32. AN ESTIMATE, BASED ON MAGNETIC INTERPRETATION, OF THE MINIMUM THICKNESS OF THE HORNBY BAY GROUP, LEITH PENINSULA, DISTRICT OF MACKENZIE

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P.H. McGrath[1] and R.S. Hildebrand
Precambrian Geology Division

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Abstract

A minimum thickness of 2 km of Hornby Bay Group northwest of Leith Ridge is deduced on the basis of magnetic modelling and upward continuation analyses of aeromagnetic profile data. The analyses are predicated on the assumption that Cleaver Diabase, which produces aeromagnetic anomalies over Great Bear Magmatic Zone and Hottah Terrane, also occurs within the basement beneath the Hornby Bay Group but with a magnetic expression masked by this group. The two analyses confirm the basic similarity of the modelling and upward continuation interpretation techniques.

Résumé

D'après l'établissement de modèles et les analyses de type ascendant de données aéromagnétiques, le groupe de Hornby Bay au nord-ouest de la crête de Leith aurait une épaisseur minimale de 2 km. Les analyses se fondent sur la supposition que la diabase de Cleaver, qui produit des anomalies aéromagnétiques au-dessus de la zone magmatique de Great Bear et du terrain de Hottah, se présente également dans le socle sous le groupe de Hornby Bay, mais que la présence de ce groupe masque son expression magnétique. Les deux analyses confirment la similarité fondamentale des méthodes d'établissement de modèles et d'interprétation de type ascendant.

INTRODUCTION

The aeromagnetic technique has been applied extensively in a reconnaissance role in petroleum exploration to determine distances below survey altitude to the upper surface of anomaly-causing magnetic sources. These distances, minus the survey elevation, often coincide with depths to crystalline basement, and as a result aeromagnetic data are employed to map variations in thickness of the overlying sedimentary section – thickness is used to mean vertical thickness above basement as opposed to stratigraphic thickness. This application of aeromagnetic technology, which is well documented by Nettleton (1976), is possible because the intensity of magnetization of sedimentary rocks is generally much less than that of crystalline rocks.

Aeromagnetic technology was utilized in a Precambrian environment by Steenland and Brod (1960) to map a portion of the Blind River Basin which contains early Proterozoic sediments deposited on an Archean basement. As with Phanerozoic sediments, no magnetic effects were detected related to the early Proterozoic sediments, which are predominantly quartzites and argillites with minor amounts of conglomerate. There are, however, extensive magnetic sources within the sedimentary section caused by basic and diabasic intrusives (Roscoe, 1956). In order to perform the analysis it was necessary to identify and eliminate this type of anomaly before the thickness of the sedimentary sequence could be determined.

In the present case, aeromagnetic anomalies produced by a dyke swarm, called Cleaver Diabase by Hoffman (1982), are used to provide an estimate of the minimum thickness of the Proterozoic Hornby Bay Group in the vicinity of Leith Peninsula at the east end of Great Bear Lake, N.W.T. Unlike the situation in the Blind River Basin where depths of the basin floor were interpreted, only a minimum estimate of thickness is possible, in that no magnetic anomalies attributable to basement are detected over the Hornby Bay Group to the northwest of Leith Ridge, and hence only the minimum thickness required to mask the dyke anomalies can be inferred, greater thicknesses being allowed by the geophysical model. The estimate was obtained using two mathematically similar interpretational procedures applied to aeromagnetic data obtained over the Great Bear Magmatic Zone, and which were digitized along a line perpendicular to the strike of the dyke swarm. One procedure involved modelling the dyke anomalies followed by the calculation of model anomaly curves at increasing altitudes above the model until the modelled dyke anomalies disappeared. In the other procedure the aeromagnetic data were incrementally continued upward until the magnetic anomalies produced by the Cleaver Diabase were lost.

The aeromagnetic data employed for the interpretation were published by the Geological Survey of Canada as Aeromagnetic Maps 8246G, 9090G, 9093G and 9106G. The survey was drape flown with a total-field magnetometer at a mean terrain clearance of 300 m by Geoterrex Limited and Northway Survey Corporation during 1976 and 1977, and the resultant data were published in map form at scales of one inch to one mile and one inch to four miles.

REGIONAL GEOLOGY

Leith Peninsula lies at the southwest corner of Great Bear Lake (Fig. 32.1). The so-called "Leith Ridge" (Balkwill, 1971) is a northeast-trending ridge of early Proterozoic rocks up to 300 m in altitude above the rest of Leith Peninsula, which is underlain mostly by flat-lying Paleozoic sedimentary rocks. The geology of the Leith Ridge has been described by Hildebrand et al. (1983, 1984), and only a brief synopsis is presented here.

The ridge is composed, for the most part, of metasedimentary and intrusive rocks of the Hottah Terrane, one of five tectonic zones of Wopmay Orogen. To the northwest, and east, Hottah Terrane is unconformably underlain by rocks of the Great Bear Magmatic Zone which comprises volcanic and plutonic rocks. Both Hottah Terrane and Great Bear Magmatic Zone were cut by northeast-trending transcurrent faults. Intrusions of Cleaver Diabase postdate the transcurrent faulting and trend about 295°.

[1] Resource Geophysics and Geochemistry Division

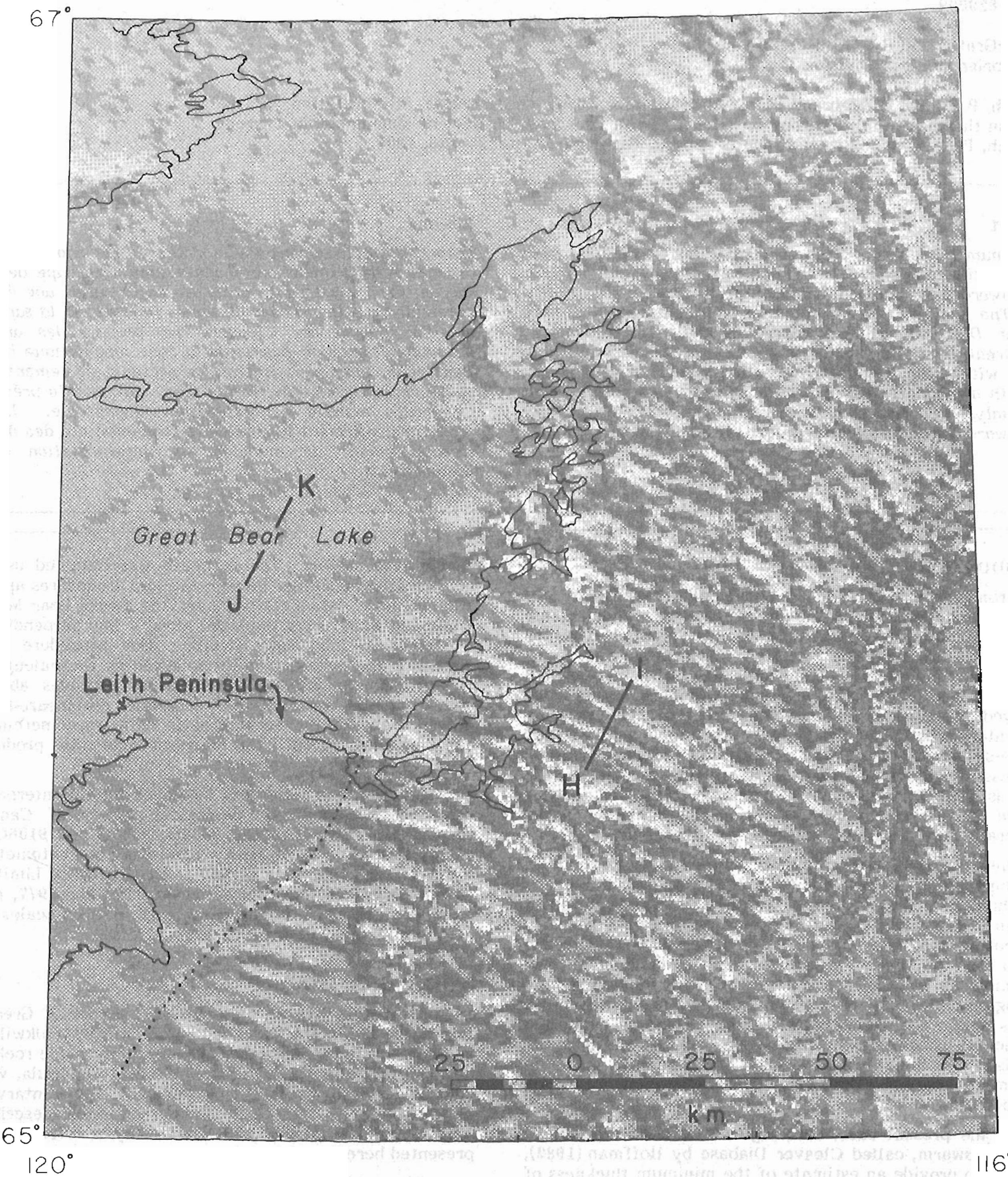

Figure 32.1. Computer-generated shaded-relief magnetic map of the Leith Peninsula area, District of Mackenzie. The original aeromagnetic data were drape flown at a 300 m terrain clearance along E-W flight lines spaced 800 m apart, and the resultant aeromagnetic maps were digitized at an 812.8 m interval. To enhance the Cleaver Diabase magnetic anomalies, the digitized aeromagnetic data were illuminated using a sun azimuth of 025° and an inclination of 40° above the horizontal. The Cleaver Diabase is represented by the strong linear features which strike 295° and are transected, in part, by line HI. Line HI is situated over Great Bear Magmatic Zone and line JK is along strike of the Cleaver Diabase but over the Hornby Bay Group. The dotted line represents the trace of northeast-trending normal faults bounding the northwest side of Leith Ridge.

On Leith Ridge (see Fig. 31.1 of Hildebrand et al., 1984) rocks of the Hottah Terrane, cut by Cleaver Diabase, are unconformably overlain by about 30 m of nearly flat-lying Hornby Bay Group. The Hornby Bay Group is capped by thin gabbro sheets that cause no, or only slight, magnetic anomalies. The northwestern side of Leith Ridge is bounded by northeast-trending, northwest-side-down normal faults of post-Hornby Bay Group age which place rocks of the Hornby Bay Group against rocks of the Hottah Terrane. In sections northwest of the faults the sub-Hornby unconformity is never seen. Thus a complete section of Hornby Bay Group is not exposed and its thickness is unknown. Because the unconformity at the base of the Hornby Bay Group has been a target for uranium exploration, and may be so again in the future, it is important to know the thickness of the sedimentary sequence. For example, how deep will exploratory drilling have to go in order to encounter the unconformity and any associated mineralization? The normal faults along the east side of the ridge are part of a much larger set of post-Hornby Bay Group extensional features found along the western and northern margins of Wopmay Orogen (Kerans et al., 1981).

On the aeromagnetic maps Cleaver Diabase dykes have conspicuous magnetic anomalies (Fig. 32.1) trending 295°. The dykes and their associated anomalies are for the most part abruptly truncated by the northeast-trending normal faults bounding the northwest side of Leith Ridge (dotted line, Fig. 32.1).

We do not see the basement to the Hornby Bay Group west of the normal faults. Thus, we have no way of knowing whether or not rocks of the Hottah Terrane or Cleaver Diabase continue west of the fault. For example, a major change in basement type across the faults might be responsible for the disappearance, or change in width, of the dykes. Therefore, this analysis is predicated on the assumption that dykes of Cleaver Diabase cut basement beneath the Hornby Bay Group west of the normal faults. If the dykes do in fact exist beneath the Hornby Bay Group west of the faults, then it could be possible that Hornby Bay weathering has affected their magnetic signature. However, this is not likely to be the cause of the disappearance of the magnetic anomalies because the depth of weathering beneath the Hornby Bay is limited to within 10 or 15 m of the unconformity (Hildebrand et al., 1983), and because Cleaver Diabase dykes found unconformably beneath Hornby Bay Group on Leith Ridge, immediately adjacent to the faults, have associated anomalies. Thus, we consider that the magnetic anomalies disappear because they are cut by the normal faults and now lie beneath sufficient Hornby Bay Group to mask the magnetic signature of the dykes.

THE GEOPHYSICAL PROBLEM

Dykes of Cleaver Diabase produce magnetic anomalies with amplitudes of <10 to 300 nanoteslas (1 gamma = 1 nT). The dyke anomalies, which strike approximately 295°, appear as linear magnetic highs on total-field magnetic anomaly maps. Their presence is obscured somewhat by magnetic anomalies caused by larger geological bodies; hence, in order to enhance the dyke anomalies, a shaded-relief map was generated from a derived set of aeromagnetic data which were digitized at an interval of 812.8 m for the 1 to 1 million Coloured Magnetic Map Series (Teskey et al., 1982). The aeromagnetic data were illuminated artificially with a sun azimuth of 025° and a sum inclination of 40° above the horizon. The shaded-relief method is described by Horn and Bachman (1978), and the appropriate software was provided by D.J. Teskey of the GSC (Dods et al., in press). The resultant data were plotted by an Applicon Colour Plotter and are reproduced in Figure 32.1 in grey tones. In this presentation the Cleaver dyke swarm is represented by the strong linear features which trend 295°.

The line HI in Figure 32.1 is situated over the Great Bear Magmatic Zone, whereas line JK is over rocks of the Hornby Bay Group now buried beneath Great Bear Lake. Aeromagnetic map data along these two lines were digitized at 190 and 380 m intervals respectively, and the regional graident defined by the International Geomagnetic Reference Field, DGRF 1976.5 (IAGA Division 1 Working Group 1, 1981), was subtracted from each profile. The resultant data, minus the mean value of each profile, are illustrated in Figure 32.2. Note the complete lack of identifiable dyke anomalies on line JK as contrasted with line HI. By modelling, and by upward continuation of the data on line HI, the minimum thickness of Hornby Bay strata required to produce a profile similar to JK was calculated.

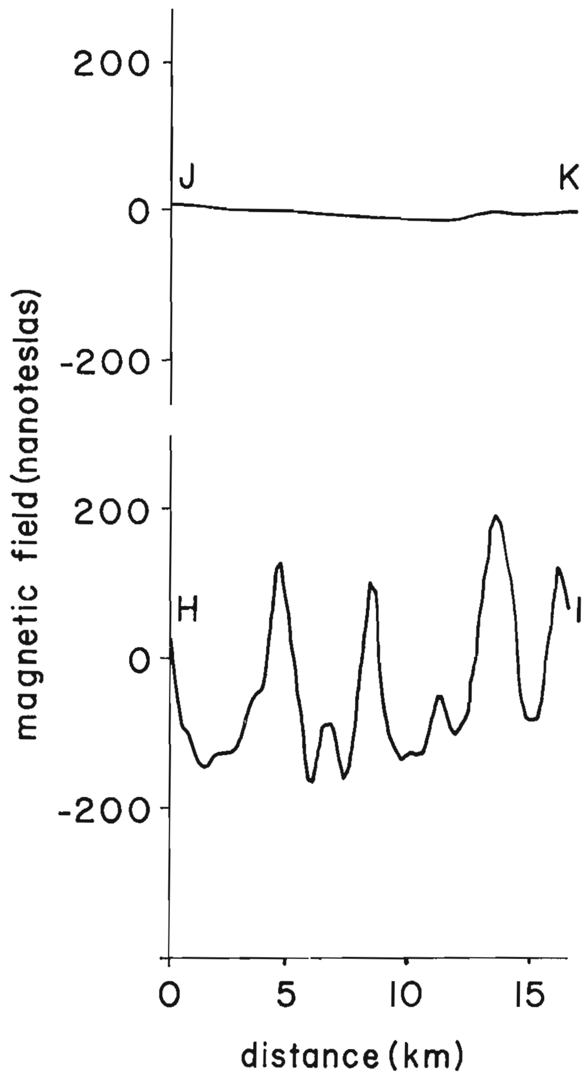

Figure 32.2. *Aeromagnetic data along lines HI and JK, which were digitized at 190 and 380 m intervals respectively on one inch to one mile aeromagnetic maps published by the GSC. A regional magnetic field represented by the Definitive Geomagnetic Reference Field for 1976.5 was subtracted from the digitized data, as was the mean value of the resultant data. The spike-like magnetic anomalies along profile HI have amplitudes from 50 to 300 nT, and are related to Cleaver Diabase which cut the Great Bear Magmatic Zone. To the northwest, profile JK is orthogonal to the 295° strike of Cleaver Diabase, and shows the lack of magnetic anomalies over the Hornby Bay Group.*

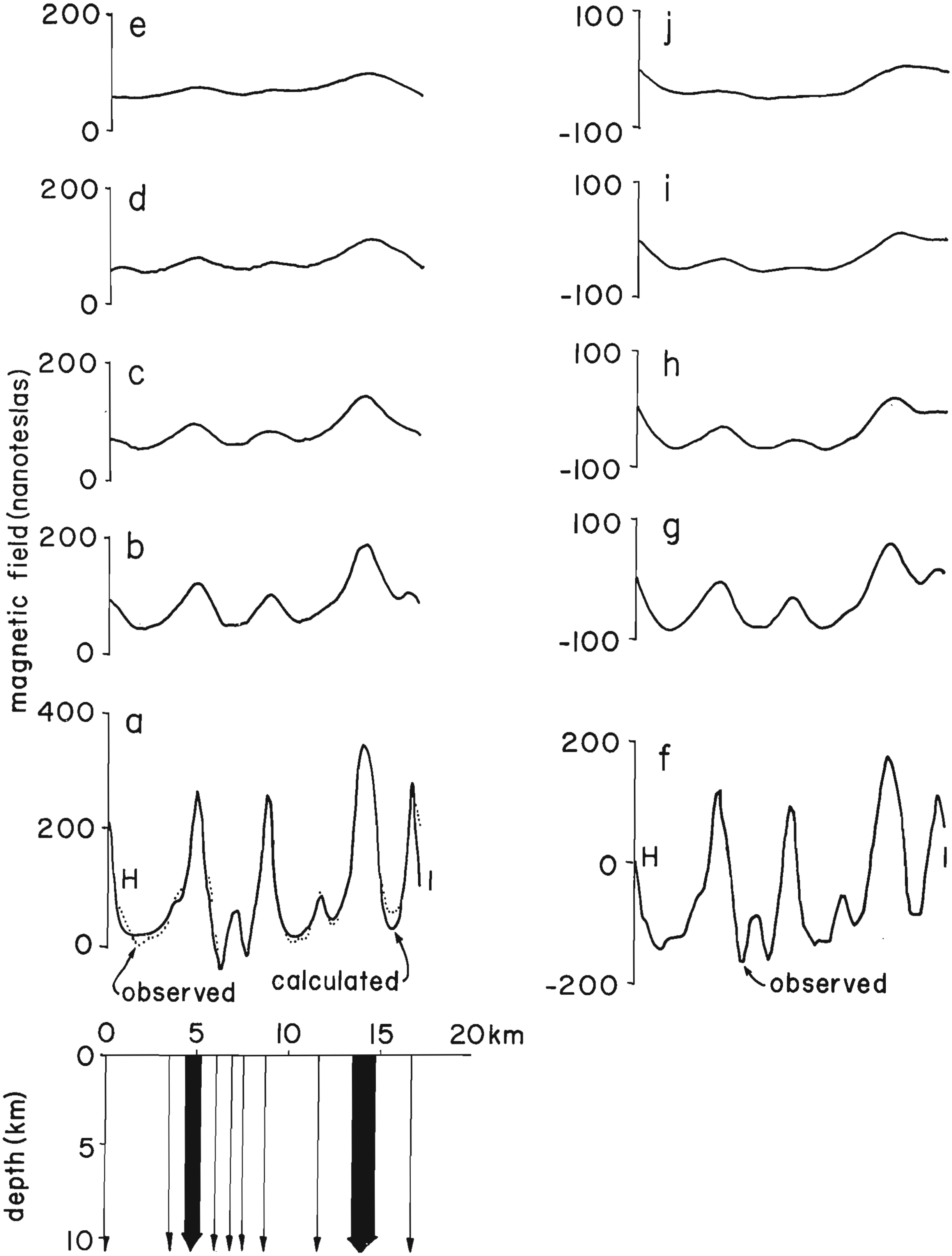

Figure 32.3. *Illustration of the results of modelling on the left, and of upward continuation on the right.*

The digitized observed magnetic profile along line HI is shown as a dotted line in Figure 32.3a and solid line in Figure 32.3f.

The calculated model profile (solid line, Figure 32.3a) was generated for a 300 m elevation from the interpreted model dykes illustrated immediately below Figure 32.3a.

Figures 32.3b-e show the magnetic field at elevations of 1.0, 1.5, 2.0 and 2.5 km above, and generated by, the same model dykes.

Figure 32.3g-j show the upward continued versions of profile 32.3f at elevations of 1.0, 1.5, 2.0, and 2.5 km respectively.

MAGNETIC MODELLING METHOD

The digitized aeromagnetic map data along profile HI (Fig. 32.1, 32.2) were modelled using a procedure described by McGrath et al. (1983). To perform the analysis, it was assumed that the Cleaver Diabase dykes were magnetized uniformly, and that it was necessary to consider only magnetization contrasts between the dykes and the surrounding country rock.

Main geomagnetic field parameters in the Great Bear Lake area were obtained from I, D and F maps of Canada for 1970 published by the Earth Physics Branch. A field declination of 039°, an inclination of 82.5°, and a field intensity of 59700 nT were used in the interpretation.

Ten two-dimensional tabular bodies were used to represent Cleaver Diabase dykes (Fig. 32.3a). No ground control for the dykes along profile HI was available for the interpretation. Hence, the causative bodies were assumed to be vertical, and except for two models, were arbitrarily assigned a thickness of 30 m, which is typical of Cleaver Diabase. Thicknesses of 800 and 1200 m were necessary to model the anomalies situated at 5 and 14 km along profile HI. The greater thicknesses of these two bodies probably reflects zones of two or more closely spaced (< flight elevation) dykes. All of the dykes were assumed to be magnetized by induction, except the two bodies at 6 and 7.5 km, which were assumed to be reversely magnetized because of associated negative anomalies. The intensity of magnetization of the dykes was assumed to be variable. This is not a critical assumption since, neglecting the two thick dyke models, it is only the product of dyke thickness with intensity of magnetization which can be resolved. Excluding the 800 and 1200 m thick bodies, it would be equally valid to assume a constant intensity of magnetization with variable dyke thickness, while using the same thickness-magnetization products of the various models.

A model anomaly profile was calcualted at the flight elevation of 300 m, and is shown in Figure 32.3a by the solid line. A base level adjustment of 180 nanoteslas was added to the aeromagnetic data (dotted line, Fig. 3a) in order to bring the original observed data along profile HI (Fig. 2) into agreement with the calculated profile in a least squares sense.

Figures 32.3b, c, d and e illustrate derived anomaly profiles at elevations of 1.0, 1.5, 2.0, and 2.5 km above ground level respectively, which were generated from the same model data used to calculate the model data shown in Figure 32.3a. In comparing these profiles with the observed profile JK (Fig. 32.2), it would appear that at least 2 km of Hornby Bay Group would be required to mask the Cleaver Diabase aeromagnetic anomalies. In this analysis we have assumed that the dykes are of large vertical extent (>1.5 km from a mathematical viewpoint). Given dykes of limited depth extent would result in a more rapid decay in the amplitudes of the calculated anomaly profile with increasing elevation than is shown in Figure 32.3b-e. However, this would seem to be an unlikely scenario.

In applying the modelling technique the possible contribution of remanent magnetization has been ignored. Measurements of remanent intensities by Strangway (1965) for Archean dykes in Ontario and Quebec indicate that remanent magnetization can make a significant contribution to the shape of the resultant magnetic anomaly. However Gay (1963) showed that the depth of a thin dyke may be determined independently from its direction of magnetization, and hence also independently of anomaly shape changes resulting from remanence effects. It is unlikely therefore that remanent magnetization would play a significant role in the present analysis other than for the two reversely magnetized models.

UPWARD CONTINUATION METHOD

The transformation of the magnetic field into what the field would be at another elevation is rather easily achieved in the spectral frequency domain (Gunn, 1975). By taking the Fourier transform of the magnetic field, the frequency domain representation of the field is obtained. Multiplying the various Fourier coefficients by $e^{2\pi h(u^2+v^2)^{\frac{1}{2}}}$ and performing an inverse Fourier transform on the modified coefficients yields the magnetic field which would exist at level h above or below the original observed field – h is negative for upward continuation and u and v are spatial frequencies.

In the present application it is assumed that the field was produced by two-dimensional sources which strike perpendicular to the profile HI (Fig. 32.1, 32.2, 32.3a, f). In order to obtain a better estimate of the spectral content of profile HI, the profile was arbitrarily extended by twelve points at each end of the profile using the Burg prediction operator (Anderson, 1974), and further extended to a total length of 2000 points with zeros (Henry and Graefe, 1971). The Fourier transform of the extended profile and the subsequent inverse Fourier transform of the modified Fourier coefficients were obtained using the discrete fast Fourier transform computer software provided by Grenner (1968) which is based on the method of Cooley and Tukey (1965). The Fourier coefficients were multiplied by $e^{2\pi hu}$, since v = 0 in this case. The resultant profiles at elevations of 1.0, 1.5, 2.0, and 2.5 km above ground level are illustrated in Figure 32.3g, h, i, and j respectively. Again in comparing these results with profile JK (Fig. 32.2), it would appear that at least 2 km of Hornby Bay Group are required to mask the magnetic anomalies generated by the Cleaver Diabase.

DISCUSSION OF RESULTS

The two estimates of a minimum thickness of 2 km of Hornby Bay Group required to mask the magnetic expression of Cleaver Diabase yielded by the modelling and by the upward continuation techniques are mutually consistent, and confirm the basic similarity of the two interpretation techniques. Conceptually, the modelling method is easier to understand, however, many more assumptions are required in its application. The upward continuation method as applied here only requires that the sources be two-dimensional, and thus it must be considered a more objective method. The central portion of the profiles obtained at a given elevation, using both the modelling and upward continuation techniques, are very similar although significant differences occur within 3 km of either end of the profiles. This end effect probably results from the fact that in applying the discrete fast Fourier transform, frequency components which are longer than the data profile are poorly resolved, hence some problem with the upward continuation method could be anticipated. In all other respects the two methods yield very similar results.

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