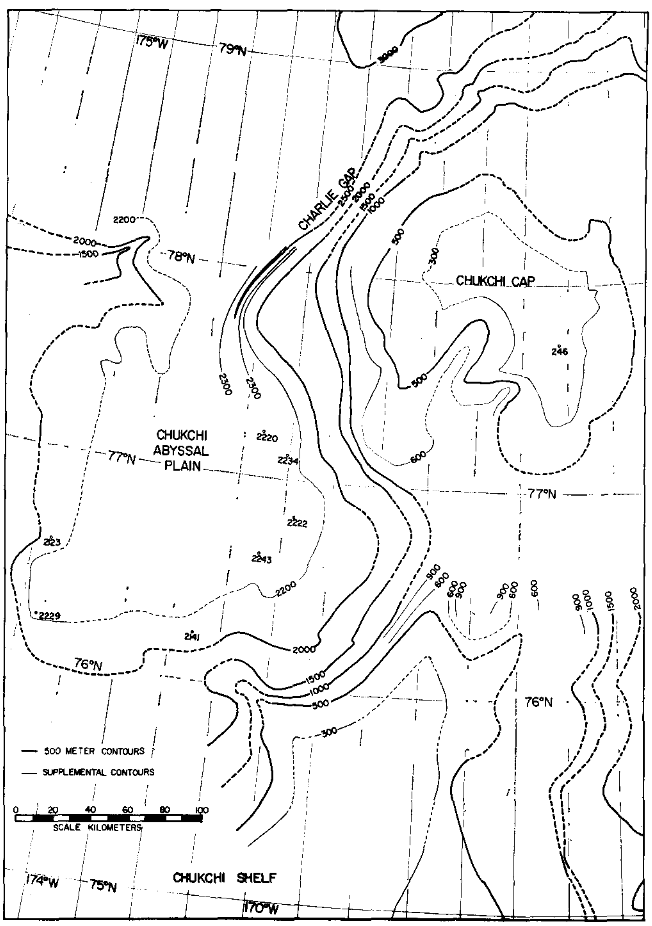

FIG. 3. Bathymetric sketch of the Chukchi Cap and Chukchi Abyssal Plain (Shaver and Hunkins 1964).

During the summer of 1962, T-3 crossed the Chukchi Cap, a marginal plateau about 150 km. in diameter. The topography of this feature (Fig. 3) was further explored and the large magnetic anomaly on its western flank was delineated more clearly. The Chukchi Cap is apparently a continental fragment which has been broken from the Alaskan continental shelf (Shaver and Hunkins 1964).

Drifting ice stations are stable platforms which can be used for experiments which are not feasible in other oceans. In October 1962, a proton-precession magnetometer with two sensing heads was installed at T-3 (Heirtzler 1967). One head was at the surface and one was suspended at a depth of 330 m. to form a vertical gradiometer. This configuration allowed magnetic anomalies to be de-

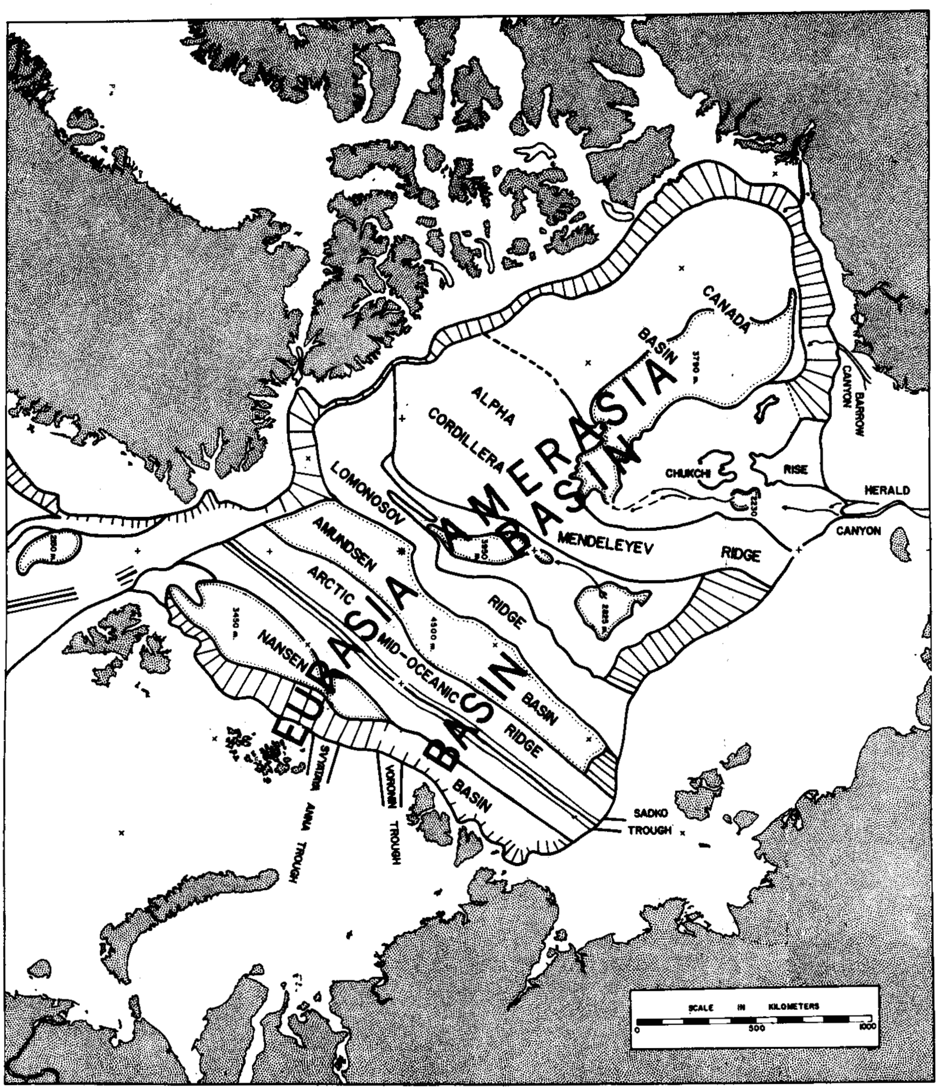

FIG. 4. Physiographic provinces of the Arctic Ocean.

tected in the presence of large time variations of the magnetic field. The observations showed a small but measurable attenuation and phase lag at the lower sensor in the 90 to 400 sec. period range. This however did not limit the use of the gradiometer for defining crustal anomalies.

A Precision Depth Recorder has operated nearly continuously at T-3 since 1963. Records from this instrument show details of bottom texture necessary for understanding sedimentary processes on the ocean floor. Deep-sea channels and abyssal plains, for example, can only be adequately resolved with the PDR. Soundings made from T-3, as well as from other drifting stations and nuclear submarines, have been essential in forming present concepts of Arctic Ocean shape and structure.

Present bathymetric knowledge of the Arctic Ocean is summarized by Beal (1968), Hunkins (1968) and de Leeuw (1967). The outlines of recognized physiographic provinces are shown in Fig. 4. Three major ridge systems cross the basin with their axes nearly parallel to each other. Each of the three ridges has its own distinctive characteristics.

The Alpha Cordillera is broadly arch-shaped in profile. The topographic texture is rough and the cordillera appears to be composed of many smaller ranges. It is about 1000 km. in width and stands 2 km. above adjacent ocean basins. It is not seismically active but has a rough magnetic texture.

The Lomonosov Ridge contrasts with the Alpha Cordillera in shape, texture and magnetic field. The Lomonosov Ridge is only 60 to 200 km. wide and has a smooth, asymmetric profile. No appreciable magnetic anomaly is found over this ridge. Like the Alpha Cordillera, it is aseismic.

The Arctic Mid-Ocean Ridge, however, is seismically active, being an extension of the Mid-Atlantic Ridge into the Arctic Ocean. The term Arctic Mid-Ocean Ridge, although it indicates the continuity between this ridge and the world-wide mid-ocean ridge system, is not quite accurate for it is located near one side of the Arctic Basin rather than in the middle. The seismic epicenters are located beneath the crest of the ridge, coinciding, as nearly as can be determined, with the rift valley which forms a cleft along the crest.

Each of these ridges plays a role in current theories of the origin of the Arctic Basin. The concept of ocean floor spreading has proved fruitful in other oceans and can be applied to the Arctic Ocean. The concept calls for movement of the ocean floor away from the ridge at a rate of a few centimetres per year. The line of rifting and seismicity marks the present locus of spreading. Mantle derivatives are introduced from below along the rift valley to form new oceanic crust.

Sea floor spreading is believed to be taking place in the Arctic Ocean at present along the Arctic Mid-Ocean Ridge. The rifting apparently split off the outer edge of the continental shelf which now forms the Lomonosov Ridge. The smooth topography of this ridge, and the match between the shelf and the Lomonosov Ridge outlines tend to support this idea.

This accounts for the origin of the Eurasia Basin but leaves the origin of the Amerasia Basin still to be explained. It has been speculated that the Amerasia Basin was also formed by rifting but at an earlier date. The Alpha Cordillera, according to this hypothesis, is an inactive mid-ocean ridge which has stopped spreading. The present evidence for the Alpha Cordillera as an extinct mid-ocean ridge is based on bathymetric, magnetic and heat flow data. However the support is still weak, and more geophysical data are needed to decide the merit of the concept.

Crustal structure in the Arctic Ocean can only be better understood if field expeditions are mounted to examine present theories. Surveys should be designed to test whether the Lomonosov Ridge is a continental shelf fragment and whether the Alpha Cordillera is an ancient locus of spreading. This will require detailed aeromagnetic flights, seismic reflection and refraction surveys as well as new tools which are still to be developed. One of the essential requirements for this work is a flexible transportation system including single- and multi-engine airplanes, helicopters, and hovercraft, operating from permanent as well as temporary ice stations. Drifting ice stations have made major contributions to Arctic Ocean geophysics but the scope of manoeuvres must now be widened if the interesting problems posed by new theories of ocean basin origins are to be solved.

ACKNOWLEDGEMENT

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