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GEOMAGNETIC REPORT

GEOMAGNETIC SURVEYS AT SKELETON LAKE, ONTARIO

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ABSTRACT

Magnetic and electrical surveys have been carried out at a near-circular structure which may be of meteoritic impact origin. This Paleozoic structure is located at Skeleton Lake, Ont. Data obtained by the multi-discipline approach have added to the available information and have provided some evidence in favour of meteoritic formation at this site. Contour maps showing total magnetic intensity over the feature exhibit low gradients of magnetic change typical of some meteorite craters. Analysis of the data has helped evaluate the several geophysical surveying techniques employed as to their usefulness and feasibility in the on-going investigations of this feature, and the model obtained from the analysis indicates it to be a typical example of a 'simple' meteorite crater, with a diameter of about 3.4 km and a depth to undisturbed bedrock of about 750 m.

RESUME

Des levés magnétiques et électriques ont été effectués sur une structure circulaire qui peut être causée par l'impact de météorites. Ce structure Paleozoic se trouve au lac Skeleton (Ontario). Les données obtenues grâce à cette approche pluridisciplinaire ont permis d'ajouter aux renseignements déjà disponibles et ont fourni certains indices qui penchent en faveur d'une formation météorique au Skeleton Lake. Des cartes de courbes illustrant les intensités magnétiques totales au-dessus de ces éléments ont été dessinées et indiquent de faibles gradients de changements magnétiques qui ont une caractéristique typique pour certaines cratères de météorites. L'analyse des données a permis l'évaluation de l'utilité des diverses techniques de levés géophysiques employées dans le cadre de l'étude continue de cette structure et d'autres éléments géologiques semblables. L'étude de la structure du lac Skeleton révèle qu'il s'agit d'un exemple typique d'un cratère météorique simple, 3.4 km en diamètre et d'une profondeur de 750 m.

I INTRODUCTION

Meteorite craters have certain characteristics which have been described by Beals (1957, 1960) Innes (1957) Beals et al (1963) Halliday and Griffin (1963, 1966, 1967) Dence (1964) and reviewed historically by Baldwin (1978). In Canada over 100 features have been identified as having some of these characteristics, such as circular or near-circular form, gravity and magnetic anomalies and crater-like depressions either surficially or sub-surface. In past years the Earth Physics Branch has conducted geophysical surveys at Skeleton Lake, Ont. to attempt to assess its origin and to add to the knowledge of its physical characteristics. Recent observations and theory are reviewed by Waddington and Dence (1979) and Grieve and Robertson (1979), who have classified the Skeleton Lake structure as a possible impact site.

Twenty-four of the many structures in Canada which have received consideration as meteoritic impact sites have been shown to contain definitive evidence of shock metamorphism to establish their impact origin. Six more (of which Skeleton Lake is one) exhibit some geologic and geophysical characteristics supportive of such an origin, but lack the definitive evidence of shock effects. The purpose of this study is to ascertain whether the magnetic and electrical characteristics can be outlined in detail at Skeleton Lake to prove useful as acceptable supportive evidence in favour of the impact hypothesis where shock metamorphism features are not visible. Skeleton Lake crater is located at Lat. 45°15'N, Long. 79°27'W, and has an estimated diameter of 3.4 km. Total force magnetic surveys, electromagnetic soundings and gravimetric surveys have been carried out at this site. This article reviews the investigations; the different survey techniques are explained and evaluated with a view to future use at other sites for evidence of causation.

II GEOLOGY AND PHYSIOGRAPHY

Skeleton Lake

Bedrock formations are of Precambrian age, principally granitic and migmatic gneisses, amphibolite and basic intrusive types. A geological map compiled by Hewitt (1967) identifies veined, banded and homogeneous grey migmatitic gneiss produced by injection and granitization of various metamorphic types, (Fig. 1). The rocks are mainly upper amphibolite and granulite metamorphic facies, exposed on the cliffs of Skeleton Bay, and around the south shore of Skeleton Lake as outcrops. In the latter area one obtains absolute values of total magnetic intensity greater than normal, suggesting the presence of magnetite and perhaps pyrrhotite. The strong glaciation in Pleistocene times has left glacial till, moraines and deposits of sand and gravel, which are quarried in the area, for example at Nutt Lake, 1.5 km south of Skeleton Bay. Many Ordovician pebbles are found here in the gravel, implying a covered outlier of Ordovician limestone sediments which were originally extant over the Skeleton Lake depression and have been partially removed and re-deposited by the southerly moving Keewatin ice sheet.

There is a pronounced synclinal axis trending NW to SE, beginning north of the Lake and bending a little to the west south of the Lake, with the appearance there of highly folded gneissic structures. Briefly, the lake is entirely surrounded by crystalline rocks, mostly hornblende migmatites moderately to strongly granitized, with breccias in the shoreline outcrops similar to those at Brent (Robertson and Grieve, 1975).

One can observe a surface expression of the geological trend lines and outcropping on the aerial photos of the district, with at least one metasedimentary occurrence emerging about 1 km northwest of Tomelin Bluffs, see Fig. 2 for location, and extending a distance of 3 km to the NW (Fig. 1). A surficial ellipse 200 m wide is clearly visible. Strike of foliation is S.E. with dips ranging from 70° to 20° down, generally to the N.E. Skeleton Lake has a mean elevation of 280 m above m.s.l. and drains into Rosseau Lake, through the Muskoka lakes system and then into Georgian Bay, Lake Huron; it has only a few streams which are unrelated to the general drainage pattern, i.e. the morphology of the lake and its environs is anomalous. For the large scale geology of this part of Grenville province see Douglas (1969).

The curved nature of the glacial grooves is noticeable on the topographic map of the area coinciding with the strike of foliation, see map reference, N.T.S., Dept. EMR, 1:250,000 Series, 31 E/SW Muskoka. The impact hypothesis for this structure is discussed by Waddington and Dence (1979), who point out its similarity to Lake Wanapitei although it is of Paleozoic age.

III DESCRIPTION OF GEOPHYSICAL METHODS

Total Magnetic force survey (F)

A Sanders MK II proton precession magnetometer and a Barringer GM-102B magnetometer were used for the surveys. Both instruments have a resolution of ± 1 nT, (1 nT = 10^{-5} Gauss). Observations were made at equal distances along a profile line or in a grid pattern. Regional gradients were then removed and profiles plotted, or a contour map constructed. The pattern obtained enables one to model the feature in a general way. From the lateral gradients of change in F assumptions can be made of the depth to basement, or source of magnetic anomalies, as described by Heiland (1946). Comparisons made between ground and aeromagnetic surveys provide additional useful information, (Zietz and Henderson 1949). A modified form of this method has been utilized by Sander et al (1964) at the Deep Bay crater, and by Andrieux and Clark (1969) at Holleford.

The total force observations were taken at Skeleton Lake along the tracks of an airborne survey projected downwards to the surface, Fig. 2.

E.M. methods (VLF)

An Apex double-dipole EM unit supplied by Apex Parametrics, Ltd., was used for reconnaissance traverses. A Geonics Ltd., EM-16 VLF unit was used for more detailed surveys at Skeleton Lake, and in addition, a Scopas SE-80 VLF receiver (Scintrex Ltd.) was utilized to investigate electrical conductivity.

The search for mineralized deposits containing base metals has led to the development of the surface and airborne electromagnetic systems beginning over a decade ago. Instruments operating in the VLF range have been manufactured and described by Geonics (1972) Apex (1973), and interpretation is discussed by Geonics (1972) Ronka (1972) Becker (1967, 1968, 1970) and Paterson (1970). For surface work, E.M. waves are generated by transmitters in the 15-25 kHz band and broadcast from stations throughout the world. A portable receiver is then used to monitor these signals and determine how they are affected by the ground beneath the observer. There is a secondary or induced field created which is directly proportional to the specific electrical conductivity, see Serson (1973). From variations in strength, amplitude and phase of signal on the receiver one may be able to infer a model of the body being surveyed, location of geological faults, contact zones and general level of electrical conductivity. The method is described by Jakosky (1957), Paterson and Ronka (1971) Barringer and McNeill (1970) and Taylor (1973). Depth penetration of only about 400 m is attainable with this equipment at present.

IV SURVEY PROCEDURES AND OBSERVATIONS

Skeleton Lake EM survey and Magnetic Surveys

Electromagnetic measurements were taken along the same tracks as the total force readings, and are plotted, Fig. 2, with these tracks as baselines. Surface e.m. data only were available; an airborne e.m. survey would be desirable. The electrical properties at Skeleton Lake are shown in Fig. 2 as vertical phase measurements. The e.m. profiles are uniformly low over the centre, rising to higher values at the rim where one is closer to altered rock. The surface drainage pattern supports a hypothesis of a highly conductive ionized solution entering the fracture zone and percolating outwards to the limit of the zone. This would affect the electrical conductivity outside the central crater basin beyond the rim, and the results are compatible with this hypothesis.

Observations of total magnetic intensity were made with a Sanders proton precession magnetometer with a specified resolution of ±1 nT. Diurnal variation measurements were made at a base station and corrections applied for time of observations. Reference was made to Agincourt magnetic observatory (160 km S) and to the Ottawa magnetic observatory (240 km E) for magnetic disturbance corrections. A Barringer magnetometer was also used at the base station.

Observations (about 50) in 1968 were mainly for reconnaissance and establishment of a reference station. Updated to 1970.0 the base datum of a station on land near Skeleton Bay is F = 58,711 nT. Diurnal variation was found to be very low, owing to the fairly low magnetic latitude; 20 nT for quiet days and about 40 nT on disturbed days. The records of F at Ottawa Observatory (Blackburn) showed no great disturbances during times of the observations although sunspots were near a cyclical maximum. During the 1969 field season 200 observations were taken at 200 metre intervals along the tracks of the airborne magnetometer survey carried out for the Geological Survey of Canada in 1953. A magnetic field contour map has been derived from the published GSC maps (Fig. 3), showing the central low and higher gradients beyond this low.

A 14 foot non-magnetic Peterborough boat was employed to obtain the measurements on the lake with the instruments placed as far away as possible from the small magnetic influence of a 5 H.P. outboard motor. The surface profiles obtained have been compared to the aeromagnetic data which were updated from the 1953 survey to the same epoch (1970.0). Profiles start and end near lakeshore, see Fig. 2. After reduction of surface data the aeromagnetic values of total field were subtracted from the surface values to obtain residuals which are plotted in Fig. 4.

An inspection of the residual profiles reveals magnetic signatures which are much more distinctive than those visible in a comparison of the surface and aeromagnetic profiles of the total field. Over the centre of the crater, where the usual source of magnetization (crystalline rock) is remote from both surface and airborne magnetometers, the resultant residuals are small. The magnetic field measured by the airborne instrument is only 25 nT less than that at the surface. Near the edges of the crater, and outside of it, the source of magnetism is much closer to the surface magnetometer than to the airborne system, consequently there is a greater difference (125 nT) between the two surveys, with larger residuals. This effect is most noticeable along lines 3, 4 and 5 which are mostly over the crater. The maximum residuals near the 'rim' and beyond it are greater than the minima in the centre by a factor of 5:1 ,on the average.

This is qualitative evidence in favour of a cavity (now filled with sediments and breccias) of considerable depth in the centre and becoming shallower in a nearly concentric pattern as one proceeds from the centre to the rim. Lines 1 and 6 are presumed to be outside the crater. An estimate of the average diameter has been made from topographic and bathymetric surveys -- 3.4 km at the surface. No diamond-drill hole data are available yet. Further details of field procedure and correction of data are given by Clark (1981).

V INTERPRETATION

To interpret these data one first considers the impact hypothesis. The impact of an 'iron' or 'stone' meteorite on the earth's surface creates a hemispherical cavity with a large volume of crushed and metamorphosed rock, including some melt-rock directly beneath the area of impact. The original magnetization may be partially nullified. One expects the integrated effect to be a reduction of the absolute strength of the total magnetic field with the space above the zone having shallower gradients of magnetic change both horizontally and vertically than previously extant. When this is found to be true it is evidence in a qualitative way favourable to an impact creation hypothesis, although it does not rule out other mechanisms (Innes, 1961, 1964) and Dence et al. (1977). The filling in of the basin by sedimentary rocks would change the magnetic pattern over the area somewhat, and could change the apparent gravitational anomaly appreciably because of substitution of less dense rocks for the original country rock. The residual Bouguer gravity negative anomaly is about 3 milligals in the centre of the crater and an analysis of the magnetic data over Skeleton Lake does in fact show a negative magnetic anomaly of 300 nT as compared with the surrounding region. The gradients of change in the magnetic field are lower over the central portion of the Lake than they are around much of the environs, Fig. 3.

A rough estimate of the depth of magnetic bodies can be derived from intercomparisons of surface and airborne magnetic surveys as described by Vacquier et al. (1963). However, over the Skeleton Lake crater there is no suitable anomaly to analyze in this way, indeed there is no positive anomaly at all inside the margins of the crater. Another way of obtaining a model is possible using the three dimensional computer program of Talwani (1965) as shown by Coles and Clark (1978). However, since this feature has a negative anomaly, owing to a deficiency of ferromagnetism, an inverse approach is required. One first calculates several probable amounts of the volume of material displaced, assuming a hemispheroidal cavity of diameter 3.4 km and for depth estimates of 0.5 km and greater up to 1.0 km. The volume ($2/3 \pi r^3$) may be equalled by constructing several hexagonal prisms of appropriate thickness and dimensions which will also simulate the morphology. One then enters the value of magnetic susceptibility, the magnetic field strength and other required parameters in the program. (Four profiles have been scaled from the aeromagnetic map to secure the residual total field data.) For this computation these profiles have been selected in a different orientation than those shown in Fig. 2, in order to have lines orthogonal to the regional field; the position of the tracks is shown in Fig. 5. One hundred data points were scaled and tabulated; the computer program calculates theoretical profiles and probable errors from the effect these values have when designated to the prisms one has constructed. The shape and dimension of the model is adjusted, within the known constraints, and iteration is continued, until a minimum probable error and best fit is obtained. One then has achieved an effect equal (and opposite) to the observed negative anomaly and the model is drawn as shown in Fig. 6. This model agrees quite well with the one derived by Waddington and Dence using rock density contrasts and gravity data. We have, in effect, secured a model of the dimensions of a body with certain properties which would compensate for the negative magnetic anomaly over the crater if placed within it.

This model has a mean absolute error of 145 nT as calculated in the computer program. One can show the fit in another way by plotting the theoretical values of total field residuals at grid points and contouring these. This has been done and the resultant map is shown, Fig. 7, converted to the same baseline as Fig. 3. The correspondence is quite good in the centre, corroborating the thickness of model chosen. Discrepancies show up in a few localized areas especially around the edge of the crater. This is to be expected since we are not modelling the surrounding regional field with its anomalies and linearities derived from the igneous rocks, and this area is virtually unaffected by the computations.

With Talwani's program one is not able to model the transition from sediments to breccia since both are very weakly magnetic. However from known geology it is reasonable to infer about 100 m of post-Paleozoic age (<450 m.y.) consolidated sediments underlying an average 50 m lake water; below the sediments would be 600 m of breccias underlain by several hundred m of fractured rock above the crystalline Precambrian basement.

The shape of the original cavity appears to have been somewhat shallower than a hemispheroidal or parabolic figure and the model shown in cross-section, Fig. 6, has a depth:diameter ratio of 1:4.2. This is not surprising since the size of the crater is nearing the transition zone from simple to complex form when the depth:diameter ratio becomes lower.

VI ACKNOWLEDGEMENTS

P.B. Robertson gave a valuable critique with helpful comments. R.L. Coles offered useful advice, and E. Dawson and L.R. Newitt assisted in organizing the material. P.H. Serson and E.R. Niblett have reviewed and revised the manuscript. E.D. Waddington and M.R. Dence kindly gave permission to include their aeromagnetic field map of Skeleton Lake. Gratitude is extended to the operator of the Word Processing machine and to the Drafting Office and Photo Unit, EPB.

FIGURE CAPTIONS

Fig. 1. Geological Sketch of Skeleton Lake area, after Hewitt (1967).

Fig. 2. Position of tracks of flight lines and surface surveys at Skeleton Lake; circle is hypothetical rim of crater; e.m. profiles plotted with tracks as baselines.

Fig. 3. Aeromagnetic field over Skeleton Lake and its environs, derived from maps published by the Geological Survey of Canada.

Fig. 4. Residuals of magnetic total intensity (Surface-Aeromag.) over Skeleton Lake area along profiles shown in Fig. 2.

Fig. 5. Tracks of profiles chosen for modelling program. Field values are scaled at 0.5 km intervals.

Fig. 6. Model of Skeleton Lake crater which compensates for the negative anomaly. F is total field, I is inclination, k is the magnetic susceptibility assigned to body. Cross-section line A-A' is located in Fig. 5.

Fig. 7. The magnetic field anomaly contour map obtained by the computer program adjusted to the same datum as Fig. 3 for comparison with it. The contour interval is 100 nT.

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VIII EPILOGUE: Origin of the name Skeleton Lake

The lake had been given a name by the Indians familiar with this region in the Muskoka district of Ontario. Early surveyors (1872) heard of it as 'Paqua-sa-ca-cun' or 'Pasqua-sa-ca-tun'. Ojibeway dialect scholars translate this to mean 'Waters-of-the-rolling hills' or 'Lake-in-the green lands'. There is no connection with any fossilized skeletal remains of archeological or modern biological life. Local inhabitants, over many years, have corrupted part of the original name to a somewhat ominous sounding 'ska-le-tun'.

Surprisingly, the Canadian Geographical Board officially approved the place-name only 30 years ago (1951) having confirmed it was not in use elsewhere on any major geographical feature. Although derivation remains a conundrum it is perhaps unimportant compared to the cosmic event which created this ancient astrobleme which is presently a tranquil and picturesque summer resort area.

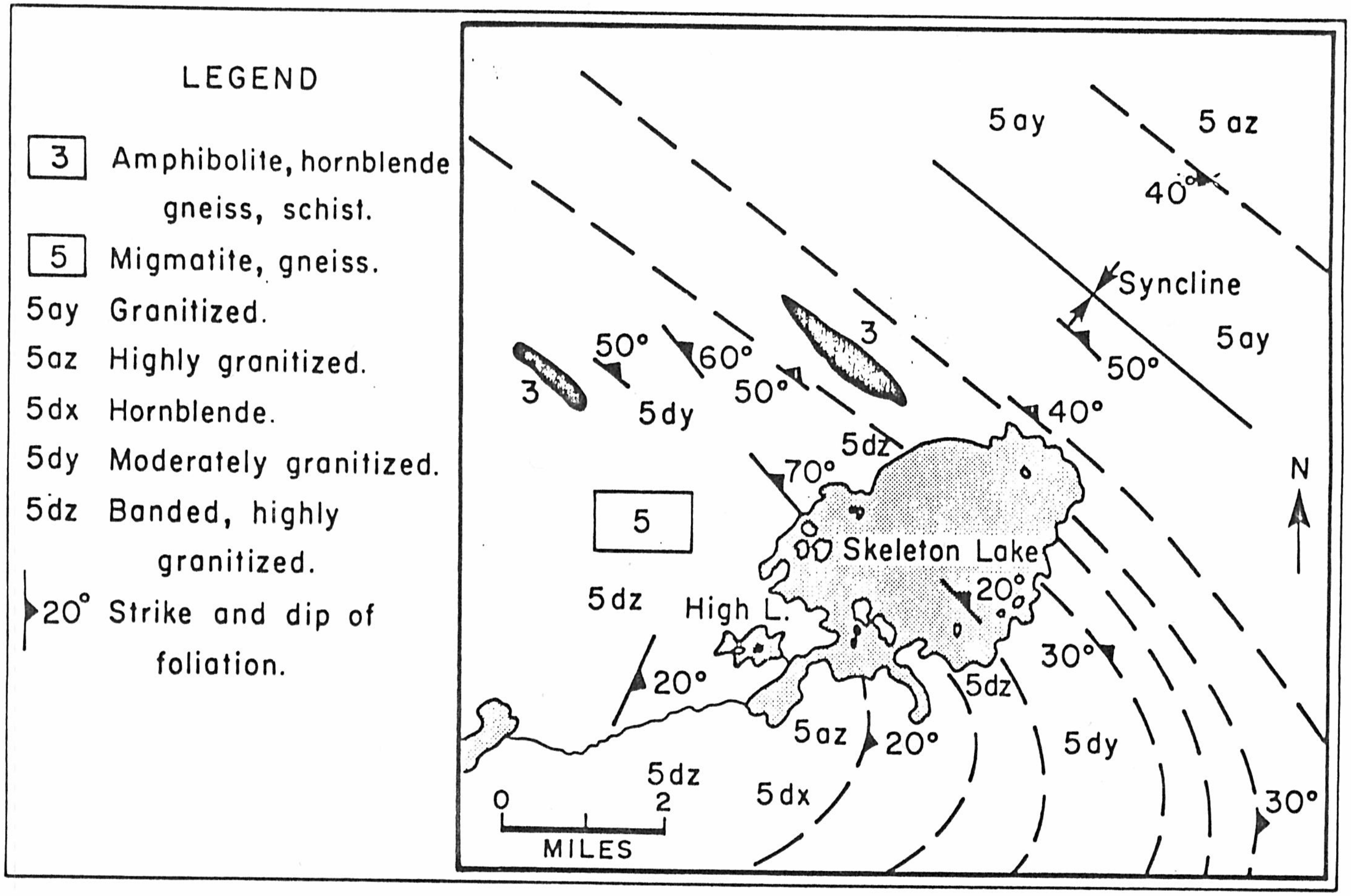

Fig. 1 Geological Sketch of Skeleton Lake area, after Hewitt (1967).

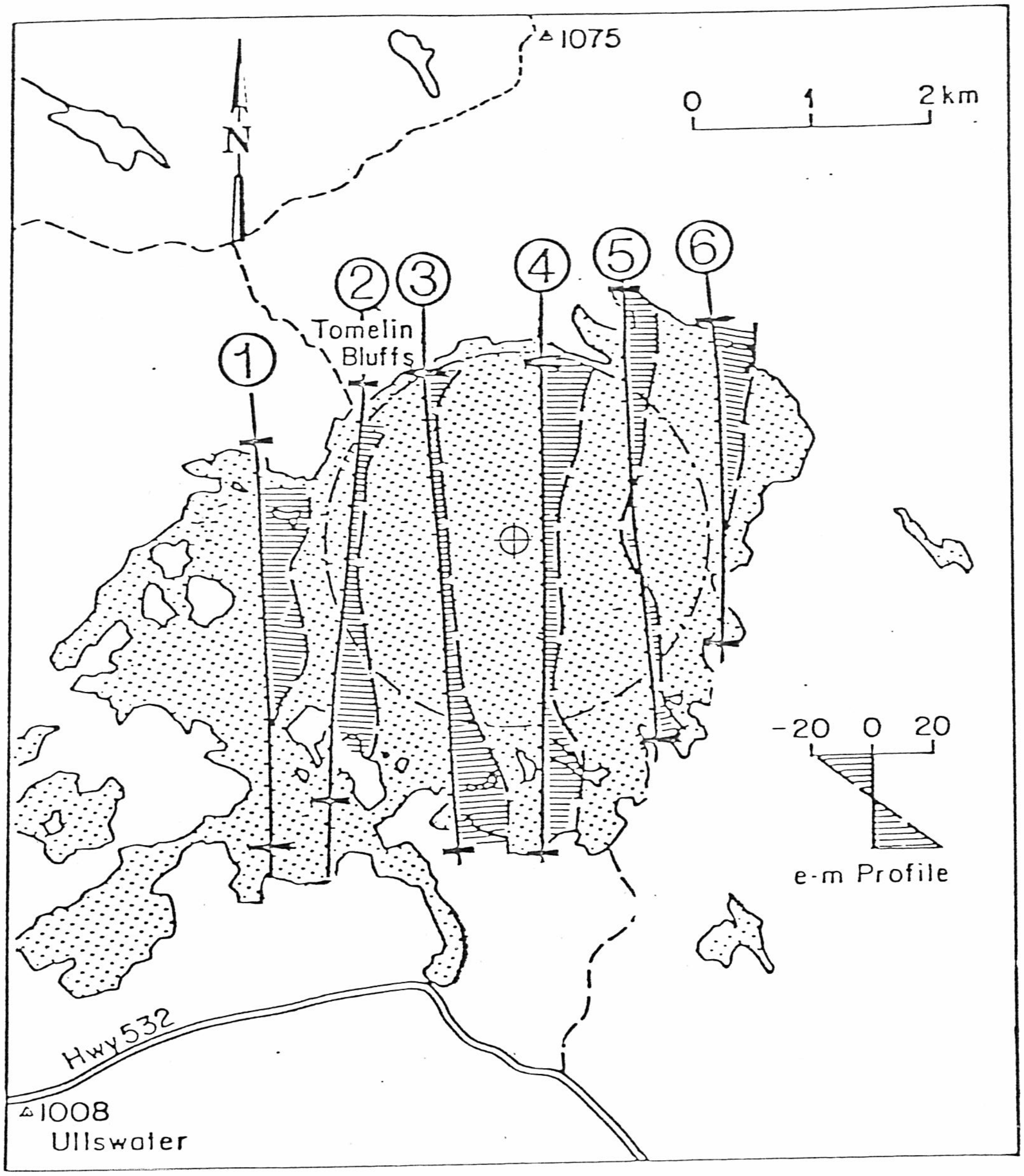

Fig. 2. Position of tracks of flight lines and surface surveys at Skeleton Lake; circle is hypothetical rim of crater; e.m. profiles plotted with tracks as baselines. Bars on tracks show length of profiles plotted in ..—— Fig. 4. The elevation for Ullswater is shewn in feet above mean sea level datum. Skeleton Lake is 920 feet [280m] above m.s.l.,North American Datum,1927.

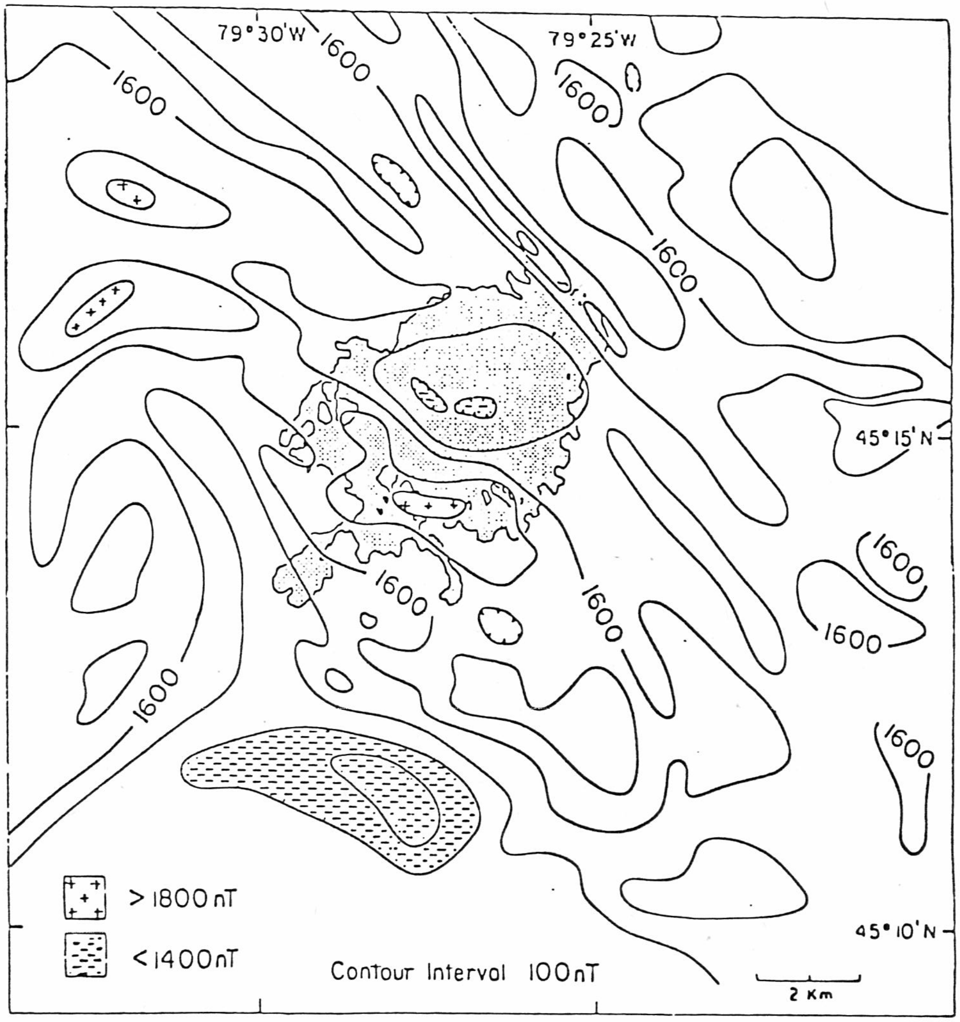

Fig. 3. Aeromagnetic field over Skeleton Lake and its environs, derived from maps published by the Geological Survey of Canada.

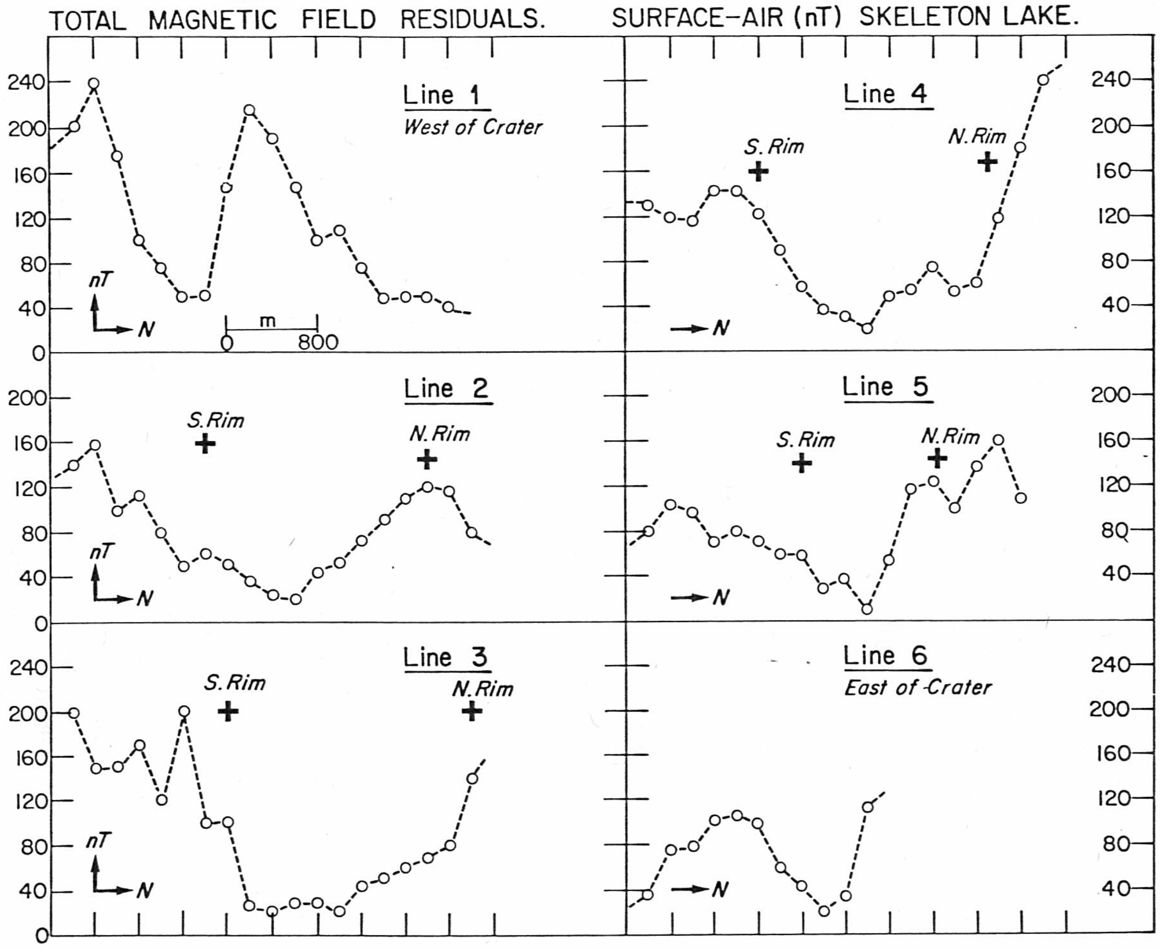

Fig. 4. Residuals of magnetic total intensity (Surface-Aeromag.) over Skeleton Lake area along profiles shown in Fig. 2.

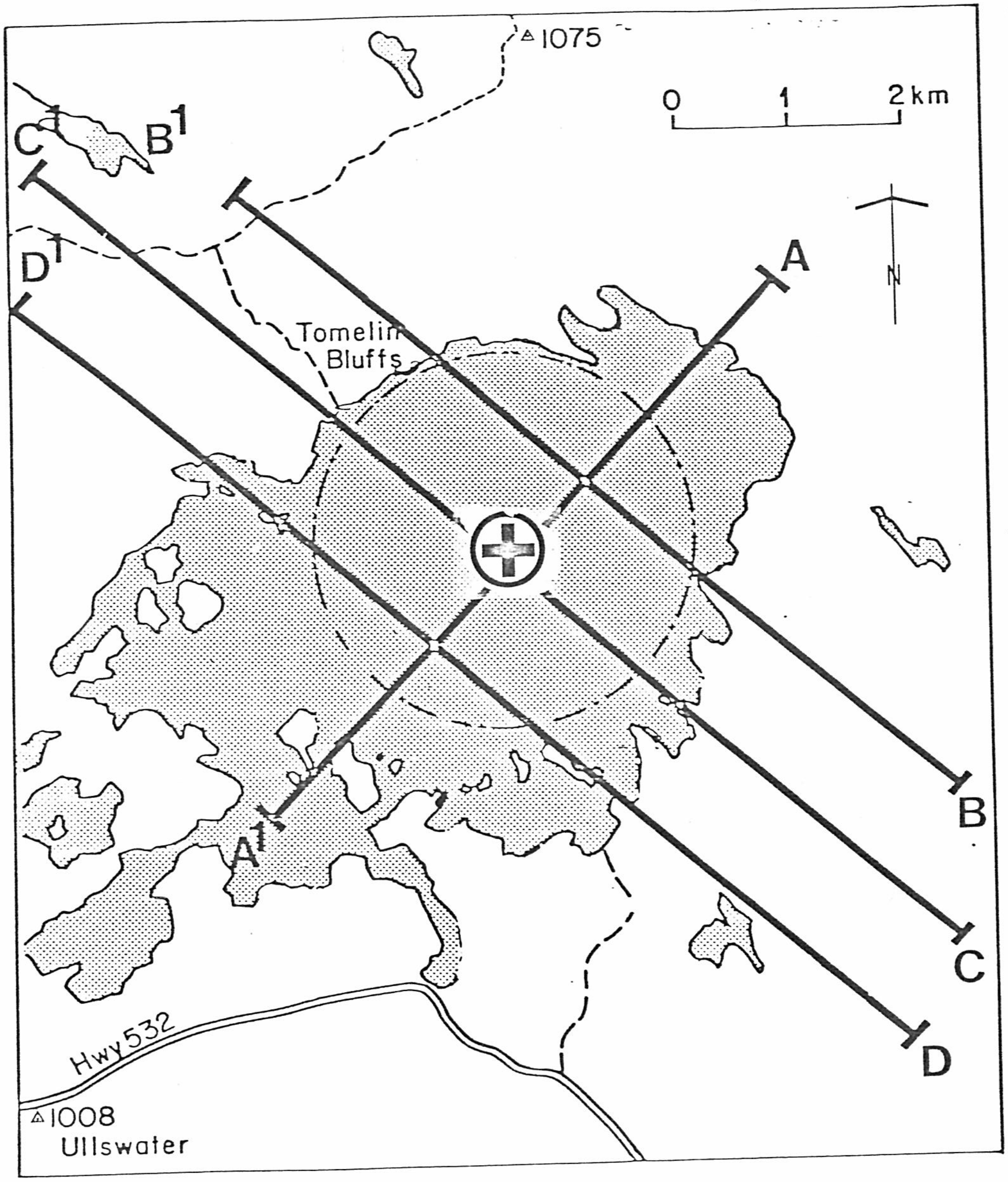

Fig.5. Tracks of profiles chosen for modelling program. Field values are scaled at 0.5 km. intervals.

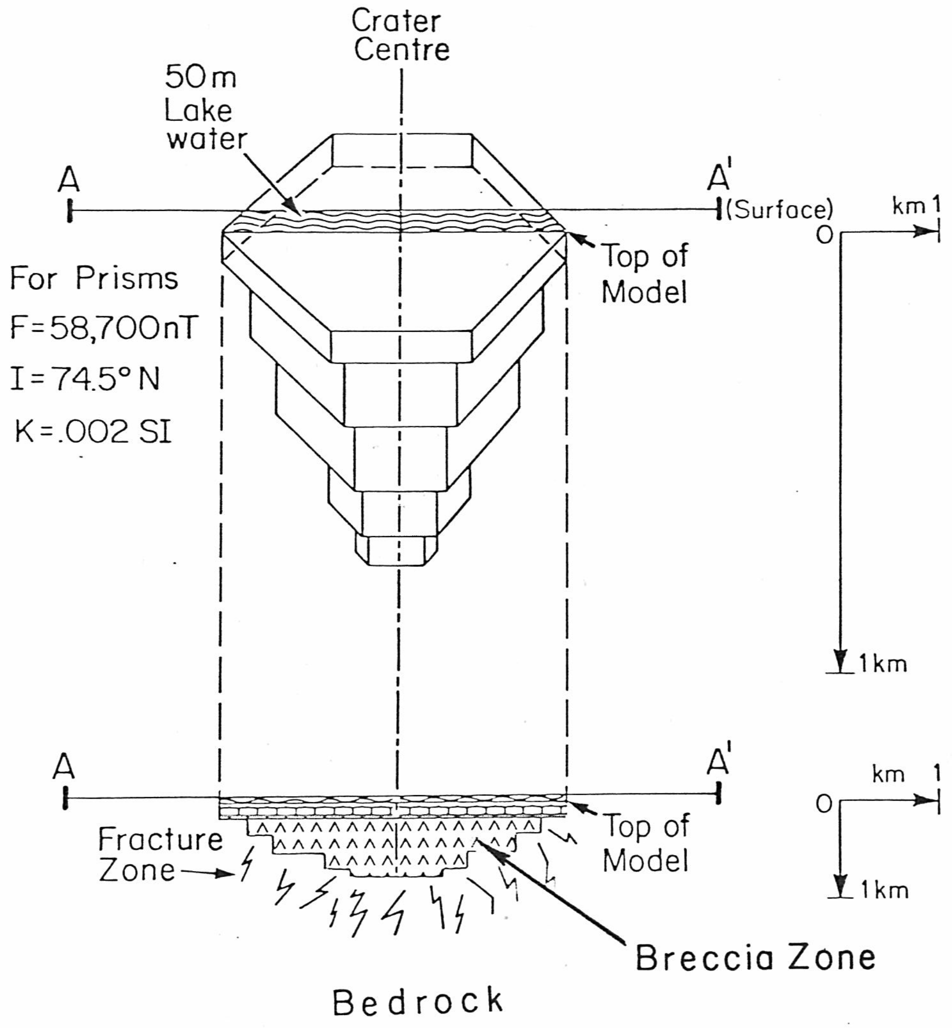

Fig. 6 Model of Skeleton Lake crater which compensates for the negative anomaly. F is total field, I is inclination, k is the magnetic susceptibility assigned to body. Cross-section line A-A' is located in Fig.5.

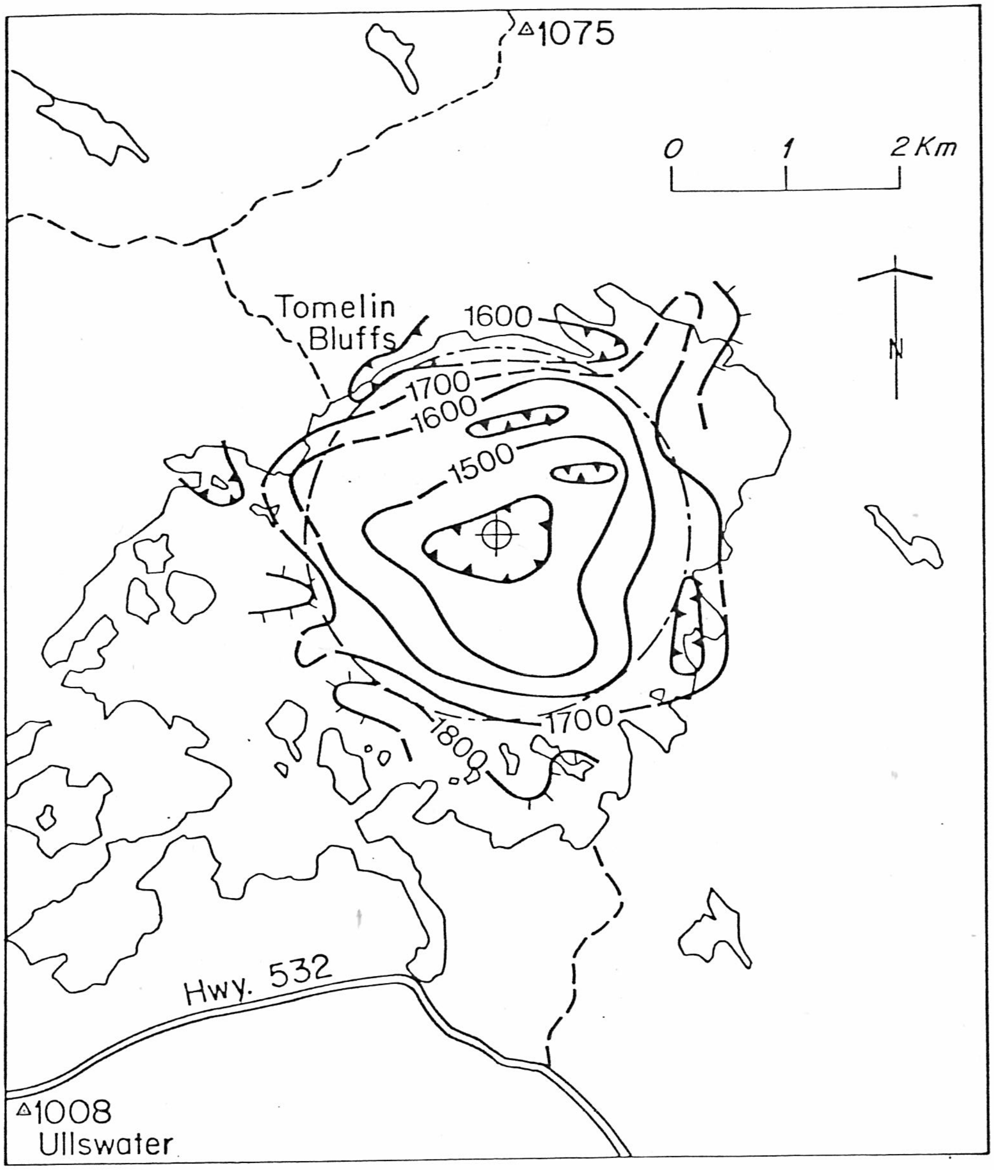

Fig.7. The magnetic field anomaly contour map obtained by the computer program adjusted to the same datum as Fig. 3 for comparison with it. The contour interval is 100 nT.

Appendix I

ROCK DENSITIES - SKELETON LAKE, ONTARIO

Sample No.	Density (g/cm^3)
1	2.80
2	2.65
3A	3.12
3B	2.83
3C	2.63
4A	2.92
4B	2.74
5A	2.62
6	2.65
7	2.83
8A	2.61
8B	2.89
9	2.69
10	2.87
11	2.66
12	2.67
13	2.67
14A	2.60
14B	2.59
15	3.08
16	2,76
17	2.62
18	2,80
19	2.72
20A	2.77
20B	2.78
21	2.76
22	3.14
23	2.72
24	2.73
25A	2.66
25B	2.62
26	2.68
27	2.65
28	2.74
29	2.74
30	2.68
31	3.04
32	2.68
33	2.62
34	2.66
35	2.64
36	2.69
37	3.00

Sample No.	Density
100	2.76
101B	2.71
102	2.75
103	2.71
104	2.67
105A	2.94
105B	2.56
105C	2.59
106	2.61
107A	2.62
107B	2.61
107C	2.54
107D	2.54
108A	2.63
108C	2.79
109B	2.57
110A	2.59
111A	2.62
112	2.57

Sample No.	Density
200A	2.66
200B	2.67
202A	2.65
202B	2.70
202C	2.77
203A	2.59
203B	2.69
204A	2.55
204B	2.73
205A	2.67
205B	2.54
205C	2.68
205D	2.53
206	2.68
207	2.65
208	2.68
209	2.66
210A	2.61
210B	2.65
210C	2.53
211	2.60
212A	2.71
212B	2.62
212C	2.65

Rene Wirthlin has measured densities on 87 samples from Skeleton Lake. I have not had a chance to identify them lithologically, but the numbers are probably reliable and should be useful. The 44 regional samples (localities 1 to 37) give a mean of 2.75 g/cm^3. There may be four (4) groups clustered around 2.62, 2.67, 2.75 and 3.0 g/cm^3, the last group having a large deviation.