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Geophysical expression of the Canadian Shield of northeastern Alberta

K. F. Sprenke,
C. S. Wavra, J. D. Godfrey

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Cover:
A mosaic of satellite imagery showing portions of the Canadian Shield and Lake Athabasca in northeastern Alberta

Alberta Remote Sensing Center

GEOLOGICAL SURVEY DEPARTMENT, ALBERTA RESEARCH COUNCIL
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Preface

The Canadian Shield of northeastern Alberta is an area of potential economic mineral deposits in which the Alberta Research Council has conducted geological, geochemical and geophysical studies. This bulletin presents the results of the geophysical studies that should aid future mineral exploration efforts.

Acknowledgments

A preliminary study of the geophysical character of the exposed Shield in northeastern Alberta was initially undertaken by Sprenke as part of a Ph.D. dissertation at the University of Alberta. A continuation of the program and a more detailed investigation was made possible by a research grant by the Alberta Research Council to Sprenke at the University of Idaho, Moscow, Idaho. This grant also supported the contributions of several post-graduate students at the University of Idaho, including C.S. Wavra. We are indebted to a team of student geologists, professionals, and a wide range of management and support staff who have made this study possible. Contributions have been made at every stage in the evolution and progress of the project, from the initial field mapping program through the compilation and analysis of data, to the final preparation of this document. Of special note are the helpful critical comments of our colleagues, Drs. C.W. Langenberg and S.P. Goff, who have been actively engaged in related areas of study in this Precambrian Shield project. The thoughtful comments of our external reviewers, Drs. R.A. Burwash, E. Irving, B.W. Charbonneau, and E.R. Kanasewich are especially appreciated.

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Abstract

The Canadian Shield of northeastern Alberta has a geophysical expression controlled by lithology and complex structural-metamorphic features. The magnetic field of the Alberta Shield (the exposed part of the Canadian Shield in Alberta), shows a variety of patterns that result from combinations of several geological factors: principally regional metamorphism, local shear, and plutonic intrusion. Magnetic susceptibility determinations for the study area indicate that, typically, the Archean granite gneisses have higher susceptibilities than do the younger granitoid masses. The gravity field of the Alberta Shield is influenced not only by the volume, shape, and distribution of exposed and near-surface masses, but also by variations in metamorphic facies, structural fabric, and lithology of the deep subsurface. Measurements of residual gravity fields and specific gravities of outcrop are generally consistent with the hypothesis that diapirism is responsible for placement of the granitoid domes in the Alberta Shield. Airborne radiometric data for the study area suggest that uranium is concentrated in six areas. The sources of radioactivity include pegmatitic phases of both granitoid and high-grade metasedimentary rock associations, rock contacts, metasedimentary inclusions in granitoids, and fault zones.

Introduction

This bulletin forms part of a series of Alberta Research Council publications on the geology of the Canadian (Precambrian) Shield of northeastern Alberta. Field mapping began in 1957 and was completed in 1975. Thirty-six district geological maps, covering the entire area on a scale of two inches to one mile, have been published by the Alberta Research Council.

The objective of this study was to summarize the geophysical aspects of the portion of the exposed Canadian Shield of northeastern Alberta that lies north of Lake Athabasca. For brevity, in this bulletin, that part of the Canadian Shield that is exposed in northeastern Alberta is referred to as the "Alberta Shield." The available geophysical data were first analyzed qualitatively and then synthesized quantitatively in conjunction with other known geological parameters.

Location and access

The study area (figure 1) is located in northeastern Alberta, between 58°30′ and 60°N, and 110° and 112°W. It forms part of the Fitzgerald and Fort Chipewyan map sheets (NTS 74M and NTS 74L, respectively).

Access to the study area is via regularly scheduled airline flights to both Fort Smith, Northwest Territories, and Fort Chipewyan, Alberta.

Previous geological work

In 1957, members of the Alberta Research Council began systematic mapping of the Precambrian Shield in northeastern Alberta (figure 2) and subsequently published several district maps and reports (Godfrey, 1961, 1963, 1966, 1980a, 1980b, 1984, in press; Godfrey and Langenberg, in press (a), in press (b); Godfrey and Peikert, 1963, 1964). Geochronological studies have been published on those portions of the Shield covered in the early phases of mapping (Godfrey and Baadsgaard, 1962; Baadsgaard and Godfrey, 1967, 1972; Kuo, 1972; Day, 1975). From air photographs, Godfrey (1958a) interpreted the structure of the Shield in Alberta, north of Lake Athabasca. Mineral showings encountered in the Andrew, Waugh, and Johnson Lakes area (figure 3) were reported by Godfrey (1958b).

In 1959, members of the Geological Survey of Canada conducted a reconnaissance geological survey of the Precambrian Shield in Alberta, north of Lake Athabasca, and published a map with accompanying notes (Riley, 1960).

In 1977, the Alberta Research Council was invited, by the Geological Survey of Canada, to participate in a project to compile a metamorphic map of the Canadian Shield. The results of that project included a map (GSC map 1475a; Godfrey and Langenberg 1978b) and a paper on the metamorphic history of the Shield in northeastern Alberta (Godfrey and Langenberg, 1978a).

A more detailed account of the metamorphic history of the study area was presented by Langenberg and

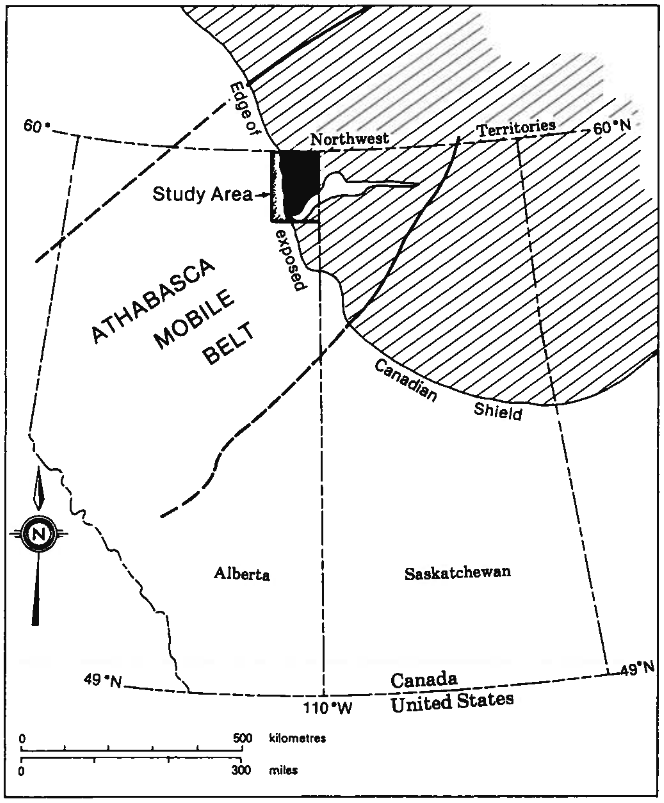

Figure 1. Location of the Alberta Shield study area in Alberta, north of Lake Athabasca.

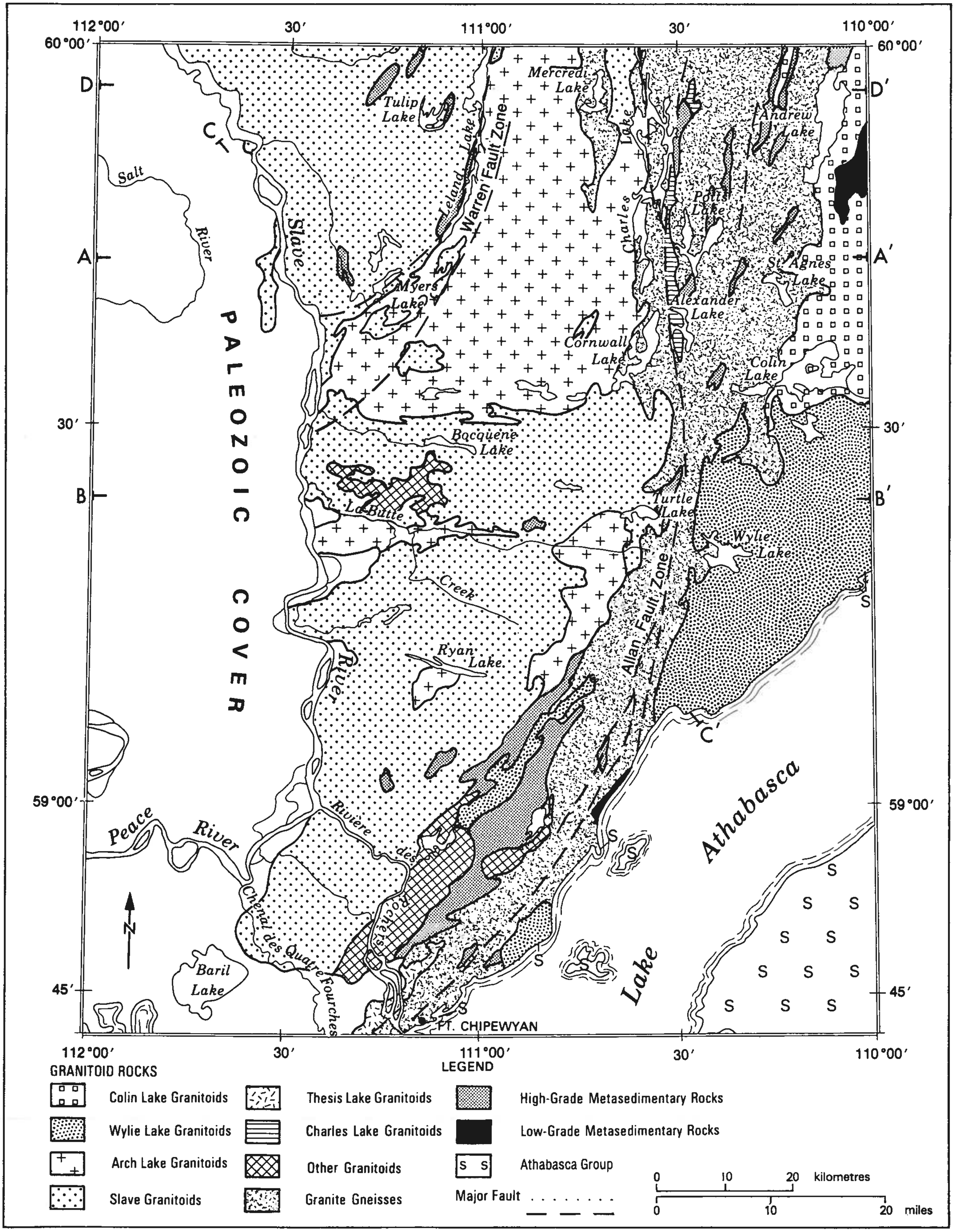

Figure 2. Simplified geological map of the Alberta Shield (Langenberg and Nielsen, 1982).

truded by plutonic rocks) are also typical of the Alberta Shield (Langenberg and Nielsen, 1982). However, granitization and plutonism may have been more intense in the study area than in the Wollaston Lake or Virgin River Fold Belts. Only relict metasedimentary rock bands now outline once-larger sedimentary rock basins.

Nielsen et al., (1981), citing recent work by Ray and Wanless (1980), have stated that the structural, metamorphic, and textural features of the rocks in northeastern Alberta are related to a Proterozoic subduction zone located in northern Saskatchewan. This hypothesis stems from the similarities in chemical composition and igneous-metamorphic associations in granitoids of the Alberta Shield with those of the southern European Hercynian mountains, whose mode of formation has been attributed to a convergent plate margin.

Ray and Wanless (1980) considered the ancient suture zone to be in the eastern portion of the La Ronge Domain, with the Needle Falls Shear Zone (figure 4) representing a continental geosuture. Some geophysical data supporting the existence of this geosuture comes from Camfield and Gough (1977) who noted a 1400 km-long zone of conductivity which extends from northern Saskatchewan (in the vicinity of the Needle Falls Shear Zone) to southeastern Wyoming. This long geophysical lineament is attributed to a major ancient geosuture, possibly a Proterozoic collision zone.

Metasedimentary units in the Virgin River Fold Belt (Virgin Schist Group) and in the Wollaston Lake Fold Belt (figure 4) of Saskatchewan host base metal deposits (Wallis, 1970; Money, 1968). Both regional and local data (Godfrey, 1958b, 1980a, 1980b) indicate that the metasedimentary rock bands of the Alberta Shield are important exploration targets for base metal and uranium mineralization. Many of the granitoid masses of the Alberta Shield are associated with gravity lows and, like similar areas along the Athabasca Axis (figure 4; Darnley, 1981), have excellent potential for uranium prospects.

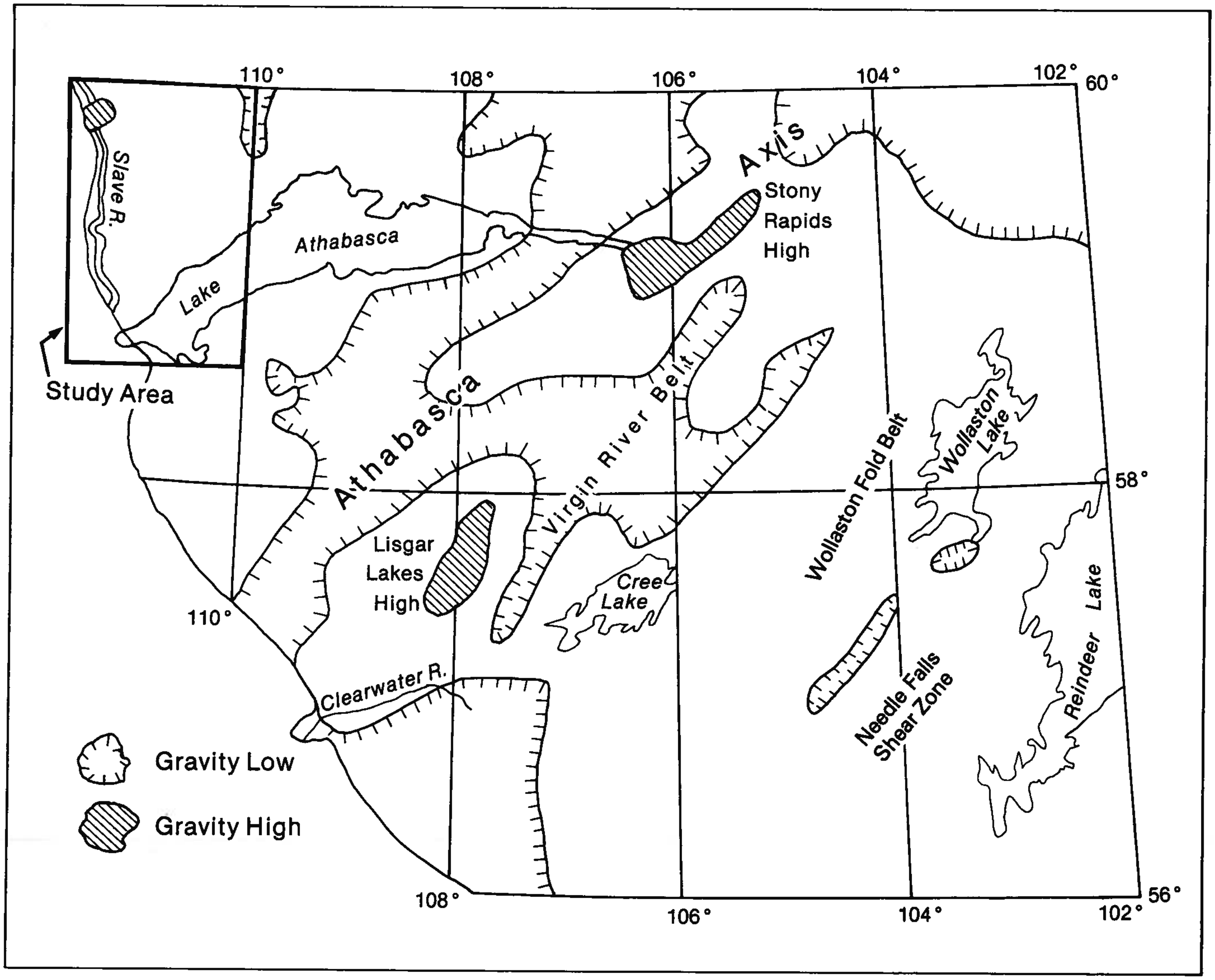

Figure 4. Gravity trends in the western portion of the Churchill Province.

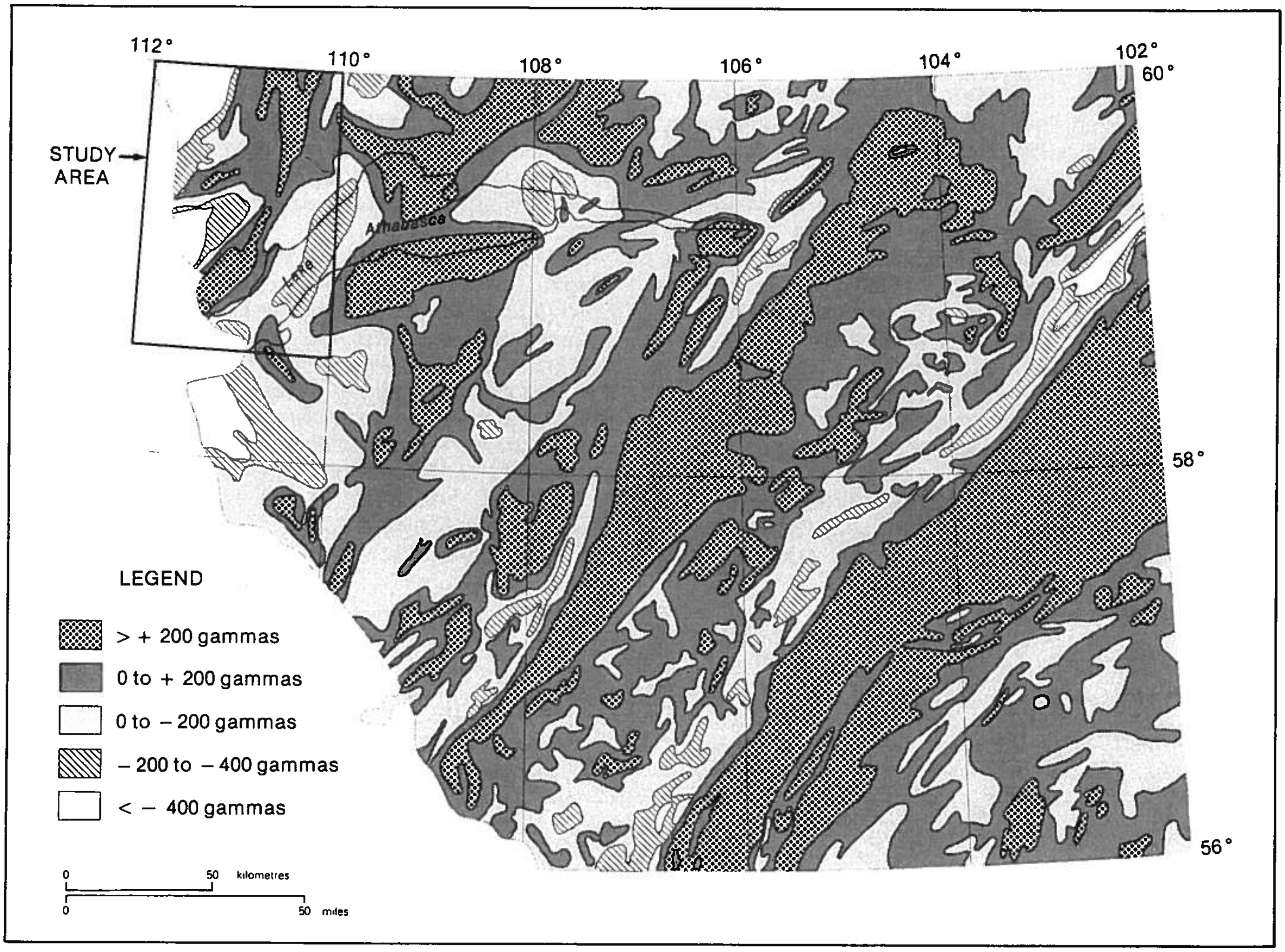

Figure 5. Magnetic trends in the western portion of the Churchill Province. See figure 4 for locations of major structural belts.

General geology

The Precambrian Shield of northeastern Alberta is composed principally of massive to foliated granitoids, granite gneiss, and high-grade metasedimentary rock (figure 2). It lies within the Athabasca Mobile Belt (Burwash and Culbert, 1976) of the Churchill Province (figure 1). Its geological history includes multiple episodes of sedimentation, deformation, metamorphism, mylonitization, and remobilization (table 1). These processes have operated during at least two identified orogenic periods (Langenberg and Nielsen, 1982), resulting in the production of complex polymetamorphic rocks. From field relationships and geochemical considerations, it appears that the migmatitic granite gneiss and high-grade metasedimentary rock were probable parent materials for most of the granitoid rocks. Thus, the granitoids largely represent Archean basement that was remobilized during the Aphebian Episode, a hypothesis which is consistent with the concept of multiple orogenic cycles, based on geochronological-metamorphic studies. Rb-Sr whole rock isochrons on pegmatites associated with granitoids, gneisses, and metasediments in the Charles Lake area yield ages of about 2500 Ma. Thus, they are considered to be part of an Archean basement gneiss complex. A low initial Sr isotope ratio from the pegmatites points to the presence of I-type granitoids. This initial Sr ratio is also consistent with a mantle-like source material.

Rb and Sr determinations on Colin Lake Granitoids (figure 2) have a well-defined isochron of 1893 Ma. A high initial Sr isotope ratio indicates derivation of these granitoids by anatexis of pre-existing sedimentary rocks. The immediate parent materials for the Colin Lake Granitoids were probably from the nearby belt of Archean granite gneisses and high-grade metasedimentary rocks. The other granitoids of northeastern Alberta are also Aphebian.

Numerous K-Ar determinations on muscovite, biotite, and hornblende yield a narrow distribution of ages. The average age of mica for many rock units is 1790 Ma, indicating that the K-Ar dates for all crystalline rocks within the region were effectively reset at

Table 1. Summary of the geologic history of the exposed Shield in northeast Alberta, north of Lake Athabasca.

Geologic Age	Rock Units/Groups	Predominant Rock Type(s)	Process/Event	
Recent	Fluvial, lacustrine deposits	Sand, silt, mud	Sedimentation	
Pleistocene	Glaciofluvial lacustrine	Till, sand, silt	Continental glaciation	
Helikian	Athabasca Group	Sandstone	Continental sedimentation	
Aphebian			Regional Faults (e.g. - Allan Fault) and mylonitization	Hudsonian Event
	Burntwood Group	Sandstone, argillite	Metamorphism (greenschist facies)	
	Waugh Lake Group	Quartzite, schist, meta-volcanics		
			Sedimentation	
			Volcanism	
	Wylie Lake Granitoids	Granodiorite, (granite, quartz diorite)		
	Colin Lake Granitoids	Granodiorite (Granite, quartz diorite)	Basic dyke intrusion	
			Metamorphism	
	La Butte Granodiorite	Granodiorite	(granulite-amph.f.)	
	Thesis Lake Granite	Granite	Remobilization	
	Chipewyan Red Granite	Granite	Granitization	
	Arch Lake Granitoids	Granite (granodiorite)	Plutonism	
	Slave Granitoids	Granite (granodiorite)		
Archean	Basement Gneiss Complex Charles Lake Granitoids	Granite, granodiorite		Kenoran Event
		Amphibolite	Basic dyke intrusion Plutonism Granitization Metamorphism (granulite facies) Sedimentation	
		Metasedimentary Rocks		
		Hornblende Gr. Gneiss		
		Biotite Granite Gneiss		

the close of the Hudsonian Orogeny. Thus, two Precambrian orogenic cycles are firmly established for the Shield of northeastern Alberta: the Kenoran and Hudsonian.

These two cycles are also evident as distinct phases of metamorphism. The Archean cycle shows high-pressure granulite facies conditions. The subsequent Aphebian cycle shows a regressive cooling sequence which can be traced through three stages: from moderate-pressure granulite facies, through a low-pressure amphibolite facies, to greenschist facies conditions.

Low-grade metasedimentary rocks and metavolcanics in the Waugh Lake area (figure 3) have primary sedimentary and igneous structures respectively. An unconformity is assumed between this low-grade metasedimentary-volcanogenic rock assemblage and the combined Archean granite gneiss/Aphebian granitoid basement complex. A K-Ar age of 1760 Ma for biotite from these prograde greenschist facies metasediments correlates very well with the retrograde greenschist facies found throughout the Alberta Shield area.

Major mylonitic shear zones affect most of the rock units and are thought to be younger than the macroscopic fold structures in the granitoids. Retrograde greenschist facies minerals in the mylonitic shear zones suggest a Late Aphebian age for this regional-scale faulting. Breccias along some transverse faults indicate brittle fracture along even younger faults at higher crustal levels.

Continental conditions prevailed during deposition of the Helikian Athabasca Group, which lies unconformably on the older crystalline basement rocks.

Glacial scouring during the Pleistocene Epoch has uncovered numerous outcrops. This greatly facilitates geologic studies in the region.

The magnetic field of the Alberta Shield

Introduction

The magnetic map of the Alberta Shield shows complex patterns and variations of field intensity. These regional and local variations are related to the magnetic properties of the underlying bedrock. The purpose of the research presented in this chapter was to compare and analyze the bedrock geology of the Alberta Shield in relation to the magnetic field.

Published interpretations of the magnetic field of the Alberta Shield have so far dealt with local areas only. In the Andrew Lake district (figure 3), an excellent correlation was found between the magnetic field and the bedrock geology (the rock units and major fault zones [Godfrey and Baadsgaard, 1962; Watkins, 1961]). In the study of a major mylonitic zone associated with the Allan Fault system (figure 2), Watanabe (1965) showed that magnetic lows near fault zones in the map area are due to the destruction and transformation of primary magnetite during mylonitization.

A comparison of Geological Survey of Canada aeromagnetic map data with a number of Alberta Research Council geological bedrock maps forms the basis of the present study. Previous Alberta Research Council laboratory studies also contain vital information on the magnetic properties of rocks from the study area.

The magnetic field of the Alberta Shield, in large part, can be directly related to bedrock features mapped in outcrop. Two types of magnetic anomalies are prominent in the map area: 1) an elongate or linear, parallel-aligned anomaly, indicative of regional metamorphism and local shear; and 2) an irregular, circular to arcuate shape, indicative of primary magmatic (plutonic) conditions. Magnetic lows within the map area usually resulted from metasedimentary bands, mylonitic zones, or low-susceptibility granitoids. Magnetic highs result from granite gneiss and high-susceptibility granitoids. Trends in the Alberta Shield, as exhibited by a two-dimensional autocorrelation analysis of the magnetic field, indicate a dominant northwest-southeast directed stress.

Methods

The correlations between magnetic field and geological bedrock parameters were made by visual comparison of overlaid maps, all transformed to a common scale. The following maps were used:

- Geological Survey of Canada Aeromagnetic Maps (Geological Survey of Canada, 1963a to 1963d, 1964a to 1964v).
- Preliminary Bedrock Geology Map of the Precambrian Shield of northeastern Alberta, scale 1:250 000 (Godfrey, unpublished).
- Structural Geological Map of the Alberta Shield (Langenberg, 1983).
- Metamorphic Facies Map of the Canadian Shield north of Lake Athabasca (Godfrey and Langenberg, 1978a).

More detailed information on bedrock geology was obtained from various district geology maps of the Alberta Shield (Alberta Research Council, Precambrian Geological Map Series; see Godfrey (1961, 1963, 1966, 1980a, 1980b, 1984, in press), Godfrey and Peikert, (1963, 1964), Godfrey and Langenberg (in press (a), in press (b)).

Data on the magnetic properties of rock samples from the Alberta Shield came from the following sources:

- Measurements of the ratio of remanent to induced magnetization of 23 core samples (Watkins, 1961).
- Optical determinations of magnetite content and laboratory measurements of susceptibility for several dozen granite gneiss and mylonite rock core samples (Watanabe, 1965).
- Measurements of the magnetic susceptibility of about 650 standard sample powders (Alberta Research Council, unpublished data).
- Field measurements of the magnetic susceptibility of about 130 outcrops in the map area (Sprenke, 1979, 1982).

Digital aeromagnetic data were obtained from a magnetic tape provided by the Geophysical Data Processing Section, Resource Geophysics and Geochemistry Division, Geological Survey of Canada. The Alberta Shield was one of the first areas to be digitized by the Geological Survey of Canada. At that time, the technique was simply to overlay a transparent grid, and manually pick off values at about one minute of longitude and thirty seconds of latitude (D.J. Teskey, personal communication).

Two-dimensional correlograms were used in this study to provide statistical analyses of the geophysical data trends to interpret regional stress patterns. This technique has been used previously in studies of other areas of the Canadian Shield by Horton et al., (1964) and Kanasewich and Agarwal (1968).

The autocorrelogram or two-dimensional autocorrelation function involves the computation of the degree of correlation between two identical contour maps at various amounts of offset. For example, when two identical maps are simply overlain, the agreement between them is perfect, and the computed correlation coefficient is $+1$. If one of the maps is then shifted relative to the other, the correlation will no longer be perfect, but rather a function of the trend direction of the map values. If the map values trend in the same direction as the offset between the two maps, then the degree of correlation will be relatively high. If, on the other hand, the map values trend in some other direction, then the degree of correlation will be relatively low, possibly even negative. The mathematical formulation of the autocorrelogram may be found in Kanasewich (1975).

The autocorrelograms for the Alberta Shield were calculated using a two-dimensional Fourier transform technique as described in Kanasewich and Agarwal (1968). The magnetic data were interpolated to a grid with a spacing between grid points of about 1 km. A total of 21 600 samples of the magnetic field were used, with autocorrelation values being obtained for offsets as great as 15 km.

Nielsen (1982). The geometry of macroscopic folds in the region was investigated by Langenberg and Ramsden (1980) and Langenberg (1983). Nielsen et al. (1981) discuss the crustal evolution of the area within a regional setting.

Previous geophysical work

Regional geophysical work on the Alberta Shield began with an aeromagnetic survey by the Geological Survey of Canada in 1958 with flight lines spaced 400 m apart. The results were published as total field, magnetic contour maps (Geological Survey of Canada, 1963a to 1963d; 1964a to 1964t), and were later compiled and reduced on two maps (Geological Survey of Canada, 1964u, 1964v), Watkins (1961), Godfrey and Baadsgaard (1962), and Watanabe (1965) have noted that magnetic anomalies in the study area correlate with bedrock structure and lithology.

In 1960, members of the Dominion Observatory (now the Earth Physics Branch) surveyed gravity fields in the study area at a station spacing of 10-12 km (Walcott, 1968). From their observations, a contoured Bouguer gravity map was prepared (map 19, Gravity Map Series, Dominion Observatory).

During the summers of 1970 and 1977, members of the Resource Geophysics Branch of the Geological Survey of Canada measured airborne gamma-ray spectrometry over the Alberta Shield along flight lines spaced 5 km apart. Contour maps and stacked profiles of the integral count, individual radioactive isotope counts, and isotope ratios were produced from the data (Geological Survey of Canada, 1977a, 1977b). Bennett (1970) and Charbonneau (1980, 1982) interpreted these data for the extreme northern portion of the study area.

Several researchers have measured certain physical properties of rock samples from the Alberta Shield. Watkins (1961) measured the ratio of remanent to induced magnetization of 23 core samples from the map area. Watanabe (1965) measured the density and magnetic susceptibility of several rock samples in a study of mylonitic rock types. The Alberta Research Council has obtained laboratory and field measurements (unpublished) of the magnetic susceptibility (from powders) and density (of hand specimens) of several hundred and thousand samples, respectively, from the study area. Sprenke (1982) performed a preliminary investigation of the geophysical properties of the Alberta Shield as part of a Ph.D. study.

The Shield in northeastern Alberta is part of the most westerly exposed section of the Churchill Province, part of the greater Canadian Shield. Many of the geological-geophysical characteristics of the Churchill Province are found in the study area. Therefore, previous geophysical investigations of the greater Churchill Province can be used to interpret features of the Alberta Shield. The rock outcrops, structural patterns, and geophysical lineaments of the Churchill Province display a pervasive northeasterly trending regional pattern. These patterns may be generally interpreted as tectonic lineaments, and include basins that were floored by an Archean basement complex, and subsequently filled with Aphebian sediments. Those sediments were later subjected to varied degrees of metamorphism and plutonism.

The western part of the Churchill Province exhibits prominent regional gravity anomalies (figure 4) which trend northeasterly and indicate transverse rock density contrasts within the basement complex (Walcott, 1968). Within the exposed Shield of Saskatchewan, higher-grade metamorphic rocks—upper amphibolite to granulite facies, and basic intrusions—are commonly associated with gravity highs (Wallis, 1970).

Metasediments, granitoid masses, retrograde-metamorphic facies, deep-seated basement faults, and low-grade, low-pressure metamorphic facies typically correspond with gravity lows (Darnley, 1981; Gibb, 1968; Walcott, 1968; Wallis, 1970).

The western part of the Churchill Province also exhibits a regional northeasterly trending linear magnetic belt (figure 5). Though some anomalies may be related to discrete metamorphic terranes, many of the linear magnetic anomalies are related to regional tectonic features, such as ancient troughs, geosynclinal structures, and orogenic fronts (Krutikhovskaya and Pashkevich, 1972).

The local magnetic signature in Shield areas such as the Churchill Province principally depends on rock type (magnetic contrast, geometry and arrangement of lithologies), metamorphic grade, and structural fabric. Magnetite-bearing metasedimentary rock, some (especially basic) migmatites, granulite-amphibolite facies metamorphic rocks, pyroxene-amphibole-bearing gneiss, and basic intrusions produce strong positive magnetic anomalies (Krutikhovskaya and Pashkevich, 1972; Krutikhovskaya et al., 1978; Money, 1968).

Granitoid masses generally display low magnetic values (Krutikhovskaya et al., 1978). Money (1968) suggested that some granitoid masses in the Wollaston Fold Belt which show high magnetic signatures may be due to mafic phases or partly assimilated amphibolites within these granitoid masses. Krutikhovskaya et al., (1978) noted that granitoids derived from materials of basic composition may show magnetic highs resulting from the incorporation of magnetite during ultrametamorphism. Granitoid masses commonly display a circular to arcuate magnetic pattern, due to an an uneven distribution of magnetic minerals.

Faults are commonly associated with linear-type magnetic lows (Wallis, 1970). However, some fault zones which cut magnetite-bearing country rock may have retained or even concentrated, rather than destroyed, magnetic minerals, and therefore can produce magnetic highs (Krutikhovskaya and Pashkevich, 1972). In general, local magnetic trends are aligned with the local rock foliation in the Churchill Province (Wallis, 1970).

Many of the geological and geophysical regional characteristics of the Athabasca Axis and the Churchill Province as a whole are also typical of the Alberta Shield. Churchill Province-type linear trends (where high-grade metasedimentary rock synforms are bounded by the basement gneissic complex and in-

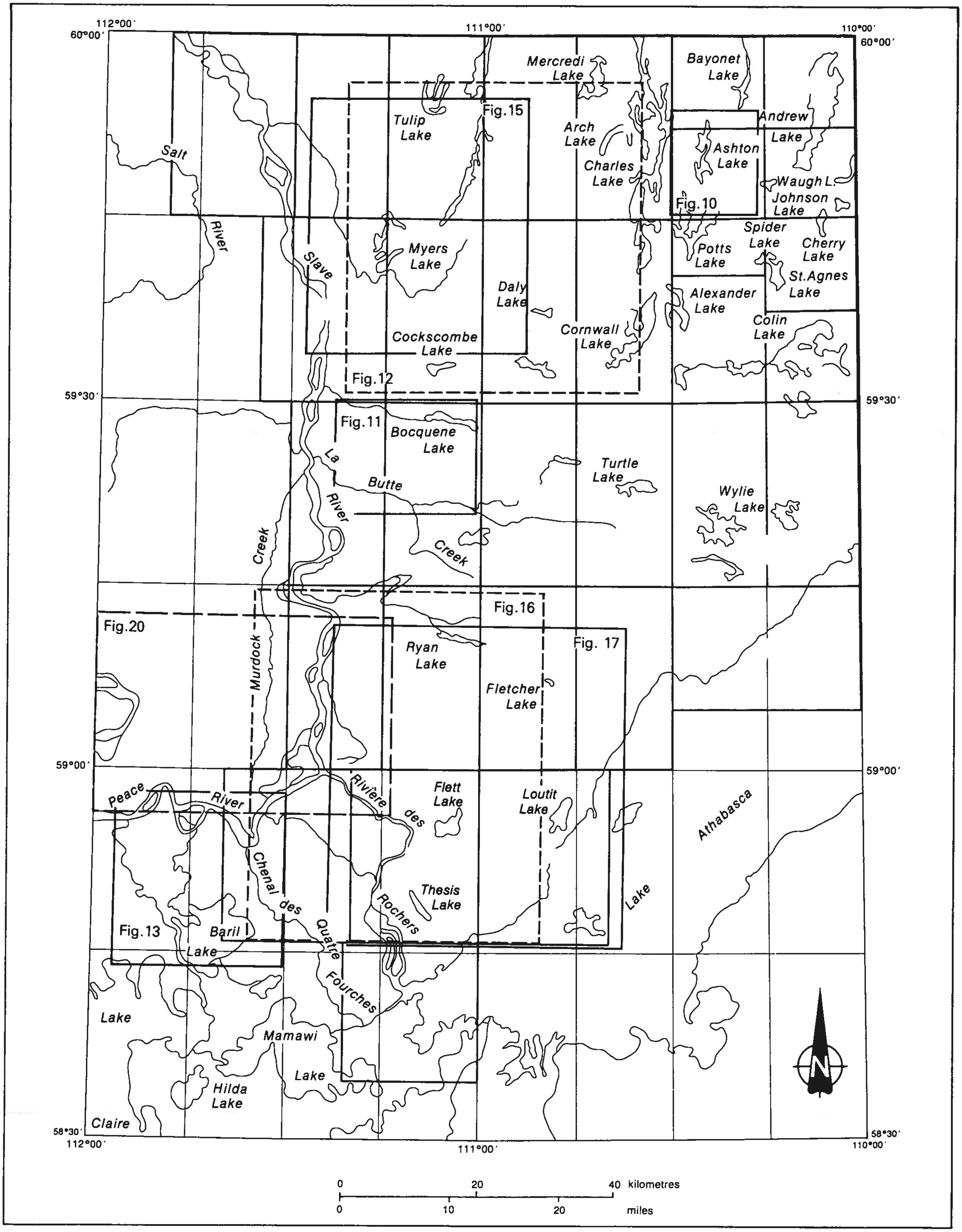

Figure 3. Index map of detailed study areas.

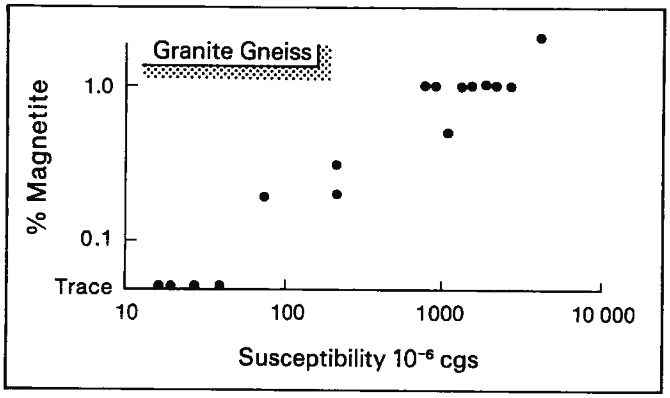

Figure 7. Cross plot of magnetite content versus magnetic susceptibility of granite gneiss samples from the Alberta Shield.

Granitoids by the Warren Fault. The lack of magnetic minerals in the Fort Smith porphyry suggests that this unit, though petrologically similar, has undergone a more severe deformational history than the Arch Lake Granitoids and thus has lost magnetite perhaps by alteration to hematite.

A quartic trend surface map of magnetic susceptibility based on the standard sample set is shown in figure 9. Though this map has smoothed contours and shows only regional variations of susceptibility, a strong correlation is apparent between rock types (see figure 2) and susceptibility. The highest susceptibilities of the Alberta Shield occur in the extreme northeast corner of the map area, and are associated with the Colin Lake Granitoids (figure 2) and a belt of low-grade volcanogenic sediments at Waugh Lake (figure 3). The center of the map area is dominated by an area of high magnetic susceptibility associated with Arch Lake Granitoids and granite gneiss (figure 2). This central high area is elongated southward consistent with the bodies of Arch Lake Granitoids and granite gneiss west of the Allan Fault Shear Zone (figure 2). Large areas of low magnetic susceptibility in the northwest, west, and southwest portions of the exposed Shield correlate with the widespread Slave Granitoids (figure 2). The pronounced low susceptibility in the southeast is associated with the Wylie Lake Granitoids (figure 2).

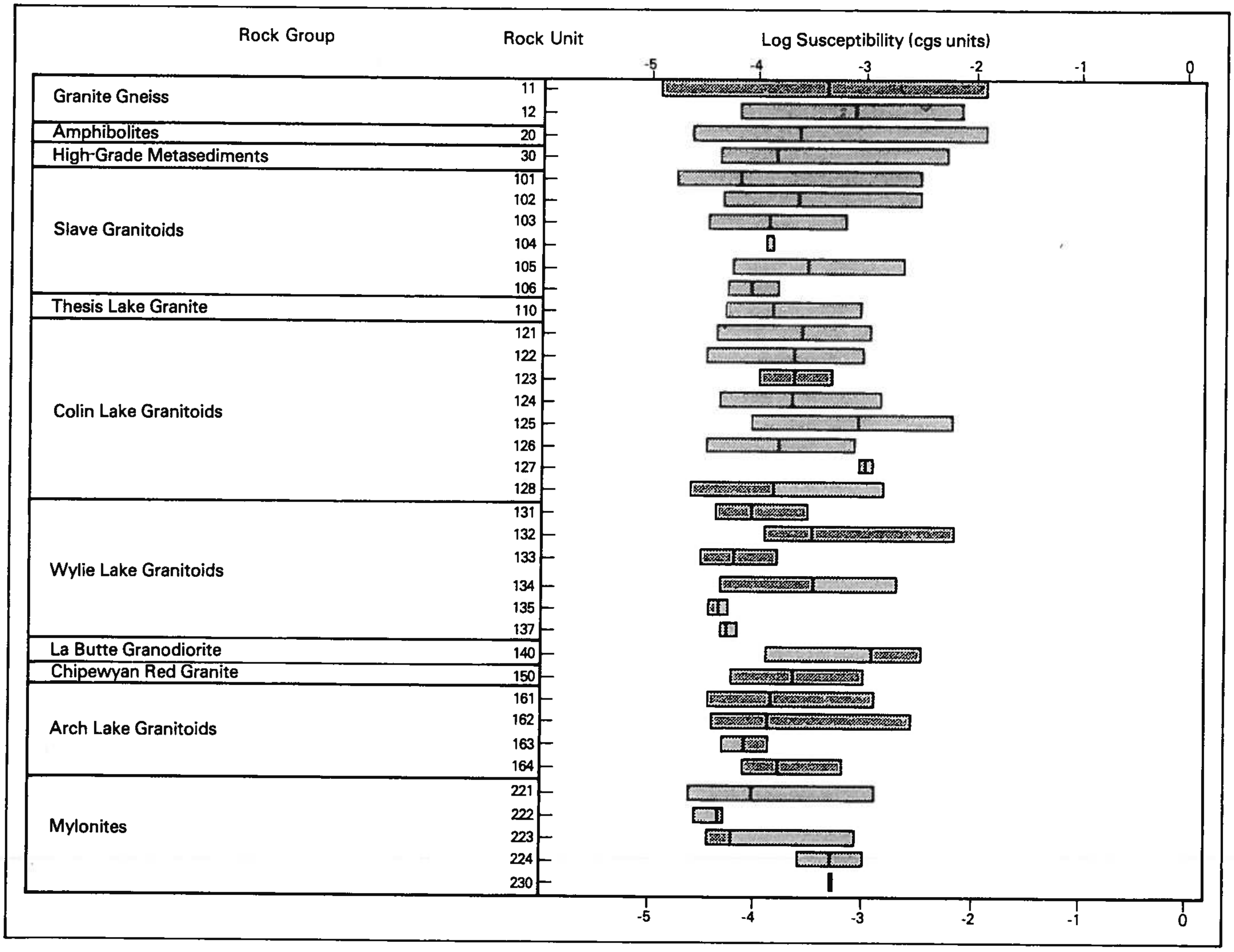

Figure 8. Magnetic susceptibility ranges of rock types in the Alberta Shield. Bar length represents total limit of range. The line in each bar is the respective mean. Sequential numbers of various rock units are map unit designations used for the Alberta Shield.

Magnetic field autocorrelograms can show directional trends in magnetic structure to an accuracy of a few degrees. Although autocorrelograms, by definition, show symmetry about a central origin, the contours on the autocorrelogram tend to be elongated in the directions of the dominant geologic trends. A magnetic map lacking distinct trends results in an autocorrelogram showing perfectly circular contours.

Horton et al., (1964) noted that in one study in the District of Mackenzie, Northwest Territories, magnetic autocorrelograms showed a dominant positive trend, a secondary positive trend, and a distinct negative trend. They interpreted these trends to indicate the planes of rupture and shear sets, and from these data, they were able to deduce the maximum principal stress for the area. The success of this technique relies strongly on the hypothesis that magnetic structure in a given region is related systematically to tectonic forces.

Another statistical technique used in this study is trend-surface analysis. This method is an important tool for analyzing the spatial distribution of data and is commonly used in the earth sciences (Agterberg, 1974). By this method, a mapped surface can be divided into a regional trend and a set of residual anomalies, both of which may be significant in geological interpretation. The trend surfaces used in this study are two-dimensional 4th-degree polynomial functions. The 4th-degree or quartic surface was chosen because it tends to produce a reasonable degree of oscillation for the study area without significant distortion in areas of few samples. The mathematical formulation of the trend surface method may be found in Agterberg (1974).

Trend surface maps retain only regional large-scale structures. Local features—even those important for regional analysis such as long narrow shear zones—may be omitted. Hence, a complete regional geologic interpretation must consider not only the trend surface, but also the original data set. Despite this limitation, trend-surface maps show regional effects which might otherwise be overlooked.

Rock magnetism

The ratio (Q) of remanent to induced magnetization of the rocks in the Alberta Shield is generally low. Figure 6 shows a cross plot of remanent magnetization, induced magnetization, and Q, for 23 core samples from the study area (Watkins, 1961). The median value of Q is 0.13, indicating that permanent magnetization is small compared to induced magnetization. However, exceptions occur, as exemplified by the amphibolite rock sample with a Q of 8.6, and the two granite gneiss samples which show reversed magnetization. Hence, permanent magnetization may be a significant local factor in the make-up of the magnetic field of the Alberta Shield. Figure 6 shows a general increase for Q with an increase of induced magnetization, indicating that rock units in the map area possessing high remanence are commonly also those of high susceptibility.

The magnetic susceptibility of rocks from the Alberta Shield depends most significantly on their magnetite content. Figure 7 shows a cross plot of magnetite content versus magnetic susceptibility for a number of granite gneiss samples from the map area. These data were obtained from tables given by Watanabe (1965). A definite log-linear relationship is apparent between magnetite content and susceptibility.

As illustrated in figure 8, rock units of the Alberta Shield show a wide range of magnetic susceptibility. These data are based on laboratory measurements on about 650 standard samples (powdered form) by the Alberta Research Council. Typically, granite gneiss samples have higher magnetic susceptibilities than do most granitoids. Apparently a simple correlation between magnetic susceptibility and mafic mineral content, as reported by Krutikhovskaya et al. (1978) for the Ukrainian Shield and Henkel (1976) for the Baltic Shield, does not exist for granitoids of the Alberta Shield. For example, the Fishing Creek Quartz Diorite, which commonly contains from 7 to 20 percent mafic minerals (Godfrey, 1980a), has very low susceptibility. Similarly, the Wylie Lake Granodiorite, a relatively mafic rock unit, also shows low susceptibility. Conversely, two rock types of granitic (felsic) composition, the Chipewyan Red Granite and the Arch Lake Granitoids, have moderately high susceptibility. On the other hand, two granitoids do fit the general rule. The La Butte Granodiorite is a granitoid of mafic composition with a high susceptibility, and the felsic Slave Granitoids show an overall low susceptibility.

The moderately high susceptibility of the Arch Lake Granitoids contrasts with that of the Fort Smith porphyry, a granitoid unit just north of the study area and thought by Charbonneau (1980) to be the equivalent of the Arch Lake Granitoids. The Fort Smith porphyry crops out immediately north of the study area but is separated from the main mass of the Arch Lake

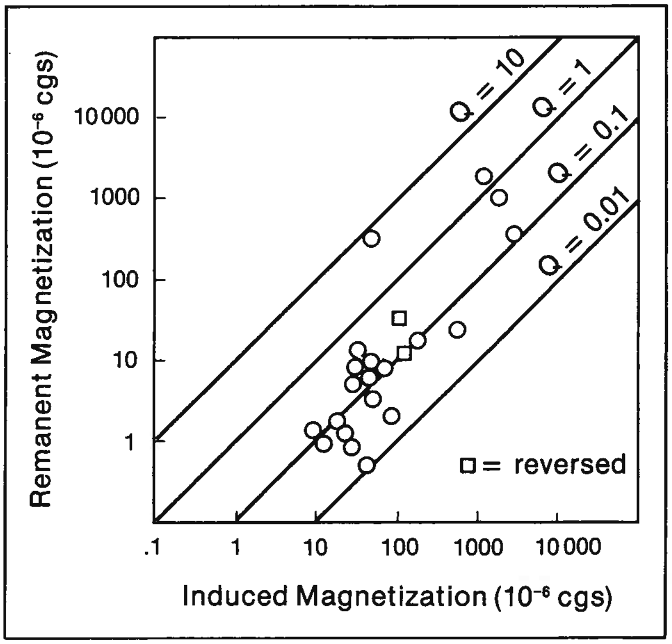

Figure 6. Cross plot of remanent magnetization versus induced magnetization of rock samples from the Alberta Shield. The ratio (Q) of remanent to induced magnetization is shown by the diagonal lines.

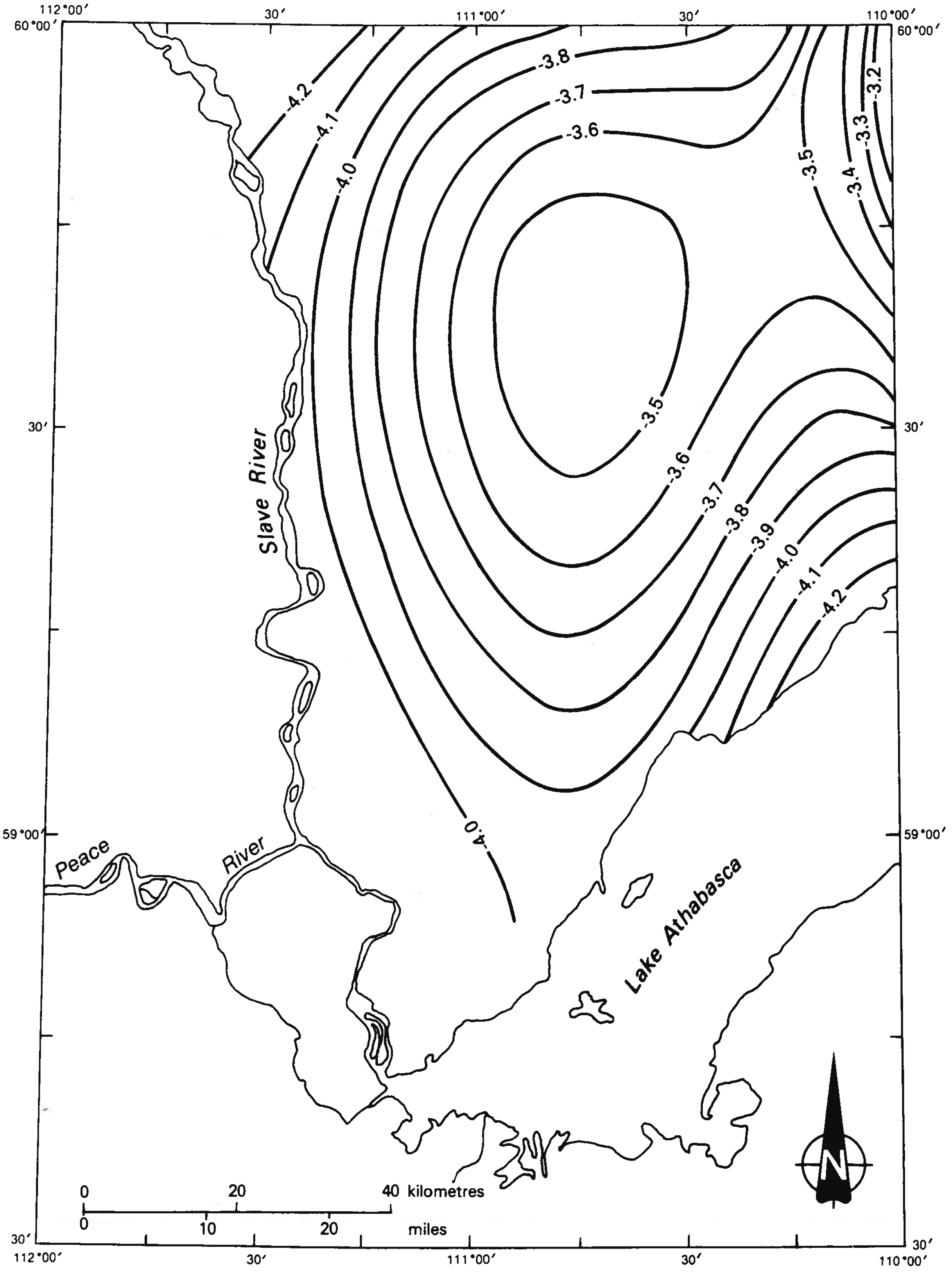

Figure 9. Trend surface map of the logarithm of the magnetic susceptibility of standard samples from the Alberta Shield. The contour interval is 0.1 logarithmic cgs units.

Magnetic patterns

The magnetic field of the Alberta Shield exhibits a complex character that reflects the distribution of magnetic minerals in the bedrock outcrop. Two types of magnetic patterns are dominant in the study area: 1) sets of linear anomalies, typically aligned north and northeast (figure 10); and, 2) sets of randomly distributed circular to arcuate anomalies (figures 11, 12, 13). The latter type of pattern generally shows less magnetic intensity than the former. The linear anomalies possibly formed in two stages. Their development was influenced initially by the grade of regional metamorphism, and secondly by the degree and extent of localized shear. The circular-type anomalies indicate less shear deformation than is the case for the linear-type anomalies, and are interpreted as a preserved state of primary magnetic mineral distribution in granitoid masses.

Magnetic contours on the Alberta Shield commonly reflect the major contacts and foliation trends of the bedrock. Magnetic highs are typically observed over the granite gneiss and certain granitoid masses of high susceptibility. In general, magnetic lows in the study area are associated with metasedimentary bands, low susceptibility granitoids, and mylonite zones. Some anomalously low magnetic field values over parts of the Slave Granitoids may be associated with localized metasomatism; such areas are also marked by a high K40 radiometric expression. A similar observation has been made for granitoids in the Ukrainian Shield by Krutikhovskaya et al., (1978).

Linear-type anomalies

Linear-type anomalies trending north and northeast are the dominant magnetic features of the Alberta Shield (figure 10). These anomalies are spatially and genetically connected with the depositional, deformational, and metamorphic histories of the area. The distribution of metamorphic facies within the rocks of the Alberta Shield is shown in figure 14. Rocks which have undergone a high grade of metamorphism show the destruction of primary textures, and acquire a metamorphic fabric, generally with a preferred orientation. Localized shear in the Alberta Shield has apparently moved magnetic minerals into concentrations that are conformably aligned within the major fault zones. It is difficult to ascertain how much of the apparent mineral redistribution and alignment is related directly to late-phase faulting, and how much is due to regional mylonitization associated with regional metamorphism. Most of the linear-type anomalies are located in granite gneiss terrane, which, typically, is both fault dissected and highly metamorphosed.

If linear-type anomalies occurred only in the Archean granite gneiss, then it might be argued that the observed pattern could represent either a relic-like Archean fabric or a ghost stratigraphy related to the original distribution of magnetite. However, rock units other than granite gneiss also form linear-type anomalies in the vicinity of major fault zones. The Warren Fault Zone, east of Tulip Lake (figures 15a & b), is one example where a wide variety of rock units exhibit linear anomalies adjacent to the fault zone.

The mineral redistribution and alignment responsible for many of the linear-type anomalies were probably produced by localized shear within major fault zones during regional metamorphism. Under granulite facies conditions, plastic deformation, accompanied likely by regional shear, caused the redistribution and the alignment of magnetic minerals along regional foliation. This first stage in the genesis of linear-type anomalies can be seen today in the magnetic field over the Slave Granitoids near Ryan Lake (figure 16), where the magnetic contours follow the metamorphic foliation as a result of regional metamorphism.

The second stage involves localized shearing on the already-formed regional foliation, resulting in the formation of linear anomalies, as seen at Ashton Lake (figure 10). Godfrey (1980a) noted that the rock foliation of granitoids in the Wylie Lake area (figure 2) became better defined close to major shear zones. Ellwood and Abrams (1982) working on the magnetization of the Austell Gneiss in northwest Georgia showed that magnetic contours agree closely with structural foliation planes. Similarly, Rathore (1982) reported that deformation events could be recognized in Dalradian rocks from southwest Scotland. This conclusion was based on both magnetic and structural data, which together, showed a high degree of correlation. As the above studies have shown, the magnetic properties of metamorphic rocks are strongly influenced and closely related to their deformational history. This observation is consistent with similar data from the Alberta Shield.

Mylonite zones are in close proximity to some linear-type magnetic anomalies. These mylonite zones are the surface expressions of deep-seated, regional shears that have involved ductile deformation during metamorphism. Much more-localized, brittle deformation has taken place along fault surfaces within the mylonitic zones, subsequent to erosional stripping and uplift.

Wide zones of mylonitic rock lie within the major shear zones of the study area. Regional geophysical model studies (Sprenke, 1982), and geological field mapping (Godfrey, 1980a), indicate that these major shear zones extend to great depth. The magnetic field pattern suggests that these zones also affect a considerable width. Linear-type anomalies were observed, transversely, as far as 10 km from the outcrop expression of the major mylonite zones. This is perhaps an indication of the lateral limits of shear related to these regional shear zones.

Fault traces within the Alberta Shield commonly show linear-type negative magnetic anomalies. Watanabe (1965) discovered that these magnetic lows are directly associated with mylonitic zones. Detailed field and laboratory work by Watanabe revealed that most of the magnetite in the mylonitic zones was altered by oxidation to hematite during mylonitization. In general, where shearing is sufficiently intense to produce regional mylonitic zones, the linear-type magnetic anomaly pattern is enhanced as a result of extensive magnetite alteration.

Linear-type magnetic anomalies can also reflect the initial stratigraphic distribution of magnetite in the

Figure 10. Linear-type aeromagnetic anomalies in the Ashton Lake area. (G.S.C., 1964q). See figure 3 for location.

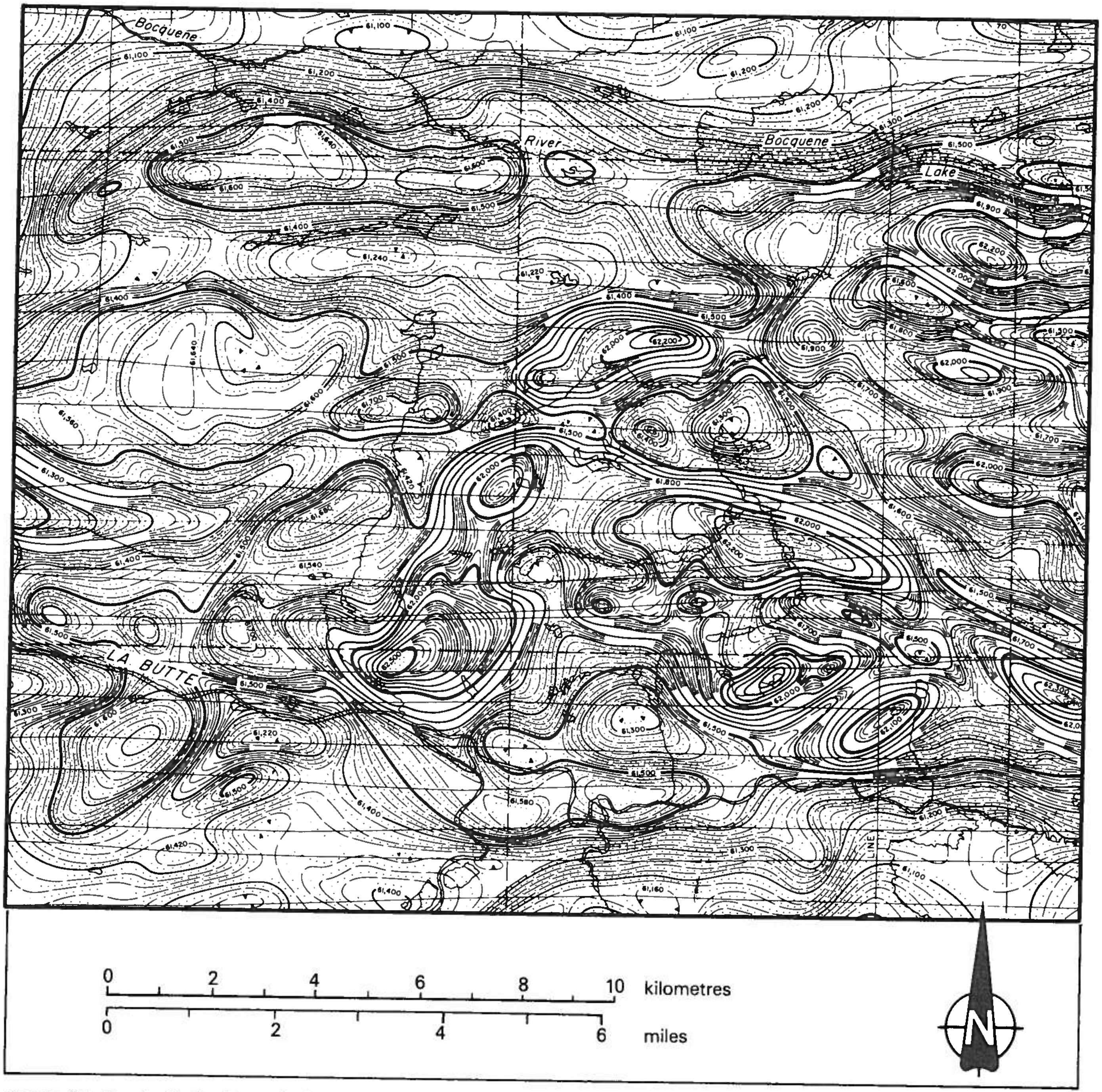

Figure 11. The La Butte Granodiorite displays a circular-type magnetic pattern. (G.S.C., 1964k). See figure 3 for location.

parent sediments. The largest metasedimentary band in the study area, exposed west of Loutit Lake (figure 3), is distinguished by a large negative linear anomaly with many small, local magnetic lows throughout its length (figure 17). Negative linear-type magnetic anomalies are also associated with other major metasedimentary bands within the Charles and Andrew Lakes regions. The rock susceptibility chart (figure 8) indicates that high-grade metasedimentary rock bands show a large range of susceptibilities with a mean value similar to the Alberta Shield as a whole. Therefore, metasedimentary rock bands within granite gneiss terrane, such as west of Loutit Lake, will produce relatively low magnetic fields. Areas within the metasedimentary rock bands which show strong positive magnetic anomalies are of exploration interest in that they represent local concentrations of magnetite. The magnetically intense Virgin River metasedimentary belt (Wallis, 1970) and Wollaston Fold Belt metasediments (figure 4)(Money, 1968) are known to have syngenetic base metal mineralization. Similar mineralization might exist in the Alberta Shield.

Not all magnetic anomalies within the metasedimentary bands should be interpreted in terms of primary magnetite distribution. Some magnetic lows may be related to mineral alteration, possibly hydrothermal in

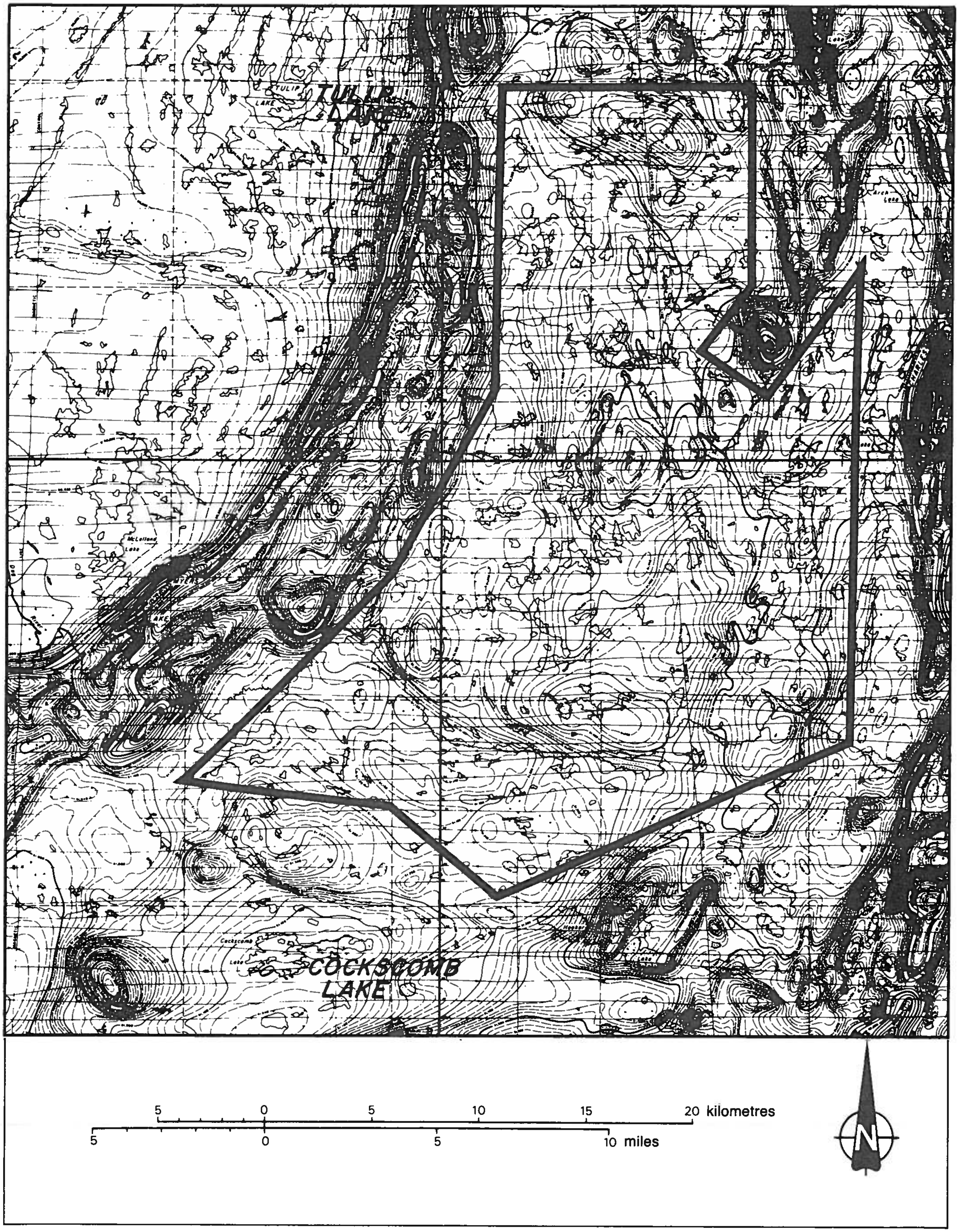

Figure 12. Aeromagnetic map over the Arch Lake Granitoids (outlined area), displaying a circular-type pattern of subdued intensity, due to the relatively low susceptibility of the granitoids. (G.S.C., 1964u). See figure 3 for location.

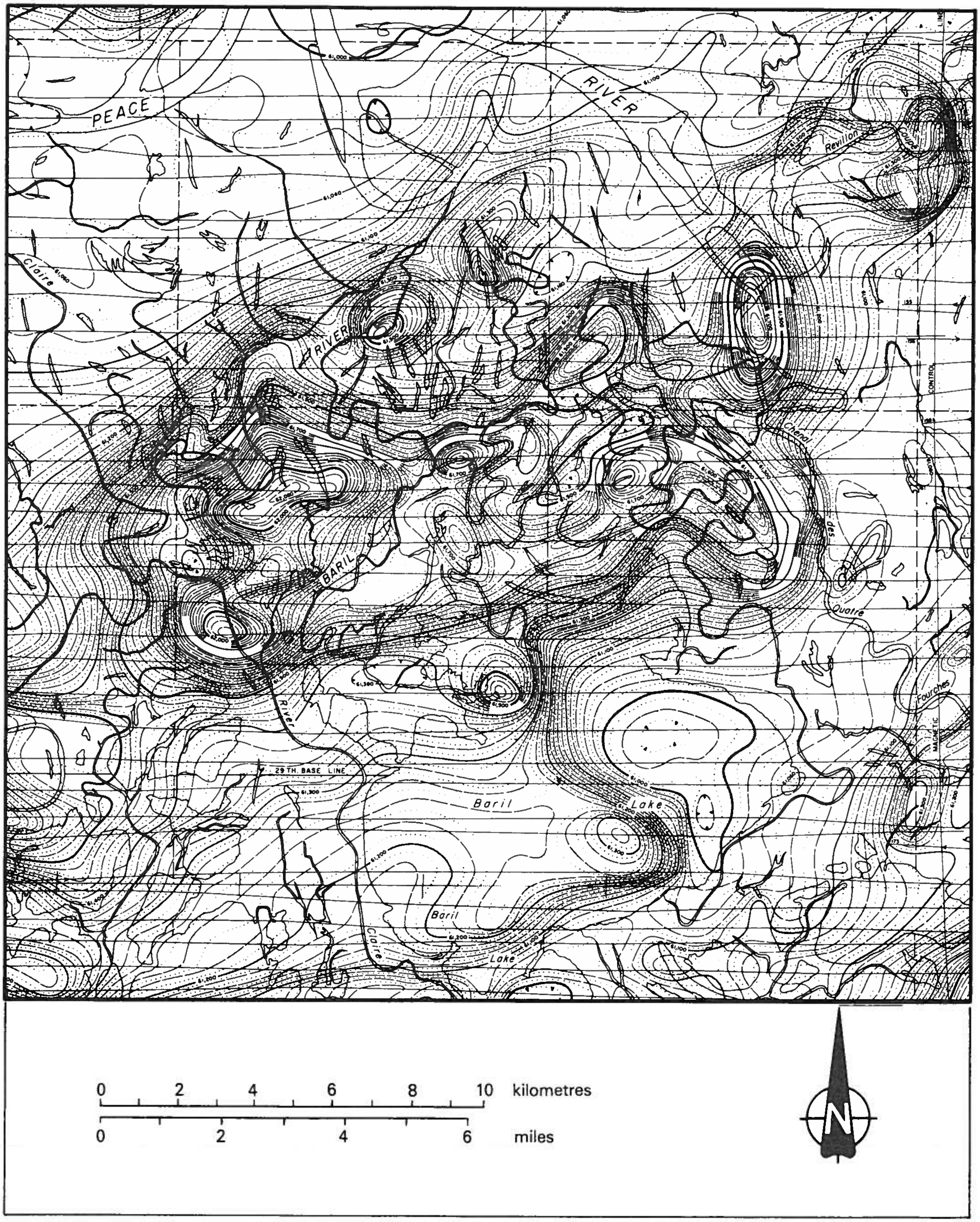

Figure 13. Aeromagnetic map showing a closed magnetic anomaly situated in the Baril Lake area. The anomaly originates in Shield rocks beneath a cover of Paleozoic rocks and recent deltaic sediments. It displays a circular-type pattern, and is probably associated with a granitoid mass similar to the Chipewyan Red Granite. (G.S.C., 1963d, 1964d). See figure 3 for location.

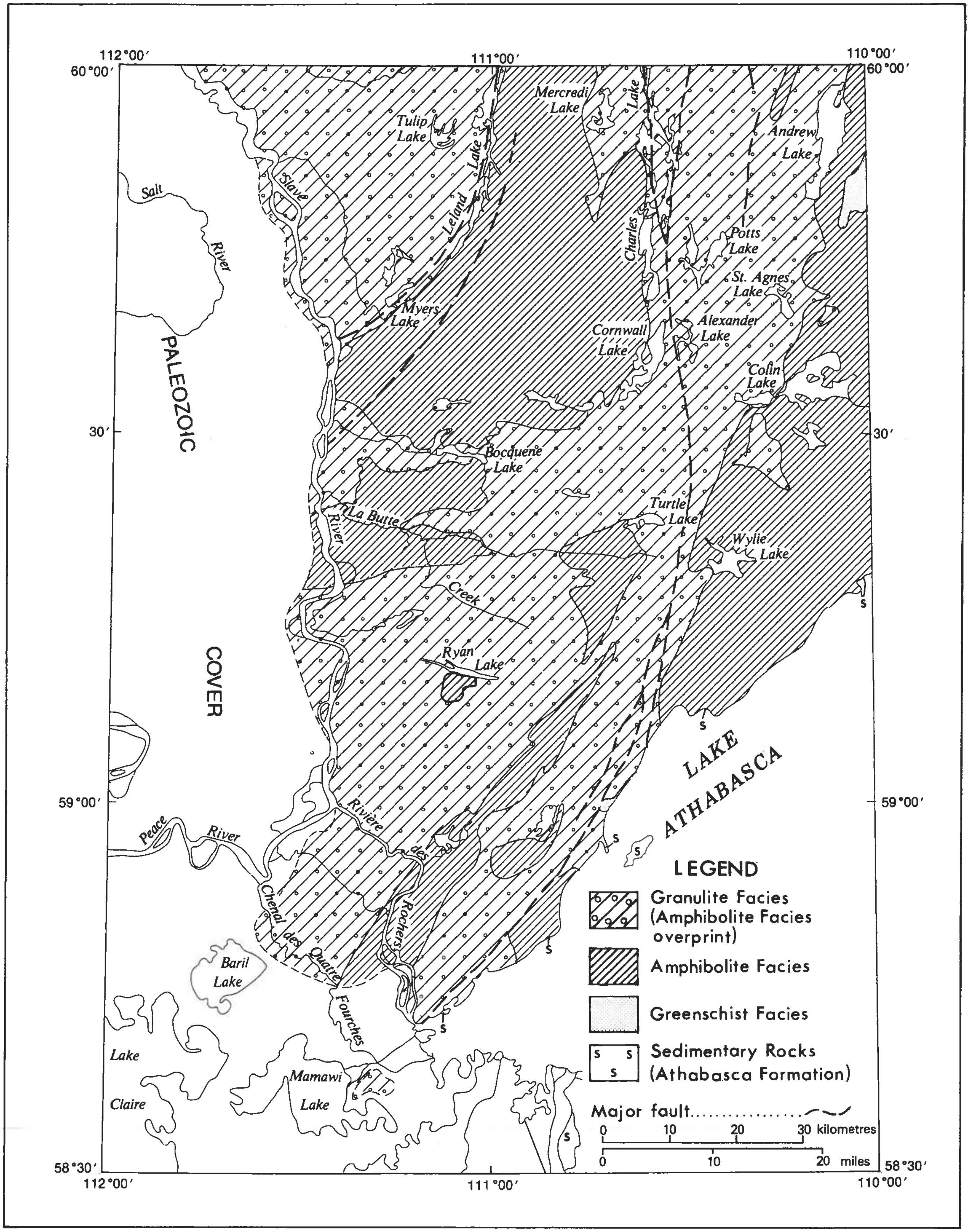

Figure 14. Metamorphic facies in the Alberta Shield (Langenberg and Nielsen, 1982).

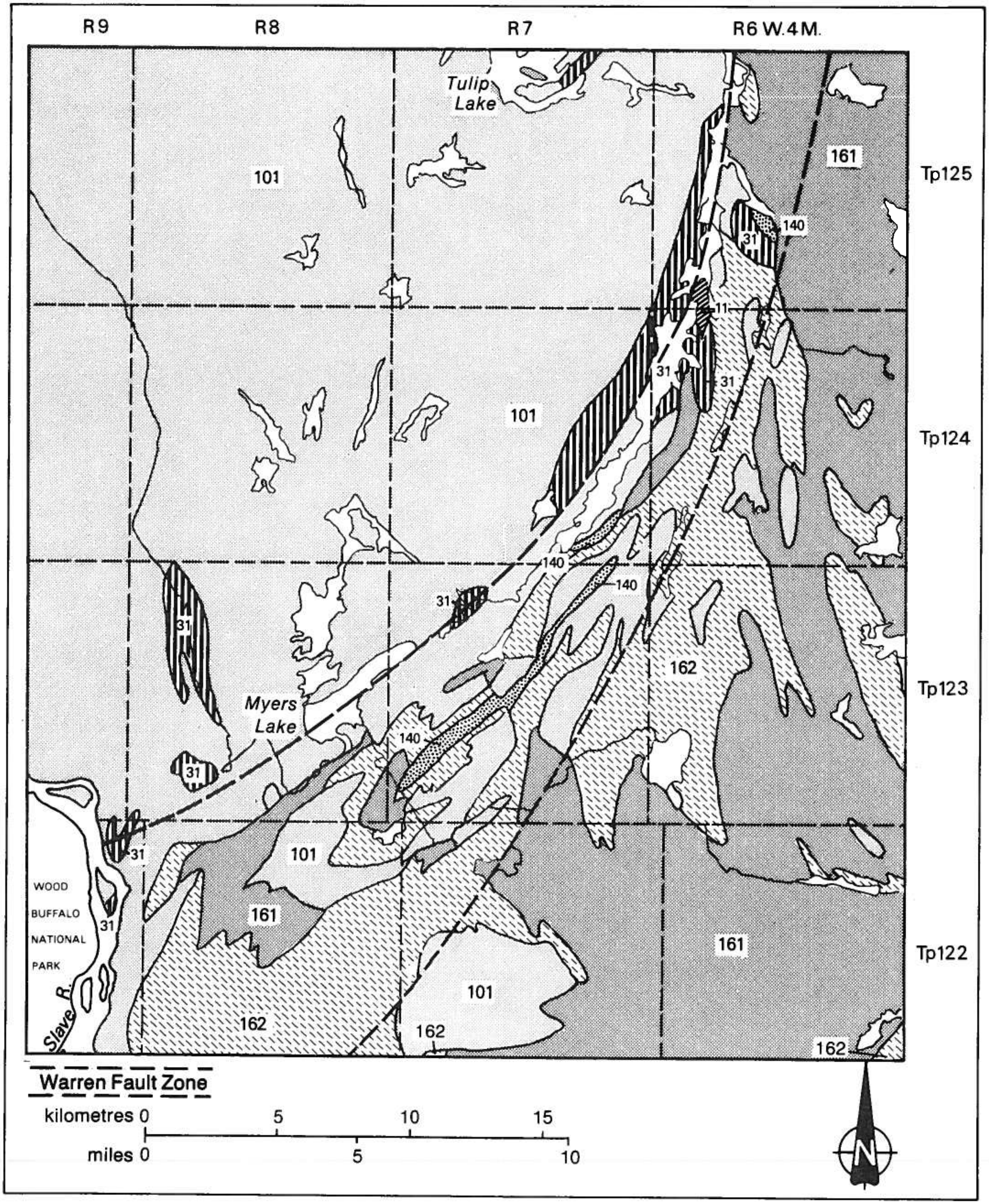

Figure 15a and b. Development of linear-type anomalies over foliated rocks, enhanced by localized shear along the Warren Fault Zone. The magnetic map 'b' (G.S.C., 1964u) is on the right, and the geologic map 'a' is on the left. In this area the linear-type anomalies have formed in a terrane virtually lacking granite gneiss. Legend: granite gneiss 11; metasediments 31; granitoids 101, 140, 161, 162. See figure 3 for location.

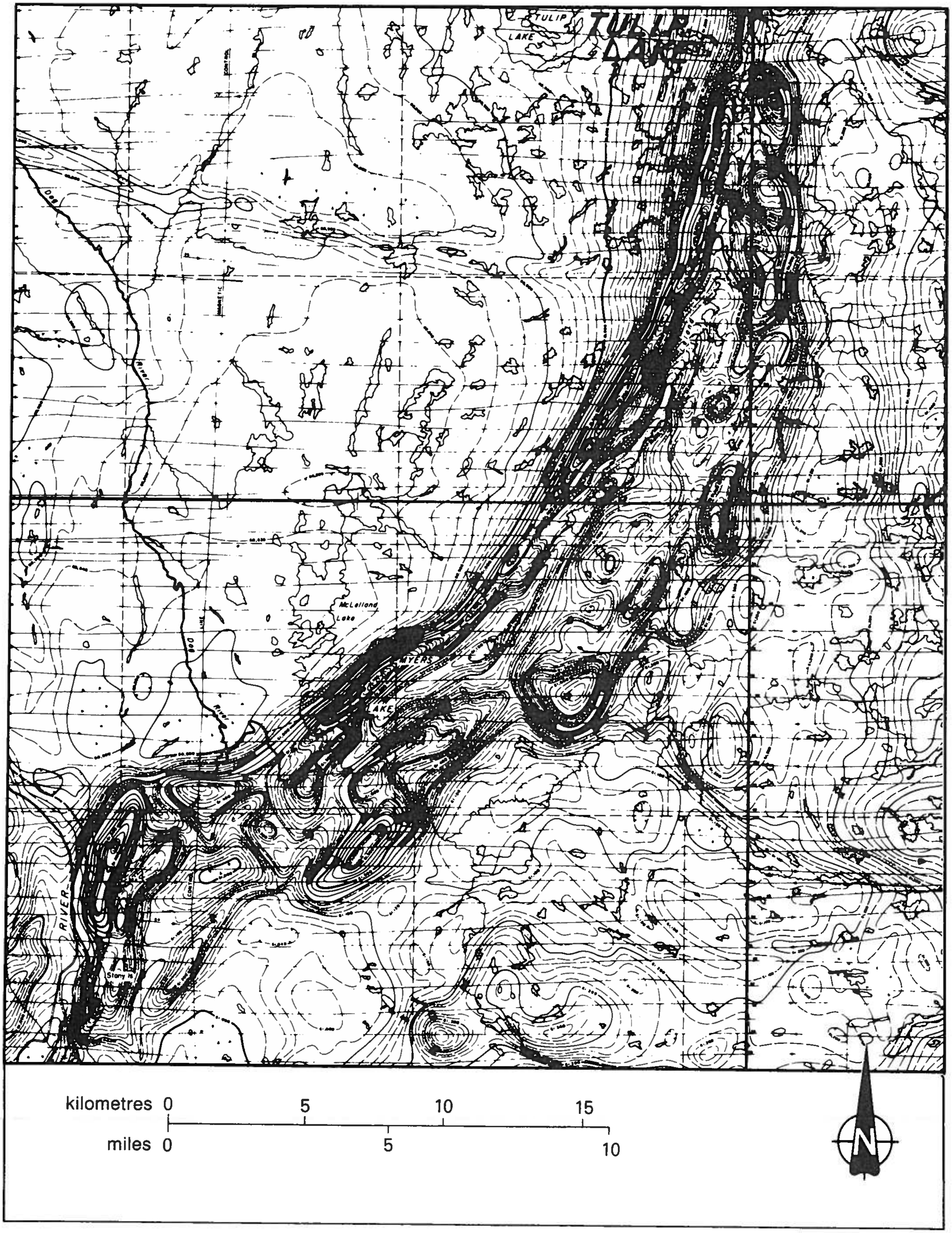
TULIP LAKE
TULIP LAKE
McLelland Lake
MYERS LAKE
RIVER
RIVER
Stony Is.
kilometres 0 5 10 15
miles 0 5 10
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Figure 15b.

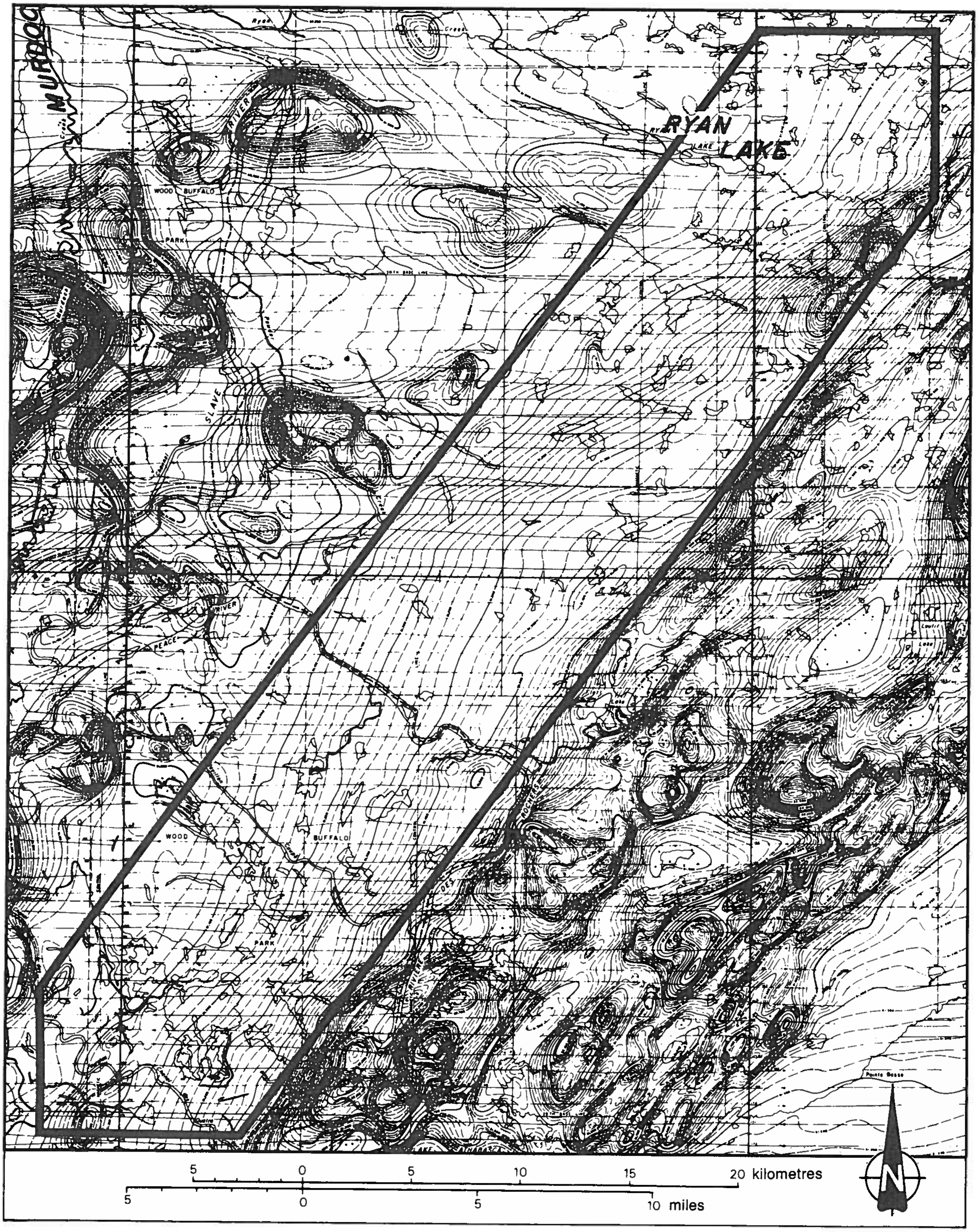


Figure 16. First stage in the development of a linear-type anomaly (outlined area) in the Ryan Lake area. Smooth magnetic contours over the Slave Granitoids result from regional metamorphism, and correspond to the regional foliation. (G.S.C., 1964c, g). See figure 3 for location.

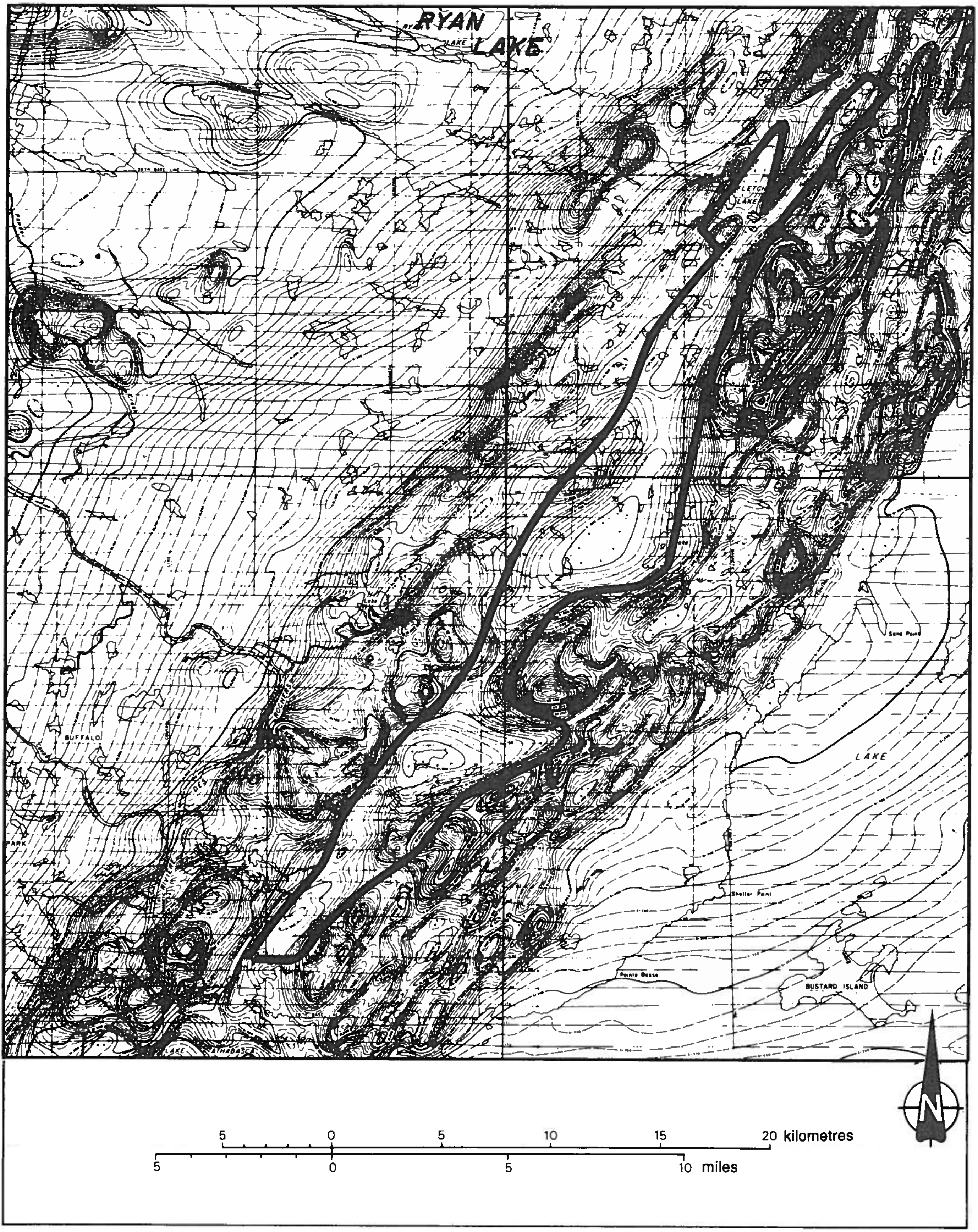


Figure 17. Aeromagnetic map west of Loutit Lake. The outlined area indicates the outcrop pattern of a large metasedimentary rock band having a low magnetic signature. (G.S.C., 1964b, c, f, g). See figure 3 for location.

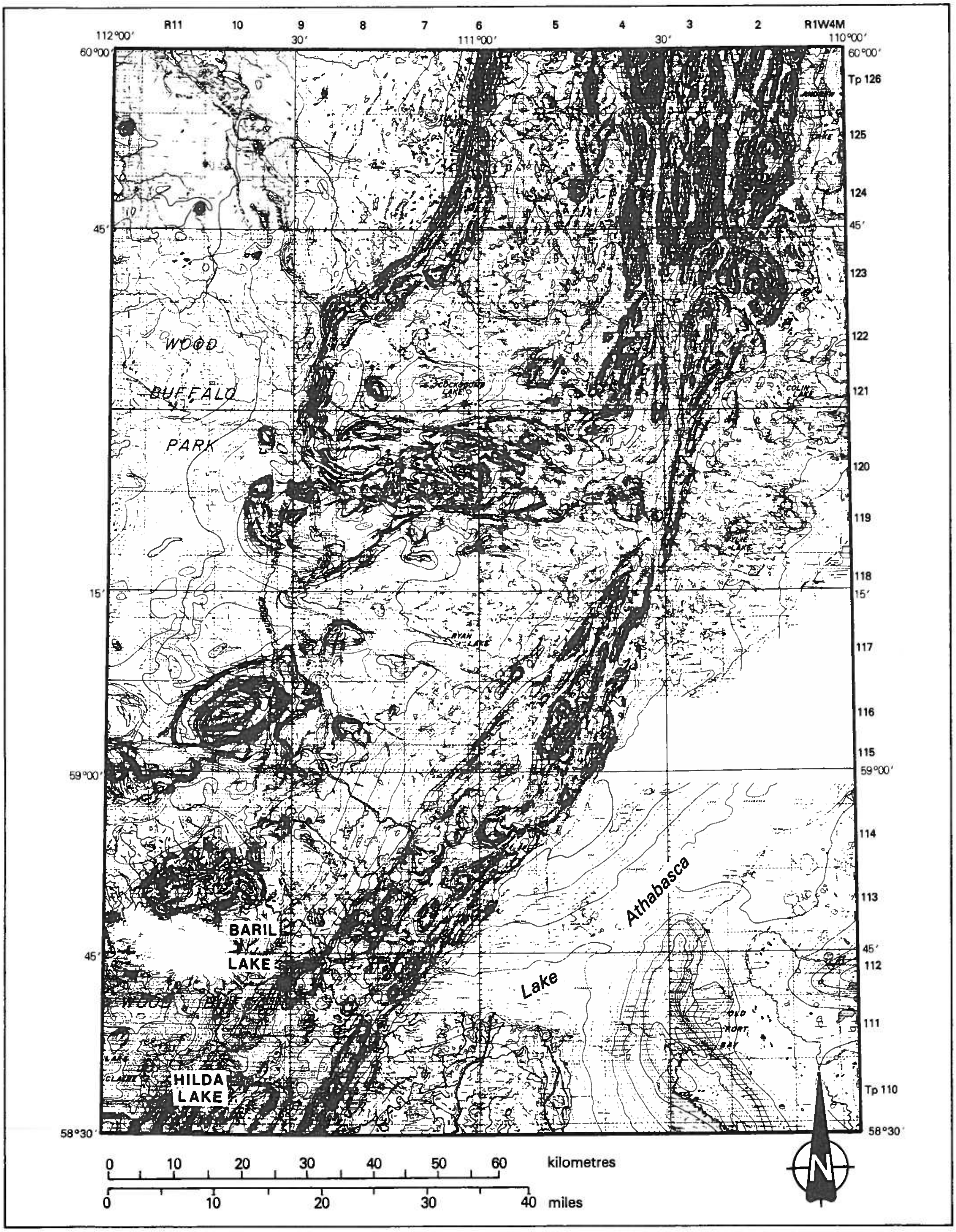


Figure 18. Aeromagnetic map of the Canadian Shield in northeastern Alberta. (G.S.C., 1964u, v).

origin. Godfrey (1958a, 1966, 1980b) noted that, in the Alberta Shield, base metal mineralization and gossans occur mainly in metasedimentary rock bands.

The highest linear-type magnetic values were found primarily in the granite gneiss units, and occasionally in minor amphibolite. A linear granite gneiss belt with a north to northeast orientation has been mapped over the entire length of the study area (figure 18), and can be easily traced from aeromagnetic data. Although Shield outcrop terminates south of Fort Chipewyan, the magnetic data shows that the granite gneiss belt continues southward, beyond the exposed Shield.

Typically, the granite gneiss has a low mafic mineral content (Godfrey, 1980a and 1980b), yet it displays one of the strongest positive magnetic trends in the study area. Watanabe (1965) analyzed the mineral contents of several granite gneiss samples, and concluded that gneiss can contain up to 1 percent magnetite by volume (figure 7), thus explaining the high magnetic intensity associated with this rock unit. However, the genesis of magnetite in the granite gneiss is unexplained.

Circular-type anomalies

The second major type of magnetic anomaly within the study area involves unevenly distributed, circular to arcuate, positive anomalies (figures 11, 12, 13). Krutikhovskaya et al., (1978) noted that granitoid domal masses in the Ukrainian Shield produce a random magnetic pattern, due to an uneven distribution of magnetic minerals within the granitoid. Similarly, circular-type patterns within the Alberta Shield are thought to result from an uneven magnetic mineral distribution within some granitoids. The circular-type anomalies (figure 10) are easily distinguished from linear anomalies (figures 11, 12, 13).

In the Alberta Shield, granitoid masses with circular-type anomalies are generally located far from major fault zones, and have undergone only amphibolite facies metamorphism. The formation of these anomalies is believed to be related to primary magmatic processes unaltered by subsequent deformation or metamorphism. Hence, unlike the linear anomalies, these anomalies arise directly from the primary magnetic signature.

Characteristic circular-type anomalies occur over the La Butte-Francis Granitoids (figure 11) and the main Arch Lake Granitoids Complex (figure 12). The La Butte Granodiorite has a greater magnetic susceptibility than the Arch Lake Granitoids (figure 8), and, for this reason, it shows a higher level magnetic signature with more amplitude.

The Chipewyan Red Granite also has a circular-type anomaly. This pluton has been mildly deformed, compared to other granitoid masses of the Alberta Shield (Godfrey, 1980b). Therefore, much of its primary geophysical character is preserved.

From the Slave Granitoids, (figure 2) much useful data are available to help unravel the interrelationships of magnetic pattern, metamorphism, and structure in granitoids of the Alberta Shield. The magnetic field over the Slave Granitoids in the Ryan Lake area (figure 16) does not show a circular-type pattern, but trends parallel to rock foliation. The Slave Granitoids have undergone granulite facies metamorphism, followed by an amphibolite facies overprint. Regional metamorphism, accompanied by shearing, has apparently destroyed the primary circular-type pattern, and caused the magnetic trends to be aligned with rock foliation. No linear-type anomalies occur in this area, possibly due to the absence of major fault zones.

Further evidence that the magnetic field over the Slave Granitoids follows the rock foliation trend can be seen in the immediate vicinity of Ryan Lake (figure 19). Here, rotational movement associated with minor faulting has led to changes and realignment of both rock foliation and magnetic contours. This example demonstrates that faulting can play an important role in the development of the local magnetic signature of a rock unit.

The Slave Granitoids show a circular-type pattern near the eastern limit of the La Butte-Francis Granitoids (figure 2), despite the fact that the granitoids in this area have undergone granulite facies metamorphism. The intense magnetic pattern over the Slave Granitoids here is very similar to the pattern over the nearby La Butte, Francis, and Arch Lake Granitoids (figures 2 and 18). Hence, the character of the magnetic field at this location is probably not due to the Slave Granitoid outcrops, but rather to another granitoid mass concealed at a shallow depth. The La Butte, Francis, and Arch Lake Granitoids have a higher magnetic susceptibility range than do the Slave Granitoids (figure 8), and their stronger magnetic character would dominate over the relatively mild magnetic response of overlying Slave Granitoids. Intrusion of the La Butte, Francis, or Arch Lake Granitoids into Slave Granitoids is consistent with some field relationships (Godfrey, 1980b).

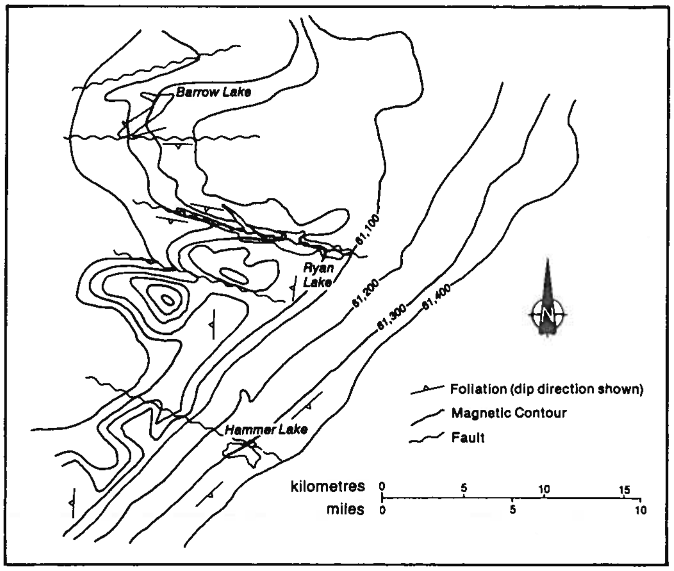


Figure 19. The simplified aeromagnetic field of a faulted area surrounding Ryan Lake (G.S.C., 1964f, g). Local variations in the magnetic field correspond with westerly trending faults. In this area the magnetic field is notably influenced by the structural discontinuities in the bedrock.

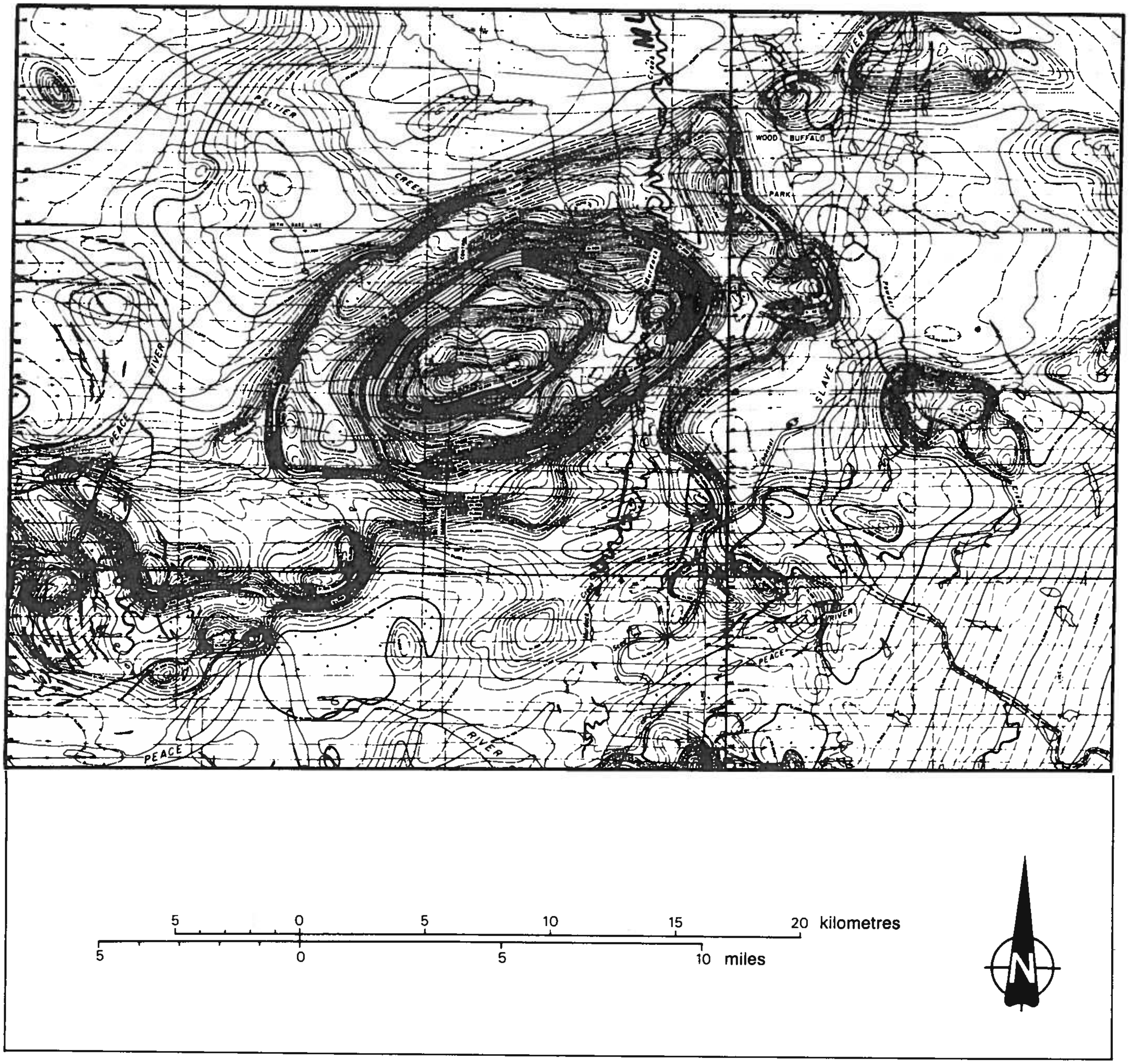


Figure 20. An elliptical aeromagnetic anomaly in the Murdock Creek area (G.S.C., 1964c, d, g, h). The form of the anomaly is unlike either the circular-type or the linear-type patterns. See figure 3 for location.

Based on anomalous magnetic patterns, distinctive rock masses are indicated beneath Paleozoic cover to the west and southwest of the exposed Shield. Two circular-type anomalies were noted: at Hilda Lake and Baril Lake (figure 18). Both anomalies indicate the possible presence of buried granitoid masses. The Hilda Lake anomaly suggests a southward continuation of the Chipewyan Red Granite. A very large, positive magnetic anomaly at Murdock Creek is peculiar in that it has a form unlike any other anomaly seen on the Alberta Shield (figure 20). Its high magnetic amplitude and elliptical form in plan view suggest that it could be caused by a relatively homogeneous basic intrusion.

Magnetic autocorrelation analysis

Statistical analysis of magnetic data from the Alberta Shield was used to help understand the tectonic setting of the area and to decipher the genetic aspects of the magnetic field. The two-dimensional autocorrelation function of the magnetic field over the Alberta Shield is shown in figure 21. An oblate ellipsoid, having its long axis in a north-south direction and short axis in an east-west direction, best describes the form of the magnetic autocorrelogram. The axes of this ellipsoid correspond to major fault trends within the Alberta Shield. The long axis corresponds to the north-south trending Allan Fault Zone (figure 2), whereas the short axis correlates with numerous east-west trending faults, such as those in the vicinity of La Butte Creek. The orientation and form of elongated lakes in the Alberta Shield also reflect the same two trends. The spatial relationships of these structures indicate that a northwest stress field operated in the Alberta Shield, at least during the latter stages of its evolution.

Magnetic autocorrelation analysis may be a useful tool in unravelling the complex metamorphic-tectonic history of the Alberta Shield. In particular, the magnetic autocorrelogram may reflect the magnetic field response in rocks to the postulated regional compressive northwest-southeast stress (the last phase of tectonic activity), just preceding its transition to a more stable cratonic block.

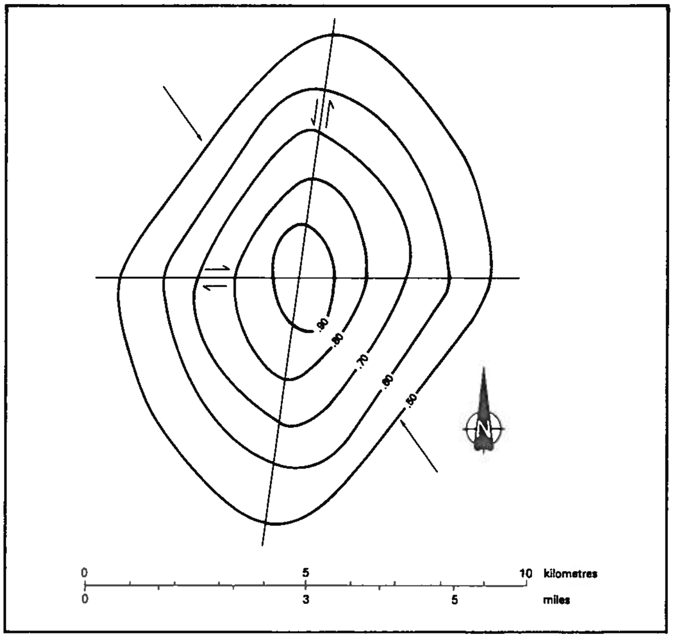


Figure 21. Two-dimensional autocorrelogram of the magnetic field of the Alberta Shield. The two shears indicated are drawn along the primary and secondary positive correlation trends. The indicated compression is assumed parallel to the direction of least correlation.

The gravity field of the Alberta Shield

Introduction

A study of the gravity field of the Alberta Shield revealed a complicated geophysical and geological problem. Gravity, surface rock density, lithology, structural geology, metamorphic facies, and magnetic data were compared and analyzed in an attempt to understand the regional geological configuration which governs the gravity expression of the study area.

Previous gravity studies in the Canadian Shield have emphasized qualitative comparisons of surface bedrock geology, surface rock density, and the observed gravity field. Gendzwill (1969), working in the Amisk-Flin Flon area, Saskatchewan, collected 1855 fresh bedrock samples within a 280 km² (110 mi²) area for density computation. These results were combined with surface bedrock geology and compared with the observed gravity field. He concluded that the gravity field over the Flin Flon area is consistent with surface bedrock geology and rock densities. Gibb (1968) collected 2000 bedrock samples from outcrop across the Churchill-Superior boundary in northern Manitoba for density determination. Like Gendzwill, he concluded that the gravity field there can be explained by the surface bedrock geology and related rock densities. He also used magnetic data and metamorphic facies relationships to support his findings.

The present study is similar to the above gravity studies in that it includes a qualitative comparison of surface bedrock geology, bedrock density at surface, and the observed gravity field. However, it goes beyond most other studies in that magnetic data, metamorphic conditions, and structural geology are also considered.

Regional tectonic stresses initially imposed a general north-to-northeast oriented structural fabric on the Alberta Shield. But this regional fabric has been locally disrupted and reoriented by another factor—probably diapiric plutonism. Diapirism is localized and limited to the shape and extent of the mobilized granitoid masses. These, in turn, are related to belts of regionally scaled tectonism, involving high-grade metamorphism and partial melting (Goff et al., in press). Therefore, regional tectonic stresses, and more locally, the processes and products related to high-grade regional metamorphism, have combined to influence the structural evolution and gravity field of the Alberta Shield.

In general, the gravity field of the Alberta Shield is influenced not only by the volume, shape, and distribution of exposed rock masses, but also by the variations in metamorphic facies, structural fabric, and rock density in the deep subsurface. The relationship between the gravity field and outcrop rock density is generally complex in the Shield of northeastern Alberta. A strong, arcuate gravity high—the Barrow-Ashton Lakes Gravity High—passes through the map area and correlates with granulite facies granitoids and granite gneisses. Gravity field and rock density data are generally consistent with the hypothesis that there is a diapiric mode of origin for the granitoid domes of the Alberta Shield.

Methods

The data for this study of the gravity field and rock densities of the Alberta Shield came from a variety of sources. Bouguer gravity data (figure 22) were obtained from the Earth Physics Branch of the Geological Survey of Canada (Walcott, 1968). In the study area, approximately 100 gravity stations were positioned on

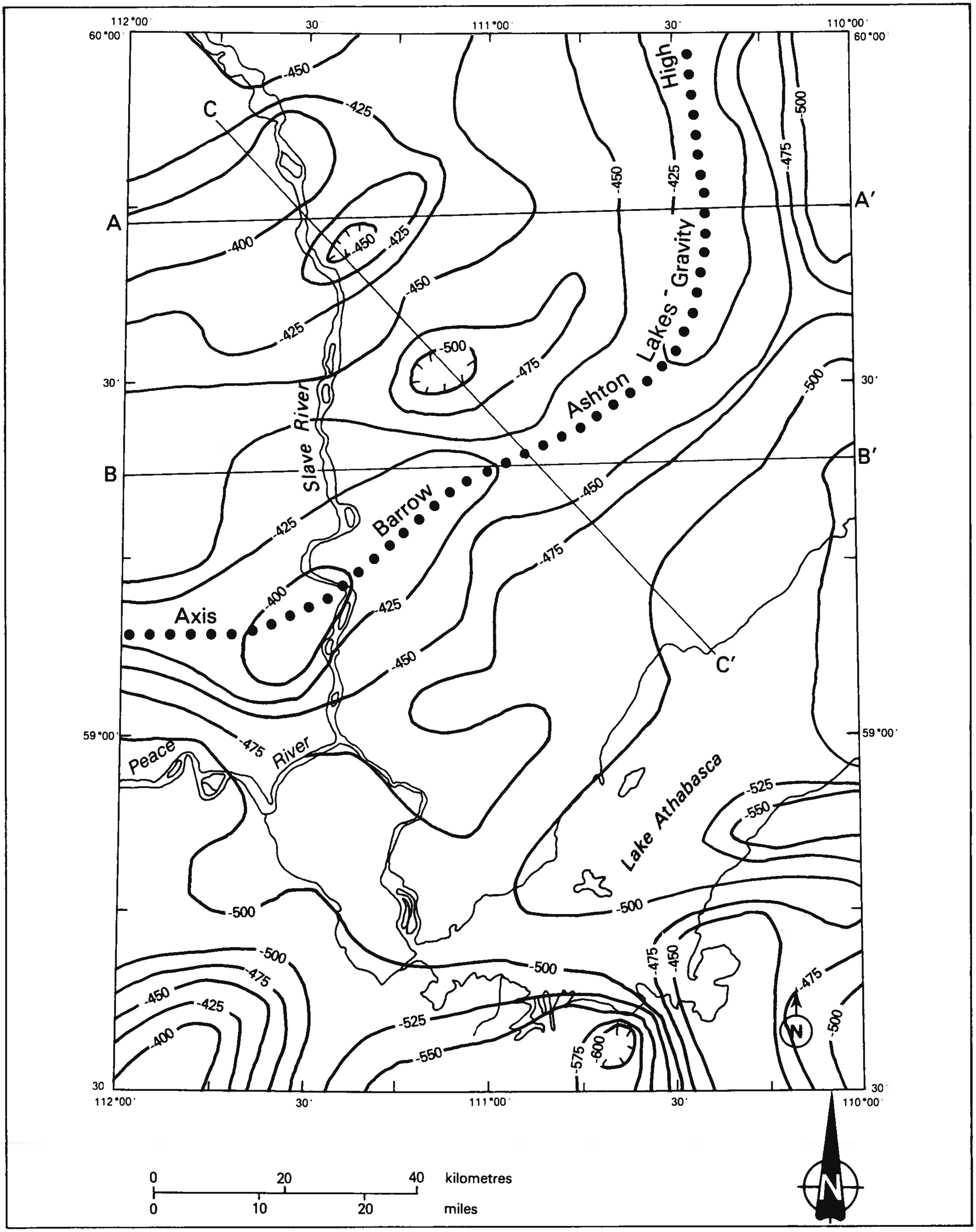


Figure 22. Bouguer gravity map of northeastern Alberta (Walcott, 1968) showing locations of profiles in figure 27. The contour interval is 25 gravity units (2.5 mgal).

a grid with lines spaced 10 km apart. Rock density averages, based on over 650 standard samples (used for mutli-analytical determinations) and over 2000 additional specimens, were all measured by the Alberta Research Council (figure 23 in pocket).

The results of this study were obtained by both qualitative and quantitative comparisons of the various data sets. Several profiles of Bouguer gravity, lithology, and rock density were drawn for direct comparisons. Maps of gravity, structure, rock density, and metamorphic facies were transformed to a common scale for easy comparison. Mean densities of rock units were derived from standard sample (outcrop) measurements by statistical analysis. Residual gravity values were determined by removing a quartic trend surface (figure 25). Trend surface analysis was also used to analyze outcrop density patterns and the relationship of outcrop density to the gravity field. Two-dimensional autocorrelation analysis was used to correlate the fabric of the gravity field with the regional tectonic framework.

Gravity and lithology

In the Alberta Shield, Bouguer gravity values range from -60 to -40 mgal (Walcott, 1968). Contours on the Bouguer gravity map of the study area (figure 24) show a series of alternating gravity lows and highs with a general northeast trend. This pattern reflects differences in the near-surface lithology, metamorphic facies, structural pattern, and subsurface rock density. The regional trend of the gravity field is illustrated by a quartic trend surface, fitted through all the gravity observations in the study area (figure 25). It shows an overall increase in gravity values from the southeast corner of the exposed Shield to the northwest corner, with a broad flat terrace in the northwest portion, underlain by Slave and Arch Lake Granitoids (figure 2).

The densities of over 650 standard rock samples from the Alberta Shield are plotted on a histogram using 80 percent fiducial limits (figure 26). The high-grade metasedimentary rocks, granitoids with a significant mafic mineral content, and granite gneisses have relatively high densities. By contrast, the more felsic granitoids have relatively low densities.

Granitoid masses within the Alberta Shield (for example, Wylie Lake, Colin Lake, and Arch Lake Granitoids), are generally associated with low gravity field values (table 2).Conversely, the Chipewyan Red Granite and Slave Granitoids exhibit moderate gravity values with locally high values. The observed gravity field over granitoid masses does not necessarily correspond with surface density values (for example, in the Wylie Lake and Slave Granitoids). This situation suggests that subsurface materials have a greater influence than surface rocks on the gravity field in the Alberta Shield. Overall, the granite gneiss units display higher residual gravity field values than do the granitoids (table 2), a result which is consistent with their relatively high density values. Metasedimentary bands show low residual gravity for the few gravity stations recorded over them.

The gravity and magnetic data show some agreement. Gravity lows tend to correspond with magnetic lows over many of the granitoid masses. Gravity highs coincident with magnetic highs are related to either granite gneiss or certain granitoids. However, there are exceptions to this general rule.

In figure 27 are three profiles of gravity, bedrock geology, and rock density along the traverse lines shown in figure 22. In profile A-A′, there is a direct correlation between Bouguer gravity, rock density, and lithology. Gravity highs are located over the granite gneiss and metasedimentary bands, and the Warren Fault Zone; gravity lows are situated over the granitoids.

In profile B-B′, on the other hand, there is an anomalous relationship between gravity and rock density. On the eastern portion of the profile, a regional gravity low is located over the relatively high-density Wylie Lake Granitoids. According to the density data, a gravity high is expected, rather than a gravity low. Lighter material probably lies at depth beneath the Wylie Lake Granitoids and causes the observed low gravity value.

In profiles B-B′ and C-C′, there is a wide range of density within some granitoid masses. These variations may be due to inclusions of mafic phases, granite gneiss, or metasedimentary bands within the granitoids.

The regional gravity data are inadequate for identifying most fault zones. The Warren Fault (figure 27 A-A′) is located near a major metasedimentary band; this may explain the gravity high in the vicinity of the fault zone at this location. Generally, mylonite zones are slightly less dense than the uncrushed, adjacent parent rock materials, and, therefore they should have low gravity values. A more detailed gravity survey would probably detect these relatively narrow mylonitic zones (Sprenke, 1982).

Gravity and metamorphism

The most prominent gravity feature in the Alberta Shield is the Barrow-Ashton Lakes Gravity High, which correlates with both structural and metamorphic features. This gravity high is bounded by the -450 mgal contour on the Bouguer gravity map (figure 22) and corresponds with high outcrop densities (figure 23, in pocket). A composite map of gravity and metamorphic facies (figure 24) shows that the Barrow-Ashton Lakes Gravity High is located predominantly in a granulite facies environment, and amphibolite facies rocks are present to a very minor extent.

The rock density distribution of standard samples from the granulite and amphibolite terranes of the Alberta Shield were combined in order to determine if there was any significant difference in density between these two terranes. The sample sizes of rock units in the standard samples do not correspond to the areal proportions of the rock units in the Alberta Shield. Table 3 compares the percentages of rock units represented in the standard samples and also in the bedrock as a whole (that is, as though all the surficial cover was stripped off). Hence, the standard sample set possesses an unavoidable bias in order for rock

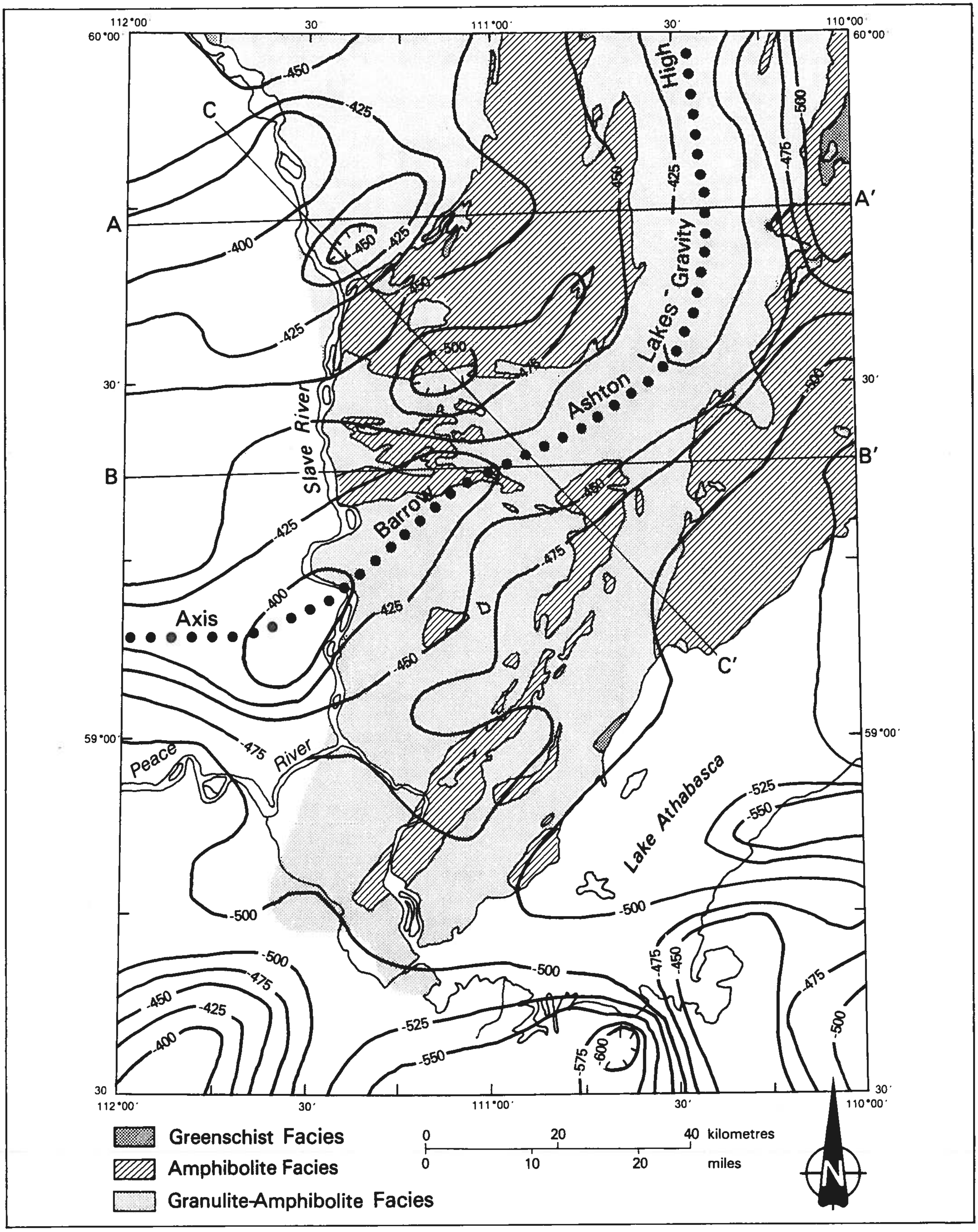


Figure 24. Bouguer gravity (Walcott, 1968) superimposed upon a modified metamorphic facies map of northeastern Alberta (Langenberg and Nielsen, 1982).

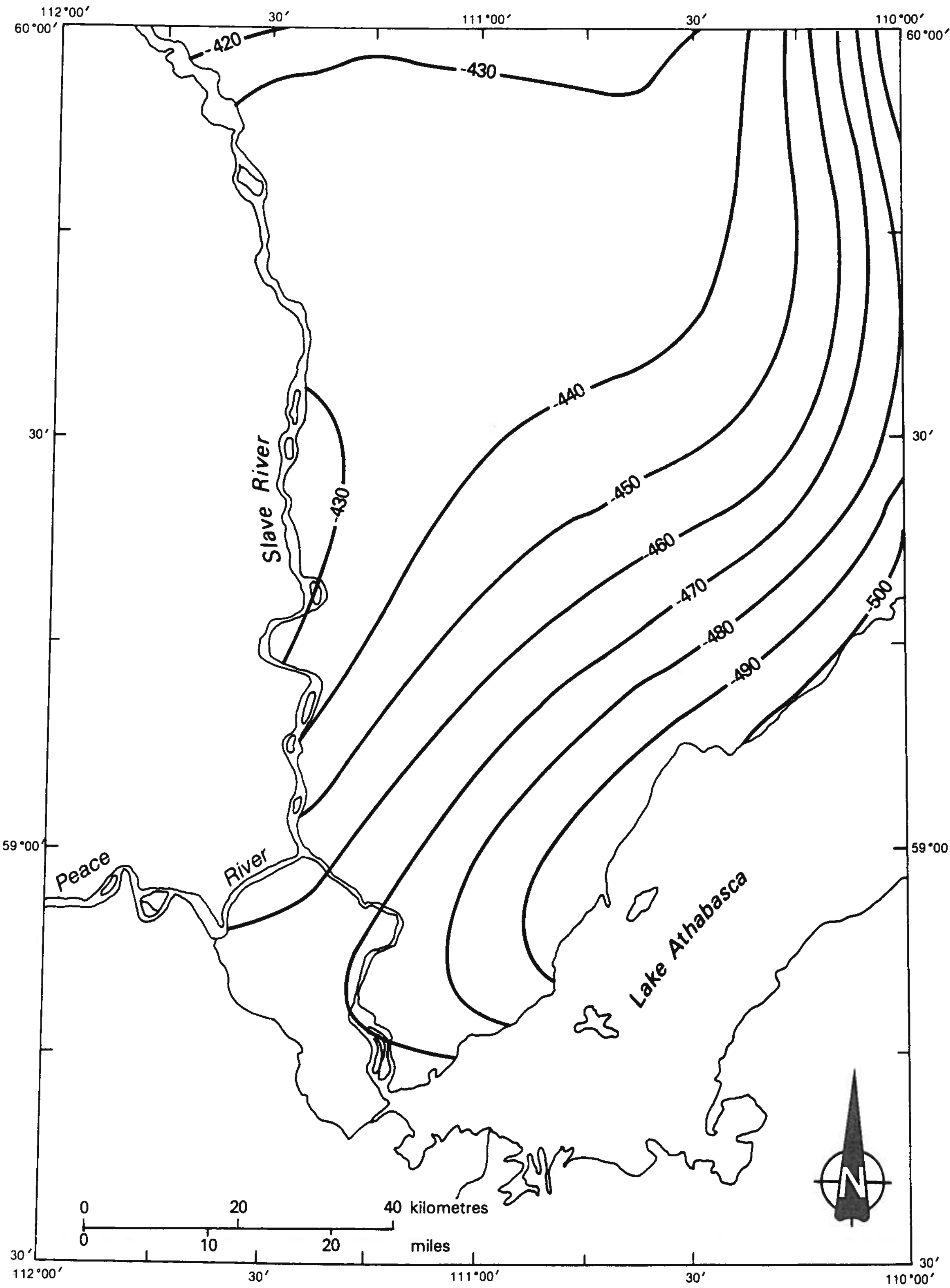


Figure 25. The regional gravity field of the Alberta Shield as determined by quartic polynomial trend surface analysis. The contour interval is 10 gravity units (1 mgal).

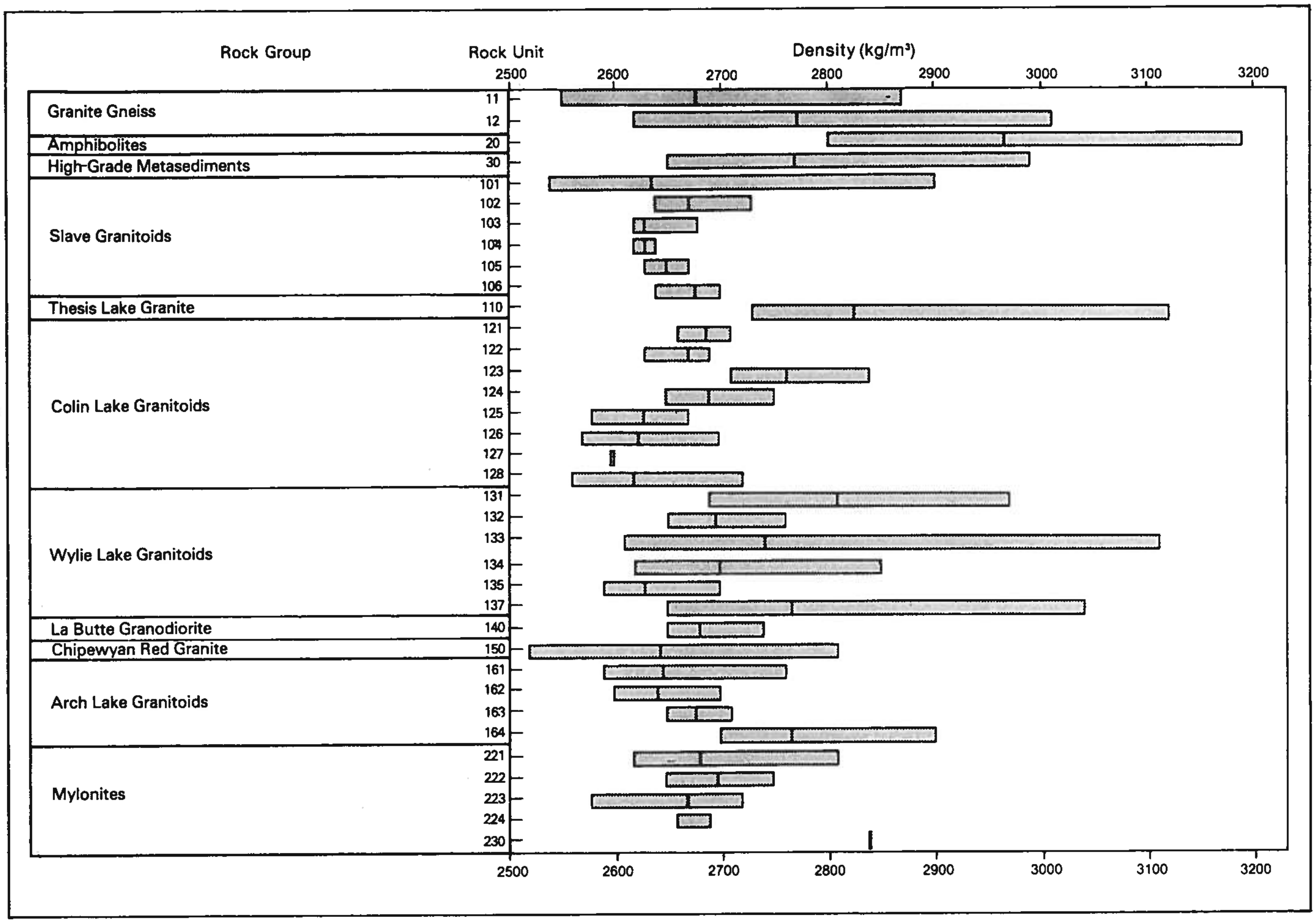


Figure 26. Density ranges for rock units in the Alberta Shield. Bar length indicates total limits of range. The line in each bar is the respective mean. Sequential numbers of various rock units are map unit designations used for the Alberta Shield.

Table 2. Residual gravity field values and mean densities of major rock types in the Alberta Shield.

Rock Group/Unit	Mean Residual Gravity Field Gravity Units ±SD	Number of Gravity Field Observations	Mean Density g/cm³ ±SD	Number of Density Samples
Slave Granitoids	+2.0 ±20.3	18	2.64 ±.037	175
Arch Lake Granitoids	−15.9 ±22.2	11	2.65 ±.038	93
Granite Gneiss	+18.5 ±24.0	13	2.69 ±.073	62
High-Grade Metasediments	−26.0 ±34.0	2	2.77 ±.059	68
Wylie Lake Granodiorite	−37.0 ±15.2	4	2.81 ±.086	50
Fishing Creek Quartz Diorite	+6.4 ±26.4	5	2.73 ±.105	22
Chipewyan Red Granite	+19.0 ±0.0	2	2.66 ±.086	10
Colin Lake Granitoids	−35.0 ±24.0	2	2.66 ±.053	59

units of low areal abundance to have adequate representation. Nonetheless, an approximation of the difference in density between amphibolite facies and granulite facies terranes can be obtained with sufficient accuracy to qualitatively interpret the gravity field.

Figure 28 displays a cumulative frequency plot of granulite and amphibolite facies rock densities in the study area. The sinuous form of the cumulative frequency plot suggests two discrete populations which, in turn, can be partitioned into two separate populations as represented by the upper and lower sloping lines on figure 28. The upper sample shows a median density of 2.96 g/cm³ and probably represents granite gneiss, high-grade metasediments and mafic granitoids. The lower partitioned sample has a median density of 2.64 g/cm³ and most likely represents granitoids of granitic composition.

Figure 29 shows separate cumulative frequency plots for granulite and amphibolite facies rock den-

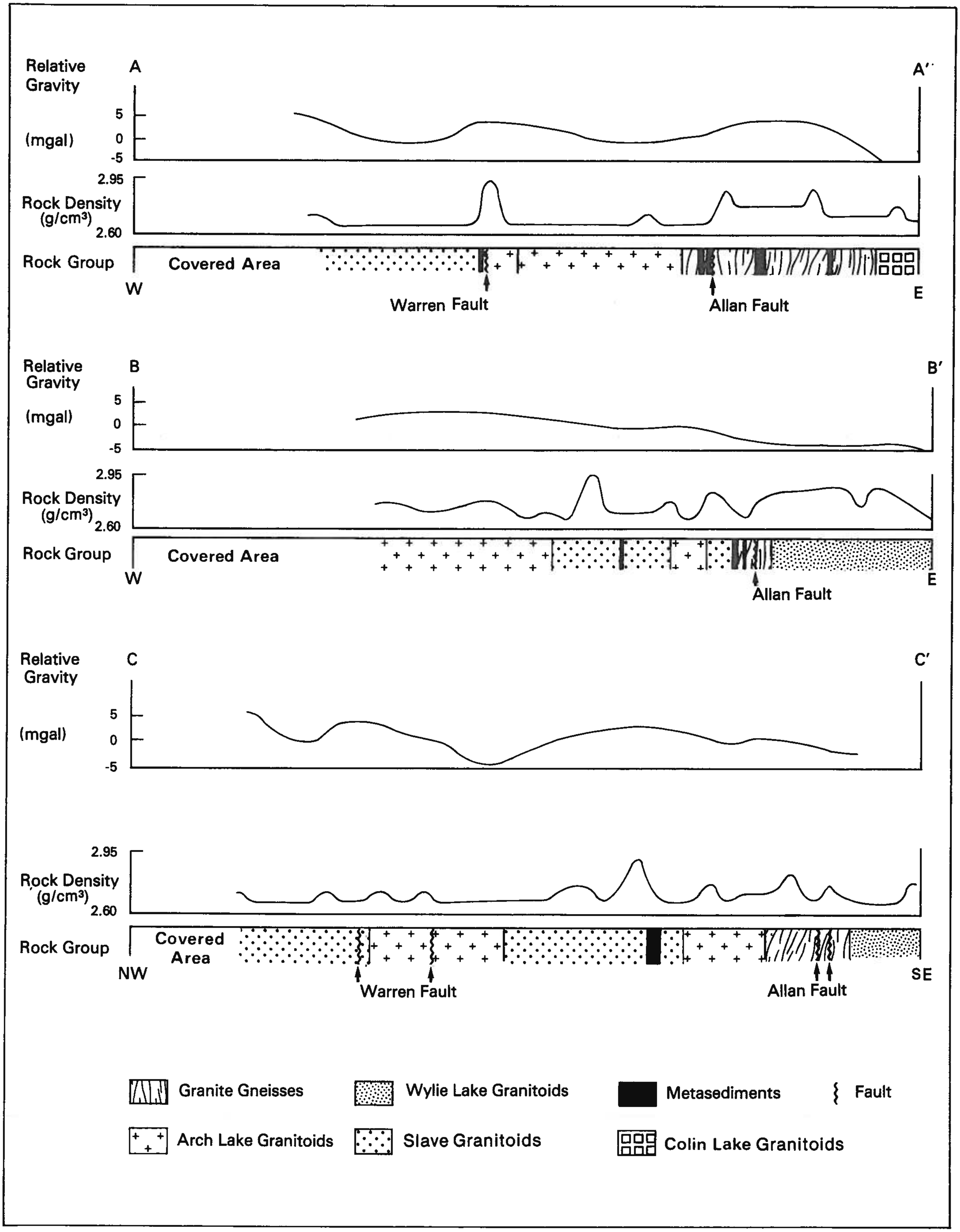


Figure 27. Profiles of Bouguer gravity, rock density, and bedrock geology along the cross-sections located in figures 22, 24.

Table 3. Areal abundances of rock groups in the bedrock of the Alberta Shield for northeastern Alberta and rock group frequency in the analyzed rock samples (in percent).

	Granite Gneiss	Amphibolite	High-Grade Metasediments	Granitoids
Standard Samples (frequency)	11	5	11	73
Areal* Abundance	20.1	0.1	6.3	73.5

*Calculated as though bedrock was exposed 100% in study area. Lithologies beneath covered areas are based on an interpretation of an aeromagnetic survey.

sities and their relationship to one another. These plots indicate that rocks in the granulite grade facies have a slightly higher mean density (0.01 g/cm^3) than rocks in the amphibolite facies environment. The lower-density portion of both curves nearly coincide, reflecting the presence of granitic rocks in both amphibolite and granulite facies terranes. However, on the higher density central portion of the curves, a pronounced deviation between the two environments can be seen. Here, the granulite facies rocks generally have a higher density than amphibolite facies rocks. The notable divergence in the density distribution at these densities may reflect: 1) the tendency for those minerals most affected by metamorphism to occur in higher-density mafic rocks rather than in the lower-density granitic rocks; 2) the difficulty in recognizing granulite facies in rocks of certain compositions; or 3) the initial density differences between (a) parent materials of the higher-density granulite facies, and (b) the higher-density amphibolite facies rocks. In general, both the original composition and the degree of metamorphism determine the metamorphic rock density.

West of the Barrow-Ashton Lakes Gravity High, the granitoid amphibolite facies belt is associated with the relatively low-density Arch Lake Granitoids and low gravity field values (figure 24, table 2). However, the eastern amphibolite facies belt is anomalous in that low gravity occurs over high-density rock—a combination of Wylie Lake Granitoids, minor granite gneiss, and the moderate- to high-density Colin Lake Granitoids. Therefore, a deficiency in crustal mass is postulated to exist in this area, especially in the Wylie Lake region (figure 3). Such a mass deficiency might be due to the presence of relatively light rock material at depth (that is, concealed extensive felsic granitoid plutons), or a local thickening of the crust.

The dominant Barrow-Ashton Lakes Gravity High appears to be due to the presence of relatively dense granulite-grade metamorphic rocks (figure 24). The northern half of the Barrow-Ashton Lakes Gravity High is located in predominantly granite gneiss, whereas its southern half is located in a continuation of Slave, La Butte, Francis, and Arch Lake Granitoids (figure 2). The granulite facies Slave Granitoids Complex occupies a large surface area in the southern half of the Barrow-Ashton Lakes Gravity High. Except on the gravity high, low-surface densities are typical of the Slave Granitoids mass, particularly in the Ryan Lake, Tulip Lake, and Leland Lakes regions (figure 3). The decrease in density of granitoid masses away from the Barrow-Ashton Lakes Gravity High may be explained by an increase of potassium content, especially in the Slave Granitoids. Figure 30 shows the distribution of high- versus low-density rocks (2.65 g/cm^3 is the boundary) within the Alberta Shield, along with radiometric

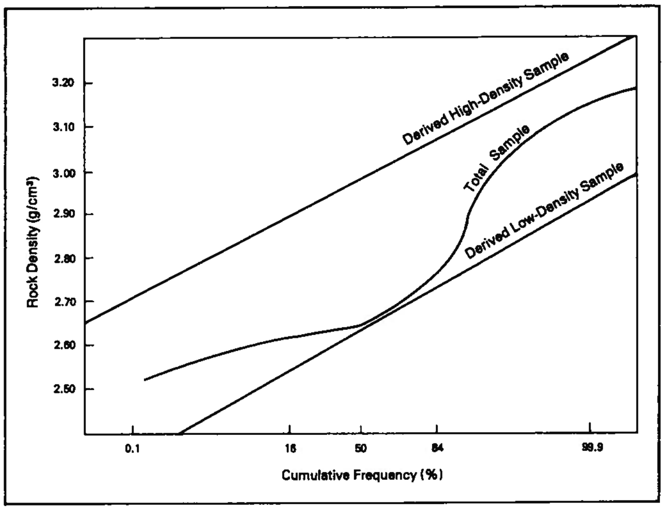


Figure 28. Cumulative frequency plot of rock densities of all the granulite facies and amphibolite facies standard samples from the Alberta Shield. Although the total population does not have a normal distribution, the curve can be partitioned into two separate normally distributed populations.

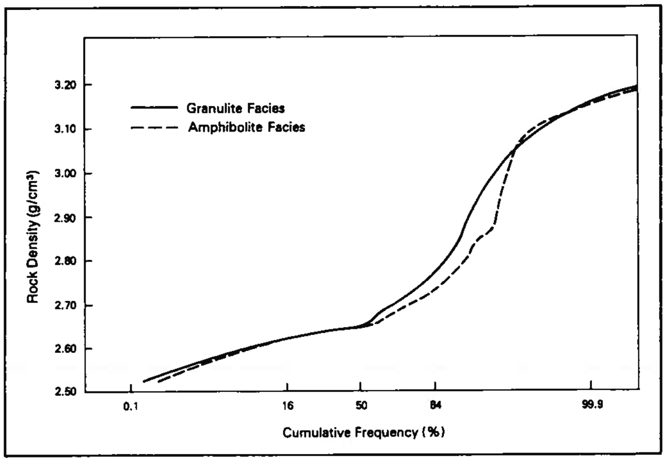


Figure 29. Cumulative frequency plots of amphibolite facies and granulite facies rock densities of standard samples from the Alberta Shield.

K40 values >2.0%. In general, low-density rocks are associated with high K40 values, an indication that potassium content is greater in these areas. Potassium metasomatism is a possible explanation for high potassium levels. The Barrow-Ashton Lakes Gravity High correlates with a region of high-rock density and low K40. The indication is that this curvilinear feature may have escaped the potassium metasomatism which is more evident in adjacent areas to the north and south.

Trend surface analyses

Figure 31 is a quartic polynomial density trend surface map of rock density for the Alberta Shield. The map shows two main zones, an eastern high-density zone and a western low-density zone. These zones are roughly separated by the contact between the granite gneiss belt and the combined Slave and Arch Lake Granitoids (figure 2). The eastern high-density zone corresponds to granite gneiss, high-grade metasedimentary rocks, and relatively mafic granitoids from the amphibolite facies. The western low-density zone correlates with granulite and amphibolite facies granitoids (figure 2).

In contrast to the trend surface rock density map of the Alberta Shield, the quartic trend surface gravity map (figure 25) shows a combination of northeast and northerly trends. This highly smoothed regional gravity field is more sensitive to deep crustal conditions than to surface rock densities (figure 32). This gravity-density trend surface map was obtained by multiplying the mean value from each data set of the two surfaces. On the regional scale, a northeast-southwest trending strip associated with the Barrow-Ashton Lakes Gravity High (dominated by granulite facies granitoids and granite gneisses) shows a weak positive correlation. However, there is no similarity over most of the map area between trend surface rock densities and the regional gravity field.

In the Wylie Lake area (figure 3), the correlation is strongly negative, the result of generally high surface rock densities (mafic granitoids) and low regional gravity. In the Leland Lake region (figure 3), the correlation is also strongly negative, but here the situation is reversed. Overall low surface rock densities (felsic granitoids) are associated with high regional gravity values.

In general, although there is a minor correlation between trend surfaces of the surface rock density and the regional gravity field within the Alberta Shield, the regional gravity trend of the Alberta Shield is best explained by regional deep crustal conditions.

Examination of the relationship between outcrop densities and the gravity field on a more detailed scale is provided in figure 33, a similarity map obtained by multiplying the residual gravity field and the residual surface rock density values. Both sets of residual values were obtained by subtracting quartic trend surfaces from their respective data sets. In order to minimize differences in sampling densities between the two data sets, the residual densities were averaged over 100 km² areas prior to synthesis with the gravity data. As in the case of the regional data, a positive correlation was noted along much of the Barrow-Ashton Lakes Gravity High. Another area of positive correlation occurs in a zone trending northeast from Flett Lake (figure 3) in the southern portion of the map area.

The regional and local similarity maps show that many areas within the Alberta Shield have inverse geophysical expressions; that is, gravity highs are associated with surface rock density lows, and vice-versa. This is particularly the case in the Wylie Lake, Cornwall Lake, Andrew Lake, and Peace River areas (figures 22 and 33). Hence, surface rock densities in many cases do not reflect the nature or cause of the observed gravity anomalies—an indication that a complex geochemical and geophysical environment underlies many areas of the Alberta Shield.

Gravity autocorrelogram

Figure 34 is a gravity autocorrelogram of the Alberta Shield. If considered analogous to a strain ellipsoid, then a prolate ellipsoid with a northeast-southwest trending long axis and a northwest-southeast trending short axis best describes its form and orientation. The gravity autocorrelation plot deviates approximately 30-40 degrees from the north-south trending fabric of the Alberta Shield. Therefore, in gravity and structure, it is more similar to the regional northeast-trending Churchill Province than to the local lithostructural trends. This observation reinforces the view stated above, that deep-seated regional features strongly influence the gravity field of the Alberta Shield.

The Chipewyan Red Granite Pluton: a case study

The Chipewyan Red Granite Pluton (figure 3) was selected as a site for testing whether rock density and magnetic data can be used to evaluate possible compositional zoning with Shield plutons. This site represents one of the least-deformed granitoid masses in the Alberta Shield (Godfrey, 1980b). Other granitoid bodies such as the Wylie Lake, Colin Lake, and Slave Granitoids (figure 2) were also considered as possible areas for this study, but these proved to be lithologically and structurally too complex.

A progressively zoned sequence typically shows mafic rocks at the fringe of the granite body and a more felsic core. Reversed zoning trends are also commonly reported. Henkel (1976) has shown that there is a correlation between high magnetic susceptibility and high mafic mineral content of a rock. Thus, if a pluton is compositionally zoned, density as well as magnetic properties should correlate with zonal differences in composition.

Figure 35 shows the outcrop outline of the southern portion of the Chipewyan Red Granite Pluton near Flett Lake (sheet 15, Godfrey, 1980b) along with quartic trend surface contours of rock density and locations of magnetic high-intensity anomalies. Amphibolite dikes, high-grade metasediments, and granite gneiss inclusions are also shown within the pluton. Forty-four randomly located sample data points were used in this

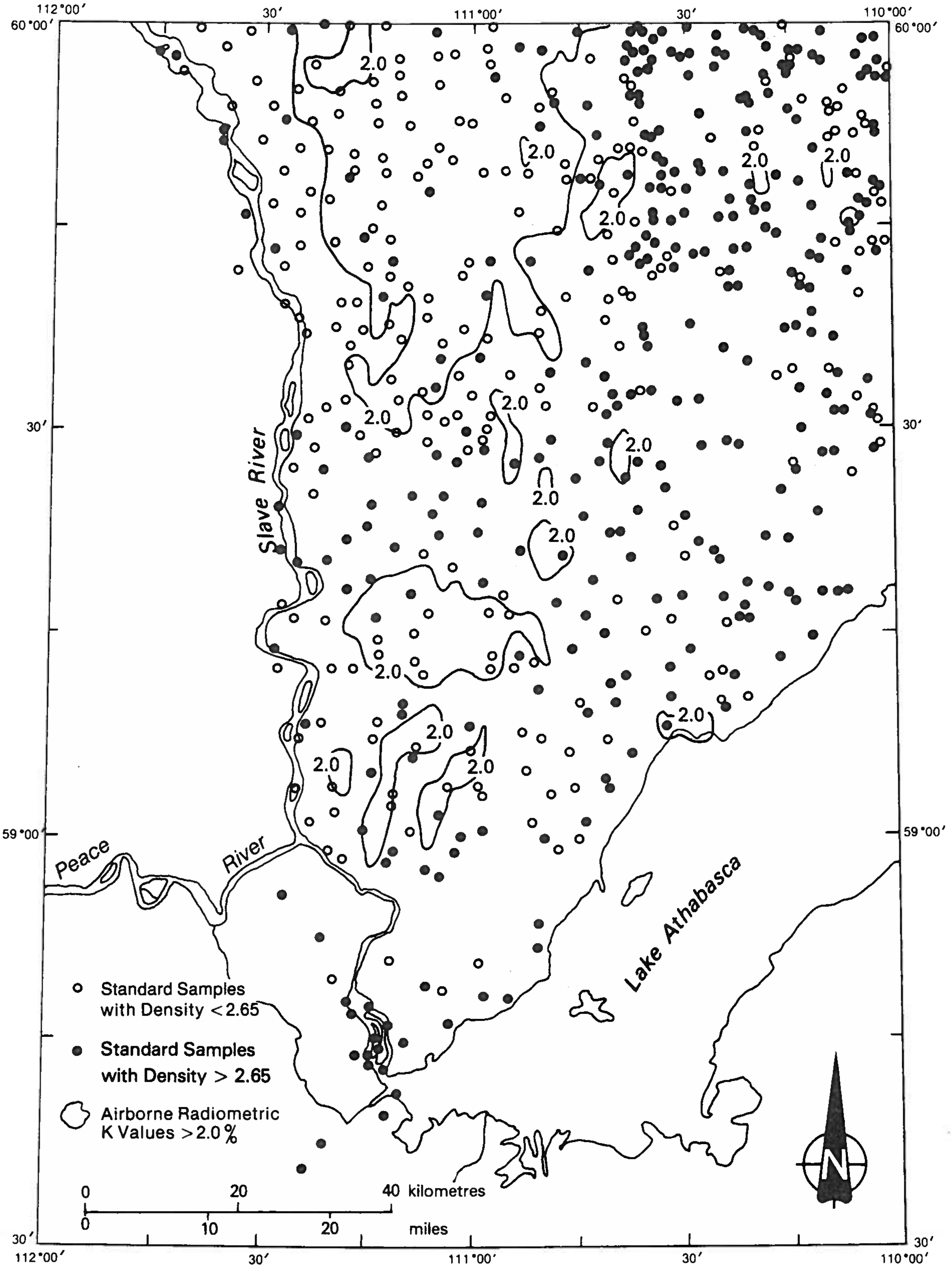


Figure 30. Comparison of radiometric K40 data (G.S.C. 1977a, b) with standard sample specific gravity data from the Alberta Shield. Rocks of low density tend to occur within regions of high potassium concentrations.

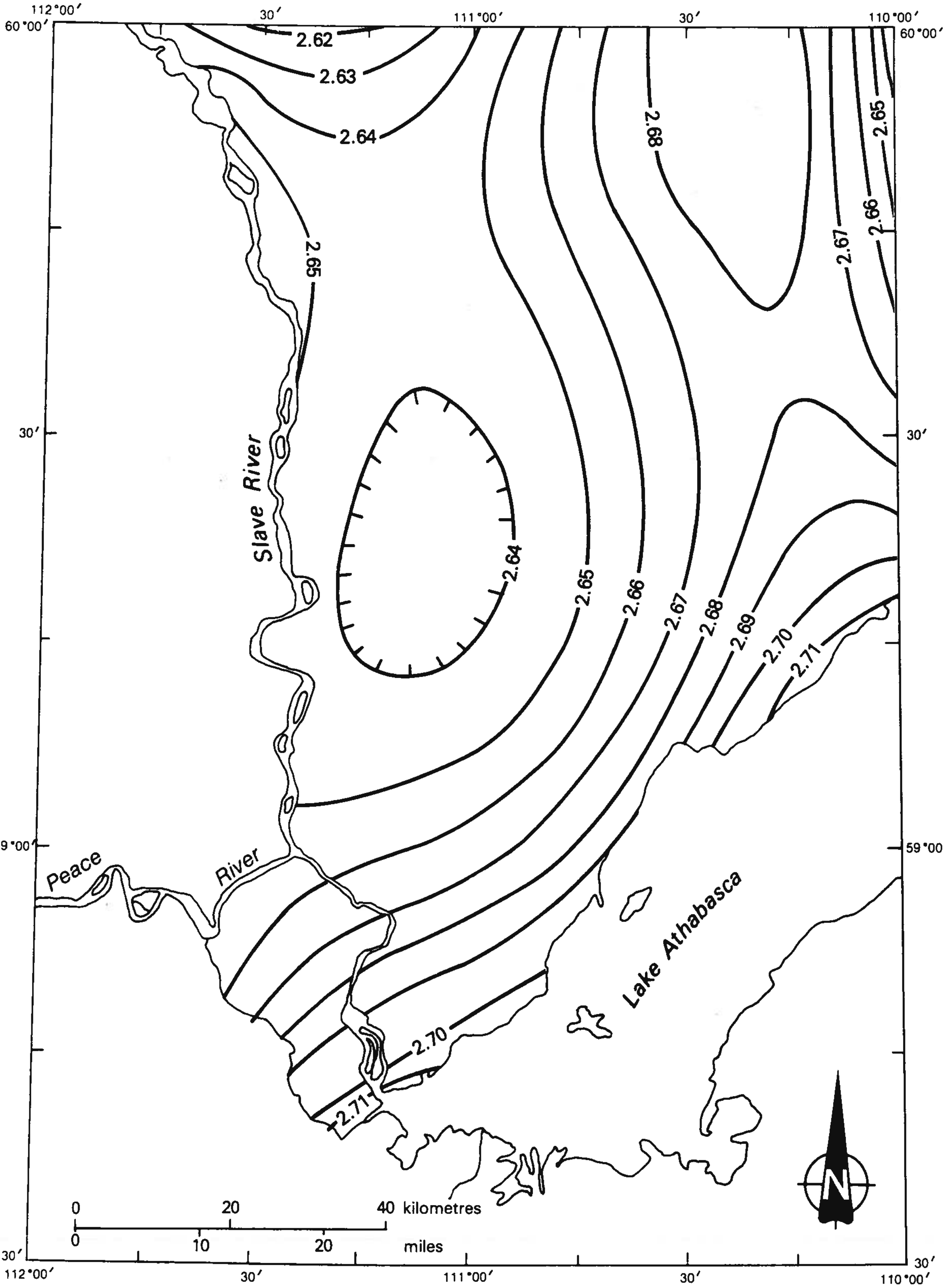


Figure 31. Quartic polynomial trend surface map of standard sample specific gravity values for the Alberta Shield. The contour interval is 0.01 g/cm³.

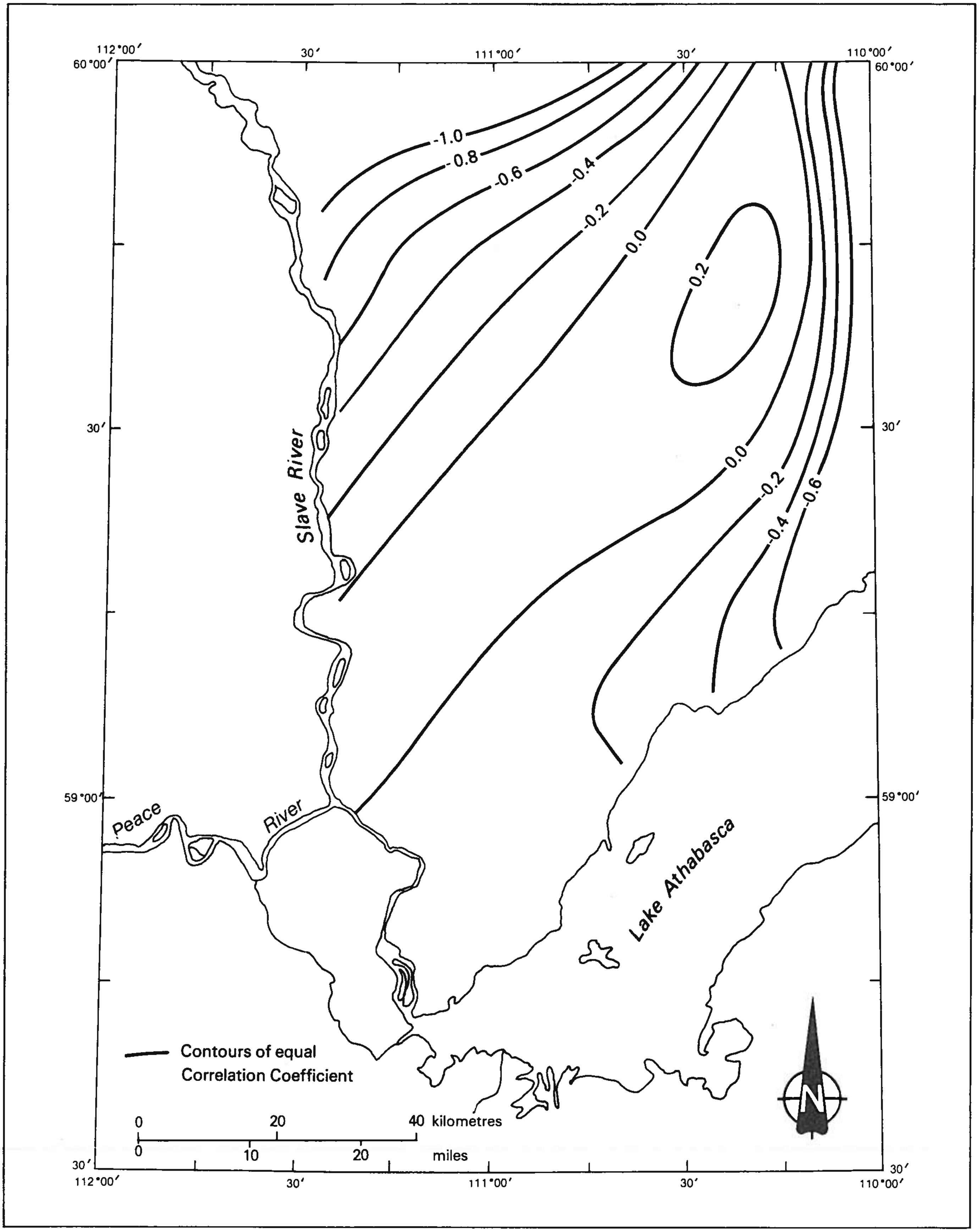


Figure 32. Similarity map between the regional gravity field and the trend surface of outcrop rock densities in the Alberta Shield. The contour lines connect points of equal correlation coefficient. The contour interval is 0.2.

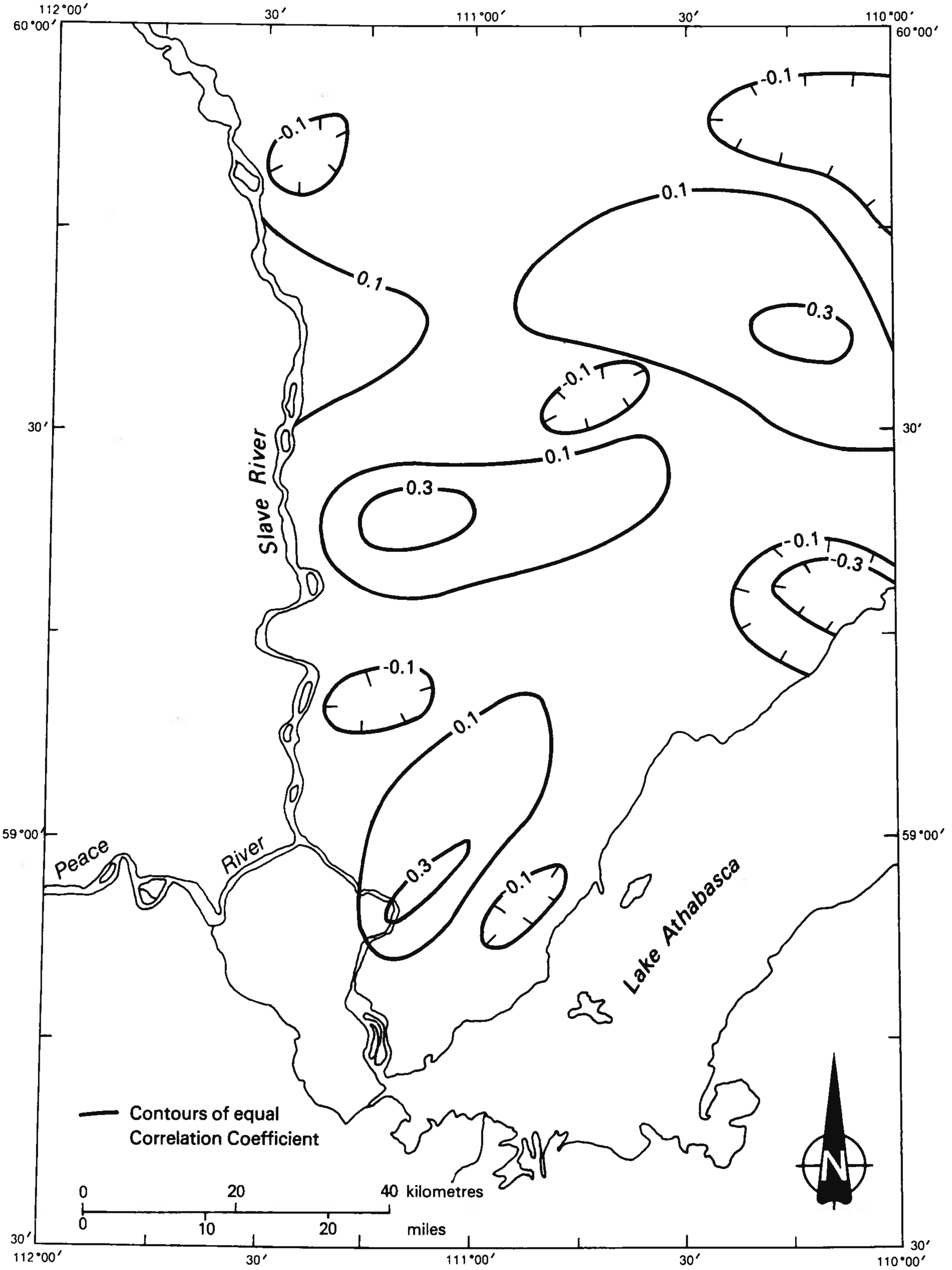


Figure 33. Similarity map between residual gravity field values and residual outcrop rock densities for the Alberta Shield. The contour lines connect points of equal correlation coefficient. The contour interval is 0.2.

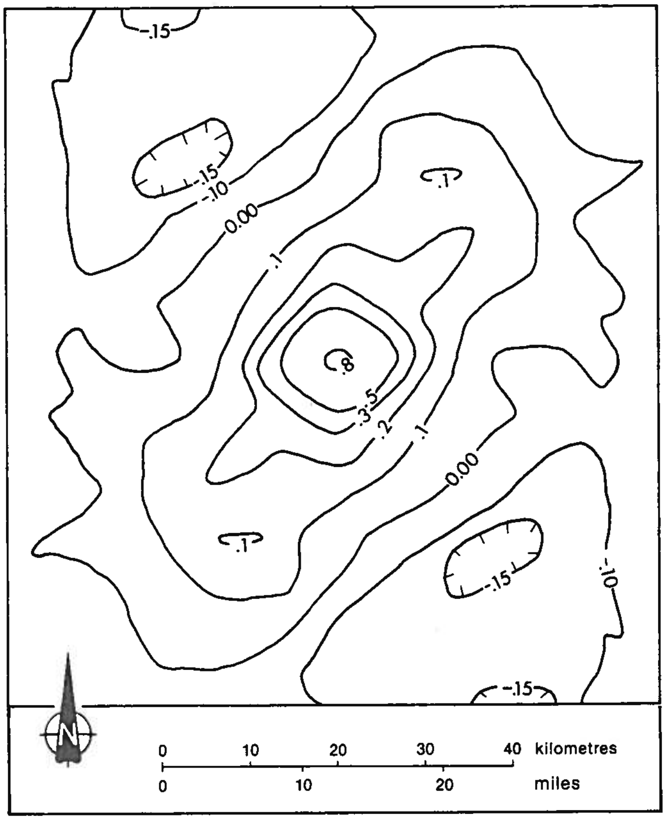


Figure 34. Two-dimensional autocorrelogram of the Bouguer gravity field in the Alberta Shield.

study. All of the data points were located within the boundaries of the intrusion, but some may represent inclusion material, particularly in the central and northern portions of the pluton.

Three anomalous areas are apparent in the Chipewyan Red Granite Pluton (figure 35). In the south, a density high and a corresponding magnetic high (D) indicate the possible presence of local, compositional zoning. In the central region, a magnetic high (C) seems to be related to a concentration of amphibolite dikes. In the northern portion of the pluton, strong magnetic (A), and density (B) highs are defined but do not coincide. The density high is located in an area of several high-density granite gneiss inclusions. A separate small magnetic high (A) over one of the larger inclusions is also apparent. The strong magnetic anomaly (B) to the east of the density anomaly may indicate the presence of either a large mass or concentration of granite gneiss inclusions at shallow depth.

Data from the Chipewyan Red Granite show some evidence for compositional zoning, particularly in the southern portion. The presence of amphibolite dikes, metasediments, and granite gneiss inclusions within the pluton complicates the bedrock geology; this makes conclusions on compositional zoning tentative. Further detailed geological and geophysical field work is required to resolve this question.

Diapirism in the Alberta Shield

The origin of the granitoid domes and basins of the Alberta Shield (figure 36) has important implications for geological models of the area. If the origin of these structures was diapiric, then they are the result of gravitational forces in a tensional tectonic environment; but, if they are superimposed sets of folds, they are the result of boundary forces in a compressive environment (Brun et al., 1981).

Current explanations of dome formation in the Alberta Shield center on a diapiric model (Langenberg, 1983; Goff et al., in press). The domes of the Alberta Shield are composed of granitoid materials and are structurally defined on maps by semi-elliptical foliation patterns. Although some granitoid domes are found in amphibolite facies terranes, most of the domes are located in granulite facies environments.

Diapirism within Precambrian Shield terranes is caused by the gravitational instability of a density inversion (high over low) between supracrustal rocks and the underlying basement complex. The analogy of a salt dome moving upward through denser sedimentary cover is mechanically analogous to granite diapirism (Schwerdtner et al., 1978). For all but the deepest levels of subsequent erosion, this model predicts outcrop patterns consisting of lower-density diapiric material surrounded by higher-density cover rock. In addition, relatively low residual gravity field values can be expected over diapiric structures.

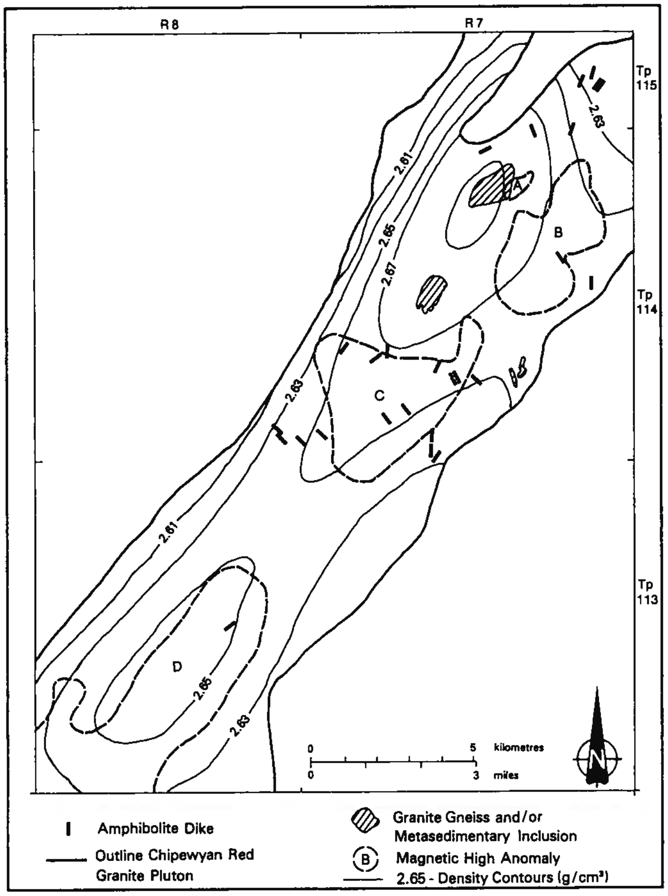
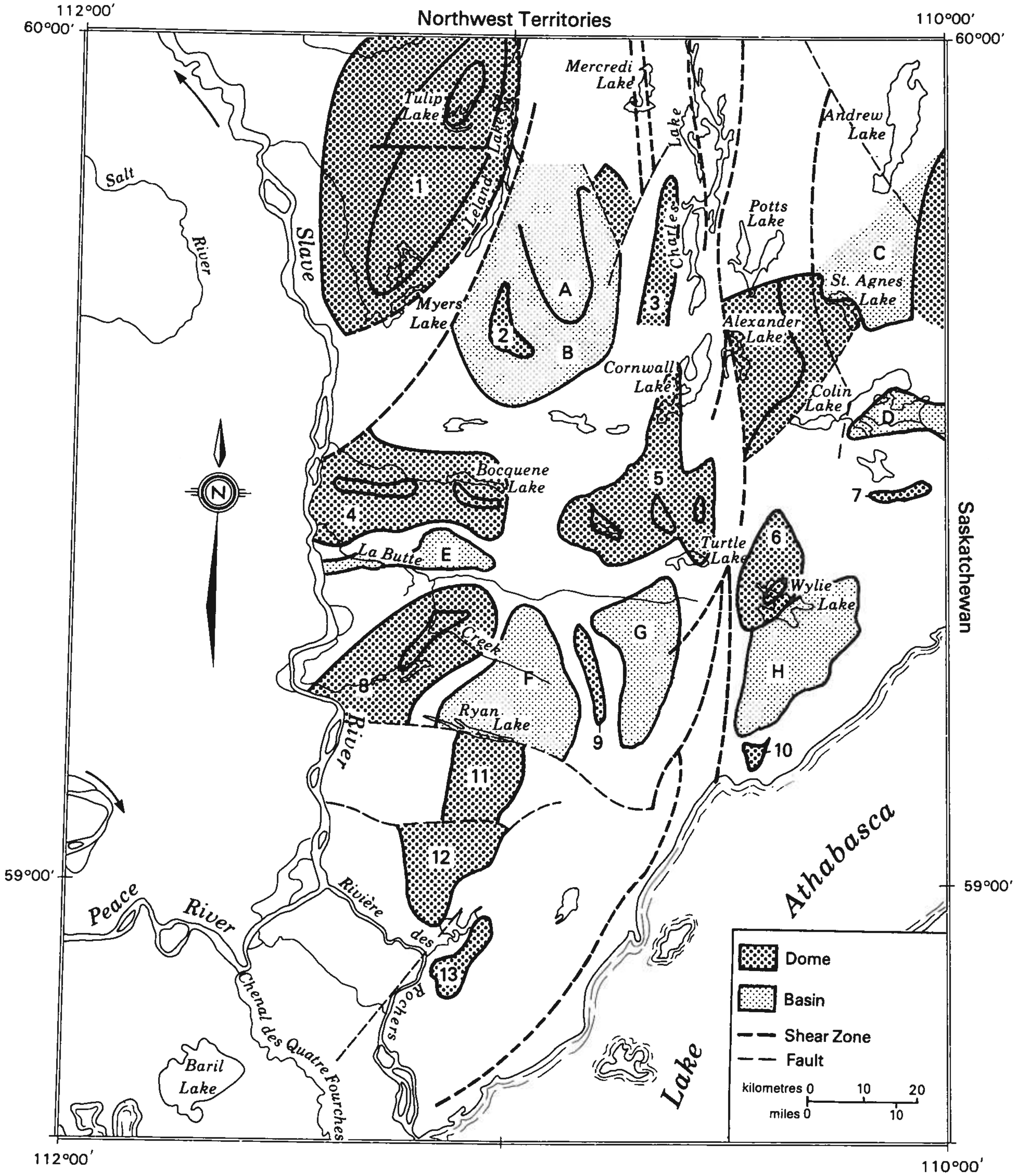


Figure 35. Outcrop of the southern portion of the Chipewyan Red Granite Pluton, along with trend-surface contours of outcrop rock density and locations of magnetic high-intensity anomalies.



Domes

1 Tulip
2 Leland
3 Arch
4 Cockscomb
5 Cornwall
6 Wylie
7 Colin
8 Peace R.
9 Sausage
10 Fidler
11 Ryan
12 Flett
13 Rochers

Basins

A Leland 1
B Leland 2
C Andrew
D Colin
E LaButte
F Ryan
G Turtle
H Wylie

Figure 36. Map of the major structural domes and basins of the Alberta Shield (Langenberg, 1983).

Figure 37 shows a cross plot of the residual gravity field versus outcrop density for the major domes of the Alberta Shield. The majority of the domes are consistent with the hypothesis of a diapiric origin; that is, they possess low outcrop densities and are associated with negative residual gravity field values. Exceptions include:

- the Wylie, Rochers, and Fidler domes—all of amphibolite facies—which show high outcrop densities (greater than 2.74 g/cm³); and
- the Peace and Cornwall domes—both of granulite facies—which show an association with positive residual gravity field values.

Although the Peace and Cornwall domes do not have negative residual anomalies, the diapirism hypothesis for the origin of these structures is not discounted. The Barrow-Ashton Lakes Gravity High, a regional feature, crosses these two domes and has probably increased their residual gravity field values.

On the other hand, the tendency of most amphibolite facies domes to have high outcrop densities is a more serious problem for the hypothesis of diapirism. Only the Arch dome, which is composed of Arch Lake Granitoids, seems to be clearly consistent with a diapiric model. The other amphibolite facies domes all show outcrop densities well above the mean rock density of the Alberta Shield.

Granitoids emplaced in the Alberta Shield under amphibolite facies grade conditions may represent a magmatic-plutonic environment, as opposed to an ultrametamorphic environment for granulite facies granitoids (Godfrey, 1980b). The dome and basin pattern in some of the amphibolite facies granitoids of the Alberta Shield may be the result, not of diapirism, but of superimposed folding. Godfrey (1980a), for example, suggested that the Wylie dome and basin are explicable in terms of interference folds as a consequence of opposing directions of lateral compression.

Schwerdtner and Lumbers (1980) noted three criteria to recognize diapiric structures: 1) an appropriate density contrast between the diapiric material and the cover material; 2) diapiric structures have circular to oval outlines in plan view; and 3) subhorizontally stretched fabrics are commonly present in the roofal region of the domes.

In the Alberta Shield, the first of these criteria depends on accepting the belt of Archean gneisses and high-grade metasediments as the mantling supracrustals, now seen largely as wallrock to the granitoid plutons. The mean densities of the granite gneiss (2.69 g/cm³) and the high-grade metasediments (2.77 g/cm³) are, with the exception of several amphibolite facies domes, substantially greater than the densities of the presumed granitoid diapiric material in the Alberta Shield (table 2, figure 37). The second criterion is satisfied in field structures of the Slave and Arch Lake Granitoids (Godfrey, in press; Godfrey and Langenberg, in press a, in press b). The third criterion requires further critical work at specific sites within the granitoid structures of the Alberta Shield.

In general, geophysical and outcrop density data are consistent with a diapiric origin for the granitoid domes of the Alberta Shield, particularly those composed of Slave and Arch Lake Granitoids. However, amphibolite facies domes composed of other rock units are more enigmatic, and may require a more complex hypothesis to explain their formation.

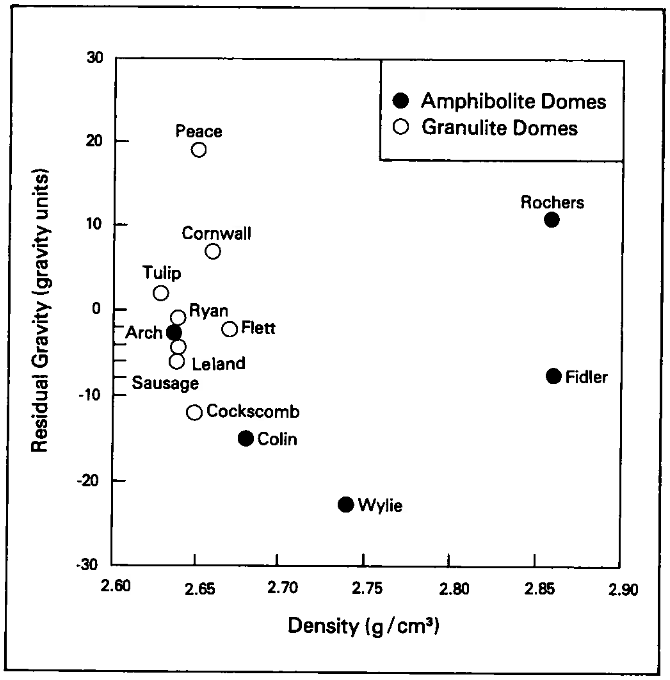


Figure 37. Cross plot of residual gravity field versus rock density for structural domes of the Alberta Shield.

Airborne radiometric survey analysis

Introduction

Airborne gamma-ray spectrometric readings over the Alberta Shield show considerable variation. The purpose of the research reported in this chapter was to analyze these radiometric data in terms of the areal geology.

From 1957 to 1975, the Alberta Research Council conducted geologic field mapping on the Alberta Shield during which geiger counter sensing for radioactivity was undertaken. Godfrey (1958b) noted many radioactive showings in the Andrew, Johnson, and Waugh Lakes areas (figure 3); the most promising uranium showings are located near Spider and Cherry Lakes (figure 3). In these latter areas, high radioactive values are found within biotite schists, biotite pegmatites, certain high-grade metasediments, and shear zones in granitoids. Anomalous radioactivity also occurs near Colin Lake, where radioactivity is related to granite pegmatitic phases (Godfrey and Peikert, 1964). Other radioactive occurrences in the Alberta Shield have been noted in high-grade metasedimentary bands in the Fort Chipewyan district (figure 2) and in leucocratic-pegmatite phases of the Fishing Creek Quartz Diorite in the Wylie Lake district (Godfrey, 1980a, 1980b).

Godfrey and Plouffe (1978) provided a semi-quantitative overview of the regional variations in radioactivity over the Alberta Shield, based on a combination of: 1) airborne scintillometer surveys by the mining industry, used for uranium exploration on mineral properties; and 2) results of geological ground traverses (accompanied by geiger counter) by the Alberta Research Council.

In the present study, airborne gamma-ray spectrometric data for various radioactive isotopes were analyzed and compared to the bedrock geology. From these comparisons, correlations of radio-elemental distribution and geological environment were sought. Results of the study show that this type of survey could be helpful in the search for economically important uranium deposits. Six domains representing areas of potential economic radioactive mineralization in the Alberta Shield were identified.

Methods

The radiometric data used in this study were published (Geological Survey of Canada, 1977a, 1977b) in the form of: 1) airborne gamma-ray spectrometric contour maps of integral counts, equivalent potassium concentration (eK), equivalent uranium concentration (eU), equivalent thorium concentration (eTh), and eU/eTh, eU/eK, and eTh/eK ratios; and, 2) stacked profiles of these seven radiometric parameters. The parallel airborne traverses were spaced 5 km apart.

The airborne radiometric measurements and subsequent data processing were performed by the Resource Geophysics and Geochemistry Division of the Geological Survey of Canada. A high-sensitivity spectrometer was used with a detector volume of 50 000 ml, flown at a height of 122 m and at 190 km/h. The concentrations of the radio-elements uranium, thorium, and potassium were measured approximately by counting gamma-ray photons of energies 1.76 MeV, 2.62 MeV, and 1.46 MeV, respectively. The data were corrected for background, ground elevation variation, and spectral scattering. The count rates were converted to equivalent radio-element concentrations using empirically determined calibration constants. The concentrations so determined are generally lower than the actual concentrations in bedrock due to partial masking by overburden and surface water. In order to produce meaningful map contours, the radiometric values were averaged over 2.2 km traverse lengths. Hence, the values on the stacked profiles are considerably more precise and sensitive than those on the contour maps.

In the present study, the radiometric data were analyzed by both qualitative and quantitative techniques. Visual comparisons were made of the radio-elemental concentrations with geological and aeromagnetic data. Statistical cross plots were used to evaluate the economic potential in a case study of the Tulip-Mercredi Lakes area.

General correlations

Specific rock groups in the study area show certain broad radiometric characteristics. Granitoid masses show the highest eU, %K, and eU/eTh values in the study area, but possess variable eTh values. On the other hand, the granite gneiss displays low to moderate eU and %K, but moderate to high eTh. Hence, the thorium content in the granite gneiss has remained fixed relative to the uranium content. The metasedimentary rock bands in the Alberta Shield commonly show moderate to very low eU, low %K, and variable eTh. Hauseux (1977) made a similar observation in a granitoid-migmatite terrane in Quebec, noting that the metasediments there are devoid of appreciable radioactivity. The mylonites and major fault zones in the Alberta Shield are characterized by very low eU, eTh, and %K. However, over a small area, the granite gneiss, metasedimentary rock bands, and fault zones can all show anomalous values.

The highest radio-elemental concentrations within the granitoids are associated with those masses having a granitic composition. For example, the Slave Granitoids, which are largely granitic in composition, have higher eU and %K values than the more basic La Butte Granodiorite. There appear to be exceptions; however, they may be explained. For example, the relatively basic Wylie Lake Granodiorite and Fishing Creek Quartz Diorite both display high eU and %K values. However, these high values may be directly related to the presence of minor felsic phases within the larger intrusions (Godfrey, 1980a).

Many of the uranium enrichments in the Canadian Shield are located either in the pegmatitic phases of granitoids or in the country rock surrounding granitoids (Ford, 1982; Hauseux, 1977). Whereas more detailed radiometric mapping is required to fully substantiate similar circumstances in the Alberta Shield, the high eU values in the leucocratic and aplo-pegmatitic phases of the granitoids, in at least the eastern part of the study area, are consistent with this observation.

There is a broad association between the airborne radiometric and magnetic surveys over the Alberta Shield. In general, high eU values are located over areas of magnetic lows. This inverse relationship is due to felsic granitoid masses which produce high radiometric counts and also generally possess low magnetic susceptibility. On the other hand, metasedimentary rock bands and mylonite belts have generally low radiometric and magnetic values.

It is difficult to make an unqualified statement about the general relationship between radiometric values and lithostructural trends along with other geological features of the Alberta Shield. Whereas an approximate north-south trend is apparent on the radiometric maps, reflecting the regional tectonic fabric, there are also many local anomalies which cut across the regional trend. Similarly, although many of the radiometric domains are clearly bounded by lithological contacts, others continue across several boundaries.

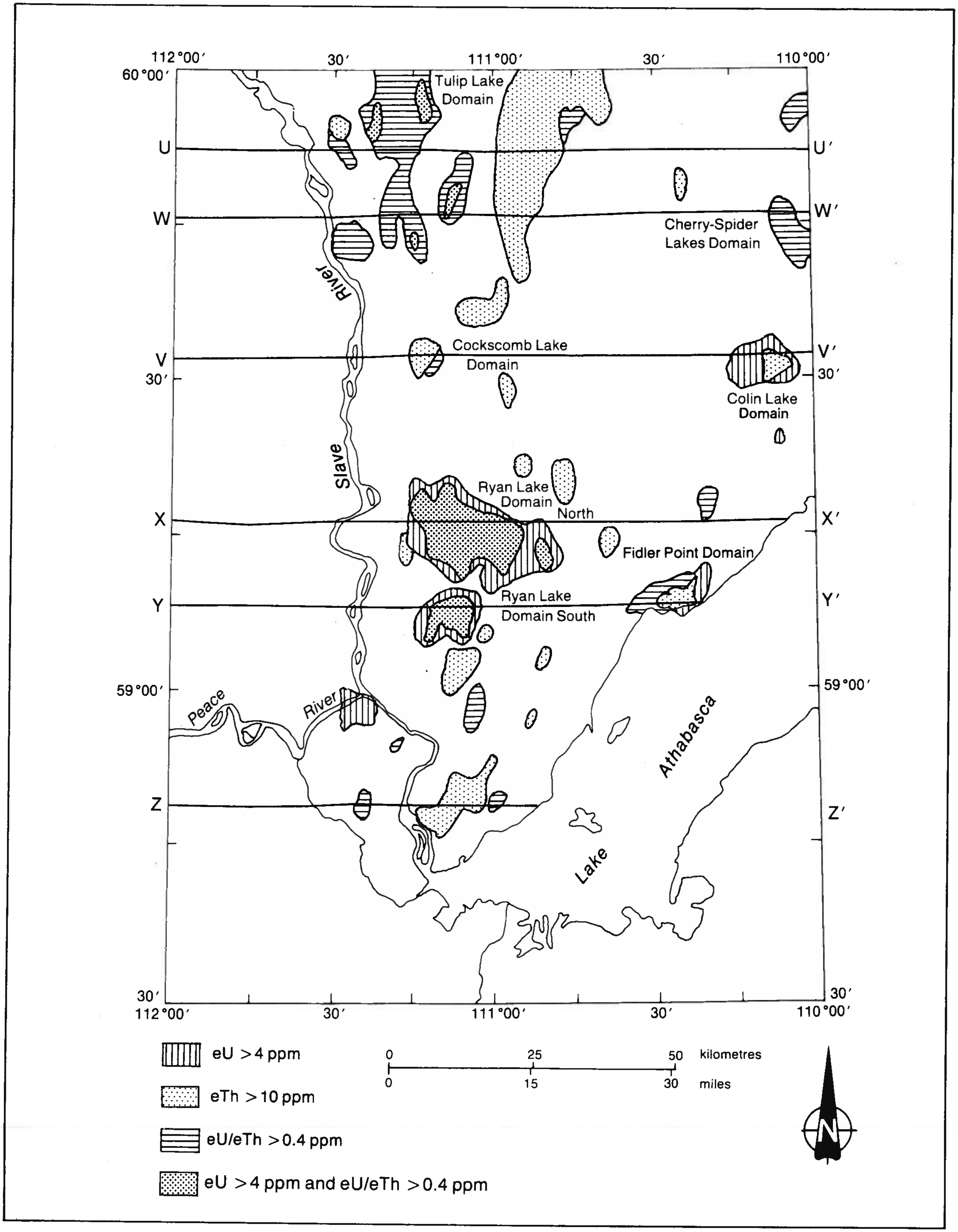


Figure 38. Areas of anomalous high radiometric values in the Alberta Shield.

Radiometric domains

Six domains of potential, economic uranium mineralization have been identified in the Alberta Shield. The criteria used in the selection of these domains were as follows: 1) high eU ppm, 2) high eU/eTh ratio, 3) local K enrichment, and 4) significant size of the anomalous area.

These domains are identified on figure 38 as the: 1) Ryan Lake Domain, 2) Tulip Lake Domain, 3) Colin Lake Domain, 4) Fidler Point Domain, 5) Cherry-Spider Lakes Domain, and 6) Cockscomb Lake Domain. From airborne gamma-ray spectrometry, these anomalous domains generally have high eU and eU/eTh. All these domains are underlain by granitoid masses, with minor metasedimentary rocks in some cases. The rock groups underlying the domains are, in order of decreasing eU abundance: Slave Granitoids, Colin Lake Granitoids, Wylie Lake Granitoids, and Arch Lake Granitoids. The easternmost uraniferous domains of Cherry-Spider Lakes and Colin Lake are low in thorium, whereas the remaining domains either possess, or are located near to, high thorium concentrations.

From airborne gamma-ray spectrometry, areas of eU concentrations greater than 4 ppm and areas of eU/eTh ratios greater than 0.4 have been delimited (figure 38). Overlap of these two values represents areas of high potential for uranium mineralization. This criterion accounts for the first four of the above mentioned six domains. The remaining two domains, Cockscomb Lake and Cherry-Spider Lakes, are not defined by such areas of overlap. In the case of the Cherry-Spider Lakes Domain, smoothing of the data in the course of the contouring process has removed the locally strong radio-elemental signature of this domain (figure 39). On the other hand, the Cockscomb Lake Domain does not have a high eU/eTh ratio, yet it is still considered to be a significant domain, from other data given below.

Areas of high thorium concentration (eTh >10 ppm) are also shown on figure 38. Except for the easternmost domains, the uraniferous areas of the Alberta Shield occur within or near areas of high thorium concentration. In general, the thoriferous areas of the Alberta Shield can be correlated with outcrops of the Arch Lake, Francis, and Thesis Lake Granitoids (figure 2) — units which are generally low in uranium concentration.

The Tulip Lake Domain

The greater part of the Tulip Lake Uraniferous Domain is bounded on the east and south by the arcuate War-

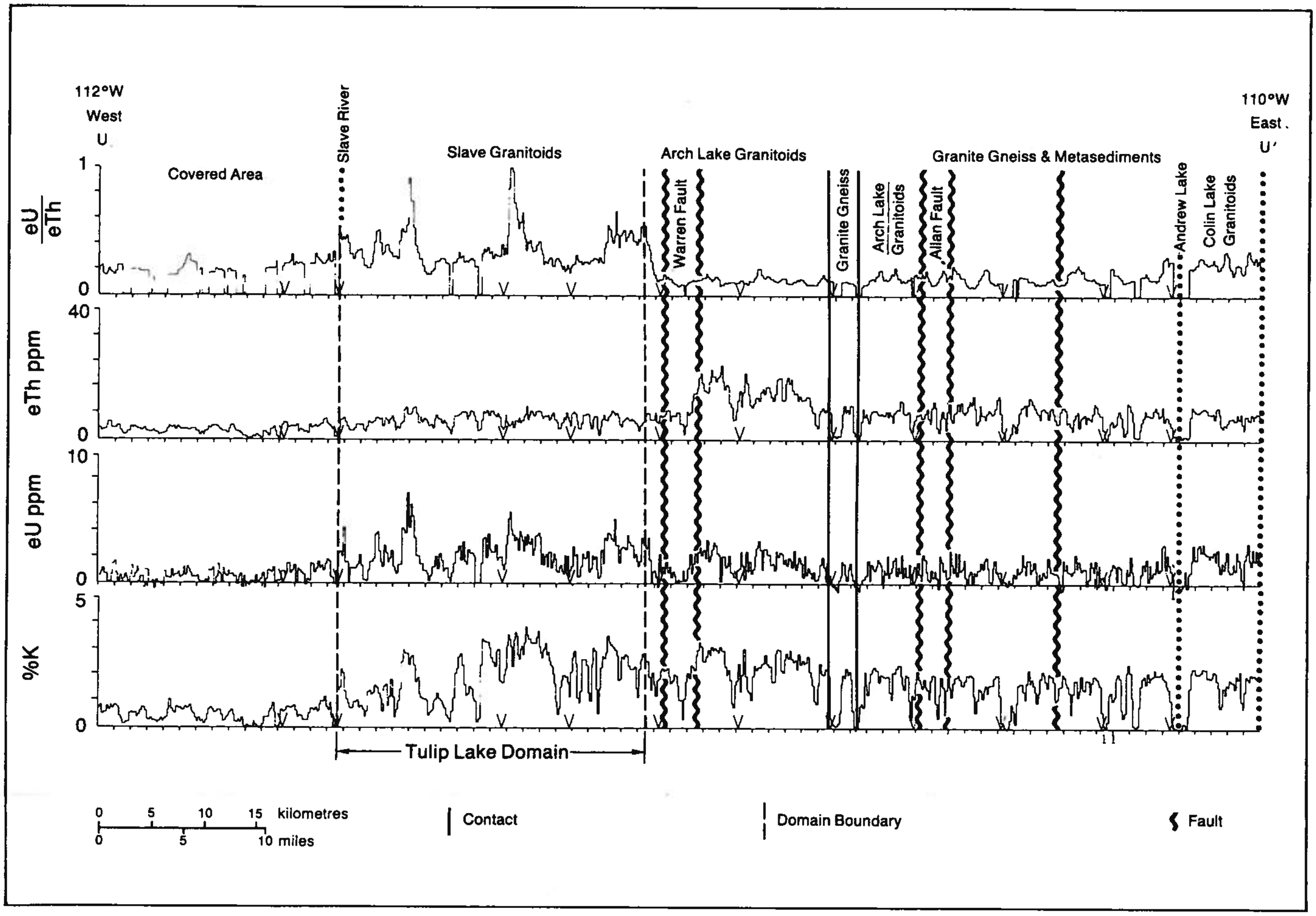


Figure 39. Stacked west-east radiometric profiles (U-U′, fig. 38) for a traverse crossing the Tulip Lake Domain. The uraniferous Slave Granitoids of the Tulip Lake Domain contrast sharply with the thoriferous Arch Lake Granitoids.

ren Fault, on the west by Paleozoic cover, and on the north by the Northwest Territories. An extension of the domain lies to the east at Mercredi Lake (figure 3). The dominant underlying bedrock is the Slave Granitoids, with minor gneisses and Arch Lake Granitoids at Mercredi Lake. Locally, small inclusions of high-grade metasediments are present. Structurally, the Tulip Lake Uraniferous Domain is located on a domal feature, as are most of the radiometric granitoid domains of the Alberta Shield.

The Tulip Lake Uraniferous Domain is on a major uraniferous trend that includes the western margin of the Fort Smith Granite in the Northwest Territories (Charbonneau, 1980, 1982, Burwash and Cape, 1981). Like the Slave Granitoids, the western margin of the Fort Smith Granite has high eU/eTh properties. This relationship is due to the fixation of thorium at an early phase of the magmatic cycle, followed by an increase in uranium with continued differentiation. Charbonneau (1982) stated that this process can lead to economically-important deposits of uranium, if the end product of differentiation is rock material high in eU and eU/eTh, but low in eTh. These radio-elemental conditions seem to exist within the Slave Granitoids of the Tulip Lake Uraniferous Domain.

Figure 39 is a set of stacked west-east profiles of a traverse line crossing the Tulip Lake Uraniferous Domain. In this domain, the approximate radio-elemental concentrations are as follows: eU = 2-3 ppm; eTh = 6 ppm; and K = 2.2 percent. Charbonneau (1982) stated that airborne radiometric values of 3-4 ppm eU over granitoids indicate rocks significantly enriched in uranium. Most impressive on figure 39 is the apparent high eU/eTh ratio over the Tulip Lake Uraniferous Domain. Darnley (1975) reports that the eU/eTh ratio is the "most versatile indicator of uranium mineralization." The Tulip Lake Uraniferous Domain therefore ranks as one of the promising uranium exploration targets in the Alberta Shield.

The Slave Granitoids may be a potential host for economic uranium mineralization. Future exploration in the Tulip Lake Uraniferous Domain should concentrate on this granitoid mass, because the metasediments and mylonites in the domain show low radio-elemental concentrations.

The radiometric characteristics of the Tulip Lake Do-

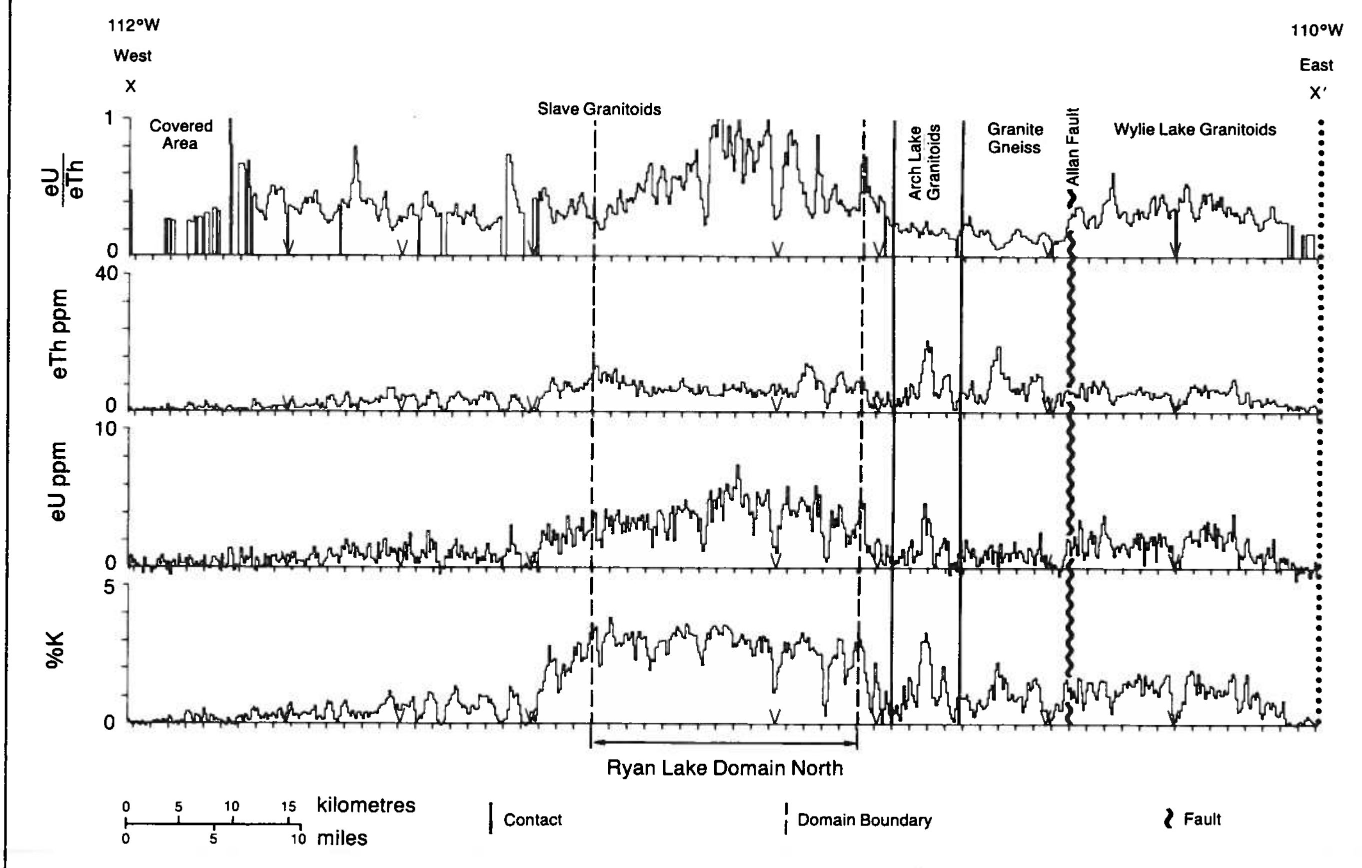


Figure 40. Stacked west-east radiometric profiles for a traverse line (X-X′, fig. 38) crossing the Ryan Lake Domain north. The Slave and Arch Lake Granitoids show contrasting radio-elemental values. The Slave Granitoids have higher eU ppm values than the Arch Lake Granitoids, but lower eTh ppm values.

main contrast markedly with those observed over a thoriferous area underlain by Arch Lake Granitoids, located on the east side of the Warren Fault. A striking difference in radio-elemental concentrations can be seen on the gamma-ray spectrometric profiles (figure 39). The Slave Granitoids shows high eU and low eTh, whereas the Arch Lake Granitoids show low eU and high eTh. Much of the uranium present in the Tulip Lake Domain may have migrated from the Arch Lake Granitoids during emplacement, leaving the Arch Lake Granitoids thorium rich but uranium poor.

The Ryan Lake Domain

The Ryan Lake Domain is the largest uraniferous domain of the Alberta Shield. This domain, roughly centered on Ryan Lake (figure 38), is composed mainly of Slave Granitoids, with minor amounts of Arch Lake Granitoids and metasedimentary rock bands. The domain can be divided into northern and southern parts, which are distinguished on the basis of eU values. In the northern part, which lies largely between Ryan and Darwin Lakes, the radio-elemental averages are approximately: eU = 3.6 ppm; eTh = 8 ppm; and K = 2.5 percent (figure 40). Pegmatites are not especially prominent in this area, hence, the uranium may be in either accessory minerals or localized along small fracture surfaces, although there is no field evidence to support the latter suggestion. The metasedimentary rock bands in the area show low radio-elemental concentrations.

At the eastern limit of the Ryan Lake Uraniferous Domain, the Slave Granitoids are in contact with the Arch Lake Granitoids. As at the eastern boundary of the Tulip Lake Domain, a vivid radiometric contrast occurs at this contact (figure 40). The eU/eTh profile shows such a sharp break that the ratio could readily be used as a mapping tool for this contact. The radio-elemental distribution in and around the Ryan Lake Domain is similar to that of the Tulip Lake Domain: the uranium enrichment probably resulted from migration of uranium from the surrounding Arch Lake Granitoids.

The southern portion of the Ryan Lake Uraniferous Domain is separated from the northern portion by a large block of Arch Lake Granitoids, south of Ryan Lake (figure 2). The southern portion of the Ryan Lake Radiometric domain differs from the northern part

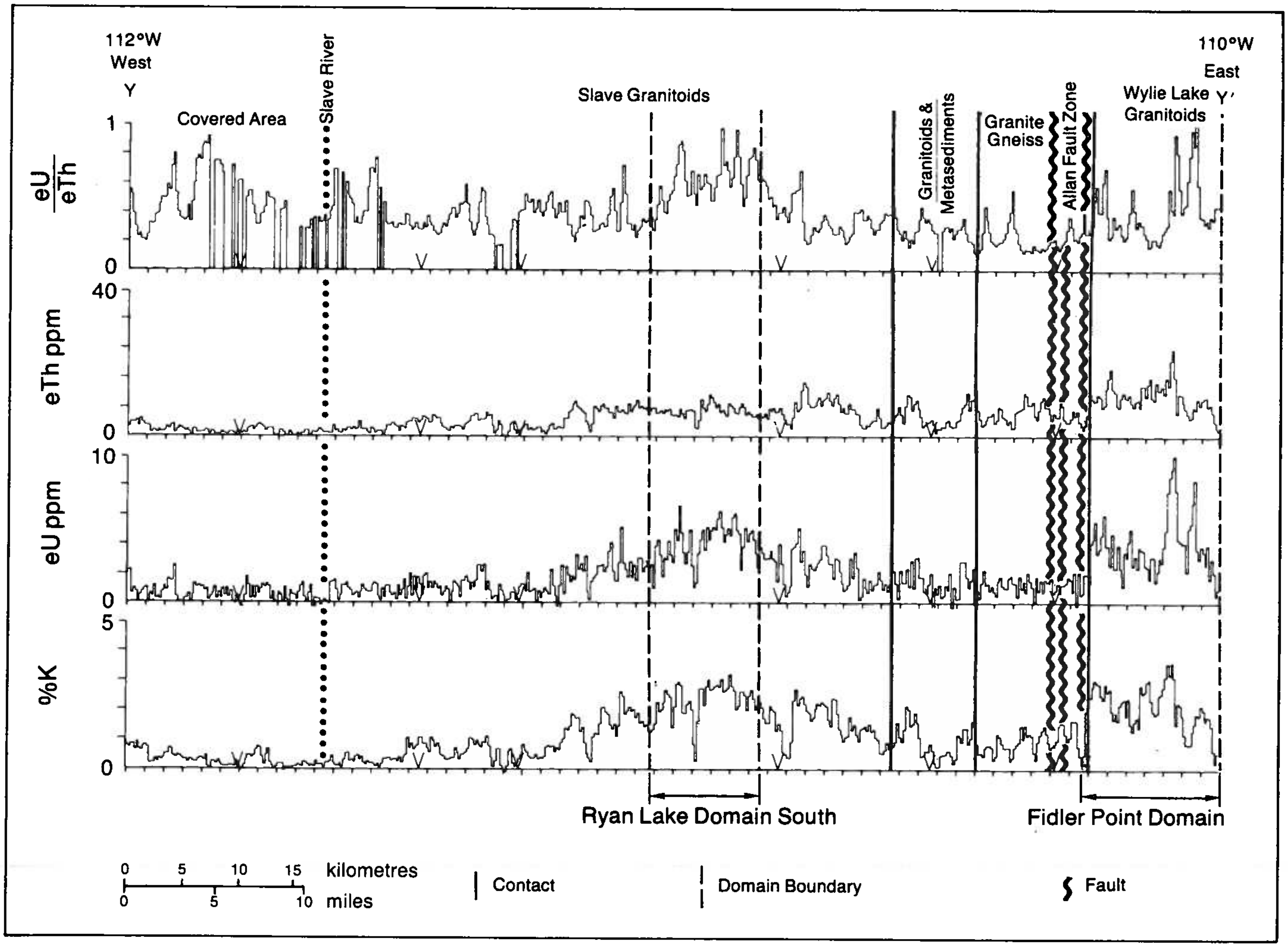


Figure 41. Stacked west-east radiometric profiles for a traverse line (Y-Y', fig. 38). The Fidler Point Domain is characterized by high eU ppm, and moderate eTh ppm values. The Ryan Lake Domain south shows high eU ppm but low eTh ppm values.

mainly by slightly lower radio-elemental values. The average radio-elemental values for this part of the domain are as follows: eU = 2 ppm; eTh = 6 ppm; and K = 1.5 percent (figure 41). The geology of the southern portion of the domain is similar to the northern portion—the Slave Granitoids being the dominant rock unit. The reason for the decrease in radio-elemental concentrations from north to south is not known. This decrease is not correlated with lithology, since the high eTh values in the granite gneiss and Arch Lake Granitoids at the eastern edge of the northern portion of the domain also decrease to the south.

The Colin Lake Domain

The Colin Lake Uraniferous Domain is located south of Colin Lake (figure 3) near the contact zone between the Wylie Lake and Colin Lake Granitoids (figure 38; also, see Godfrey and Peikert, 1964). Field relationships suggest that the Colin Lake Granodiorite is younger and has intruded into the Wylie Lake Granitoids, (Godfrey, 1980a). The recognition of this type of relationship is important, because many contact zones in the area are enriched in uranium. Many granite pegmatites occur close to the contact between those granitoids. Southward from the contact zone, the Wylie Lake Granitoids persist with the concentration of pegmatites. Virtually all the radioactive occurrences noted during geological field mapping in this domain (Godfrey and Peikert, 1964) are in pegmatites.

The Fidler Point Domain

The Fidler Point Uraniferous Domain is located in the area immediately north of Fidler Point on the north shore of Lake Athabasca (figure 38). This domain has been discussed in some detail by Godfrey (1980a). The main rock types are the Fishing Creek Quartz Diorite and the Wylie Lake Granodiorite (figure 2). Subordinate amounts of high-grade metasediments also occur. Radioactive occurrences at surface, which have been noted during geological mapping are situated in pegmatitic phases of the Fishing Creek Quartz Diorite and at the margins of metasedimentary rock inclusions within the quartz diorite (map 19, Godfrey, 1980a).

Conglomeratic Helikian Athabasca Group, a rare occurrence in outcrop in Alberta, crops out on the north shore of Lake Athabasca, just west of Fidler Point. Located within this uraniferous domain, this outcrop is of some economic interest (Godfrey, 1980a).

Figure 40 shows a set of stacked radiometric profiles which cross the Fidler Point Uraniferous Domain. The radio-elemental concentrations average approximately

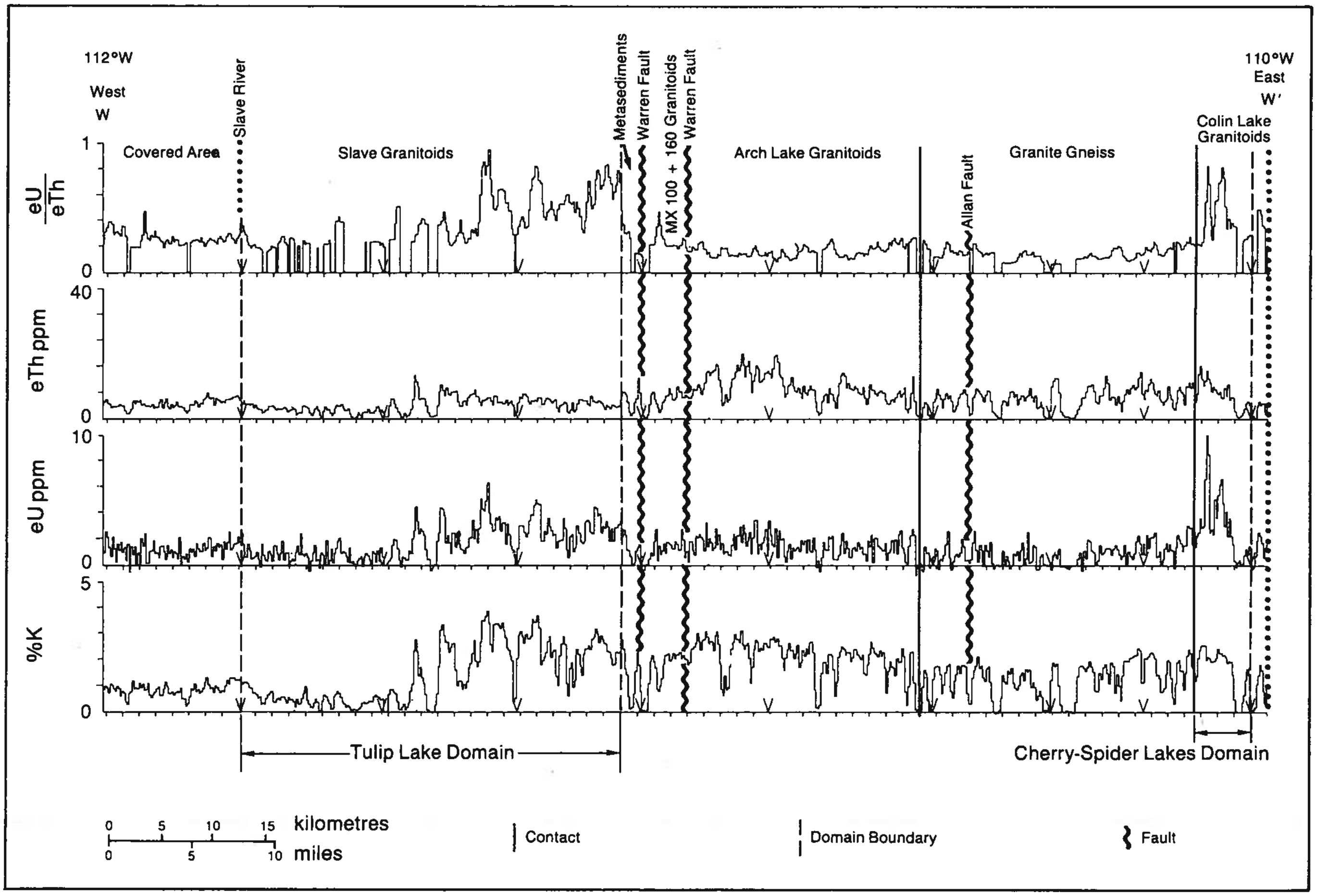


Figure 42. Stacked west-east radiometric profiles for a traverse line (W-W', fig. 38) crossing the Cherry-Spider Lakes Domain. Domain shows high eU ppm, high eU/eTh, moderate to high K, and low to moderate eTh ppm values. Based on these radio-elemental characteristics, the Cherry-Spider Lakes Domain is ranked as one of the most promising uranium exploration areas within the Alberta Shield.

3-3.5 ppm eU, 10 ppm eTh, and 2 percent K. The eU/eTh ratio is generally moderate. However, localized peaks in both eU and eU/eTh ratio occur (figure 41). These peaks indicate that the domain is probably worthy of further detailed investigation.

The Cherry-Spider Lakes Domain

The Cherry-Spider Lakes Uraniferous Domain lies due south of Andrew Lake between Cherry and Spider Lakes (figure 38). High surface radioactivity, as noted during geological mapping of this domain, occurs mainly in the Colin Lake Granitoids and in high-grade metasedimentary rock bands (Godfrey and Peikert, 1964). Near Cherry Lake, surface radioactivity was noted in pegmatitic phases of the Colin Lake Granitoids, in fractures, and at margins of metasedimentary rock inclusions within the granitoids. At Spider Lake, a northeast-trending band of high-grade metasediments was found to be the site of intense surface radioactivity. The radioactivity at Spider Lake is related to an intimate mixture of small pegmatites and quartzitic-schistose metasediments. The sites of surface radioactivity occur within or adjacent to pegmatitic pods. The granitoid material is probably responsible for much of the airborne radioactivity observed in the area.

The Cherry-Spider Lakes Uraniferous Domain is apparent on the airborne gamma-ray spectrometric profile which cuts through the area (figure 42). The domain is characterized by moderate to locally high eU and high eU/eTh values. The average eU concentration is approximately 2.4 ppm with peak values up to 10 ppm near Cherry Lake. The eTh value is approximately 9 ppm, whereas K = 2.0 percent. These data suggest that, in this domain, uranium is associated with pegmatite formation and was enriched relative to thorium, possibly in conjunction with potassium metasomatism.

The Cockscomb Lake Domain

The Cockscomb Lake Uraniferous Domain covers a small area immediately west of Cockscomb Lake (figure 38). It is composed entirely of Arch Lake Granitoids and is associated with the northern fringe of the Cockscomb Lake Dome. The domain is characterized by high eU, eTh, and K% radio-elemental values, as well as an anomalously high magnetic field. The domain has an average eU of approximately 4 ppm with peak values as high as 8 ppm (figure 43). However, the eU/eTh ratio for this domain is low, due

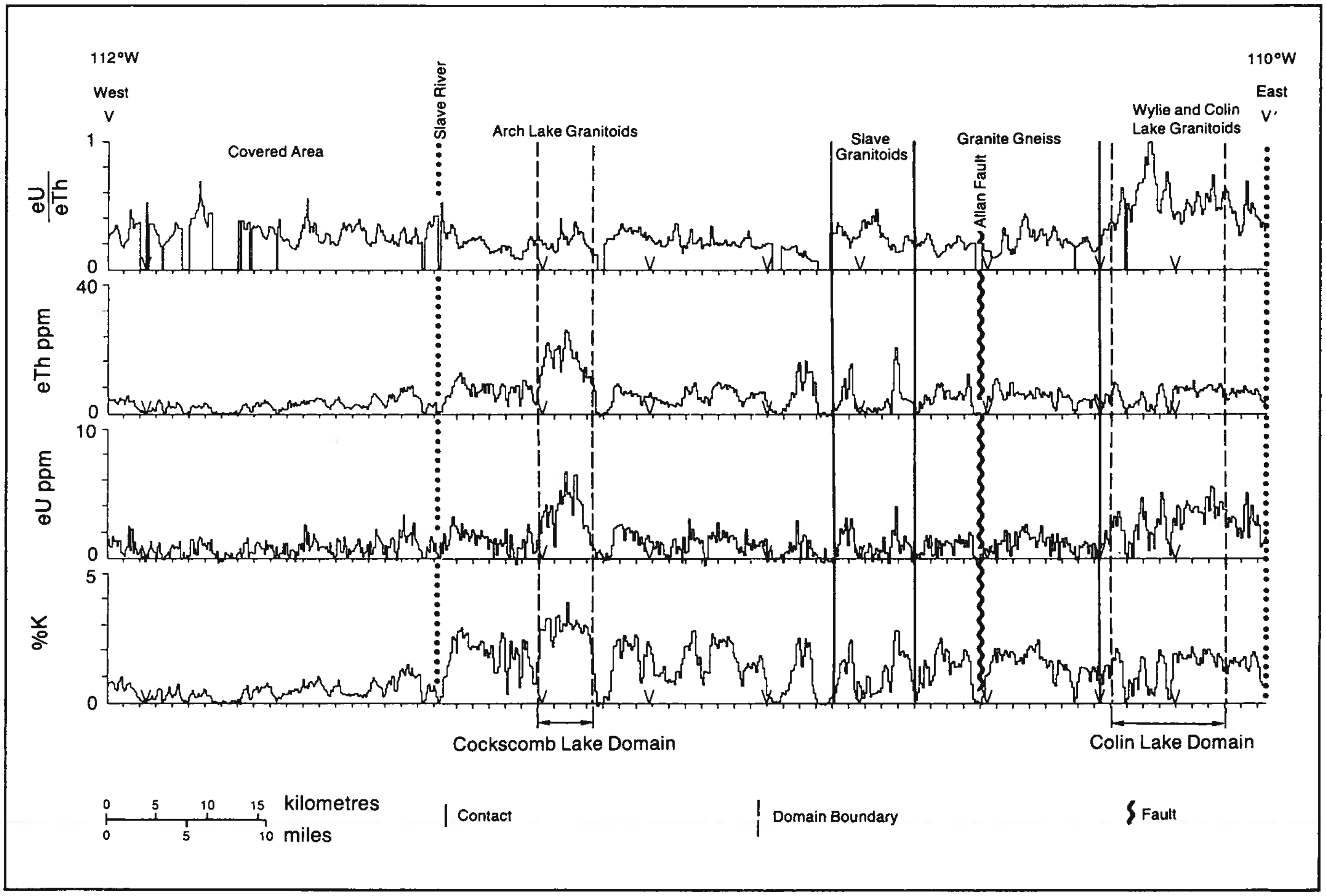


Figure 43. Stacked west-east radio-elemental profiles (V-V′, fig. 38) which cross the Cockscomb Lake and Colin Lake Domains. The eU ppm values for both anomalies are comparable. However, the eTh ppm values for the Colin Lake Domain are lower and the eU/eTh ratios are much higher. These ratios suggest that the Colin Lake Domain is more highly prospective as a uranium mineral exploration area than the Cockscomb Lake Domain.

to eTh concentrations averaging 20 ppm. Hence, despite its impressive gamma-ray output, this domain is probably not a good uranium exploration target. Nonetheless, in view of the anomalous nature of this domain, not only radiometrically but also magnetically and structurally, it is an area worthy of more detailed scientific investigation.

Because the Cockscomb Lake and Colin Lake Uraniferous Domains occur on the same east-west radiometric traverse line, it is instructive to compare their relative responses. The data (figure 43) indicate that the Cockscomb Lake Uraniferous Domain and the Colin Lake Uraniferous Domain have similar concentrations of eU and K%, but very different eTh values. The Cockscomb Lake Uraniferous Domain has an eTh of about 20 ppm whereas the Colin Lake Uraniferous Domain shows only 8 ppm. Accordingly, the Cockscomb Lake Uraniferous Domain has a very low eU/eTh ratio relative to that of the Colin Lake Uraniferous Domain. This difference can be expanded to the other radiometric anomalies on the Alberta Shield. In general, the Tulip Lake, Ryan Lake, Cockscomb Lake, and Fidler Point Domains are associated with the Fort Smith belt of thorium-uranium enrichment, whereas the domains to the east are related to the Tazin Lake-Uranium City trend of uranium enrichment (Burwash

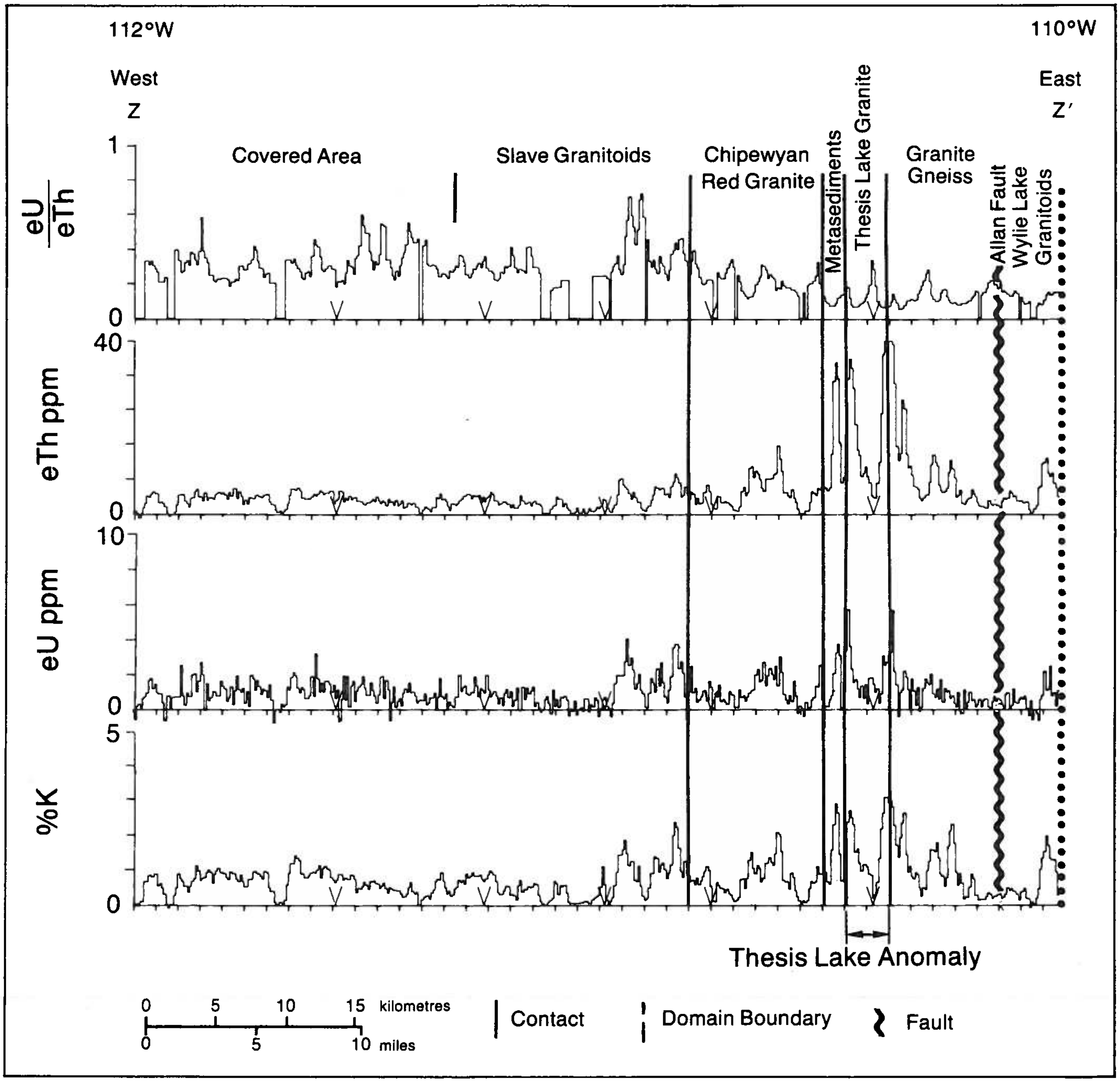


Figure 44. Stacked west-east radiometric profiles for a traverse line (Z-Z′, fig. 38) crossing the Thesis Lake area. High eTh ppm, high %K, moderate eU ppm, and a low eU/eTh value suggest a low rating for the Thesis Lake area as a uranium exploration target within the Alberta Shield.

and Cape, 1981). Thus, the Alberta Shield includes two fundamentally different types of uranium occurrence: both are of economic potential.

The Thesis Lake area

Though not ranked as a uraniferous domain in this study due to its low eU, low eU/eTh, and small area, the Thesis Lake locality (figure 3) of the Alberta Shield has interesting radiometric characteristics. This area is composed dominantly of Thesis Lake Granitoid surrounded by granite gneiss and high-grade metasedimentary rock. Godfrey (1980b) reported that locally up to 90 percent of the Thesis Lake Granitoid occurs as a pegmatitic phase. Field mapping in the domain has not recorded any radioactivity from the Thesis Lake Granitoid or from the rocks in contact with it (map 13, Godfrey, 1980b). Detailed ground radiometric surveys would be helpful in delineating the cause of the airborne radiometric expression over this domain (figure 44). The Thesis Lake Granitoid averages approximately 1.8 ppm eU, 12-18 ppm eTh, and 1.5 percent K. The eU/eTh ratio is very low due to the anomalously high eTh concentration and the low eU value.

The Tulip-Mercredi Lake area: a case study

Airborne gamma-ray radiometric data over the Tulip-Mercredi Lakes region shows large anomalous radio-elemental values which lie on the lithostructural trend with the Fort Smith, Northwest Territories radiometric belt (Charbonneau, 1982). This area was selected for statistical radio-elemental studies based on its large areal extent and relatively homogeneous geologic nature. An underlying theme of this part of the study was to evaluate the economic potential of the Tulip Lake Uraniferous Domain in more detail than was described previously in this chapter.

The Tulip Lake Uraniferous Domain (figure 38) is primarily underlain by Slave Granitoids, although high-

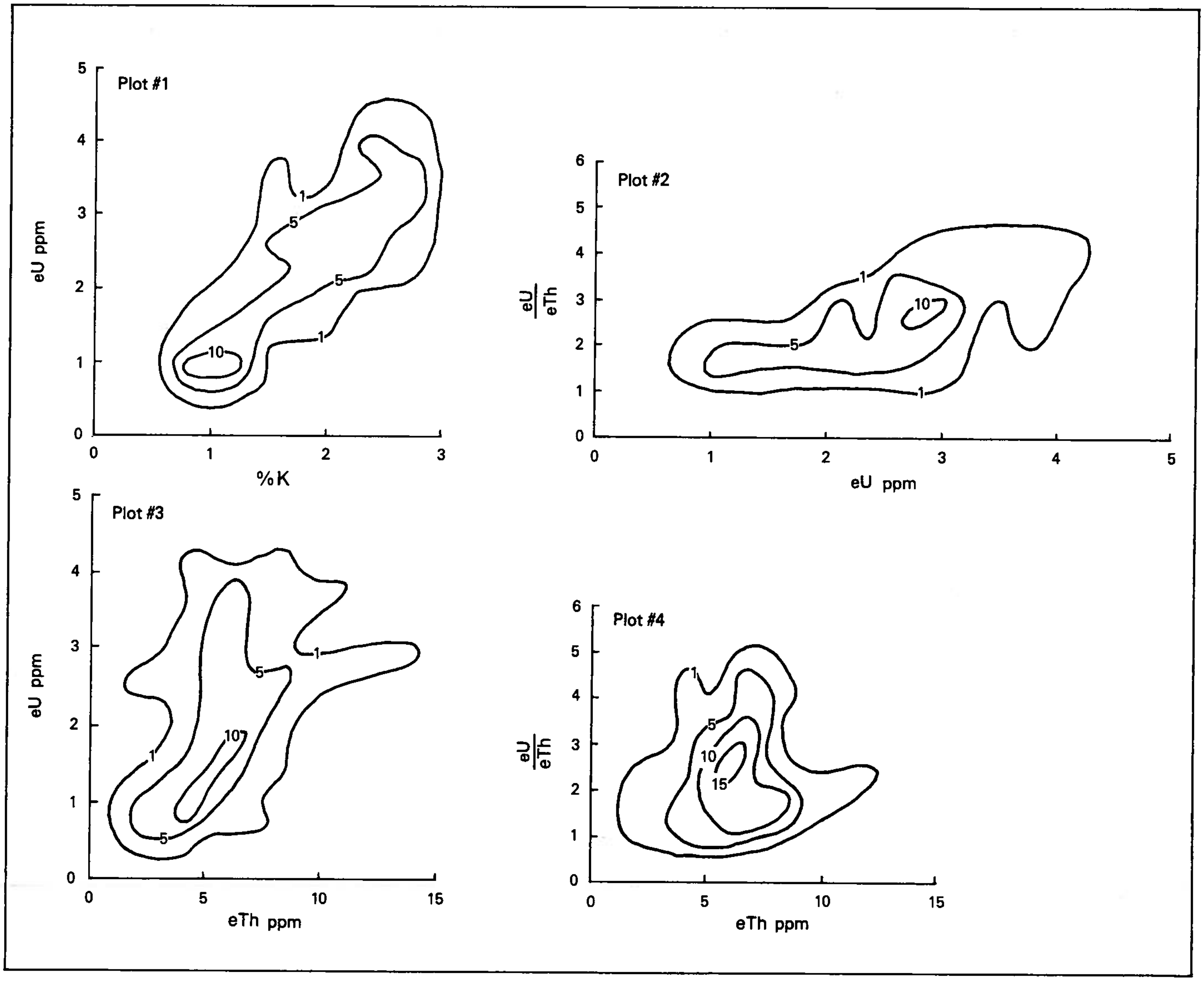


Figure 45. Radiometric cross plots for the Tulip Lake area. The contoured values indicate the number of sample points in the domain which show the characteristics indicated on the two axes.

grade metasedimentary rock bands occur as inclusions at this locality. Thorium-rich Arch Lake Granitoids border this domain.

Six airborne gamma-ray spectrometric flight lines were flown across the Tulip-Mercredi Lakes region at approximately 5 km spacings. From these traverses, the basic data for this study were obtained. A total of 141 samples were taken along the six flight lines at approximately 1.5 km intervals. A computer program was then used to produce a series of cross plots for eU ppm, eTh ppm, eU/eTh ratio, and K%.

Cross plot analysis for determining the radio-elemental trends and economic potential of granitoid bodies has been used in other studies of the Canadian Shield (Charbonneau, 1982; Gandhi and Prasad, 1982). Charbonneau (1982) outlined criteria for an economic evaluation of radio-elemental plots as follows:

1. If the eU/eTh ratio increases with respect to eU ppm, but not with eTh ppm, then post-magmatic redistribution of uranium is likely, and a favorable economic target is available.
2. If the eU ppm versus eU/eTh ratio does not show variation within the intrusion, it is most likely that uranium has not been redistributed after the intrusive event, and hence the bulk of the uranium remains in stable accessory minerals.
3. If the eU/eTh ratio is inversely correlated with the eTh ppm the radio-elemental distribution is, in part, magmatically governed. However, if the end product of the differentiation shows a tendency for increase of the eU ppm to eU/eTh ratio, then economic mineralization is a possibility.

Figure 45 shows four radio-elemental cross plots derived from airborne gamma-ray spectrometric data over the Tulip Lake Uraniferous Domain for eU ppm, eTh ppm, eU/eTh, and K%. Two strong correlations are evident between the eU versus K% and eU/eTh ratio versus eU ppm plots.

In plot #1, as eU ppm increases so does K%. It was noted earlier in this report that many of the radiometric highs in the Alberta Shield are located in or near pegmatite bodies associated with moderate to high K% values. Possibly the uranium highs in the Tulip Lake Uraniferous Domain are also associated with pegmatitic phases. However, very few pegmatitic bodies have been encountered during field mapping in the Tulip Lake area. Hence, the correlation in plot #1 probably indicates the difference in potassium content between the Arch Lake and Slave Lake Granitoids.

Plot #2 reveals that the eU/eTh ratio increases with eU ppm. According to Charbonneau's first criteria listed above, this relationship suggests favorable uranium enrichment trends within the Tulip Lake area, and the Slave Granitoids.

Plot #3 indicates that thorium has remained fixed with respect to uranium as the uranium content has increased, a key sign for possible uranium enrichment.

Plot #4 displays similar trends showing a fixation of thorium with an increase in the eU/eTh ratio.

In summary, the Tulip Lake Uraniferous Domain shows enrichment trends for uranium, whereas thorium appears to remain fixed with respect to uranium. In general, according to Bennett (1970), Charbonneau (1982), and other workers, such relationships are favorable not only for economic uranium mineralization, but also for hydrothermal enrichment of other metals, such as molybdenum, tin, and copper.

Conclusions

The Canadian Shield of northeastern Alberta has a geophysical expression governed not only by rock composition but also by complex structural-metamorphic conditions. A dominant northwest-southeast directed stress, regional metamorphism, diapirism, and local shearing all affect the present-day geophysical features of the Alberta Shield.

North- to northeast-trending anomalies — gravity, magnetic, and radiometric — are common in the Churchill Province as a whole, and in the Alberta Shield in particular. These features can be generally interpreted as an expression of high-grade metasedimentary rock synforms surrounded by a basement gneissic complex, both intruded by younger granitoids produced by reworked plutonic rocks under conditions of ultrametamorphism.

The magnetic field of the Alberta Shield correlates with bedrock features seen in outcrop. Two patterns of aeromagnetic anomaly are discernable in the study area: linear anomalies, related to regional metamorphism and local shear; and a circular to arcuate form, indicative of primary magmatic conditions. Magnetic lows in the Alberta Shield are usually associated with metasedimentary rocks, mylonite zones, or magnetite-poor granitoids. Magnetic highs are commonly caused by granite gneiss and magnetite-rich granitoids. The magnetic field of the study area shows a distinct northeast-southwest fabric, probably the result of a formerly dominant northwest-southeast directed stress.

The gravity field of the Alberta Shield is affected not only by the volume, shape, and distribution of exposed rock masses, but also by variations in metamorphic facies, structural fabric, and rock composition in the deep subsurface. The relationship between gravity field values and outcrop rock densities is generally complex in the Alberta Shield. Overall, the granite gneiss units display higher residual gravity field values than the granitoids and metasedimentary units, a result which is consistent with standard rock sample density determinations. However, the residual gravity field over granitoid units commonly does not correspond with outcrop density, a result which indicates the influence of buried materials on the gravity field. A curvilinear northeast- to north-trending gravity high, "the Barrow-Ashton Lakes Gravity High", correlates with granulite facies granitoids. Gravity field observations, as well as outcrop density determinations on domal structures in the Alberta Shield, are generally consistent with the hypothesis of a diapiric origin for these features.

Airborne radiometric values over the Alberta Shield indicate six distinct radio-elemental domains in the study area. These domains show anomalously high eU, eTh, %K, or eU/eTh values. All of the domains are underlain by granitoid masses and are associated with radio-elemental enrichment in either the Fort Smith belt or the Uranium City trend. The radioactive positive anomalies are underlain by the following map units in order of decreasing eU abundance: Slave Granitoids, Colin Lake Granitoids, Wylie Lake Granitoids, and Arch Lake Granitoids. The major sources of radioactivity are pegmatite phases, followed by rock contacts, metasedimentary rock inclusions, and fault zones.

The magnetics, gravity, and radiometrics of the Alberta Shield have been shown in this bulletin to be intimately intertwined with the spatial and temporal geological heterogeneity of the area. The complexity of the geological history precludes the generation of a simple geophysical model for the area.

The geophysical expression of the Precambrian Shield in Alberta can be understood only in the context of the area's polyphase metamorphic and deformational history.

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Figure 23. Outcrop rock density in the Alberta Shield.