GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 60-6

GEOLOGICAL INTERPRETATION OF AEROMAGNETIC PROFILES FROM THE CANADIAN ARCTIC ARCHIPELAGO

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Price 50 cents

1960

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GEOLOGICAL INTERPRETATION OF AEROMAGNETIC PROFILES FROM THE CANADIAN ARCTIC ARCHIPELAGO[1]

INTRODUCTION

In 1955, a reconnaissance airborne geophysical survey was conducted in the Arctic Archipelago in conjunction with Operation Franklin, a geological exploration program carried out by the Geological Survey of Canada (Fortier, et al., in press) [2]. Nine thousand line miles of widely spaced profiles were flown in a cobweb pattern centred on the base of operations at Resolute Bay on Cornwallis Island. Flights were made during the period from June 14th to July 2nd inclusive, with a nominal flight altitude of 800 feet above ground and a speed of 120 miles per hour.

The following data were recorded:

(1) the total magnetic field, measured with an airborne fluxgate magnetomer (type ASQ-3A);

(2) the total gamma radioactivity, measured with a large crystal scintillation counter (M.E.L., type A.E.P. 1903R, Mk. II);

(3) the terrain clearance, measured by radioaltimeter;

(4) a positioning film strip photographed with a 35 mm aerial camera.

This paper is particularly concerned with the geological significance of the aeromagnetic data. The geophysical profiles and detailed analyses of both the aeromagnetic and aeroradiometric data will be published separately (Gregory, et al., in press).

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(in press): Geology of the North Central Part of the Arctic Archipelago, Northwest Territories (Operation Franklin); Geol. Surv., Canada, Mem. 320.

Fortier, Y.O., and Morley, L.W.
1956: Geological Unity of the Arctic Islands; Trans. Roy. Soc. Can., vol. 50, ser. III, pp. 3-12.

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[1] This report is one of several summary papers prepared by officers of the Geological Survey of Canada and presented at the First International Symposium on Arctic Geology, Calgary, Alberta, 1960. Preliminary publication is by arrangement with the organizing committee of the symposium.

[2] Names or names and dates in parentheses refer to publications listed in the References

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(in press): Geological Interpretation of Aerial Magnetic and Radioactivity Profiles, Arctic Archipelago, N.W.T.; Geol. Surv., Canada, Bulletin in preparation.

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1949: The Direct Approach to Magnetic Interpretation and its Practical Application; Geophysics, vol. 14, No. 3, pp. 290-320.

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(in press): Summary Account of the Structural History of the Canadian Arctic Archipelago Since Precambrian Time: Geol. Surv., Canada, Paper 60-7.

GEOLOGICAL ENVIRONMENT OF THE FERROMAGNETIC ROCKS

The regional structural geology of the Arctic Archipelago has been fairly well established (see Fortier, et al., in press, and Tozer, in press). Relatively shallow, ill-defined, remnant basins comprising lower Palaeozoic sediments lie upon the edge of the Precambrian Shield. These basins are separated by variform, broad, basement arches. Beyond these shallow features, the main Palaeozoic basin deepens, and farther north it is deformed into fold belts. The Mesozoic and Permo-Carboniferous strata of the Sverdrup Basin lie unconformably on the older rocks. Within the Sverdrup Basin, moderate structural deformation and basic igneous activity culminate in the eastern part and decline to the west. Gypsum piercement domes are prominent features, especially in the eastern half of the basin. The character of the northern rim of this basin is obscured by a cover of coastal-plain sediments on the northwestern islands of the Queen Elizabeth group. Beyond these, lie the Continental Shelf and the deep basin of the Arctic Ocean.

Ferromagnetic bodies are known to occur in six types of geological environment:

(1) the igneous and metamorphic rock complex and basic dykes of the Archaean basement;

(2) sills and dykes cutting Proterozoic sedimentary rocks;

(3) the igneous and metamorphic rock complex comprising pre-Pennsylvanian basement in the Northern Ellesmere fold belt;

(4) Permo-Carboniferous volcanic rocks in the Eureka Sound fold belt;

(5) sills, dykes and local extrusive rocks of probable Cretaceous age within the Sverdrup Basin;

(6) rare dykes of probable Cretaceous age in the fold belts at the edge of the Sverdrup Basin.

The ferromagnetic bodies in the Precambrian rocks and within the Svèrdrup Basin appear to be the most extensive and probably are the major influence on the magnetic anomaly field.

INTERPRETATION OF THE AEROMAGNETIC DATA

Flight lines were laid out so as to traverse the main geological regions of the Archipelago and continuous magnetic recordings were obtained along them. The location and general character of the aeromagnetic profiles have been described by Fortier and Morley (1956) and are shown in Figure 1. In this illustration, the amplitude of the total magnetic intensity of the profiles is relative to a separate, arbitrary base for each profile. Accordingly, the amplitudes should not be quantitatively compared from line to line. These profiles show a general correlation with different geological regions—e.g. irregular regional and small local anomalies over Archaean and pre-Pennsylvanian basement; frequent local anomalies, often very intense, over the fold and dyke belt in the east end of the Sverdrup Basin; and smooth, flat profiles over thick sedimentary sequences.

Maximum depths to basement were calculated using published techniques (Henderson and Zeitz, 1948; Peters, 1949). By considering the limitations of the calculation, average values, or occasionally most probable values, of depth to basement were obtained (Fig. 2). The term 'basement' here denotes a predominantly ferromagnetic, igneous and metamorphic rock complex in contrast to the varying thicknesses of essentially non-ferromagnetic, sedimentary strata which overlie it. In view of the ambiguity inherent in the interpretation, especially from single-profile data, it is emphasized that the depth estimates are maximum values. The true depth may be less. Further, since the Proterozoic rocks are generally flat-lying, and thus cause no magnetic anomaly, the calculated thicknesses of the geologic section may include Proterozoic as well as Palaeozoic strata.

Magnetic Features of the Basement and Related Basins of Sedimentary Rocks

From the aeromagnetic data (Fig. 3), the Boothia Arch is interpreted as extending to the southeastern corner of Bathurst Island where the basement core, and probably the whole arch, terminates or plunges to the north. These magnetic data also suggest that the north end of the arch has been offset for a distance of 10 to 20 miles along a fault or sharp flexure.

The core of the arch is at considerable depth near Bathurst Island, as a sedimentary cover greater than 10, 000 feet thick is estimated in this vicinity. The proportion of Proterozoic rocks in the sequence is unknown. At the time of interpretation, it was conceivable that such rocks might outcrop on the southeast corner of Bathurst Island in an area for which there were no published geological data. The occurrence of three local magnetic anomalies suggested near-surface, dyke-like bodies similar to those known to intrude both the Proterozoic rocks and the Palaeozoic fold belts. While the magnetic data did not indicate the age of the exposed rocks in this locality, the associated radioactivity data suggested the continuation into this area of certain radioactive Silurian and Devonian rocks which only occur farther north on Bathurst Island. An exposure of Proterozoic rocks on southeast Bathurst Island was thus considered improbable. Recently, McNair (1959) found that basic intrusions cut the Palaeozoic rocks in this location.

The Boothia Arch appears to be bounded on its west side by steep faulting. The eastern edge may in part be faulted although in the vicinity of Aston Bay on northwestern Somerset Island it appears to have a regular slope with upturned beds lying on it (Fig. 4). The Boothia Arch thus is interpreted as being an imperfectly developed horst (or faulted anticline) rising 5, 000 to 10, 000 feet above the general basement level.

On Cornwallis Island (Fig. 3) two positive regional anomalies, which appear to be related to the Boothia Arch anomaly, are interpreted, by analogy with this latter feature, as structural uplifts in the basement. The larger of the two anomalies underlies, in part, the Centre anticline, which is the major structural feature of Cornwallis Island. The smaller anomaly coincides with a lesser anticline. However, the magnetic data for the eastern part of the island are incomplete and the correlation cannot be fully established. Nevertheless, these data suggest a close genetic relationship between structures in the basement and in the younger sedimentary rocks of at least the southern part of the Cornwallis fold belt.

On Victoria Island, the Minto Arch has poor magnetic expression, presumably because of a relatively thick cover of Proterozoic strata. The thickness of these rocks is estimated to be in excess of 10, 000 feet. The occurrence of a few small regional anomalies in the vicinity of Wynniatt Bay and Hadley Bay suggests that in these areas, basement may approach the surface or that folded sills are abundant in the Proterozoic rocks. Field work in the summer of 1959 (Thorsteinsson, R., personal communication) located Archaean rocks outcropping near the location where the flight lines crossed the end of

Hadley Bay. Profiles in Viscount Melville Sound suggest that the Minto Arch probably does not extend very far north of the coast of Victoria Island.

A magnetic discontinuity cutting across the northeastern end of the Minto Arch suggests that beneath a thin cover of Palaeozoic strata, the eastern side of the arch is faulted with the east side down. The lower Palaeozoic rocks between the Minto and Boothia arches may thus occupy a basement graben. The thickness of these sedimentary rocks, including possible Proterozoic strata, is calculated to be in excess of 10,000 feet in the centre of the structure. The northwestern edge of the Minto Arch appears to be a gradual slope down into the deeper portion of the sedimentary basin underlying Viscount Melville Sound. The thickness of the stratigraphic section here is calculated to be in excess of 10,000 feet.

The basement on northwestern Baffin Island may be overlain by more than 10,000 feet of Proterozoic strata. The surface of the basement appears to slope gradually downward into the sedimentary basin north and west of Baffin Island. In the vicinity of Prince Regent Inlet the section may include 5,000 to 10,000 feet of lower Palaeozoic and/or Proterozoic strata, while in the vicinity of Lancaster Sound a depth to basement of over 10,000 feet is estimated. The partly faulted eastern edge of the Boothia Arch bounds this basin on its western side.

On Devon Island, a magnetic discontinuity located northwest of Maxwell Bay is interpreted as the western edge of a basement uplift. The Palaeozoic strata are observed to be essentially flat-lying on the basement east of this feature (i.e. on the interpreted uplift) but are systematically westerly dipping over the interpreted deeper basement to the west. A sharp magnetic discontinuity at the southeast corner of Devon Island (Fig. 1) suggests the presence of regional faulting. A steep linear coastline, a rapid increase in calculated depths, and a sudden increase in depth of water, support this postulated fault[1] and indicate a westerly trend. This fault may also offset the Boothia Arch. If so, the indicated relative movement is northside upward (approximately 10,000 feet in the vicinity of Devon Island) and to the west (10 to 20 miles near Bathurst Island). Such movement would also explain the unexpected appearance of basement-type, regional magnetic anomalies on Cornwallis Island and southwestern Devon Island.

In Jones Sound to the north of Devon Island, limited magnetic data suggest that eastern Devon Island may be a westerly-trending basement arch and possibly a horst.

Accordingly, the so-called Jones-Lancaster Basin (Fortier, et al., in press) may have a complex structure as it rests upon and includes fault-block structures of regional extent.

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[1]The Parry Channel lineament of Fortier, et al., (in press).

Magnetic Features of the Palaeozoic Fold Belts

The generally smooth, flat or undulating aeromagnetic profiles over the Cornwallis, Parry Islands and Central Ellesmere fold belts show that no ferromagnetic rocks are involved in the deformation, with the exception of basement uplifts in the southern part of the Cornwallis fold belt. Elsewhere in these fold belts, basement is very deep. Sporadic dyke-like anomalies suggest the presence of near-surface basic dykes or small plutons in the fold belts near the edge of the Sverdrup Basin and also in southern Bathurst Island (Fig. 2); a few basic plugs and dykes have been observed in some of these areas. There is no indication in the magnetic data of any more extensive development of extrusive or intrusive rocks in these fold belts.

Magnetic Features of the Sverdrup Basin

The Sverdrup Basin comprises Permo-Carboniferous and Mesozoic sedimentary rocks with basic intrusive and, locally, extrusive rocks. The basic rocks are especially abundant in the eastern half of the basin where a multiplicity of local anomalies (Fig. 1) from near-surface features overwhelm regional anomalies that might have allowed calculation of basement depths. While such calculations are lacking, the very smooth profiles in the more westerly parts of the basin suggest that basement is at very great depth.

Within the traversed area, the anomalies decrease in both intensity and frequency westward from Axel Heiberg Island and suggest a correlative general decrease in both igneous dyke activity and intensity of folding in the strata (which include basic sheets). Available field data indicate a correlative decrease in both content of magnetite and size of the known plutons. A relatively sharp western limit to the occurrence of these anomalies is located just west of Ellef Ringnes Island (Fig. 2). This magnetic feature probably represents the western boundary of moderate deformation and igneous dyke activity. West of this line, magnetic anomalies suggesting dyke-like bodies are absent within the basin and if such plutons are present, they occur at depths precluding their resolution. However, the widespread occurrence of basic rock sheets (probably sills) in this western part of the Sverdrup Basin is indicated by sporadic local anomalies suggestive of faulting and gentle folding of such ferromagnetic strata. The total thickness of basic rock is probably small. The presence of basic rock within the geologic section of the southwestern part of the basin is revealed by gabbro blocks brought to surface in the gypsum piercement domes on Sabine Peninsula, Melville Island.

Within the Sverdrup Basin, remarkable magnetic anomalies, with central minima and marginal maxima, are observed over known gypsum domes. These are discussed in detail in a subsequent section.

Magnetic Features of the Arctic Coastal Plain and the Continental Shelf

On the Arctic Coastal Plain, unconsolidated sediments cover bedrock, thus hiding from observation the northwestern edge of the Sverdrup Basin and the underlying rocks. Flat aeromagnetic profiles with several noteworthy dyke-like anomalies are characteristic of traverses in this area. Elsewhere in this survey, similar profiles have been observed only over a thick Proterozoic sequence or over the Parry Islands and Central Ellesmere fold belts. Over the Proterozoic rocks, however, dyke-like anomalies generally occur more frequently than they do on the Coastal Plain profiles and they are often associated with small regional anomalies. Hence by analogy to the known basic-rock occurrences, the anomalies on the profiles over the Coastal Plain are tentatively interpreted as resulting from small plutons in a structural complex similar to the Palaeozoic fold belts.

Four traverses extended over the polar Continental Shelf for a distance of about 120 miles, but none reached to the Arctic Ocean basin. In the aeromagnetic profiles, there is no evidence that basement (i.e. an igneous and metamorphic complex) occurs along the northwestern rim of the Sverdrup Basin at depths of the order of 10,000 feet or less. However, on the Continental Shelf north of Ellef Ringnes Island, probable basement occurs at a depth greater than 10,000 feet. This interpreted basement may comprise a westward extension of the Northern Ellesmere fold belt complex as it is located west of the known occurrences of these rocks on Ellesmere Island.

Aeromagnetic Anomalies over Gypsum Domes

Within the Sverdrup Basin, a number of local aeromagnetic anomalies of unique character were observed over gypsum piercement domes. These anomalies, in profile, generally have a central minimum and marginal maxima (Fig. 5). The magnitude (10 to 600 gammas) and shapes of the anomalies vary greatly with the presence and inclination of sills in the formations intruded by the gypsum. Magnetic complexity may result from dykes and large blocks of basic rock which are known to occur within some of the domes. In addition, several acres of massive magnetite occur in at least one of the domes on Axel Heiberg Island and may occur within a dome in the same general area which was traversed in this survey (Fig. 5f).

The Malloch dome on Ellef Ringnes Island intrudes and upturns strata which apparently contain little basic rock. The central minimum anomaly probably results from the diamagnetism of gypsum, and the marginal maxima may represent upturned sediments and possibly minor volcanic flows. (Blocks of pillow lava were found within this dome). The domes on the Sabine Peninsula of Melville Island are similar except that the maxima are slightly greater, probably as a consequence of upturned, relatively thin gabbro sills. Blocks of gabbro occur within these domes although no basic sills have been reported in the observed geological section.

The other gypsum domes intrude strata in which basic rock sheets are more abundant. With the exception of the South Fiord dome, the intruded strata are steeply upturned near the domes. The central minimum magnetic anomaly for these domes is markedly greater in magnitude than that expected from the diamagnetic effect of gypsum alone. In addition, it probably results from the induced negative anomaly from the lower edge of the upturned sills and/or from remanent magnetization effects in the disrupted sills. Similarly the intense maxima at the edges of the dome probably result from analogous positive-anomaly fields. In a few instances, the ferromagnetic strata appear to be upturned on only one side of a dome.

On Axel Heiberg Island, the South Fiord dome (Fig. 5g) intrudes but does not cause significant upturning of the strata which include relatively abundant flows and sills. The marked minimum anomaly is attributed to a greatly increased magnetization contrast between the gypsum and the igneous and sedimentary rocks intruded by the dome. The absence of upturned strata precludes the occurrence of intense magnetic maxima at the edge of the dome.

CONCLUSIONS

While the interpretations presented here may require some revision in view of magnetic detail subsequently obtained, these aeromagnetic data from the Canadian Arctic Archipelago unquestionably reveal the existence of magnetic contrasts of geological significance. As a corollary, we suggest that aeromagnetic surveys in this region will provide valuable assistance in defining both regional and local structures which are not only of academic interest, but also of economic importance in the search for petroleum and mineral deposits.

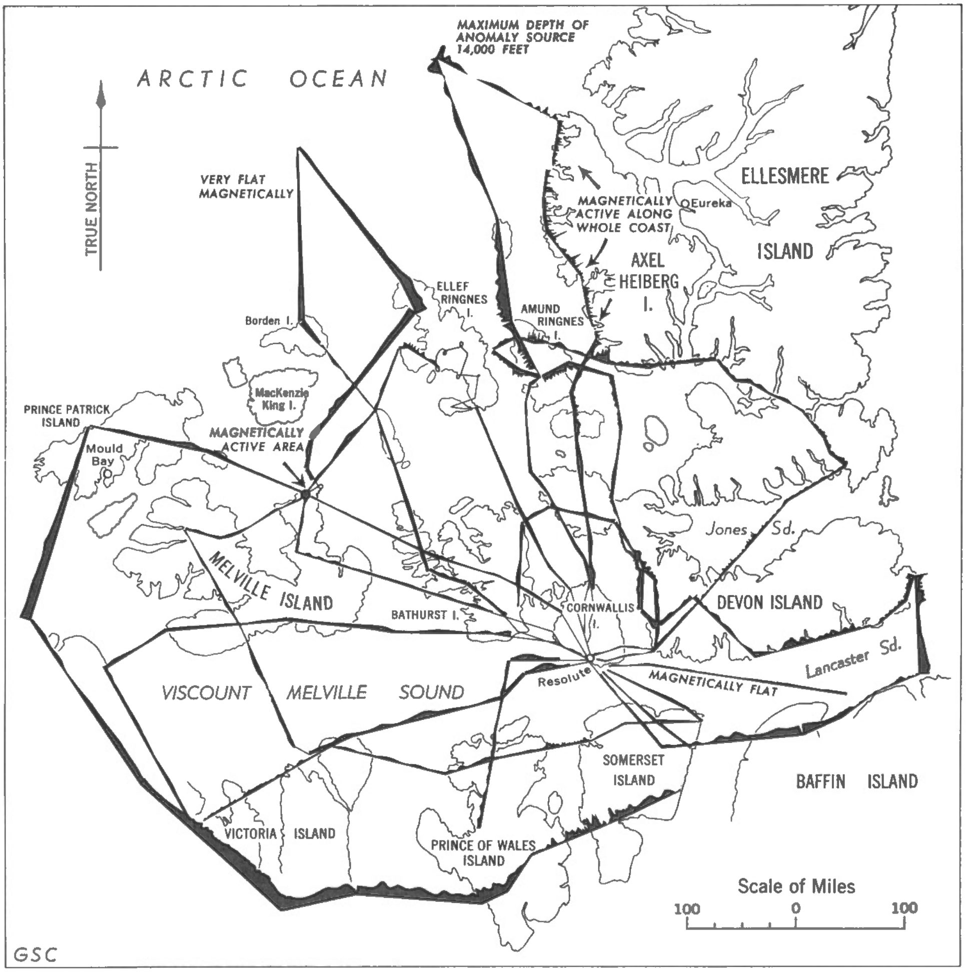

Figure 1. Location and general character of the aeromagnetic profiles (after Fortier and Morley, 1956). Magnetic intensities should not be quantitively compared as they are relative to arbitrary bases for each segment of the profile

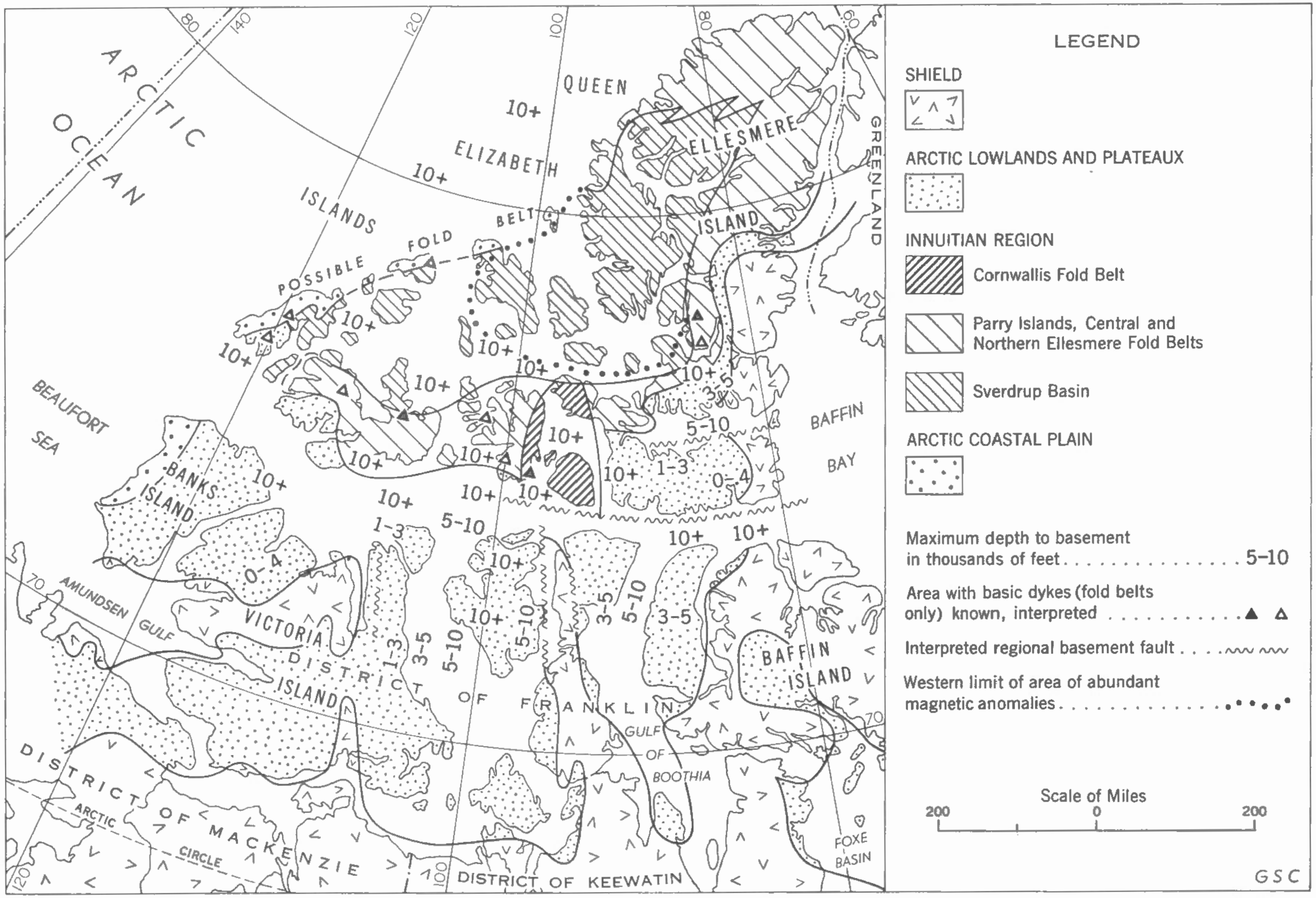

Figure 2. Geological regions and maximum depths to basement in the Arctic Archipelago

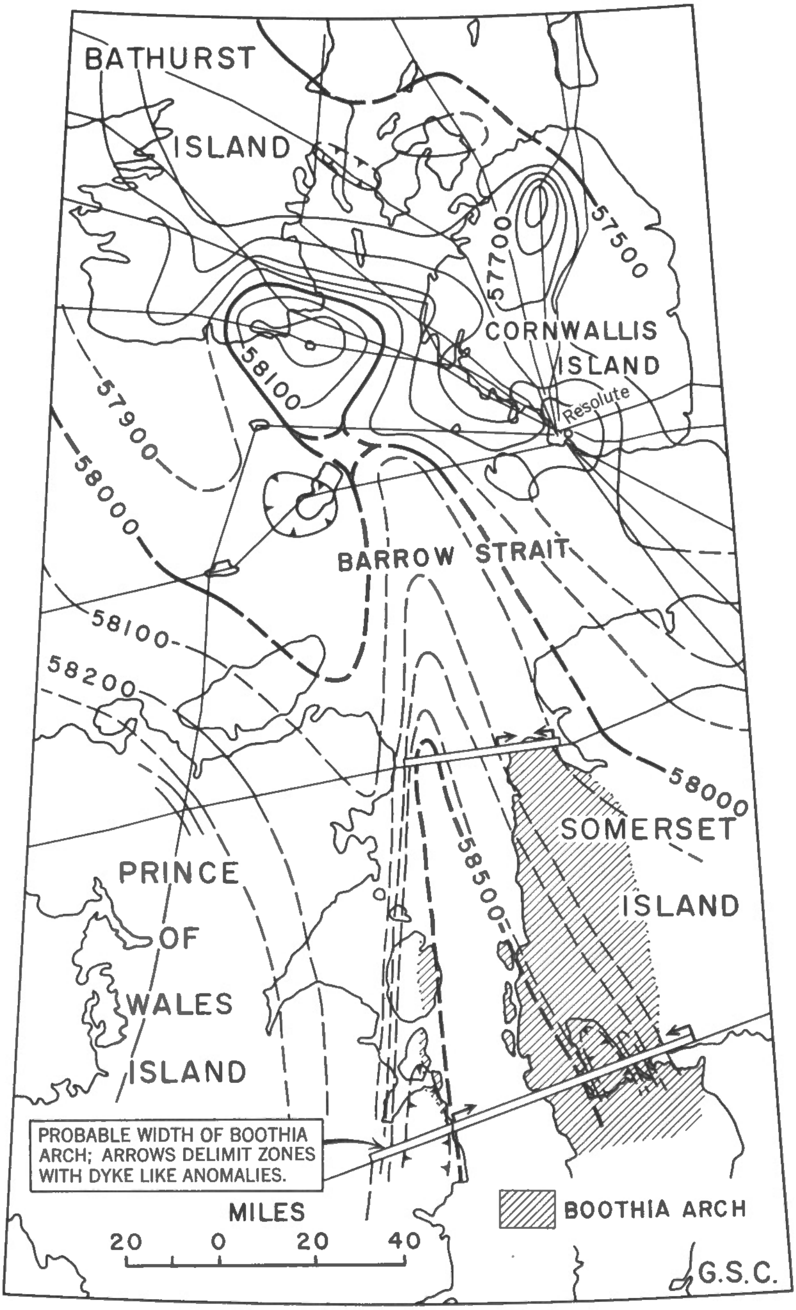

Figure 3. Aeromagnetic map of the Boothia Arch and vicinity. Because of the widely spaced control lines, generalized 100 gamma contours are portrayed

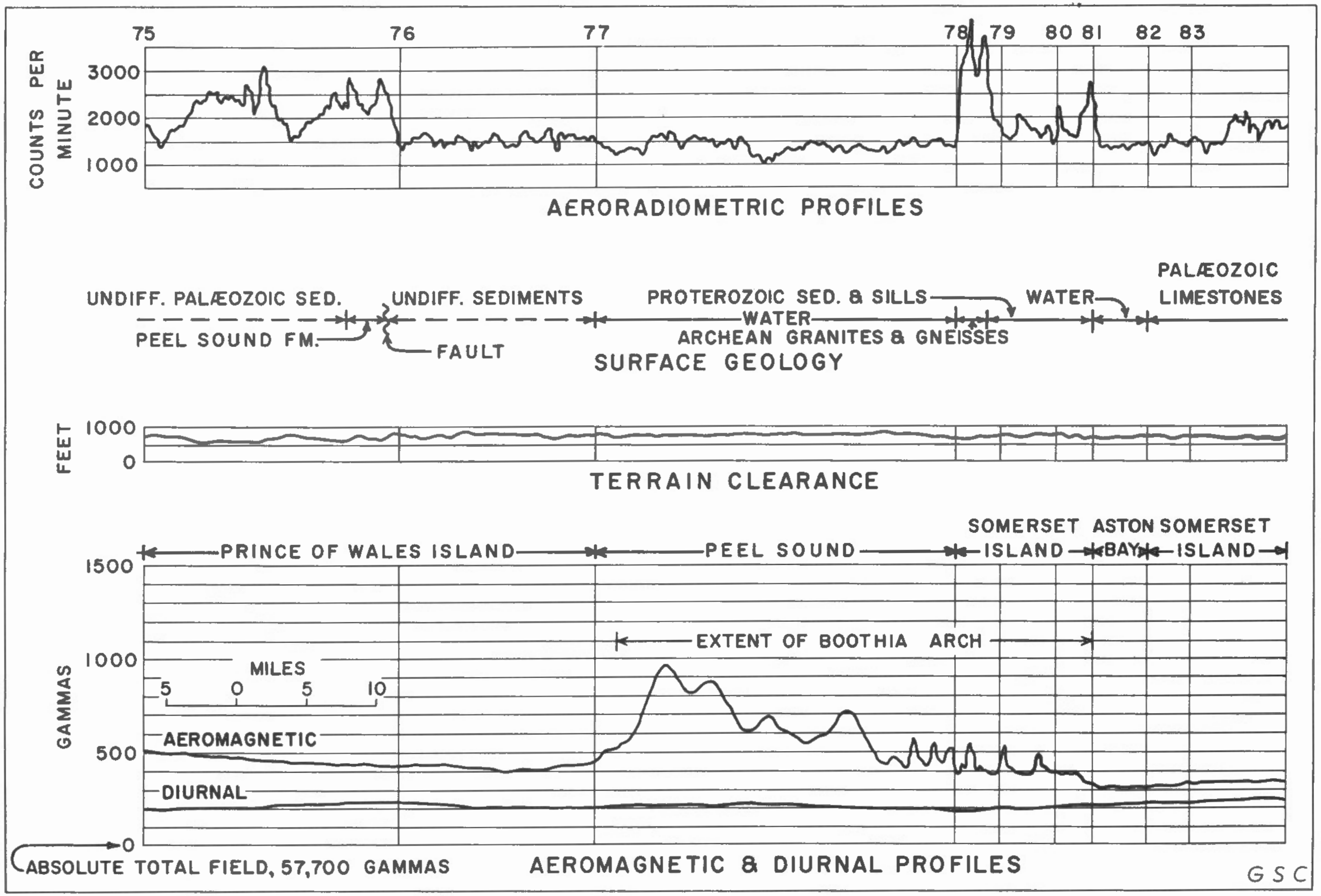

Figure 4. Geophysical profiles across the Boothia Arch. This illustration is typical of the 115 pages of profiles which were interpreted

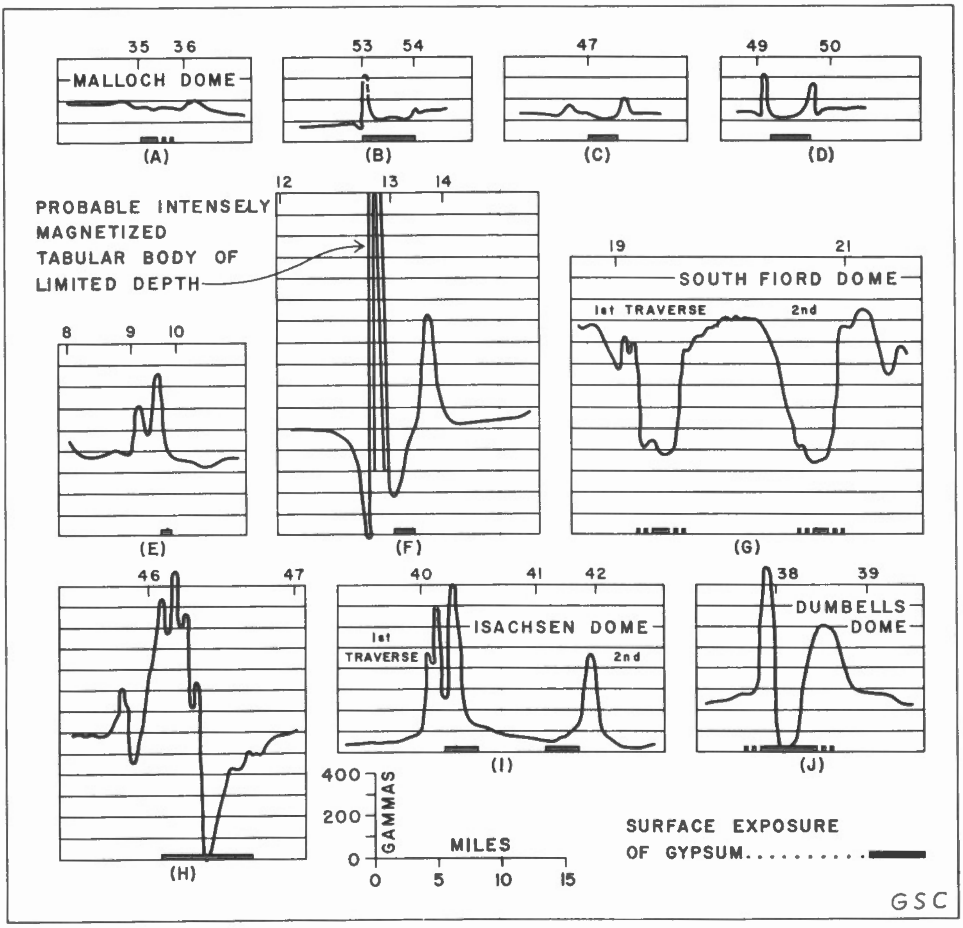

Figure 5. Aeromagnetic anomalies over gypsum domes.