CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Geological Survey of Canada

ATHABASCA FORMATION BASIN:
GRADIOMETER FEASIBILITY STUDY

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OPEN FILE 494

Ottawa

1977

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INTRODUCTION

This open file contains data obtained with the Geological Survey of Canada's Queenair inboard vertical gradiometer system over a portion of the Athabasca Formation basin in northern Saskatchewan. The purpose of the survey was to assess the value of future gradiometer surveys in the southern fringe areas of this basin. The area surveyed was a long narrow strip from longitude 104°30' and latitude 57°15' to longitude 106°00' and latitude 58°30'. Eight parallel traverse lines with a 450 metre separation were flown at an altitude of 150 metres above ground level, plus additional control lines. This data was collected during the summer of 1976 as a small project incorporated into the ferry flight from Ottawa, Ontario to Victoria, B.C.

The survey was strictly of a reconnaissance nature; no ground control stations were employed; the equipment had some malfunctions during the survey; and the flying conditions (turbulence) were not ideal. The flight line spacing was too great to allow the data to be contoured and therefore the information is presented as profiles. It is also unfortunate that recent or adequate geological maps are not available for the Precambrian basement of this area.

It must be stressed that the survey was of a reconnaissance nature and that these data do not meet specifications for standard publication. Lack of ground control and excessive noise levels dictates that the data be used only in a qualitative way.

A regional setting for the study area is presented as background material for the interpretation of the vertical gradiometer survey data.

REGIONAL SETTING

The general geology basically consists of Precambrian basement overlain by the Athabasca Formation. The northern portion of the survey area is underlain by the Athabasca Formation which was mapped by Fahrig (1961) and more recently Ramaekers (1975, 1976) worked on the eastern edge of the Athabasca Formation. Fahrig (1961) indicates from paleo-current studies that the Athabasca Formation was deposited in a basin with a fairly consistent west-facing paleoslope. The present Athabasca Formation configuration differs from this shape and the relative thicknesses appear to be controlled to a large degree by post-Athabasca events (Hobson and MacAulay, 1969; Kornik, 1970). Relative movements between adjacent fault bounded blocks appear to be the mechanism controlling the present configuration of the southeastern portion of the Athabasca Formation. Sibbald (1976) shows the influence of post-Athabasca faulting on the Rabbit Lake orebody. Ramaekers (1976) states that considerable evidence of faulting and crustal movement is present along the northeast edge of the Athabasca Formation. There is therefore considerable evidence that post-Athabasca Formation faulting and crustal movements are important factors in determining the present configuration of the Athabasca Formation.

Federal-Provincial aeromagnetic maps of the basin were studied to determine the regional structural setting of the southeastern fringe of the Athabasca Formation in the vicinity of the 1976 gradiometer survey. These maps indicate that the main geological units in the Precambrian basement as deduced from their magnetic expression are reflected in the Athabasca basement topography. Aeromagnetic data indicates that a shelf-like area covered with a thin (less than 300 metres) cover of Athabasca Formation occurs in the southeast corner of the basin (Figure 1). This area of thinner cover is shaded in Figure 1. Aeromagnetic lineaments interpreted from the federal-provincial aeromagnetic maps are shown in Figure 1. These aeromagnetic lineaments which are interpreted to be major faults or fault zones are represented as dashed lines. Faults or major joints mapped by Ray (1975, 1976) are represented as solid lines on Figure 1.

Three major sets of faults are present and interpretable from the aeromagnetic maps. A set of northeast faults and shears which parallel the main geological trends is dominant and establishes the fabric in the area.

A set of northwest faults is present which disrupts the earlier northeast trends. A third late set of north-south sheared faults is present which appears to cut all other structural features. Although these three sets of faults were in all probability present before the deposition of the Athabasca Formation, it would appear that some of these faults were again active after the basin filling as some of these faults appear to be controlling or influencing the configuration of the present Athabasca basin.

The area of interpreted thinner Athabasca Formation has a linear northern boundary which may be due to a northeast strike fault. Many of the northwest and particularly the late north-south faults interpreted from the aeromagnetic data affect the underlying Precambrian rocks and in all likelihood many also disrupt the Athabasca Formation too.

The southern portion of the study area (NTS 74 H) is underlain by Precambrian rocks which also extend under the Athabasca Formation. Money (1968) places these underlying Precambrian basement rocks in the Wollaston Lake fold-belt system. A correlation of the interpretation of Lewry and Sibbald (1975) in the adjoining area to the southwest to the federal-provincial aeromagnetic data and an extension of their domains suggests a three-fold subdivision of the study area. The southeast corner of this study area is part of the Rottenstone domain (Lewry and Sibbald, 1975) and is separated from the central Wollaston domain by the Needle Falls shear zone. The northwest half of the study area occurs in the extension of the Mudjatik domain. These domains are considered crustal subdivisions which display distinct lithological and/or structural character (Lewry and Sibbald, 1975).

These three domains are recognizable geologically and aeromagnetically, however the aeromagnetic maps suggest that further correlations and subdivisions are possible within the Wollaston and Mudjatik domains in the study area. The extensive drift cover seriously hampers geological mapping but has minimal effect on the aeromagnetic data. Aeromagnetic data, therefore should be utilized to its fullest extent and in fact can be used to extend the geology across under the Athabasca Formation.

The Wollaston domain is dominated by rocks with strong magnetic relief in part of and to the south and north of the study area (see aeromagnetic maps 7017G, 7153G, 7156G, 7157G, 7289G. However in the study area (74 H) the strongly magnetic rocks in the Wollaston domain become less magnetic northward along their structural trend.

These rocks change from strongly magnetic, through moderately magnetic, into essentially non-magnetic rocks. The adjacent Mudjatik domain also suffers a structural change in this locality, a change from the arcuate pattern present in the Mudjatik domain (Lewry and Sibbald, 1975) to the south into a linear pattern in northern Saskatchewan (Fahrig, 1956; Chandler, 1977) and northern Manitoba (Weber, et al, 1975). There appears therefore to be a change of major proportions occurring in the Precambrian basement along a northwest trending direction near the centre of the study area.

The magnetic character of the original metasedimentary rocks change in different parts of the Wollaston domain. Chandler (1977) in his report on part of the Wollaston Lake fold-belt interprets this change in the magnetic character of rocks in the Wollaston fold-belt as a metamorphic effect. Chandler indicates how progressive granitization changes similar metasediments into rocks with different appearances and magnetic properties. Progressive granitization causes the breakdown of biotite in non-magnetic metasediments into potash feldspar and iron and titanium oxides in the more magnetic (Metarkose) metasediments (Chandler, 1977). Chandler (1977) assumes that the rocks in all three of his migmatite zones were derived from similar metasediments by progressive granitization. Near the southern end of the Wollaston domain Forsythe (1975) states that magnetite produced by metamorphic effects occur as curving zones which commonly cross rock contacts. Chandler and Forsythe therefore document two localities where metamorphism affects the magnetic character of the metasediments in the Wollaston domain.

Magnetic metasedimentary rocks which Chandler (1977) places in his eastern migmatite zone can be followed southwards into the 1976 survey area on the aeromagnetic maps. These rocks are magnetic north of the study area, become non-magnetic in the study area and then become magnetic again in the southern portion of the study area. Non-magnetic rocks of Chandler's (1977) central migmatite zone can be projected along structural strike and correlated on the basis of aeromagnetic data to pass into the Mudjatik domain of Lewry and Sibbald (1975).

The changing magnetic character of the rocks along structure, as suggested by the aeromagnetic data in the study area, is probably due to the effects of differing metamorphic environments. A tenuous structural and aeromagnetic correlation can therefore be made between lithologies in the Wollaston and Mudjatik domains. In the Mudjatik domain Lewry and Sibbald (1975) state that the supra-crustal sequence is essentially uniform in character, and apparently of limited thickness, throughout the entire Mudjatik domain and the Virgin River domain.

In northern Manitoba Weber et al (1975) suggests the correlation of the stratigraphy of the "Wollaston fold-belt" and the "Hurwitz basin". They suggest a direct comparison between certain units which are lithologically similar and grade laterally into one another (Weber et al, 1975). They state that these units differ mainly as a result of increased metamorphism along strike towards the southwest. Weber et al (1975) also extend the dolomite unit and the meta-arkose unit with interbedded carbonates eastward across northern Manitoba to Hudson Bay.

The Kisseynew gneisses in northern Manitoba, which may be considered to be broadly correlative in age, are suggested to extend in an east-west direction from the Churchill-Superior boundary into eastern Saskatchewan and south-north from Flin Flon to Lynn Lake by Bailes (1975). Bailes indicates that the similarity of strata throughout the belt suggests broad regional correlations may be possible. At a later geologic date and on an even more regional scale Pettijohn (1970) considers that the later Aphebian sediments such as the Athabasca Formation and the Dubawnt Group are large residuals of a once more extensive, mainly continental sedimentary event.

SUMMARY

An attempt has been made to show through correlation and extension, perhaps tenuous at times, that the Aphebian metasediments which are found in the Wollaston domain are part of a much more extensive group of similar rocks. It would appear that the western Shield area in general has been blanketed by many sedimentary assemblages in the geologic past, starting with the Phanerozoic sediments overlying its southern areas and progressing back through time. Sequences such as the Athabasca Formation and the Dubawnt Group which are large residuals of a formerly more extensive coverage (Pettijohn, 1970) preceeded these Phanerozoic sediments before the beginning of the Hudsonian orogeny. Previously, older sediments, the Hurwitz Group in the N.W.T., which predate (Bell, 1970) the Hudsonian orogeny were deposited. If the Hurwitz is correlatable with similar metasediments in Saskatchewan and Manitoba, then these sediments too, were part of an areally extensive sequence of sediments. Bell (1970) suggests the Hurwitz was deposited on a metastable craton in the period between the Hudsonian and Kenoran orogenies. It is presumably at the end of this period of time that the sediments became highly metamorphosed and involved in deformation to the extent that in places even the original nature is in doubt, and only bulk composition provides meagre clues. It then becomes very difficult to unravel any areally extensive sedimentary events before the Kenoran orogeny, which accepting the Law of Uniformity must have occurred.

In summary, evidence from successive sedimentary sequences can be interpreted to suggest that this central area of the Churchill structural province has acted as a single metastable craton, as far back as geological evidence can be interpreted, as early as the Kenoran orogenic event.

GRADIOMETER EVALUATION

A study of the gradiometer and total field data enables a rough division of the area surveyed in 1976 into two regions. The southern region is underlain by outcropping or shallow-buried Precambrian basement. This portion of the survey, where the magnetic sources are less than approximately 300 metres below the surface, contains magnetic anomalies and patterns which are more numerous and detailed than those previously available from the 1:63,360 Federal-Provincial aeromagnetic maps. In these areas the amplitude of the anomalies on the gradiometer profiles is sufficiently large to be recognizable in the large noise swath present in the data. Basically this is the type of situation for which the gradiometer system was designed and the results, although of poor quality, do indicate the greater detail and better resolution possible with the gradiometer system. A much greater amount of information is available from the vertical gradient data than the total field data.

In the northern portion of the survey, in the deeper areas of the Athabasca basin where the subsurface depths to the magnetic sources exceed approximately 300 metres, the noise levels in the gradiometer data reach proportions where the reliability and useability of the signal is in question. This open file presents only data from the southern 40 kms of the survey area, the southern fringe area of the Athabasca Formation.

The profile data in Figures 2, 3 and 4 are all at a horizontal scale of 1:63,360. The vertical scale in Figure 2 is 0.2 gammas per metre per division and the vertical scale in Figure 3 is 100 gammas per division. These profiles start at the south end of the survey area and in Figure 2 and 3 the eight profiles presented have the easternmost profile at the bottom and the westernmost profile at the top of the diagram. The total field data and the vertical gradiometer data were collected simultaneously and the numbers along the profile represent the tape fiducials (fiducials are time of the measurement in seconds with the last digit representing fraction of seconds). The profiles in Figures 2, 3 and 4 can be aligned by the X in the lower left near the beginning of the profiles.

Standard sensitivity 1:63,360 scale aeromagnetic maps of this area were flown in 1963 and published in 1964. These aeromagnetic maps were used as the control in assessing the 1976 high sensitivity total field and vertical gradiometer data. A profile constructed from the 1964 total field map along profile 10011 is presented as Figure 4 for comparison with the 1976 data.

A comparison of the high sensitivity total field profiles to the 1964 standard sensitivity total field maps shows that the anomalies on the high sensitivity profiles have greater amplitudes and better definition than the corresponding anomalies on the standard sensitivity maps (Figures 2 and 4). The standard sensitivity profile (Figure 4) has the same vertical scale as the 1976 profile 10011 (Figure 2). The lower survey altitude and greater sensitivity of the newer equipment improves the resolution of the anomalies and increases the number of recognizable anomalies. More detail and therefore more information is available (Figure 2). As an example anomalies 1, 2 and 3 are basically one single anomaly on the 1964 total field maps and in the profile. However, on profile 10011 the bottom profile in Figure 2, obtained with the high sensitivity system, these anomalies are clearly separated into three anomalies. The profile also indicates that anomaly 2 has a flat peak and is probably further separable into two anomalies. Anomaly 3 also can be shown to consist of two or perhaps three anomalies.

Anomaly pairs 4 and 5, 6 and 7, and anomaly 8 all appear as single features on the 1964 total field map. On the 1976 profile anomalies 5, 6 and 7 have single peaks, however anomalies 4 and 8 each consist of two peaks.

A change in character of the total field anomalies occurs in the vicinity of anomaly 9 in the 1976 profile. Beyond anomaly 9 the profile becomes very smooth and regular, no short wave length anomalies are present and anomalies have much lower amplitudes.

It is evident from a comparison of profile 10011 to the 1964 map that much better resolution of individual anomalies is possible with the high sensitivity data. It can be further shown from a comparison of the high resolution total field profile to the vertical gradient profile that an even greater resolution and definition is possible from the gradiometer data.

A comparison of the vertical gradient profile (Figure 3) to the high sensitivity total field profile of traverse line 10011 clearly shows the greater amount of information available from the vertical gradient data. A note of caution is needed here because the noise levels in the data from this particular survey have amplitudes equal to normally valid gradient anomalies.

Examination of the vertical gradient profile shows anomaly 1 as a single spike, anomaly 2 has two separable peaks and anomaly 3 has two distinct peaks with a series of lesser anomalies detailed between anomalies 3 and 4. Anomaly 4 consists of two sharp and distinct peaks. Several weaker anomalies occur between anomalies 5 and 6, 7 and 8 and 8 and 9. Again there is a marked change in the character of the anomalies in the vicinity of anomaly 9.

An examination of the other seven profiles from the 1976 feasibility survey shows the same increase in anomaly resolution and detail as outlined in profile 10011. The vertical gradient profiles contain the greatest amount of information and would be most useful in delineating and extrapolating the geology near the fringe area of the Athabasca Formation.

An overview of all the profiles, as indicated earlier for profile 10011 reveals a change in anomaly character along the profiles. The first part of the profiles contain shorter wavelengths and higher amplitude anomalies. This pattern is typical of vertical gradient anomalies observed in other gradiometer surveys of near-surface Precambrian basement. The change apparent in the vicinity of anomaly 9 and beyond can be related to two likely causes. First, the distance to magnetic sources is increasing, in other words the Athabasca basin is deepening away from its borders. Secondly, the magnetic basement itself has less magnetic material and activity and therefore does not produce any magnetic anomalies. A combination of these two causes could also be responsible for the change near anomaly 9. The preferred interpretation is the deepening of the Athabasca basin because the gradient anomalies present are more regular in shape and have longer wavelengths. These features would tend to indicate a more distant source for these anomalies.

Seismic depth determinations (Hobson and MacAulay, 1969) and magnetic depth determinations (Kornik, 1969, 1970) indicate thinner Athabasca Formation in this southeastern corner of the basin. It was noted that the first 40 km of the survey profiles flown in 1976 contained anomalies attributed to surface or shallowly buried sources and that these anomalies changed character beyond anomaly 9. This change in character is also recognizable on the Federal-Provincial aeromagnetic map and may be attributed to an abrupt change in basement depth. The total field profile data from the 1976 survey were used to compute depths to basement using a computer program written by Phillips (1975). These depths also substantiated the presence of shallower (less than 300 metres) depths to magnetic basement in this area of the Athabasca basin. This area of less than 300 metres of Athabasca Formation is shaded in Figure 1.

Results from the 1976 survey indicate that future vertical gradiometer surveys in this area of thinner Athabasca Formation should be extremely useful in delineating the basement geology.

RELATION TO URANIUM MINERALIZATION

The uranium occurrences in northern Saskatchewan occur in a band west of the Needle Falls shear zone with the exception of the uranium deposits in the Carswell Lake structure and the Uranium City district (Sibbald, et al, 1976). Airborne gamma-ray spectrometry surveys by the Geological Survey of Canada extend this uranium mineralization into north-western Manitoba. The great length of the distribution of uranium occurrences across northern Saskatchewan and Manitoba and the different types of occurrences suggests a fundamental mineralization control which is not strictly related to the unconformity at the base of the Athabasca formation. It would appear that the Athabasca Formation served to protect and preserve from glacial scouring and removal, what may be considered as supergene deposits related to the underlying weathered pre-Athabasca basement. The areas covered with a thin sequence of Athabasca Formation as outlined in Figure 1 are therefore areas which are economically feasible to explore for preserved secondarily or supergene enriched uranium deposits in the weathered basement. The distribution of the occurrences, however, suggests that primary uranium deposits related to some unknown fundamental control are possible along the entire length of the band in northern Saskatchewan and Manitoba containing the uranium occurrences.

The vertical gradiometer would be an ideal tool to use in exploring this area of economic interest by assisting in delineating the basement geology.

REFERENCES

Bailes, A. H. (1975)
Geology of the Guay-Wimapedi Lake Area; Manitoba Dept. of Mines, Resources and Environmental Management, Geol. Services Br. Publ. 75-2.

Bell, R. T. (1970)
The Hurwitz Group - a prototype for deposition on metastable cratons: in Symposium on Basins and Geosynclines of the Canadian Shield: Geol. Surv. Can. Paper 70-40: 159-169.

Chandler, F. W. (1977)
Geology of part of the Wollaston Lake Fold Belt, north Wollaston Lake, Saskatchewan. Geol. Surv. Can., Bull. 277.

Fahrig, W. F. (1958)
Wollaston Lake, Saskatchewan: Geol. Surv. Can., Map 27-1957.

Fahrig, W. F. (1961)
The Geology of the Athabasca Formation: Geol. Surv. Can., Bull. 68

Forsythe, L. H. (1975)
The Geology of the Nimeiben Lake Area and the La Ronge Area; Sask. Dept. Mineral Res., Report No. 152.

Hobson, G. D., and MacAulay, H. A. (1969)
A Seismic Reconnaissance Survey of the Athabasca Formation, Alberta and Saskatchewan (part of 74): Geol. Surv. Can., Paper 69-18.

Kornik, L. J. (1969)
A Magnetic Interpretation of the Eastern Portion of the Athabasca Formation; Geol. Surv. Can., in Report of Activities, Part B: Paper 69-1B, pp. 29-31.

Kornik, L. J. (1970)
Aeromagnetic survey of the Athabasca Formation: a quantitative interpretation; Canadian Mining Journal, August pp. 50-53.

Lewry, J. F. and Sibbald, T.I.I. (1975)
Variation and Tectonometamorphic Relationships in the Western Part of the Hudsonian Mobile Belt and Adjacent Cratonic Elements of Northern Saskatchewan, Open House Meeting on Geological Programs, Regina, Sask.

Money, P. L. (1968)
The Wollaston Lake fold-belt system, Saskatchewan-Manitoba; Can. J. Earth Sci., 5, 1489-1504.

Pettijohn, F. J. (1970)
The Canadian Shield, A Status Report 1970, in Symposium on Basins and Geosynclines of the Canadian Shield, Geol. Surv. Can., Paper 70-40.

Phillips, J. (1975)
Statistical Analysis of Magnetic Profiles and Geomagnetic Reversal Sequencies. Unpbl. Ph.D. Thesis, Stanford University.

Ramaekers, P. (1975)
Athabasca Formation, Southeast Edge (74H): I Reconnaissance Geological Mapping, in Summary of Investigations 1975, Sask. Geol. Surv., Sask. Dept. Min. Res. pp. 48-52.

Ramaekers, P. (1976)
Athabasca Formation; Northeast Edge (64L, 74I, 74P); Part 1, Reconnaissance Geology, in Summary of Investigations 1976, Sask. Geol. Surv., Sask. Dept. Min. Res. pp. 73-77.

Ray, G. E. (1975)
Reconnaissance Geological Mapping of Foster Lake (NE) and Geikie River (SE) Areas; in Summary of Investigations 1975, Sask. Geol. Surv., Sask. Dept. Min. Res. pp. 13-18.

Ray, G. E. (1976)
Reconnaissance Geological Mapping of Foster Lake (NW) and Geikie River (SW) Area; in Summary of Investigations 1976, Sask. Geol. Surv., Sask. Dept. Min. Res. pp. 18-23.

Sibbald, T.I.I. (1976)
Uranium Metallogenic Studies - Rabbit Lake; in Summary of Investigations 1976; Sask. Geol. Surv., Sask. Dept. Min. Res. pp. 115-123.

Sibbald, T.I.I., Munday, R.J.C. and Lewry, J.F. (1976)
The Geological Setting of Uranium Mineralization in Northern Saskatchewan; in Uranium in Saskatchewan, Sak. Geol. Soc., Special Publ. No. 3, pp. 51-98.

Weber, W., Schledewitz, D.C.P., Lamb, C.F. and Thomas, K.A. (1975)
Geology of the Kasmere Lake - Whiskey Jack Lake (N/2) Area; Man. Dept. Mines, Res. and Envir. Man., Pub. 74-2.

FIGURE CAPTIONS

Figure 1. Location of 1976 gradiometer survey over the southeast edge of the Athabasca Formation Basin. The area of thinner Athabasca Formation cover and aeromagnetic lineaments interpreted from aeromagnetic data and faults mapped by Ray (1975, 1976) are also shown.

Figure 2. Eight total field aeromagnetic profiles from the 1976 survey are illustrated as stacked profiles with the lowest profile (10011) being the easternmost and the upper profile (10080) the westernmost. The profiles start at the southern end of the survey area. The numbers on some anomalies in profile 10011 are referred to in the text.

Figure 3. Eight vertical gradiometer profiles from the 1976 survey are illustrated as stacked profiles with the lowest profile (10011) being the easternmost and the upper profile (10080) the westernmost. The profile start at the southern end of the survey area and are coincident with the position of the profiles in Figure 2. The data in Figures 2 and 3 were collected simultaneously and Figures 2 and 3 can be aligned with the X in the bottom left of the Figures. Numbers along profile 10011 are referred to in the text.

Figure 4. Total field aeromagnetic profile constructed from 1964 data along profile 10011 in Figures 2 and 3. Position of the edge of the Athabasca Formation and several aeromagnetic lineaments are also indicated.