THE DIAMOND POTENTIAL OF ALBERTA: A REGIONAL SYNTHESIS OF THE STRUCTURAL AND STRATIGRAPHIC SETTING, AND OTHER PRELIMINARY INDICATIONS OF DIAMOND POTENTIAL

MDA PROJECT M93-04-037
ALBERTA RESEARCH COUNCIL OPEN FILE REPORT 1994-10

PREPARED BY

M.B. DUFRESNE and R.A. OLSON
APEX Geoscience Ltd.

D.R. SCHMITT
University of Alberta

B. McKINSTRY
Elad Enterprises Ltd.

D.R. ECCLES, M.M. FENTON,
J.G. PAWLOWICZ, W.A.D. EDWARDS
and
R.J.H. RICHARDSON
Alberta Geological Survey

TABLE OF CONTENTS

PAGE

PAGE

LIST OF FIGURES

FIGURE **PAGE**

FIGURE **PAGE**

FIGURE		PAGE

FIGURE		PAGE

FIGURE		PAGE

FIGURE		PAGE

FIGURE **PAGE**

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

Several individuals assisted with the preparation of this study. These include: (a) Ms. S. Schonbeck of the Alberta Geological Survey who assisted in the typing of the final manuscript, (b) Mr. D. Magee of the Alberta Geological Survey who assisted in the preparation of some figures, (c) Mr. W.N. Hamilton of the Alberta Geological Survey who provided information about the geology of Alberta, and (d) Mr. M.E. Freeman of APEX Geoscience Ltd. who assisted with the compilation of data and the preparation of some of the figures and tables. As well, Dr. Schmitt would like to thank Dr. D. Gendzwill of the University of Saskatchewan for sharing details on the seismic observations on a kimberlite pipe prior to publication.

SUMMARY

The primary objectives of this study were to identify favourable geological anomalies and target areas for diamond exploration that would act to encourage industry to explore in Alberta, and to provide selected geological, geophysical and geochemical data that would assist industry in their exploration for diamonds in Alberta. We believe the following text, figures, tables and appendices provide much information and data that will be useful to industry in their exploration of Alberta for diamondiferous deposits.

Alberta is favourable for diamondiferous deposits because:

(a) Alberta is underlain by large areas of Precambrian crust that acted as 'cool roots', hence there is a good possibility that diamond-bearing source rocks exist at least locally in the mantle beneath Alberta.

(b) Alberta contains major faults and other tectonic features that may have acted as near surface conduits for the intrusion of diamond-bearing kimberlitic or lamproitic diatremes.

(c) Kimberlite and lamproite intrusions, several of which are diamondiferous, exist in several provinces, territories and states adjacent to or near Alberta. Although at present no definite kimberlite or lamproite intrusions have been definitely reported in Alberta, with the exception of the Mark 1 diatreme cluster which straddles the Alberta - British Columbia border north of Golden, B.C., there are indications, or at least rumours, that such diatremes have been found in outcrop or intersected by drilling west of Hinton and near Peace River Alberta. In southern Alberta, although it has been suggested the region of the Sweetgrass Intrusions has low diamond potential because the intrusions which crop out in Canada are predominantly or entirely minettes, there may still be potential for diamondiferous deposits in this area because of the interpreted extensive dyke swarm that has been identified from recently published aeromagnetic data. As well, two diamonds were reported to have been discovered at Etzikom Coulee near Legend in southern Alberta not far north of where the Sweetgrass Intrusions crop out. Furthermore, in the Missouri Breaks and Smoky Butte region of central Montana, age equivalents to the Sweetgrass Intrusions locally include kimberlitic and lamproitic diatremes.

(d) There is evidence of at least four, and possibly five, ages of volcanic activity in Alberta. Diamondiferous diatremes of equivalent ages exist elsewhere in North America or the world. It is possible that the most important of the igneous events in Alberta occurred during the early Late Cretaceous, that is during deposition of the Shaftesbury Formation and the enclosed Fish Scales Horizon, because diamondiferous diatremes, vent facies and volcaniclastics have been found in stratigraphically equivalent successions in Saskatchewan. In addition, early

Tertiary strata (Paleocene, Eocene) in Alberta should also not be ignored because the reported ages for the potentially economic diatremes that have been discovered in the Lac de Gras region of the N.W.T. are about 52 Ma.

(e) Numerous bentonites and tuffs exist in the Phanerozoic succession in Alberta, and in several places there are anomalously thick bentonitic horizons (e.g., Drumheller, Duagh and Irvine-Bullshead bentonites), some of which are localized and have a trend that crosses the major sedimentary depositional strike. This may indicate local volcanic venting as opposed to the bentonites being wind-blown debris derived entirely from outside Alberta. Interestingly, all of the above thick bentonites are of late Late Cretaceous age, which is perhaps the most extensive and voluminous period of diamondiferous magmatism in the world.

(f) There are numerous diamond indicator mineral anomalies at several places within Alberta, with some indicator grains having excellent chemistry which indicates they may have been derived from local kimberlitic or lamproitic diatremes. As well, diamonds have been found in drift and fluvial sediments in at least three publicized locales in southern and central Alberta.

(g) There are a large number of geological, geophysical or geochemical anomalies in Alberta, at least some of which may have been or are related to emplacement of potentially diamondiferous kimberlitic or lamproitic diatremes, or reflect erosional secondary deposits derived from such primary diamondiferous source rocks.

(h) Lastly, although much remains to be known about the bedrock and surficial geology of Alberta, particularly in the northern half of the province, there exists an extensive geological and geophysical database of information that is available from various government agencies or from brokers of industry-generated data.

In conclusion, the above indicates that Alberta has at least moderate to, possibly, high potential to contain diamondiferous diatremes and vent-related deposits, yet at present the province has been barely explored for such deposits, even though extensive staking has occurred. As well, if primary diamondiferous deposits are found in Alberta, then exploration should also be directed towards the discovery of secondary diamondiferous deposits in selected sedimentary strata which are geologically analogous to the setting found to contain such economically important secondary deposits in southern and western Africa, and in Russia.

1. INTRODUCTION

The existence of diamondiferous kimberlitic diatremes in the Lac des Gras area, Northwest Territories, and the Fort à la Corne area, Saskatchewan indicates that there is potential for the discovery of diamonds in other areas of Canada that are underlain by thick Precambrian basement rocks, such as the majority of Alberta. Further, the emplacement of diamondiferous diatremes are controlled, in part at least, by extensional faults or fracture zones associated with regional fault systems, arches and other structural zones that transect either the Precambrian basement or overlying Phanerozoic rocks, or both. In several parts of Alberta these types of structural zones transect Phanerozoic cover rocks that are underlain by thick Precambrian basement with no or little extensive reworking, hence the potential may be high for the discovery of kimberlite or lamproite hosted diamond deposits. In addition, if such diamondiferous diatremes exist in bedrock, then potential also exists for economic concentrations of paleoplacer or placer diamonds in Alberta.

Diamonds are reported to have been discovered in surficial sediments west of Edmonton near Evansberg, and in southeast Alberta near the Sweetgrass Hills. As well, diamond indicator minerals have been reported in several places in Alberta. These preliminary data, plus the fact that about 200 companies and individuals have acquired exploration mineral permits which encompass about 36.5 million hectares of Alberta, indicate that industry believes Alberta has a high potential for the discovery of important diamond deposits.

In Alberta, a vast literature database exists on geological features that may be important in the search for diamondiferous kimberlite or lamproite diatremes. This database includes information about Precambrian basement crustal composition and thickness, sub-Phanerozoic basement structures, regional Phanerozoic structures, alkaline volcanism, volcanic bentonite layers, surficial geology and other geological anomalies. Therefore, these data from government sources, universities and private industry provide an extensive database from which structural, stratigraphic and geophysical information can be used to delineate regional tectonic and other features that may be important to industry in the exploration for diamondiferous deposits within Alberta. This study was undertaken on behalf of the Canada-Alberta Partnership on Minerals Agreement (MDA project M93-04-037) by scientists of the Alberta Geological Survey, in conjunction with the principals of APEX Geoscience Ltd., Mr. McKinstry of Elad Enterprises Ltd. and Dr. D.R. Schmitt, an Assistant Professor in the Department of Geophysics at the University of Alberta, in order to summarize and synthesize some of the key existing data that pertain to the potential of Alberta to contain important diamond deposits.

The objectives of preparing a regional synthesis of structural, stratigraphic, geophysical, geochemical and diamond mineral indicator information and data for Alberta, were several fold:

1. The primary objective is to identify favourable geological anomalies and target

areas for diamond exploration that would act to encourage and assist exploration by industry.

2. The second objective is to provide information about certain geologic and geographic domains in Alberta based upon selected criteria, such as: (a) the potential for kimberlite versus lamproite diatremes based on the underlying Precambrian basement rocks, (b) the possible timing of kimberlite of lamproite magmatism, (c) the regional structures along which kimberlites or lamproites may have been intruded, (d) the stratigraphic data that may be indicative of local diatreme extrusion, and (e) to what extent such diatremes may been preserved or eroded under the conditions that then existed in Alberta.

3. The third objective is to identify what exploration methods have been used worldwide for diamond exploration, and which of these methods have been or may be useful for diamond exploration in Alberta. Such information is important to diamond exploration in the context of the Alberta situation because: (a) any Phanerozoic kimberlite or lamproite diatreme activity in Alberta would probably have occurred under marine conditions, hence the results of any such activity will be associated with extensive Phanerozoic deposits, and (b) the glacial history of Alberta, particularly in the west, is complex due to the interference effects created by the interaction of Rocky Mountain and Cordilleran glaciation with Continental glaciation. Thus, exploration for diamondiferous deposits in Alberta may present a more difficult exploration problem in comparison to the exposed Precambrian Shield in the Lac de Gras region of the N.W.T.

1.1 Kimberlites and Lamproites, and Models For Emplacement

Kimberlites and lamproites are the only two known economic primary sources of diamonds worldwide. Primary diamonds or graphite pseudomorphs after diamonds are also known to occur in some lamprophyres, alkali basalts and alpine type peridotites, but significant quantities of diamonds have not yet been found in these rocks (Mitchell 1991, Helmstaedt 1992, 1993). Although they are small in total combined volume relative to all known igneous rocks worldwide, much more is known about kimberlites and lamproites than other ultramafic igneous rock types because of their economic significance. Both kimberlites and lamproites are products of deep-seated continental intraplate alkaline volcanism, hence they are geologically similar in many respects. There are, however, a number of significant differences between these two classes of rocks, as summarized below.

Two types of kimberlites are recognized worldwide, and these are commonly referred to as Group I and Group II kimberlites. These two groups correspond to the original classification by Wagner (1914) of olivine kimberlites and micaceous kimberlites. According to Mitchell (1989, 1991) and Skinner (1989), **Group I kimberlites** are petrographically complex rocks, and may contain crystals derived from three different sources: (1) the fragmentation of upper mantle xenoliths (xenoliths are wall rock fragments that fall into the magma as it rises to the surface), (2) the primary phenocryst and groundmass minerals, which crystallize directly from the kimberlite magma (these primary minerals include olivine, phlogopite, perovskite, spinel, monticellite, apatite, calcite and primary serpentine), and (3) the megacryst/macrocryst or discrete nodule suite. Xenolithic minerals in Group I kimberlites include Cr-rich subcalcic pyrope (G9 and G10 garnets), olivine, Cr-diopside, high-Cr chromites and diamond (Mitchell 1989, 1991; Skinner 1989; Gurney and Moore 1993). Megacrysts are large (1 to 20 cm) single crystals of low-chrome titanian pyrope (G1 or G2 garnets), magnesian (picro) ilmenite, subcalcic to calcic diopside, olivine, Ti-poor chromite, enstatite, phlogopite and zircon. Lamellar intergrowths between pyroxenes and magnesian ilmenites are common. Macrocrysts are somewhat smaller crystals, but tend to be rounded to subrounded and are compositionally similar to the megacryst suite of minerals with the exception that macrocrysts include abundant olivine. It is not clear whether the megacryst/macrocryst suite of minerals are xenocrysts or cognate phenocrysts, or a combination of the two. The megacrysts are believed to have formed in the upper mantle, and the existence of such megacryst minerals is generally believed to be an indicator of kimberlite magmatism. The overall mineralogy of Group I kimberlites varies widely, and depends on the relative contribution of each of the three contributing sources. In general, Group I kimberlites are characterized by the presence of abundant olivine, the characteristic megacryst/macrocryst suite and by only minor amounts of phlogopite.

Group II kimberlites comprise principally rounded olivine macrocrysts in a matrix of abundant phlogopite and diopside, with spinel, perovskite and calcite (Mitchell 1989, 1991, Skinner 1989). In contrast to Group I kimberlites, Group II kimberlites lack the megacryst suite and minerals such as monticellite and ulvöspinel. In addition, spinels and perovskite are relatively rare. While Group I kimberlites are found worldwide, Group II kimberlites are only known from southern Africa.

There are three textural-genetic groups of kimberlites recognized worldwide: (1) crater facies, (2) diatreme facies and (3) hypabyssal facies (Mitchell, 1986, 1989, 1991) (Figure 1.1). The crater facies of kimberlites includes epiclastic deposits and rocks which may represent tuffs. Kimberlite lavas have not yet been recognized. The crater facies typically forms a ring around the perimeter of the kimberlite. Diatremes are vertical or steeply inclined cone-shaped bodies that consist primarily of tuffisitic kimberlite breccia or volcaniclastic kimberlite breccia (Mitchell 1991). The steep sides (75°to 85° dip) and downward tapering margins of the diatreme result in the cross-sectional area decreasing regularly with depth, and lead to the characteristic 'carrot-shape' description of their shape. Approximately subcircular or elliptical outcrop plans of the diatreme facies are also characteristic, and the axial lengths of the diatremes range from about 300 m to 2,000 m. Kimberlite diatremes grade downward into irregularly-shaped root zones that are the hypabyssal facies of the intrusive. Kimberlite crater facies rocks can be significant sources of diamonds, as is the case at the Orapa and Jwaneng pipes in Botswana and the Mwadui pipe in Tanzania (Helmstaedt 1992, 1993). Both the diatreme and root zones

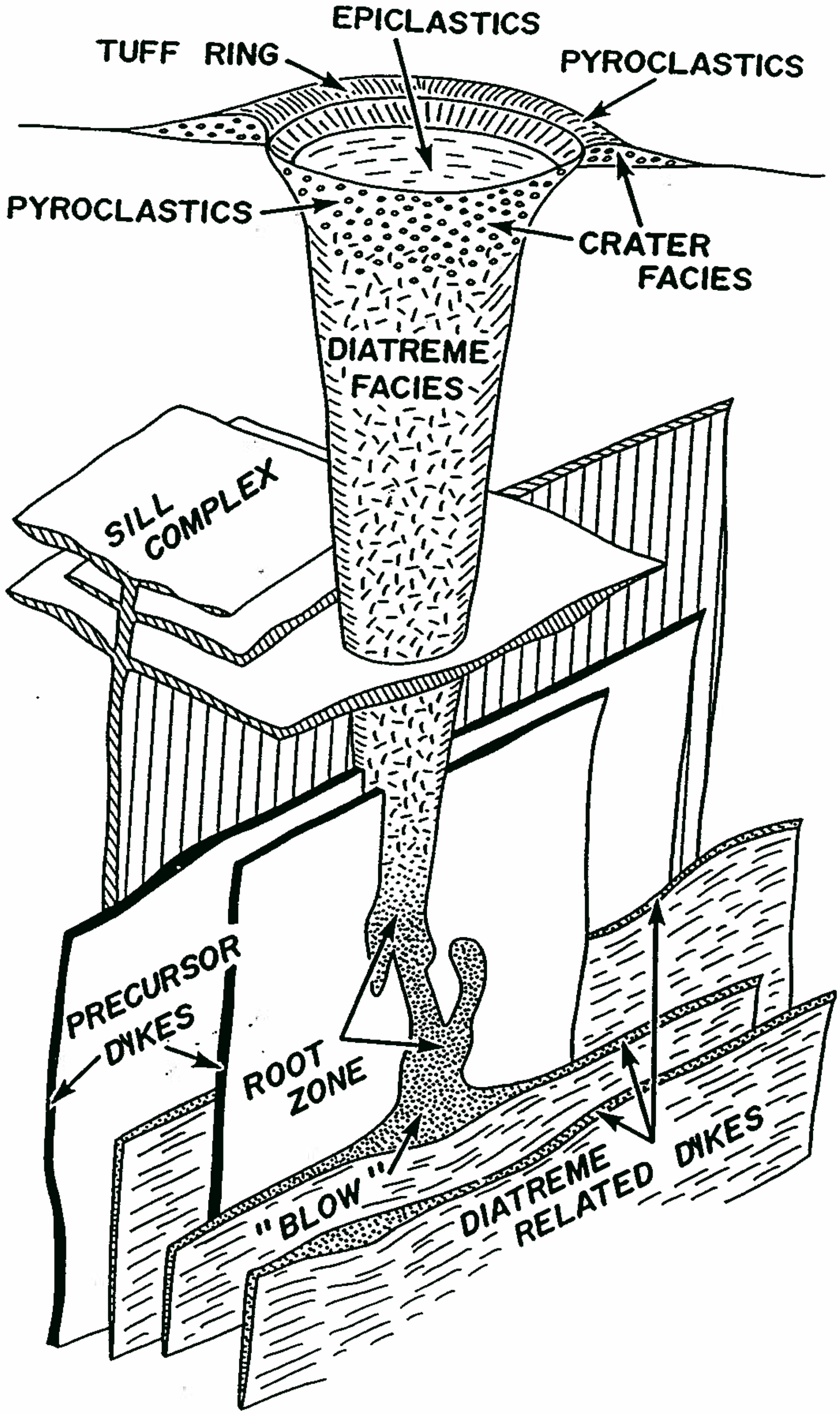


Figure 1.1: Model of an idealized kimberlite magmatic system (not to scale) illustrating the relationships between crater, diatreme and hypabyssal facies rocks. The diatreme root zone is composed primarily of hypabyssal rocks (Mitchell 1986).

within a kimberlite can also be diamondiferous, but diamond grades can be highly variable, even in separate zones within individual pipes.

Like kimberlites, lamproites are petrographically complex, hybrid rocks consisting of complex mixtures of magmatic phenocrysts with upper mantle xenoliths and xenocrysts (Helmstaedt 1993). Lamproites are commonly referred to as ultrapotassic, peralkaline mafic to ultramafic rocks that exhibit a characteristic exotic mineralogy and distinctive geochemical signature (Bergman 1987; Mitchell 1989, 1991; Scott Smith 1992). Lamproites are typically ultrapotassic ($K_2O/Na_2O \geq 3$), containing 6% to 8% K_2O as compared to 2% or less in Group I kimberlites, peralkaline ($K_2O+Na_2O/Al_2O_3 \geq 1$), and they are more enriched in the incompatible elements Zr, Nb, Sr, Ba , La and F, and the compatible elements Co, Ni, Cr and Sc than are kimberlites. Lamproites display a wide range of modal mineralogies making classification based on mineralogy difficult at best. Lamproites have a number of major (olivine, diopside, phlogopite) and minor (apatite, perovskite, ilmenite, spinel) mineral phases in common with kimberlites, but they also have a number of additional minerals that serve to distinguish them from kimberlites. These minerals include leucite, amphibole (K-Ti richterite), sanidine, priderite, wadeite, armalcolite and jeppeite (Bergman 1987; Mitchell 1989, 1991; Scott Smith, 1992). Lamproites also differ from kimberlites in having matrix glass and a relatively low calcite content. Mantle derived xenocrysts including olivine, chromite and pyropegarnet may also be present. Minerals which are characteristically absent from lamproites include nepheline, sodalite, kalsilite, melilite, plagioclase, alkali feldspar, monticellite and melanite. The absence of these minerals serves to distinguish lamproites from other (non-kimberlitic) potassic and undersaturated alkalic rocks (Mitchell 1991).

Lamproites occur principally as extrusive, subvolcanic and hypabyssal rocks (Mitchell 1991). They do not form carrot-shaped diatremes and root zones analogous to those of kimberlites, but instead their vents are shallow and wide, and commonly are compared to the shape of a champagne glass. Composite crates with associated bedded volcaniclastic deposits and volcanic debris are common where the craters are preserved. Lamproite diatremes also tend to be smaller than kimberlites and do not extend to great depths (Figure 1.2). An atypical style of lamproite emplacement is that noted by Kent *et al.* (1992), who described the presence of Cretaceous (Aptian) horizontal, tubular to cylindrical shaped titanium and phosphorus-rich olivine lamproite intrusions within the Permian Jharia coalfield of India. There are estimated to be between 3,000 to 4,000 such intrusions within the coalfield, with the 1 m to 3 m wide tubes interconnected to produce wormburrow-like patterns.

The crater facies of a lamproite is commonly intruded by magmatic lamproite. Diamonds occur mainly in the pyroclastic rocks of the crater facies, with the magmatic lamproite phases generally being diamond-poor. As a result, the diamondiferous tonnage potential of lamproites tends to be restricted to the volume of pyroclastics preserved in the vent (Helmstaedt 1992, 1993).

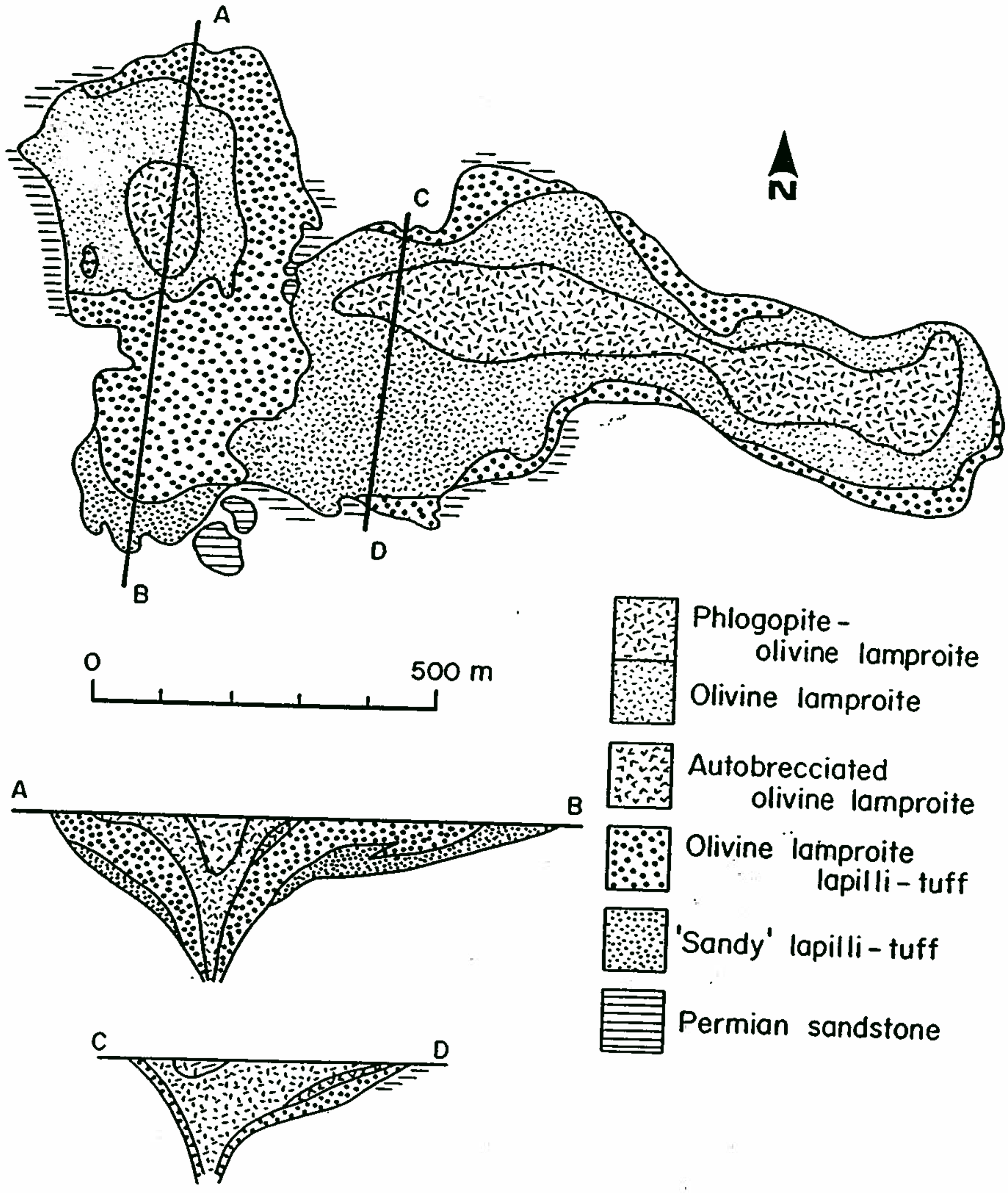


Figure 1.2: Plan and cross-sections of the Ellendale 4 lamproite vent. Note the distinctly different morphology as compared with kimberlite diatremes (Figure 1.1) and the presence of hypabyssal magmatic rocks within the crater facies pyroclastic rocks.

Both kimberlites and lamproites are not truly primary diamond deposits in the sense that all or at least most of the diamonds did not originate within the source magma. Instead, the macrodiamonds in these igneous host rocks are actually derived from the disaggregation of sometimes highly diamondiferous source rocks that exist in places in the lithospheric upper mantle (Kirkley *et al.* 1991, 1992; Gurney and Moore 1993). Therefore, the kimberlite and lamproite magmas simply provided the transport medium to move diamonds formed in the upper mantle source rock to the surface. Studies of mineral inclusions in diamonds and diamond-bearing xenoliths indicate that the diamond-bearing mantle sources worldwide are predominantly associated with two rock types: (1) garnet peridotites in which garnet and/or chromite harzburgites predominate over garnet lherzolites, and (2) eclogites. Minerals which are associated with diamonds within these xenoliths have distinctive compositions, and the presence of these minerals as detrital grains on the Earth's surface can indicate the presence of a diamondiferous kimberlite or lamproite source nearby (Gurney and Moore 1993). In general, diamonds with peridotitic inclusions (P-type diamonds) predominate over diamonds with eclogitic inclusions (E-type diamonds). P-type diamonds from South Africa and Russia have been dated at approximately 3,300 million years of age (Ma). E-type diamonds, on the other hand, have yielded younger ages, from 2,700 Ma to as young as 990 Ma. Based on the inclusions found in diamonds and diamond bearing xenoliths, both P-type and E-type diamonds occur in every known diamond deposit worldwide (Kirkley *et al.* 1991, 1992; Gurney and Moore, 1993; Helmstaedt 1993). Although the relative proportions of P-type to E-type diamonds can vary widely from deposit to deposit, P-type diamonds appear to be much more abundant on the South Africa (Kalahari) Craton (Gurney and Moore 1993). At present, it is hotly debated whether single or multiple events or processes are required to form P-type and E-type diamonds.

It has been estimated that most diamonds worldwide were formed at pressures corresponding to depths of 150 km to 300 km below the Earth's surface, and at temperatures generally not exceeding 1,200 °C. These conditions occur within relatively cool lithospheric roots (mantle roots), in which the downward deflection of isotherms causes a corresponding upward expansion of the diamond stability field. As Figure 1.3a shows, kimberlites or lamproites which originate from within or below the diamond source rocks have the potential to transport diamonds to the Earth's surface. This is in contrast to kimberlites or lamproites that originate at the craton margins because they do not sample the diamondiferous source rocks and hence cannot transport diamonds to the surface. There are four requirements for a large primary diamond deposit to occur at the Earth's surface: (1) the kimberlite or lamproite host rock must originate in or below a diamond-rich source region of the upper mantle where diamonds have remained stable since the time of their formation; (2) the kimberlite or lamproite intrusion must sample the diamond-bearing source region(s); (3) the kimberlite or lamproite magma must ascend fast enough and provide a suitable reducing chemical environment for diamonds to survive the transport to the Earth's surface; and (4) the host magma must encounter emplacement sites where conditions are conducive to the formation of sufficiently large pipes (Helmstaedt 1993).

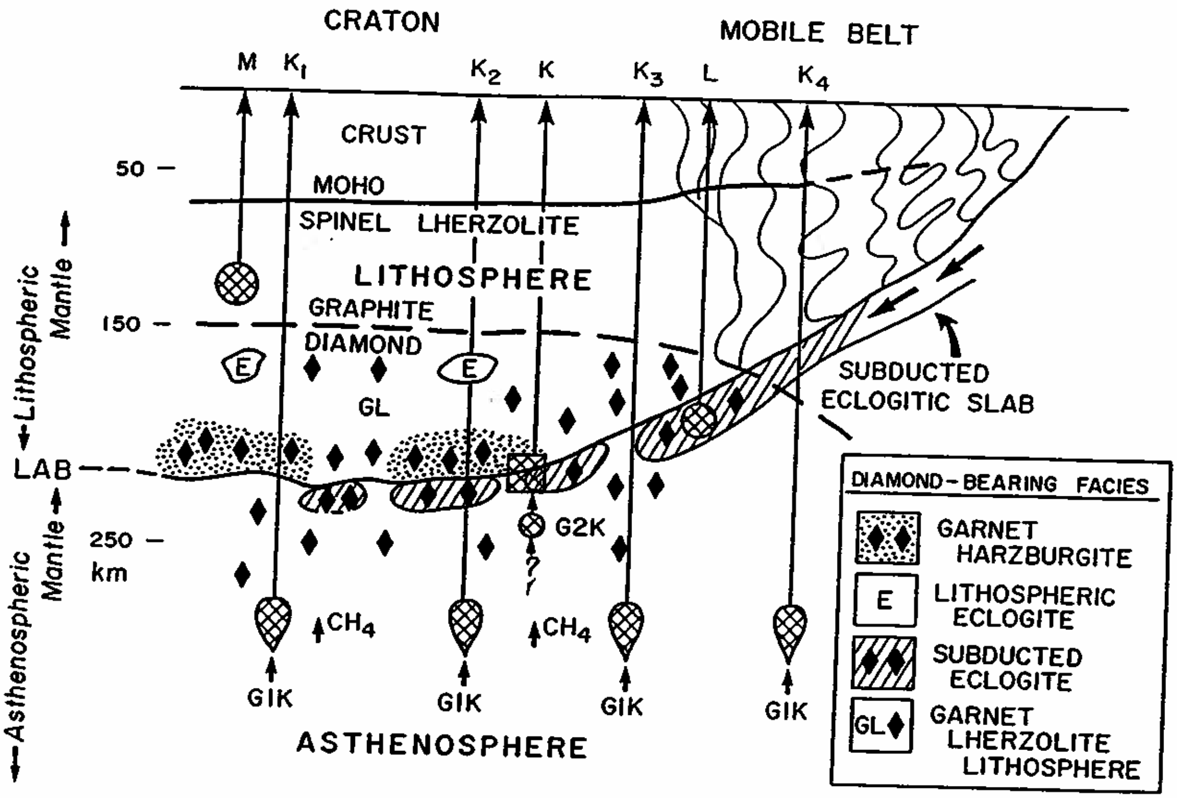


Figure 1.3a: Hypothetical cross-section of an Archean craton and adjacent cratonized mobile belt, showing the location of the lithosphere-asthenosphere boundary (LAB) relative to the stability fields of diamond and graphite. The diagram illustrates why different group 1 kimberlites (G1K) differ with respect to sources of xenocrystal diamond. K_1 may contain lithospheric and asthenospheric garnet lherzolite diamonds together with garnet harzburgite-derived diamonds. K_2 contains diamonds from the aforementioned sources plus diamonds derived from lithospheric eclogites and subducted eclogites, i.e., five distinct sources. K_3 contains only lithospheric and asthenospheric garnet lherzolite diamonds. K_4 does not pass through any diamond-bearing regions and is barren of diamonds. Group 2 kimberlites (G2K) are shown originating at the LAB and contain diamonds derived from garnet harzburgites and subducted eclogitic sources. An asthenospheric component may be involved in their genesis. Lamproite (L) contains diamonds derived form subducted eclogite and lithospheric garnet lherzolite sources. Melilititic (M) magmas are shown to be derived from depths within the graphite stability field and hence they are barren of diamond.

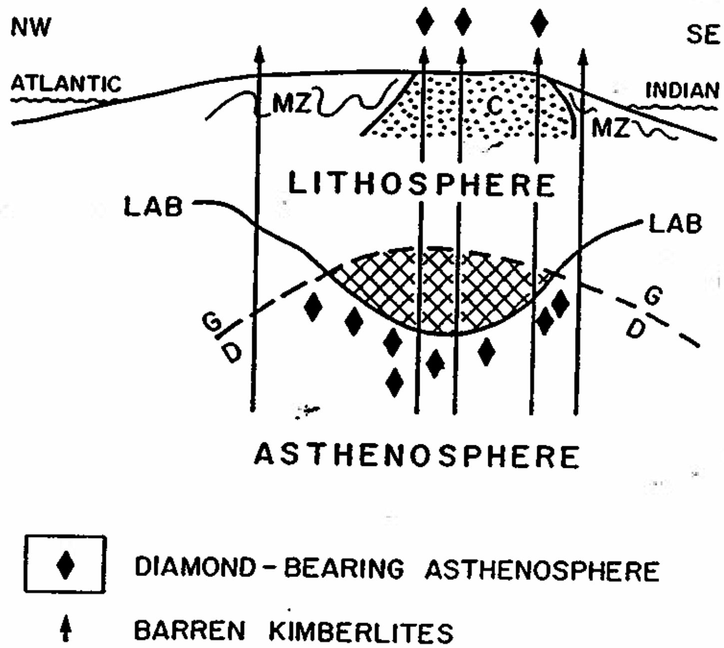


Figure 1.3b: Haggerty (1986) and Mitchell (1986, 1987) model illustrating why diamond group 1 kimberlites are restricted within the bounds of the Kaapvaal craton and barren kimberlites are confined to the adjacent mobile belts. Kimberlites are derived from similar depths within the asthenosphere as a result of the partial melting or upwelling asthenospheric material. The graphite-diamond univariant curve (D-G) is covex toward the Earth's surface due to the low geothermal gradient of the Archean craton. Asthenospheric diamonds are formed by methane oxidation at the lighosphere-asthenosphere boundary (LAB) in the vicinity of the deepest parts of the craton root (Haggerty, 1986). Lithospheric diamonds occur in the highly depleted garnet harzburgite root of the craton. Only kimberlites which pass through the craton root regions traverse diamond-bearing horizons. Kimberlites which are emplaced in mobile belts do not pass through diamond-bearing regions of the asthenosphere.

Kimberlites and lamproites are not just confined to the Archean parts of cratons. They also can occur within mobile belts, either during periods of normal faulting prior to the orogenic movements or subsequent to deformation and cratonization of the mobile belt. Nonetheless, 'Clifford's Rule' states that economically viable diamond deposits tend to be confined to the Archean cratons (Janse 1991; Figure 1.3b). However, there is one very important exception to Clifford's Rule, the Argyle deposit in Australia. This deposit is hosted in a lamproite that has intruded into a Proterozoic fold belt. As well, the majority of the diamonds within the Argyle lamproite are E-type diamonds of Proterozoic age. The Argyle example illustrates that it is possible for large accumulations of post-Archean, eclogitic diamonds to occur outside of, but adjacent to, an Archean craton (Helmstaedt 1993).

1.2 History Of Diamond Exploration In Canada

1.2.1 Outside Alberta

Diamond-bearing kimberlite and lamproite pipes occur in Archean cratons and Proterozoic mobile belts worldwide; most notably in South Africa, Russia and Australia. Although Canada contains abundant rocks of a similar geological setting and age, the existence of an important diamond deposit being present in this country has only recently been given credence.

Until 1991, diamond exploration in Canada had been limited to a very few companies, and had largely been unsuccessful. Although several kimberlite pipes had been discovered across the country, they were generally estimated to contain uneconomical grades of diamond. In 1991, however, Dia Met Minerals Ltd. announced the discovery of possible economic-grade diamond-bearing kimberlite in the Lac de Gras region of the Northwest Territories, thereby sparking one of the largest staking rushes in world history (N.W.T. Government 1993). By the fall of 1993, more than 40 kimberlite pipes had been discovered in the Lac de Gras region, many of which occur on land held by Dia Met Minerals Ltd. and their partner, Broken Hill Proprietary of Australia, by Southern Era Resources Ltd. and Aber Resources Ltd. and their partner, Kennecott Canada Inc., and by numerous smaller companies (N.W.T. Government 1993). Presently, bulk sampling is being conducted at many of the pipes, with the intent being to bring one or more of them into production. In addition to the diamond discoveries in the Archean Slave Structural Province at the Lac de Gras region, two separate diamond occurrences have been reported in lamproites in the Keewatin region of the Northwest Territories, one near Dubawnt Lake (George Cross Newsletter, 1993), and one near Baker Lake (Armitage *et al.* 1994). The existence of these diamond occurrences indicates that potential exists for diamondiferous diatremes in the Proterozoic Churchill Structural Province.

While Dia Met Minerals Ltd. was searching for kimberlite in the Northwest Territories, diamond exploration was also being conducted in Saskatchewan, where, in 1988, a diamond-bearing kimberlite pipe was discovered by Uranerz Exploration and Mining Ltd. near Prince Albert (Lehnert-Thiel *et al.* 1992). Bulk sampling of pipes in the Fort à la Corne area has shown that diamond grades in these pipes range from less than 2 carats/100 tonnes (cts/100t) up to 10.5 cts/100t, with most of the diamonds being gem-quality (Lehnert-Thiel *et al.* 1992). The kimberlites in the Fort à la Corne area are of Lower Colorado Group age (94 to 96 Ma), and form relatively flat, tabular to possibly mushroom-shaped bodies of bedded volcaniclastics. Two kimberlite facies are recognized at Fort à la Corne: a volcaniclastic crater facies and a hypabyssal kimberlite facies. To date, feeder diatremes have not been intersected in drilling at Fort à la Corne (Lehnert-Thiel *et al.* 1992). Continued sedimentation in Late Cretaceous times buried the Fort à la Corne kimberlites, but subsequent erosion has removed the Upper Cretaceous formations to approximately the same level that existed at the time of intrusion. Numerous targets in this region and in the nearby Sturgeon Lake area require further testing.

Although diamond exploration in British Columbia has not been as extensive as elsewhere in Canada, the discovery of diamondiferous lamproites near Golden, B.C. is significant to Alberta exploration because many of these pipes, including the Jack and Mark diatreme clusters straddle the B.C. - Alberta border (Northcote 1983a, b; Pell 1987a, b; Fipke 1990).

1.2.2 Within Alberta

The occurrence of diamond-bearing kimberlites and lamproites in several regions surrounding Alberta indicates that such diamond sources may occur in this province as well. The history of diamond exploration in Alberta, although not lengthy, is most certainly colourful. Primarily sparked by the recent discovery of diamond-bearing kimberlite pipes in the Northwest Territories and Saskatchewan, and the realization that similar favourable conditions exist for the preservation of such pipes in Alberta, diamond exploration in the province has markedly escalated in the last three years. Although, to date, no diamond source has been publicly identified in Alberta, the discovery of numerous diamond indicator minerals, as well as several diamonds in overburden and Phanerozoic sediments, has been extremely encouraging to major and junior diamond explorers alike.

Since 1988, Monopros Ltd., the Canadian subsidiary of DeBeers Consolidated Mines Ltd., has been exploring a large block of ground in the vicinity of the town of Peace River. As yet they have not released any information on their work. However, an article in the Peace River Gazette (1992) stated "they [Monopros] did quite a bit of drilling and we have reason to believe that they did encounter a lamproite pipe while drilling for trace minerals".

One of the most well known, as well as the most controversial, diamond discovery in Alberta is the Opdahl diamond. This diamond, reportedly a perfect octahedron and estimated at 1 carat in weight (Edmonton Journal 1992a), was discovered by farm worker Einar Opdahl in 1958 in the Evansburg area, although the exact whereabouts of the discovery remain uncertain. Also referred to as the Pembina or Burwash diamond, the stone was apparently sold to an Edmonton gem cutter who brought it to Dr. R. Burwash at the geology department at the University of Alberta for positive identification. Its present whereabouts are unknown, although no less than three junior exploration companies have staked ground on what they all claim to be the original discovery site (Edmonton Journal 1992a).

During 1992, the first documented diamond discovery was confirmed for Alberta. A prospector, Tom Bryant, was reported to have found two diamonds, weighing 0.14 and 0.17 carats, in glacial till at Etzikom Coulee near Legend southern Alberta (Edmonton Journal 1992b; Morton *et al.* 1993; Takla Star Resources Ltd. 1993a, b). Although Bryant discovered the diamonds during 1988, his prospecting activity was prompted, at least in part, by the increased claim staking in the area and, four years later, he brought the two diamonds to the geology department at the University of Alberta for analysis and to record their discovery (Edmonton Journal 1992b). The samples were positively identified as gem-quality diamonds.

Diamonds have also been discovered in gravels of the North Saskatchewan River and associated tributary creeks east of Edmonton (T. Bryant *pers comm.* 1993; Morton *et al.* 1993), and in sedimentary bedrock at the Cretaceous-Tertiary boundary along the Red Deer River in Central Alberta (Science City News 1992).

From 1992 until late 1993, claim staking, most of which has been for diamond exploration, reached a frenzied pitch in Alberta, and as is often the case, claim maps which were valid in the morning were obsolete by afternoon. During this time, Alberta became the playing field for both major exploration companies and junior companies, with the former being largely responsible for initiating the staking rush in the province, and significant land holdings were acquired by several well known diamond exploration companies.

Dia Met Minerals Ltd., with partners Cameco Corp. and Uranerz Exploration and Mining Ltd. of Saskatchewan, staked a 7,000 km^2 property just east of Jasper National Park (Edmonton Journal 1992b, d). Chuck Fipke, the president of Dia Met Minerals Ltd. and the geologist responsible for his company's success in diamond exploration in the Northwest Territories, has apparently been searching for diamonds in the Jasper area since 1981 and he has publicly stated he believes that there may be diamonds on their Jasper area claims, and that Dia Met Minerals Ltd. hopes to outline a new field and duplicate what they have already achieved in the Northwest Territories (Northern Miner 1992; Edmonton journal 1993).

Following the acquisition of the land near Jasper by Dia Met Minerals Ltd., the surrounding land was staked by Monopros Ltd., who are the Canadian exploration arm of De Beers Consolidated Mines Ltd. The presence of Monopros Ltd. had earlier added legitimacy to the diamond rush in Alberta because in 1992 they had staked 6,000 km^2 of land in the Peace River area, at a then cost to them of $6 million, which had to be posted as a work deposit with the government of Alberta. This world-wide diamond producing giant is thought to hold numerous additional parcels of land in Alberta, staked under the name of individual Monopros employees (Edmonton Journal 1992d). Several additional large land holdings have been acquired since 1992, including: (a) 22,000 km^2 by Prime Equities International Corp. and its subsidiaries, (b) 7,000 km^2 west of Edmonton plus additional land in southern Alberta by Takla Star Resources Ltd., and (c) over 16,000 km^2 by Mark Weir of Calgary, possibly on behalf of Pure Gold Resources Inc. and their joint venture partner, Ashton Mining of Australia (Edmonton Journal 1992e). In addition to these, perhaps, more well recognized diamond exploration companies, numerous gold exploration and junior companies have joined the Alberta diamond exploration rush, with over 140 claim holders registered in the province to date.

Although no bedrock diamond sources are reported as yet, exploration in Alberta has been successful in discovering numerous occurrences of diamond indicator minerals, many of which may indicate a nearby diamond source, and in identifying abundant geophysical anomalies which may represent kimberlite or lamproite pipes or dykes. A complicating factor in Alberta is that the kimberlites or lamproites may have intruded into subaqueous environments, as is the case with the Fort à la Corne kimberlites in Saskatchewan (Lehnert-Thiel *et al.* 1992). Similar depositional conditions existed in Alberta during the time that the Saskatchewan kimberlites were being intruded, and it is likely that any kimberlites or lamproites discovered in Alberta would also have their crater facies preserved.

According to Brian Hudson, Alberta Energy's mineral agreements manager, to March 1, 1994, approximately 34 million hectares, or 60% to 75% of the total crown land in Alberta, have been staked, and approximately 85% of this area will be the focus of diamond exploration (Figure 1.4). Therefore, the 1992 to 1993 acquisition of mineral rights by industry in Alberta represents one of the most extensive staking rushes in history. The success in diamond exploration in the Northwest Territories and Saskatchewan, and the

2. REGIONAL GEOLOGY OF ALBERTA

2.1 Introduction

The geology of Alberta is both diverse and complex. Ages of stratigraphic units range from Archean (>2.6 Ga) to Recent. A regional stratigraphic correlation chart for southern, central and northern Alberta is given in Table 2.1.

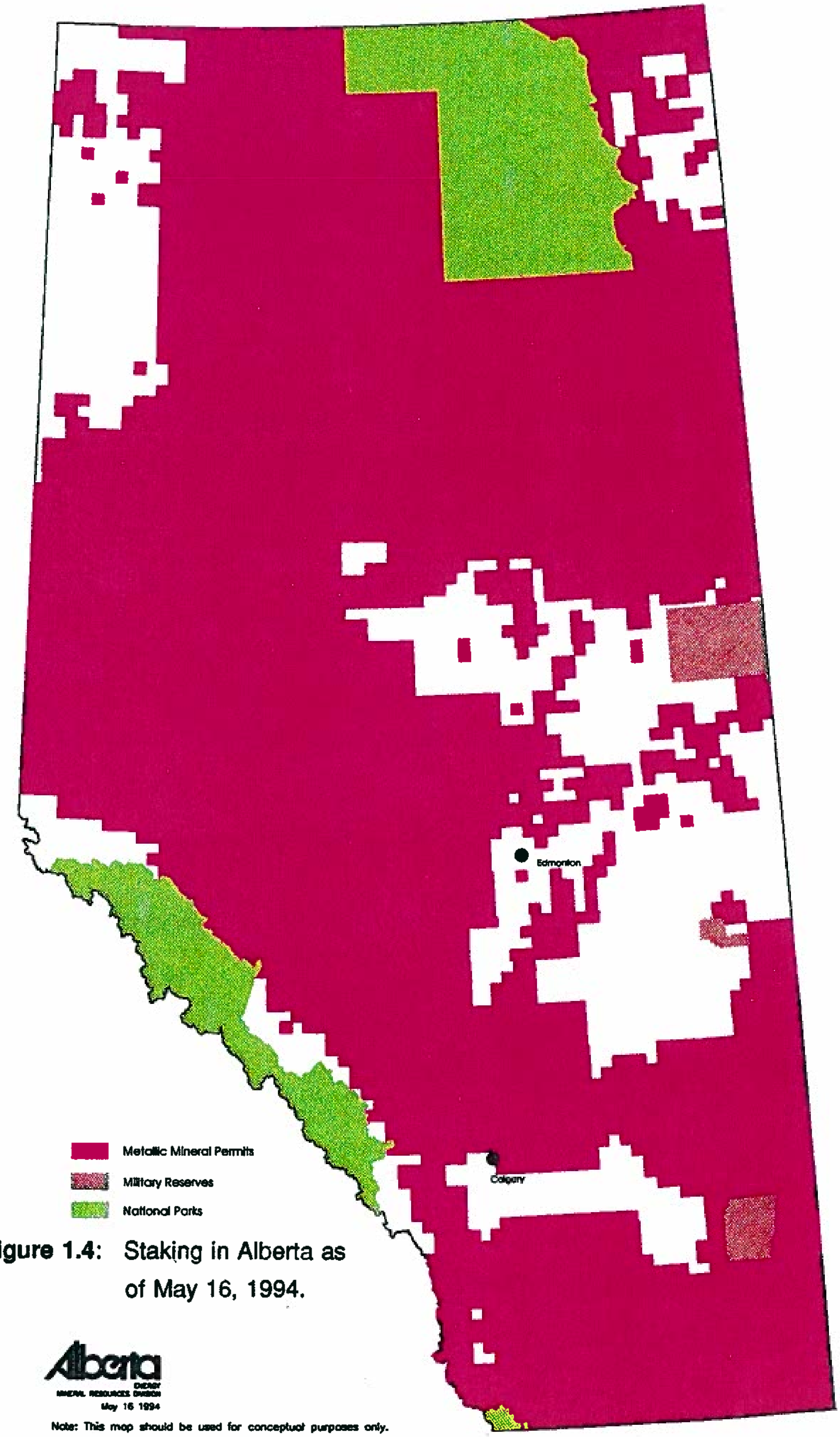


Figure 1.4: Staking in Alberta as of May 16, 1994.

From northeast to southwest across the province, the geology can be divided into several broad belts. In the northeast, Precambrian Shield rocks are exposed (Figure 2.1). To the southwest, the Precambrian Shield rocks are overlain by a homoclinal sequence of westerly dipping Phanerozoic strata that comprise Devonian carbonate, evaporite and clastic rocks which reach a total thickness of up to about 3,000 m or greater. Cambrian, Ordovician and Silurian sedimentary rocks exist at depth beneath the Devonian strata in southern and southeastern Alberta, but are not exposed at surface except in the Rocky Mountains and Foothills. Cretaceous sedimentary rocks occur over an extensive area of Alberta, stretching from the northeast, where they unconformably overlie the Devonian rocks, to the Rocky Mountains in the west and southwest. In the southwest, the Cretaceous rocks are up to 2,000 m in thickness. Lower Tertiary (Paleocene) rocks, which locally reach a thickness of about 1,500 m, overlie Cretaceous strata in a belt along the Foothills that stretches from southern Alberta, northwest to just south of Grand Prairie. As well, Oligocene to Miocene continental clastic rocks exist in a few places, such as at Cypress Hills, Hand Hills and Wintering Hills in southern Alberta, and at Whitecourt Mountain, House Mountain, Saddle Hills, Clear Hills and Caribou Mountains in northern Alberta. These middle and upper Tertiary strata tend to be thin, and typically are less than a few tens of metres thick. In the Rocky Mountains and Foothills, there is a thick sequence of sedimentary and, locally, volcanic rocks that range in age from Helikian to Tertiary. These rocks have been complexly folded and faulted as a result of the Cordilleran orogeny.

Regional overviews of the Paleozoic, Mesozoic and Cenozoic strata which exist in the Western Canada Sedimentary Basin and the Cordilleran Orogen in Alberta, are provided by McGrossan and Glaister (1964), Douglas (1970), Ricketts (1989), Gabrielse and Yorath (1992), Mossop and Shetsen (1994), and Stott and Aitken (*1993*). Ricketts (1989) stated that the "*Western Canada Sedimentary Basin is the general name given to the wedge of* [predominantly] *sedimentary rocks that thickens westward from a zero-edge on the Canadian Shield to the Foreland Belt. It was an extremely long-lived depositional realm having a sedimentary record as 'youthful' as Early Tertiary, and reaching as far back in time as the Middle Proterozoic.*"

The Plains Region of Alberta is underlain by a sequence of marine to non-marine sedimentary rocks that become younger to the southwest (Figure 2.1). In the northeast, Devonian strata are exposed in a belt that extends from the 60th parallel, southeasterly to the Alberta-Saskatchewan border (Green 1972). Unconformably overlying these Devonian rocks is a thick sequence of Cretaceous strata that stretch the length of Alberta, from the Alberta-British Columbia-Northwest Territories juncture in the northwest, to the Canada-United States border in the south. Adjacent to the Rocky Mountains, the Cretaceous rocks are overlain conformably, in places, to disconformably by Tertiary strata. The Tertiary rocks mainly exist in a belt that extends from near the Grande Prairie-Lesser Slave Lake area in the north to just south of the Canada-United States border. Tertiary strata also exist locally capping highlands in the Caribou Mountains, Clear Hills and Saddle Hills of northern Alberta, and at the Cypress Hills in southeast

Alberta. In the Rocky Mountains and Foothills, the exposed rock units comprise a thick sequence of predominantly sedimentary strata that range in age from Middle Proterozoic to Tertiary. The Paleozoic to Tertiary strata are extensively mantled by Quaternary surficial materials throughout much of the Plains region.

An understanding of the makeup of the Precambrian basement, the Phanerozoic succession and major structural elements is important to the evaluation of Alberta's diamond potential for the following reasons: (a) areas underlain by thick Archean crust, such as those which exist in South Africa and the Siberian Platform, have been to date far more productive in terms of the existence of economic kimberlite or lamproite hosted diamond deposits in comparison to areas underlain by Proterozoic basement or Proterozoic to Phanerozoic mobile belts; (b) thicker and therefore colder continental roots are considered by many (Haggerty 1986; Mitchell 1986, 1987, 1991; Gurney 1990) as a prerequisite for the preservation of diamonds in the deep crust (or "in the asthenosphere"); (c) diamonds are considered to be xenocrystic in kimberlites and lamproites and, as such, have been carried from the lower crust to surface by kimberlitic or lamproitic magmas during many periods throughout the earth's history (Mitchell 1989, 1991; Gurney 1990; Gurney and Moore 1993; Kirkley *et al.* 1991, 1992; Helmstaedt 1992, 1993) and (d) certain structural elements such as anticlese's (Jennings 1990; Helmstaedt 1992, 1993) are considered by some workers to be more favourable for the emplacement of diamondiferous alkaline rocks such kimberlites or lamproites.

The crystalline basement which is exposed in the Canadian Shield, the Proterozoic to Phanerozoic strata and the major structural features of Alberta, have all been studied, to a greater or lesser degree, by several workers. A brief summary of these important geological aspects as they pertain to the potential for diamondiferous diatremes in Alberta, follows.

2.2 Precambrian

According to Hoffman (1988) the North American Craton is essentially an aggregation of several Archean microcontinents, such as the Wyoming, Superior, Slave, Nain and the Churchill Structural Provinces (including both the Rae and Hearne Sub-provinces), that were welded together during the Early Proterozoic. A few of these Structural Provinces, such as the Churchill, record a strong Proterozoic orogenic event that has thermally reset most isotope systems used for dating of the basement rocks. The Precambrian crystalline basement rocks that are exposed in northeast Alberta and which lie buried beneath younger sedimentary cover rocks in the remainder of Alberta, are an extension of the Churchill Structural Province. Burwash (1993), Ross (1993, 1991) and Ross and Stephenson (1989) have subdivided the basement rocks benenath the Western Canada Sedimentary Basin into distinct tectonic-metamorphic domains, with ages ranging from Archean to early Proterozoic (3,278 Ma to 1,779 Ma). Ross (1993) stated "*Major structures that segment the basement include the subsurface extensions of the Great*

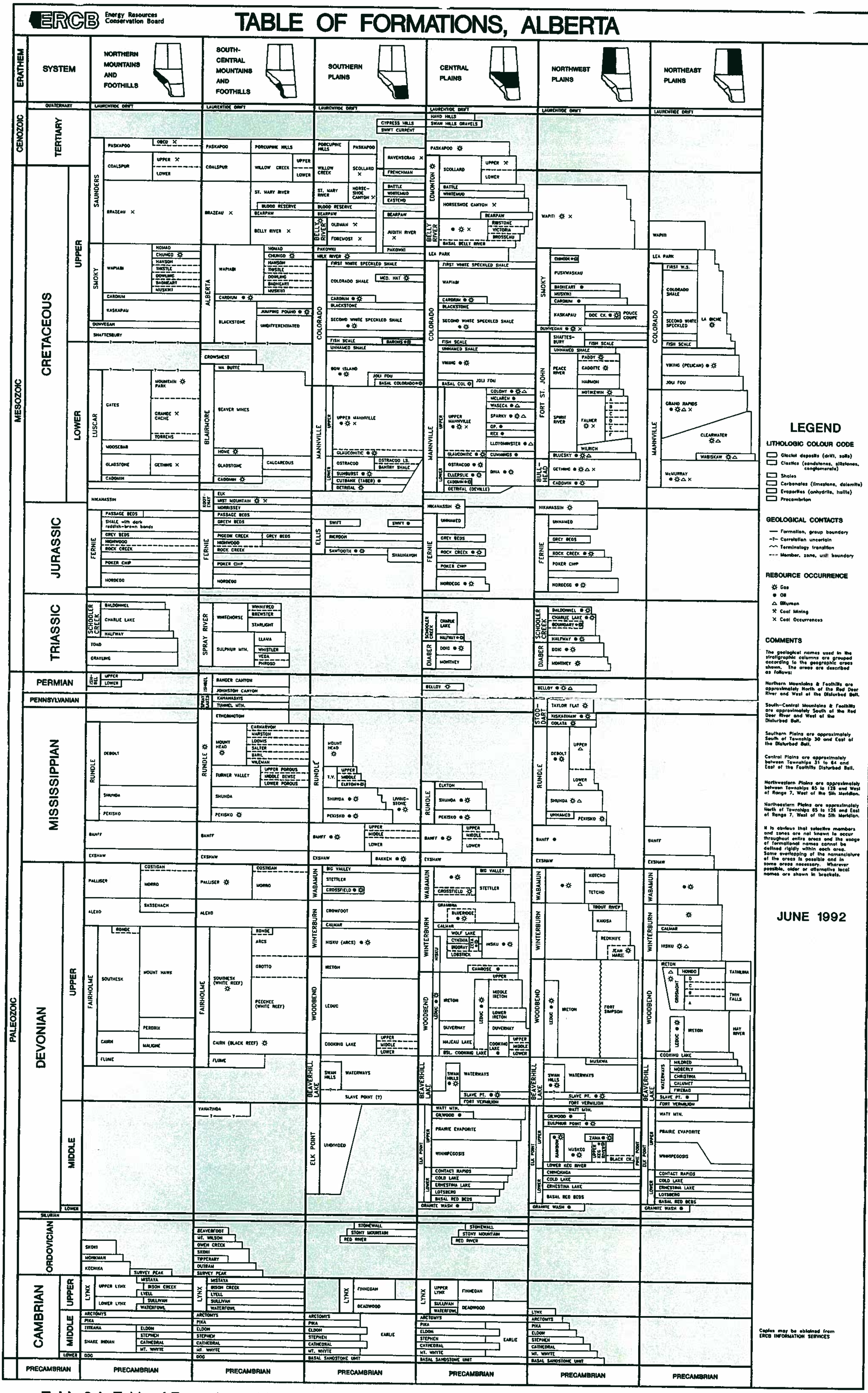


Table 2.1: Table of Formations - Phanerozoic Strata in Alberta.

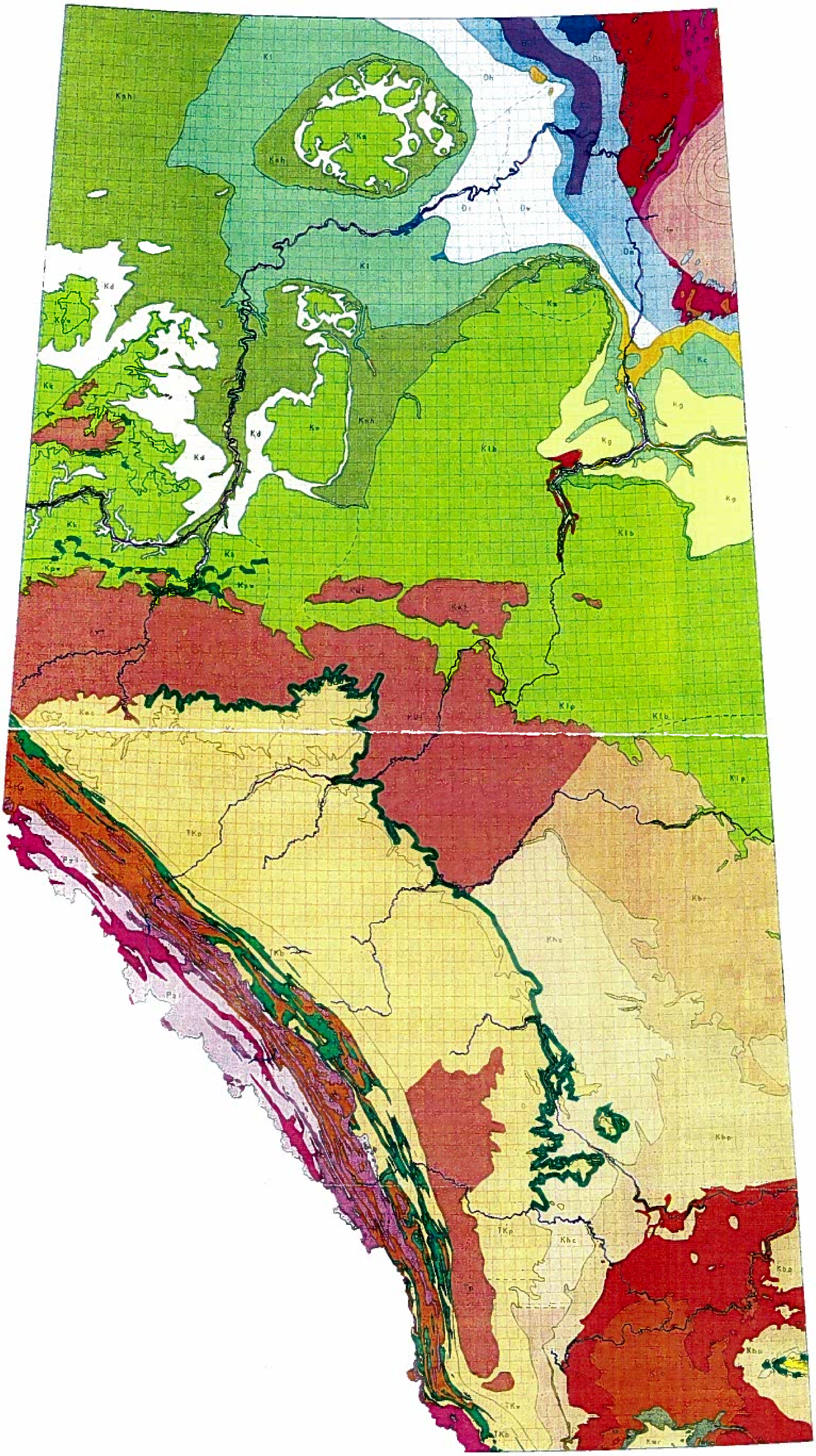


Figure 2.1: Geological map of Alberta. Legend on accompanying page (Hamilton et. al., 1994).

NORTHWESTERN ALBERTA

TERTIARY AND CRETACEOUS

- Paskapoo Formation

CRETACEOUS

- Wapiti Formation
- Puskwaskau Formation
- Bad Heart Formation
- Kaskapau Formation
- Dunvegan Formation
- Shaftesbury Formation
- Peace River Formation
- Loon River Formation

SOUTHWESTERN ALBERTA

TERTIARY

- Porcupine Hills Formation

TERTIARY AND CRETACEOUS

- Willow Creek Formation

CRETACEOUS

- St. Mary River Formation
- Blood Reserve Formation
- Bearpaw Formation
- Oldman Formation
- Foremost Formation
- Pakowki Formation
- Milk River Formation
- Alberta Group

NORTHERN ALBERTA

DEVONIAN

- Grosmont Formation
- Mikkwa Formation
- Ireton Formation
- Waterways Formation
- Caribou Member, Slave Point Formation
- Nyarling Formation

HELIKIAN

- Otherside Formation
- Locker Lake Formation
- Upper Wolverine Point Formation
- Lower Wolverine Point Formation
- Manitou Falls Formation
- Fair Point Formation

NORTH CENTRAL ALBERTA

CRETACEOUS

- Wapiti Formation
- Smoky Group
- Dunvegan Formation
- Shaftesbury Formation
- Loon River Formation
- Basal Cretaceous?

SOUTHEASTERN ALBERTA

TERTIARY

- Cypress Hills Formation

TERTIARY AND CRETACEOUS

- Ravenscrag Formation

CRETACEOUS

- Whitemud and Battle Formations
- Eastend Formation
- Bearpaw Formation
- Oldman Formation
- Foremost Formation
- Pakowki Formation
- Milk River Formation
- Alberta Group

NORTHEASTERN ALBERTA

DEVONIAN

- Hay River Formation
- Caribou Member,
- Fort Vermilion Member, Slave Point Formation
- Muskeg Formation
- Keg River Formation
- Chinchaga Formation
- Fitzgerald Formation

(Fort Vermilion Member through Fitzgerald Formation grouped as: Devonian Undivided)

APHEBIAN

- Low Grade Metasedimentary Rocks
- Granitoids

NORTHEASTERN ALBERTA

CRETACEOUS

- Labiche Formation
- Pelican Formation
- Joli Fou Formation
- Alice Creek Tongue, Grand Rapids Formation
- Grand Rapids Formation
- Clearwater Formation
- McMurray Formation

CENTRAL AND EASTERN ALBERTA

TERTIARY

- Hand Hills Formation

TERTIARY AND CRETACEOUS

- Paskapoo Formation

CRETACEOUS

- Horseshoe Canyon Formation
- Bearpaw Formation
- Belly River Formation
- Lea Park Formation

ROCKY MOUNTAINS AND FOOTHILLS

TERTIARY AND CRETACEOUS

- Brazeau Formation

CRETACEOUS

- Alberta Group

MESOZOIC

- Lower Cretaceous, Jurassic and Triassic

PALEOZOIC

- Upper Paleozoic
- Lower Paleozoic

HADRYNIAN

- Miette Group

HELIKIAN

- Purcell Supergroup

APHEBIAN/ARCHEAN – Undivided

- Mylonitic Rocks
- Granitoids
- Undifferentiated

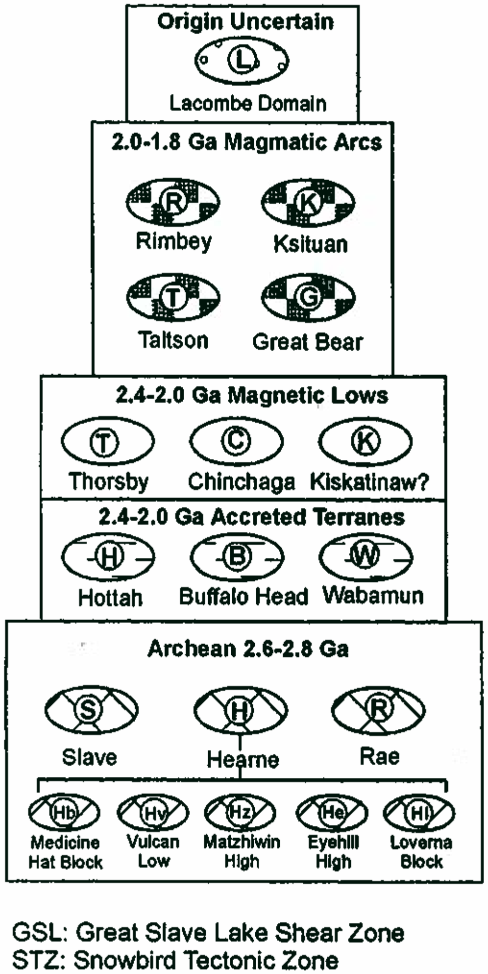
ARCHEAN

- Charles Lake Granitoids
- High Grade Metasedimentary Rocks
- Granite Gneisses

Slave Lake shear zone [in northwestern Alberta], *Snowbird Tectonic Zone* [in central Alberta] *and the Vulcan Low in southern Alberta, all of inferred Early Proterozoic age (ca. 1.8-2 Ga)*". Most of the basement north of the Snowbird Tectonic Zone (STZ) in Alberta is either accreted juvenile Proterozoic terranes or thermally reworked Archean basement that is part of the Rae Sub-province (Figure 2.2). Basement south of the STZ is predominately Archean in age and is part of the Hearne Sub-province.

Most workers agree on the interpretation as to the origin of basement south of the STZ, but there are at least three different interpretations to explain the many Proterozoic ages (mostly Aphebian) obtained for most of the basement rocks in northern Alberta and, for that matter, over other large portions of the Churchill Province. Each of these interpretations has different ramifications for the potential development and preservation of diamonds in the upper mantle or lower crust and their eventual transport to the surface by kimberlitic or lamproitic magmas. The first school of thought interprets most of the Aphebian dates to represent Archean basement that has had its isotope systematics reset by Proterozoic magmatism and cataclasis brought about by the collision of strictly Archean microcontinents during the Proterozoic (Burwash *et al.* 1962, Burwash and Culbert 1976, Burwash *et al.* 1994). Frost and Burwash (1986) used Sm-Nd isotope systematics to show that where certain rocks had yielded Aphebian ages from K-Ar dating in southern Alberta, the Sm-Nd systematics yielded Archean ages. Burwash (1993) stated that "*Archean crust which was thermally overprinted during the Hudsonian Orogeny (1,850 ± 100 Ma) underlies the southeastern third of Alberta*". More recently, U-Pb dating of either zircon or monazite by Ross *et al.* (1991) has confirmed the Archean ages for basement rocks in southern Alberta. Burwash (1993) further stated, "*In northwestern Alberta ... intense cataclasis ... accompanied early, middle and late stages of the Hudsonian metamorphism of pre-existing Archean crust. ... Major shear zones are probably responsible for most of the strong lineaments on aeromagnetic maps. ... Hudsonian igneous complexes were emplaced in early (1,900-2,000 Ma) and later (1,750-1,850 Ma) stages. ... Hudsonian metamorphic belts related to the Wopmay Orogen and Trans-Hudson Orogen underlie parts of northwestern Alberta.*"

A second, more recent, interpretation of the Aphebian dates for basement rocks north of the STZ is presented by Ross and Stephenson (1989) and Ross *et al.* (1991), who suggested that Aphebian U-Pb zircon or monazite dates from northern Alberta are the result of discreet juvenile Proterozoic terranes that have been accreted to the Archean age Rae Sub-province. Ross and Stephenson (1989) and Ross *et al.* (1991) suggest that northern Alberta is underlain by extensively deformed, but recognizable, magmatic arc, passive continental margin and foreland basin sedimentary rocks that were all formed during the Early Proterozoic. Interestingly enough, however, Villeneuve *et al.* (1993), Ross *et al.* (1993) and Thériault and Ross (1991) also have reported that a strong Archean component is present in these Proterozoic terranes as indicated by Sm-Nd isotope systematics.



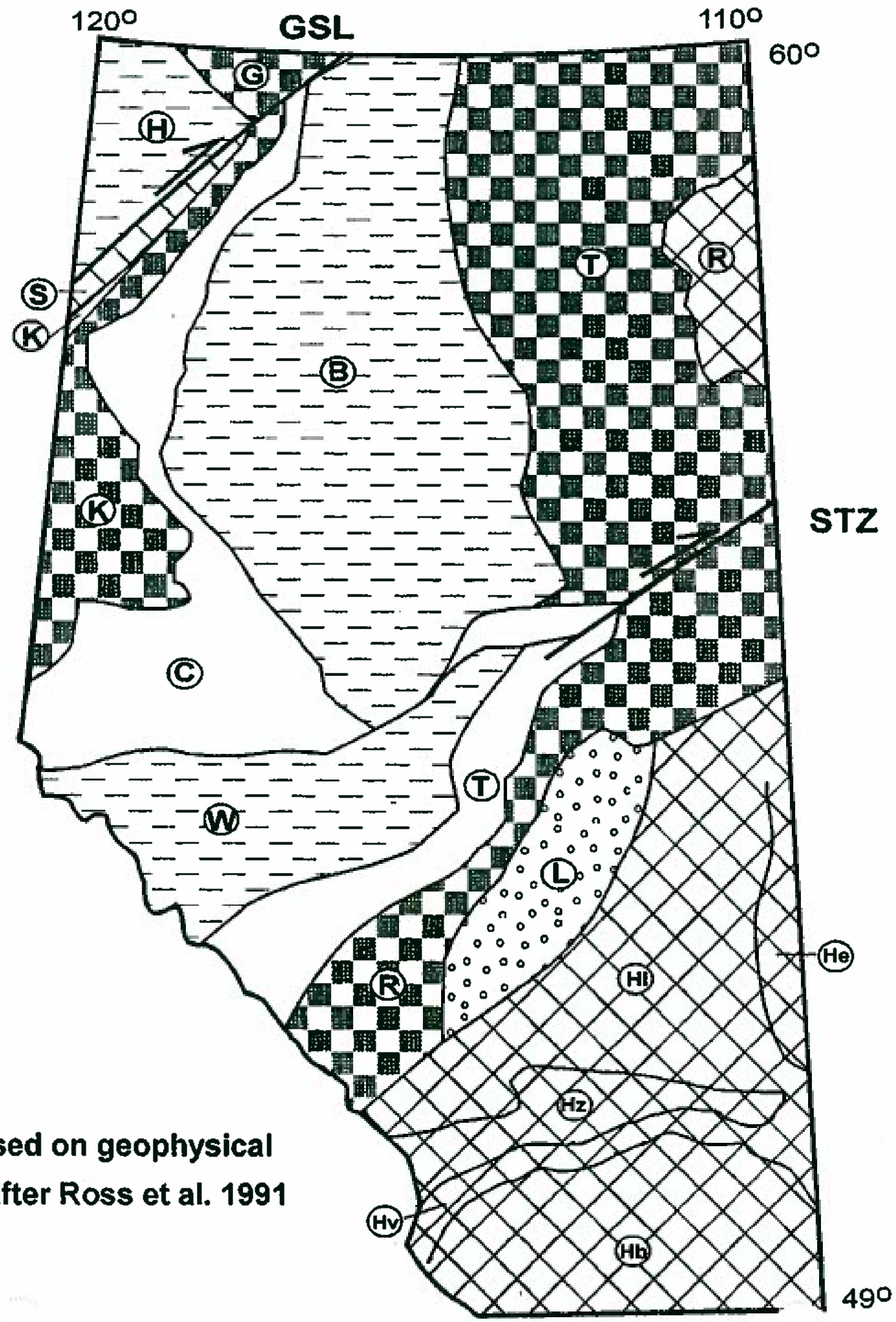


Figure 2.2: Domain map of the Alberta basement based on geophysical properties and U-Pb age data, modified after Ross et al. 1991

A third possible interpretation for the basement of northern Alberta is based on similar Sm-Nd isotope work and ongoing seismic reflection studies that are a part of the

Lithoprobe program for Saskatchewan. The Trans-Hudson orogenic belt that divides the Superior and the Churchill Provinces in central Saskatchewan has long been regarded as comprised of accreted juvenile Proterozoic terranes, including volcanic island arcs and associated fore-arc and back-arc basins (Lewry 1981; Green *et al.* 1985a, b). More recent work, however, has indicated that rocks of the Trans-Hudson orogenic belt may contain a significant Archean component based on Sm-Nd isotope systematics (Collerson *et al.* 1988). Not only are rocks from the Trans-Hudson orogenic belt interpreted to contain a significant Archean component, but well documented juvenile Proterozoic terranes further east within the orogenic belt are interpreted to represent tectonically emplaced Proterozoic crustal slices that are likely underlain by Archean basement (MacDonald 1987; Chiarenzelli *et al.* 1987; Collerson *et al.* 1988; Lewry *et al.* 1990). Finally, recent Lithoprobe results indicate that the Proterozoic terranes in northern Alberta may actually represent thin-skinned thrust slices emplaced during the Proterozoic (Hajnal *et al.* 1993).

2.3 Proterozoic

Helikian Purcell Supergroup in southwest Alberta and southeast British Columbia "*reaches a maximum thickness of 11 km* ...[and] *comprises a sequence of shallow-marine and nonmarine rocks and an underlying sequence expressed by fine grained, basinal clastic rocks in the west and platformal, clastic and carbonate rocks in the east. The base is not exposed. Facies changes are generally distinct near the northeastern limit of exposure, but become more subtle to the southwest*" (Aitken and McMechan 1992). Hadrynian Windermere Supergroup strata are not present in southwest Alberta, but in western Alberta "*south of latitude 56° N in the central Rocky Mountains the Windermere Supergroup is represented by the Miette Group, a thick succession of fine to coarse clastic strata with locally important carbonate units*" (Gabrielse and Campbell 1992). In British Columbia and the adjacent United States of America, the Purcell Supergroup hosts several economically important stratiform and epigenetic Pb-Zn-Ag and Cu-Ag sulphide deposits. In southwest Alberta, the Helikian strata are host to a number of stratabound copper occurrences (Hamilton and Olson 1994; Williamson *et al.* 1993).

In northeastern Alberta, the Helikian Athabasca Group comprises a flat-lying sequence of clastic sedimentary rocks in excess of 1,255 m thick that exists in outcrop and subcrop south of and immediately north of Lake Athabasca (Wilson 1985a, b). In Saskatchewan, there are numerous economically important uranium deposits that are spatially associated with the unconformity between the Athabasca Group and the underlying Precambrian basement rocks (Sibbald and Quirt 1987; Sibbald *et al.* 1991).

2.4 Paleozoic

In the northeastern Alberta Plains, the Paleozoic strata comprise Middle and Upper Devonian marine shale, carbonate and evaporitic lithologies (Green *et al.* 1970). The Devonian rocks in northeast Alberta increase in thickness to the west from 0 m at 58°00' north latitude / 110°00' west longitude to a total thickness of up to about 1,175 m or greater at 55°00' north latitude / 114°00' west longitude. At or near the exposed outcrop or subcropping edge in northeastern Alberta, there has been extensive corrosion of the evaporitic units which has resulted in widespread brecciation of the overlying Devonian strata. In most places the Devonian rocks are poorly exposed, with the best and most continuous stratigraphic sections occurring along the major rivers and secondary watercourses.

In the Rocky Mountains and Foothills, the exposed Paleozoic strata range in age from Cambrian to Permian (Gabrielse and Yorath 1992). Much of the Paleozoic succession in this region consists of thin to thick sequences of carbonate rocks, interlayered with predominantly marine fine- to medium-grained clastic sedimentary rocks. Numerous disconformities and unconformities exist within the Paleozoic succession, and are indicative of periods of uplift and erosion or they represent nondepositional hiatuses.

2.5 Mesozoic

In the Plains region, Cretaceous rocks exist in outcrop or in subcrop beneath Quaternary drift over greater than two-thirds of Alberta (Figure 2.1). In the northeastern Plains, Lower Cretaceous marine to deltaic clastic sedimentary rocks unconformably overlie Paleozoic strata. To the south and west, the Lower Cretaceous strata are conformably overlain by Upper Cretaceous marine to continental clastic sedimentary rocks. In northern Alberta, the exposed Upper Cretaceous strata are up to 900 m thick, whereas in southern Alberta the Lower Cretaceous succession is greater than 750 m thick and the Upper Cretaceous succession is greater than 1,650 m thick.

In the Rocky Mountains and Foothills, Triassic, Jurassic and Cretaceous rocks are exposed. The Mesozoic strata occur throughout the Foothills and Main Ranges, beginning just north of Waterton National Park and continuing northwestwards into British Columbia northwest of Grande Cache, Alberta. Following the deposition of the Permian units, there was a period of regression of the sea and nondeposition, which accounts for the Cordilleran-wide sub-Triassic unconformity. This disconformity is overlain by the Triassic system, which comprises a westward thickening marine sequence of easterly derived siliclastic and carbonate lithologies that is greater than 1,200 m thick. The Triassic period ended with uplift, regression of the sea and probable erosion (Gordey *et al.* 1992).

The Jurassic System in western Canada records the transition from an essentially passive continental margin to an active one which, in Late Jurassic time, was characterized by orogenic uplift in the west (Columbian Orogen) and an associated narrow arcuate foredeep to the east in western Alberta (Poulton 1989). In general, the Jurassic Period in Alberta was characterized by several incursions and regressions of the sea. Marine rocks are dominant in the lower part of the Jurassic succession, but interfingering of marine and continental sedimentary rocks characterizes the upper part of the Jurassic. The Jurassic succession ranges from a few metres thick in west central and southern Alberta up to a maximum of about 2,100 m in places in the Rocky Mountains.

Several major cycles of clastic sedimentary wedges, which were derived from uplift associated with the Cordilleran Orogen, characterize the Cretaceous and conformably overlying early Tertiary strata of the Western Canada Sedimentary Basin (Poulton 1989). In the southern part of the Foreland Belt, the sedimentary succession reflects uplift in the Cordillera beginning in the Late Jurassic, whereas to the northwest in the Yukon, sedimentation was not influenced by Cordilleran uplift until Late Early Cretaceous time (Yorath 1992). During the Early Cretaceous there were several cycles of Cordilleran orogenesis and associated westerly-derived clastic continental sedimentary wedges. This is in contrast to the Late Cretaceous to Paleocene period which was characterized by widespread marine flooding of the continental interior and widespread deposition of marine fine clastics and, locally, near-marine to deltaic fine- to medium-grained clastic sediments. In southwest Alberta, volcanic rocks of Late Albian Crowsnest Formation conformably overlie and are interbedded with upper Lower Cretaceous sedimentary rocks of the Blairmore Group. The Upper Jurassic-Cretaceous sedimentary strata also contain abundant coal in the Rocky Mountains, Foothills and Plains of Alberta.

2.6 Tertiary

Continental sedimentation continued without interruption through uppermost Cretaceous into Paleocene time in most of western Canada (Yorath 1992). Paleocene strata of Upper Willow Creek, Porcupine Hills, Paskapoo and Ravenscrag Formations were deposited during the last part of the uppermost Cretaceous-lowermost Tertiary clastic wedge. In the western part of the Interior Plains of Alberta, the Paleocene succession ranges in thickness from more than 1,525 m in the Porcupine Hills of southwestern Alberta to about 70 m for the Ravenscrag Formation in the Cypress Hills of southeastern Alberta (Taylor *et al.* 1964). In southwestern Alberta, Upper Cretaceous to Lower Paleocene Willow Creek Formation is overlain disconformably by Upper Paleocene Porcupine Hills Formation. Towards the north near Calgary, however, the Upper Willow Creek Formation and, possibly, the Porcupine Hills Formation grade into Paskapoo Formation. In central, western and northwestern Alberta, Paskapoo Formation conformably overlies various Upper Cretaceous rock units. In southeast Alberta, Ravenscrag Formation conformably overlies Cretaceous Frenchman Formation.

During the Miocene and Pliocene the Rocky Mountains and Interior Plains continued to be eroded as a result of earlier uplift. Erosion of the plains surface during this time exceeded 1,000 m in many areas and left scattered granular deposits in many areas and at various elevations. This Tertiary and early Quaternary erosion was so extensive that only small scattered patches of Oligocene to Pliocene age fluvial deposits are left in isolated preglacial valleys and on uplands, with the younger deposits preserved in the valleys. These include, for example, fluvial deposits at the Caribou Mountains, Clear Hills, Saddle Hills, House Mountain, Whitecourt Mountain, Hand Hills, Wintering Hills and Cypress Hills (*Ibid*). Most of these deposits range in thickness from a few metres or less up to, at most, a few tens of metres.

In southern Alberta and northern Montana there are several basic intrusions and dykes that are commonly referred to as the "Sweet Grass Intrusions". These intrusions cut Upper Cretaceous strata and have been dated at about 48 Ma (*Ibid*), or of Eocene age.

2.7 Quaternary

The investigation of the Quaternary sediments of western Canada began with the early expeditions to the region during the 1800's (examples include Dawson 1875, 1885, 1898; Dawson and McConnell 1895, McConnell 1885, Tyrrell 1887). Recent papers which provide information on the history and stratigraphy of the Quaternary succession, as well as pertinent references, include those by Bobrowsky and Rutter (1992), Clague (1989b), Dyke and Prest (1987), Fenton (1984), Fulton *et al.* (1984), and Fullerton and Colton (1986 - this paper focuses on Montana), Klassen (1989) and Prest (1984).

In Alberta, the Quaternary glacial deposits have been geologically mapped mainly at 1:253,440 scale and, locally, at larger scales. However, the surficial mapping of Alberta is incomplete, and even at the reconnaissance scale (about 1:250,000), the existing mapping is restricted to the southern, central and northeastern parts of the province (Figure 2.3). Much of the Quaternary deposits in the northern and northwestern part of the province have not been systematically mapped, hence the type and thickness of the glacial and other surficial lithologies is either unknown or poorly known. Pertinent references for the Quaternary geology of Alberta include Barton *et al.* (1964), Prest (1970), Fenton (1987) and Fulton (1989).

Prior to glaciation, the Alberta plains consisted of broad, generally northeast trending valleys separated by low uplands. Stream deposits in the valleys consisted predominantly of quartz sand and gravel dominated by clasts of resistant quartzite, argillite and chert derived from the Cordillera and Rocky Mountains, or reworked clasts derived by glacial or fluvial processes from older Tertiary and Cretaceous deposits.

Repeated glacial and nonglacial intervals left a complex sequence of glacial, fluvial, lacustrine and minor amounts of eolian and organic sediment of different ages (for

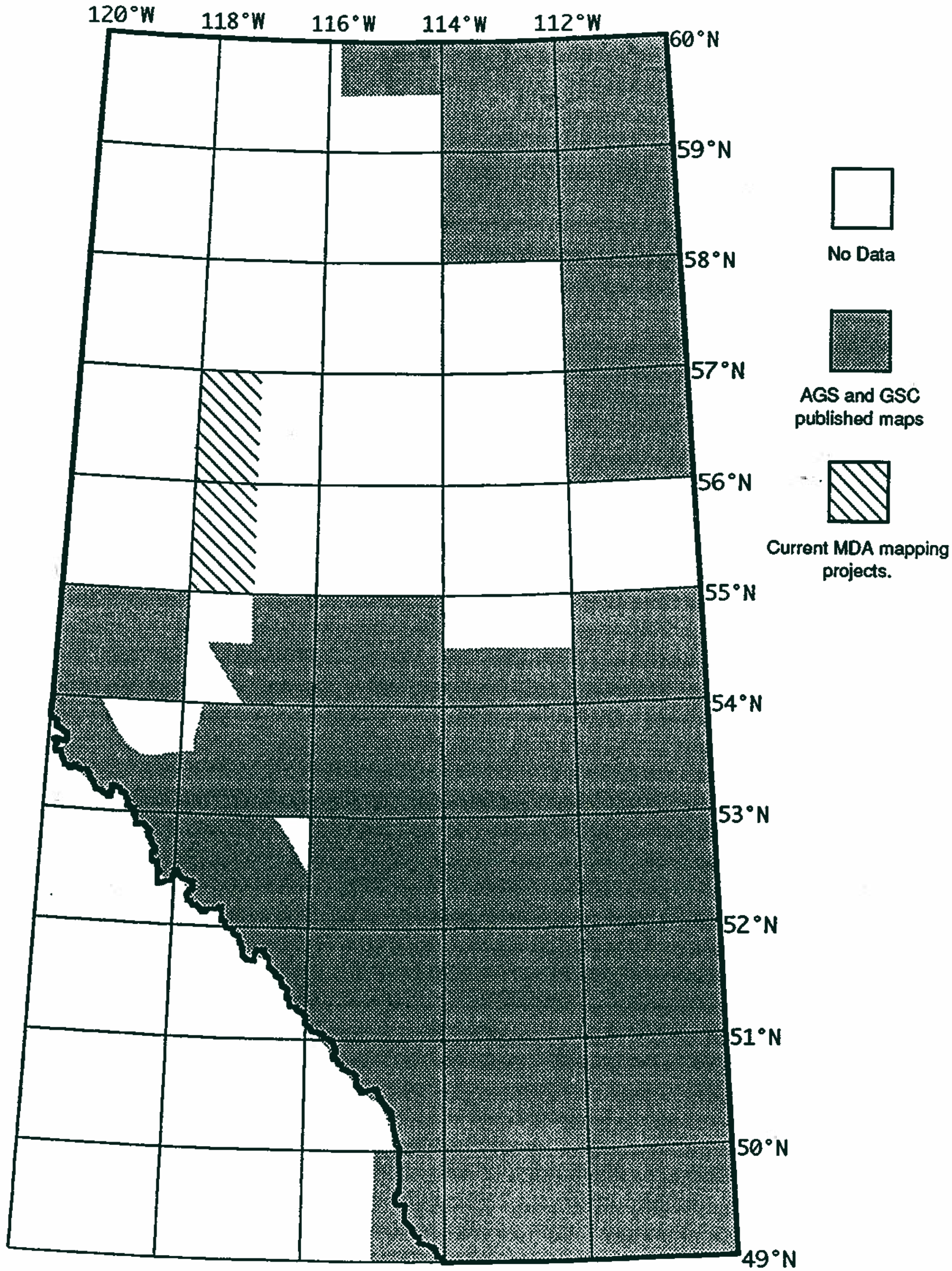


Figure 2.3: Distribution of published reconnaissance scale surficial geology maps.

example, see Andriashek and Fenton 1989). The major portion of the sediment is till (glacial diamicton), with lacustrine sediment the next most abundant. The till deposited by the Laurentide glaciers contains clasts of Precambrian and Paleozoic bedrock that have been glacially transported from the east and north. The till deposited by the Cordilleran or Rocky Mountain glaciers contains clasts of resistant quartzite, carbonate, argillite and chert.

Locally the till can be subdivided into a number of units or facies (see for example Proudfoot 1985; Mougeot 1991 and Levson and Rutter 1988).

The surface sediments in Alberta are composed of a variety of terrain types of which about 70% are of glacial origin and 20% are of lacustrine origin (Shetsen, 1981 and 1990). The geomorphological terrain can be divided into a number of types, all of which can be recognized on air photographs and each type is characterized by being predominantly underlain by certain sediment types (for example, see Prest 1970 and Mougeot 1991).

Multiple glacial advances from the east, northeast and/or north (the Laurentide source), and the west (either the Cordilleran or the Rocky Mountain source) have been documented. Note that the term 'Cordilleran glaciers' is used herein specifically to refer to those glaciers that originate in the interior of British Columbia, west of the Rocky Mountain Trench. However, elsewhere the term 'Cordilleran glaciers' also is used by some to refer to all glaciers flowing from the Cordillera and Rocky Mountains, particularly in the literature focusing on the major portion of Alberta that was affected only by the Laurentide glaciers.

During each Laurentide ice advance the northeasterly drainage systems of the entire Interior Plains were dammed so that lakes developed in the valleys and depressions, and drainage was diverted to the south (Christiansen 1979; Clayton and Moran 1982; St. Onge 1972). During ice retreat proglacial, ice marginal lakes developed as the ice melted, and steep-walled valleys were cut where (1) meltwater flowed from one lake basin to the next, (2) flow was channelled southward along the ice margin, and (3) drainage was re-established in sediment-filled segments of preglacial valleys. Commonly, the drainage systems that developed during nonglacial time roughly followed the preglacial valleys with, in many places, the channel eroding into the thick sequence of sediment left behind by the retreating ice. Locally, flow was diverted from one valley system to another through trenches cut by meltwater. The stream deposits which were laid down during nonglacial periods, in part consist of sands and gravels that contain resistant pebbles similar to those deposited during preglacial times. However, the stream deposits also include important and distinctive admixtures of material from the Precambrian Shield and the adjacent fringe of Paleozoic carbonate bedrock that had been transported westward and southward by the glaciers. In short, the repeated glacial and nonglacial intervals have left a complex sequence of glacial, fluvial and lacustrine sediment of different ages in Alberta. Holocene rivers subsequently have cut new valleys into these complex deposits. The most extensive exposures of these Quaternary deposits are in southern Alberta along the old valleys of the South Saskatchewan and Oldman Rivers.

Evidence for the age of the earliest glacial advance from the Rocky Mountains comes from a section exposed on Mokowan Butte in southwestern Alberta just east of Waterton National Park. The third till down in a five till sequence lies within the highest, hence, youngest, magnetically reversed zone; that is within the Matuyama reversed polarity zone which extends in age from 720,000 to 2,470,000 years (Barendregt *et al.* 1991a). Therefore the two underlying tills may be considerably older.

Evidence for the earliest Laurentide advance into the southwestern Plains comes from the Wellsch valley site, which is in southwestern Saskatchewan east of the Alberta border. There, in one section, magnetically reversed stratified sediments lie below an ash layer dated at 690 ka (see Barendregt *et al.* 1991b for the latest interpretation and earlier references). Further along the bluff at another section at Wellsch valley, stones derived from the Precambrian Shield are present in the lowest stratified unit. Tentative correlation between these two sections indicates that Laurentide ice may have reached southwest Saskatchewan during the Matuyama magnetically reversed period. The stratigraphy at the section exposed in the Medicine Hat area of Alberta west of the Saskatchewan border, indicates the Laurentide glaciers advanced over this area at a later date because the preglacial Saskatchewan Gravels and Sands contain an ash layer dated at 435 ka (Klassen 1989).

2.8 Regional Structures

The regional structures and tectonic evolution of the Western Canada Sedimentary Basin and of Alberta have been discussed by several workers, including Webb (1964), Lorenz (1982), Cant (1988), Podruski (1988), Leckie (1989), Cant and Stockmal (1989), Osadetz (1989), McMechan and Thomson (1989), McMechan *et al.* (1992), Ross (1991), and Ross and Stephenson (1989) (Figure 2.4).

The major structures of Precambrian age in Alberta include the Great Slave Lake shear zone in northern Alberta, the Snowbird Tectonic Zone in central Alberta, and the Southern Alberta Rift (or Vulcan Low) in southern Alberta (Ross 1993; Kanasewich 1968; Kanasewich *et al.* 1969; Williamson *et al.* 1993). These features all are inferred to be of Early Proterozoic age (ca. 2.0 to 1.8 Ga), but were periodically active to a greater or lesser degree throughout the Proterozoic and into the Phanerozoic.

Other tectonic features that were active and affected the deposition of Phanerozoic strata, from approximately oldest to youngest, include: (a) the Peace River Arch in northwest Alberta; (b) the West Alberta Arch in western Alberta; (c) the Meadow Lake Escarpment in east-central Alberta; (d) the Sweet Grass Arch and Alberta Syncline in southern and western Alberta; (e) the Rocky Mountain Fold and Thrust Belt; (f) transverse, tear and normal faults in the Rocky Mountains and Foothills; and (g) fracturing and salt dissolution features in some parts of the Plains region, particularly in northeast Alberta.

2.8.1 Great Slave Lake Shear Zone and Snowbird Tectonic Zone

The Great Slave Lake shear zone (GSLSZ) is a major northeast trending crustal lineament that the regional aeromagnetic data indicate extends from near Chantrey Inlet in the Keewatin District of the N.W.T., southwesterly across northwestern Alberta and into northeastern British Columbia (Ross 1991, 1993; Ross *et. al.* 1991). This crustal-scale fault zone was mainly active about 1.9 Ga (Hoffman 1987), but tectonic movement occurred along the GSLSZ until at least Middle Givetian during the late Middle Devonian (Skall 1975). In northwestern Alberta, the GSLSZ is recognized by the juxtaposition of different aeromagnetic domains, and the predominant sense of movement is dextral (Ross *et al.* 1991).

The Snowbird Tectonic Zone (STZ) is also a major northeast trending crustal lineament that extends from near Baker Lake, Northwest Territories, southwesterly to just north of the Lac La Biche area, Alberta. It splits the Churchill Province into two separate basement domains (Ross *et al.* 1989, 1991). The STZ is a prominent lineament on the aeromagnetic and gravity maps of Canada (GSC 1990a, b). Ross *et al.* (1989, 1991) suggested that the STZ bifurcates into two zones below the Phanerozoic basin that is southwest of the Lac La Biche area. The southern zone, which encompasses the Thorsby Low, exhibits a sinuous projection to the southwest where it appears to intersect the Foothills region of Alberta in the vicinity of Nordegg. Interestingly, some other important northeasterly trending geological features also exist in the vicinity of Nordegg. These include the axis of the doubly plunging Late Cambrian to Devonian West Alberta Arch (Verrall 1968), the Late Devonian Cline Channel (Geldsetzer and Mountjoy 1992) and the Cretaceous Bighorn Tear Fault (Verrall 1968). In addition, more recent work by Edwards and Brown (1994) has documented the existence of basement faults that extend into the Paleozoic and Mesozoic succession in the vicinity of the Thorsby Low. Further work is needed to clarify the actual position of the STZ and to document its relationship to other Phanerozoic structures which exist in the vicinity of Nordegg in the Rocky Mountains, and in the Foothills and Plains of Alberta.

2.8.2 Southern Alberta Rift

The Southern Alberta Rift, which also is known as the Vulcan Low, was first described by Kanasewich (1968) and Kanasewich *et al.* (1969) using deep seismic reflection, magnetic and gravity data. Kanasewich (1968) suggested the Southern Alberta Rift is traceable for 450 km from just north of Medicine Hat near the Alberta-Saskatchewan border, to the Rocky Mountains southwest of Cranbrook near the British Columbia-Idaho border. Kanasewich *et al.* (1969) suggested that this rift is Precambrian in age, penetrates the crust to the Mohorovicic discontinuity and has associated faults with vertical displacement of up to 5 km. McMechan (1981) described evidence of graben-like,

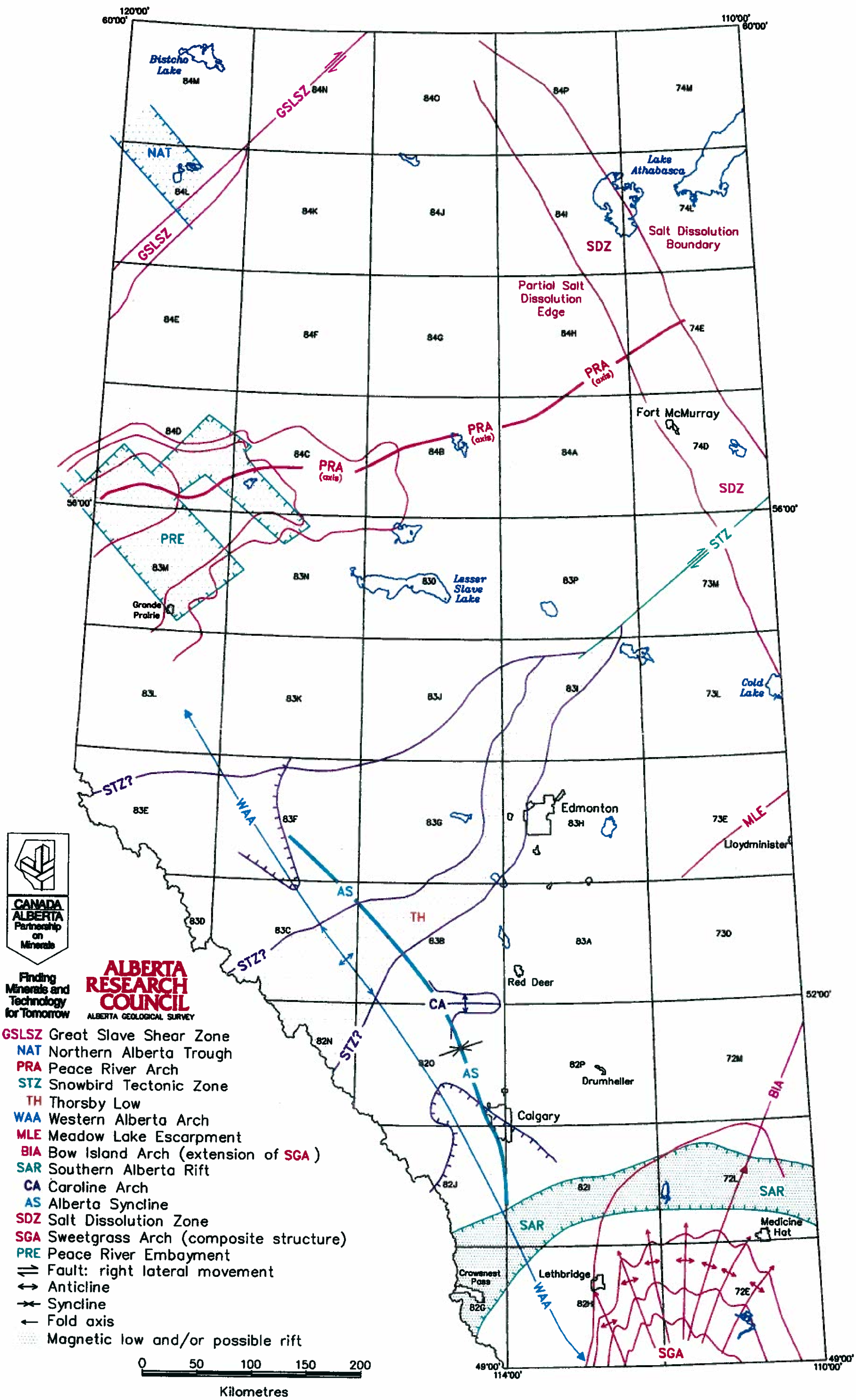


Figure 2.4: Major structures and tectonic features in Alberta.

synsedimentary normal faulting throughout the Precambrian Belt-Purcell Supergroup. She stated that the northeast trending St. Mary-Boulder Creek Fault near Kimberly, British Columbia and the Moyie-Dibble Creek Fault further to the southeast, were active periodically during much of the Proterozoic and that they correspond to the location of the subsurface trace of the Southern Alberta Rift identified by Kanasewich (Ibid.). Regional Bouger gravity anomaly maps show significant differences in the gravity field on either side of these faults, which may mark the margins of a long-lived, crustal scale rift (Price 1981, Fountain and McDonough 1984). Examples of such rifting during Belt-Purcell Supergroup, Windermere Supergroup and Late Proterozoic to Early Cambrian time at the edge of the North American continent, have been described by a number of authors (e.g., Leech 1962, Stewart 1972, Lis and Price 1976, Benvenuto and Price 1979, Struik 1987, Devlin and Bond 1988;=, Devlin 1989).

Evidence for younger reactivation of the Southern Alberta Rift, associated with faults of lesser magnitude, has been presented by a number of authors (Olson *et al.* 1994). Price and Lis (1975), for example, described significant differences in thicknesses and facies of Upper Paleozoic rocks across the Moyie-Dibble Creek Fault. Brandley and Krause (1993) and Brandley *et al.* (1993) suggested that increased thicknesses of Mississippian carbonates are spatially associated with the location of the Southern Alberta Rift and therefore are indicative of subsidence during that period. Pope and Thirlwall (1992) suggested that group II ultrapotassic dykes and diatremes of kimberlitic affinity in southeast British Columbia are indicative of passive margin rifting, and possibly are related to reactivation of the Southern Alberta Rift during the Permian-Triassic period. Hopkins (1987, 1988) described synsedimentary subsidence of Lower Cretaceous rocks in the Cessford hydrocarbon field and postulated this subsidence is associated with a narrow graben that reaches from the Precambrian basement into the Cretaceous section. The Cessford field is located southeast of Calgary near the inferred northern margin of the Southern Alberta Rift. Reactivation of the rift during the Early to Late Cretaceous is further supported by deposition of the thickest portions of the Crowsnest volcanics which are centred within the bounds of the rift (Pearce 1970; Adair 1986), and increased thicknesses and abrupt facies changes of the Cretaceous sedimentary rocks within and adjacent to the approximate boundaries of the rift (Jerzykiewicz and Norris 1993a, b). The volcanics are trachytic to phonolitic in composition and, if compared to other trachyte and phonolite provinces, are indicative of continental rifting. The Lewis and Clark Fault System and the Great Falls Tectonic Zone, which exist in the northern United States of America, can be regarded as step-like sympathetic structures to the Southern Alberta Rift. These two fault zones are deep-seated and have a history of recurrent fault movements very similar to the Southern Alberta Rift. Episodic fault movement along the Lewis and Clark Fault System and the Great Falls Tectonic Zone has been documented from early Proterozoic to the Tertiary, and perhaps occurred as recently as the Holocene (Lorenz 1984; O'Neill and Lopez 1985; Wallace *et al.* 1990). In short, the syndepositional faults which are subparallel to the regional trend of the graben, the associated sedimentary facies changes and the locally syndepositional volcanism, indicate the Southern Alberta Rift has been periodically active over a long period of time from the Precambrian to at least the Late Cretaceous.

2.8.3 Peace River Arch

Regional syntheses of the Peace River Arch (PRA) have recently been published by Cant (1988), O'Connell *et al.* (1990), and O'Connell (1994). This east-northeasterly trending structure extends from the Front Ranges in northeastern British Columbia across north-central Alberta and has a total length of approximately 750 km. At the Alberta-British Columbia border, the Peace River Arch stands approximately 1,000 m above the regional elevation of the basement. This elevation decreases towards the east. It is approximately 500 m at the fifth meridian in central Alberta, and less than 50 m near the fourth meridian in eastern Alberta. The Arch has created a wide zone of structural disturbance and has a width of approximately 140 km at the sixth meridian in northwest Alberta.

There are no distinct aeromagnetic or gravity anomalies that coincide with the axis of the Peace River Arch, but seismic refraction analysis shows that there is a subtle crustal uplift at the Moho level that is partially coincident with the Arch axis (Zelt 1989; Stephenson *et al.* 1989; Ross 1990). Although the trend of the Peace River Arch parallels the tectonic strike of the exposed Precambrian Shield in northeast Alberta, the location of the Arch does not coincide with any northeast trending tectonic elements in the Alberta basement and is apparently not the result of the uplift of a single or discrete Precambrian structure.

It appears that the Peace River Arch was superimposed upon a pre-existing Precambrian basement geology. That is, the Peace River Arch overprinted the earlier basement structure and was active as early as the Late Proterozoic (O'Connell *et al.* 1990; Ross 1990). The oldest expression of the Peace River Arch consists of uplifted and truncated Upper Proterozoic and Lower Cambrian sediments that are exposed in the Cordillera (McMechan 1990). Pre-Middle Devonian rocks are largely absent in the vicinity of the Arch. The first significant sedimentary deposits consist of coarse grained clastics that are known as the Granite Wash and are believed to be middle Devonian in age. These clastics were deposited within a series of extensional graben structures that were formed on the crest and flanks of the Arch during uplift, and have a relief of up to 100 m.

Throughout the middle and late Devonian the Peace River Arch was an emergent feature that was gradually onlapped by predominantly carbonate sediments. Episodic tectonism led to the reactivation of Precambrian fault zones and influenced sedimentation patterns within and around the Arch (Dix 1990). By the end of the Devonian the Arch was no longer emergent and shallow marine deposition reflected a continuation of Devonian subsidence trends (O'Connell 1990).

During the late Early Carboniferous a tectonic inversion occurred in which the central region of the Devonian emergent Peace River Arch began to subside and form a large northwest trending basin. By the lower Visean, the region of the Peace River uplift had been fundamentally transformed by the development of a series of linked grabens that formed the Peace River Embayment. The development of the Embayment is the product of a complex extensional regime with kilometre scale subsidence and significant displacements along growth type block faults (Barclay *et al.* 1990). The Embayment persisted throughout the Permian and Triassic.

During the Cretaceous, accentuated subsidence occurred in the Peace River region which indicates an underlying local structural control of basin configuration in this area. This has influenced lower Cretaceous channel and shoreline trends, and minor structural offsets within the Late Cretaceous may have been caused by the reactivation of underlying Peace River Arch and Embayment structures (e.g., Hart and Plint 1990).

O'Connell *et al.* (1990) have demonstrated the possibility that regionally significant Precambrian fault zones in the Peace River region have been reactivated throughout the Phanerozoic. Some major basement terrane contacts are coincident with: (a) the trends of Devonian and Carboniferous grabens, (b) the emplacement of Late Devonian dolomite occurrences and (c) a linear Cretaceous erosional feature.

The Peace River Arch intersects the Rocky Mountains and Foothills just west of the Alberta border in British Columbia, but its influence on the Alberta-portion of the Rocky Mountains is uncertain. In northeastern British Columbia, however, Stelck *et al.* (1978) documented that Peace River Arch tectonics had affected sedimentary rocks as early as the Late Proterozoic in the Rocky Mountains at the Vreeland and Ice Mountain areas. Burwash (1990) suggested that the effects of the Peace River Arch can be seen as far east as the Shield exposure in the Marguerite River area near the Saskatchewan border, and that its persistence to the present is evidenced by positive relief and high heat generation in the basement rocks.

Various mechanisms have been proposed for the origin and development of the Peace River Arch, none of which is entirely satisfactory. These vary from a completely thermal origin, to a non-thermal passive flexural origin, or a combination of both. In summary, the Arch is a deeply buried structural feature that has had a complex tectonic history extending from the Late Proterozoic until at least the Late Cretaceous. It is clear that several episodes of crustal extension have been focussed in this region throughout the Phanerozoic.

2.8.4 West Alberta Arch

The West Alberta Arch (WAA) is a northwest-trending structure at least 500 km in length, with its axis located at about the eastern limit of the Rocky Mountains (Verrall 1968). This uplift formed a southern extension of the Peace River Arch. It was active from at least Silurian to Middle Devonian time as evidenced by the lack of Late Cambrian to Middle Devonian carbonates and shales, and the presence of Middle to Upper Devonian fringing reefs (Geldsetzer and Mountjoy 1992). The Middle Devonian succession in central Alberta was deposited within a shallow, restricted epicontinental seaway that was separated from the open ocean to the north and west by the landmass formed jointly by the Peace River and West Alberta Arches. Verrall (1968) suggested that the West Alberta Arch might have been active as early as Late Cambrian. As well, the WAA may have been reactivated during the late Paleozoic. For example, Geldsetzer and Mountjoy (1992) described the presence of debris flows, spectacular megabreccias and deep-water channels (such as the Cline Channel) within Upper Devonian carbonates, with no evidence of subaerial exposure associated with the WAA. They (Ibid.) suggested earthquake generated debris flows may have been responsible for these deposits. However, local grabens might also have caused the debris deposits and these structures may have been active in a few places along the WAA during the Late Devonian, after the major uplift of the Arch. As well, some evidence exists that indicate the WAA and other structures were reactivated during the Lower Carboniferous (Brandley and Krause 1993; Brandley *et al.* 1993). Verrall (1968) shows the WAA as a northwest trending, doubly plunging antiformal feature with its northeast trending hinge located in the vicinity of the Upper Devonian Cline Channel, the approximate projected trend of the Snowbird Shear Zone within the crystalline basement and the northeasterly trending Bighorn Tear Fault, which offsets Cretaceous thrust faults. It has not been established whether the approximate spatial overlap of these structures is coincidence or whether they are tectonically related.

The reason for uplift of the WAA is not known, but Bingham *et al.* (1985) reported that a conductive ridge underlies the Eastern Rocky Mountains. They suggested that in the American Rockies, similar conductive structures are correlated with high heat flow and low seismic velocities in the lower crust. They further suggested that partial melting and periodic uplift might have been associated with the conductive ridge. Perhaps partial melting during the Paleozoic beneath the present-day location of the Eastern Rocky Mountains was responsible for uplift of the WAA.

2.8.5 The Meadow Lake Escarpment

The northeasterly trending Meadow Lake Escarpment is formed by the erosional edge of the Ordovician Red River Formation carbonates (van Hees and North 1964). To the east in Saskatchewan and Manitoba, the Meadow Lake Escarpment trends easterly and runs south of and parallel to the Kisseynew Lineament. Towards its western end in Alberta, the Meadow Lake Escarpment widens out and flattens (Figure 2.4). In general, the Meadow Lake Escarpment is believed to have formed as a result of broad uplift to the north, with the Meadow Lake Escarpment acting as a hinge line, during latest Silurian to earliest Devonian time. This caused erosion of the Ordovician-Silurian strata north of the Escarpment, and resulted in Devonian strata unconformably overlying Precambrian rocks north of the Escarpment whereas to the south they unconformably overlie Ordovician rocks. Some authors, however, have referred to the Meadow Lake escarpment as a "cuesta" or attribute its origin to transcurrent faulting (Douglas *et al.* 1970; Haites 1960).

2.8.6 Sweet Grass Arch and Alberta Syncline

The Sweetgrass Arch is a northward plunging, complex antiform located in southeastern Alberta and covers a region of approximately 32,000 km^2 (Christopher 1990). Recent summaries of the Sweetgrass Arch are provided by Herbaly (1974), Lorenz (1982), Leckie and Rosenthal (1986), Podruski (1988) and Christopher (1990). The structural complex forms a broad divide between the Rocky Mountain foreland basin to the west and the Williston Basin to the east. The Sweetgrass Arch rises in Montana at the northwest trending Kevin-Sunburst Dome. The Arch plunges northwards into Alberta where it meets the southwest plunging anticlinal nose of the Bow Island or Battleford Arch. This structural low between the Sweetgrass and Bow Island Arches is known as the Suffield Saddle (Herbaly 1974).

The initial structural expression of the Sweetgrass Arch is seen in the Proterozoic. The location of the Arch during Precambrian time may be due to its position, which at that time was at the flexural hinge of the continental shelf margin, and also possibly due to thermal uplift associated with localized igneous activity.

There are indications of Sweetgrass Arch uplift and erosion in pre-Devonian times (Kent 1986, 1994). Carboniferous and Permian sediments wedge out against the eastern flanks of the Arch, accentuated by downwarp of the Williston basin. The cumulative tectonic relief of the Sweetgrass Arch throughout this time is estimated to have been approximately 600 m (Christopher 1990). Uplift was enhanced during the Triassic and the Arch was widely emergent, with deposition onlapping its eastern flanks. Widespread uplift and erosion of the Arch succeeded the Carboniferous-Triassic epeirogeny. Major erosional valley systems were cut into the Arch which strongly influenced later deposition in successor basins.

Lorenz (1982) suggested that during the Jurassic the Sweetgrass Arch was uplifted as a peripheral bulge within the foreland basin, along pre-existing zones of weakness. Evidence for this comprises erosional unconformities within the Jurassic succession throughout the region of the Sweetgrass Arch. During the Early Cretaceous, uplift and southwesterly tilting of the Arch was followed by a general episode of subsidence. During the late Cretaceous and early Tertiary Laramide orogeny, the Sweetgrass Arch was uplifted by horizontal compressive forces, which created the present configuration of the Arch. The orogeny also activated many long lived fault-zones and linears in the area. The region became an active centre of igneous intrusion. These include the plutonic intrusions that form the Sweet Grass Hills, which have been dated at 50 to 54 Ma, and occur along the axis of the Sweet Grass Arch in northern Montana. These intrusions affected sedimentation of the lower Tertiary clastic wedge in southwestern Saskatchewan and Alberta.

With respect to the Alberta Syncline, Leckie (1989) has stated "*The Alberta Syncline, situated between the Sweet Grass Arch and the deformed belt of the Rocky Mountains, is a relatively young structural feature, having been formed during Late Cretaceous to Early Tertiary time. The eastern limb of the Alberta Syncline parallels the west-dipping Precambrian basement; the western limb is formed by east-dipping strata representing the eastern margin of the Rocky Mountain Foothills.*"

2.8.7 Rocky Mountain Fold and Thrust Belt

In the Alberta portion of the Canadian Cordillera, there are three linear belts of distinctive style: the Foothills, Front Ranges and Main Ranges Foothills bedrock geology is characterized by thrust faults with Tertiary and Mesozoic strata in the footwall and either Mesozoic strata or Carboniferous and younger strata in the hanging wall. The Front Ranges, which are marked by the Lewis and McConnell thrusts, place Devonian to Proterozoic thick carbonates onto Cretaceous rocks. In the Main Ranges, the thrust sheets are predominantly composed of Paleozoic and Proterozoic strata where Mesozoic strata are not preserved. The structural style changes from southeast to northwest in Alberta, and into British Columbia. In the south, discrete overthrust faults of significant stratigraphic offset are present, whereas to the northwest there are large amplitude box and chevron style folds with little stratigraphic separation that are underlain by blind thrusts of significant stratigraphic offset (*Ibid*). This change in structural style from south to north coincides with a significant change in the dominant lithology of the deformed rocks. That is, it occurs where Paleozoic platformal carbonates which are characteristic of the southern Alberta Basin give way to basinal mudstone-dominated strata to the northwest (McMechan *et. al.* 1992).

In Alberta, the Rocky Mountains and Foothills are dominated by northwest-trending folds and thrust sheets that developed during accretion of land masses west of the Rocky Mountain Trench. For example, the Lewis Thrust carried the Precambrian and some overlying Paleozoic rocks from as far west as Cranbrook, British Columbia and superimposed them on Paleozoic and younger rocks. Also present within southwestern Alberta are numerous other thrust faults as well as some normal faults which are transverse to the regional strike. The geological base maps (Figures 2.4, 2.5 and 2.9) which accompany this report, are simplified and only selected faults and fold structures are shown. The structural geology of the Eastern Rocky Mountains and Foothills is well-summarized by Charlesworth (1959), Shaw (1963), Bally *et al.* (1966), Dahlstrom (1970), Jones (1971) and Price (1981). Work during the 1970's and 1980's has been focused on the details of imbricate thrusting and the actual mechanisms responsible for the formation of such structures as floor thrusts, roof thrusts and duplexes (Price and Lis 1975; Fermor and Price 1987; Price 1994).

The Canadian Cordillera formed during the Laramide Orogeny, with most of the deformation occurring from the late Cretaceous to early Tertiary. However, uplift to the west is documented as early as the Jurassic by the Kootenay Group-Blairmore Formation clastic wedge (Eisbacher *et al.* 1974). Therefore, the formation of the Eastern Rocky Mountains and Foothills of Alberta was probably an ongoing process from Late Jurassic to Paleocene time, but the last major stage of uplift is thought by many authors to have occurred during Late Eocene to Oligocene. The evidence for this is the deformation of sedimentary rocks as young as Paleocene and the deposition of undeformed Eocene and Oligocene conglomerates (Shaw 1963; Bally *et al.* 1966; Eisbacher *et al.* 1974).

2.8.8 Transverse, Tear and Normal Faults

Northeast-trending transverse, tear and normal or subvertical faults, with or without evidence of vertical movement, have been reported or geologically mapped in a few places along the Alberta Rocky Mountains and Foothills by several workers, including Beach (1942), Birnie (1961), Fitzgerald (1962), Price (1967), Verrall (1968), Dahlstrom (1970), Moffat and Spang (1984), McGugan (1987) and McMechan (1988). Excellent summaries of the early mapping and geological setting of these structures are given in Price (1967) and Dahlstrom (1970).

Large prominent tear faults that have been identified in the Alberta Rocky Mountains include the Bighorn Tear Fault (Verrall 1968; Dahlstrom 1970), the Ghost River Fault (Fitzgerald 1962) and a possible tear fault near Moose Mountain (Beach 1942). The Bighorn Tear Fault exists along the North Saskatchewan River southwest of Nordegg, and it marks the southern termination of the Bighorn Range. Verrall (1968) suggested that the Bighorn Tear Fault exhibits vertical movement along with shearing because the south side is significantly downthrown. The major period of movement on this structure was during the Laramide Orogeny because the Bighorn Tear Fault cuts Upper Cretaceous rocks in the Cripple Creek thrust sheet, but is overridden by the McConnell thrust sheet. The poorly exposed Ghost River Fault is near vertical and exhibits at least 140 m to 185 m of vertical movement, with the south side downthrown (Fitzgerald 1962). The western end of the fault appears to be overridden by the Exshaw thrust fault. A possible tear fault was mapped southwest of Moose Mountain by Beach (1942), although subsequent mapping by Ollerenshaw (1975) indicated that this structure may be an oblique thrust fault.

Areas where northeast trending, transverse and normal faults have been documented in the Alberta Rocky Mountains and Foothills, include: (a) Indianhead Creek, (b) the headwaters of the Clearwater River, (c) southwest of Banff, (d) southwest of Canmore, (e) in the Elk, Opal and Misty Ranges east of Kananaskis Lakes, and (f) in the Mount Head area. Birnie (1961) described a series of four northeast trending normal faults that cut the Third Range thrust sheet at Indianhead Creek and have an average of 460 m of north-side-down displacement. Verrall (1968) described faults along the headwaters of the Clearwater River as right lateral shears that cut the Siffleur and Sulphur Mountain thrust sheets. He also described some faults southwest of Banff as left lateral shears that do not cut the Sulphur Mountain thrust sheet. Moffat and Spang (1984) described transverse faults in the Sulphur Mountain and Rundle thrust sheets southwest of Canmore. They suggested these transverse faults developed during thrust movement in response to differential sheer along the moving thrust sheet. McGugan (1987) described several northeast trending transverse faults with apparent right lateral movement that cut rocks above the Lewis Thrust east of Kananaskis Lakes in the Elk Range. McGugan (1987) stated that at least one of the faults has an apparent displacement of 150 m, and noted that although the faults exhibit tear movement, vertical movement cannot be ruled out. McMechan (1988) has mapped dozens of northeast trending transverse faults north and east of the Elk Range along the eastern border of Peter Lougheed Provincial Park within the Opal and Misty Ranges. Many of these faults exhibit apparent right lateral displacement. Price (1967) concluded that the steep dip-slip-movement indicators which exist along these faults, indicate the faults formed prior to thrusting as extensional gravity faults whose orientation was controlled by the Hudsonian basement fabric. Lastly, Douglas (1958) described northeast trending vertical faults in the vicinity of the Highwood River. He suggested that they are tear faults with up to 305 m of horizontal offset in places.

2.8.9 Folds, Faults, Fractures, Salt Dissolution Features and Other Structural Anomalies in the Plains Region

In addition to the foregoing major tectonic features that affected the Western Canada Sedimentary Basin, there are other, more local, major structural elements, including: folds, faults, fractures, salt dissolution features, and a few problematical structures which are commonly inferred to be of astrobleme origin (Osadetz 1989) (Figure 2.5, Table 2.2).

The major folds and faults are of compressional origin and are associated with the Laramide Orogeny which formed the Rocky Mountain thrust and fold belt. East of the Rocky Mountain deformed belt, faults, folds and other tectonic elements are uncommon, but do exist locally. "*Faults occur throughout* [the] *southern Interior Platform and although many reports indicate or infer their presence, their description and analysis is sparse. Faults can be subdivided into three general groups: normal faults observed or inferred to cut crystalline basement, normal faults that do not reach basement, and wrench faults that are Laramide compressive structures*" (Osadetz 1989). As well, there are faults associated with salt dissolution collapse. "*There are many other faults inferred to explain linear facies patterns, oil field trends or surficial lineaments whose position or existence remains to be substantiated" (Moffat and Gardner 1981). Osadetz and Haid (1989) stated that "faults are not commonly reported in the Interior Platform although faulting is an important component of petroleum plays in the Tippecanoe sequence* (Middle Ordovician to Lowest Devonian). *Most faults have stratigraphic offsets that terminate at the sub-Middle Devonian erosion surface. ... Some dolomitization patterns are believed to be controlled by fluids that moved through basement faults.*"

Fractures have had a profound influence on the location of many oil and gas pools, and the quality of reservoirs in Western Canada as a result of their affect on host rock porosity (Osadetz 1989). The conditions of such fracturing are controlled by crustal stresses (Bell and Babcock 1986). "*Several regions in the Interior Platform exhibit complex and anomalous structures. Most of these are considered to be astroblemes*" (Osadetz 1989). In Alberta, possible astrobleme structures include the Steen River Structure (SRS) in the north and the Eagle Butte structure in the southeast (Winzer 1972, Sawatzky 1975) (Figure 2.5).

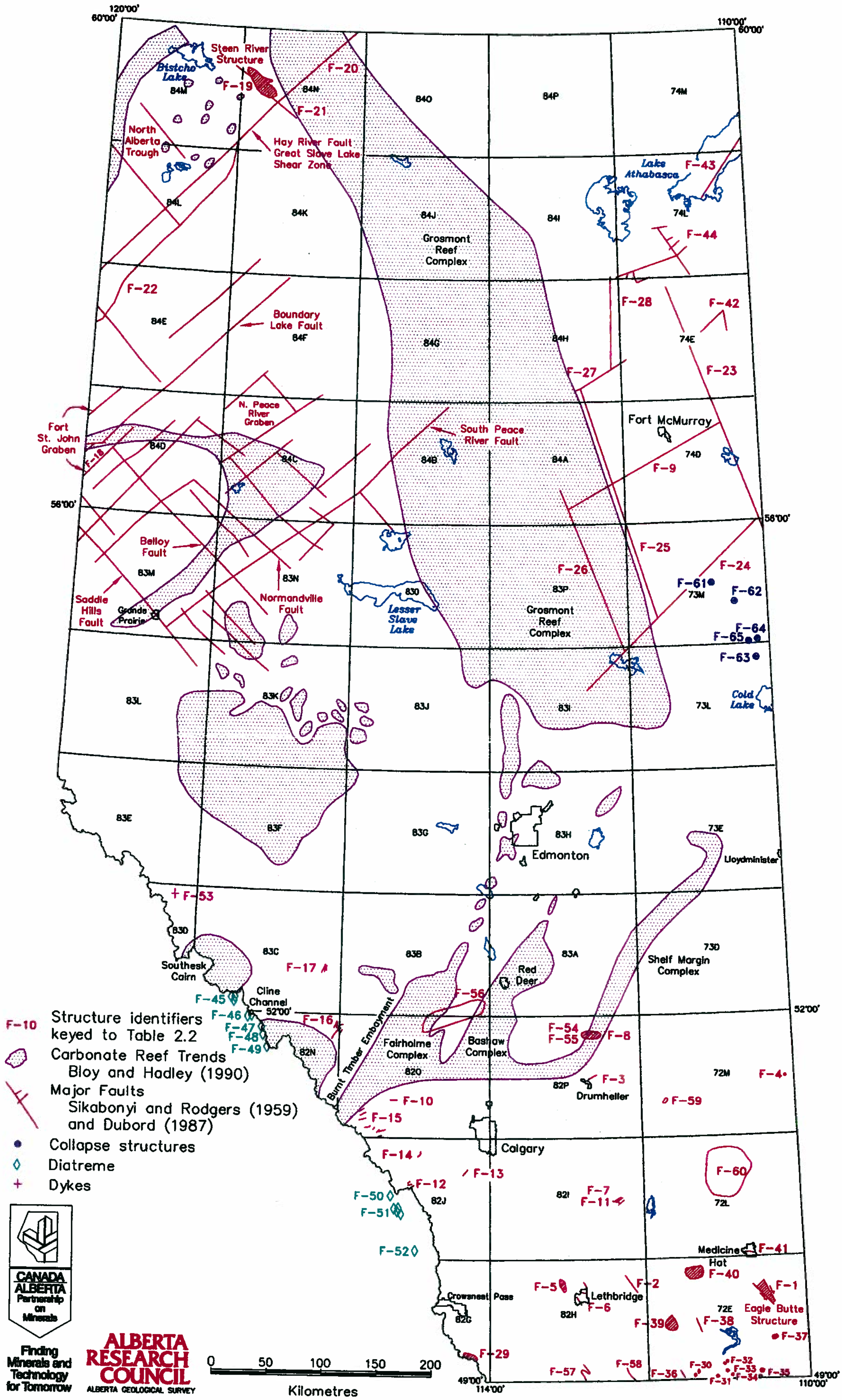


Figure 2.5: Major faults, carbonate reefs, diatremes, dykes and collapse structures in and adjacent to Alberta.

Table 2.2 Summary of Major Faults and Other Structural Anomalies in Alberta

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
FAULTS CUTTING PHANEROZOIC STRATA								
F-1 (Eagle Butte)	Twp. 7-9, R. 4-5W4M	Two transcurrent faults, connected by three thrust faults and one normal fault.	The Bullstead Creek Fault is at least 27 km long, and the Medicine Lodge Coulee Fault at least 20 km. Displacements of up to 165 m vertically. Note: 1,000 m vertical dis-placement cited in Westgate (1968).	BCF= N44°W MLCF= N26°W BCF= sinistral movement MLCF= dextral movement	Post-Cretaceous	Positive gravity anomaly; close proximity to bentonite occurrence #'s B1-7	There are numerous other smaller-scale faults in the vicinity, and there is evidence that a deep-seated plutonic dome or plug may be the source of this anomaly.	Haites and van Hees (1962); Gallup (1956) and Westgate (1968)
F-2 (Taber)	Twp. 9-10, R.16-17W4	Transcurrent to normal, dextral (?) fault.	The fault is at least 20 km long with up to 30 m vertical and 2 km horizontal displacement.	Strike = N37°W Dip = 65°SW	Post-Cretaceous	None	A N-S channel, over 100 m deep, of early Early Cretaceous age cuts Jurassic and Mississippian rocks in the same area.	Haites and van Hees (1962); Russell and Landes (1940)
F-3 (Drumheller)	14-29-20W4	Transcurrent, dextral fault.	At least 5 km long, with variable vertical displacement (up to 25 m) and about 1.5 km of horizontal displacement.	Strike = N37°W Dip = 80°SE(?)	Post-Cretaceous	Close proximity to bentonite occurrence #'s 8-9 and 25-27	Vertical displacement changes sign along the strike of the fault (normal to reverse to normal), indicating dominant strike-slip movement.	Haites and van Hees (1962); Haites (1960)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-4 (Albercan)	1-12-29-2W4	One or two (?) normal faults.	Up to about 100 m of vertical displacement.	Unknown	Post-Mississippian and Pre-Cretaceous, with possibly some post-Cretaceous movement.	None	About 100 m of Devonian to Mississippian rocks are missing from the anomalous hole, while at the same time 60 m of Mississippian carbonates are present in this hole and no where else. Evidence of graben-type faults.	Workman (1954); Haites and van Hees (1962)
F-5 (Monarch Fault Zone)	Twp. 9-10, R.23-24W4	An imbricate series of E-dipping thrust faults of small displacement.	The faults are present in an area about 10 km long and about 3 km wide.	Strike = N20°W to N25°E Dips to the SW and NW	Post-Cretaceous (Laramide)	None	None	Irish (1971)
F-6 (Lethbridge)	Twp. 8-10, R.21-22W4	Three or more small-scale tear faults, with normal components.	Faults are up to 10 km long, with up to 30 m of vertical displacement and definite, but undetermined horizontal displacement.	Main fault strike is N35°W, other faults strike about N40°W and N60°W	Post-Cretaceous, cuts across Sweetgrass Arch folding.	None	Small-scale faults, unknown extent at depth.	Russell and Landes (1940); Haites (1960)
F-7 (Bassano Fault Block)	Twp. 17, R.18W4	Small-scale normal fault.	About 7 km long, with unknown vertical displacement.	About N75°W	Post-Cretaceous	Intersects anomaly F-11.	None	Stewart (1943) Irish (1971)
F-8 (Mud Buttes and Tit Hills and/or Misty Hills)	Twp. 33, R.19-20W4	Severely folded and faulted beds, on a local scale.	About 15 km E-W and 5 km N-S.	Strike = N100°E Dip 20° to 50°N	Bearpaw and "Pale" beds of Cretaceous age. Structures are Quaternary, related to glacial activity.	None	Glacial in origin; "ice-thrust" bedrock.	Slater (1927); Williams and Dyer (1930)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-9 (Clearwater River)	Extends SW from Twp. 90, R.4W4	Transcurrent fault?	About 160 km long	About N55°E	Basement structure. May be younger movement affecting overlying units.	Salt dissolution (F-54 and F-55)? Intersects anomalies F-9, F-25 and F-26.	None	Dubord (1987); Garland and Bower (1959)
F-10 (Ghost River)	Twp. 27, R.9-10W5	Dextral transcurrent (or normal) fault.	About 8 km long; stratigraphic throw from 150 m to 200 m (N side up).	About N85°E	Syn-Laramide Orogeny. Cuts one thrust fault and is terminated at its ends by other thrust faults.	None	None	Fitzgerald (1962)
F-11 (Bassano Fault Block)	Twp. 17-18, R.17-18W4	Three normal faults.	Up to 6 km long, with unknown amounts of vertical displacement.	Faults strike about N50°E.	Post-Cretaceous	Intersects anomaly F-7.	None	Irish (1971); Stewart (1943)
F-12 (Kananaskis Country)	Twp. 19, R.8W5	Five transcurrent faults, containing "horses" of fault transported rock.	Up to 2.5 km long. The northern most fault has ≈ 80 m sinistral displacement, while the other 4 faults have 90 m to 300 m dextral displacement.	Between N40°E and N55°E.	Post-Jurassic. They are also believed to be pre-Laramide Orogeny.	None	There is evidence that these are not tear faults between thrust sheets, but instead are extensional faults related to the Hudsonian basement below.	McGugan (1987)
F-13 (Turner Valley Fault)	Twp. 21, R.3W5	Transverse fault.	Approximately 7 km in strike length.	N37°E	Post-Cretaceous	None	None	Hume (1931)
F-14 (Near Moose Mountain)	Twp. 21, R.8W5 Twp. 22, R.7W5	Transverse fault.	Approximately 7 km in strike length.	N45°E	Cretaceous to Post-Cretaceous	None	None	Beach (1942)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-15 (Canmore Area)	Twp. 10-13, R.23-26W5	Several (8 or more) transcurrent "tear" faults.	Up to about 10 km long, with variable amounts of both dextral and sinistral displacement.	Between N40°E and N60°E	Post-Cretaceous, syn-Laramide Orogeny.	None	These faults have been proven to be directly related to folding and thrusting in the area.	Moffat and Spang (1984); Verrall (1968)
F-16 (Indianhead Creek Area)	Twp. 33-34, R.14-15W5	Four large normal faults, with numerous smaller associated faults.	Up to about 6 km long, with variable displacement ranging from 0 m to 500 m, NW side down, along each fault.	Strike between N15°E and N45°E. Dips from 45° to 90° to the NW, becoming progressively shallower with depth and to the NW.	Syn-Laramide Orogeny, with possibly some pre-Laramide movement.	None	Movement on these faults appears to both pre-date and post-date the movement along the Third Range Thrust Fault.	Birnie (1961); Verrall (1968)
F-17 (Bighorn Tear)	Twp. 39, R.16W5	Transcurrent fault, with significant vertical movement.	Up to about 5 km long, with vertical displacement to the S along entire length.	Strikes about N30°E, dips nearly vertical.	Pre- or syn-Laramide Orogeny. Cuts entire Bighorn thrust sheet, but is overridden by McConnell Thrust.	None	None	Verrall (1968)
F-18 (Worsley)	Twp. 86-87, R.11-13W6	Two normal faults.	At least 25 km long, each with vertical displacements up to 30 m.	One fault strikes about N40°E, and terminates in the other, which strikes N80°E. Both faults dip 60°-70°N, with N-side-down.	Post-Cretaceous, cutting Baldonnel Fm. May be reactivation of basement faults.	Silver occurs in fault zone. Anomaly 83M-M-02 in Olson *et al.* (1994)	None	Baykal (1968a)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-19 (Steen River Structure)	Twp. 120-122, R.20-23W5	Possible meteorite impact feature, with associated normal and reverse faults.	About 25 km across, with surrounding area uplifted and disturbed up to 30 km away.	Circular. Associated faults are radial in nature.	Mid-Cretaceous, about 95 ± 7 Ma.	Adjacent to Great Slave Lake Shear Zone (F-20) and NW-striking basement fault (F-21).	Same approximate age as Fort à la Corne kimberlites in Sask., and Fish Scales unit.	Winzer (1972) and others (eg., Wilson et al, 1989)
F-20 (Hay River Fault and Great Slave Lake Shear Zone)	Strikes SW from Twp. 126, R.13W5 to Twp. 103,R.12W6	Transcurrent fault, with vertical component. Has ≥ 300 km dextral displacement, as well as substantial S-side-up movement.	In Alberta, about 320 km long, extends NE into N.W.T. and SW into B.C.	About N40°E. Dip near vertical.	Precambrian in origin. Continued movement through Cretaceous (?)	Fault F-22 is a splay off this fault.	Extends for >1,000 km to the NE, past the East Arm of Great Slave Lake. SW extension of McDonald Fault System and Great Slave Lake Shear Zone.	Haites (1960); Wilson *et al.* (1989)
F-21	Strikes NW from Twp. 118, R.19W5 to Twp. 124, R.3W6	Transcurrent fault, possibly with some vertical component.	100 km or more long. Sinistral displacement of ≥ 3 km across Great Slave Lake Shear Zone (F-20). Unknown vertical displacement.	About N45°W. Dip likely near vertical.	Precambrian in origin? Movement through Cretaceous?	Cuts through F-19 (Steen River Structure).	None	Wilson *et al.* (1989);
F-22	Strikes SW from Twp. 116, R.1W6 to Twp. 99, R.13W6	Transcurrent fault, possible with some vertical component.	In Alberta, about 200 km long. Extends SW into B.C.	About N40°E. Dip likely near vertical.	Precambrian in origin? Movement through Cretaceous.	Great Salve Lake Shear Zone (F-20).	Splay off at fault F-20.	Haites (1960); Wilson *et al.* (1989)
F-23	Strikes NNW from Twp. 80, R.1W4 to Twp. 103, R.8W4	Transcurrent fault, inferred from aeromagnetic data.	In Alberta, about 230 km long. Extends SE into Saskatchewan.	About N25°W. Dip likely near vertical.	Basement structure. May be younger movement affecting overlying units.	Intersects anomalies F-9 and F-24.	No data.	Dubord (1987); Garland and Bower (1959)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-24	Strikes NE from Twp. 66, R.18W4 to Twp. 81, R.2W4	Transcurrent Fault, inferred from aeromagnetic data.	About 220 km long.	About N°40E. Dip likely near vertical.	Basement structure. May be younger movement affecting overlying units.	Intersects anomalies F-23, F-25 and F-26.	No data.	Dubord (1987); Garland and Bower (1959)
F-25	Strikes NNW from Twp. 72, R.10W4 to Twp. 94, R.16W4.	Transcurrent fault, inferred from aeromagnetic data.	About 210 km long.	About N25°W. Dip likely near vertical.	Basement structure. May be younger movement affecting overlying units.	Intersects anomalies F-9, F-24, and F-27.	No data.	Dubord (1987); Garland and Bower (1959)
F-26	Strikes NNW from Twp. 69, R.14W4 to Twp. 84, R.19W4	Transcurrent fault, inferred from aeromagnetic data.	About 160 km long.	About N25°W. Dip likely near vertical.	*Basement structure. May be younger movement affecting overlying units.*	Intersects anomalies F-9 and F-24.	No data.	Dubord (1987); Garland and Bower (1959)
F-27	Strikes NE from Twp. 94, R.17W4 to Twp. 96, R.12W4	Transcurrent fault, inferred from aeromagnetic data.	About 60 km long.	About N55°E. Dip likely near vertical.	*Basement structure. May be younger movement affecting overlying units.*	Intersects anomalies F-25 and F-28.	No data.	Dubord (1987); Garland and Bower (1959)
F-28	Strikes N-S from Twp. 96, R.14W4 to Twp. 104, R.13W4	Transcurrent fault, inferred from aeromagnetic data.	About 80 km long.	About N00°E. Dip likely near vertical.	*Basement structure. May be younger movement affecting overlying units.*	Intersects anomaly F-27.	No data.	Dubord (1987); Garland and Bower (1959)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
INTRUSIONS IN SE AND SW ALBERTA								
F-29 (LaCoulotte Peak & Ridge)	Twp. 2-3, R.2-3W5	Series of syenitic intrusives.	Dykes occur within an area about 10 km E-W and 5 km N-S.	Dykes generally strike northeasterly.	Dykes cut Mississippian rocks, and are believed to be Late Cretaceous or Early Tertiary.	None	Equivalent to Anomalies 82G-G6 and equivalent others in SW Alberta (see Olson *et al.* 1994).	Baykal (1968b); Goble (1974a)
F-30 (Sweetgrass Hills, Deadhorse Coulee)	5-18-1-11W4 and 20,28,29,32,33-1-11W4	Minette intrusive and anticlinal structure.	Small dyke < 100 m long. Anticline is ≥ 5 km long and about 1.5 km wide.	Dyke strikes NNE, dips vertically. Anticline trends N to NNE, plunges gently N.	Eocene: ca. 48 Ma - postdates Sweetgrass Arch.	Extends SW towards West Butte intrusion of Sweetgrass Hills in Montana.	Anticline and dyke are probably both related to emplacement of West Butte intrusion. Anticline may be cored by intrusive?	Williams and Dyer (1930); Russell and Landes (1940)
F-31 (Sweetgrass Hills at Pinhorn area)	5,8,9-1-9W4 and Twp. 1, R.9W4	Minette intrusive and domal structure.	Intrusive is about 30 m long in exposure, and up to 1.5 m thick. Domal structure is ≥ 5 km across.	N05°E strike dips vertically. Dome is semicircular, slightly steeper on W and N sides.	As for F-30.	Dyke extends S towards East Butte intrusion of Sweetgrass Hills in Montana.	Dyke and dome are probably both related to emplacement of East Butte intrusion. Dome may be cored by intrusive?	As for F-30.
F-32 (Sweetgrass Hills)	NE-13-2-9W4 and 16-19-2-8W4	Two minette intrusives about 2 km apart.	Small intrusive mass about 20 m x 15 m, and about 15 m high (16-19-2-8W4). Other intrusion is similar.	Semicircular, vertical bodies.	As for F-30.	None	Has inclusions of sulphurous limestone, indicating that it pierced Mississippian carbonates which are about 1,000 m below. Therefore deep in origin.	As for F-30.
F-33 (Sweetgrass Hills)	NE-30-1-8W4	Minette intrusive.	Small dyke.	Approximately N-S. Vertical dip.	As for F-30.	None	None	As for F-30.

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-34 (Sweetgrass Hills, Black Butte)	13-10-1-8W4	Minette intrusive.	About 400 m long x 100 m wide, up to 30 m high. Oval in shape.	Generally NE-SW. Vertical body.	As for F-30.	None	Has inclusions of dioritic rock and limestone, indicating that it originated at great depth.	As for F-30.
F-35 (Sweetgrass Hills, Comrey area)	SW-5-1-5W4 and Twp. 1, R.5W4	Minette intrusive and domal structure	At least 100 m long in exposure, and up to 1.5 m thick. Domal structure is ≥ 4 km across.	Strikes N58°E, dips vertically. Dome is elongated slightly E-W.	As for F-30.	Dyke extends SW towards East Bluff intrusion of Sweetgrass Hills.	Dyke and dome are probably related to emplacement of East Butte intrusion. Dome may be cored by intrusive?	As for F-30.
FOLD STRUCTURES								
F-36 (Erickson Coulee)	Twp. 1, R.12-13W4	Asymmetrical anticline.	≥ 4 km long, and about 1 km across.	Trend is N15°W. Plunge to the N.	Tertiary (Ecocene) Postdates Sweetgrass Arch.	Extends SE to West Butte intrusion of the Sweetgrass Hills.	Structure is steeper on W side than on E, which indicates that it postdates Sweetgrass Arch. May be cored by intrusive?	Russell and Landes (1940).
F-37 (Sage Creek)	Twp. 4, R.3-4W4	Anticlinal to domal structure.	≥ 7 km E-W, and ≥ 5 km N-S.	Axis is oriented ENE, closure is steep to N, moderate to E and S, and gentle to the W.	Tertiary? Related to or postdates Sweetgrass Arch.	None	Anomalous structure relative to gentle W dip in region. Possibly cored by intrusive?	As for F-36.
F-38 (Foremost area)	Twp. 5-6, R.10-11W4	Anticlinal structure.	About 15 km long and 8 km wide.	Trend is about N20°W. Plunge is moderate to NW.	Tertiary? Post-Sweetgrass Arch?	None	Cuts across trend of Sweetgrass Arch. Possibly related to intrusive activity?	AAas for F-36.

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-39 (Skiff area)	Twp. 5-6, R.13-14W4	Anticlinal or domal structure.	Broad structure, about 20 km N-S and 15 km E-W.	Trends generally N-S, plunges gently to N, E and W; possibly also to S.	As for F-38.	None	As for F-38.	As for F-38.
F-40 (Bow Island area)	Twp. 10-11, R.10-12W4	Series of fold noses (complex anticline); at least 4 separate noses.	$\geq$ 25 km long and 15 km across.	Trends generally NW. Plunges to NW.	As for F-38.	None	As for F-38.	As for F-38; also Williams and Dyer (1930)
F-41 (Medicine Hat)	Twp. 12, R.5-6W4	Synclinal structure, possibly with anticlinal noses on flanks.	$\geq$ 10 km long and 3 km across.	Trends generally E-W, plunges moderately E.	Tertiary. Syn- or post-Sweetgress Arch.	Close proximity to bentonite occurrence #B3-7.	Part of structure which forms a saddle across the Sweetgrass-North Battleford Arch. Plunge of this arch(s) reverses direction here.	As for F-38; also Meyboom (1960)
FAULTS CUTTING PRECAMBRIAN ROCKS								
F-42 (Johnson Lake)	Twp. 98-100, R.3-5W4	Two basement faults, transcurrent in nature. One fault has ≈ 7 km dextral displacement.	One fault is $\geq$ 25 km long, the other is $\geq$ 15 km long.	Strike about N45°E and N10°W.	Basement structures; may affect overlying units.	The longer, western fault has coincident EM and weak negative magnetic anomalies.	A pre-Cretaceous and post-Cretaceous (glacial) erosional channels are in the same area as the faults.	Meyboom (1960); Dufresne *et al.* (1994)
F-43 (South shore of Lake Athabasca)	Strikes SW from Twp. 115, R.1W4 to Twp. 111, R.4W4	Normal fault, with some possible strike-slip movement.	$\geq$ 60 km long in Alberta. Has NW-side-up movement.	Strikes almost N40°E. Dips nearly vertically.	Basement structure. Cuts Helikian Athabasca Group. Some possible movement since Proterozoic time.	None	S.W. extensions of Black Bay Fault in Saskatchewan.	King (1969)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-44 (Richardson River)	Twp. 103-108 R.6-12W4	Normal or strike-slip faults.	Faults ≥ 5 km long. Two faults are ≥ 50 km long.	Two sets: - N45°E to N80°E - N10°E to N30°W	Basement structures. Some later movement?	None	None	Walker (1981); McWilliams *et al.* (1979)
ULTRABASIC DIATREMES AND INTRUSIONS								
F-45 ("Larry Diatremes" near Golden, B.C.)	117°23', 35"W and 52°04', 23" N; approx. 76 km NW of Golden, B.C. and 3 km SSW of Columbia Icefield	Lamproite Dykes & diatremes	1,185 m dyke and diatreme system trending N-S.	Strikes Nrly.	< 60 Ma, post Laramide Orogeny.	None	Abundant chromites (100 - 200 grains), some low Cr- garnets and low-Cr clinopyroxenes from bulk sample.	Fipke (1990)
F-46 ("Jack Diatremes" near Golden, B.C.)	117° 07'20" W and 51° 54'16" N. Approximately 60 km NW of Golden B.C. and 4.5 km west of BC/AB border.	Tuffisitic breccia diatreme with lamprophyre-lamproite clasts.	About 700 m long in NW-SE direction	NE-SW	Between 98 and 60 Ma (late Laramide Orogeny).	None	76 Chromites, 47 high-Cr garnets, 63 low-Cr garnets, 82 picroilmenites, 7 high-Cr clinopyroxenes and 31 low-Cr clinopyroxenes from bulk sample.	Fipke (1990)
F-47 ("Mike diatremes" near Goldon, B.C.)	Immediately West of BC/AB border at 117°00'33"W and 51° 49'27"N. 46.5 km NW of Golden, B.C.; 5.5 km NW of Mark diatremes.	Diatreme facies tuffisitic breccia of possible lamproite affinity.	100 to 400 m long	WNW-ESE	Diatremes are post-thrusting on Mons Fault; also are post folding of sedimentary rocks. Therefore, probably post Laramide and <60Ma).	None	5 discreet bodies of diatreme breccia. Got >100 chromites and 1 high-Cr clinopyroxene from bulk sample.	Fipke (1990)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-48 ("Mark diatremes" near Golden, B.C.)	Astride BC/AB border; 41 km NW of Golden, B.C. 116° 57'50"W and 51° 46'48"N	Diatreme facies tuffisitic breccia	250 x 550 m+ (Mark I); is one of the largest known diatremes in the Canadian Rockies. Other diatremes (Mark 2 to 5) are about 65 x 220 m.	N E-W	At least post-Columbian Orogeny (<98 Ma). Emplacement probably occurred at end of or just after Laramide Orogeny (<60 Ma).	None	Diatreme cluster definitely extends across divide into Alberta, but is mostly covered by the Niverville Glacier. Bulk sample: chromites, high-Cr and low-Cr garnets and 1 low-Cr clinopyroxene.	Fipke (1990)
F-49 ("HP diatreme" near Golden, B.C.)	51° 41'30"N and 116° 575'00"W	Ultrabasic, alkaline lamprophyre with alnoitic affinites.	About 100 m x 100 m	Fairly circular to kidney shaped	Rb-Sr ages for mica from diatreme breccia is 348 Ma. (Pell 1987). May be younger based on structural evidence and fact that mica could be xenocrystic in origin	None	Bulk sample: 85 chromites, and high-Cr and low-Cr clinopyroxenes.	Fipke (1990)
F-50 ("Joff diatremes" near Joffrey Cr., B.C.)	55 km east of Invermere, B.C.; south of Palliser Range on ridges west of Joffrey Creek; no exact location given.	Breccia: hypabyssal facies; phlogopite-bearing kimberlite.	About 500 m x 130 m	Circular	Unknown	None	Bulk sample: 82 chromites, plus low-Cr- garnet, ilmente, and high-Cr and low-Cr clinopyroxene.	Fipke (1990)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-51 ("Russ diatremes")	UTM coordinates are 553700N, 625950E; near Fairmont Hot Springs	Tuffisitic box: alkaline lamprophyre or possible olivine melilite.	About 50 m x 50 m		Unknown	None	Pipe exposed on surface and face of cliff (good cross-section).	Pell (1987a, b)
F-52 ("Cross diatreme")	N side of Crossing Creek, 88 km NW of Elkford, B.C. 114° 59'30"W and 50° 05'25"N	Kimberlite diatreme (Group I kimberlite)	70 m x 15 m	E-W (flattened)	240 - 250 Ma from Rb-Sr age on phlogopite.	None	Bulk sample: abundant chromite, high-Cr and garnets, ilmenite, and high-Cr clinopyroxenes.	Fipke (1990)
F-53 Geike siding west of Jasper	On old Yellowhead Rd, 5/8 mile NW of Geike Siding	Igneous intrusive rock; only known occurrence in Jasper region	About 3 m long	Unknown	Intrudes Old Fort Point Fm, hence emplaced prior to Laramide Orogeny.	None	Green, fine-grained igneous rock, probably altered diabase. Intrusion is highly altered, veined and fractured.	Charlesworth *et al.* (1967)
MISCELLANEOUS STRUCTURES								
F-54 and F-55	3-30-33-19W4 and 10-24-33-20W4	Salt removal causing drop in known geologic contacts	Unknown	Unknown	Late Cretaceous; salt dissolved in Devonian Wabamun Group	Possibly F-8	Devonian Wabamun Group was likely thinned during Late Cretaceous then compensated by thickening of Upper Cretaceous shales.	Oliver and Couper (1983)
F-56	Twp. 32-37, R1-7W5M	Caroline Arch - discovered through lineament analysis	About 60 km x 20 km	Approx. E-W		None	The Caroline Arch rose by 61 m in late Paleozoic and early Mesozoic times.	Haman (1975)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-57 (Del Bonita Structure)	Twp. 1-2, R.21-22W4M	Asymmetrical syncline-anticline pair.	About 10 km long by 10 km wide.	Fold axes trend and plunge NW.	Post-Cretaceous	None	None	Russell and Landes (1940)
F-58 (Kevin Sunburst Dome)	Twp. 1, R.17W4M	Broad NW - plunging anticline.	About 10 km long.	About N40°W, plunge is to NW.	Post-Cretaceous	None	None	Meyboom (1960)
F-59 (Berry Field)	Twp. 26-27, R.13W4M	Anomalous sedimentary structure, area of local subsidence.	About 8 km long by 2 km wide.	Approximately NE-SW.	Upper Cretaceous or Tertiary.	None	Possibly a product of local salt dissolution from Devonian horizons.	Hopkins (1987)
F-60 (Suffield)	Twp. 18-22, R.6-10W4M	Faulting and juxtaposition of sandstone beds.	Roughly circular area about 40 km across.	Roughly circular.	Affects Lower Cretaceous Mannville Group.	None	Possibly related to salt dissolution, or more likely to uplift associated with the Sweetgrass-North Battleford Arch.	Tilley and Longstaffe (1984)
F-61	10-16-75-6W4M	Paleo-low, unrelated to salt solution.	Unknown.	Unknown.	Cretaceous	None	Abnormally thickened Cretaceous section, with no evidence of salt removal.	D. McPhee (Pers. Comm., 1994)
F-62	7-34-73-4W4M	Paleo-low, unrelated to salt solution.	Unknown.	Unknown.	Cretaceous	None	Abnormally thickened Cretaceous section, with no evidence of salt removal.	D. McPhee (Pers. Comm., 1994)
F-63	Sec. 17-18, Twp. 68, R.2W4M	Bedrock low, possibly related to salt solution collapse.	Unknown.	Unknown.	Cretaceous or younger?	None	No data.	R. Stein (Pers. Comm., 1994)

Anomaly # (General Area)	Location	GEOLOGICAL FEATURES						Source
		Nature of Anomaly	Approximate Size	Orientation	Relative Age or Horizons Affected	Associated Anomalies	Comments	
F-64	Sec. 4-5, Twp. 70, R.2W4M	Bedrock low, possibly related to salt solution collapse.	Unknown.	Unknown.	Cretaceous or younger?	None	No data.	R. Stein (Pers. Comm., 1994)
F-65	Sec. 3, Twp. 70, R.3W4M	Bedrock low, possibly related to salt solution collapse.	Unknown.	Unknown.	Cretaceous or younger?	None	No Data.	R. Stein (Pers. Comm., 1994)

In places, folds or faults or both have formed as a result of differential compaction, by dissolution of underlying salts in the Paleozoic evaporitic successions or by other mechanisms related to post-Laramide epeirogenesis. "*Large and small-scale Devonian salt dissolution features are a common phenomenon which occurred throughout the late Paleozoic to Tertiary. The effects of salt removal were to create topography prior to or contemporaneous with sedimentation, thus affecting depositional patterns. Salt solution may have postdated sedimentation causing the collapse of overlying sediments and creating structural-stratigraphic traps*" (Leckie 1989).

2.8.10 Igneous Activity

Plutonic and volcanic rocks are common in the exposed Precambrian of northeastern Alberta (Godfrey 1986, Goff *et al.* 1986). Large areas are underlain by pluton-size granitic and granitoid rocks. Langenberg *et al.* (1993), however, stated that "*field contact relationships and bulk compositions suggest that the migmatitic granitic gneisses and high-grade metasediments were parent materials for several of the granitoid rocks during the process of partial melting (Goff et al. 1986). Consequently, the granitoids may represent Archean basement remobilized during the Aphebian.*"

Mafic to, locally, more felsic intrusive and extrusive rocks are relatively common throughout the Paleozoic succession in the northern Cordillera in the Yukon and N.W.T., but are scarce in the miogeoclinal Paleozoic strata of the southeastern Cordillera in Alberta and British Columbia (Souther 1992). In Alberta, igneous intrusive or volcanic rocks are not common, but they do exist at several locales, including, for example: (a) those in the Proterozoic rocks of the Clark Range in southwest Alberta (Hunt 1962; Price 1962; Goble 1974a, b; Hoy 1989); (b) the metadiabase Crowfoot Dyke near Lake Louise (Smith 1963); (c) a metadiabase dyke that is reported to cut Cambrian rocks near Jasper (Charlesworth *et al.* 1967); (d) the late Early Cretaceous Crowsnest Formation volcanics near Coleman in southwest Alberta (Pearce 1970; Dingwell and Brearly 1985; Adair 1986; Peterson and Currie 1993); and (e) the early Tertiary Sweetgrass Intrusions in southern Alberta and northern Montana (Williams and Dyer 1930, Russell and Landes 1940, Irish 1971, Kjarsgaard 1994a, b; Kjarsgaard and Davis 1994). The various intrusions range in age from Middle Proterozoic to Tertiary (Folinsbee *et al.* 1957; Hunt 1962; Price 1962; Pell 1987a.

Igneous activity in the Clark Range of southwest Alberta is of at least three types and ages. The oldest is represented by Moyie-type diorite or diabase sills and dykes that have been dated as old as 1,580 Ma and as young as 1,400 Ma (Hunt 1962, Hoy 1989). The second type is the Purcell Lavas, which are andesitic in composition and form an excellent marker horizon throughout the Belt-Purcell Supergroup. Hunt (1962) suggested that the Purcell Lavas were extruded at about 1,100 Ma. The third type of igneous activity in the Clark Range is trachytic to syenitic alkalic intrusions that straddle the Alberta-British Columbia border near the headwaters of the Castle River (Price 1962; Goble 1974a, b). Price (1962) stated that these intrusions are likely of Cretaceous or Tertiary age.

The Crowsnest Formation comprises an assemblage of alkaline trachytic to phonlitic volcanic rocks that is restricted to the eastern part of the Fernie Basin in southwestern Alberta (Dingwell and Brearly 1985, Adair 1986, Peterson and Currie 1993). The Crowsnest volcanics range up to 425 m thick locally, and are interbedded with and grade laterally into sandstone and shale of the upper Blairmore Group. The volcanic rocks are mainly pyroclastic and epiclastic deposits, with rare flows and associated intrusive rocks. Folinsbee *et al.* (1957) obtained a K-Ar date of 96 Ma for the Crowsnest Formation, which is late Early Cretaceous (Albian).

In southeastern British Columbia, the Howell Creek alkalic intrusions cut Lower Cretaceous strata and have yielded K-Ar ages that range from 112 to 72 Ma (Gordy and Edwards 1962). Souther (1992) stated that the Howell Creek intrusions include syenite and trachyte that are chemically similar to, and may be co-magmatic with, the Crowsnest Volcanics. Several alkalic ultramafic diatremes and dykes have also been discovered north of the Southern Alberta Rift near the Alberta-British Columbia border between Golden and Elkford (Pell 1986, 1987a, b). Pell (1987b) reported ages of between 348 Ma and 396 Ma for the HP pipe, which is part of the Mark diatreme cluster that straddles the Alberta-British Columbia border (diatreme locality F-48 on Figure 2.5). The alkali ultrabasic diatreme breccias and dykes which exist in the Western and Main Ranges of the Rocky Mountains in southeastern British Columbia and, locally, in Alberta, intrude Upper Cambrian to Permian miogeoclinal rocks and were emplaced prior to Jurassic-Cretaceous deformation. "*At least one of these diatremes is a true kimberlite*" (Souther 1992).

Other than the minettes of the Eocene Sweetgrass Intrusions, the other Phanerozoic volcanic rocks in the Alberta Interior Plains comprise tuffs or tuffaceous beds, or their bentonitized equivalents, which exist in the Lower Exshaw Formation (Folinsbee and Baadsgard 1958; Packard *et al.* 1991; Meijer Drees and Johnston 1993; Richards *et al.* 1993) and in Cretaceous to Tertiary strata (Ower 1960; Ritchie 1960; Lerbekmo 1963; Binda 1969; Amajor and Lerbekmo 1980; Amajor 1977, 1980, 1985). The best known of these is the Kneehills Tuff marker horizon in Late Cretaceous Edmonton Group (Ower 1960, Ritchie 1960; Binda 1969). Most of the tuff horizons are thin, typically being a few centimetres to a tens of centimetres thick, but locally they are reported to reach thicknesses of up to 10 m or more (Scafe 1975). Although most of the tuffs probably represent wind-blown volcanic debris from distal sources, it is possible that some of the tuffs may be derived locally from volcanic or diatreme activity which occurred within the Western Canada Sedimentary Basin.

2.8.11 Metamorphism and Metasomatism

In the Precambrian rocks of northeastern Alberta, Langenberg and Nielsen (1982) stated that there are "*two distinct cycles of metamorphism. During the Archean metamorphic cycle, metasediments were metamorphosed under high pressure granulite conditions (M1). In a second cycle, probably related to remobilization during the Aphebian, the* *metasediments were subjected to conditions of granulite-amphibolite transitional facies retrogressing to greenschist facies metamorphism."*

Elsewhere in the exposed rocks in Alberta, however, metamorphic conditions are low-grade. "*Except for metamorphic culminations in ... a local area east of the Southern Rocky Mountain Trench most of the regional metamorphism in the Foreland Belt is of low-grade burial type. Precambrian rocks are commonly in greenschist facies, Paleozoic and some Mesozoic strata are mainly in prehnite-pumpellyite facies, and most Mesozoic strata are in zeolite facies. ... In the western part of the Foreland Belt, regional metamorphism appears to be stratigraphically controlled and related to depth of burial; pelitic rocks typically have a slaty cleavage. Precambrian rocks generally reach chlorite or biotite zones. ... Locally, Cretaceous and lower Tertiary sediments in the Alberta Syncline contain zeolites. Heulandite-clinoptilolite cements some sandstones of the Paskapoo and Bearpaw formations and Wapiti Group to as far north as 55°N. ... Most Cretaceous and lower Tertiary sediments of the Alberta Syncline have carbonate, illite, montmorillonite, chlorite, and interstratified clay minerals (typical of but not diagnostic of the zeolite facies), and coal ranks ranging from sub-bituminous C to high volatile bituminous B (well within the range of zeolite facies rocks)*" (Greenwood *et al.* 1992).

The western Canada sedimentary basin is unusual in that it contains a large number of extensively dolomitized carbonates. Dolomitization is widespread in the Paleozoic carbonate rocks of Alberta, and particularly within the Cambrian to Devonian carbonate formations, with most of this dolomitization probably being of post-diagenetic origin (Douglas *et al.* 1970). Some examples of dolomite occurrence in the Alberta basin are: (a) the dolomite belt that is present at the western margin of the Cooking Lake platform in east-central Alberta (Andrichuk 1958); (b) the Leduc buildups of the Rimbey-Meadowbrook trend in central Alberta (Machel and Mountjoy 1987) and the Leduc platform in the Peace River Arch region (Dix 1993); (c) the Nisku buildups of central Alberta (Machel and Anderson 1989); and (d) the linear dolomite trend that is present within the Wabamun Formation in the Peace River Arch region (Stokes 1987; Workum 1991).

Dolomitization patterns may be a product of fluid movement along fault systems. However, they also may reflect fluid-driving mechanisms such as basin compaction flow and meteoric input, and be a function of the chemical variability of underlying strata which supply the source of magnesium. Therefore, dolomitization patterns, particularly over wide areas, may indicate relatively uniform basin-wide controls on dolomite emplacement and bear little relation to local tectonic influences.

Dawson (1886) reported extensive marblization and dolomitization in southwest Alberta, and Hitchon (1993) concluded that "*the extensive dolomitization found in the Devonian of the Alberta Basin may be relatively rare in a platform-type setting such as is found in western Canada. It might be more than coincidence that many of the strongly dolomitized trends seem related to underlying basement structures.*" Recent work by Nesbitt and

Muehlenbachs (1993a, b) has documented extensive pre-thrusting, likely Late Devonian, fluid flow leading to the formation of massive epigenetic to replacement dolomites with local deposition of base metals, magnesite and talc in southeastern British Columbia and the Rocky Mountains and Foothills of Alberta. This fluid event (Event 1) is characterized by a west to east flow of saline (20 to 25% equivalent weight % NaCl) fluids with a minimum temperature of 150°C to 200°C and high concentrations of Mg and Ca.

3. OCCURRENCES OF KIMBERLITES, LAMPROITES AND OTHER RELATED ALKALINE IGNEOUS AND VOLCANIC ROCKS

3.1 Introduction

The geographic and temporal distribution of kimberlites and lamproites worldwide has been extensively reviewed by Dawson (1980 1989), Janse (1984), Bergman (1987), Helmstaedt (1993), and Mitchell and Bergman (1991). Kimberlites and lamproites occur on all major continents and span an age range from Lower Proterozoic to Recent (Table 3.1). Although kimberlites and lamproites are not restricted to Precambrian cratons, diamondiferous varieties of these rock types predominantly are. Kimberlites with economic concentrations of diamonds, regardless of their age, occur almost exclusively on Archean cratons. This was first pointed out by Clifford (1966; 1970) and has since been referred to as Clifford's Rule (Janse 1991). The Argyle lamproite of Western Australia contains the only known economic deposit of diamonds in a primary rock type other than kimberlite in the world. The Argyle lamproite is hosted in a Lower Proterozoic mobile belt that is accreted to the Archean Kimberly Block and, as such, represents the only primary economic deposit of diamonds that exists on a Proterozoic craton. The diamondiferous lamproites of Western Australia are reviewed in detail by Jaques *et al.* (1984b, 1986).

To date, no definite occurrences of kimberlites or lamproites have been reported in Alberta. The potential existence and age of such rock types in Alberta are discussed in the following section by reviewing known occurrences of these rock types in the vicinity of Alberta and by examining the evidence for volcanic activity within Alberta.

3.2 Kimberlites And Lamproites In Western And Northern Canada, And The Adjacent United States Of America

Although kimberlite and lamproite magmatism has occurred throughout almost every time period around the world (Table 3.1), certain periods have been more favourable for the emplacement of diamondiferous varieties of these rocks. These periods are: (a) Late Middle Helikian, represented by the Premier kimberlite of South Africa and the Argyle lamproite of Western Australia; (b) Late Devonian to Mississippian, represented by many of the Yakutian pipes on the Siberian Platform, such as Mir and Internationalnaya; (c) Middle Jurassic to Late Cretaceous, represented by most of the famous South African diamond producers, such as Klipfontein, Swartruggens, Finsch, New Elands, Roberts Victor, Bellsbank, Frank Smith, DeBeers, Wesselton, Koffiefontein, Orapa and Jagersfontein; and (d) Late Cretaceous to Early Tertiary, represented by Mwadui in Tanzania and the Dia Met/BHP Utah pipes in the Lac de Gras region, N.W.T. (Tables 3.1 and 3.2). Dawson (1989) suggested that the Middle Jurassic to Middle Cretaceous activity was the most prolific period of kimberlite magmatism in the world.

Most of the important worldwide ages for kimberlite or lamproite magmatic events are represented on the continent of North America, and, in some instances, diatremes occur very near to Alberta (Figure 3.1 and Table 3.1). For example, diamondiferous kimberlites, lamproites or related ultramafic lamprophyres of a variety of ages exist in close proximity to Alberta, in the Northwest Territories, British Columbia, Saskatchewan and Montana (Olson *et al.* 1994).

The Aphebian Christopher Island Formation of the Dubawnt Lake area, N.W.T. represents one of the largest lamproitic magmatic provinces in the world (Peterson 1993). Recently, a microdiamond was discovered in a lamproite diatreme from the Dubawnt Lake area (George Cross Newsletter 1993) and in a lamproite dyke near Baker (Armitage *et al.* 1994). Other mafic to ultramafic Proterozoic magmatic rocks exist in the vicinity of Alberta, such as southeast of Great Slave Lake near Rutledge Lake, N.W.T. (Barlet and Trigg 1986), and the Moyie sills and Purcell lavas in southeastern British Columbia. These latter rocks, however, are not potassic and exhibit few compositional similarities to kimberlites, lamproites or other potassic-rich mafic to ultramafic rocks such as ultramafic lamprophyres.

Paleozoic diatreme breccias, dykes, sills and stocks that predate Columbian compressional deformation in the Canadian Cordillera exist in the Rocky Mountains of British Columbia between Williston Lake and Cranbrook (Figure 2.5). They form a complex suite of rocks comprised of carbonatites, nepheline and sodalite syenites, some ijolite series rocks, numerous ultramafic and lamprophyric diatreme breccias and associated dykes, and one kimberlite diatreme (Pell 1987a, b). Dating of these intrusions by many workers has been summarized by Pell (1987a, b), who stated that there are at least three discreet periods of Paleozoic alkaline mafic to ultramafic magmatic activity in British Columbia. These are: Ordovician-Silurian, Late Devonian-Mississippian and Permian-Triassic. The Mark and Jack diatreme clusters, which exist north of Golden, British Columbia, are believed to be part of the Devonian-Mississippian group of intrusions based on age dates from the HP pipe (Table 3.1), which exists near the Mark diatreme cluster (Pell 1987b). The Mark diatreme cluster straddles the Alberta-British Columbia border and contains some of the largest diatremes in the Canadian Cordillera, such as the Mark 1 diatreme, which has a surface areal extent of about 250 m by 1,200 m (Fipke 1990). The Mark 1 diatreme extends well across the border into Alberta (Fipke 1990). Bulk samples of the Jack and Mark diatremes, and of nearby stream sediments contain lamproitic indicator minerals, including a few microdiamonds (Northcote 1983a, b; Dummett *et al.* 1985; Fipke 1990). Pell (1987a, b), and Ijewliw and Schulze (1988)

TABLE 3.1 AGES OF KIMBERLITE AND LAMPROITE INTRUSIONS

PERIOD	Series	Stage	Kimberlites World Wide	Lamproites World Wide	Kimberlites North America	Lamproites & Ultramafic Lamprophyres North America	Alberta Volcanic Events
QUATERNARY		Holocene 0.01		Gaussberg, ANT (Recent)			
		Pleistocene 1.6				Leucite Hills, WY (1-2)	
TERTIARY		Pliocene 6		Mercia & Almeira, SP (6-8)			
		Miocene 24		Kef Hahouner, AG (9-11) **Noonkanbah (18-20) & Ellendale (20-25), AL**	Buell Park, AZ & Green Knobs, NM(25	Navajo Volcanic Field, UT & AZ (UML's 20-30)	
		Oligocene 37			Mule Ear & Moses Rock, UT (28-30)	Smoky Butte, MT (27)	
		Eocene 58	**Mwadui, TZ(41)** Nzega, TZ (51-54)		Williams, MT (47-52) **Lac de Gras, NT (52)**	Kamas & Moon Canyon, UT (40) Bearpaw Mountains, MT (50-54)	Sweetgrass Intrusions (48)
		Paleocene 66	Mukorob, NB (61), Deutsche Erde NB (66)				Kneehills Tuff (66)
CRETACEOUS	Upper	Maastrichtian 75	**Mbuji-Mayi, ZA (71)**				Belly River Bentonites (75)
		Campanian 84	**M1, BT (77), Bultfontein, SA (78-84), Dutoitspan, SA (84)**		Isom Creek, Elliot Co., KY (80)		
		Santonian 88	**Jagersfontein, SA (86)**		**Somerset Island, NT (88-105)**	Rose & Hills Pond, KN (88-91)	
		Coniacian 89					
		Turonian 91	**DeBeers, SA (90), Wesselton, SA (90)** **Koffiefontein, SA (90), Monastery, SA (90)**				
		Cenomanian 98	**Koidu, SL (92), Orapa, BT (93), Finsch, SA (94), Kimberly Pool, SA (95)**		**Fort a la Corne, SK (94-96)**	**Ile Bizard, QU (UML? 96-115)**	Crowsnest Volcanics (96)
	Lower	Albian 113	Uintjes Berg, SA (100)		Riley County, KN (110)	**Prairie Creek, AK (106)**	Viking Bentonites (100)
		Aptian 119	**Newlands (114), Frank Smith (114), Mayeng (117) all SA**				
		Barremian 124	**Bellsbank (119), Finsch (119), Star (124) all SA**	Lomam, CIS (119-124)			
		Hauterivian 131	New Elands, SA (126) **Roberts Victor, SA (128)**				
		Valanginian 138	Obnazhennaya, CIS (135-143)	Murun (132-138), Kayla (133) & Ryabinovaya (137-142) all CIS			
		Berriasian 144		Yakokut, CIS (142-147)	Ithaca, NY (139-146)		
JURASSIC	Upper		**Swartruggens, SA (156), Mzongwana, SA (152)** Slyudyanka (147), Irina (149), Muza & Tokur (151), Marichka (156), Khrizolitovaya (159) all CIS		**Kirkland Lake, ON (151-160)**	James Bay, ON (UML 152)	
	Middle		**Klipfontein, SA (159), Wandagee, AL (160), Orroroo, AL (170)** Elandskloof, SA (165-176),				
	Lower	208	Pyramidefjeld, GL (193) **Dokolwayo, SZ (204)**		**Lake Ellen, MC (190)**	James Bay, ON (UML 180)	
TRIASSIC	Upper		Pozdnyaya, CIS (217), Nigerdlikasik, GL (220)	**Kapamba, ZM (220?)**			
	Middle						
	Lower	245	**Jwaneng, BT (235)**		Cross Diatreme, BC (240-244)		
PERMIAN	Upper						
	Lower	286					

PENNSYLVANIAN	Upper		295		Pendennis Point, UK (280-320?)			
	Middle		310					
	Lower		320					
MISSISSIPPIAN	Upper			**Sytykanskaya, CIS (344)** Rassvet (344), Svetlaya (344) & Kollektivnaya (347) all CIS			Ospika River, BC (UML 323-334)	
	Lower		360	Festivalnaya, CIS (358) **Internationalnaya, CIS (360)**		**Sloan, CO (350)**	HP Pipe, BC (UML 348-396)	
DEVONIAN	Upper	Famennian	367	**Mir, CIS (361), Fuxian, CH (366-398)** Iskorka, CIS (363)				Exshaw tuffs
		Frasnian	374	Zagadochnaya, CIS (370), Svetlaya, CIS (372)			Elbow Diatreme, SK (Comp. unknown)	
	Middle	Givetian	380			Avon, MI (377-399)		
		Eifelian	387					
	Lower	Emsian	401			**Kelsey Lake, CO (390)**		
		Siegenian		Tayezhnaya, CIS (403)				
		Gedinnian	408					
SILURIAN			438	Druhza, CIS (412)	Mt. Bayliss, ANT (413-430)		**Mountain Diatreme, NT (UML? 427-445)** Russell Peak, BC (UML 435-440)	
ORDOVICIAN	Upper			Amakinskaya, CIS (450), Muna Field, CIS (450)				
	Middle							
	Lower		505	**Shengli, CH (482-498)**				
CAMBRIAN	Upper		515					
	Middle		540					
	Lower		570					
PROTEROZOIC	Upper	Hadrynian	955	**Venetia, SA (600)** Holsteinsborg (587), Umivit (589) & Sarfartoq (593-598) all GL Skerring, AL (810), Pteropus Ck, AL (810), Lattavaram, IN (940-1023)		**George Creek, CO (600)**		
	Middle	Helikian	1,735	**Majhgawan, IN (1,056-1,140)** **Premier, SA (1,202)** Zero (1,635), Elston (1,674) & Bathlaros (1,649) all SA	**Argyle, AL (1,178), Bobi, IC (1,400)** Yinnigou, CH (1,100-1,200), Chelima, IN (1,200) Holsteinborg, GL (1,214-1,227)			Purcell Lavas (1,100) Moyie dykes (1,400-1,580)
	Lower	Aphebian	2,480				**Outlet Bay & Gibson Lk, NT** Christopher Island Fm, NT (1,840)	
ARCHEAN								

AG=Algeria, AK=Arkansas, AL=Australia, ANT=Antarctica, AZ=Arizona, BC=British Columbia, BT=Botswana, CH=China, CIS=Former USSR, CO=Colorado, GL=Greenland, IC=Ivory Coast, IN=India, KN=Kansas, KY=Kentucky, MC=Michigan, MI=Missouri, MT=Montana, NB=Namibia, NM=NewMexico, NT=NorthwestTerritories, NY=NewYork, ON=Ontario, QU=Quebec, SA=SouthAfrica, SK=Saskatchewan, SP=Spain, SZ=Swaziland, TZ=Tanzania, UK=England, UT=Utah, WY=Wyoming, ZA=Zaire, ZM=Zambia, BOLD=Diamondiferous, HIGHLIGHTED INTERVAL=Most Prospective Age Interval To Discover DIAMONDIFEROUS Intrusions In Alberta

Note: Sources of Worldwide and North American data are denoted in the reference list with an Asterisk. Sources for Alberta volcanic events are discussed and identified in the text.

suggested that the diatremes are alkalic, ultramafic lamprophyres and not kimberlites or lamproites. Fipke (1990), however, suggested that the main Jack pipe is a lamproite and that the Mark 1 diatreme is lamproitic based on mineralogy and whole rock chemistry. The Cross kimberlite, which crops out near the Alberta border about 8 km northwest of Elkford, British Columbia (diatreme F-52 on Figure 2.5), is the only recognized occurrence of kimberlite in the Canadian Rocky Mountains (Grieve 1982; Hall *et al.* 1989). The Cross kimberlite is of Permian-Triassic age and has been reported not to contain diamonds (Grieve 1982; Pell 1987a, b; Hall et al. 1989). The Colorado-Wyoming State Line District kimberlite field contains the only other known Paleozoic kimberlites in western North America. The Kelsey Lake kimberlite and the Sloan kimberlite, both of which are diamondiferous, are well studied examples from this field (Shaver 1988; Otter and Gamey 1989; Coopersmith 1991, 1993a, b). Interestingly, in Eurasia in the former U.S.S.R., most of the economic and prolific diamond producing kimberlites of the East Siberian platform, such as Mir, Internationalnaya and Udachnaya, are Late Devonian to Early Mississippian in age (Davis *et al.* 1982; Milanovskiy and Mal'kov 1982; Jerde *et al.* 1993).

TABLE 3.2: Main ages of diamondiferous intrusive events, world wide

PERIOD	AGE RANGE (Ma)	EXAMPLES
Early Tertiary	35 - 60	Mwadui, Tanzania; some pipes in the Lac de Gras region, N.W.T.
Late Cretaceous to Middle Jurassic	80 - 170	Finsch, De Beers and numerous other famous southern Africa diamond producers
Mississippian to Late Devonian	340 - 370	Mir and other diamond producing pipes in Yakutia on the Siberian Platform
Late Middle Helikian	1,100 - 1,200	Premier, South Africa; Argyle lamproite, Western Australia

Paleozoic diatremes of unknown composition are believed to have been intersected in three oil wells in Saskatchewan (Gent 1992). For example, Upper Devonian carbonate breccias that contain one or more of olivine, eclogitic pyrope garnet, chromite, phogopite, zircon and shocked quartz were intersected by Imperial Elbow No. 1, Birsay Crown No. 1 and Imperial Barnes wells (Gent 1992). The Imperial Elbow No. 1 and Birsay Crown No. 1 diatremes exist in south-central Saskatchewan near the town of Elbow. The Imperial Barnes diatreme exists northwest of Meadow Lake, in northwest Saskatchewan about 100 km east of the Alberta border. The diatremes exist in structures that have all the appearances of being related to salt solution, but in fact may be the result of post emplacement collapse of the diatremes. Unusual and perhaps "out of place" salt solution structures in Alberta should be evaluated for potential diamondiferous kimberlite diatremes.

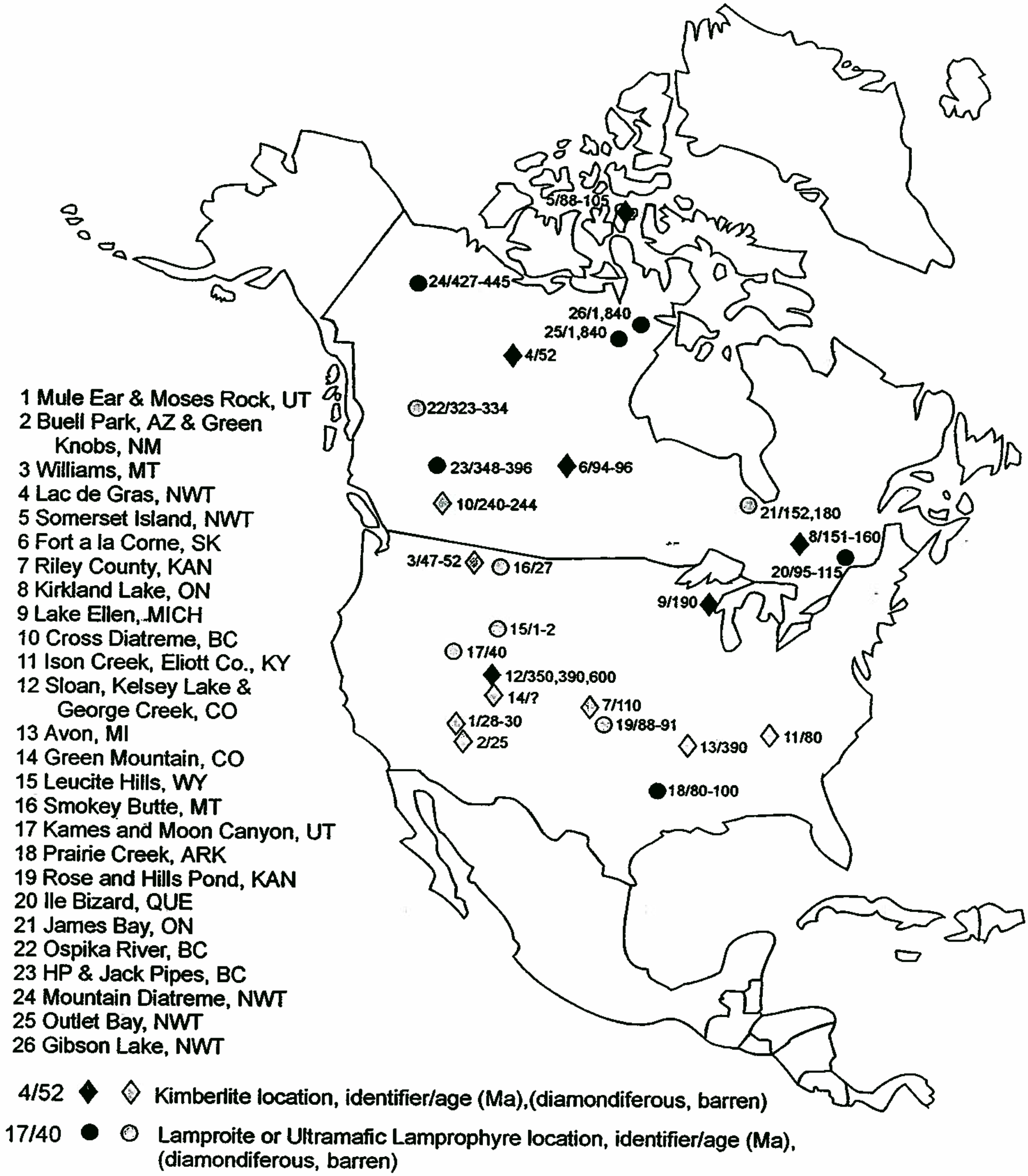


Figure 3.1: Location and Age of North American Kimberlites, Lamproites and Ultramafic Lamprophyres.

Middle Jurassic to Middle Cretaceous was perhaps the most extensive and voluminous period of diamondiferous kimberlite magmatism in the world (Dawson 1989). Diamondiferous kimberlites of Middle and Late Jurassic age have been recognized at Lake Ellen, Michigan, (Jarvis and Kalliokoski 1992; Duskin and Jarvis 1993) and at Kirkland Lake, Ontario (Brummer 1978, 1984; Fipke 1990). Few, if any, kimberlites, lamproites or ultramafic lamprophyres of Early Cretaceous age have been documented in North America to date. However, more significant to the Alberta setting is the discovery of Middle Cretaceous aged diamondiferous kimberlites on Somerset Island, N.W.T. (Fipke 1990; Kjarsgaard 1993; Pell and Aitkinson 1993) and at Fort à la Corne, Saskatchewan (Lehnert-Thiel *et al.* 1992). In addition, Middle Cretaceous diamondiferous lamproites have been discovered at Prairie Creek, Arkansas (Gogineni *et al.* 1978; Scott Smith and Skinner 1984; Fipke 1990) and Twin Knobs, Arkansas (Waldman *et al.* 1987). At Fort à la Corne, three clusters that contain up to seventy kimberlitic bodies have been identified by airborne or ground geophysics (Lehnert-Thiel *et al.* 1992). Eighteen kimberlites that range in age from 94 to 96 Ma have been positively identified by drilling. A total of 160 diamonds were recovered from 186 tonnes of material processed from an unknown number of the drilled kimberlites (Lehnert-Thiel *et al.* 1992). One of the more significant aspects of the Fort à la Corne kimberlites is the fact that they are mostly flat to mushroom shaped in cross-section, with a large bedded volcaniclastic to pyroclastic component. Lehnert-Thiel *et al.* (1992) reported that no feeder diatremes have been identified to date. This indicates that the diatreme and root zone facies of the pipes are likely to be insignificant in terms of volume, even if found in future work. The likely reason for this is the emplacement of the kimberlites into a continental marine environment. Therefore, it is reasonable to assume that any Middle Cretaceous kimberlite magmatic activity in Alberta is likely to have formed rootless, flat to mushroom shaped kimberlites similar to those near Fort à la Corne, Saskatchewan.

Early to Middle Tertiary kimberlites and lamproites have been discovered in the western United States of America in New Mexico, Utah, Montana and in the Lac de Gras region, N.W.T (Figure 3.1, Table 3.1). Although the Mwadui kimberlite in Tanzania is the only known early Tertiary producer of diamonds, there are indications that several of the Tertiary kimberlite pipes in the Lac de Gras region have near economic concentrations of gem quality diamonds and at least four of the pipes are currently being bulk sampled in order to test their grades and the quality of the contained diamonds prior to full scale feasibility studies. Eocene, subaerially extruded kimberlites and lamproites exist in central to northwestern Montana. Hence, in Alberta any Eocene kimberlites or lamproites are likely to have been subaerially extruded and therefore should have formed pipes with shape more typical of kimberlite or lamproite magmatism.

3.3 Igneous And Volcanic Rocks In Alberta Potentially Related to Diamondiferous Alkaline Volcanism

There is evidence of at least four, and possibly five, ages of volcanic activity in Alberta, some of which may be related to possible diamondiferous kimberlites or lamproites (Olson *et al.* 1994). The ages of volcanic activity are: Helikian, Late Devonian to Early Mississippian, Middle Cretaceous, Late Cretaceous and Early Tertiary. Alkaline mafic volcanic activity has been evident in Alberta during at least three of these episodes (Table 3.1).

The oldest generation of volcanic activity is represented by the Helikian Moyie Sills and Purcell Lavas which are restricted to the Clark Range in southwest Alberta (Hunt 1962; Hoy 1989). The composition of the Helikian dioritic Moyie Sills and the andesitic Purcell Lavas differs significantly from the potassic, mafic to ultramafic compositional fields of kimberlites and lamproites, which are the most common primary host rocks for economic concentrations of diamonds.

The second oldest generation of volcanic activity, consists of Upper Devonian to Lower Mississippian alkaline, mafic to ultramafic diatreme breccias, dykes and sills that are spatially and temporally related to the cluster of diatremes in southeast British Columbia (F-45 to F-49 in Figure 2.5). Specifically, the Mark diatreme cluster straddles the Alberta-British Columbia border and a few dykes within the Mark cluster exist on the Alberta side of the border (Fipke 1990; Pell 1987a, b). Other evidence of Late Devonian to Early Mississippian volcanic activity includes a massive marine extinction and an iridium anomaly (Wang *et al.* 1993) associated with volcanic tuffs that have been identified in the Lower Exshaw Formation at the type section at Jura Creek near Exshaw (Richards *et al.* 1993). Other volcanic tuffs also have been identified in the Exshaw shale near Nordegg (Folinsbee and Baadsgard 1958), and in oil wells in the Peace River area (Packard *et al.* 1991; Meijer-Drees and Johnston 1993).

The third generation of volcanic activity in Alberta is represented by the Middle Cretaceous Viking Formation bentonites and the Crowsnest Formation volcanics. At least three regionally correlatable bentonites that are used as marker horizons across a large portion of Alberta have been identified within the Viking Formation (Amajor and Lerbekmo 1980; Amajor 1985). These bentonites exist just below the Fish Scales marker horizon and have an average radiometric age of 100 Ma (Tizzard and Lerbekmo 1975). Bentonites with a much more local distribution have also been identified in the Viking Formation (Tizzard and Lerbekmo 1975; Amajor and Lerbekmo 1980). As well, Carrigy (1968) reported the presence of numerous thin tuff layers interbedded with undisturbed Lower Cretaceous shales in the oil well I.O.E. Steen 16-19.

The Crowsnest Formation volcanics are restricted to southwest Alberta in the vicinity of Coleman. The volcanics are sodic-rich trachytes to phonolites and do not appear to have a chemistry that is favourable for diamonds (Peterson and Currie 1993). However, the reported age for the Crowsnest volcanics is 96 Ma (Folinsbee *et al.* 1957), which corresponds closely to the reported age of 94 to 96 Ma for several diamondiferous kimberlites in the Fort à la Corne area of Saskatchewan (Gent 1992; Lehnert-Thiel *et al.* 1992). These dates for the Crowsnest volcanics indicate that alkaline volcanism was occurring in the Alberta Rocky Mountains and Foothills at the same time as diamonds were being transported from the upper mantle to the surface during the Middle Cretaceous in Saskatchewan, Quebec, Arkansas and across much of southern Africa. As a result, Middle Cretaceous continental marine sedimentary rocks, such as those in the Viking Formation, may be a potential host to diamondiferous bedded kimberlite or lamproite volcaniclastics or crater facies sediments.

Bentonites in the Belly River Formation and in the Kneehills Tuff Zone within the Edmonton Formation, both of which are late Late Cretaceous in age, represent the fourth distinct generation of volcanic activity in Alberta. The Kneehills Tuff Zone is widespread and can be identified across much of the southern half of Alberta (Ower 1960). Evidence for alkaline diatreme activity during this time period also exists at Somerset Island, N.W.T. and in Kentucky and Kansas, but none of these locales contain potentially important diamond deposits (Table 3.1).

The youngest generation of magmatic activity in Alberta is represented by the Tertiary Sweetgrass Intrusions in southeast Alberta (Williams and Dyer 1930; Irish 1968). Price (1962) suggested that the trachytic to syenitic stocks and dykes, which straddle the Alberta-British Columbia border in the Clark Range in southwest Alberta, are also early Tertiary in age. However, the chemistry of these intrusions indicates they may have a closer affiliation with the magmatic event responsible for the Crowsnest Formation volcanics. The Sweetgrass Intrusions are alkalic minette intrusions that have been dated at 48 Ma to 54 Ma or Eocene (Folinsbee *et al.* 1965; Taylor *et al.* 1964; Kjarsgaard and Davis 1994). Kjarsgaard (1994a, b), from fieldwork and laboratory studies, suggested that the intrusions are mostly minettes with low diamond potential based on their overall geochemistry and the contained indicator minerals. However, kimberlites of a similar age do exist in the Missouri Breaks area of central Montana (Hearn 1989) and in the Lac de Gras region, N.W.T. (Table 3.1). Initial indications are that some of the Lac de Gras kimberlites contain near economic concentrations of gem quality diamonds.

4. TUFFS, BENTONITES AND VOLCANICS IN THE PHANEROZOIC SUCCESSION

4.1 Introduction

Current theory on the formation of diamond bearing diatremes recognizes the development of several facies within the uppermost part of the pipe. Specifically, a vertical to steeply dipping pipe-shaped core of diatreme breccia facies intrudes increasingly younger stratigraphy upwards from the diatreme root zone. The pipe, upon reaching the earth's surface, establishes a ring-shaped pyroclastic crater facies about the epiclastic core (Mitchell, 1991). Included within these pyroclastics, as well as distal from the vent, are successive overlapping tuff layers and interbeds (Garnett 1994, who cites the Orapa deposit in Botswana as an example). From an exploration point of view, these tuff deposits provide a relatively large target if they are preserved from erosional processes. If, for example, the eruptive event occurs in a subaqueous environment in a depositional basin, then the pipe, including its uppermost vent facies, may be preserved. Deep burial and subsequent diagenesis will alter some of the vent facies rocks, including the tuffs.

'Bentonite' is defined as a clay formed from the devitrification and alteration of volcanic ash or tuff and is largely composed of clay minerals of the montmorillonite group plus colloidal silica (Bates and Jackson 1987). Thus, it is likely that alteration of the preserved diatreme tuff horizons would produce thick apron to elongate domal shaped bentonites having a geochemistry indicative of the original ash deposits.

One aspect of this diamond study of Alberta is to investigate the role bentonites can play in diamond exploration. Following are some of the aspects considered in the present study:

(1) Examine the regional character of selected anomalously thick bentonites in Alberta which have been reported in the literature.

(2) Interrogate existing government databases and published literature for anomalous occurrences of tuff, volcanics and bentonites (for example, chemistry, thickness and geological associations).

(3) Provide guidelines in the use of bentonites as a diamond exploration tool.

Figure 4.1 and Appendix 4.1 identify the localities in Alberta having anomalously thick occurrences of bentonite, as cited in various publications. Several of these localities were selected for a more detailed investigation in this study. They include the bentonite occurrences in the Drumheller area, the Bickerdike and Rosalind area showings, and the localities in the Irvine-Bullshead area (Figure 4.2). Also included in this study is an appraisal of subsurface information on bentonites in the Duagh area near Edmonton.

4.2 Volcanism and Bentonites in Alberta

Within Alberta, recognized products of volcanic activity are restricted to the Moyie dykes and Purcell lavas (Middle Proterozoic), the Exshaw Formation bentonites (Late Devonian-Early Mississippian), the Viking Formation bentonites (late Early Cretaceous), the Colorado Group bentonites (mid to Late Cretaceous), Crowsnest Formation volcanics (late Early Cretaceous), Belly River Group bentonites (late Late Cretaceous), Horseshoe Canyon Formation bentonites (late Late Cretaceous), Kneehills Tuff (late Late Cretaceous) and the Sweetgrass Intrusions (Eocene) (Figure 4.3).

The Proterozoic lavas and sills are restricted to the Clark Range of southwest Alberta and are compositionally very different from kimberlites and offer little incentive for diamond exploration potential.

Little information is available on the source volcanism for the thin volcanic tuffs identified in the Devonian-Missisippian Exshaw Formation lower shale in the Peace River Arch area (Bloy and Hadley 1989). However, beds and laminae of marine tuff up to 1.5 m thick are present in the Exshaw shale at many localities from southwestern Alberta into east-central British Columbia (Richards *et al.* 1993). These authors consider volcanism to have taken place in the western Prophet Trough and westward of this.

The Viking Formation bentonites are considered isochronous and genetically related to the Crowsnest volcanics (98 Ma) and the bentonitic Vaughn Member of the Blackleaf Formation of Montana (Amajor 1985). Amajor (*Ibid*) determined that within each bentonite bed, biotite grain size decreased in a northeasterly direction away from the volcanic source. Up to eight bentonite beds have been recognized, with thicknesses ranging from 5 cm to 60 cm. The bentonites are rich in biotite grains and are considered regional ash fall products that were deposited distally in marine waters. The observed variation in thicknesses has been attributed to later reworking by current and wave action. In studying the late Early Cretaceous Viking Formation, Amajor and Lerbekmo (1980) used three of these bentonite beds to subdivide the formation and each layer could be differentiated by its chemical signature using ternary XRF plots.

Overlying the Viking Formation is the Colorado Group of Albian to Santonian age. Within this Group are three very distinctive formations that span the time frame from 92 Ma to 99 Ma. Within the time interval from 97 Ma to 99 Ma is a regional marker unit known as the Fish Scale Formation (Figures 4.4 and 4.5). This formation is characterized by high total organic carbon content (average is 3.2%, and range is 1.8 % to 8.0%), phosphatic bioclastic debris, fish remains and algal cysts, numerous bentonites with some containing biotite and feldspar (sanidine?) grains, black phosphatic beds and a pronounced increase in gamma response on the geophysical log (Bloch *et al.* 1993). Conformably overlying these series of bentonitic claystones and mudstones is the Belle Fourche Formation (93-97 Ma) which is correlative with the Belle Fourche Member of the Ashville Formation of Manitoba. The geophysical log signature of the Belle Fourche Formation is characterized by an abrupt decrease in sonic transit time and formation density while the gamma ray response declines upsection (Bloch *et al.* 1993). This formation is a westward thickening wedge of non-calcareous to slightly calcareous mudstones and siltstones. The contact with the underlying Fish Scales Formation is transitional and may be difficult to discern without determination of organic matter type and abundance. Both formations are notable for their rarity or lack of foraminifera. It is particularly significant that it is at this general stratigraphic horizon that explorationists have discovered diamond bearing kimberlite diatremes (94-96 Ma) in the Fort à la Corne area of Saskatchewan (Lehnert-Thiel *et al.* 1992; Garnett 1994). In the Fort à la Corne area, a reworked horizon containing enriched concentrations of diamonds, ilmenites, chrome diopsides and other heavy minerals overlies kimberlitic breccia, ejecta and tuffaceous kimberlite. Aprons of waterlain bedded tuffs can be recognized as a connective interlayered pyroclastic facies between adjacent kimberlite pipes. These marine tuffs are underlain and overlain by black shale and mudstone (Garnett 1994). Overlying the Belle Fourche is the Second White Speckled

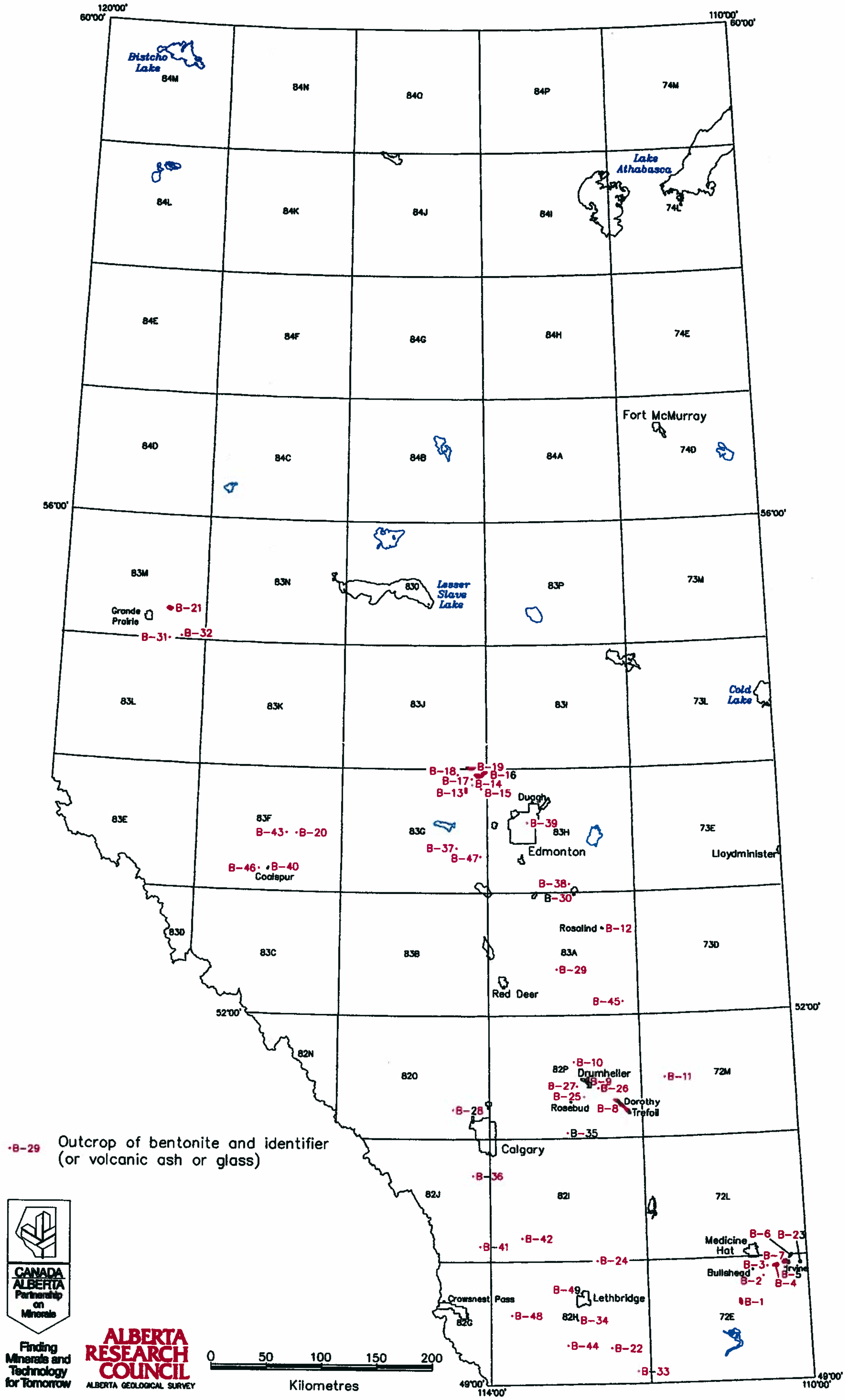


Figure 4.1: Location of bentonite occurrences in Alberta (refer to Appendix 4.1).

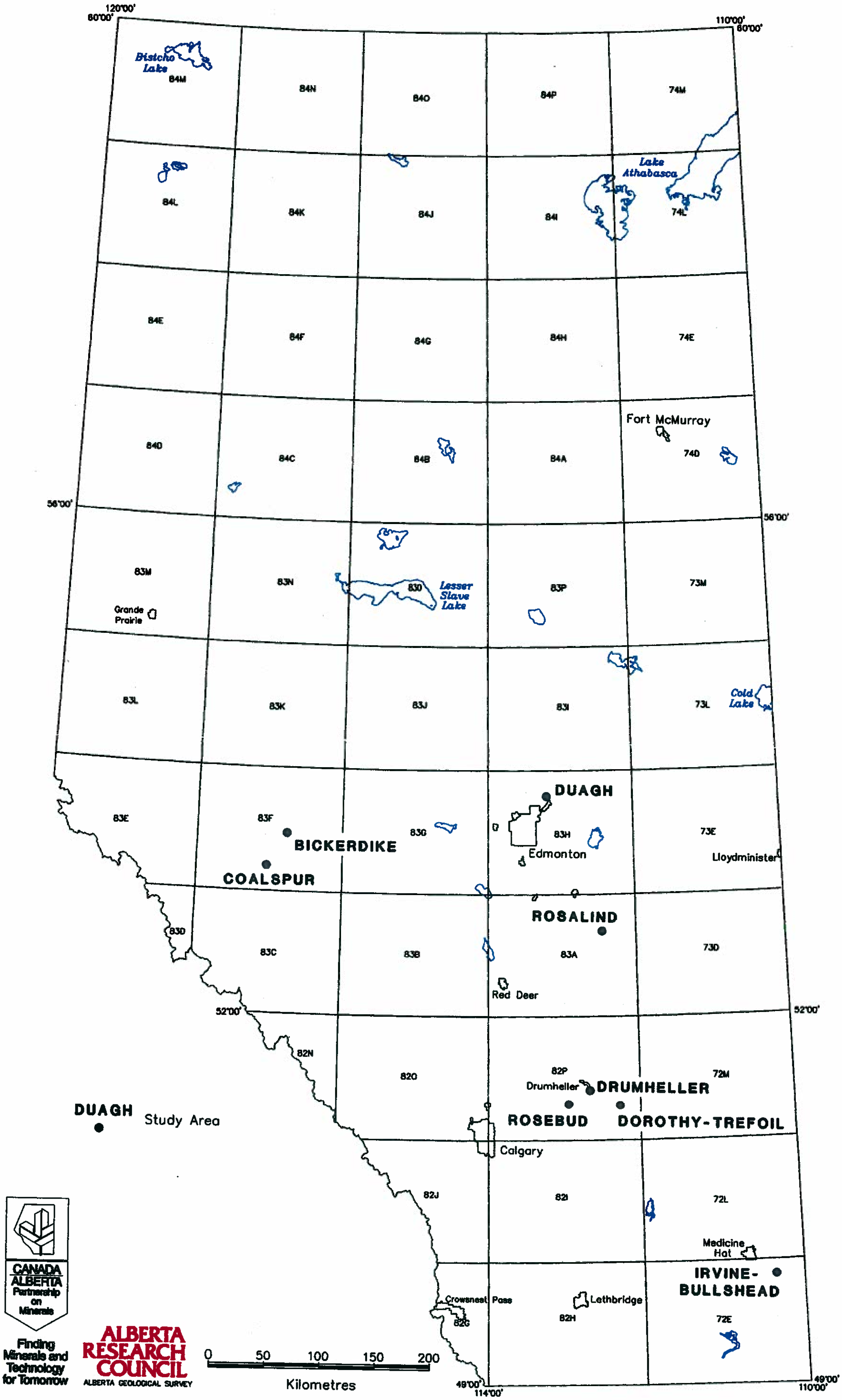


Figure 4.2: Location of detailed bentonite study areas.

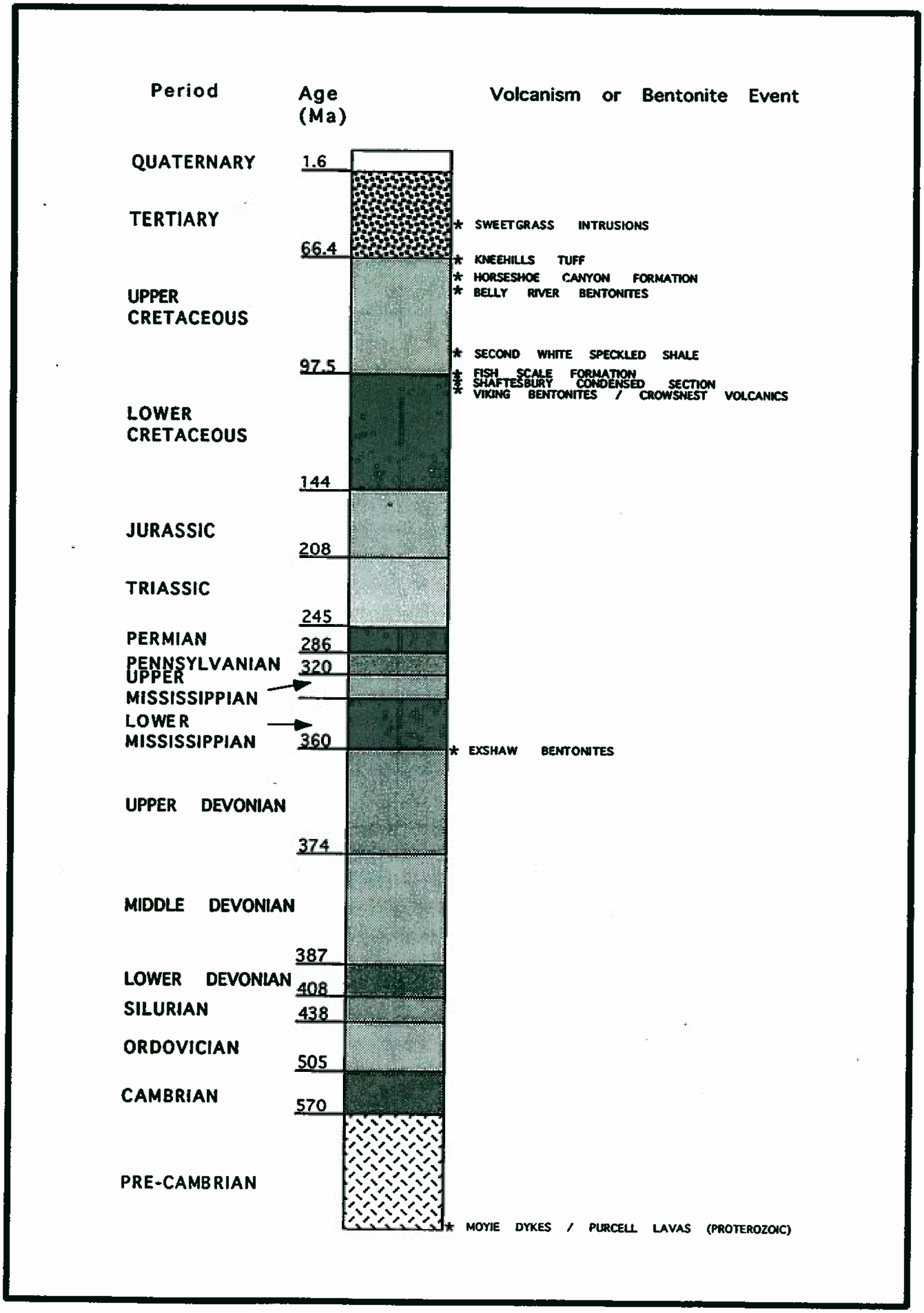


Figure 4.3: Schematic Time Scale - Alberta Volcanism and Bentonite Development.

Shale consisting of claystones and siltstones. The base of this unit is defined by a distinctive and regionally persistent bentonite bed. The general increase in gamma response for this Speckled Shale is attributed to an increase in the number of thin bentonite beds and lens intercalated within the fine grained sediments. However, it is the presence of fecal pellets composed of coccoliths which best characterize this rock unit.

The Upper Cretaceous Belly River Group bentonites are best developed in the uppermost part of this 610 m to 760 m thick rock group. The sediments are predominantly mudstones with minor amounts of coal, bentonites, sandstones, conglomerates and nodular limestone. The bentonites can range up to 1.1 m in thickness and are alteration products of glassy volcanics. K-Ar dating of the biotite/sandine in the bentonites gave an age of 74 to 77 Ma. Based upon grain size, the bentonites which have been studied in the southwest part of Alberta, are considered to have had a western volcanic source within 160 km of the sediments (Lerbekmo 1963) .

Within the Horseshoe Canyon and Battle Formations there are several bentonite tuff horizons. The most well known of these is the Kneehills Tuff Zone near the top of the Battle Formation. The Kneehills Tuff Zone is widespread and can be recognized across much of Alberta, being traceable for some 480 km in a northwest to southeast direction (Figure 4.6). The Kneehills Tuff is within the Maastrichtian Battle Formation and can be either a single tuff bed or a series of up to four beds over a 1.5 m interval. The tuff is comprised of greater than 90% silica, with vugs often filled with opaline silica or bentonitic clay (Ritchie 1960). Heavy mineral suites of this vitric crystal tuff compare well with that of the Butte Rhyolite of Montana and the age is considered to be 66 Ma (Binda 1969). Using a thin section study, Binda (1969) demonstrated that size sorting of the fragments in the tuff occurs away from this rhyolite source.

From the foregoing, there is evidence that volcanism persisted from the Albian to the Paleocene in relative close proximity to Alberta. Additionally, it is apparent that distal products of a volcanic eruption, such as the Kneehills Tuff or the Viking Formation bentonites, are characterized by extensive areal distribution and relatively good stratigraphic continuity, heavy mineral grain size gradation away from the volcanic source, thin bed thickness and may have a mineralogical composition reflective of the volcanic source. However, Byrne (1955), Babet (1966), and Scafe (1975) have identified numerous occurrences of thick, locally developed bentonites in Alberta, including some with unusual mineralogical compositions (Figure 4.1 and Appendix 4.1). This is in contrast to the above cited characteristics for distally deposited tuffs. The following discussion will present the results of recent detailed subsurface studies carried out to identify and characterize some of these reported occurrences (Figure 4.2).

4.3 Bentonite Subsurface Investigations

4.3.1 Method of Study

Scafe (1975) detailed numerous thick bentonite showings throughout the province of

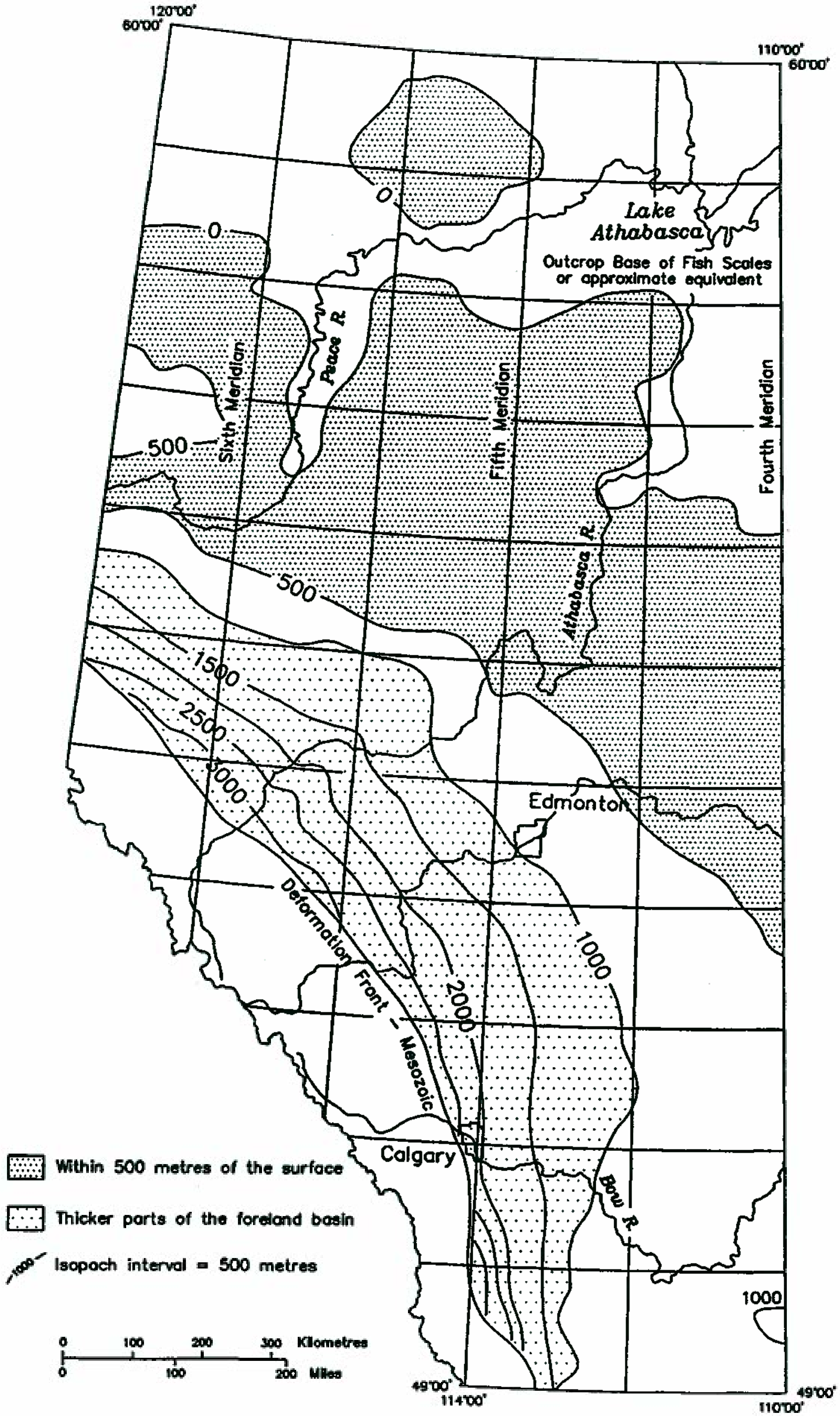


Figure 4.4: Kelly Bushing (top of drill stem) to the base of the Fish Scales isopach.

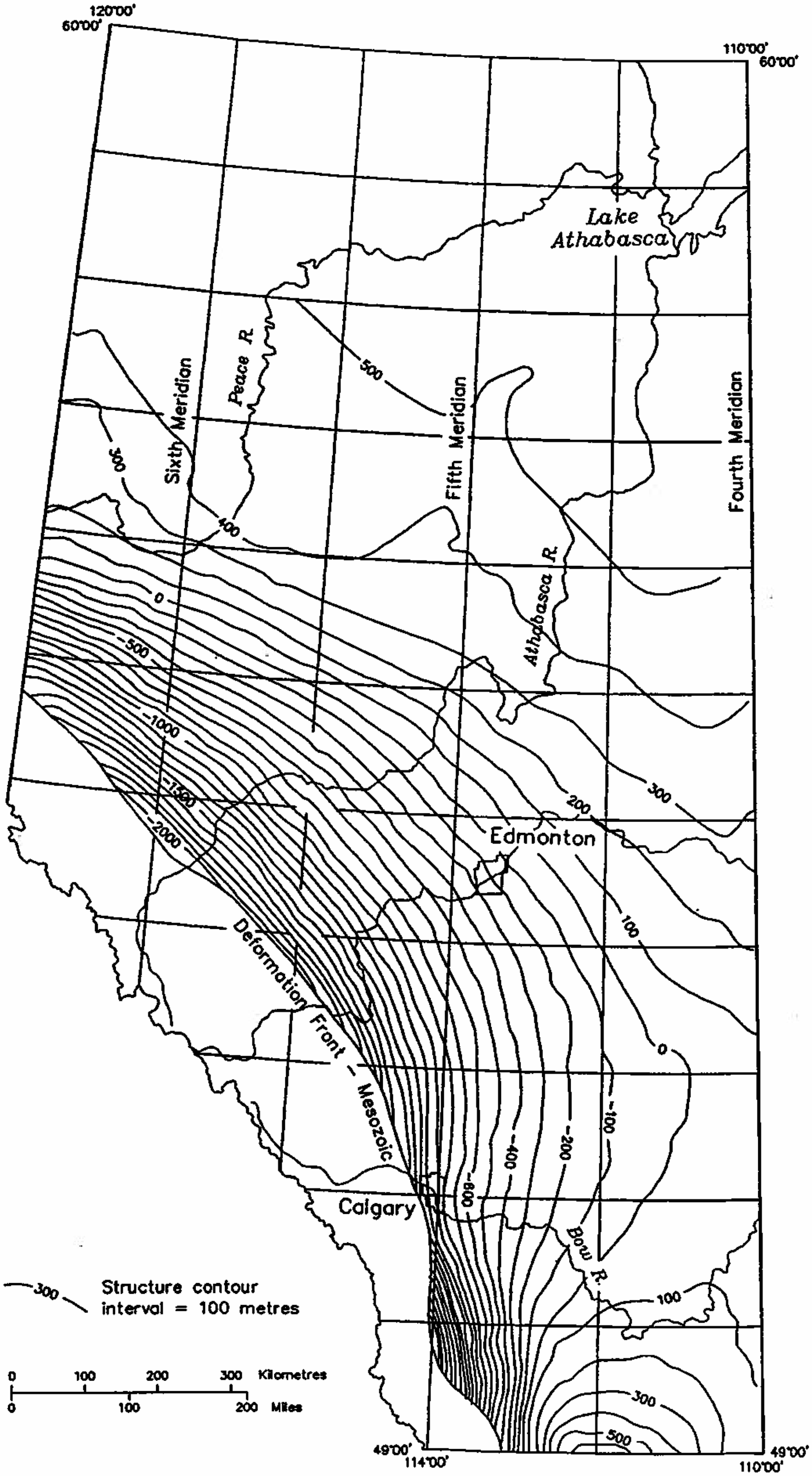


Figure 4.5: Structure contours on the base of the Fish Scales (relative to sea level).

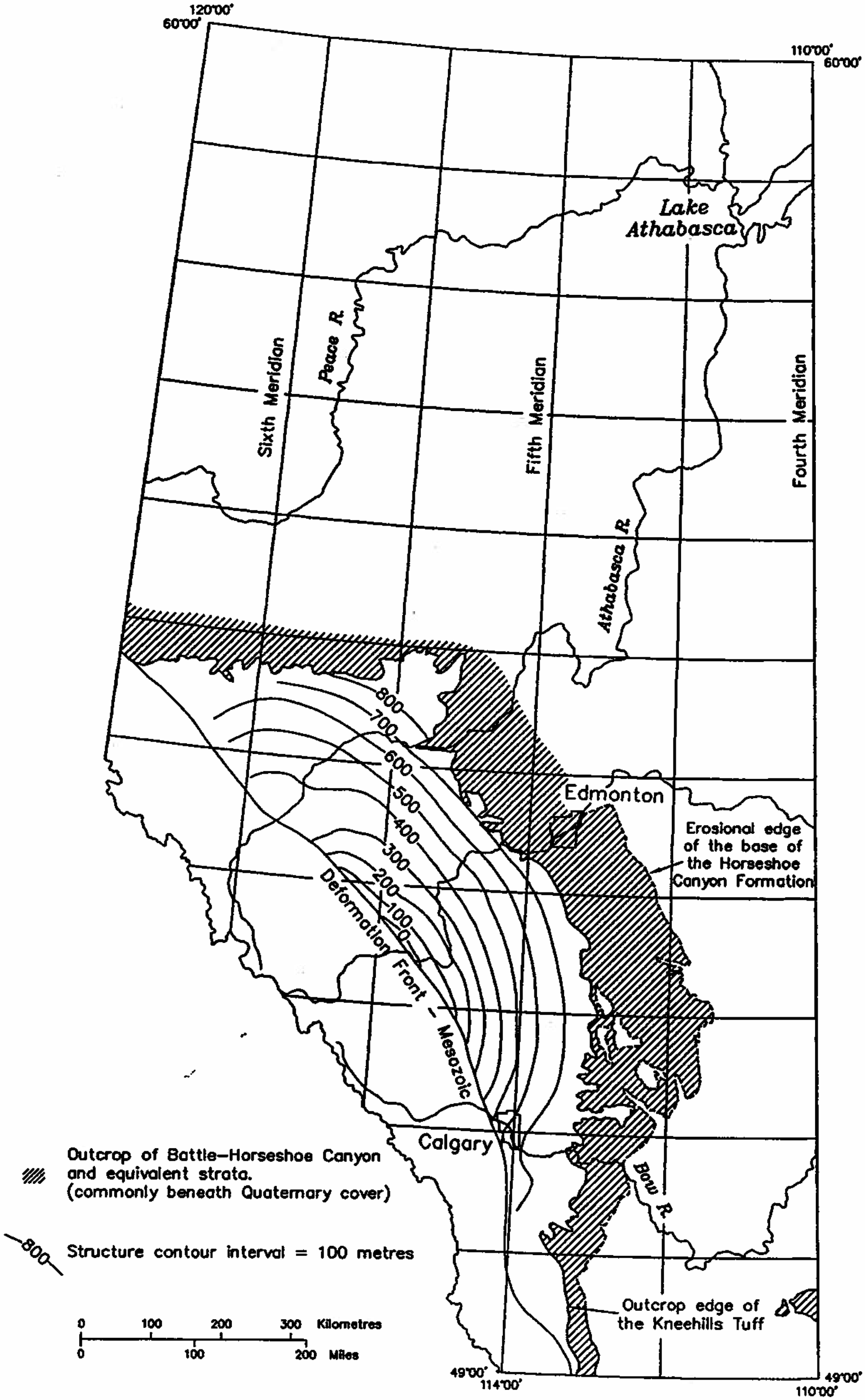


Figure 4.6: Structure contours for the top of the Kneehills Tuff.

Alberta (Appendix 4.1). In addition, a computer search of reported bentonite occurrences within the Alberta Research Council coal database identified 248 drillhole intersections with bentonites that exceed 3 m in thickness (Appendix 4.2). Using information from these tabulations, four localities were selected for the present study: (a) the Drumheller-Dorothy-Trefoil area of south-central Alberta [Townships 24-31, Ranges 16-22 W4]; (b) the Irvine-Bullshead area in southeast Alberta [Townships 10-12, Ranges 4-6 W4]; (c) the Bickerdike showing near Coalspur [Townships 48-54, Ranges 18-23 W5]; and (d) the Rosalind bentonite [Township 43 Range 17 W4M]. An additional study (e) near Edmonton [Townships 54-56, Ranges 22-24 W4] has also examined the subsurface Duagh bentonites which were identified during coal prospecting in 1978 (Shell Canada Limited 1978).

Initially, the subsurface data which pertained to bentonites was assembled and compiled for each of the five areas. This included searching for drilling and geophysical information from both the coal and oil/gas geophysical log datafiles of the Energy Resources Conservation Board (ERCB) of Alberta. These data are available on microfiche at various establishments, including the ERCB and the Alberta Geological Survey.

As a rule, oil/gas drilling requires the setting of 200 m to 300 m of casing. Therefore, this prevents the detection of bentonite in these holes at shallow depths. However, coal drilling often investigates the stratigraphy in detail at these shallow depths. In those places where coal drillholes have been drilled to depths greater than 250 m, they can provide a means of integrating the information from the shallow coal wells with the deeper information from oil and gas wells. This proved to be the case for the bentonites studied in the Drumheller area.

Bentonite can be best discerned on the Gamma Ray Log as a sharp increase in gamma response. Although there are no empirical guidelines, a response greater than 150 API units may be considered significant. However, it is the contrast of the bentonite 'spike' to the rest of the gamma ray trace, in particular the 'shale line', which provides the best means of identification. Occasionally, swelling of the bentonite in interaction with the drilling fluids may reduce the hole diameter and affect the Caliper Log. Bentonite also exhibits a strongly conductive nature on the Resistivity Log.

Distinctive responses of specific lithologies to the various geophysical tools provide the means to effectively correlate key beds from one borehole to the next (Wyllie 1963; Pirson 1963; Schlumberger 1972; Asquith 1982; Crain 1986). This study utilized various geophysical logs, including Gamma Ray - Density, Sonic, Gamma Ray - Neutron, and Spontaneous Potential - Resistivity, to enhance the correlation effort. Initially, geophysical logs along with drill cutting and core descriptions, where available, were scanned for the presence of anomalously thick bentonite. Any detection of a bentonite response on a geophysical log then required the correlation of the bed to other boreholes in the area. This correlation effort often involved utilizing the log responses of various other lithologies, including coal seams and fining or coarsening upward clastic sequences.

Upon successful correlation, isopach maps and structure contour maps of the base of each bentonite were constructed. In addition, lithologies were interpreted using both the Gamma Ray - Density Log and cuttings/core descriptions, and a stratigraphic columnar section was drafted for each area of interest. The results of these efforts are detailed in the following discussions.

4.3.2 Drumheller-Rosebud Bentonites

Among the reported thick accumulations of bentonite in Alberta (Byrne 1955; Scafe 1975), are zones up to 5 m thick in the Drumheller area of central Alberta (Figure 4.2). This thickness should be given added significance in the light of cited compaction rates for tonsteins of about 5:1 (Bohor and Triplehorn 1993). These montmorillonite-rich beds are located within the coal bearing sediments of the Horseshoe Canyon Formation (Campanian-Maastrichtian) in close proximity to the city of Drumheller. The Horseshoe Canyon Formation is noteworthy for the presence of extensive interbedded bentonite (Glass 1990). The sand/silt fraction of a heavy mineral analysis on one of these bentonites indicates a primary mineralogy of plagioclase, biotite and quartz, with secondary calcite, cristobalite, gypsum, barite and witherite (Scafe 1975).

In addition, about 32 km to the south and east of Drumheller between townships 26 to 28 and ranges 16 to 18 (Figure 4.1), is a 10 m thick bentonite exposed along the Red Deer river between the towns of Dorothy and Trefoil (Scafe 1975). This bentonite bed is considered to be within the Bearpaw Formation, some 30 m beneath the upper contact. The Horseshoe Canyon and Bearpaw Formations are, however, stratigraphically equivalent in part. Heavy mineral analysis of the Dorothy-Trefoil bentonite unit indicates a primary mineralogy of plagioclase, biotite, zircon and apatite, with secondary cristobalite, calcite, barite, gypsum, siderite, heulandite and hematite.

In a followup on the Drumheller-Dorothy-Trefoil bentonites, a study of both coal and oil/gas gamma-density well logs was undertaken to investigate the subsurface distribution of the reported bentonite occurrences. It was determined that between the top of the Viking Formation (Albian) and the middle of the Horseshoe Canyon Formation of Edmonton Group, only two bentonite horizons were correlatable over a wide area: the Drumheller and Rosebud bentonites (Figures 4.7 to 4.13, inclusive). Figure 4.7, which uses information from coal borehole 47-84 (1-27-22 W4), details the stratigraphic position of these two bentonite beds within the Horseshoe Canyon Formation.

The Drumheller bentonite is the stratigraphically lowest bed within the Basal Coal Zone, which comprises an interfingering relationship of marine sediments of the Bearpaw Formation and terrestrial clastics and coal measures of the Horseshoe Canyon Formation. The coal seams are thin and not as continuous as those within the Drumheller Coal Zone. This zone varies from 20 m to 60 m in thickness and represents the first major regressive sequence above the Lethbridge Coal Zone of the Belly River Group. It is recognized as a coal bearing zone underlying major coarsening upward sequences of marine shoreface clastics (McCabe *et al.* 1986). The Drumheller bentonite (Figures 4.11 to 4.13 inclusive), is within the Basal Coal Zone, approximately 30 m above the contact with the Bearpaw Formation, 80 m to 100 m above the Belly River Group and 60 m stratigraphically above the bentonite reported at Dorothy-Trefoil. The Drumheller bentonite is evident as a pronounced gamma log 'kick' on sections D-D', E-E' and F-F' within the Basal Coal Zone in the publication of McCabe *et al.* (1986). This bentonite interfingers with shale in the north part of the study area and is observed to shale out eastward. It is distributed over a wide area [Townships 26-31, Ranges 16-22 W4], with its thickest development in the vicinity of the town of Beynon, Alberta (holes ARC 7-80 and PCP 16-12-27-21).

Overlying the Basal Coal Zone, the Drumheller Coal Zone comprises much of the economically attractive coals of the Horseshoe Canyon Formation. A strong marine influence is still evident in the form of major coarsening upward clastic sequences adjacent to and underlying the coal seams of the Drumheller coal zone. Fining upward sequences become more frequent and influence the stratigraphic position, lateral continuity and thickness trends of the coals. The stratigraphy is thought to represent a depositional environment of shore-parallel peat swamps some distance from actual shorelines of the Bearpaw sea. Peat development was interrupted during periods of marine transgression. Repeated regressive-transgressive cycles produced a series of interfingering coal seams and coarsening upward sequences (McCabe *et al.* 1986).

The second bentonite, here termed the 'Rosebud' bentonite' (Figures 4.8 to 4.10 inclusive), is located some 190 m further upsection from the Drumheller bentonite and within the Drumheller Coal Zone. This bentonite is best developed locally near the town of Rosebud, Alberta, which is about 25 km southwest of Drumheller. Geophysical log evidence indicates this bentonite rapidly thins to the east, west and north. There is also a subtle thin interfingering relationship with enclosing shale to the northeast.

A geophysical log analysis, using a combined total of 90 wells, provided the control for the drafting of structure contour and isopach maps for each of these bentonites (Figures 4.9, 4.10, 4.12 and 4.13). Correlation was facilitated using four continuous and regionally extensive coal seams in the Basal Coal Zone, as well as a prominent 30 m thick coarsening upward clastic sequence.

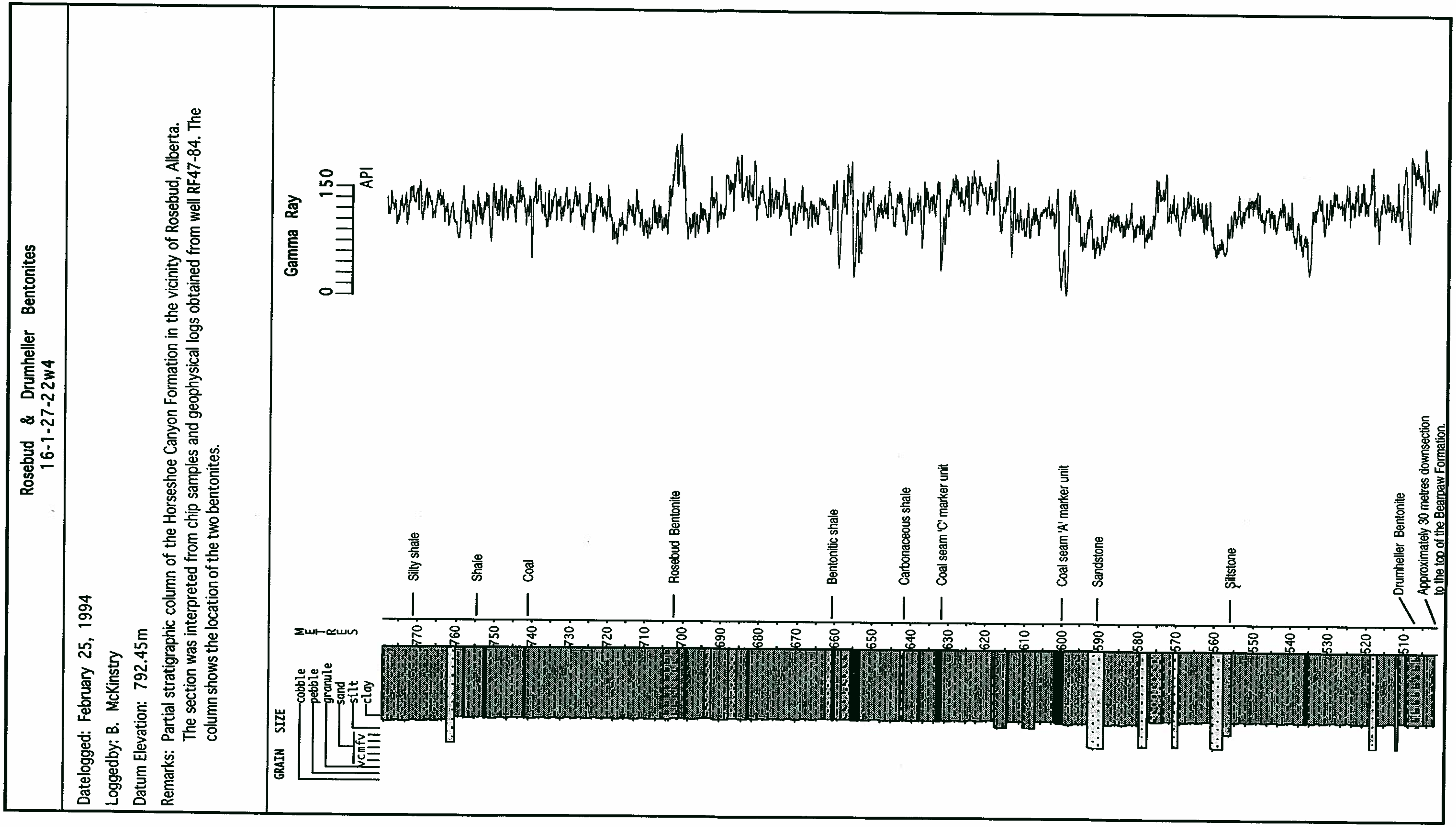
Both bentonites trend north-south and dip westward between 5 m and 7 m per kilometre (Figures 4.10 and 4.13). However, there is a sharp contrast in the isopach map patterns between the two bentonites (Figures 4.9 and 4.12). The Rosebud bentonite appears to have a pronounced elongate thickness trend oriented west-northwesterly. As well, there is a facies transition to shale to the north. The thickness isopach trend for the Drumheller bentonite, on the other hand, is to the north or northeast.

Nurkowski and Rahmani (1984) carried out a detailed study of Upper Cretaceous stratigraphy (Maastrichtian) in an area approximately 16 km north of Drumheller. Dips

Scale 1: 1000

REGIONAL DIAMOND STUDY OF ALBERTA
MDA PROJECT M93-04-014

Figure: 4.7
BENTONITE HORIZONS WITHIN THE HORSESHOE CANYON FORMATION, DRUMHELLER AREA, ALBERTA



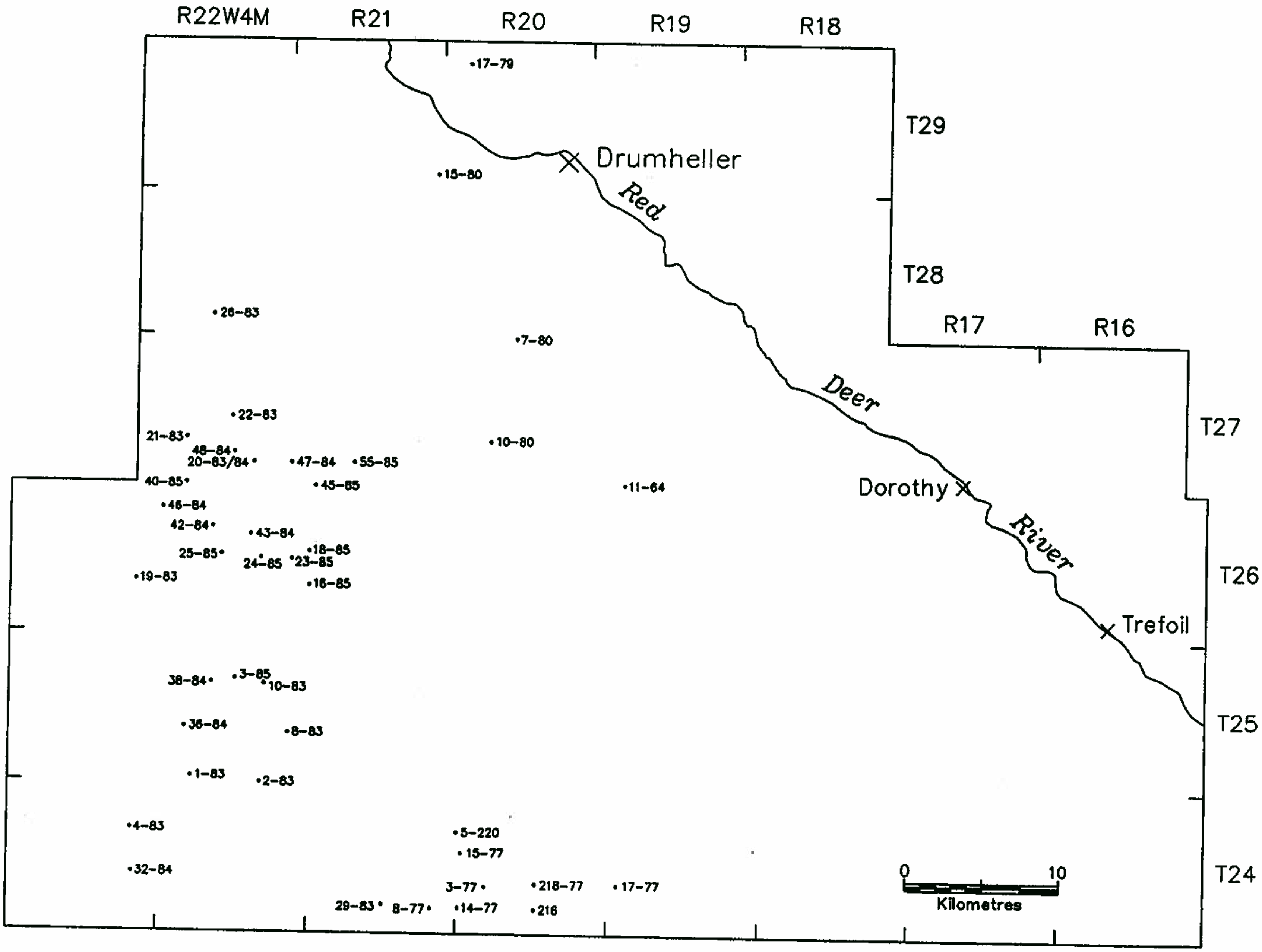


Figure 4.8: Well control, Rosebud bentonite.

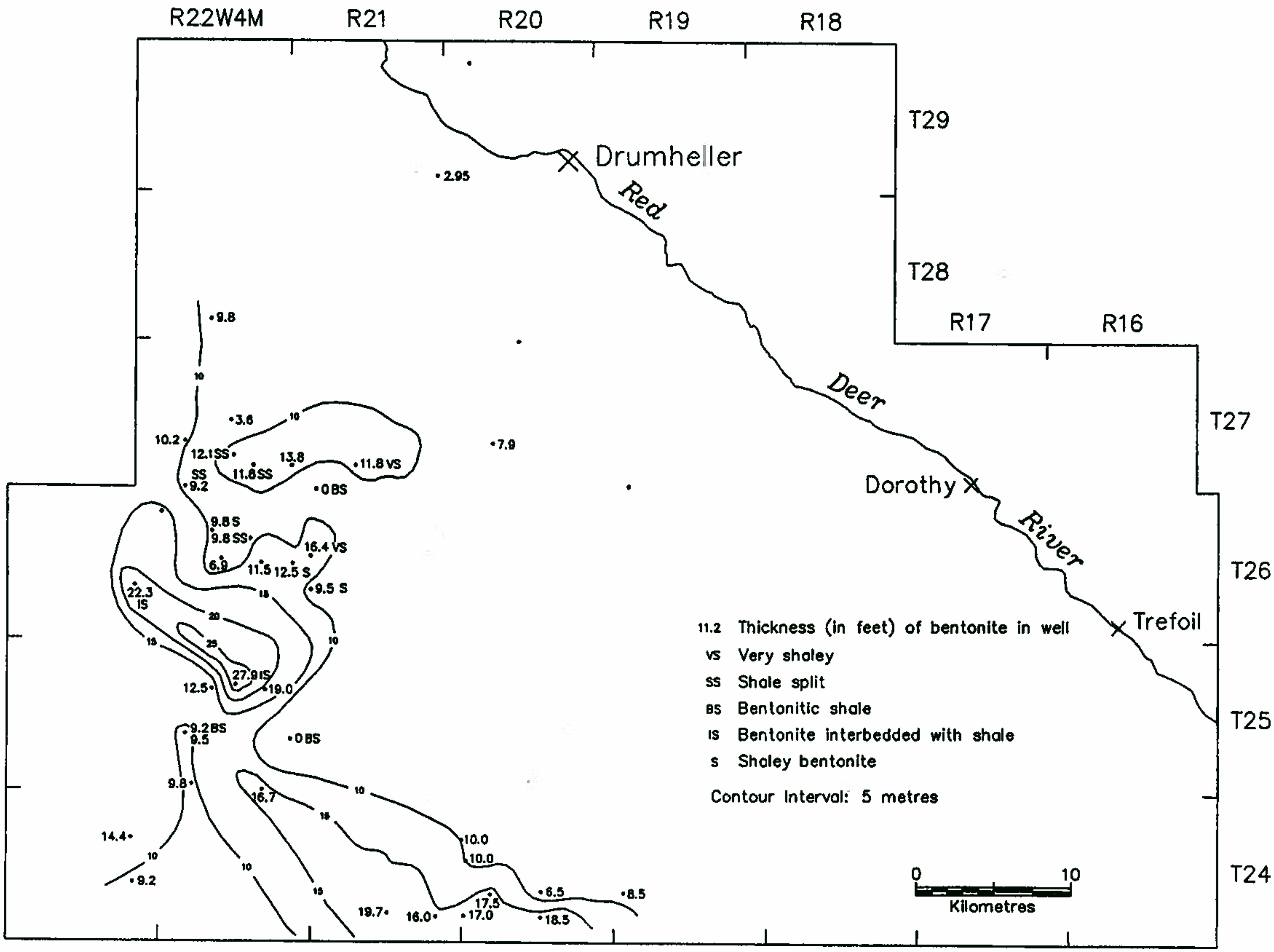


Figure 4.9: Thickness isopach map of the Rosebud bentonite.

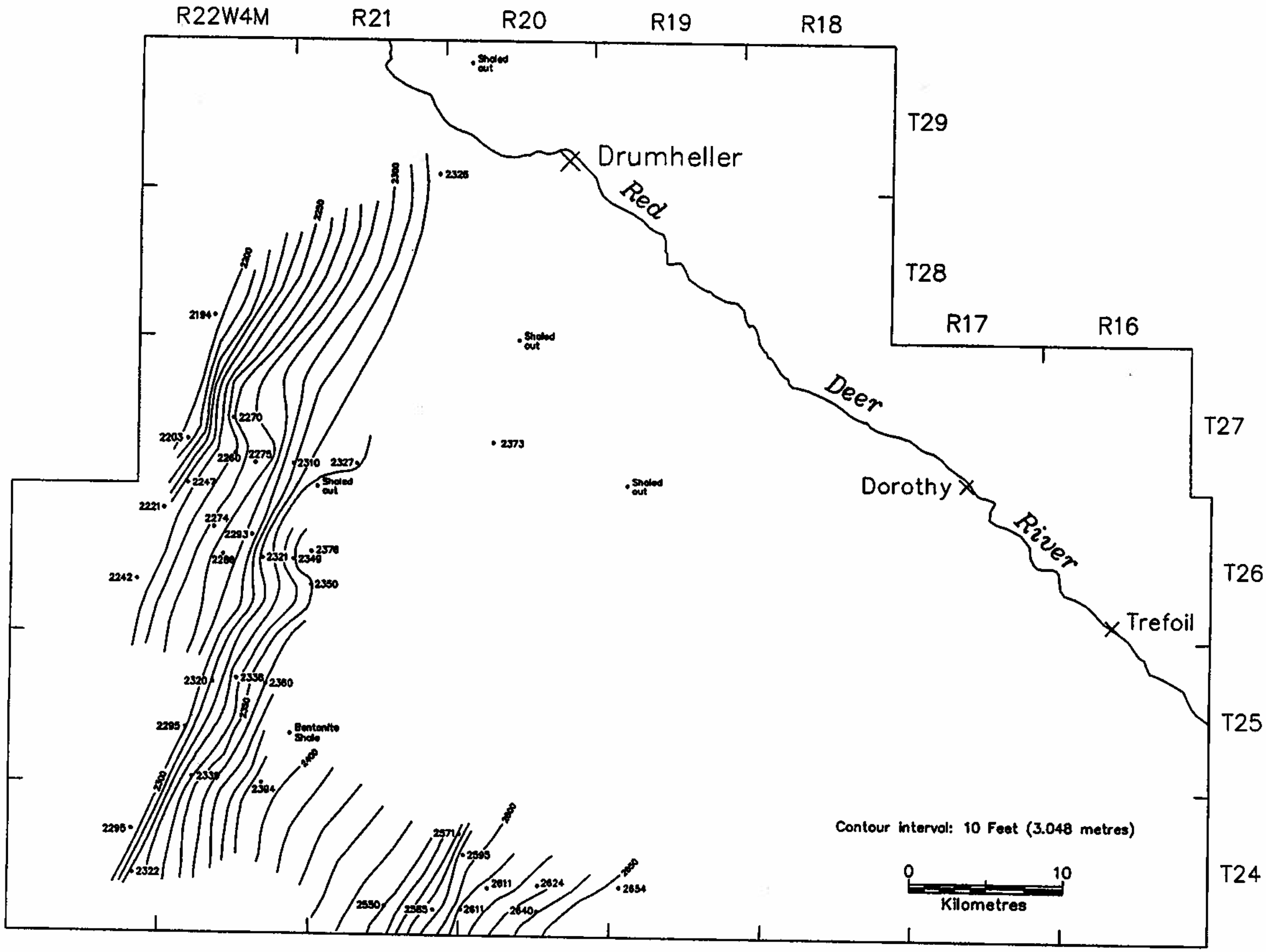


Figure 4.10: Structure contour map of the base of the Rosebud bentonite.

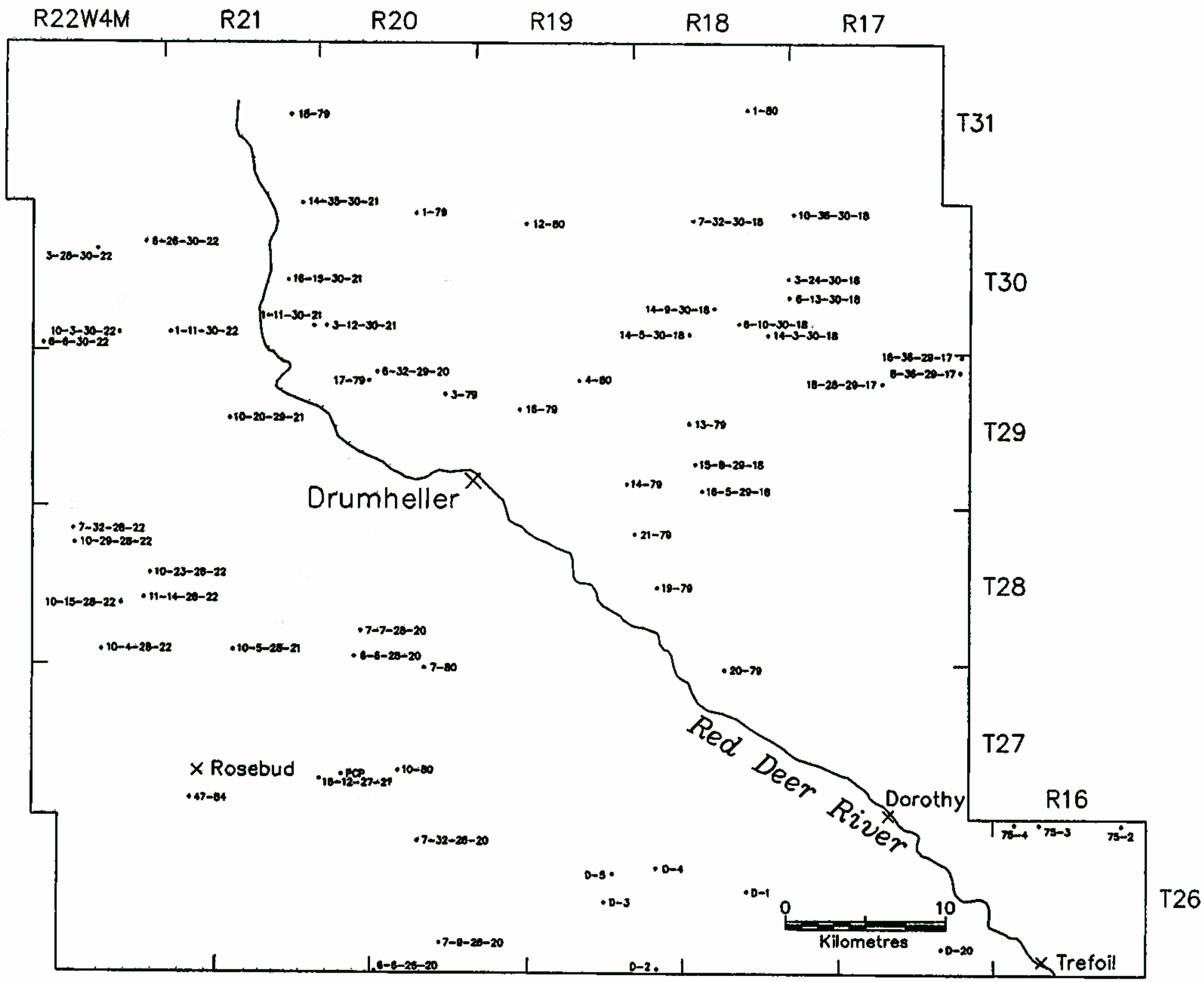


Figure 4.11: Well control, Drumheller bentonite.

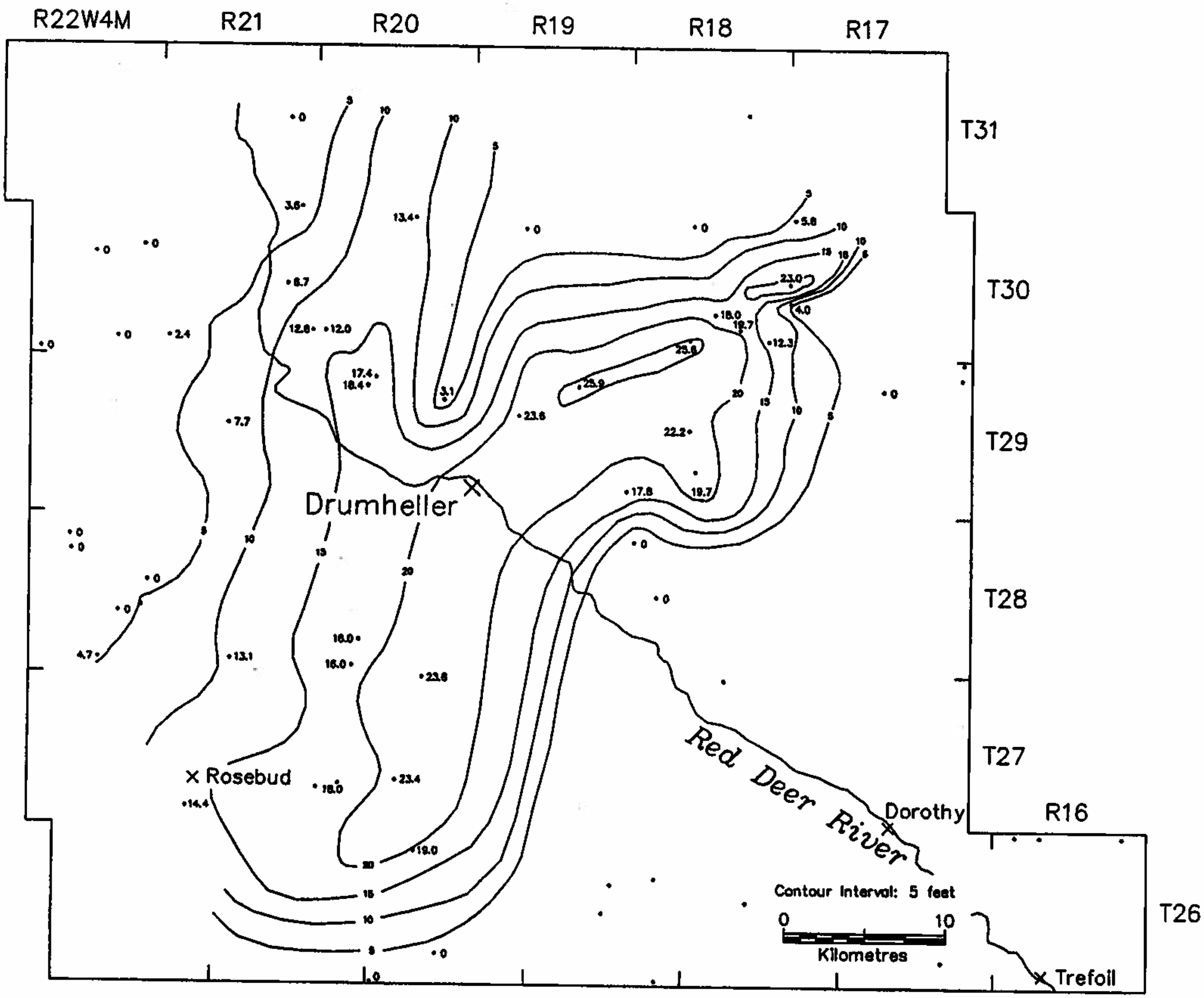


Figure 4.12: Bentonite thickness isopach map of the Drumheller area (thickness in feet).

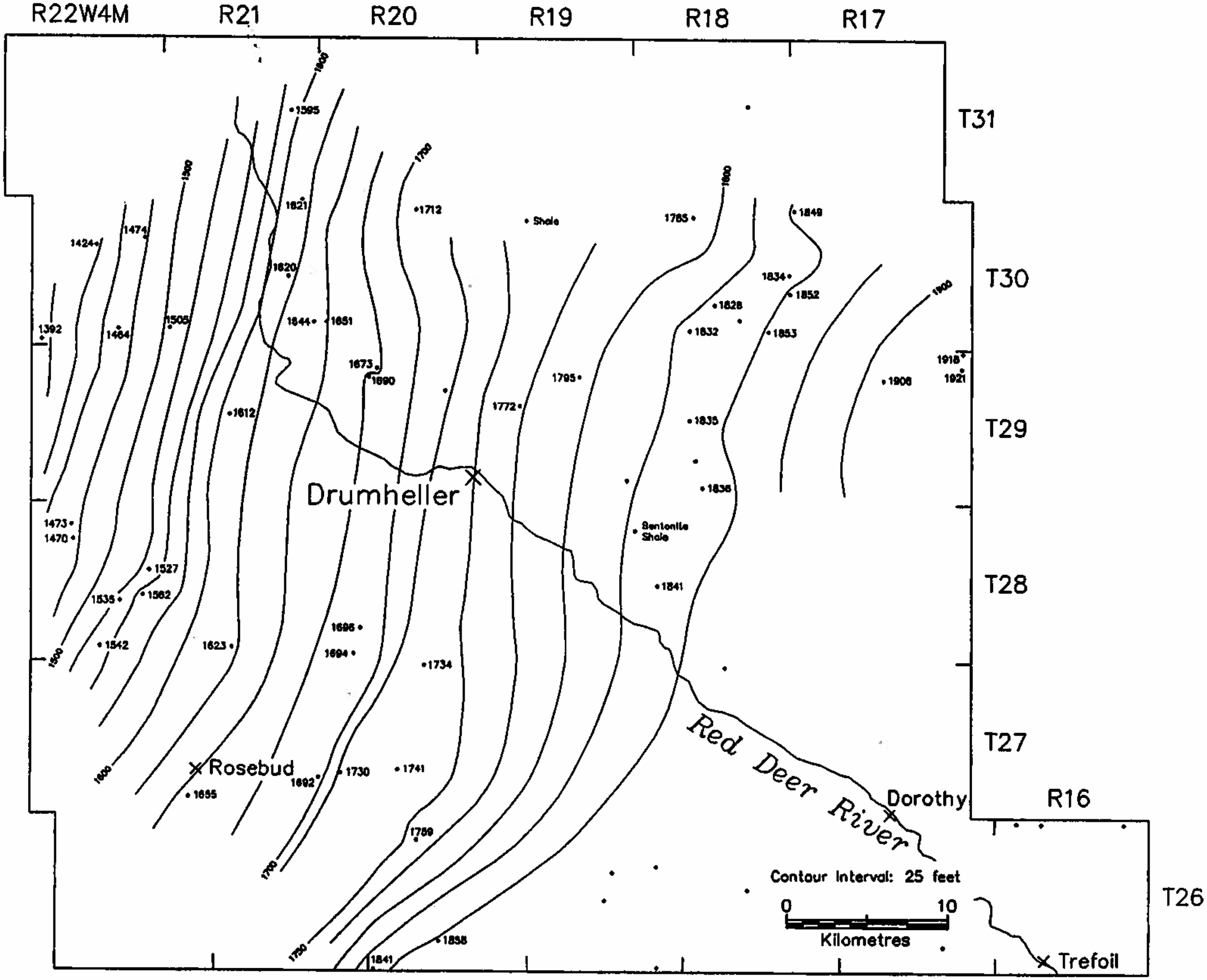


Figure 4.13: Structure contour map of the base of the Drumheller Bentonite.

in this area are 2.5 m to 9 m per km and the results of the study reconfirmed previous work (Eisbacher *et al.* 1974) which established a paleodrainage trend from northwest to southeast. This paleodrainage is reflected in elongate, linear northwest-southeast cumulative thickness isopach patterns for both coal and sandstones lithologies. Geophysical log responses suggest the fluvial pattern was of a meandering style with fining upward sequences and a sharp contact at the base of each sequence. Figure 4.9 illustrates that the Rosebud bentonite conforms to this general pattern. Localized thicknesses up to 8.3 m are preserved in two narrow elongate domal bodies trending west-northwesterly. This indicates that the volcanic ash may have been reworked after deposition, with thicker accumulations occurring in interfluve areas between stream or river channelways in a fluvial floodplain environment. This may explain the absence of bentonite in hole 8-83 and thinning of the bentonite west of this locality, between the two elongate bodies.

However, it is more difficult to suggest this process was responsible for the Drumheller bentonite isopach pattern. The thickness trend is almost perpendicular to the depositional northwest to southeast depositional trend (Figure 4.12). Moreover, a regionally persistent and extensive thin coal seam immediately overlies this bentonite (Figure 4.7), suggesting that a relatively quiescent depositional environment was established after the volcanic tuff was deposited. The preceding evidence, as well as the elongate broad domal shape, and the rapid transition to shale to the north, west and southeast offer the possibility of a more proximal location for volcanic activity than is currently considered.

Neither the Rosebud nor the Drumheller bentonite is a viable subsurface extension of the Dorothy-Trefoil bentonite occurrence. Careful examination of boreholes east and west of the Dorothy area failed to show any geophysical signature indicative of bentonite at the appropriate stratigraphic level (holes D-1 to D-5 inclusive on the west and 75-2 to 75-4 inclusive on the east, Figure 4.11). Indeed the most likely candidate, the Drumheller bentonite, thins rapidly south of borehole ARC 14-79 and is not present south of hole ARC 21-79 (Figure 4.11). Either the Red Deer river outcrops are very limited in extent or the bentonite in the subsurface does not have the necessary mineralogical composition to be detected by geophysical means.

4.3.3 Duagh Bentonites

A coal exploration program carried out by Shell Canada Limited in 1978 in the Duagh area, which is some 20 km northeast of the city of Edmonton, intersected two thick bentonite beds within the Upper Cretaceous Horseshoe Canyon Formation (Figures 4.2, and 4.14 to 4.20, inclusive). After Shell's initial drilling results, the emphasis was shifted from coal to bentonite exploration (D. Fietz, *pers. comm., 1994*). Based upon the coal seam development and geographical location of outcrops, the incomplete 80 m thick section which was investigated at Duagh, is probably part of the Weaver Coal Zone (McCabe *et al.* 1986). This zone is characterized by thin discontinuous marginally economic coal seams that are intercalated within coarsening upward clastic sediments.

The Duagh section contains up to six relatively thin coal seams within a predominately shale-rich sequence. Although thin sands are present, they are fine grained and lensoid with no distinctive signature on the gamma response. Moreover, they occur in the basal part of the section beneath the bentonites. Strata dip gently southwest at about 4 m per km (Figures 4.16 and 4.19) and are eroded to the northeast, and to the west and northwest by the incising profile of the Sturgeon River valley.

Bentonite #1 is located some 3 m upsection of a thin persistent coal seam and attains a maximum thickness of about 2.4 m (Figures 4.20 and 4.15). The isopach map for this bentonite reveals a domal elongate shape trending southwest-northeast. However, deep erosional effects to the northeast, west and east may be biasing this pattern (Figure 4.16). Nonetheless evidence in borehole 60-120 indicates a rapid thinning of the bentonite to the west into adjoining shales. Interestingly, the observed thickness isopach trend is perpendicular to the depositional trend and the bentonite is overlain by a series of thin bedded shales.

Some 30 m downsection of Bentonite #1 is Bentonite #2 (Figure 4.20). Its lower stratigraphic position provides better well control for the construction of isopach and structure contour maps (Figures 4.18 and 4.19). Thickness varies from zero to about 5.8 m with isopach contours defining a broad elongate domal pattern trending northwest-southeast, but thinning rapidly to the northwest approaching the Sturgeon River valley (Figure 4.19). A somewhat surprising feature is the absence of this bentonite in borehole 60-85. This may be a product of local reworking of the tuff after deposition. Additionally, the isopach trend of this bentonite is parallel to the depositional trend (Nurkowski and Rahmani 1984) and, hence, post-depositional reworking of the ash layer may have been a significant factor in developing the observed pattern. However, the overlying coal seams and carbonaceous shales provide little evidence to support the presence of strong fluvial, wave or current forces in action.

Although neither of these bentonites have been reported in the literature, this may be a function of the level of erosion in the area, lack of outcrop exposure and the thickness of glacial overburden.

4.3.4 Irvine-Bullshead Bentonites

Byrne (1955) and Scafe (1975) reported several bentonite occurrences in the Irvine-Bullshead area near Medicine Hat which is north and west of the Cypress Hills (Figure 4.2). The thickness of these reported bentonites varies from 0.8 m to 3 m and they all are within the Bearpaw Formation. The thickest bentonite lies approximately 30 m stratigraphically above the base of the Bearpaw Formation, and varies in thickness from 0.5 m to 3 m. In the present study, no well control could be obtained for the Bearpaw Formation from coal exploration drillholes. Additionally, oil/gas casing requirements prevented the Bearpaw from being effectively logged in any of the nearby oil and gas exploration drillholes.

However, the coal drillhole database did provide geophysical information from a series of 28 exploration wells which intersected much of the underlying Belly River Group (Campanian) south and west of Irvine, in townships 10 to 12 , Ranges 4 to 6 west of the fourth meridian. These holes intersected a bentonitic horizon that is located between sandstone cycles of the Oldman Formation, approximately 50 m above the Taber Coal Zone (Figures 4.21 to 4.24, inclusive). The stratigraphic interval studied in the Irvine area included 160 m of section within the Belly River Group (Figure 4.19).

The Taber Coal Zone comprises from 7 to 11 thin coal seams which are difficult to correlate. The thickest accumulations of coal are found along a northwest-southeast trend. The coals are thought to have formed from peat swamps in a coastal plain environment some distance westward of the paleoshoreline (McDonald *et al.* 1987). This coal zone separates coarse clastic deposits of the overlying Oldman Formation from the finer grained sediments of the underlying Foremost Formation.

The Oldman Formation sediments were deposited in southeast draining estuarine channels as coarse clastics or an inclined heterolithic series of channel sediments (Koster 1987). These stacked channel deposits often display sharp erosional bases. The Irvine-Bullshead bentonite which was recognized in the boreholes, is stratigraphically located approximately 40 m downsection of the Lethbridge Coal Zone and is not part of the Bentonitic Zone of the Upper Belly River Group. It is preserved at the top of a fining upward channel sandstone sequence and is overlain by another channel sandstone development. The gamma ray log signature indicates a strong shale component to the bentonite, particularly with the thicker accumulations, suggesting intimate mixing of very fine grained clastic sediment with the ash during deposition. However, this bed can still be effectively correlated throughout all boreholes. Figure 4.24 indicates the bentonite bed trends northwest and dips approximately 3 m per km to the northeast. There is a suggestion that the Sweetgrass Arch to the west was exerting a slightly positive, although not emergent, influence on sedimentation at this time (McLean 1971).

The depositional environment in which the Irvine-Bullshead bentonite was preserved would likely have promoted intense reworking of any pyroclastic airfall by strong fluvial or offshore current forces. However, the thickness isopach trend is oriented northeasterly (Figure 4.23), which is perpendicular to the regional depositional trend (McDonald *et al.* 1987). If the paleoshoreline during this time was some distance to the east, this pattern is difficult to explain as a product of fluvial erosion and subsequent reworking. However, if the shoreline was considerably nearer, offshore currents acting parallel to shoreline may have concentrated the water lain tuffs into the present observed trend. Alternatively, the anomalous trend may also reflect a local volcanic source for the bentonite precursor material.

4.3.5 Bickerdike Bentonites

A 2 m to 5 m thick bentonite has been reported (Byrne 1955) from the Bickerdike area of west-central Alberta [Township 52, Range 18 W5M] (Figure 4.2). This showing occurs in the Paskapoo Formation (Paleocene) or in rocks of Late Cretaceous age. The Paskapoo Formation consists of interbedded mudstone, siltstone and sandstone that is often developed into thick, sharp-based, fining upward, fine to medium grained clastic sequences.

A subsurface study, using coal exploration well logs in this area, indicates the presence of at least two bentonite layers within the Paskapoo Formation. A bentonite drilling program carried out by Imperial Oil Limited in 1977-1978 intersected two bentonitic horizons west of the Bickerdike showing in the vicinity of Prest and McNeil Creeks (Table 4.1 and Figure 4.25). Boreholes that intersect the upper bentonitic mudstone had vertical thicknesses ranging from 3 m to 16.7 m. Vertical thicknesses for the lower bentonite ranged from 0 m to 10 m. The two bentonitic zones are separated by 12 m to 14 m of fine grained sediments. Further east, Occidental Petroleum carried out a coal exploration program in 1981-1982 in order to investigate the McPherson Coal Zone within the Coalspur Formation. Seven boreholes have intersected a distinctive bentonite with vertical thickness ranging from 3.5 m to 6 m (Table 4.1 and Figure 4.25). This bentonite was intersected some 265 vertical m stratigraphically above the McPherson Coal Seam. The proximity of the Occidental holes to the Bickerdike outcrop indicate these bentonite intersections may be the subsurface expression of this showing, although a lack of structural control in the area makes this assessment difficult. Regrettably, a lack of well control and surface geological information prevented the construction of isopach and structure contour maps for the Bickerdike bentonites.

4.3.6 Rosalind Bentonites

Previous reports have documented bentonite occurrences in the Rosalind area [Township 43, Range 17 W4M] with thicknesses ranging from 1.5 m to 2.5 m (Scafe 1975) (Figure 4.2). In fact, this is one of the few localities where bentonite has been actively mined in the past. Strata in the area dip southwest at about 3 m per km. The bentonite is reported to occur within the Horseshoe Canyon Formation and is underlain by black carbonaceous shale. A search of the coal and oil/gas geophysical logs within Townships 42 and 43, Ranges 16 to 30 failed to indicate any significant and correlatable subsurface bentonitic horizons to a depth of 305 m. However, locally there were several intersections of thick bentonitic material, namely 5.5 m in borehole TH34-74 [20-43-26 W4M] and 7.0 m within borehole TH33-74 [16-43-27 W4M].

4.4 Discussion

Regional airfall tuff deposition from distal volcanic sources (e.g., Kneehills Tuff and the Viking Formation bentonites) is characterized by extensive areal distribution, relatively thin bed thickness and good stratigraphic continuity. These sediments can provide an excellent reference frame for the timing of geological events, and they often develop a graded size distribution away from their volcanic source. Additionally, the volcanic source is often identifiable and the tuff or bentonite may occasionally be correlated compositionally with the source. However, several anomalously thick, locally developed,

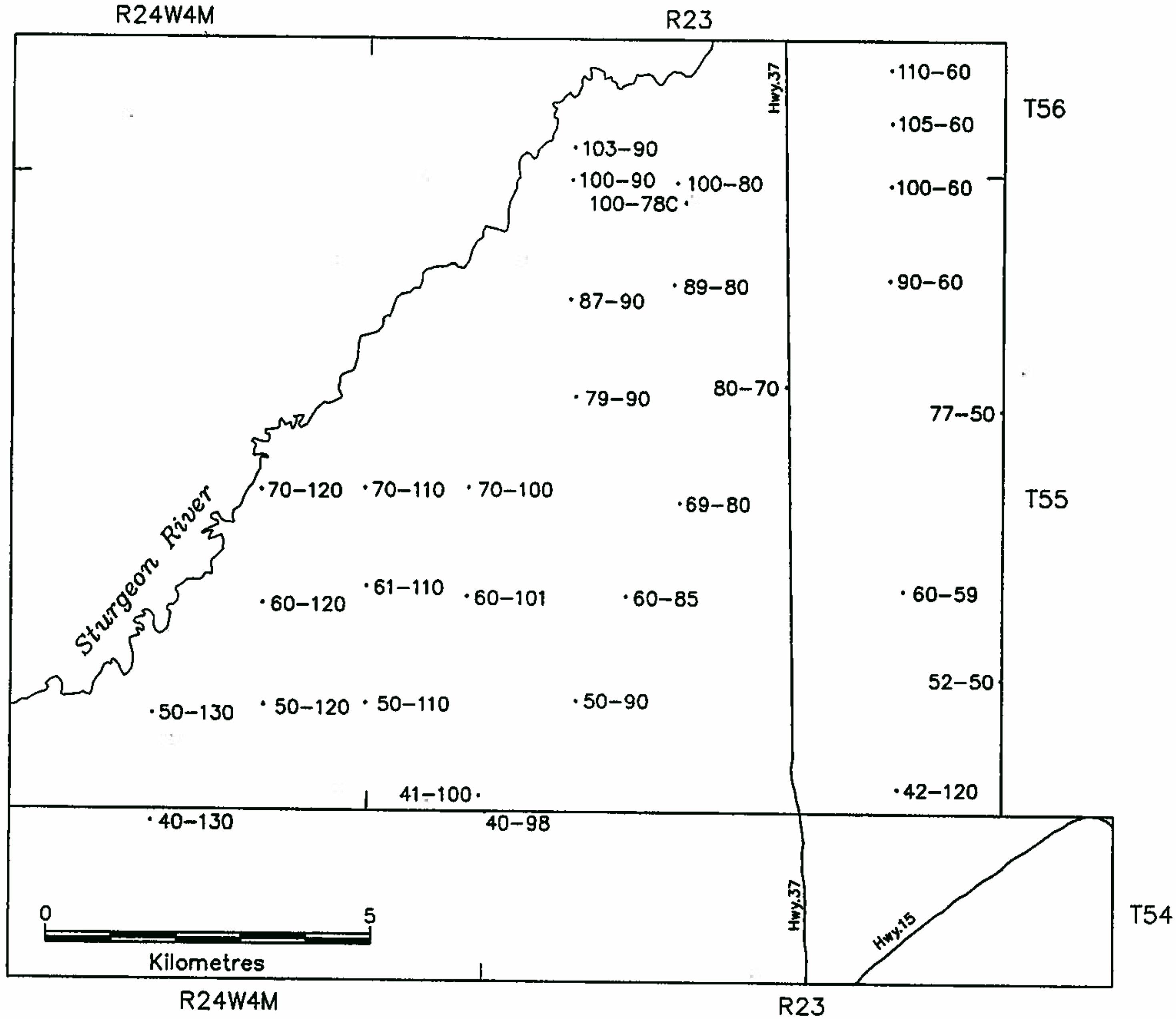


Figure 4.14: Well location, Bentonite #1 in the Duagh area.

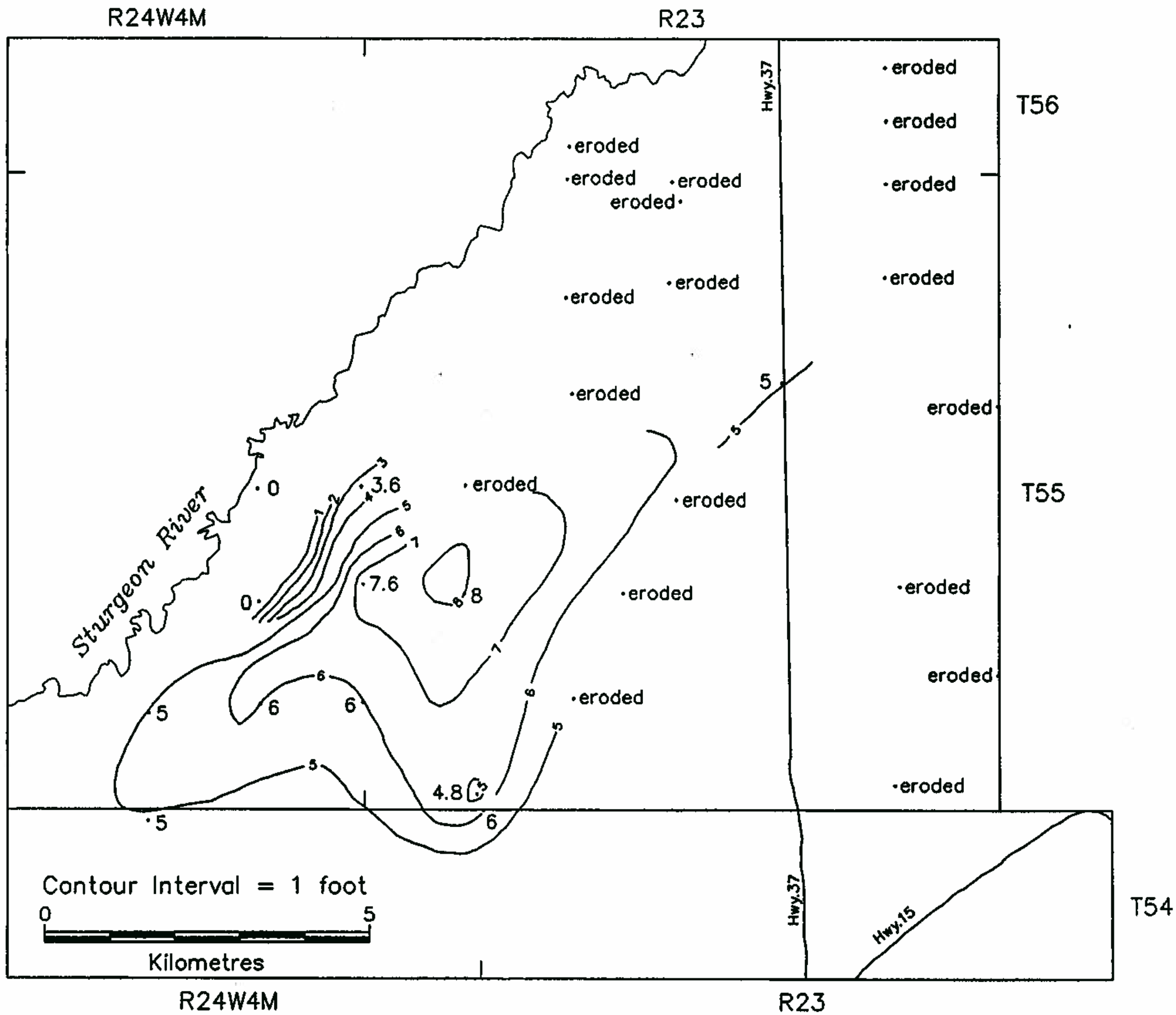


Figure 4.15: Bentonite thickness isopach map of Bentonite #1 in the Duagh area (thickness in feet).

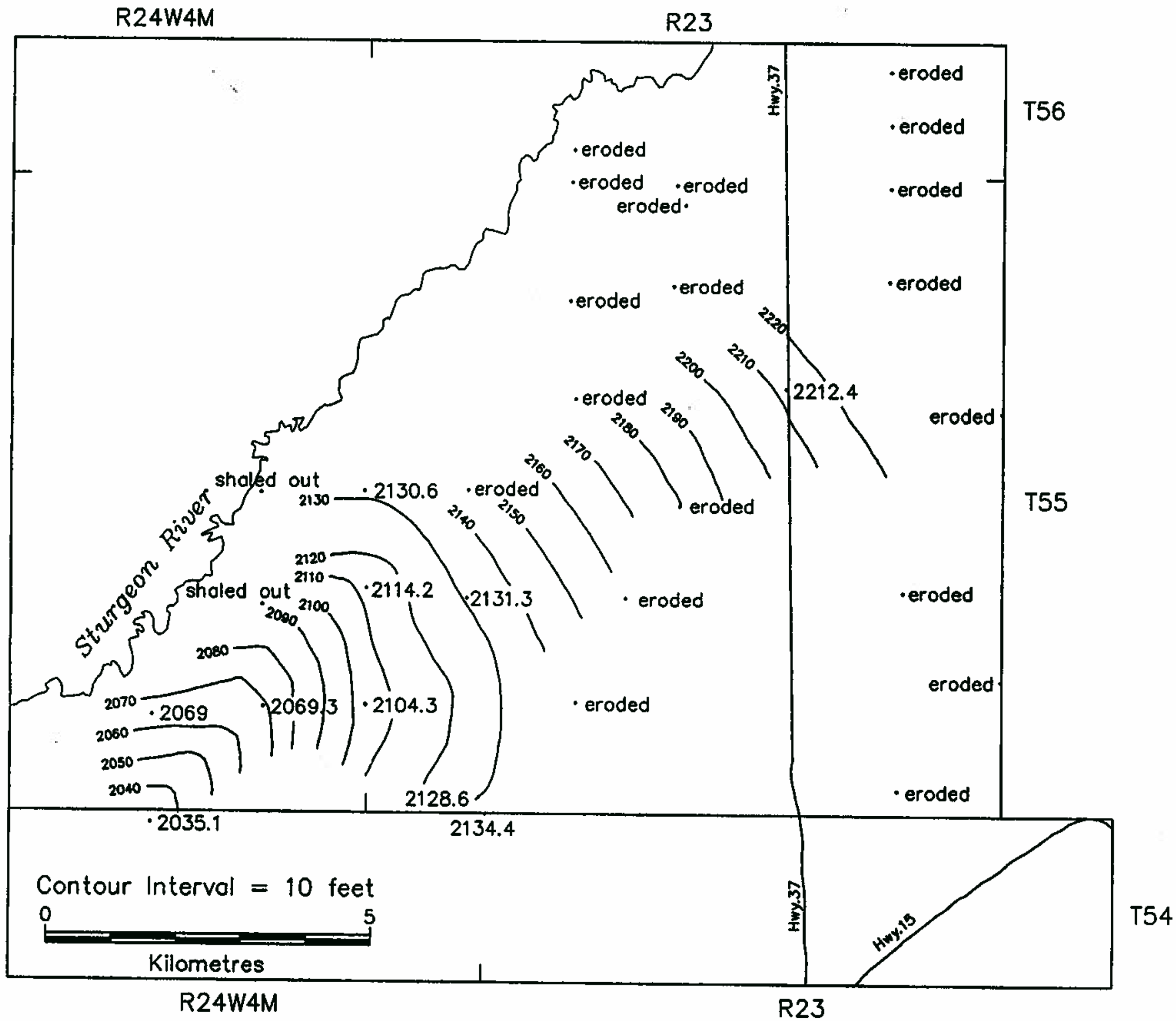


Figure 4.16: Structure contour map of Bentonite #1 in the Duagh area.

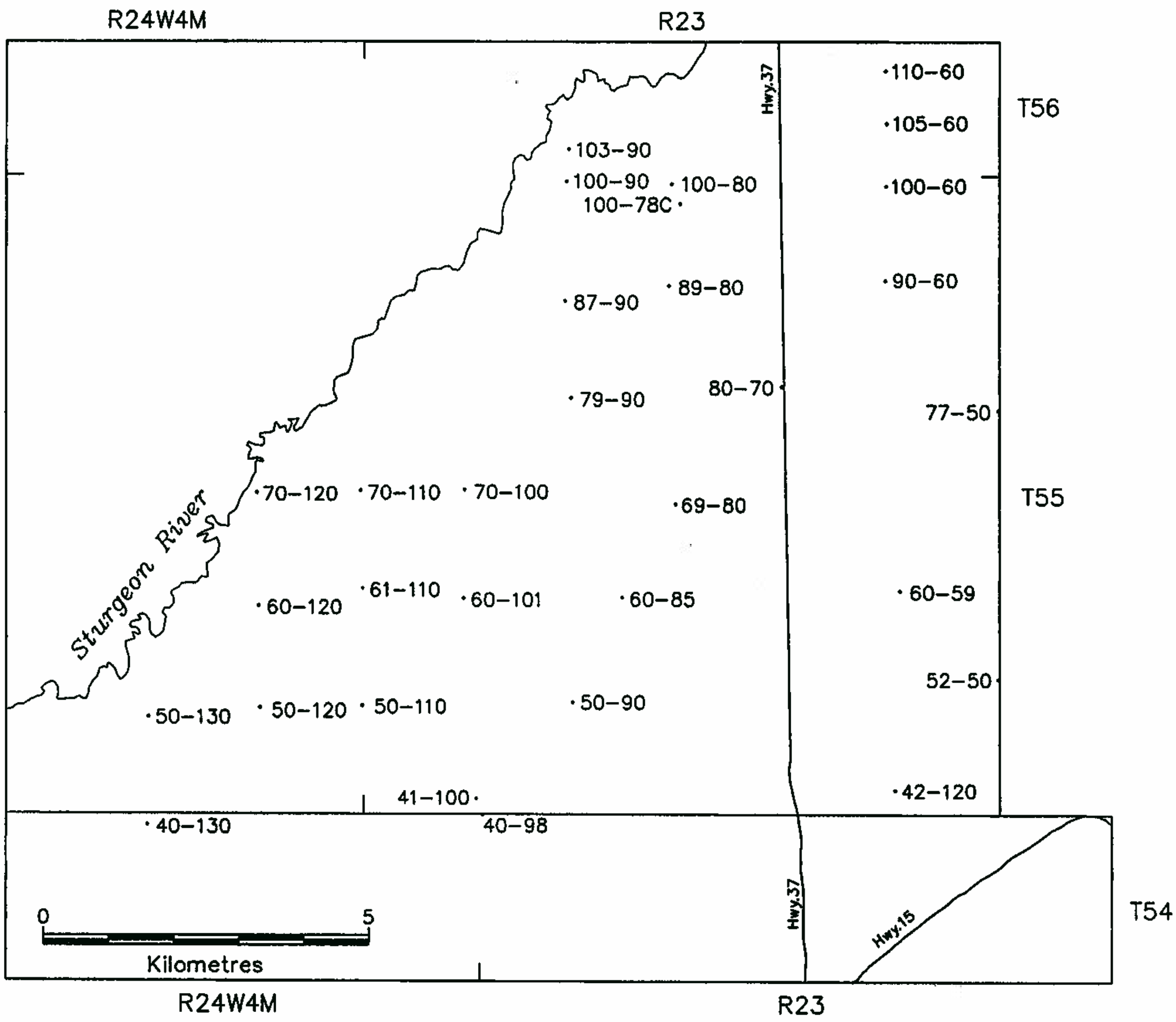


Figure 4.17: Well location, Bentonite #2 in the Duagh area.

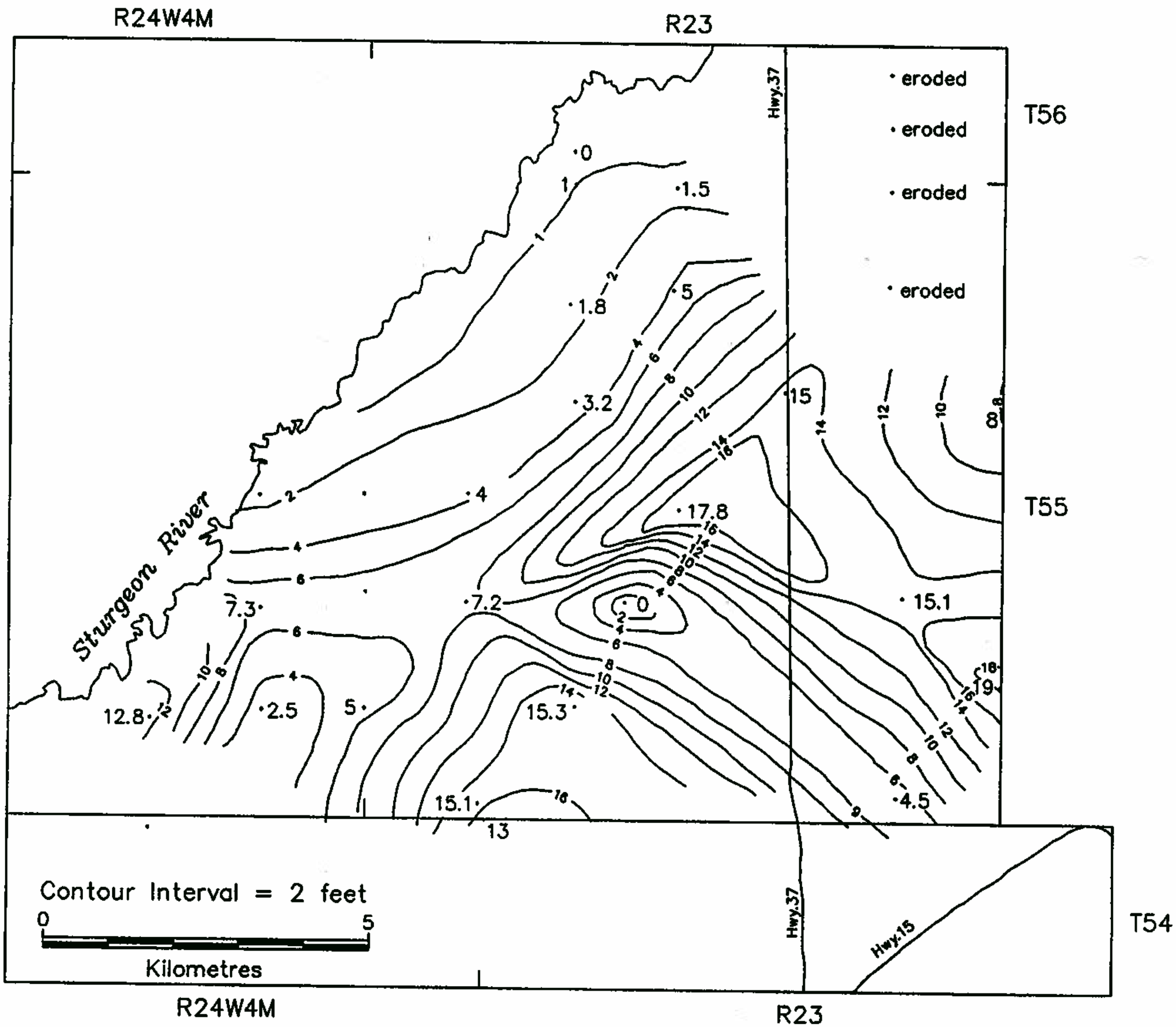


Figure 4.18: Bentonite thickness isopach map of Bentonite #2 in the Duagh area (thickness in feet).

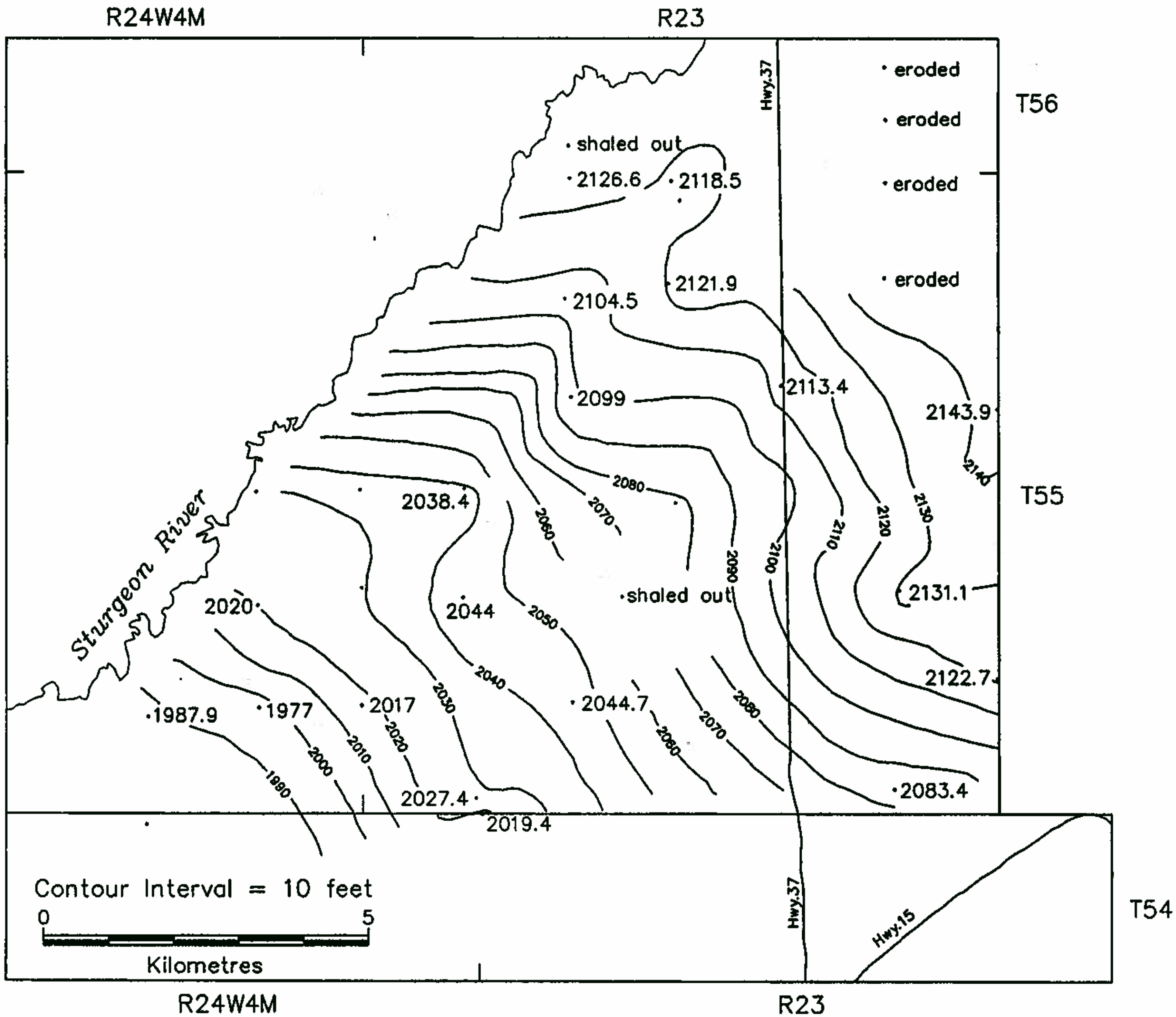
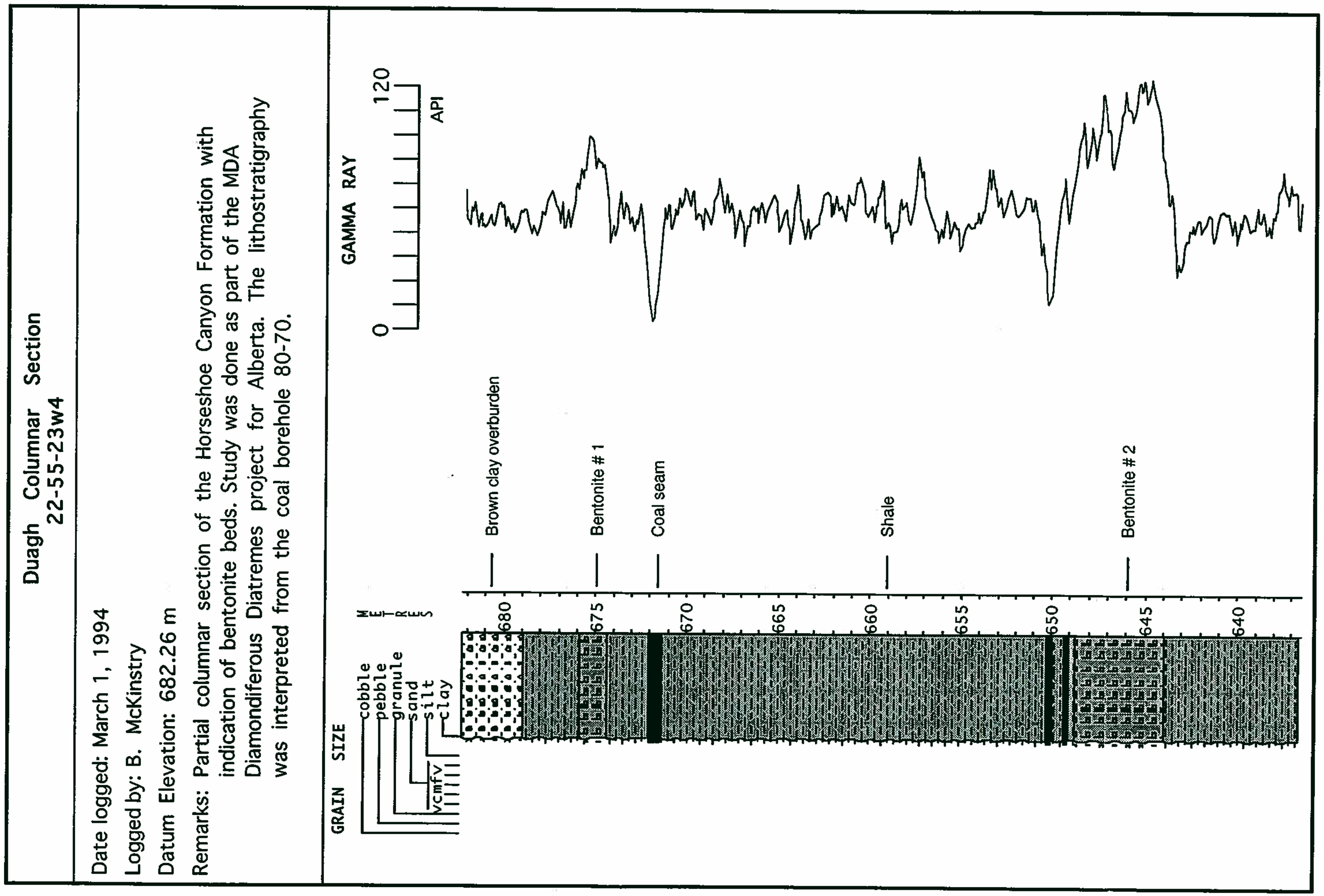


Figure 4.19: Structure contour map of the base of Bentonite #2 in the Duagh area.

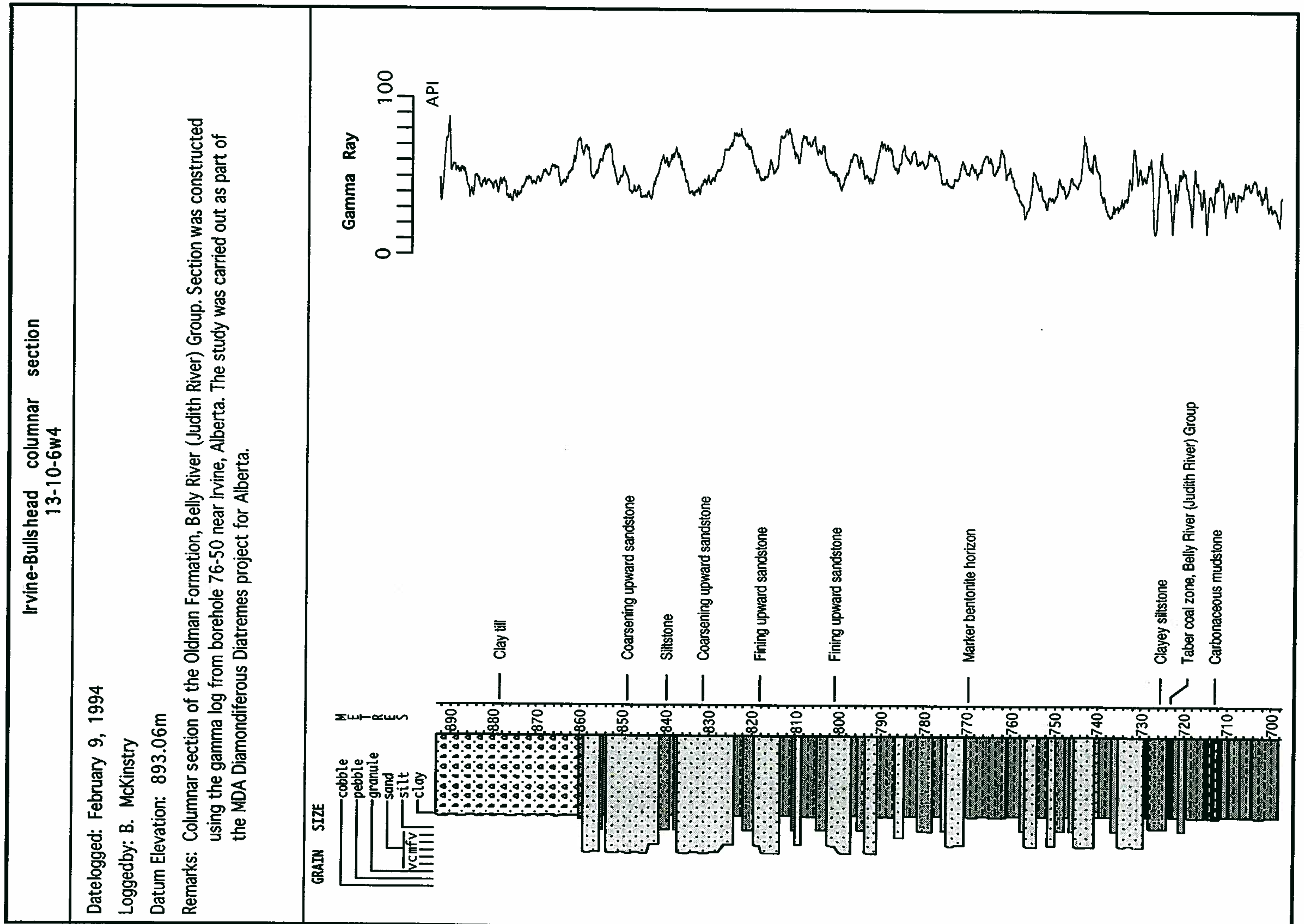
Scale 1: 250	REGIONAL DIAMOND STUDY OF ALBERTA MDA PROJECT M93-04-014	Figure: 4.20 LITHOSTRATIGRAPHY OF PART OF THE HORSESHOE CANYON FORMATION, DUAGH AREA, ALBERTA.



Scale 1: 1000

REGIONAL DIAMOND STUDY OF ALBERTA
MDA PROJECT M93-04-014

Figure: 4.21
BENTONITE OCCURRENCES IN THE IRVINE AREA, SOUTHEAST ALBERTA



Note: Borehole 76-50 has only two feet of marker bentonite but provides the best control for interpreting the lithostratigraphy of the section.

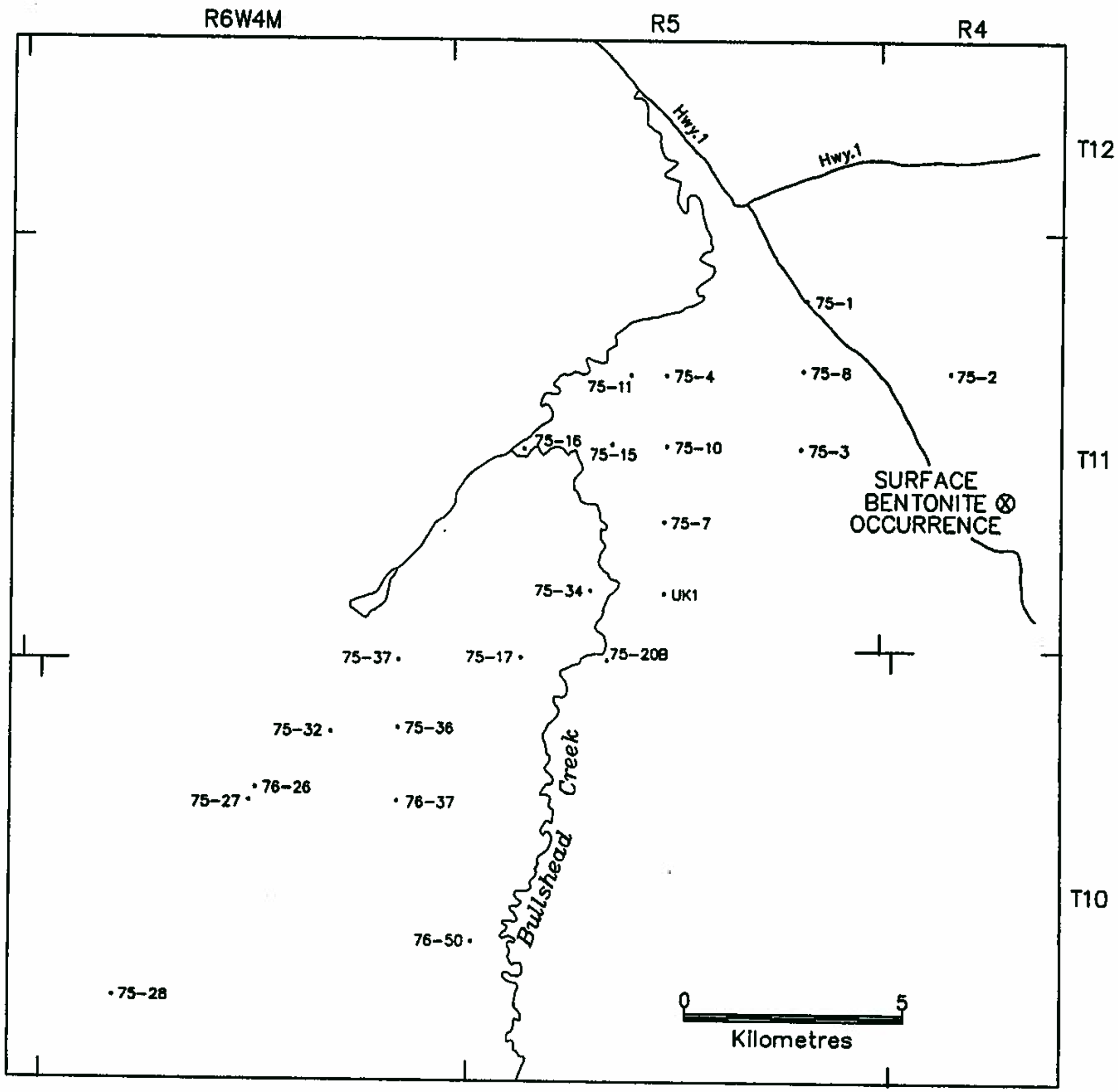


Figure 4.22: Well control, Bullshead Creek bentonite.

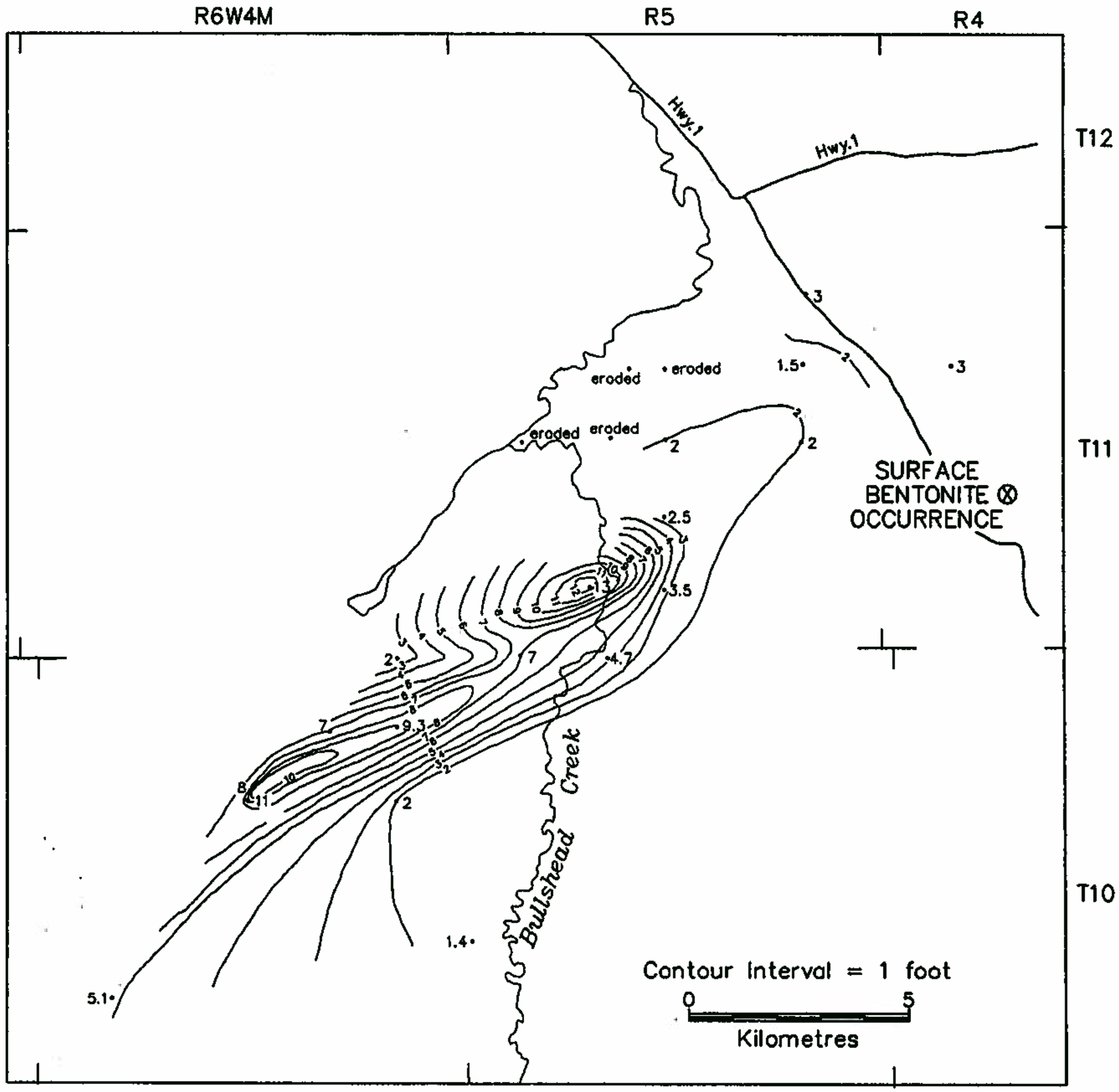


Figure 4.23: Bentonite thickness isopach map of the Bullshead Creek bentonite (thickness in feet).

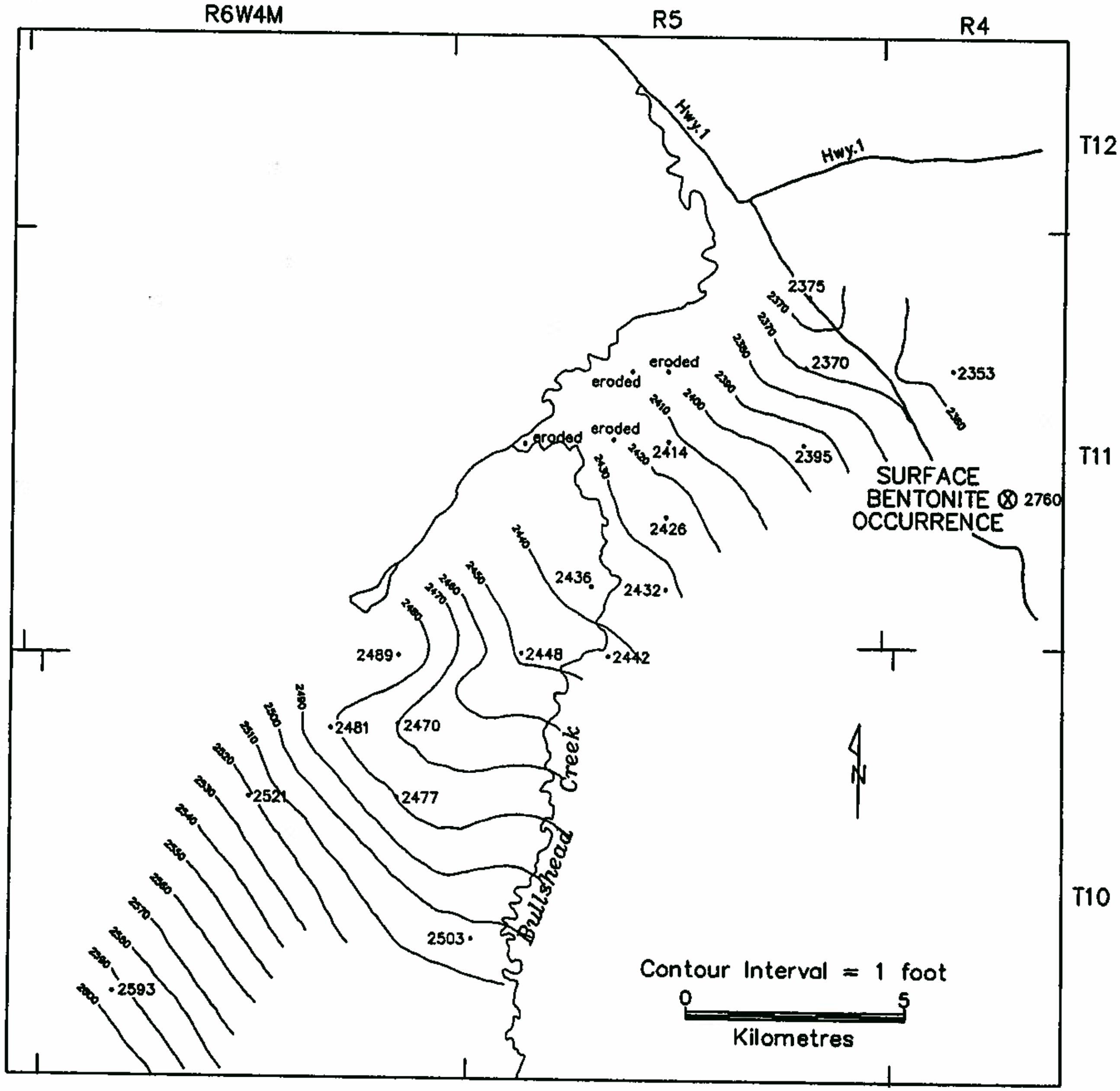


Figure 4.24: Structure contour map of the base of the Bullshead Creek bentonite.

TABLE 4.1 Bickerdike bentonite study

Imperial Oil Limited Drillhole Data Prest and McNeil Creek Area						
Hole Id	Bentonite # 1			Bentonite # 2		
	Top (m)	Base (m)	Vertical Thickness (m)	Top (m)	Base (m)	Vertical Thickness (m)
7	77.1	84.1	7.0	98.1	108.2	10.1
2	45.4	57.0	11.6	72.2	80.1	7.9
17-78	99.0	104.5	5.5			
18-78	112.5	115.7	3.2			
5	61.5	73.7	12.2			5.2
6	35.7	52.4	16.7	67.6	76.5	8.8
9	67.4	81.1	13.7			
Canadian Occidental Petroleum Drillhole Data Bickerdike Area						
Hole Id	Top (m)	Base (m)	Vertical Thickness (m)			
81-06	150.4	155.6	5.2			
82-05	148.5	152.5	4.0			
82-03	118.5	123.0	4.5			
82-04	117.5	122.5	5.0			
82-08	120.0	123.5	3.5			
82-02	147.5	152.5	5.0			
3-27-51-19	135.0	141.0	6.0			

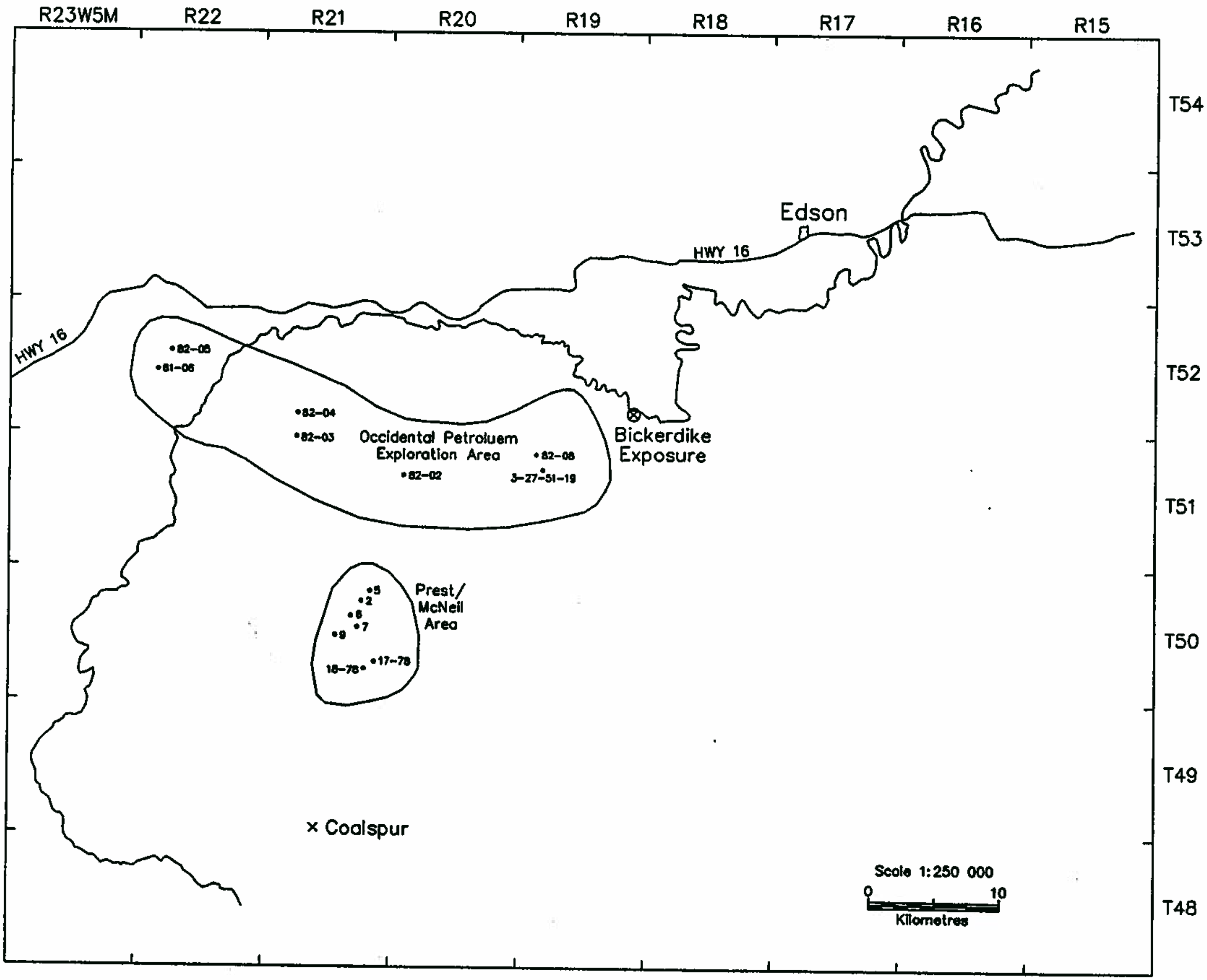


Figure 4–25: Bickerdike bentonite location map.

discontinuous bentonites in Alberta do not readily fit this mold. To account for these anomalously thick bentonites, one may postulate either secondary sedimentological processes or a more proximal position for the volcanic source.

The present study has examined some thick bentonite occurrences located in southeast, central and west-central Alberta. The bentonites range in age from Upper Cretaceous (Campanian) to Tertiary (Paleocene) (Figure 4.26). Although the geometry of some deposits are undoubtedly a product of sedimentary processes such as reworking, not all are adequately explained in this manner (e.g., the Drumheller and Irvine-Bullshead bentonites). Indeed, except for the paleoenvironment that exists at the Irvine-Bullshead bentonite area, there is little evidence to suggest there was contemporaneous or post-depositional dynamic fluvial processes available to rework the tuffs. Instead, it is more likely that any secondary sedimentological controls comprised wave or current action as suggested by Amajor (1985).

The emplacement of the Boulder batholith and adjacent satellite bodies in western Montana are considered to have occurred between 83 and 68 Ma (Decelles 1986). These igneous intrusions, as well as volcanic activity in the magmatic arc to the west of the thrust-fold belt (Dickinson 1976), are often cited as the volcanic source for ashfall tuffaceous horizons within the Late Cretaceous and early Tertiary sediments in Alberta. This ongoing volcanic activity certainly contributed significantly to tuff-bentonite development in Alberta. However, the anomalously thick Upper Cretaceous bentonite deposits which have an isopach thickness trend that is perpendicular to subperpendicular to paleodrainage patterns, are enigmatic and may offer evidence of more localized volcanic activity within the Alberta portion of the Cordilleran retroarc foreland basin during the Cretaceous and Early Tertiary.

4.5 <u>The Exshaw Bentonites, the Fish Scales Horizon and Condensed Sections</u>

Loutit *et al.* (1988) defined a 'condensed section' as a thin marine stratigraphic unit consisting of pelagic to hemipelagic sediments characterized by very low sedimentation rates. In terms of sequence stratigraphy (Van Wagoner *et al.* 1988), condensed sections overlie the onlapping retrogradational stacking of a transgressive system tract and are overlain by the prograding clinoforms of a highstand system tract. The condensed section is produced during a period of relative sea level rise and is associated with maximum water depths (maximum flooding surface). The marine transgression and increasing water depth significantly reduces the rate of terrestrial sedimentation and can be characterized by either non-deposition or reduced hemipelagic to pelagic deposition. Authigenic minerals (potassium-rich glauconite, phosphorite and siderite), organic matter, bentonites, and an elevated uranium and iridium content all may be preserved in a condensed section. The deeper water levels and reduced oxygen concentration may initiate important changes in microfossil taxa with lower oxygen values often related to lower concentration of benthic foraminifera. If non-deposition is prevalent, the surface is often characterized by burrowing or boring textures. Understandably, the geochemistry

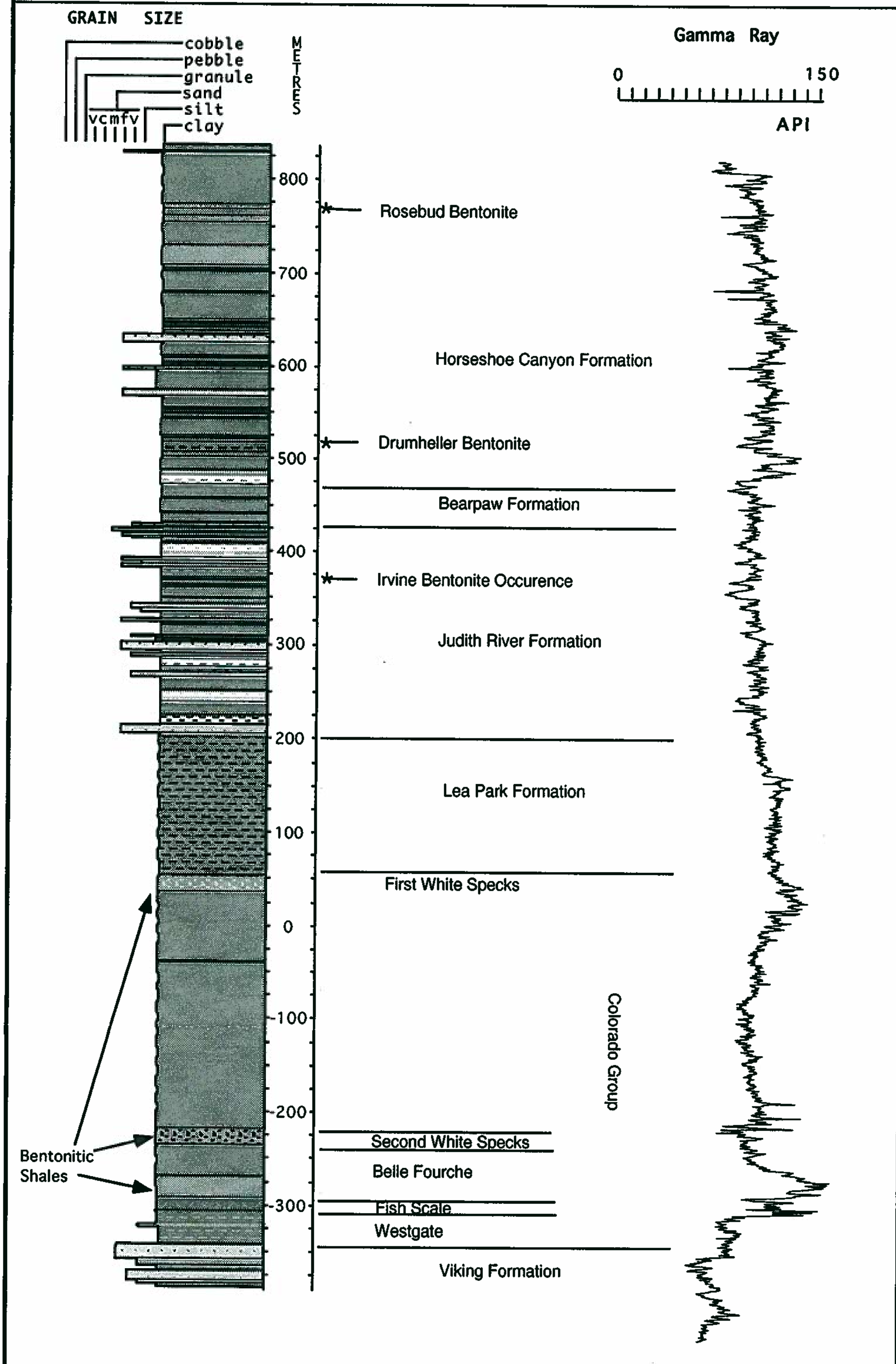
Scale: As Shown

REGIONAL DIAMOND STUDY OF ALBERTA
MDA PROJECT M93-04-014

FIGURE 4.26
STRATIGRAPHIC COLUMN: ALBIAN TO CAMPANIAN; CRETACEOUS, DRUMHELLER AREA, ALBERTA

Stratigraphic Column
7-7-28-20w4

Date logged: February 25, 1994
Logged by: B. McKinstry
Datum Elevation: 836.07 m
Remarks: Interpreted stratigraphic column from middle Horseshoe Canyon Formation to upper Viking Formation. Lithology was compiled from wells 7-7-28-20 and 47-84.



of condensed sections can be complex and is directly related to the prevalent oceanographic conditions in the overlying water column (Loutit *et al.* 1988).

An example of this complexity is the condensed section that has been recognized in the basal part of the Shaftesbury Formation near Peace River, British Columbia (Leckie *et al.* 1990a). Here, the section consists of a shale unit (Shale Facies 2) of Albian age that is located 4 m to 10 m above the contact with the underlying Peace River Formation. The basal 30 cm is a conglomeratic (lag) bone bed consisting of chert and quartzite pebbles, wood fragments, and fish bones, teeth and vertebrae. Overlying this is approximately 5 m of shale. The lowest 2 m of this unit displays an unusual and interesting geochemistry. Within this interval, the uranium content has been measured at five times the background value, providing an elevated natural gamma response on geophysical logs. As well, the total organic carbon content (2.75% to 5.56%), and also the boron and vanadium contents, are anomalously high and a sulphur/carbon crossplot indicates elevated sulphur values above normal marine conditions, more typical of euxinic conditions (e.g., the Black Sea). The shale contains a low diversity or absence of benthic foraminifera assemblages as well as abundant fish remains (scales). There is also a high percentage of algal cysts which is inversely proportional to foraminifera content. The authors interpret these characteristics as representative of a restricted marginal marine depositional environment, possibly involving somewhat euxinic conditions.

Similarly, Richards 1989 and Richards *et al.* (1993, 1994) consider the lower shale-dominated member of the Devonian-Carboniferous Exshaw Formation to be representative of a maximum flooding surface, hence this rock unit may be a condensed section. The evidence indicates anerobic to dysaerobic conditions prevailed in a moderately deep water environment during Exshaw Formation time. A basal resedimented lag deposit contains clasts of phophatic nodules, abraded bone fragments, fish teeth and scales. This thin basal unit (1 cm to 6 cm) is overlain by a black, 7 m thick shale unit that has a moderately high organic carbon content (4.2% to 5.5%). This shale lacks macroscopic benthic fossil organisms and can be traced in the subsurface in southern Alberta and Saskatchewan due to its elevated geophysical gamma log response (Meijer-Drees and Johnston 1993). An anomalously high Iridium content and paleontological evidence indicates the base of this shale unit defines a mass extinction boundary (Wang *et al.* 1993). In addition, both the lag deposit and shale unit are metal-rich with anomalous concentrations of Fe, Mo, Zn, Cr, Ni and Cu (Richards *et al.* 1993). Again, many of these characteristics are remarkably similar to those previously discussed for the Fish Scales Formation of the Cretaceous (Albian-Cenomanian) Colorado Group (Bloch *et al.* 1993).

The definition of a condensed section provided by Loutit *et al.* (1988) recognizes the presence of abundant and diverse planktonic and benthic microfauna. Indeed, the age-diagnostic microfossils that are found within a condensed section provide the key to age determination and correlation efforts in continental-margin sequences. The general lack of micofaunal evidence in the previously discussed examples, as well as the euxinic environmental conditions and anomalous heavy mineral geochemistry are noteworthy and require a distinction from the classical definition for a condensed section.

Regardless, the association of the Fish Scales Horizon with extensive kimberlitic diatreme activity in Saskatchewan may be highly significant. That is, this relationship may provide a powerful exploration tool for diamond prospecting in the Phanerozoic cover of Alberta. Figure 4.4 outlines the areal extent of the Fish Scales Horizon within Alberta and highlights the stratigraphic interval between surface exposure and the 500 m depth contour to the base of the Fish Scales. As well, Figure 4.5 provides a structure contour map of the base of the Fish Scales Horizon for Alberta.

4.6 Alberta Basement Structural Elements and the Bentonite Study Areas

Figure 4.27 combines the locations of the bentonite study areas with those structural features interpreted by aeromagnetic, seismic and gravity evidence to be part of the Proterozoic and Archean crystalline basement (Ross *et al.* 1991). The outline of the Devonian reef complexes has also been included, because the position of these reefal bodies is suspected to be partially controlled by pre-existing basement structures (Burton and Machel 1992; Edwards and Brown 1993). Interestingly, Figure 4.27 shows that the Bickerdike and Coalspur bentonite showings are along the proposed southern margin of the Beaverhill Reef Platform edge. The Drumheller showings are also near the edge of the Shelf Margin Reef Complex and the Duagh bentonites are near the southern edge of the Redwater Reef Complex and the proposed western extension of the Snowbird Tectonic Zone (Figure 2.4). Moreover, the Irvine-Bullshead showings are in proximity to the Eagle Butte structure [F-1 structure in Figure 4.27; Twp 8-9, R 4-5] (Haites and van Hees 1962; Sawatzky 1976). The only bentonite locality not associated with any significant basement structure or reef trend is the Dorothy-Trefoil occurrence which lacks any substantial areal distribution and was not observed in the subsurface.

Current thinking on the genesis of diamondiferous kimberlites considers emplacement of a diatreme from a mantle source to occur in a very short time frame. This rapid ascent of the magma assists in retarding the oxidation of diamonds to CO_2 or graphite. However, these conditions of emplacement almost certainly necessitate movement of the magma to the Earth's surface along pre-existing deep seated fractures within the crust. Although no association is conclusively postulated between kimberlite emplacement and the bentonites examined in this study, the spatial association of these relic tuff deposits with suspected deep seated basement structures is of both academic and potential exploration interest.

4.7 Aspects of Bentonite Composition

As previously stated, bentonites are primarily composed of the clay mineral, smectite. Where kaolinite is the principle clay mineral (greater than 50%), the term 'tonstein' is

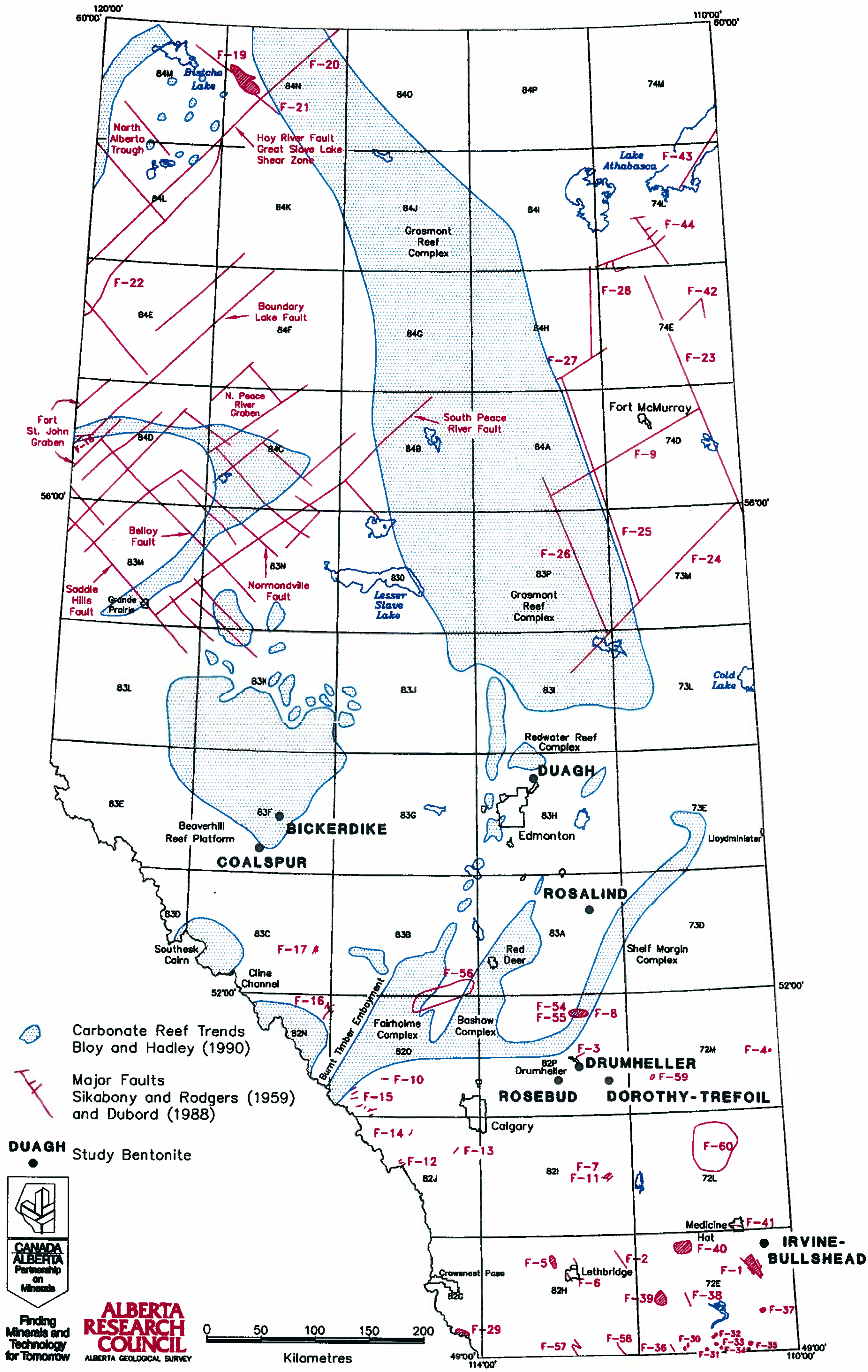


Figure 4.27: Relationship of study bentonites to major faults and carbonate reef trends in Alberta.

used (Lyons *et al.* 1992) and these deposits are best considered as in situ alteration of air-fall volcanic ash associated with nonmarine coal-forming environments. Demchuk and Nelson-Glatiotis (1993) described the presence of tonsteins in the Ardley coal zone near Wabamum, Alberta. They observed that areas of thick peat accumulation or mires provide suitable sites for preservation of volcanic ashfalls. If the mires are raised above groundwater level, a highly acidic environment is developed. This environment provides optimum conditions for the diagenetic mineralization of kaolinite from the ash. Strong dissolution processes are also evident within this setting and detrital minerals are few, but may include plagioclase feldspar, muscovite, calcite and minor amounts of quartz. Where there is peat accumulation under conditions of low-leach rate, flow-through groundwater and near neutral pH, diagenetic alteration to smectite would be more likely to occur. This sensitivity of clay diagenesis to depositional environment has been demonstrated in mapping the lateral transformation of bentonites to tonsteins from marine to nonmarine depositional settings (Waage 1961).

Bentonite mineralogy can be subdivided into clay and sand/silt size fractions. The clay mineralogy may be considered products of the diagenetic alteration of parent volcanic material responding to the depositional environment. The silt/sand size mineralogy is a composite of both the coarse (phenocryst) fraction of the volcanic tuff as well as the influence of nearby fluvial systems and attendant argillaceous contamination of the ashfall material. Typical bentonite mineral composition for the sand/silt size fraction includes quartz, plagioclase, muscovite, biotite, apatite, volcanic glass, montmorillonite and potassium feldspar. Montmorillonite (smectite) and devitrified volcanic glass are prevalent in the clay size fraction. Typical ratios K_2O/Na_2O average 0.2 and range from 0.01 to 0.5. Tonsteins generally contain a restricted suite of primary volcanic minerals such as beta-quartz, sanidine, zircon, biotite, rutile, ilmenite, magnetite, apatite, allanite and other accessory minerals indicative of a siliceous volcanic source.

Atypical or unusual mineral composition within bentonites/tonsteins would be best reflected in the sand/silt fraction. The presence of garnet, olivine, phlogopite and pyroxenes in this fraction may indicate anomalous volcanic or detrital sources. As noted by Bohor and Triplehorn (1993), the mafic character of a tuff may be inferred by the presence of abundant hornblende and zoned plagioclase and absence of sanidine. Within the clay size fraction, unusual ash chemistry may suggest unique volcanism. Appendix 4.1 lists several localities where atypical or unusual mineralogy or geochemistry was observed in Alberta bentonites. In particular, localities 28 (Bow River), 46 (Embarass River), 48 (Oldman River) and 49 (St. Mary River) warrant further investigation.

4.8 Commercial Database Investigations:

A search was initiated within a Calgary-based commercial database for observed occurrences of igneous, volcanic or bentonitic rock types that had been logged in previously drilled conventional oil and gas exploration drillholes.

All igneous rock type listings proved to be cuttings descriptions from deep boreholes intersecting Precambrian basement rocks. Moreover, a complex pattern of interlayered volcanics, thin bentonites and sedimentary rocks in two boreholes near the Waterton area of southwest Alberta was the result of drilling through a series of imbricate thrust sheets involving Crowsnest Formation volcanics and associated sedimentary formations. However, four holes within the database intersected unexpected volcanic intervals within a sequence of interlayered sedimentary lithologies. These anomolies include wells CS Sabine Keho 16-31 (16-31-11-23 W4M), Imperial Fedorah No. 1 (13-22-57-23 W4M), Pacific Petroleum Angelus Ashmont No. 1 (13-03-60-11 W4M) and Westcoast Petroleum AEC Suffield 6-30EP (06-30-18-08 W4M). Holes (16-31-11-23 W4M), (13-22-57-23 W4M) and (13-03-60-11 W4M) lacked any anomalous geophysical response to the logged volcanic intervals. However, hole (06-30-18-08 W4M) showed a moderate resistivity response at the top of the logged volcanic interval. Interestingly, the volcanics logged in hole (16-31-11-23 W4M) are stratigraphically situated immediately beneath the Fish Scales Horizon. Further study of the presence of volcanics is recommended for these four boreholes.

All bentonite occurrences in this commercial database are less than 3 m in vertical thickness, with the majority of reportings being less than 2 m in thickness (Table 4.2). The depths at which most of these reportings occur offer little assistance in the exploration for diatremes. However, their existence re-affirms the presence of anomalously thick bentonite layers, both at surface and in the subsurface, at least locally, within the Alberta portion of the Western Canada Sedimentary Basin.

5. REGIONAL GEOPHYSICS AND OTHER REMOTELY SENSED DATA

5.1 Introduction and Background Information

This chapter describes the regional details of a number of geophysical signatures that can be related to the structure of the crust and upper mantle beneath the province of Alberta. From the perspective of petroleum exploration, the Western Canadian Sedimentary Basin is among the most heavily geophysically explored regions on the earth in terms of seismic reflection profiling. Despite this, however, as in most parts of the world, the larger scale features of the upper mantle and crust beneath Alberta have not been studied in great detail. This report will review the existing literature for a variety of geophysical techniques that include seismic, magnetic, gravitational, electrical and geothermal measurements which exist within and near Alberta. It should be noted that the data can be quite sparse, except from a few types of data that have been systematically compiled by the Federal and Provincial governmental agencies. However, new results that will be obtained by the presently ongoing Lithoprobe Alberta Basement transects may provide new insights and interpretations about the crust beneath Alberta than what might be obtained from the presently available data sets.

The following is a brief description of the gross structure of the earth from which to set the stage for more regional geophysical observations about Alberta. This is also important background information in light of the fact that the source regions for diamonds probably occur at depths of about 150 km or more. That diamonds are observed at the surface attests to the interactions between the upper mantle and the crust of the earth upon which we reside.

5.1.1 Earth Structure

In its most simple sense, the earth may be characterized as consisting of three distinct shells: the core, the mantle and the crust. Prior to the beginning of the 20th century there was little direct evidence, save for astronomical observations of the earth's density and moment of inertia, for delineation of the earth into three zones. After the turn of the century, however, seismic recording techniques and the increasing density of observations allowed a much more detailed picture to be obtained. This model for the earth is being continually refined to the present day and the reader is referred to Fowler (1990) for general reviews.

The radius of the earth of about 6,420 km. The seismic data indicate the existence of a dense core at the centre of the earth. The inferred density of this core is consistent with a mixture of iron and nickel contaminated with lighter elements such as oxygen, nitrogen, carbon or sulfur. The core may be further divided into inner and outer regions. The inner core has a radius of about 1,250 km and extends from the centre of the earth to depths of about 5,170 km below the earth's surface; this inner core is apparently solid. The surrounding outer core which reaches to depths of 2,900 km, does not transmit seismic shear waves and hence is liquid; rapid convective motions within this region produce the earth's strong magnetic field via a dynamo effect. This liquid region further suggests that there is substantial heat retained at these depths. The exact sources of this heat are unknown, but probably include: (a) release of gravitational energy during the formation of the earth and differentiation of the core materials, (b) short lived radioactive decay in the early history of the earth, and (c) the possibly ongoing formation of the inner core due to the release of the latent heat of freezing. In any event, the core is important to the dynamics of the planet because it is an enormous reservoir of heat energy, the leakage of which into the base of the mantle drives the shallower convection that is eventually manifested at the surface of the earth as volcanism and plate tectonics.

The region separating the core from the mantle is a chemical and thermal boundary layer often referred to as the 'D' shell (Morelli and Dziewonski 1987). Chemically, it separates the liquid outer core from the overlying silicate mantle. Thermally, the temperatures above and below this region may differ by more than 2,000°C if recent high pressure experiments on the melting temperature of iron are valid (Jeanloz 1988). The thickness (less than 200 km) and exact depth (within 10 km) of this core-mantle boundary are not well understood, but the region appears to be extremely heterogeneous on the basis of some seismic measurements and from laboratory experiments that suggest some

TABLE 4.2: Bentonite occurrences identified in oil/gas drillholes

Hole Identifier	Land Description	From (m)	To (m)	Vertical Thickness (m)
A8	11-06-12-9 W4M	766.2	769.0	2.8
A486	12-11-12-24 W4M	1399.0	1400.6	1.6
A3235	10-25-12-26 W4M	1916.6	1918.7	2.1
A689	2-35-13-16 W4M	780.9	781.8	0.9
A688	10-11-13-17 W4M	783.3	784.9	1.6
A688	10-11-13-17 W4M	792.5	794.9	2.4
A714	7-18-14-11 W4M	760.5	762.0	1.5
A1027	7-14-15-11-W4M	734.6	735.5	0.9
A1027	7-14-15-11-W4M	952.2	954.0	1.8
A1060	2-29-15-18 W4M	1126.8	1128.7	1.9
A4190	6-4-15-24 W4M	1487.4	1488.3	0.9
A4190	6-4-15-24 W4M	1699.0	1699.9	0.9
A9047	11-12-15-28 W4M	2190.6	2191.5	0.9
A9047	11-12-15-28 W4M	2556.4	2557.3	0.9
A4553	14-5-15-29 W4M	2942.8	2944.4	1.6
A3842	7-22-15-29 W4M	2570.4	2572.2	1.8
A410	8-13-16-24 W4M	1408.2	1409.4	1.2
A1059	15-19-17-23 W4M	1498.7	1499.6	0.9
A1049	1-5-18-23 W4M	1508.8	1510.3	1.5
A1049	1-5-18-23 W4M	1517.6	1519.7	2.1
A9063	4-25-18-28 W4M	1865.1	1866.0	0.9
A392	5-28-22-13 W4M	810.5	812.6	2.1
A392	5-28-22-13 W4M	842.8	844.3	1.5
A802	1-13-23-7 W4M	761.4	762.3	0.9
A802	1-13-23-7 W4M	767.2	768.1	0.9
A12	1-3-23-27 W4M	1743.5	1745.0	1.5
A928	16-7-24-16 W4M	975.4	976.3	0.9

Hole Identifier	Land Description	From (m)	To (m)	Vertical Thickness (m)
A928	16-7-24-16 W4M	1140.3	1141.2	0.9
A346	16-10-25-21 W4M	1283.2	1284.1	0.9
A346	16-10-25-21 W4M	1286.3	1287.2	0.9
A346	16-10-25-21 W4M	1302.1	1303.3	1.2
A346	16-10-25-21 W4M	1324.7	1325.9	1.2
A154	9-29-28-20 W4M	1209.4	1210.4	1.0
A42	4-12-29-5 W4M	827.5	828.8	1.3
A416	4-10-29-18 W4M	1189.0	1189.9	0.9
A1552	4-10-35-18 W4M	1217.1	1218.9	1.8
A9147	6-18-40-21 W4M	1303.6	1304.5	0.9
A9111	6-23-42-12 W4M	875.1	876.0	0.9
A5556	2-1-5-2 W5M	831.0	832.5	1.5
A5556	2-1-5-2 W5M	893.5	895.5	2.0
A5556	2-1-5-2 W5M	2523.0	2525.0	2.0
A5140	11-7-27-5 W5M	2061.0	2062.2	1.2
A945	10-22-30-1 W5M	2031.8	2033.6	1.8
A4239	7-29-37-6 W5M	2311.9	2314.3	2.4
A5175	7-22-42-2 W5M	885.0	887.0	2.0
A1795	10-18-43-2 W5M	1865.4	1866.0	0.6
A5153	14-24-53-8 W5M	545.0	546.5	1.5
A41285	10-30-54-25 W5M	3554.9	3555.8	0.9
A4139	6-27-57-13 W5M	1385.0	1386.0	1.0
A528	13-35-80-24 W5M	730.0	730.9	0.9
A4088	7-24-63-3 W6M	1923.0	1923.9	0.9
A4354	5-30-65-6 W6M	1544.7	1545.9	1.2
A4129	10-29-67-10 W6M	1203.0	1204.0	1.0
A4129	10-29-67-10 W6M	1207.0	1207.9	0.9
A773	4-15-88-2 W6M	968.3	969.3	1.0

temperatures and pressures expected at these depths. Again, although the core-mantle boundary is relatively thin, an understanding of it is important because all the heat transferred to the mantle from the core must pass through this region.

The silicate mantle lies above 2,900 km depth and extends nearly to the surface. It comprises the bulk of the mass of the earth. The lower mantle below 700 km is characterized seismically by a gradual increase in both compressional and shear seismic wave velocities. These velocity increases are consistent with the changes anticipated in a homogeneous medium subject to an increasing pressure with depth and suggest that there may be little structure to the lowermost regions of the mantle. Indeed, laboratory experiments indicate that a high pressure form of (Mg, Fe)SiO_3 called silicate perovskite is stable throughout the pressure and temperature range anticipated in the lower mantle.

5.1.2 The Upper Mantle

The upper mantle above 700 km, however, is of more interest to the explorationist because it is within this region that the temperature and pressures regimes sufficient for the formation of diamond are encountered. This upper mantle structure is manifest as discontinuities, or sharp changes, in the seismic velocities of the upper mantle near depths of 670 km and 400 km. These discontinuities are thought to originate from densification due to rearrangement of the molecular structure of the mineral olivine, an important component of ultramafic rocks, due to increasing pressure with depth. The phase changes across these two discontinuities, each raise the density of the material about 10%. The depth ranges over which these phase changes occur are not well known, but probably are not more than 20 km. The material compressional and shear wave velocities also increase rapidly between these two discontinuities and this region of the upper mantle is often referred to as the transition zone (Anderson and Bass 1986). These changes are primarily evident at the surface as variations in the compressional (P) and shear (S) wave velocities, and a standardized reference plot of P and S wave seismic velocity versus depth to 1,000 km within the earth is shown in Figure 5.1 (Dziewonski and Anderson 1981) .

An interesting, and complicating, coincidence with the 670 km discontinuity is that there are no earthquakes observed below this depth. Deep earthquakes occur in cold downgoing oceanic slabs entrained into the upper mantle by subduction; the 670 km limit may indicate that these slabs do not penetrate further into the mantle. This observation has prompted some workers to suggest that the 670 km discontinuity delimits a compositional boundary where the gross chemical constitution of the upper and lower mantles differ. Under this scenario there is little exchange of material across the 670 km discontinuity with the result that there may be independent convective motions of material between the upper and lower mantles.

It is interesting to note in Figure 5.1 that there is a small decrease in the P wave velocity with depth near 200 km. Although this negative trend is not completely understood, it has

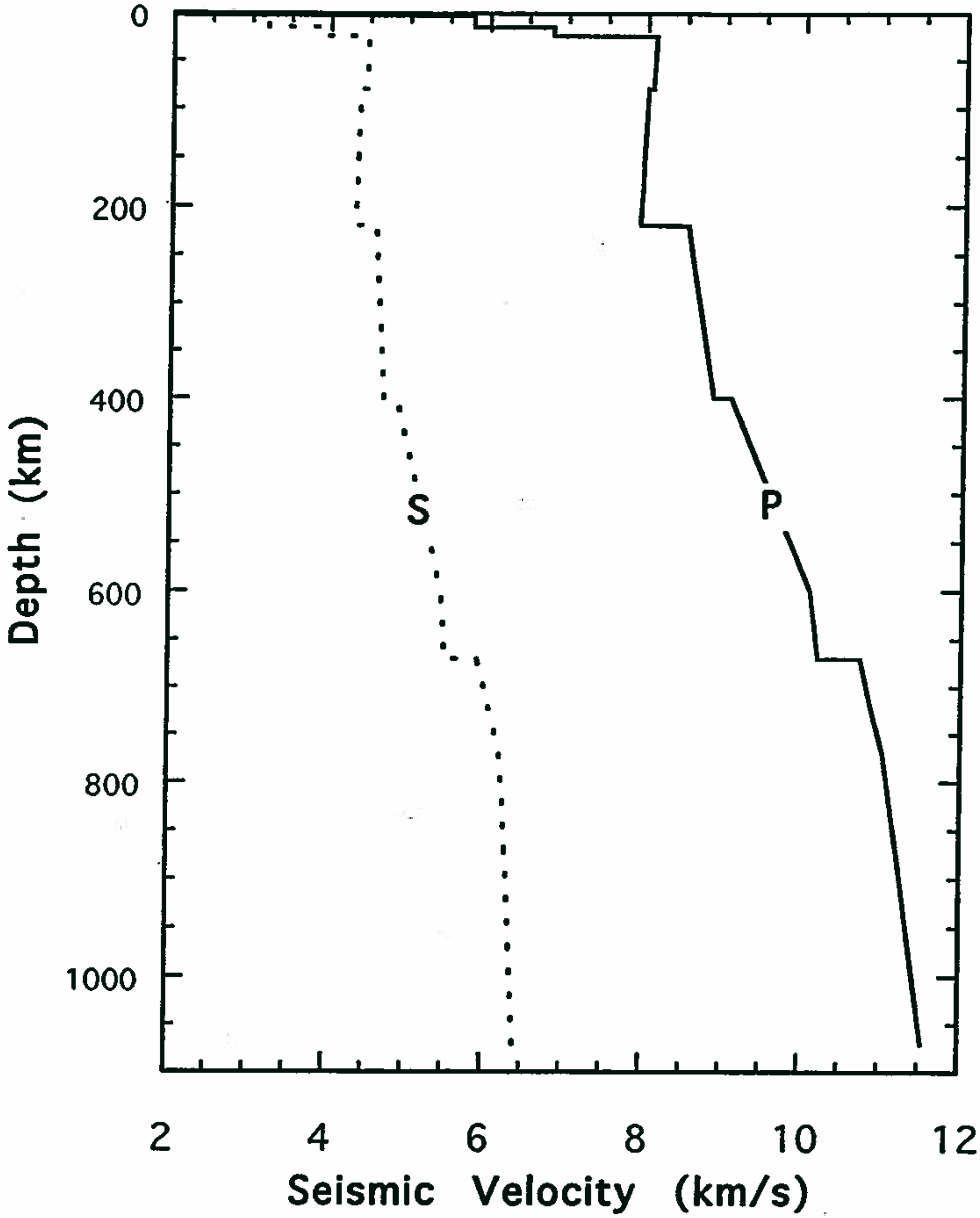


Figure 5.1 Compressional (P) and shear (S) wave velocities versus depth from the earth's surface. Data from the preliminary reference earth model of Dziewonski and Anderson (1981).

been suggested that this velocity decrease is due to a partial melting of the rocks at these depths. This agrees well with other geophysical evidence of a zone of high electrical conductivity and with an inferred zone of low viscosity from observations of the rebound in elevations of the crust after the relatively rapid removal of load associated with large lakes or glacial ice caps. In general, this weak region, often called the asthenosphere, may be thought of as the region where the solidus (the point at which rock first melts) is reached. Under these conditions the region is possibly a source of magma. Further, materials very near their melting temperature are in a highly ductile state and will flow at sufficiently long time scales under deviatoric stresses; such stresses could arise as part of the convective motions within the mantle.

5.1.3 The Lithosphere and Crust

Above the asthenosphere and to the earth's surface lies the outermost shell of more rigid rock called the lithosphere. Definitions of the lithosphere vary depending upon the type of geophysical measure used (see Anderson (1989) for a full discussion), but the lithosphere is generally taken to mean the highly viscous surface unit of the Earth. The thickness of this unit strongly depends on the temperature at depth because the viscosity of materials are highly temperature dependent, with the rule of thumb definition between a fluid and a solid being set at a viscosity of 1013 Poise. Generally, in continental regions the lithosphere includes from 100 to 200 km of the uppermost mantle beneath the continental crust (Walcott 1970).

It is difficult to know exactly the chemical composition of the upper mantle as we have no means of directly observing it from the surface. Evidence is instead obtained from noting the average compositions from certain classes of primordial stony meteorites and from the ratios of differing elemental abundances within the solar corona, both of which are presumed to be representative of the material which came together in the early formation of the earth. Other evidence comes from mantle xenoliths, some of which are diamond bearing, that are carried by magma from great depth to the surface. On these bases, the mantle is defined (Meissner 1986) to be a zone with P wave seismic velocities in excess of 7.6 km/sec and S wave velocities in excess of 4.4 km/sec, and with a density greater than 3.1 g/cm^3. These high velocities and densities are due to the fact that these rocks are ultramafic in composition. In the upper mantle the predominant minerals, and their derivative high pressure polymorphs are fosterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4), together with major amounts of pyroxene and garnet. These latter minerals are often used as indicators for diamond exploration purposes. The resultant rock types are peridotite, dunite and garnet-bearing eclogite. Chemically, MgO and FeO are thought to comprise more than 37% and 7%, respectively, whilst SiO_2 is below 44%, of the chemical composition of the upper mantle.

The crust of the earth lies immediately above the upper mantle and it too has many definitions which are further complicated by the two very distinct continental and oceanic characterizations. Seismically, the crust is taken to represent the outer shell of the planet with P and S wave velocities less than 7.6 km/sec and 4.4 km/sec, respectively. The contrast between the crust and the top of the mantle results in a distinctive critically refracted seismic arrival (Fowler 1990) that was observed early in the history of seismology by Mohorovicic in 1909 and in his honor this boundary is called the Mohorovicic discontinuity or, more commonly, the Moho. A second definition of the crust derives from observations of changes in density within the earth from gravitational measurements. In particular, classical geophysical studies demonstrated that a free pendulum is deflected less by a mountain range than might be expected if the earth were of a uniform density.

These gravitational observation lead to the theories of isostatic compensation of Pratt and Airy (Fowler 1990) in which the crust is considered to have a density lower than 3.1 g/cm^3. The seismic and density definitions are inter-related and are mostly the result of the differing chemical composition of the crust relative to the mantle, which is reflected by changes in the physical properties of the rocks. Mineralogically, the crust is feldspar rich, with the proportion of feldspar being in excess of 50% and consisting primarily of orthoclase plus albite (31%) and plagioclase (19%). Chemically, the oceanic and continental crusts differ, with the SiO_2 component comprising 49% and 60%, respectively. Other important chemical constituents include Al_2O_3 (15%), CaO (12% in oceanic and 6% in continental crust), and Fe_2O_3 (6% in oceanic and 4% in continental crust). As the result of these chemical and mineralogical proportions, the predominant continental crustal-forming lithologies are various sedimentary rocks, gneiss, granite, granodiorite, gabbro, amphibolite and granulite. The oceanic crust, on the other hand, consists essentially of various sedimentary rocks, basalt, gabbro and serpentinite.

The continental crust contains substantially more granitic rocks, than the oceanic crust, hence the continental crust generally is less dense and much thicker. The thickness of the continental crustal varies from about 20 km on continental shelves to almost 70 km beneath the highest mountain ranges. Further, the crustal thickness appears to increase with age. In contrast, the oceanic crust ranges in thickness from nearly zero at oceanic spreading centres to as much as about 7 km in the oldest oceanic crust.

The thickness of the crust, but more likely the lithosphere, may be important to diamond exploration (Gent 1992). One school of thought holds that the survival of diamonds may be increased if they were transported from their source region at about 200 km in depth to the surface through relatively thick, and hence cooler, lithosphere. This is important because at more elevated temperatures and lower pressures, graphite is the preferred carbon mineral. Consequently, diamonds produced at depth could be destroyed by transport through hot lithosphere which, by definition, will also be thinner.

A review of the current knowledge of the regional structure of the continental crust and lithosphere specifically related to Alberta follows.

5.2 Seismic Data Relevant to the Regional Scale in Alberta

This and subsequent sections reviews the literature pertinent to regional scale observations within and near Alberta. These data include inferences formed from: (a) seismic observations made at many scales, (b) measurements of the variations in the acceleration of gravity, (c) the strength of the earth's magnetic field, (d) electrical measurements, and (e) geothermal observations. These regional analyses of the existing, public domain data are important to the explorationist for two purposes. Firstly, to present the existing geophysical evidence, albeit limited, as to the state of the upper mantle, lithosphere and crust that could be important in evaluation of the potential of the region for the existence of diamonds. And, secondly, to point out the geophysical basis for delineating a number of regional, and primarily crustal, features which could serve as the locus of exploration. For example, regional scale magnetics are able to highlight zones of intense deformation produced during construction of the craton during the Phanerozoic; these zones might in some cases be expected to be weak in the sense that they probably cross through the entire crust to the mantle and hence provide a preferred path for migration of intrusive igneous melts.

5.2.1 Seismological Observations of the Upper Mantle Beneath Alberta

A diamond crystal, which is composed in its purest form solely of elemental Carbon, requires extreme temperatures and pressures for formation. These conditions are expected to be encountered at depths in excess of 150 km or more within the earth. Consequently, it is useful to review the existing public knowledge of the upper mantle and lithosphere beneath Alberta. A number of seismic observations in the literature are pertinent; however, it must be noted that the power of these techniques to resolve features is limited by the large wavelengths of the seismic energy used. Since these can exceed 100 km for certain types of long period seismic arrivals, the spatial resolution of these techniques is of nearly the same order and the observations must be interpreted with this limitation in mind.

Wickens (1977) provided the results of an analysis of how the velocities of certain surface waves observed at a number of fixed seismometer sites across Canada and produced by distant earthquakes, varied with frequency from 0.1 Hz to 0.0125 Hz. The analysis technique exploits this dispersion (i.e., change of velocity with frequency) of these types of waves.

Essentially, the longer the wavelength (or lower the frequency) the greater the depth that the seismic wave senses and by extracting the variation of the velocity with wavelength one can estimate a one dimensional geologic structure represented by variations in the seismic velocity with depth. Wickens (1977) delineated a number of differing regions on the basis of variations in his observed velocity-depth relationships. His 'South' region includes much of the southern portions of the Prairie provinces, which was distinguished by a relatively thick crust of 44 km underlain by a higher velocity seismic 'lid' with S wave velocities in excess of 4.64 km/sec and with a thickness of about 50 km above a low velocity zone with velocities below 4.61 km/sec from depths of about 90 to 200 km. This structure contrasts markedly from that in other regions such as: (a) his 'West' region, which is roughly coincident with the Cordillera where a thin crust of about 30 km lay above a very low velocity layer at quite shallow depths, thus indicating that the lithosphere may be quite thin in this region, and with (b) his 'Shield' that is centred near Hudson's Bay with a crust also of about 30 km, but with a thick seismic high velocity 'lid' extending to depths of 120 km. Taken together this may suggest that the lithosphere thickens from the Cordillera to the Shield, with the region within much of Alberta being intermediate to these two extreme cases. Wickens (1976, 1977) suggested that these observations of lithospheric thickness were concordant with those of the flexural rigidity, and hence thickness, of the lithosphere of Walcott (1970). One cautioning note, however, is that the observations obtained over the 'South' region were difficult to interpret, which suggests that there may be considerable variations in lithospheric thickness over the southern portions of the Prairie Provinces.

More recently, Anderson and coworkers (Nakanishi and Anderson 1984; Nataf *et al.* 1984, 1986) analyzed a more global set of observed seismic surface waves. The dispersions of the surface waves in their analysis allowed resolution of the S wave velocity and anisotropy (i.e., the change in the velocity with direction in the earth) to depths as great as 450 km. They generally noted that the observed S wave functions with depth correlated well with the surface tectonic features, such as shields, subducting slabs and oceanic ridges at depths above 200 km, but below this depth and especially in oceanic regions the comparisons were less favourable. Shield regions, however, were generally of high seismic velocity, which is indicative of cool, and hence fast, mantle and in these regions the fast velocities extended below 200 km. Their results are in good qualitative agreement with the more averaged results of Wickens (1977) in that the velocities tended to increase from west to east as one travels from the Cordillera to the Canadian Shield.

These variations in velocity if interpreted as being a consequence of the effect of temperature on the seismic velocity of the rock, also indicate that the uppermost portions of the mantle cool from the Cordillera to the Shield. This corresponds with a concomitant increase in the rigidity at depth and hence a thickening of the lithosphere might be expected.

Instead of analyzing the Love and Rayleigh (Fowler 1990; Bullen 1980) surface waves, an alternative approach to delineating the seismic structure of the upper mantle relies on a class of seismic waves called P or S body waves. Unlike surface waves which exist only because of the large discontinuity in properties at the earth's surface, body waves propagate directly through the volume of the earth from their source (usually an earthquake) to a seismic detector. The path taken by a body wave is controlled by the velocity structure of the earth at depth. Consequently, one may obtain information about the velocity structure from the time it takes a given body wave to travel from its source to the seismometer. When a large number of these travel times are assembled in a single data set for differing source and detector locations one may use them to calculate the velocity structure. This calculation process is termed 'seismic tomography' and the idea is intimately related to the 'Computer Aided Tomography' more commonly called CAT-scanning in the medical fields which use X-rays to image the body. A brief review of the principals of seismic tomography is provided by Anderson and Dziewonski (1984) and a number of different studies have been undertaken.

Dziewonski and Woodhouse (1987) reported on their analysis of the travel times of waves produced by earthquakes to various seismometer stations worldwide. Their travel time data are continuously recorded by the International Seismological Centre which records the observations made at over 1,000 individual stations. Their map of the shear wave velocities at 150 km depth shows the existence of fast velocities as much as 4% greater than that expected in the standard earth model of Figure 5.1. Their data also appear to indicate that across Alberta there is a rapid increase of the shear wave velocity in a more or less northeasterly direction. A depth profile further indicates that there is a fast and hence potentially cooler region that extends to depths of more than 300 km beneath the Canadian Shield immediately to the north of Alberta.

The most important regional tomographic study for the present purposes, however, is that of Grand (1987) who inverted differing types of S wave arrivals. His study is important because it used a large number of observed travel times (3,923) and also in that he determined directly these times, thus avoiding the potential for inconsistencies and errors associated with the travel times published by the International Seismological Committee (ISC). His final model consisted of average velocities determined over a horizontal grid with square cells of 500 km dimension and with variable thicknesses of about 100 km with depth. He noted the existence of a high velocity root extending to depths of 400 km directly beneath the Superior Province of the Canadian Shield. Although care must be taken in the interpretation of his results due to the relatively low spatial resolution set by the 500 km grid size, his results are consistent with earlier suggestions that Alberta appears to fall along the axis of a transition between the slow seismic velocities of the Cordillera and the fast velocities of the Canadian Shield. At depths above 140 km, the average velocities in his model are 3% higher than his standard velocity model (Grand and Helmberger 1984) over almost all of Alberta, with the transition between the slow and fast regions being roughly coincident with the Continental Divide. Grand's (1987) plots of the average velocity between 140 km and 235 km retain high velocities in the northern sections of the province, with values which are more typical of much of North America. Below 235 km to 405 km the velocity differences across the province are moderate, but a general increase from expected to 2% faster values exists from west to east across Alberta. This trend continues into Saskatchewan, with 3% faster deviations occurring near the Saskatchewan-Manitoba border. Beneath depths of 400 km, the velocities underneath Alberta appear to diverge little from those expected for S waves in Figure 5.1.

In summary, the large scale seismic surface wave analyses and the tomographic studies appear to be consistent with one another in that they both indicate that seismic velocities generally increase from west to east across Alberta at all depths above 400 km. This behaviour differs from the more uniform slow and fast velocities observed in the Cordillera and Precambrian Shield, respectively, and these observations indicate that the present day upper mantle beneath Alberta may be transitional between these two well defined tectonic regimes. These velocity variations could be primarily related to temperature, with fast mantle indicative of cooler temperatures (Hoffman 1990), although Jordan (1981) and Boyd (1989) indicate there may be subtle variations in mineralogy of the rocks which is partially responsible. If such is the case, the thickness of the lithosphere also would be expected to increase from west to east across Alberta.

These seismic observations of lateral heterogeneity in velocity are also concordant with modelling of the deformation (flexure) of the lithosphere due to its loading since the Lower Jurassic by the advancing Rocky Mountain thrust sheets. Wu (1991) used the shape of the Mississipian unconformity in the Western Canada Sedimentary Basin as a measure of the deformation. He could only produce the Mississipian surface if his model included an eastward lithospheric stiffening which would be the result of lithospheric cooling and consequent thickening.

The refraction and the reflection methods are the two principal seismic techniques used to study the crust. The reader is referred to Fowler (1990) for a detailed description of the methods. Briefly, however, the refraction method records the times of arrivals of seismic rays (i.e., the map of the path taken by a seismic wave through the earth) that are either critically refracted along geologic interfaces between two rock types of differing velocities (head waves) or turned by the general increase in seismic velocity with depth (turning rays). The explorationist commonly applies the same principles at a much smaller scale in the derivation of the near surface velocity of the weathered layer for static corrections. The sophistication of the analysis of such types of data can vary from very simple fits of lines, to observed travel times, to full fledged computer interactive computer modelling, but essentially the end result is a description of the geologic structure in terms of the seismic velocity with depth in the earth. As such, the refraction technique is most useful for delineating flat-lying contacts and is the method used by Mohorovicic to discover the discontinuity between the crust and upper mantle. In the simplest analyses, the refraction method can resolve well the changes in the actual velocities with depth, but provides poor lateral resolution of lateral variations in seismic velocity.

In contrast, the seismic reflection technique uses reflections from geologic interfaces to image the subsurface. A reflected 'echo' is produced when a P or S wave travelling into the earth encounters any change in the rock velocity and density. In modern analysis of reflection data, the observed travel times are subject to a number of corrections which allow an image of the subsurface that may be likened to a geologic cross-section to be formed. The process which is required to create such seismic profiles, forms the basis for the large seismic industry in Alberta and the reader is again referred to Fowler (1990) for an introduction to this field.

In any event, reflection seismics are highly useful to resolve lateral changes in the geology, but are prone to error in the determination of the velocity structure with depth. This is a common problem in industry reflection profiling where additional steps, such as comparisons to well logs or check shot seismic surveys in wellbores, are conducted in order to calibrate the depth to a given reflector within the sedimentary sequence.

There have been a number of deep seismic studies carried out in and near Alberta over the last 40 years. This is partly due to the fact that in the early years petroleum explorationists took an interest in the large scale geologic structure of the Province. Further advantage was often taken of explosive testing at military sites within Alberta. Most recently, industry has shown renewed interest in delineating the regional scale features as a necessary aid to the development of models of the geologic framework which will aid further mineral and petroleum exploration. This interest is evidenced by support for presently operating scientific programs such as the Lithoprobe Alberta Basement Transects. In this section, the literature relevant to deep refraction profiling and its implications for crustal structure are briefly reviewed. The observations of crustal thickness or depth to the Mohorovicic discontinuity within and near Alberta are shown in Figure 5.2.

5.2.2 Refraction Experiments

Richards and Walker (1959) presented the earliest results from a collaborative effort of 15 company seismic parties in the operation of a deep refraction experiment carried out to the east of Calgary. This experiment was motivated by earlier efforts in 1958 by various companies and the then Dominion Observatory to measure the thickness of the crust across the Rocky Mountains by the refraction method as part of the research associated with the International Geophysical Year. This earlier experiment exploited as its source the large explosion at Ripple Rock, British Columbia (1,375 tons of high explosive) the purpose of which was to clear a channel for shipping, but the results of the refraction study were somewhat ambiguous (Richards and Walker 1959). The follow-up experiment in southern Alberta had two shotpoints, with 450 kg charges at locations approximately 55 km southeast and 100 km north of Calgary; the 15 seismic recording parties were distributed more or less uniformly along this line. Note that it is standard practice to have shotpoints at both ends of a refraction line in order to account for any possible dip of the refracting geologic horizons, and this is usually called reversing the profile. On the basis of the observed travel-times from both of the shotpoints, Richards and Walker (1959) observed two seismic arrivals. The first they associated with a midcrustal discontinuity thought at the time to be a general feature of the continental crust worldwide, which was called the Conrad discontinuity. This geologic interface appeared to dip at 3° towards the south at depths slightly shallower than 30 km and to be produced by the difference in the mean rock velocities of 6.2 km/sec for the upper crust and 7.2 km/sec for the lower crust. The second seismic arrivals were associated with the Mohorovicic discontinuity, representing the change from the value of 7.2 km/sec to the upper mantle velocity of 8.2 km/sec. Their results also indicated that the Moho lay at a

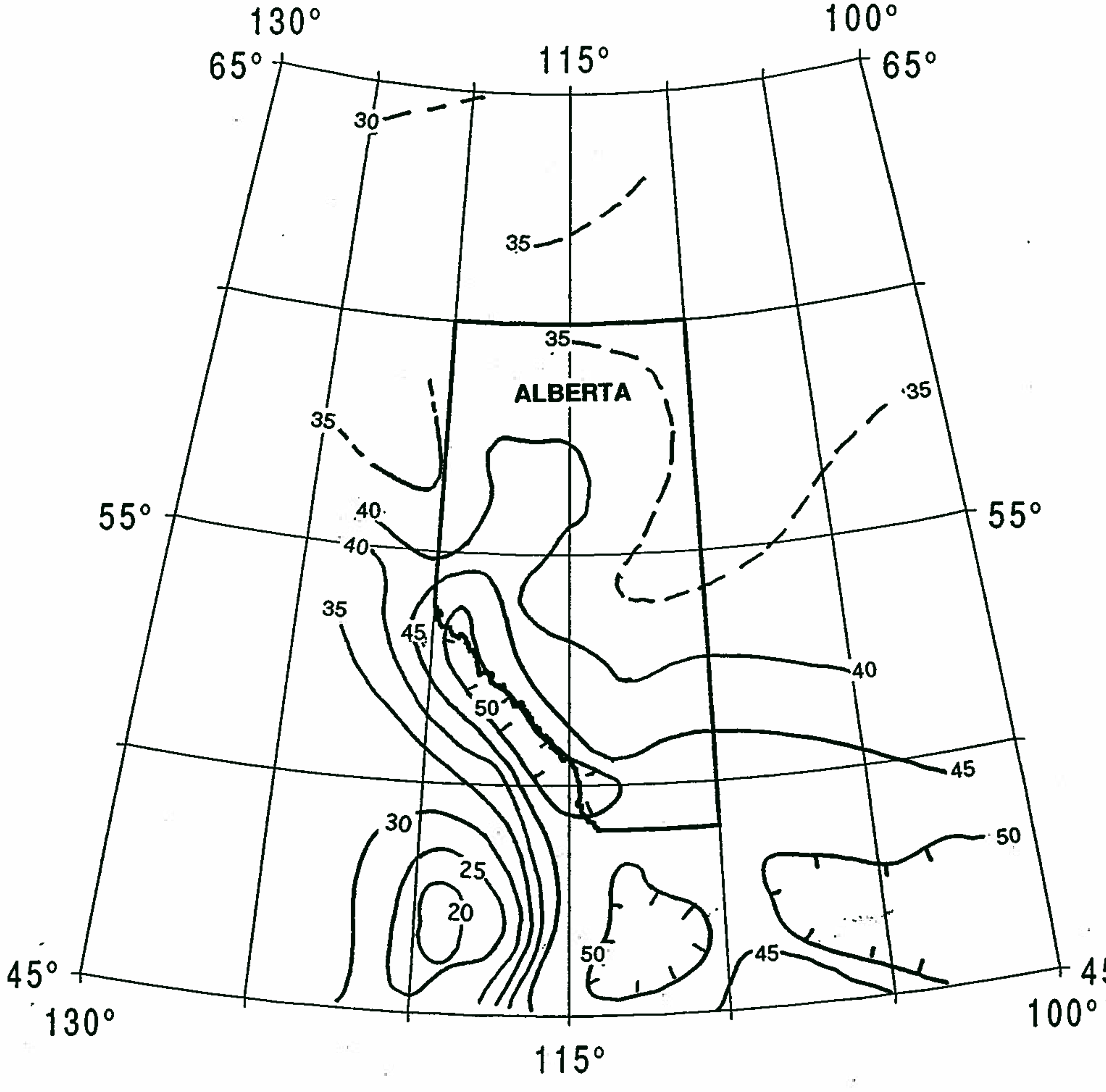


Figure 5.2: Contour map of crustal thickness or depth to the Mohorovicic discontinuity in kilometres as measured from sea level. Depth determined from refraction seismic profiles.

depth of 43 km near the centre of their seismic profile; this depth was generally larger than findings in other parts of the world at that time.

Chandra and Cumming (1972) reviewed the refraction results obtained by a number of earlier studies that had been conducted from 1962 to 1969 (Weaver 1962; Maureau 1964; Chandra 1966; Kanasewich 1966; Cumming and Kanasewich 1966; and Kanasewich *et al.* 1969). These reports discussed measurements along a 700 km long transect from Greenbush Lake, British Columbia to Swift Current, Saskatchewan. Chandra and Cumming's (1972) analysis indicated lateral variations in the upper crustal velocities ranging from 6.1 km/sec to 6.5 km/sec. The boundaries between these differing zones appeared sharp and possibly are due to near vertical discontinuities which cut the entire crustal section to the Mohorovicic discontinuity. Lateral variations in the upper mantle velocities ranging from 8.0 km/sec to 8.3 km/sec were also found between Vulcan and Suffield, Alberta, with the high velocities being roughly coincident with the Sweetgrass Arch. They (Ibid) mapped variations in crustal thickness (i.e., the depth to the Mohorovicic discontinuity) in a region roughly bounded by latitudes 51°N to 50°N and longitudes 112°W to 114°W, and found that the crustal thickness within this region of southern Alberta varies from 34 km to 47 km, with the thinnest parts possibly spatial correlating with a low in the Bouguer gravity and in the magnetics (i.e., the Vulcan Low of Kanasewich *et al.* 1969).

Chandra and Cumming (1972) also noted the existence of a deep seismic structure to 50 km, coincident with the Rocky Mountain fault along their profile, and a possible rapid thinning of the region above the Moho to the west to as shallow as 30 km.

Although not conducted within Alberta, the seismic refraction experiment of Forsythe and Berry (1974) in the Cordillera of British Columbia are of interest in a comparative sense. They recorded refraction profiles, which stretched from Prince Rupert on the north-central Pacific coast of British Columbia to Greenbush Lake in southern B.C., that crossed the Coast Plutonic Complex and the Intermontane and Hinterland belts. These results indicated that the Mohorovicic discontinuity, being only 25 km deep, was much shallower in the interior insular belts than that observed in both southern Alberta and over the Front Range of the Rocky mountains. Both the upper mantle and average crustal velocities were lower in this section of British Columbia than in southern Alberta, being 8.06 km/sec at 6.9 km/sec, respectively.

Mereu *et al.* (1976) analyzed the travel times from the same seismic shots at Greenbush Lake which were used by Chandra and Cumming (1972), but along a northeasterly trending profile through Jasper and extending to Fort McMurray, Alberta. These data show that the Mohorovicic discontinuity near Jasper is relatively flat and undisturbed, but deep at about 50 km. A second interesting observation in this study was that a very high velocity mantle with velocities from 8.5 to 8.8 km/sec existed only 10 km beneath the Moho in this region.

In another study in a region adjacent to Alberta, Morel-al-L'Huissier *et al.* (1987) recorded eight refraction profiles across parts of the Williston Basin and the Trans-Hudson orogen in southern Saskatchewan. This region roughly extends between 49°N and 52°N latitudes and 100°W and 100°W longitudes. These workers also suggested there is a relatively thick crust that varies smoothly over the region with thicknesses ranging from 41 to 48 km. The seismic velocity of the uppermost mantle beneath the Moho ranges from 8.0 to 8.4 km/sec. In contrast to the interpreted structure of southern Alberta which has been distinguished by rapid lateral changes in seismic velocities in the depth to the Moho, there was no evidence in the Morel-al-L'Huissier *et al.* (1987) study for abrupt changes in southern Saskatchewan.

More recently, an extensive refraction survey was carried out in 1985 over the Peace River Arch region in northwestern Alberta in order to obtain further clues as to the possibly deep seated processes which resulted in the region's anomalous history of vertical motions. In particular, it was hoped that the measurements might resolve whether the Peace River Arch had a thermal origin, possibly associated with Devonian rifting, or was a result of a passive vertical isostatic compensation movements. The area of the study covers a region roughly bounded by the 54°N to 57°N latitudes and 116° W to 121°W longitudes, and the results have been reported on by a number of workers. Studies by Zelt and Ellis (1989a, b, 1990), and Stephenson *et al.* (1989) indicated average crustal velocities of 6.35 km/sec and upper mangle velocities of 8.25 km/sec with an average crustal thickness of 40 km. Their data indicated regional variations in the seismic structure as shown in crustal thickness variations that are possibly related to the dominant northerly trending character of the craton, otherwise there were more subtle variations in the shallowing of lower crustal velocities and the thickening of the crust associated with the more easterly trend of the Peace River Arch. In general, however, these were difficult to distinguish as a result of the weak variations in the structure.

Halchuk and Mereu (1990) independently carried out a second analysis of the same data and found several features common to both interpretations, including the shallowing of lower crustal velocities in the northern section of the survey area and the thickening of the crust beneath the Peace River Arch. Halchuk and Mereu (1990) also suggested that there is little expression of the Peace River Arch at depth. Based on their observations, they suggested that the driving mechanism could not be established for the formation of the Arch; this contrasts with the geologic inference of Stephenson *et al.* (1989) that the Peace River Arch was the result of a thermal event during the Paleozoic. In contrast, Ross (1990) interpreted the lack of correlation between seismic structure and the potential field measurements to indicate that the processes producing the Peace River Arch resulted in little modification to the crust. His interpretation rules out a thermal event which would be accompanied by crustal changes.

5.2.3 Reflection Surveys

Very few of the thousands of kilometres of seismic reflection profile data acquired which have been within Alberta over the last half century, have provided information on the crust or upper mantle beneath Alberta because these industry surveys have focused essentially on mapping the structure of the shallower sedimentary column. As a result, until recently, there were few studies of the deeper crust which employed seismic reflections. Despite this, however, some of the pioneering research in obtaining reflections from the deep crust, which was thought by many to be impossible, was conducted at the University of Alberta. Kanasewich and Cumming (1965) and Cumming and Kanasewich (1966) reported reflected arrivals from a deep geologic interface at 34 km beneath southern Alberta. This reflector appeared to correlate well with a refracted arrival that had been seen in earlier work and was interpreted to be the Conrad discontinuity which at the time was thought, with the limited data available, to be a universal feature of the earth's continental crust.

These results were expanded upon in later publications by Clowes *et al.* (1968) who conducted four reflection profiles with a total length of nearly 90 km in southern Alberta to the west of Bow City and Bassano. In this study the strong reflected arrival, which is now called the 'Riel' discontinuity by Dr. D.H. Hall (Ibid) in recognition of the fact that the velocity change associated with the southern Alberta midcrustal seismic discontinuity, differed from that observed initially by Conrad on another continent. This reflection was continuous over a 25 km length of a 40 km long reflection profile with the interesting observation, for the time, of 8 km of relief that indicated the continental crust in this region is complex. Clowes *et al.* (1968) further observed weak reflections returning to the surface nearly 15 seconds after detonation of the explosive seismic sources; he suggested these weak reflections were possibly from the Mohorovicic discontinuity. The important conclusion of this (Ibid) paper was that the crust could contain considerable complexity even at great depth and this was further confirmed in a later, more detailed analysis (Clowes and Kanasewich 1970) that indicated the deep reflections were most consistent with a geology consisting of thin, interleaving layers with differing properties.

Kanasewich *et al.* (1969) provided a more detailed interpretation of these data and suggested that the steep dips associated with the over 11 km of relief which was observed on both the Riel and Mohorovicic discontinuities at this locale, were representative of geologic structure associated with a Precambrian rift in the basement beneath 2.5 km of overlying sediments. This structure, named the Vulcan Low or Southern Alberta Rift, correlated well with the Bouguer gravity and magnetic anomaly measurements (see Section 5.3) and the structure appear to trend for several hundred kilometres across Alberta and into British Columbia. This gravity low was modeled as lighter density material infilling the rift on the Precambrian surface.

In central Alberta, Ganley and Cumming (1974) reported on a series of short (6 km) reflection profiles that were conducted to obtain a better understanding of crustal conditions near the University of Alberta Seismic Observatory (EDM) which is located to the east of Leduc. The lines were centred in Township 50, Range 23W4. The interpreted model in this case showed the presence of a steeply dipping interface in the deep crust, possibly suggestive of a fault. They (Ibid) further noted that the potential Mohorovicic discontinuity reflection appeared at a much earlier, 11.7 seconds of travel time, which indicates that the crust might be thinner at this locale.

Except for these early experiments, little deep crustal reflection profiling had been carried out in Alberta until very recently. Zelt and Ellis (1989a) obtained petroleum industry vibroseis data which were nearly coincident with a position of the reflection data reported in Zelt and Ellis (1989b). Through novel processing of these data they were able to extract deep reflections to two way travel times of 13 seconds. Their seismic profile contained a strong eastward dipping event at ~29 km depth that correlated well with an arrival in the refraction records and which they possibly related to the Riel discontinuity discussed above in southern Alberta. Reflections with travel times of 13 seconds corresponded well with the refraction Moho observed at a depth of 41 km. As in the study of Clowes and Kanasewich (1970), the character of the reflections returned from the Mohorovicic discontinuity are suggestive of a complex and possibly layered transition zone between the crust and mantle. The character of this reflection profile, which was much shorter than the adjacent refraction lines, generally indicated that the Moho and the deep crustal reflection are shallowly dipping and continuous, although the crust mantle transition may be laterally variable on the scale of a few kilometres.

Near Alberta, in northeastern B.C. between 56°N and 59°N along the Alaska highway, Petrl Robertson Ltd. acquired a deep seismic profile with a 15 second two way travel time. Varsek and Hutton (1992) provided a preliminary interpretation of these proprietary data that shows generally west dipping sub-Phanerozoic reflectors. These are interpreted to indicate an early stage of thrust faulting that may have formed a ramp system with up to 15 km of relief.

Otherwise, Vasudevan *et al.* (1992) showed examples of the reprocessing of a number of short seismic profiles that were provided by industry. No interpretation of these data are given, but in a number of the lines considerable complexity appears. The complexities could be processing artifacts or out of plane arrivals, although one N-S line about 50km long which was acquired to the west of Lloydminster, may show a coherent package of reflections from 13.5 seconds of travel time. If related to the Mohorovicic discontinuity, the data from this line might indicate a crustal thickness on the order of 40 km to 45 km for assumed upper crustal velocities from 6.0 to 6.5 km/sec. These industry data cross the Lithoprobe Alberta transect 1992 seismic profile level 10 which runs east-west. The preliminary displays of these data in Vasudevan *et al.* (1992) show considerably more coherent structure to greater than 14 second two-way travel time on the extreme east end at the Alberta-Saskatchewan border; the structures at depth dip towards to the east.

Preliminary reports on the interpretation of Lithoprobe seismic profile level 10, which runs from Lloydminster to Entwistle, have been reported by Kanasewich *et al.* 1993). The preliminary analysis of these data indicate considerable variation of the depth to the Moho, between 35 to 45 km, with the thicker crust observed towards the east. At midcrustal depths, a series of east dipping reflections are seen and abrupt changes in reflection patterns appear which may correlate with the crossing of basement domains previously defined on the basis of potential field data. These data, together with complete interpretations, are expected soon to be published.

Intermediate Lithosphere plans include further deep seismic profiles across Alberta with an industry-government-university consortium presently being arranged for the acquisition of approximately 560 km of data across the Peace River Arch. Future plans also include a north-south line running from the U.S.-Canada border to potentially tie with the already acquired 1992 east-west data. Interested industrial participants should contact the Lithoprobe Secretariat at (604) 822-4138 for more information on having early access to these data by joining the consortium.

The available refraction estimates of crustal thickness are abstracted in Figure 5.2 which shows the contoured depth below sea level to the Mohorovicic discontinuity. The map was developed from the data described in the papers above, as well as other refraction measurements summarized by: (a) Allenby and Schnetzler (1983), and associated references therein, for the United States of America, (b) Barr (1971) and Berry (1973) for the Northwest Territories, and (c) Hall and Brisbin (1965) for an area near the Saskatchewan-Manitoba border (longitude 100°W) near Flin Flon. Figure 5.2 does not include as close a contour interval as the details given in Chandra and Cumming (1972) for southern Alberta or in Stephenson *et al.* (1989), nor does it include the estimates of crustal thickness derived from recent reflection profiles described below. Due to the paucity of data for many sections of Alberta, the map may be modified in future on the basis of the results of an extensive modern refraction program planned as part of the Alberta Lithoprobe transect. It is interesting to note, however, a general trend of decreasing crustal thickness towards the north which may continue with further thinning into the N.W.T. As well, the crust thins towards the west into the Cordillera. The deepest crust of 50 km or more is seen beneath the Rocky Mountains and is probably related to isostatic adjustment beneath this mountain range. It is also interesting to note that the crust over much of Alberta is relatively thick, being ~40 km deep; this contrasts with older models of 'typical' continental crust with a thickness on the order of 30 km.

5.3 <u>Regional Gravity Anomalies</u>

Measurements of the acceleration of gravity are useful both in the context of determining the deeper structure of the upper mantle and for delineating regional structures within the crust. In this section, regional and Alberta-scale maps of the gravity measurements are provided and discussed in terms of their relevance to gross structures.

Briefly, however, the important parameter measured in gravity surveys is the acceleration of gravity. To be meaningful, data collected in a typical gravity survey must be corrected for a number of factors which address the affects of latitude and shape of the earth, rotation of the earth, terrain effects, and elevation; Kearny and Brooks (1991) provide details with respect to these factors. The final data set produced is called a Bouguer Gravity Anomaly map which essentially represents the deviation of the acceleration of gravity from the value expected at the reference, or datum, elevation. A large scale map of the regional Bouguer gravity which is centred on Alberta and encompasses the region between 100°W and 130°W longitude and 45°N to 65°N latitude is shown in Figure 5.3. This map is to the same projection as that of Figure 5.2 and, as well, the position of Alberta is highlighted. In Figure 5.3, the range of colours from red through yellow, green, blue, to purple represent decreasing values of the Bouguer gravity covering a range of approximately 22 mgal (1 mgal = 10^{-3} cm/sec^2); exact values cannot be taken from this map, or the other colour photos shown later, because the data have been processed to enhance the variations. However, red represents high values of Bouguer gravity corresponding to areas where the acceleration of gravity is strongest, whereas the other extreme is purple which represents low Bouguer gravity values where the acceleration of gravity is weak. In general, a high Bouguer value indicates high density rock of increased mass and hence gravitational acceleration. Correspondingly, a low Bouguer value represents diminished densities and lower gravitational acceleration.

With this in mind, a number of features may be outlined in the regional map of Figure 5.3. Most prominent is a region of high gravity in the southwest corner of the map, where high gravity values are roughly delineated by the Pacific coastline along southern British Columbia, and the state of Washington and northern Oregon. The high acceleration of gravity is due to the more mafic, and hence denser, composition of the oceanic crust. Further, the oceanic crust is generally much thinner, meaning the dense rocks (3.1 g/cm^3) of the upper mantle are much closer to the surface and hence exert a greater gravitational acceleration. Moving across British Columbia towards the east, there is a region of very low Bouguer gravity represented in purple and blue which corresponds to the Rocky Mountains; the lowest values in purple trend in a northwesterly direction and are nearly coincident with the continental divide. The low values are a consequence of a thick continental crust beneath the Rocky Mountains as evidenced in the Refraction crustal depth estimates of Figure 5.2. Bouguer gravity values are low over mountain ranges due to their deep roots which allow the additional elevated mass of the mountains to be supported (for example, much as an iceberg of density lower than the surrounding seawater will float). This deep crust under the highest ranges of the Rocky Mountains indicates that they are, for the most part, isostatically compensated according to the theories of Airy (Fowler 1990).

In general, the gravity increases across Alberta, both to the north and east of the Rocky Mountains (Thomas *et al.* 1987). In a simplest case interpretation, these increasing values could be attributed to a thinning of the continental crust which, via an Airy isostatic adjustment, means the denser rocks of the upper mantle are closer to the earth's surface and hence exert a greater gravitational pull (Sprenke and Kanasewich 1982).

This inference is in qualitative agreement with the crustal thicknesses estimated from refraction seismics in Figure 5.2. However, using those portions of the map in Figure 5.3

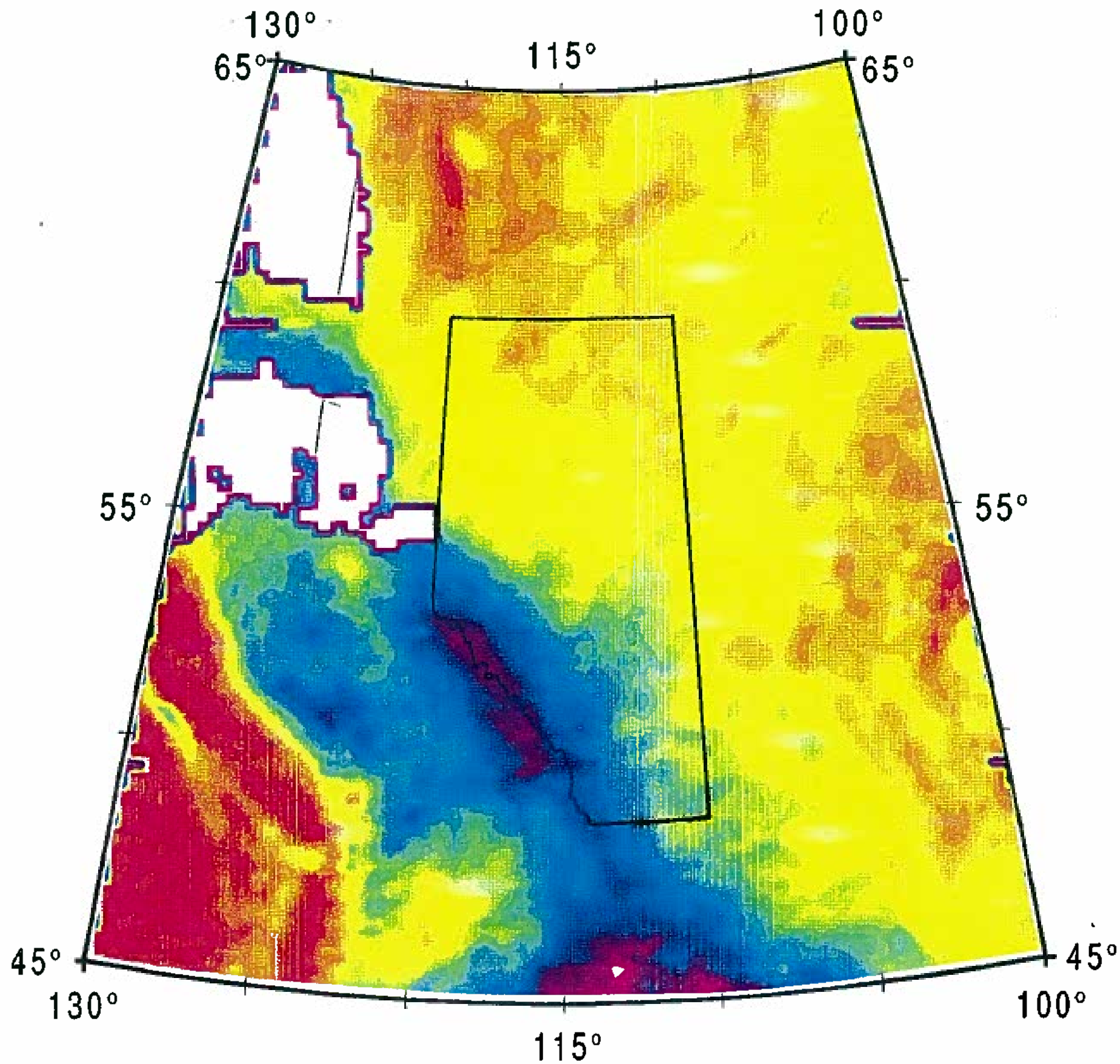


Figure 5.3: Bouguer gravity anomalies over Western North America. Data extracted from the Gravity of North America CD-ROM compiled by the National Geophysical Data Center. Colour scheme of purple-blue-green-yellow-red corresponds to increasing Bouguer magnitudes, but due to the enhancements used in making the map, the colours do not represent absolute values Bouguer gravity. Regions where data do not exist or are not publically available are shown without colour.

which cover the Prairie Provinces and southern N.W.T., Sprenke and Kanasewich (1982) estimated the Airy anomaly using Fourier analysis. The Airy anomaly they (Ibid) calculated represents departures of the observed Bouguer anomaly shown in Figure 5.3 and an isostatic correction. At low resolution, these Airy anomalies are high to the north of Alberta and Saskatchewan, with a minimum seen in the northeast corner of Saskatchewan. This suggests that these regions may be isostatically overcompensated; that is, these Airy anomalies may be a consequence of an as yet incomplete rebound of the continental mass due to the rapid unloading of the Pleistocene ice loads and, furthermore, suggest that as much as 200 m of glacial rebound might yet be expected. Sprenke and Kanasewich (1982) also examined the higher spatial resolution (~500 to 1,000 km) components of their isostatic anomaly map and suggested that the magnitudes of these anomalies were far too great in lateral extent for them to be masses supported by the lithosphere. Stephenson *et al.* (1989) also calculated the isostatic anomaly maps, but by a different technique. As such they indicated that these anomalies might represent fundamental divisions of the lithosphere that are indicative of ancient tectonic regimes and of the earth's attempt to maintain isostatic equilibrium. At this higher resolution, an isostatic high resides in the north-central portions of Alberta in the region referred to at the time as the Athabasca mobile belt according to the early classification of Burwash and Culbert (1976). This anomaly could be attributed to either crustal thinning or an anomalously high upper mantle density. East of the Rocky mountains, southern Alberta is covered by an isostatic low region which suggests that the crustal load in these more southerly regions may be supported by the lithosphere.

In the absence of other information across the stable craton portions to the north and east of the Bouguer map of Figure 5.3, it is difficult to distinguish differing zones of the crust. One interesting long narrow region of low gravity, however, is seen striking northeasterly (in green) from the Rocky Mountains (at about 54°N, 112°W) and trending to the maps left edge at 64°N, 100°W. This low gravity trend has been discussed in the literature by Burwash and Culbert (1976) and is all the more enigmatic in that although it strikes subparallel to magnetic trends (as discussed below) which are used to delineate basement tectonic divisions (Hoffman 1988; Ross *et al.* 1991), it appears to obliquely cross a number of these trends. Burwash and Culbert (1976), however, concluded on the basis of earlier data sets that the magnetic and gravity anomalies are coincident and if this holds true, then this anomaly follows along the Snowbird tectonic zone (see Figure 2.2).

Figure 5.4 details the observed Bouguer gravity field within Alberta at a higher resolution. Figure 5.4a is the observed Bouguer gravity, much of which has been discussed above. More evident in Figure 5.4a is the western end of the linear northeasterly trend of low gravity values just mentioned above. As well, a nearly horizontal accurate trend of low gravity is seen which starts on the eastern boundary of Alberta north of 50°N latitude. This corresponds to the possible Precambrian and younger Southern Alberta Rift or Vulcan Low that was identified from seismic observations by Kanasewich *et al.* (1969). More recently, however, the Vulcan Low has been interpreted instead as a collision suture on the basis of truncated magnetic fabrics (Thomas *et al.* 1987; Hoffman 1988).

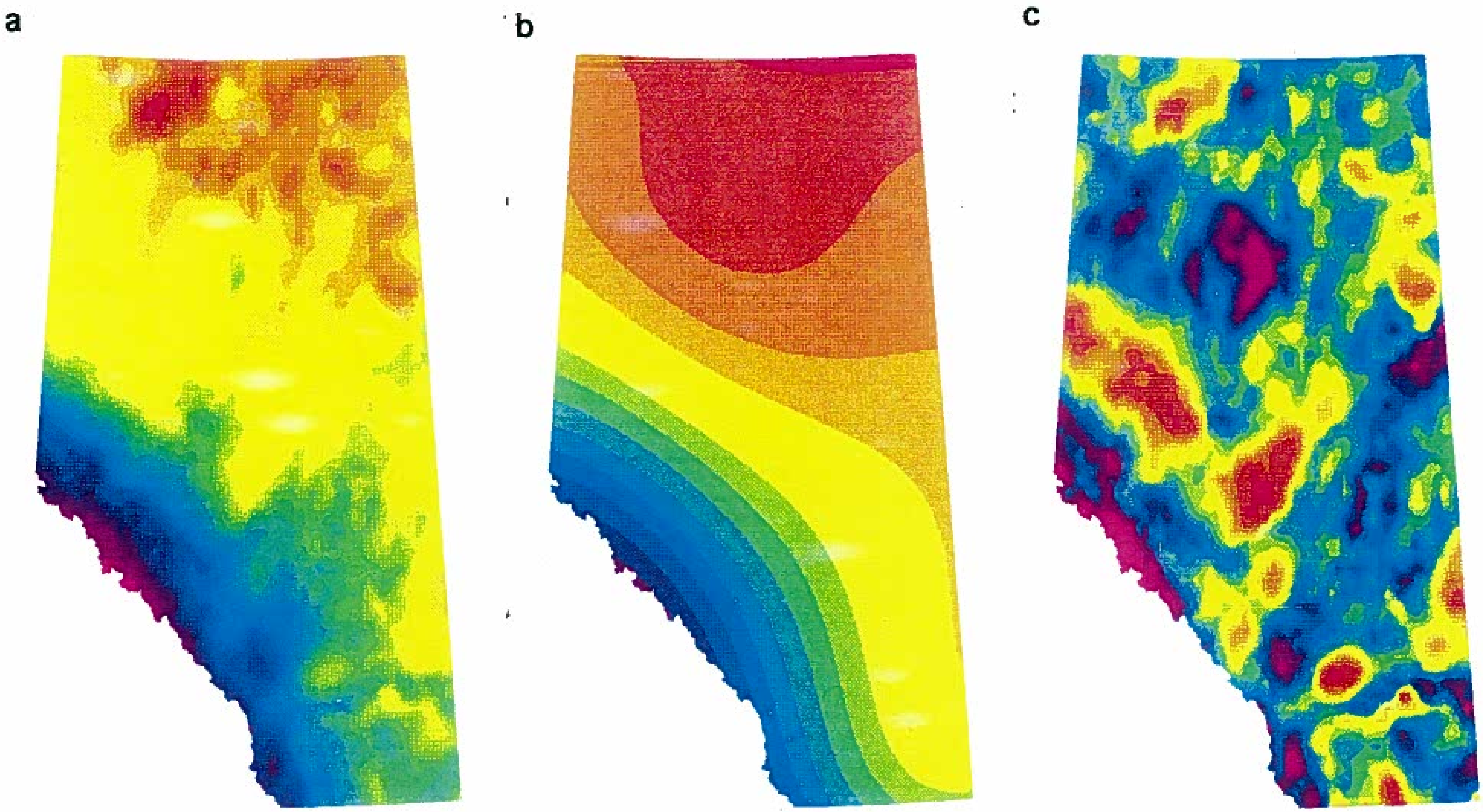


Figure 5.4: Bouguer gravity map for Alberta: a.) Observed Bouguer gravity. Map is not enhanced and the colour scheme of purple-blue-green-yellow-red represents variations in Bouguer gravity from -21 mgal to -3.1 mgal; b.) Regional trend of Bouguer gravity. Colour scheme of purple-blue-green-yellow-red represents variations in Bouguer gravity from -20.1 mgal to -46.7 mgal; and c.) Residual Bouguer Gravity (difference between data of 6a and 6b). Colour scheme of purple-blue-green-yellow-red represents increasing values of the Bouguer gravity residual.

Figure 5.4b is the average low resolution (large wavelength) trend of the Alberta Bouguer gravity as determined by fitting a polynomial surface by a least squares regression analysis. This smoothed map shows the grosser details of the Bouguer gravity within Alberta and should be sensitive to the larger scale variations of the crust and upper mantle. Extreme low values are seen beneath the rocky mountains (purple); low gravity values also exist in the north (orange and red) as has already been noted and may possibly be related to a thinning of the crust to the north and east.

Figure 5.4c is the de-trended, or residual, Bouguer gravity anomalies which are the simple difference between the data of Figures 5.4a and 5.4b. The Figure 5.4c map enhances the higher resolution (shorter wavelength) variations in the Bouguer gravity. The features observed in this map are more representative of changes within the crust and uppermost mantle and more useful from the perspective of the tectonic structural framework. The colour scheme again runs from low values in purple to high values in red. The anomaly trends of Figure 5.4c should be interpreted with care, but the map does highlight a number of features. As before, the large linear northeast trending Bouguer gravity low as well as the Vulcan low are apparent, although in this map the latter appears more as a boundary of low values separating parallel linear trends of high gravity, the consequences of which have not been studied. Otherwise, the large region of low gravity values (in purple) in the central-northern section of Alberta is highlighted. To the south and southwest of this low is a bulge of high values that are roughly coincident with the Peace River Arch at the western border of Alberta, although in a more extensive detailed study of this region using a different image enhancement process, Ross (1990) found no correlation between the observed gravity field and the Peace River Arch. Finer gravity details can also be discerned, such as the two narrow trends of high gravity values that strike north-northeast and flank the large low region in north-central Alberta. These narrower trends may be related structurally to the crust and appear to parallel trends seen in the magnetic data.

5.4 Regional Magnetic Anomalies

Magnetic field measurements across Alberta are principally useful at the regional scale for delineating the tectonic framework of the crust beneath Alberta. In contrast to the gravitational potential field data which are sensitive to variations of material densities both within the nearby crust and more removed upper mantle over the scale of Alberta, the magnetic anomaly maps herein provide structural information related to variations in rock magnetism only whilst the rocks remain magnetic. At elevated temperatures in the lower crust, the critical Curie temperature is reached at which point magnetic minerals lose their magnetic character and as such are 'invisible' from the perspective of magnetic measurements. This temperature is 575°C for magnetite. As such, the magnetic anomaly maps, represent local deviations of the observed magnetic field strength from the large scale field of the earth and reflect only those portions of the crust shallower than the Curie temperature isotherm. The actual source of a given magnetic field variation depends principally on variations in the magnetic susceptibility of the rocks at depth. The value of which is roughly proportional to the percentage of magnetic minerals, particularly primarily magnetite, forming the rock, although other factors such as the degree of coherent alignment of the magnetic minerals also plays a role; the reader is referred to texts such as Telford *et al.* (1990) for further information in this regard.

Figures 5.5 and 5.6 show the regional and Alberta scale variations in the magnetic field, respectively. The projection of Figure 5.5 is the same as that in Figure 5.2 for purposes of reference. The data in Figure 5.5 are obtained from a recent North American compilation (National Geophysical Data Centre 1990), but an updated and more comprehensive set of these data are available for purchase from the Geophysics Division of the Geological Survey of Canada. Regions of non-publicly available data, which unfortunately include much of Alberta, have no colour. Figure 5.5 is a relatively low resolution plot and finer scale features, such as magnetic reversal lineaments existing in the oceanic crust off of Washington and British Columbia, have been averaged out in the attempt to enhance the grosser scale crustal features.

Figure 5.5 highlights a number of large, crustal scale features that are primarily related to the evolution of the craton. In the east, a broad 500 km wide arcuate magnetically high region which initially strikes southwesterly from about 60°N latitude and 100°W longitude, shows the position of the large zone of crustal deformation remnant from the collision of the Hearne and Wyoming Structural Provinces with the Superior Structural Province (see reviews by Hoffman 1988). This crustal deformation occurred approximately 1.9 Ga. and is called the Trans-Hudson orogen.

There are a number of other regional features which directly intersect Alberta. Ross *et al.* (1991), as previously suggested by Burwash and Culbert (1976), provided a regional synthesis of the basement of Alberta, which is mostly hidden from view by the sedimentary cover, on the basis of age dating of core and on both public and proprietary magnetic field maps (Figure 2.2). Without reference to the regional scale magnetic anomaly map of Figure 5.5, the structures within Alberta as shown in Figure 5.6 are difficult to interpret. Below is a summary of Ross *et al.'s* (1991) findings which are presented in Figure 2.2 of section 2.

A striking feature in Figure 5.5 is the Great Slave Lake Shear Zone (Hoffman 1987), which is a narrow lineament of magnetic highs that commences near the western border of Alberta at about 57° N latitude (Figure 5.6) and trends more than 1,000 km to the northeast. Hoffman (1987) suggested that the Great Slave Lake Shear Zone represents a continental transform that is associated with an oblique collisional indentation of the Churchill Structural Province by the Structural Slave Province. A present day analog to the Great Slave Lake Shear Zone might be the ductile deformations that are produced by motions occurring in the present day Adaman sea as a result of collision of India with Eurasia.

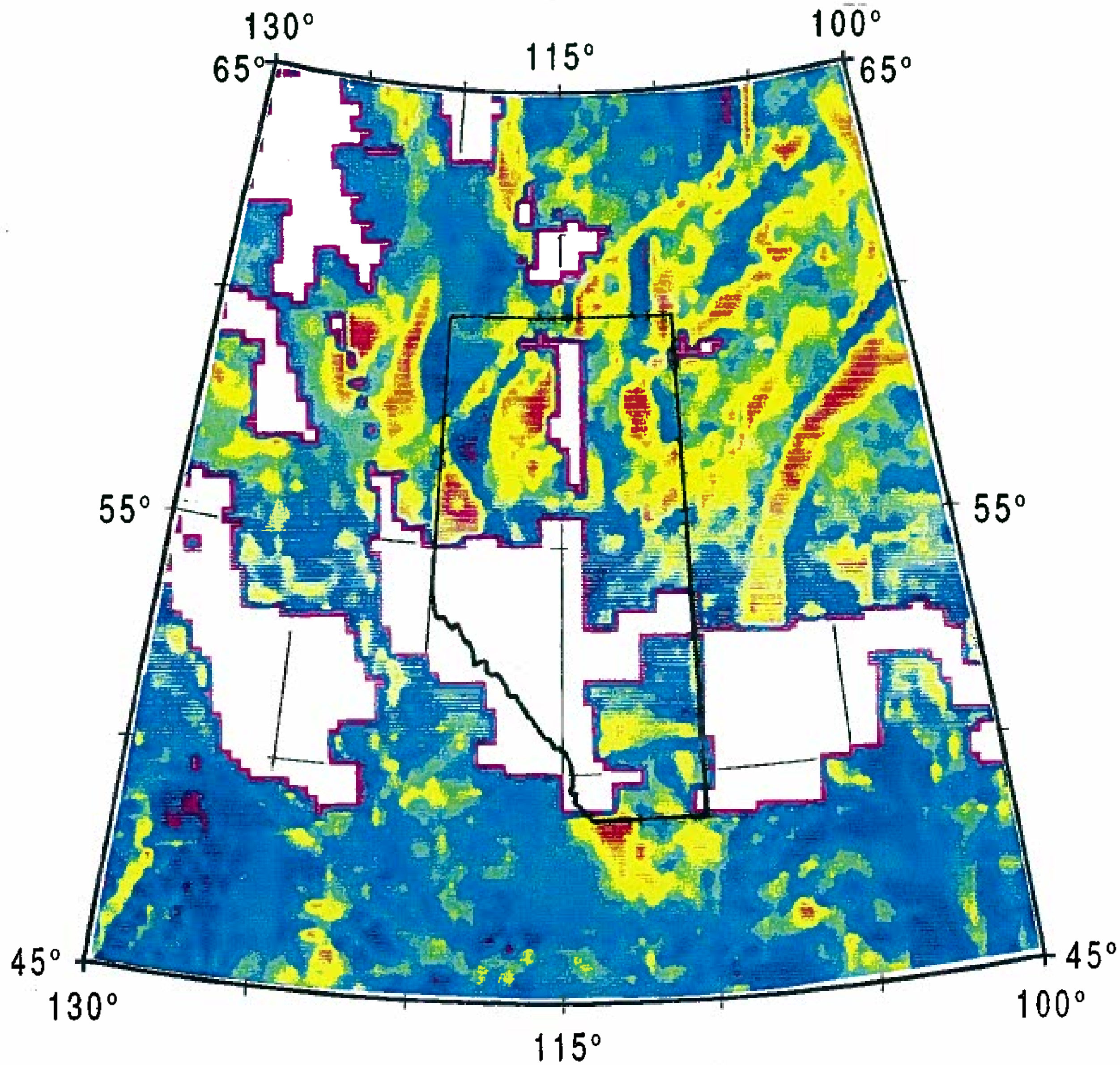


Figure 5.5: Total magnetic field anomalies over western North America. Data extracted from the Geophysics of North America CD-ROM complied by the National Geophysics Data Center. Colour scheme of purple-blue-green-yellow-red corresponds to increasing magnetic field intensities, but due to the enhancements used in making the map, the colours do not represent absolute values of field strength. Regions where data do not exist or are not publically available are shown without colour.

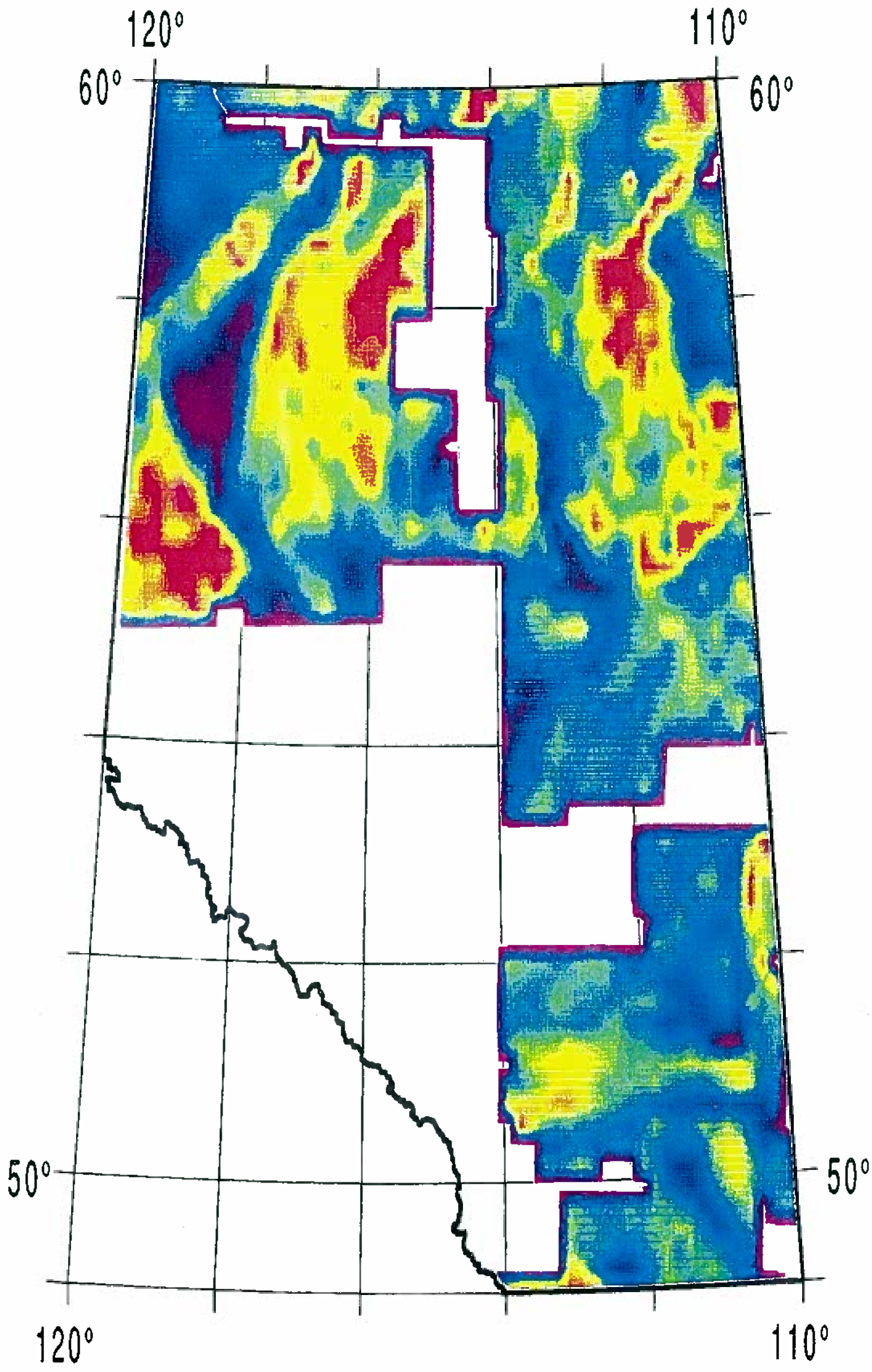


Figure 5.6: Total magnetic field anomalies over Alberta. Data extracted from the Geophysics of North America CD-ROM compiled by the National Geophysical Data Center. Colour scheme of purple-blue-green-yellow-red corresponds to increasing magnetic field intensities, but due to the enhancements used in making the map, the colours of not represent absolute values of field strength. Regions where data do not exist or are not publically available are shown without colour.

Another regionally significant anomaly that crosses Alberta is the subsurface extension of the Snowbird Tectonic zone, which is a northeast trending crustal discontinuity extending from the Foothills to Hudson Bay (Ross *et al.* 1991). In Figure 5.5, this zone roughly extends from the northeast corner of Saskatchewan (60°N, 100°W) and intersects the Alberta border at (56°N, 110°W). Regionally, this tectonic zone on the exposed Canadian Shield separates the Churchill Province into the two archean domains of the Rae and Hearne Provinces which have experienced differing levels of Proterozoic deformation. In Alberta, Ross *et al.* (1991) suggested that the Snowbird Tectonic Zone bifurcates into two separate strands which enclose a wedge shaped domain referred to as the Wabamun High which, unfortunately, is not encompassed by the publicly available aeromagnetic data in Figure 5.6 (see Ross *et al.* 1991). Two highly magnetic domains which were produced by Proterozoic magmatism, are separated by the Snowbird Tectonic zone (see Figure 2.2). These are the Rimbey high to the south of the zone and the truncated north trending Taltson Magmatic Area. The Taltson area encloses on its east side a region of low magnetic field strength underlain by the Rae Structural Province.

The Buffalo Head terrane is a largely magmatic accreted terrane immediately to the west of the Taltson area. Its west boundary is delimited by a steep gradient in the magnetic field across which the magnetic susceptibility decreases to the low values of the Chinchaga Low centred in Figure 5.6 near 57°N latitude, 119°W longitude. The abrupt change in the magnetic field between the Chinchaga Low and the Buffalo Head terrane suggests that this boundary may be a faulted contact. The region of high magnetic field strength on the western side of this Chinchaga Low is called the Ksituan Magmatic Area which is sharply bounded in the northwest corner of Alberta by the Great Slave Lake Shear Zone.

In Southern Alberta, a prominent magnetic feature in Figure 5.6 is an arcuate trend of low magnetic values coincident with the gravity low of the Vulcan Low of Figure 5.4. Immediately to the south of the Vulcan Low is the Medicine Hat Block distinguished by north-northwest trending areas of high and low magnetic fabric, and to the north is the magnetic Matzhiwin High which more or less runs parallel to the Vulcan Low. The relative magnetically flat region to the north of the Matzhiwin High distinguishes the Lovema Block. Near the eastern Alberta border above 52° N latitude is an area of high positive magnetic anomalies referred to as the Eyehill High.

Aside from their utility as a guide to the characterization of the tectonic regimes within the Alberta crust, the magnetic maps could serve the explorationist in detailing regions where the crust had been faulted in earlier times. These regions can serve as zones of weakness in the crust which, speculatively, might offer a preferred pathway for magma migration from deep-seated sources. Obvious potential weak zones are the Slave Lake Shear Zone, the Snowbird Tectonic Zone and the Vulcan Low. As well, the rapid changes in the magnetic character between the Buffalo Head terrane and the Chinchaga Low also may be indicative of faulting.

The application of the regional magnetic data sets to more local and directly exploration-oriented high resolution based geophysics, as well as the availability of the magnetic data, will be briefly discussed in a later section.

5.5 Electrical Measurements of the Crust.

The seismic, gravitational and magnetic data essentially are used to describe the structure of the crust in terms of variations in seismic wave velocity, density and magnetic susceptibility, respectively. A fourth extensive parameter which can represent the material properties at depth, is the electrical conductivity. The electrical conductivity of rock depends on many competing factors, such as the temperature, the porosity, the permeability and on the chemistry of any pore fluids, including magmas. In general, the conductivity of a rock decreases with temperature, but increases with fluid saturation (Olhoeft 1980). Geophysical methods distinguish only the conductivity structure with depth, and although electrical measurements are useful they must be considered together with other geologic clues to allow interpretation as to the actual source of the conductivity. For example, a highly conductive structure that is observed at depth could be indicative of saline fluids or graphite concentrated along a zone of earlier deformation which signals potentially weak crust. Indeed, Gent (1992) in his analysis of diamond potential in Saskatchewan indicates a possible association between the occurrence of diatremes and a prominent electrical conductivity anomaly that bisects southern Saskatchewan and is referred to as the North America Central Plains Conductivity Anomaly (Alabi *et al.* 1975). This large structure is roughly coincident with the Trans-Hudson Orogen (Handa and Camfield 1984) which is outlined in the regional magnetics of Figure 5.5, and the low conductivity associated with it is a consequence of graphite or fluid filled fractures. In this context the Trans-Hudson Orogen is possibly a zone of crustal weakness and hence is, or was, a preferred pathway for magma movement upwards through the crust. In the regional context, the North American Central Plains Conductivity Anomaly is perhaps the best documented electrical anomaly, but there are good indications of other electrical anomalies within Alberta. A number of deep electrical soundings have been carried out in and near Alberta and these are reviewed in this section.

Deep electrical soundings of the earth's crust and upper mantle are obtained by observations of the changes with time in the geomagnetic and geoelectric fields at the earth's surface. The input signal to the earth is the magnetic field created by magnetospheric and ionospheric currents that result primarily from the interaction of the earth's magnetic field with the variable solar wind. This upper atmosphere magnetic field in turn induces the flow of current (i.e., telluric currents) within the solid portion of the earth. The resulting signal is recorded by three or more orthogonally oriented magnetometers. The analysis of this signal is beyond the scope of this report (for details see Gough 1983), but the final result that is obtained at a given station position essentially reduces to a determination of the conductivity structure beneath the station. The resolution of depth from these measurements is poor, with the depth typically being set in terms of a maximum limit, but laterally anomalous conductivities can be discovered and mapped. A typical survey consequently consists of measuring the magnetotelluric responses along a profile or over a grid of stations, thus allowing the two or three dimensional regional variations in the conductivity to be plotted.

A number of magetotelluric soundings surveys have taken place within and near Alberta. Caner *et al.* (1969, 1971), for example, conducted measurements in Alberta and British Columbia. On the basis of these early measurements, they (Ibid) defined two main regions lying between 49°N and 54°N latitudes, with a transitional zone following the trend of the Rocky mountains north of 51°N latitude and then trending south towards the 49°N latitude. Generally, these western and eastern regions were both characterized by a relatively conductive upper mantle (30 to 50 ohm-m) below 35 km, but were distinct in that at shallower depths the western region or Cordillera was more conductive than the eastern region beneath southern Alberta below 54°N latitude.

Cochrane and Hyndman (1970) followed this study with a more sophisticated analysis, the results of which were generally consistent with Caner *et al.* (1969) findings, but which showed conductive layers in the top 90 km in the western region.

The later results of Gough *et al.* (1982), Gough (1986) and Hutton *et al.* (1987), also show that the region west of the Rocky Mountain Belt is characterized by low conductivities. Gough *et al.'s* (1981) study also pointed out the existence of low conductivities, which result from either shallow fluid-filled sediments or deeper regions of partial melt that are centred near Tete Jaune Cache to the west of Jasper and delimited by station locations into Alberta. This anomaly is possibly associated with the Anahim Volcanic Belt which contains volcanoes of Recent origin (post-dating the last glaciation).

The above anomaly is not far removed from the study region of Ingham *et al.* (1983), which is within Alberta between 53°N and 54°N latitudes and 116°W and 118°W longitudes near Hinton and Edson. The purpose of their (Ibid) study was to find the source of the relatively high temperatures that had been observed in petroleum exploration well bores in parts of this region by Lam *et al* (1982). The Ingham *et al.* (Ibid) study was of particular interest due to the close station spacing (15 km), which allowed detection of highly conductive volumes of rock below Lam *et al.'s* (1982) thermal anomaly. These conductive zones must exist from depths at least as deep as 5 km and extending at least to lower crustal depths. Given the proximity to the Anahim Volcanoes, Ingham *et al.* (1983) suggested that these conductive zones resulted from locales of partial melt within the crust.

In the plains of Alberta there have been numerous magnetotelluric measurements. Reddy and Rankin (1971, 1972), for example, carried out measurements in a band crossing Alberta below 55°N latitude. Their (Ibid) observations indicated that much of the magnetotelluric response is a consequence of the geometry of the Western Canada Sedimentary Basin.

Lastly, but perhaps of greatest interest, is a zone of low conductivity called the Southern Alberta-British Columbia Conductor which was discovered by Gough *et al.* (1982). This highly conductive zone, as depicted in Hutton *et al.* (1987), trends in a northeasterly direction and, although possibly related to the more east trending Vulcan Low, appears to deviate to the north of it. Gough *et al.* (1982) provide a review of the results of other magnetotelluric soundings in Southern Alberta in the context of this structure (Vozoff and Ellis 1966, Peeples and Rankin 1973, and Reddy and Rankin 1971, 1972).

5.6 Measurements of the Geothermal Gradient and Heat Flow

The earth is a steadily cooling planet and the rate at which heat is transported to the earth's surface can provide clues as to the state of the mantle and to the structure of the crust (Sclater *et al.* 1981). Although the distributions are relatively large, the heat flow is generally a function of the age of continental crust with the oldest crust having the lowest heat flows to their base from the mantle of about 25 mW/m^2. However, there are hints that heat flows may very modestly increase in crust as young as 500 Ma. Crust younger than this, however, has rapidly increasing levels of heat flow in excess of 50 mW/m^2. Continental heat flows are affected by many competing factors, such as (a) the concentration of heat producing radioactive elements, (b) speed of erosion and deposition, (c) the time since the latest tectonic event in the region, and (d) whether volcanism (which is also tectonically related) might recently have been active. Heat flow is also difficult to measure because the temperature near the surface in well bores accessible for measurements can be disturbed by flow of ground water, by inappropriate estimates of the rock's thermal conductivity, or by effects related to the interaction of the drilling fluids with the formation, to name only a few.

The fact that the sedimentary basin of Alberta has been heavily drilled during petroleum exploration has provided the opportunity for researchers to measure how rapidly temperatures vary with depth in determination of geothermal gradient, the value of which is indicative of the quantities of heat being transported, and has also supplied an extensive database on bottom hole temperatures. Using these data, there have been a number of independent studies of the geothermal field within Alberta (Anglin and Beck 1965, USGS-AAPG 1976, Majorowicz *et al.* 1984). Bachu (1988) suggested that all of these studies show a definite trend of increasing geothermal gradients from south-southwest to north-northeast across the Alberta basin.

Jessop (1992), however, in redrafting the heat flow maps of Majorowicz *et al.* (1984, 1986) also showed this trend, which rises from 60 mW/m^2 in the south to more than 80 mW/m^2 in the north. However, this trend in the geothermal gradient exists only for the heat flows calculated on the basis of bottom hole temperatures and rock thermal properties within the upper Mesozoic and Tertiary strata. In the lower Paleozoic sections of the sedimentary column, however, the situation appears more complex, but the data generally indicate nearly the reverse situation, with high heat flows in the south and low heat flows in the north. Jessop (1992), under the assumption that the heat transported to the base of the crust from the mantle would be more or less uniform over the region of Alberta with a value near 30 mW/m^2, attempted to estimate the heat flow to the top of the crystalline basement by adding to this the heat produced by radioactive decay of naturally occurring potassium, uranium, and thorium in the crystalline crust. The concentrations of these elements were taken from the values measured in an extensive collection of basement core samples by Burwash and Cumming (1976), and are after Jones and Majorowicz (1987).

On this basis, Jessop (1992) outlined a number of basement zones. A region of high values of basement heat flow (>80 mW/m^2) follows a linear trend that roughly parallels the Rimbey High which was delineated by Ross *et al.* (1991) (see Figure 2.4). Moderate basement heat flows are also expected from Ross *et al.'s* (1991) Ksituan Arc, Chinchaga and Buffalo Head Zones, and in the south associated with the Medicine Hat Block. In any event, the map of expected basement heat flow (Figure 5-4 of Jessop 1992) shows no correlation with the heat flows in the Paleozoic, nor with those in the shallower Mesozoic and Tertiary (Majorowicz *et al.* 1984, 1986). This noncorrespondence in heat flow, both laterally and vertically, between the differing geologic units suggested to Jessop (1992), after Majorowicz and Jessop (1981), Jessop *et al.* (1984), Jones *et al.* (1984), Jones and Majorowicz (1987), Majorowicz *et al.* (1984, 1986) and Jessop (1989), that the complex pattern of vertical and lateral heat flow in the Western Canada Sedimentary Basin is a consequence of disruptions due to lateral transfer of fluids through permeable aquifers and, hence, differs from the normal heat flow patterns in crystalline rocks which show no vertical variation. In contrast, Bachu (1988) argued that the strongest signal of the geothermal gradient in the Western Canada Sedimentary Basin is a southwest to northeast trend of increasing heat flows and provides arguments that the aquifers cannot transport fluid masses sufficiently rapidly to influence the heat flow.

The above geothermal studies are general in nature and do not provide any indication of potential structures that could serve as the focus of further work for diamond potential. Identification of such potential structures would require additional detailed surveys of the existing temperature data. One detailed study of well bore temperatures which were recorded from 3,360 petroleum industry wells in a region of west-central Alberta centred near Hinton, was carried out by Lam *et al.* (1982). They calculated the vertical thermal gradients in the wells and then mapped these data. Despite the type of mapping procedure used by them, an area of relatively high vertical geothermal gradient of 36°C/km was identified between Hinton and Edson and comprises an oblong shape that strikes approximately southwesterly. Furthermore, this area of relatively large, high geothermal gradient is in contrast with the value averaged over all their observation wells of 25.7°C/km. Lam *et al.* (1982) suggested that these high values were a consequence of flow of high temperature fluids along the numerous thrust fault planes in the region; this was further supported by an extrapolation of this trend to the locale of Miette Hot Springs.

5.7 Summary

A listing of the regional scale geophysical anomalies in the literature which are pertinent to diamond exploration in Alberta, follows.

1) Seismic tomography and surface wave studies indicate that the upper mantle beneath Alberta is a transitional zone between the shallow, slow seismic velocities in the Cordillera and the deep, fast seismic velocities in the Canadian Shield, which are representative of hot and cool mantle, respectively. This is supported by studies of the flexure of the Alberta Foreland Basin which indicate that the lithosphere thickens to the north and east of Alberta.

2) Controlled source seismic refraction experiments indicate a general shallowing of the depth of the Mohorovicic discontinuity in the northeastern sections of the province (Figure 5.2). The crust in the southern portions of Alberta, but removed from the Rocky Mountains, is thicker than 'normal' continental crust. However, the crust in southern Alberta may show thinning beneath the locale of the Vulcan Low.

3) Deep reflection seismic experiments show a complex deep crustal structure in southern Alberta and perhaps also in central Alberta near Edmonton. In contrast, the Peace River Arch region may show less lateral variation in depth to the Mohorovicic discontinuity and seismic velocity. These earlier studies, however, will soon be supplanted by higher resolution seismic profiles as part of the Lithoprobe Alberta Basement Transect.

4) Bouguer gravity increases from the Rocky Mountains to the north and east and may also indicate a general thinning of the crust away from the mountains. A large, nearly linear Bouguer gravity low, possibly related to the Snowbird Tectonic Zone, strikes northeast from the Rocky Mountains (51°N latitude, 115°W longitude) across the province to the Alberta-Saskatchewan border at 55.5°N latitude (Figures 5.3 and 5.4c). A nearly horizontal, arcuate region of low Bouguer gravity, which is commonly referred to as the Vulcan Low, traverses the southern portion of Alberta.

5) Magnetic data show the existence of major regional crustal features, such as the Great Slave Lake Shear Zone, the Snowbird Tectonic Zone and the Vulcan Low (Figures 5.5 and 5.6).

6) A northeast trending low electrical conductivity lineament, which possibly is related to the Vulcan Low, traverses the southern portion of Alberta.

7) Regional heat flow studies do not identify any major structures of potential interest within Alberta, and the geothermal data appear to be complicated by basin wide fluid transfers through aquifers. One study has highlighted a region of high

geothermal gradient that exists between the cities of Edson and Hinton. The geothermal anomaly in this region is possibly related to deep magma or to transfer of hot fluids along faults

6. GEOCHEMICAL, GEOLOGICAL AND GEOPHYSICAL ANOMALIES IN ALBERTA

6.1 Introduction

Other than a few lamproitic intrusions from the Mark diatreme cluster that exists in Alberta just east of the British Columbia border within Banff National park (Fipke 1990; Olson *et al.* 1994), the current publically available information indicates that no other kimberlites or lamproites have been discovered to date in Alberta. However, because of the presence of kimberlites and/or lamproites in (a) Montana at Williams Ranch and Smoky Butte, (b) the Northwest Territories at Lac de Gras and Outlet Bay, (c) British Columbia at the Crossing Creek and Jack pipes, and (d) Saskatchewan near Prince Albert and at the Fort à la Corne area, and elsewhere in western North America (Figure 3.1), it is likely only a matter of time before such ultramafic intrusions are discovered in Alberta. Whether any of these intrusions will prove to be economically diamondiferous may take many years of concerted exploration to determine.

The following section will discuss the potential for diamondiferous diatremes in Alberta based on the present state of knowledge of the basement geology, structural setting and considering the potentially favourable stratigraphic intervals, with the latter mainly inferred from evidence from outside of Alberta. In addition, other reported geological, geophysical and geochemical anomalies will be summarized, including the results to date of regional diamond indicator mineral surveys that have been conducted by various government agencies within Alberta.

6.2 Potentially Favourable Basement Terranes And Structures

It is now generally well accepted that diamonds in kimberlites or lamproites are xenocrysts derived from the dissaggregation of mantle peridotite or eclogite that exist at depth beneath thick, cool crust. In addition, most peridotitic diamonds are thought to be Archean, whereas eclogitic diamonds span an age range from Archean to at least 990 Ma (Kramers 1979; Richardson *et al.* 1984, 1990; Richardson 1986, 1989; Smith *et al.* 1989). Based on these observations, the most favourable areas for the intrusion of diamondiferous kimberlites or lamproites in Alberta should be those areas that are underlain by basement terranes comprised of old, thick and cold crust that has not been subjected to thermal reheating through time.

6.2.1 Southern Alberta

Well documented Archean basement terranes in Alberta include the Medicine Hat Block, Vulcan Low (Southern Alberta Rift), Matzhiwin High, Loverna Block and the Eyehill High in the southern third of the province (Figure 2.2). These terranes are favourable for the formation and preservation of diamonds based on their Archean age and long time crustal stability. The petrogenesis of the Crowsnest Volcanics of southwest Alberta (Peterson and Currie 1993), the minette intrusions of southern Alberta (Kjarsgaard 1994a; Kjarsgaard and Davis 1994; Luth 1994) and many mafic alkalic intrusions in Montana (MacDonald *et al.* 1992; Dudas 1991; O'Brien *et al.* 1991) indicates that considerable partial melting of the lower crust has occurred at least locally in the southern portion of the Medicine Hat Block. If this partial melting is related to a widespread Cretaceous to Tertiary thermal event that has heated the lower crust and upper mantle in the area from the Cordilleran deformation front to the Sweetgrass Arch, then the potential for diamond preservation in this area may be low. If, however, the thermal event was more localized, then it is possible that the region of the Milk River Drainage Divide may represent a favourable area to explore for diamondiferous intrusions based on the existence of potassic minette intrusions (Williams and Dyer 1930; Russell and Landes 1940; Irish 1971; Kjarsgaard 1994a, b; Kjarsgaard and Davis 1994) and potentially extensive dyke swarms identified by Ross *et al.* (1994b) and Teskey *et al.* (1994) as a result of the recently released Cypress Hills airborne magnetic survey (Geological Survey of Canada 1993). In addition, the Milk River Drainage Divide is a major continental divide that separates the drainage to Hudson Bay from the Columbia River drainage to the Pacific Ocean. Such drainage divides may reflect thickened crust, with sub-cratonic roots or keels that penetrate well into the upper mantle, based on the laws of isostasy, and they are sometimes referred to as crustal Anticlinoria or Anticleses. These sub-cratonic roots or keels are the preferred locus for the formation and preservation of diamonds (Haggerty 1986; Gurney 1990).

Other potentially favourable areas for the intrusion of kimberlites or lamproites in the southern third of Alberta might include the margins of the Vulcan Low (Southern Alberta Rift), the southwest trending Meadow Lake Escarpment and the Eyehill High basement terrane (Figures 2.2 and 2.4). Deep seated graben-like movement in the vicinity of the Vulcan Low (Southern Alberta Rift) is documented during the Proterozoic (Kanasewich 1968; Kanasewich *et al.* 1969; McMechan 1981), the Upper Paleozoic (Price and Lis 1975; Brandley and Krause 1993; Brandley *et al.* 1993) and possibly as young as Middle Cretaceous based on extrusion of the Crowsnest volcanics, which have their thickest portions centred within the bounds of the Vulcan Low (Southern Alberta Rift). Further evidence of possible Cretaceous movement associated with the Vulcan Low (Southern Alberta Rift) exists in the Alberta Plains near Brooks, where Hopkins (1987, 1988) has described synsedimentary subsidence associated with possible movement along faults that reach from the Precambrian basement into the Cretaceous section.

Little is known about the Meadow Lake Escarpment, but it is believed to be a Devonian escarpment that corresponds to a shelf margin reef complex (Figures 2.4 and 2.5; Kent 1994; Oldale and Munday 1994; Switzer *et al.* 1994; Wright *et al.* 1994). Local faulting, attributed to salt removal in the Devonian Wabamun Group, has been documented along the trend of the escarpment about 40 km northeast of Trochu, Alberta (Oliver and Cowper 1983). Interestingly, microdiamonds were discovered by Drs. D. Braman (Tyrrell Museum) and D. Carlisle (Environment Canada) along the west bank of the Red Deer River at the Cretaceous-Tertiary boundary (Science City News 1992; Braman *pers comm.* 1994) approximately 20 km northwest of the abnormal sections near Trochu which were documented by Oliver and Cowper (1983).

Ross *et al.* (1994c) suggested that seismic data from the Lithoprobe Central Alberta Transect indicate significantly thickened crust beneath the Archean Eyehill High near the Saskatchewan border (Figure 2.2). As a consequence, the lower crust and upper mantle below the Eyehill High may have been favourable for the formation and preservation of diamonds, and therefore this area may be a favourable place to explore for diamondiferous kimberlites or lamproites. In particular, perhaps the most favourable portion of the Eyehill High to explore is where the Meadow Lake Escarpment overlies it.

6.2.2 Central and Northern Alberta

Of the Proterozoic or reworked Archean terranes in the northern two thirds of Alberta, the least favourable areas for diamond formation and preservation are likely the strongly magmatic terranes, such as the Taltson, Great Bear, Rimbey and Ksituan terranes, because they are indicative of high thermal gradients in the crust during the Proterozoic (Figure 2.2). The strong thermal pulse responsible for the magmatic rocks in these terranes would likely have destroyed any pre-existing diamonds in the upper mantle below these terranes. If, in fact, some of these terranes represent accreted microcontinents (Villeneuve *et al.* 1993), then there is potential to have created Proterozoic or younger diamonds in subducted eclogite during accretion of these microcontinents. The more favourable terranes are likely the Chinchaga and Thorsby Lows, and possibly, the Wabamun and Buffalo Head Terranes because Villeneuve *et al.* (1993) suggested that these terranes may have a significant Archean component to them based on their Sm-Nd isotope systematics (Figure 2.2). The Thorsby Low and its margins are of particular interest because it possibly represents the southwest extension of the Snowbird Tectonic Zone (Figures 2.2 and 2.4), which is a major crustal lineament that divides the Churchill Province into the Rae and Hearne subprovinces. The Snowbird Tectonic Zone can be traced to the northeast at least as far as Baker Lake, and perhaps into Hudson Bay. A major continental drainage divide coincides very nearly with the north margin of the Thorsby Low. This may reflect thickened crust, which is somewhat corroborated by seismic data from the Central Transect of Lithoprobe (Ross *et al.* 1994c). Other local structures and faults in the basement and overlying sedimentary rocks indicate that the Thorsby Low has been periodically active during the Phanerozoic as recently as Cretaceous. These include extensional basement faults (the Erith Graben) that offset

Cambrian carbonates to Cretaceous sedimentary rocks in the Erith and Hanlon hydrocarbon fields (Edwards and Brown 1994), the Cline Channel in Devonian carbonates (Figure 2.5; Geldsetzer and Mountjoy 1992), and the Bighorn Tear Fault which exists along the North Saskatchewan River southwest of Nordegg (Figure 2.5; Verrall 1968; Dahlstrom 1970). The Bighorn Tear Fault marks the southern termination of the Bighorn Range. Verrall (1968) indicated that this fault has experienced vertical movement along with shearing because the south side is significantly downthrown. The major period of movement was during the Laramide Orogeny because the fault cuts Upper Cretaceous rocks in the Cripple Creek thrust sheet, but is overridden by the McConnell thrust sheet.

Other areas of interest include the Chinchaga and Buffalo Head Terranes where they have been affected by periodic movement associated with the PRA or the GSLSZ (Figure 2.5). The Peace River Arch was a positive feature during the Late Proterozoic to Late Devonian (Stelck *et al.* 1978; O'Connell *et al.* 1990) and, possibly, during the Late Cretaceous to Tertiary (Leckie 1989; Hart and Plint 1990). The Peace River Arch failed during the Late Paleozoic, forming the Fort St. John Graben Complex (Peace River Embayment), which was a negative relief feature from the Late Paleozoic to Early Cretaceous (Cant 1988; Leckie *et al.* 1990b; O'Connell *et al.* 1990). Many of the pronounced faults that were formed during Late Paleozoic to Cretaceous subsidence influenced sedimentary depositional patterns and they parallel and overlie prominent basement fabrics. An example of this is the Lower Cretaceous Fox Creek Escarpment (O'Connell *et al.* 1990), which overlies the Late Paleozoic Belloy Fault (Sikabonyi and Rodgers 1959), both of which overlie and parallel the contact between the Ksituan and Chinchaga basement terranes (Figures 2.2 and 2.5). Hart and Plint (1990) suggested that this escarpment influenced Upper Cretaceous sedimentation patterns, and as such is indicative of renewed uplift during that time. Coincidentally, these structures trend southwest through the centre of the southern half of the ground near Peace River, Alberta that is currently held and being actively explored for diamonds by Monopros Ltd.

The Kimiwan basement anomaly which was described by Muelenbachs *et al.* (1993, 1994), is a distinct northwest trending linear oxygen and deuterium isotope depletion anomaly in basement rocks that exists northwest of Edmonton. The anomaly is the result of extensive chlorite-epidote alteration in the basement rocks and corresponds spatially to the strong linear magnetic high that forms the southwest margin of the Buffalo Head Terrane in contact with the Chinchaga Terrance (Figure 2.2). The alteration along this trend may be indicative of a strong structural control, such as by a fault, and therefore this anomalous trend may be an area to explore for kimberlites or lamproites.

6.3 Other Regional Structural Elements

Other regional structural elements that may have played important roles in the emplacement of kimberlite or lamproite diatremes in Alberta include the West Alberta Arch (WAA) and the Great Slave Lake Shear Zone (GSLSZ), which includes associated intersecting structures such as the Northern Alberta Trough and the Steen River Structure

(Figures 2.4 and 2.5). With respect to the WAA, the Paleozoic alkalic igneous intrusions in the Rocky Mountains of British Columbia are distributed west of, but sub-parallel to the Alberta - British Columbia border. The northwest trending WAA was periodically active during the Paleozoic, and its western edge crudely approximates the distribution of these Paleozoic, alkalic intrusions in British Columbia. Bingham *et al.* (1985) suggested that a conductive ridge below the Eastern Rockies may be indicative of high heat flow in the lower crust and it also may be responsible for periodic uplift, extension and igneous activity such as that which occurred during the Paleozoic. Therefore, perhaps the eastern margin of the WAA, which exists well within Alberta, is also a favourable location to search for kimberlites and lamproites, particularly because it is closer to being 'on Archean craton', which is considered important for the existence of diamondiferous kimberlites and, possibly, lamproites.

Movement along the GSLSZ was predominantly during the Proterozoic, but, Skall (1975) has documented movement at least as recently as Devonian. The Steen River Structure (SRS) is an elliptical to subcircular basement high that exists very near the junction of the GSLSZ and a major northwest trending lineament that corresponds to the basement contact between the Hottah and Great Bear Magmatic terranes (Figures 2.2 and 2.5). The SRS is postulated to be a meteorite impact feature with spatially associated horst-and-graben-like structures, with direct evidence of 'shock metamorphism' coming from a single oil well (I.O.E. Steen 12-19) and associated seismic data (Winzer 1972; Wilson *et al.* 1989). Carrigy (1968), however, has suggested that the structure may have formed as a result of either volcanic activity or a meteorite impact. Several of the horizons which were intersected in the oil well, resemble mafic alkaline volcanic to volcaniclastic or pyroclastic layers. In addition, extensive bentonites and pyroclastic horizons have been identified in adjacent drillholes through the rim syncline (Carrigy 1968; Winzer 1972). In Well I.O.E. Steen 12-19, Carrigy (1968) also reported the presence of vesicular volcanic agglomerate and "*five feet of dark green glassy rock (pitchstone), in the bottom of the hole...* [that has] *a more basic chemical composition than the plutonic or vesicular rocks above.*" Radiometric K-Ar dating of pyroclastic material in I.O.E. Steen 12-19 indicates an age of about 95 Ma (Carrigy 1968), which is approximately the same age as (a) the kimberlites near Fort à la Corne, Saskatchewan, (b) the Crowsnest volcanics in southwest Alberta, (c) the Fish Scale's Horizon which is purported to be the result of a condensed section formed in an anoxic basin, and (d) bentonites associated with the Fish Scale's Horizon. It seems highly fortuitous that a massive fish extinction, thought to be related to a change to an anoxic environment during a quiescent period associated with a transgressive still stand (Leckie *et al.* 1990a, 1992), occurred at about the same time that a meteorite is thought to have impacted in the Steen River area and widespread volcanic eruptions took place in southwest Alberta and in the Fort à la Corne area, Saskatchewan. Further geoscientific work is needed to determine the origin of the SRS. The area surrounding the SRS may be a favourable area to search for kimberlites or lamproites.

6.4 Potentially Favourable Stratigraphic Intervals and Structures

Kimberlite and lamproite volcanism spans most periods of time throughout the world, but the dominant episodes of diamondiferous kimberlite and lamproite volcanism are Late Middle Helikian, Late Devonian to Mississippian, Middle Jurassic to Middle Cretaceous and Early Tertiary (Tables 3.1 and 3.2). Volcanism during each of these more important time intervals is evident in one form or another within or near Alberta. As well, alkaline mafic volcanic activity was evident in Alberta during at least three of these episodes. During most or all of these three periods, much of Alberta was covered by seas marginal to the North American continent or by continental inland seas. As a result, large thicknesses of sedimentary rocks of the Western Canada Sedimentary Basin cover most of Alberta. Based on the kimberlites near Fort à la Corne, Saskatchewan (Lehnert-Thiel *et al.* 1992) and those in South Africa, the appropriate diamond exploration model for Alberta may consist of searching for stratabound, horizontal to lenticular reworked kimberlite or lamproite deposits with a significant distal volcanic component that is sediment dominated. It is even conceivable that the most important diamond concentrations in Alberta might be discovered as stratabound deposits rather than the more typical pipe-like deposits. As a result, to effectively explore and evaluate Alberta for the presence of diamondiferous kimberlites or lamproites, it is critical to know which stratigraphic horizons are most likely to contain evidence of these intrusions in the form of diatremes, volcaniclastics or bentonites. Following are the most likely time stratigraphic horizons where evidence of kimberlite or lamproite volcanism should be found in Alberta and where these horizons might be successfully explored for, based upon the known basement and structural setting and the depth below surface of these selected horizons.

6.4.1 Late Devonian to Mississippian

There are at least three episodes of Paleozoic kimberlitic volcanism in British Columbia, Northwest Territories and the western United States (Figure 3.1, Table 3.1). Two of these episodes, Ordovician-Silurian and Devonian-Mississippian, have yielded diamondiferous diatremes. These include a number of microdiamonds from the Silurian Mountain Diatreme in the N.W.T. (Godwin and Price 1986; Fipke 1990), and grades of up to 20 ct/100 t from Devonian-Mississippian kimberlites in the State Line District, Colorado (Fipke 1990, Coopersmith 1991, 1993a, b). The last period of Paleozoic kimberlitic volcanism, during the Permian to Triassic, is evidenced by the Crossing Creek (Cross) kimberlite near Elkford, British Columbia (Grieve 1982; Pell 1987a, b; Hall *et al.* 1989; Fipke 1990). No diamonds have been recovered from the Cross kimberlite.

There are only a few known Orovician-Silurian mafic alkaline intrusions in North America and these are all present in the Canadian Cordillera and the Mackenzie Mountains (Figure 3.1, Table 3.1). The Mountain Diatreme is the only diamondiferous intrusion of this time period, and its identification as a kimberlite is tenuous (Fipke 1990). In Alberta, Ordovician-Silurian carbonates are restricted to mountainous regions and in the deepest portions of the Western Canada Sedimentary Basin. As a result, the potential for discovery and development of Ordovician-Silurian kimberlites or lamproites in Alberta is low.

To date, the Cross kimberlite is the only North American example of the Permian-Triassic alkaline volcanic event. As a result, the likelihood of extensive Permian-Triassic volcanism in Alberta is low, even though the potential for preservation in the Western Canada Sedimentary Basin is high due to regionally extensive Permian-Triassic sedimentary rocks. This stratigraphic interval, however, should not be ignored because the Jwaneng kimberlite pipe in Botswana is Triassic in age and is one of the richest diamond mines (140 ct/100 t) in the world (Helmstaedt 1992, 1993).

The most prospective time-stratigraphic interval to find **Paleozoic diamondiferous** kimberlites or lamproites in Alberta is probably in the Late Devonian to Mississippian succession. This is based on (1) the existence of diamondiferous alkaline diatremes near to or straddling the Alberta-British Columbia border (Northcote 1983a, b; Dummett *et al.* 1985; Fipke 1990); (2) possible diatremes of this age in Saskatchewan (Gent 1992); (3) the presence of volcanic related rocks that have been identified in the Upper Devonian Big Valley Formation in Saskatchewan (Halbertsma 1994) and Lower Mississippian Exshaw Formation at several locations in Alberta (Folinsbee and Baadsgard 1958; Packard *et al.* 1991; Meijer-Drees and Johnston 1993; Richards *et al.* 1993); (4) the wide distribution and large volume of Upper Devonian to Mississippian rocks in the Alberta basin, and (5) several regional structures that were active in Alberta at that time. Another favourable aspect is that the most prolific diamondiferous kimberlite event in the northern hemisphere occurred during this time period on the east Siberian platform in Yakutia (Table 3.1). World class diamond producers, such as the Mir, Internationalnaya and Udachnaya pipes, are Upper Devonian to Mississippian in age (Davis *et al.* 1982; Milanovskiy and Mal'kov 1982; Jerde *et al.* 1993). This Upper Devonian to Mississippian event is already known to be an important event in North America based on the discovery of more than twenty diamondiferous kimberlites in the State Line District, Colorado with grades of up to 20 ct/100 t in the Sloan pipe (Fipke 1990; Coopersmith 1991, 1993a, b).

The depth from surface to the top of the Devonian ranges from zero to more than 2,000 m from northeast to southwest across Alberta (Mossop and Shetson 1994). Exploration for diamondiferous deposits in Devonian and older Phanerozoic rocks will generally be restricted to northern Alberta, and the Rocky Mountains and Foothills, where Upper Devonian to Mississippian rocks are at depths less than 500 m below surface. Important structures that were active during this time in northern Alberta include: (a) the Peace River Arch, which was transitional from a Devonian arch to a Mississippian graben (Cant 1988; O'Connell *et al.* 1990), (b) the Great Slave Lake Shear Zone and the spatially associated Northern Alberta Trough (Sikabonyi and Rodgers 1959; Skall 1975), and (c) other various poorly documented structures in northeast Alberta (Garland and Bower 1959; Martin and Jamin 1963; Stewart 1963; Hackbarth and Nastasa 1979; Dubord 1987; Dufresne *et al.* 1994). In the Rocky Mountains and Foothills, important tectonic elements that may have influenced the intrusion of deep-seated Devonian-Mississippian diatremes include the West Alberta Arch (WAA), the Thorsby Low and the Southern Alberta Rift (SAR). The northeast axis of the northwest trending, doubly plunging WAA approximately coincides with a number of important basement and Phanerozoic tectonic elements in the vicinity of the mountain corridor of the North Saskatchewan River. These elements include the Thorsby Low basement terrane which is likely the southwest extension of the Snowbird Tectonic Zone, extensional faults that extend from the basement into the Phanerozoic succession well south of Edson (Edwards and Brown 1994), and the Devonian Cline Channel (Geldsetzer and Mountjoy 1992). The boundary zones of the SAR may also have been a favourable location for the intrusion of Devonian-Mississippian diatremes. Brandley and Krause (1993) and Brandley *et al.* (1993), for example suggested that substantial thickening of Mississippian carbonates approximately within the SAR is indicative of Late Paleozoic subsidence due to reactivation of the SAR during Antler orogenic activity.

6.4.2 Middle Cretaceous

In reference to the time distribution of kimberlites and lamproites, Dawson (1989) stated "*Even accounting for the possibility of enhanced recognition of relatively young activity compared with older magmatism (due to decreased chance of subsequent sediment burial), the Upper Jurassic/Cretaceous activity was the major epoch of kimberlite intrusion.*" Not only is the Late Jurassic to middle Cretaceous the most prolific period of kimberlite intrusion worldwide, it is also by far the most prolific period of diamondiferous kimberlite intrusion, most of which has been restricted to the African continent (Table 3.1). To date, evidence indicates that this epoch also has been a modest, if not strong, period of kimberlite and lamproite activity across the North American continent (Table 3.1).

Evidence of kimberlite or related rocks which intruded during the Jurassic in North America, is mostly restricted to eastern Canada and the United States of America. Examples include the James Bay Lowlands and at Kirkland Lake, Ontario (Brummer 1978, 1984; Reed and Sinclair 1991), Lake Ellen, Michigan (Jarvis and Kalliokoski 1988; Duskin and Jarvis 1993) and Ithaca, New York (Watson 1967; Meyer 1976; Zartman *et al.* 1967; Basu *et al.* 1984). Diamonds have been discovered in kimberlitic diatremes at both Kirkland Lake and Lake Ellen. In western Canada and the western United States of America, however, there is little evidence of volcanism during this period. Therefore, the potential for diamondiferous intrusions of this age are regarded as low for Alberta. Nonetheless, rocks of this age are present throughout most of the Alberta Basin, hence because of the importance of this time period in South Africa, and the presence of diamondiferous intrusions of this age in eastern North America, the Jurassic succession should not be discounted entirely as an exploration target.

Multiple middle Cretaceous diamondiferous kimberlites and lamproites have been discovered in the Fort à la Corne area, Saskatchewan (Gent 1992; Lehnert-Thiel *et al.* 1992), at Somerset Island, N.W.T. (Fipke 1990; Kjarsgaard 1993), and at Prairie Creek, Arkansas (Zartman *et al.* 1967; Zartman 1977; Gogineni *et al.* 1978; Scott Smith and

Skinner 1984; Morris 1987; Waldman *et al.* 1987). The Fort à la Corne diamondiferous kimberlites were intruded about 94 to 96 Ma (Lehnert-Thiel *et al.* 1992), which is the approximate age of the Fish Scales Horizon (Leckie *et al.* 1990a, 1992; Bloch *et al.* 1993), the Crowsnest volcanics in southwest Alberta which have been (dated at 96 Ma by Folinsbee *et al.* (1957), and the subsurface Viking Formation bentonites which have been dated at about 100 Ma by Tizzard and Lerbekmo (1975). In addition, Dr. M.E. McCallum (Fipke 1990) has suggested that many of the undated and dated alkaline intrusions, such as the Jack and Mark diatremes, along the Alberta-British Columbia border, are in fact syn- to post-orogenic and were likely intruded between 60 and 98 Ma based on structural relationships. Another potentially important igneous event includes volcanism associated with the Steen River Structure (SRS) in northern Alberta, which has been dated at 95 Ma and may be a result of a meteorite impact or of volcanic activity, or both (Carrigy 1968; Winzer 1972; Wilson *et al.* 1989). These various events, including the fish extinction, are likely indicative of widespread volcanic activity across the Western Canada Sedimentary Basin during late Early to Late Cretaceous time (mainly about 100 to 90 Ma). In short, the middle Cretaceous interval, in the vicinity of the Fish Scales Horizon, is probably the most favourable Mesozoic succession to explore for diamondiferous kimberlites or lamproites in Alberta.

The depth from surface (Kelly Bushing) to the top of the Fish Scales Horizon is illustrated in Figure 4.4. In general, economic considerations probably will restrict diamond exploration to where the Fish Scales Horizon is at depths less than about 500 m below surface. Hence, the most prospective areas include: (1) northern Alberta in a southeasterly belt that trends from Grande Prairie to Cold Lake, (2) beneath the Caribou Mountains near the N.W.T. border, and (3) in the Rocky Mountains and Foothills (Figure 4.4). Important structures that may have been active in these areas during the middle Cretaceous include the PRA, the SRS and, possibly, reactivation of faults associated with the GSLSZ, the STZ, the Meadow Lake Escarpment and the SAR (Figures 2.4 and 2.5). As discussed in a prior section, the Peace River Arch was a negative relief feature during the Jurassic to Early Cretaceous (Cant 1988; Leckie *et al.* 1990b; O'Connell *et al.* 1990), but during the middle Cretaceous uplift likely was renewed and continued until at least the Tertiary in response to Cordilleran orogenesis (Leckie 1989; Hart and Plint 1990). Many of the faults associated with this subsidence and renewed uplift of the PRA are deep-seated and extend from basement into the Cretaceous succession. These faults are obvious loci to search for kimberlite or lamproite intrusions and any associated volcanic related rocks in the middle Cretaceous Shaftesbury Formation at about the level of the Fish Scales Horizon. Other areas where middle Cretaceous rocks might be explored include the Steen River area in the vicinity of the SRS and in the Caribou Mountains. Fish Scale's age strata are preserved beneath the Caribou Mountains (Figure 2.1) and volcanic effects are associated with the SRS as evidenced in several wells in its vicinity.

In east-central Alberta, middle Cretaceous strata in the vicinity of Phanerozoic faults or fractures associated with the STZ and Meadow Lake Escarpment may also be favourable loci to explore for diatremes and associated volcanic rocks. Evidence of local faulting has been documented along the trend of the Meadow Lake Escarpment, most of which has been attributed to the removal of salt horizons in the underlying carbonates (Oliver and Cowper 1983). However, diatremes with kimberlitic indicator minerals are documented in some inferred salt solution collapse structures in Saskatchewan (Gent 1992). As well, abundant bentonites with an average radiometric age of 100 Ma have been identified in the Viking Formation, just below the Fish Scales Horizon, in east-central Alberta (Tizzard and Lerbekmo 1975). Furthermore, thick bentonites with a much more local distribution have been identified within the more widespread bentonites that exist in the Viking Formation (Ibid, Amajor and Lerbekmo 1980).

In the Rocky Mountains and Foothills, important regional structures that might have been active during the middle Cretaceous include the Southern Alberta Rift (Vulcan Low) and the STZ. Evidence of Early to middle Cretaceous movement associated with the SAR is indicated by thickening of the stratigraphic section within the bounds of the rift (Jerzykiewicz and Norris 1993a, b) and the fact that the thickest portions of the Crowsnest volcanics are centred in the SAR (Price 1962; Pearce 1970; Adair 1986). As well, Cretaceous Howell Creek intrusions in southeastern British Columbia (Gordy and Edwards 1962) were intruded near the approximate southern boundary of the SAR. Even though the chemistry of the Howell Creek intrusions and the Crowsnest volcanics is believed to be indicative of low diamond potential (Peterson and Currie 1993), this does not preclude the possibility of more potassic younger or older intrusions that are derived from deeper sources with higher diamond potential. McCallum (Fipke 1990), for example, pointed out that many of the ultramafic lamprophyres to lamproitic diatremes along the Alberta-British Columbia border may have, in fact, been intruded during Cordilleran orogenic activity between 60 and 98 Ma. As well, some structures in the vicinity of the Thorsby Low indicate that the STZ may have been reactivated during Cordilleran orogenesis. Verrall (1968), for example, has suggested that significant synorogenic vertical movement was associated with the Bighorn Tear Fault, and Edwards and Brown (1994) have suggested that extensional basement faults which are associated with the Erith Graben, offset Cambrian carbonates to Cretaceous sedimentary rocks in the Erith and Hanlon hydrocarbon fields. Therefore, the middle Cretaceous sedimentary successions in the vicinity of these structures and possibly other undiscovered structures which overlie the Thorsby Low, may be a favourable target for exploration of kimberlites and lamproites.

6.4.3 Tertiary

Although the late Cretaceous to early Tertiary is documented as a minor period for the intrusion of diamondiferous kimberlites on the African continent and a relatively non-event on other continents (Tables 3.1 and 3.2), it may well prove to be the dominant diamondiferous kimberlite event on the North American continent based on early indications from the Lac de Gras area, N.W.T. where initial age dates indicate the diamondiferous diatremes were emplaced during the Eocene about 52 Ma. Therefore, selected early Tertiary strata in southern and western Alberta warrant exploration for diamondiferous diatremes.

In particular, early Tertiary strata that overlie favourable basement terranes (Figure 2.2), and/or are associated with major structural zones, such as the STZ, WAA, PRA, SAR or other such anomalies (Figures 2.4 and 2.5), should be explored for diamondiferous diatremes.

In addition to the potential for diamondiferous diatremes to exist in early Tertiary rocks, if such primary deposits are present in Alberta, then there also is potential for secondary diamondiferous deposits to occur in later Tertiary or even Quaternary gravels or other clastic strata that have been deposited by fluvial, alluvial eluvial or other such erosional-depositional processes. That is, these secondary deposits may be geologically analogous to the placer beach sands or alluvial river deposits that are mined for diamonds in southern and western Africa (Helmstaedt 1992, 1993; N.W.T. Government 1993; Levinson *et al.* 1992; Gurney and Levinson 1991).

6.5 Diamond Indicator Mineral Anomalies

6.5.1 Summary of Government Till And Sediment Surveys

Sampling for diamond indicator minerals across Alberta is being conducted by both the federal and provincial Geological Surveys and involves the sampling of tills, and fluvial sand and gravel from preglacial deposits and modern drainages. Table 6.1 gives the details of the known sampling surveys conducted mid 1994 in Alberta and the pertinent references where the data have been or will be released. The regional coverage for tills in central to southern Alberta which has been provided by the GSC (Garrett and Thorliefson 1993; Thorliefson and Garrett 1993; Thorliefson *et al.* 1994) is good, with an average sample density of about 20 sample sites per NTS 1:250,000 map-area for 13 such map-areas (Figures 6.1 and 6.2). However, the coverage across the remainder of Alberta is much less comprehensive, with a total of 114 till sample sites distributed over 33 NTS 1:250,000 map-areas. At least 16 of the remaining 33 map-areas have 2 or less sample sites per 1:250,000 map-area. Some of the major preglacial sand and gravel deposits have been sampled in Alberta, but the coverage for sand and gravel from modern drainages is also much less comprehensive. The interpretation for data derived from modern sand and gravel deposits is extremely difficult because there may be significant contributions of indicator minerals from a variety of sources, including tills, preglacial deposits, Mesozoic to Tertiary clastic sedimentary rocks and, possibly, local diatremes. Much of the analytical work is still in progress, therefore, the interpretations that are presented in the following sections will be subject to change once all the surveys are completed and a more comprehensive data set is available.

The reader is referred to the individual referenced sources in Table 6.1 for the details with respect to methodology for processing of the samples and microprobe analyses. The AGS and GSC microprobe data for selected favourable indicator minerals that were used to construct Figures 6.3 to 6.43 are included in Appendix 6.1. For the complete analytical

TABLE 6.1: **Summary of indicator mineral sampling for Alberta**

Year Sampled	No. of Samples	Material & Location	Status of Results	Reference
1991 (GSC)	14	Till (Orientation Survey)	All Data Released	Garrett & Thorliefson 1993
1992 (GSC)	252	Till (Central & Southern Alberta)	All Data Released	Thorliefson & Garrett 1993; Thorliefson *et al.* 1994
1992 (GSC)	36	Sand & Gravel (Foothills, N. Saskatchewan & Red Deer R.'s	Chromite Data Only	Ballantyne & Harris 1994
1993 (GSC)	8	Till (NE Alberta)	In Progress	Bednarski *et al.* *In Preparation*
1992 (AGS)	34	Till (Northern Alberta)	Data Partially Released; Probe Analysis Ongoing	Fenton & Pawlowicz 1993; New Data This Volume; Fenton *et al.* 1994a
1993 (AGS)	70	Till (Northern Alberta)	Data Partially Released; Sampling & Probe Analysis Ongoing	This Volume; Dufresne *et al.* 1994; Fenton *et al.* 1994a
1992-1993 (AGS)	22	Sand & Gravel (Preglacial Deposits Alberta Wide)	10 Samples Released; 12 Samples Probe Analysis In Progress	This Volume; Edwards *et al.* *In Preparation*
1993 (AGS)	3	Sand & Gravel (NTS 74E)	All Data Released	This Volume; Dufresne *et al.* (1994)
1993 (AGS)	8	Sand & Gravel (NTS 82 G,J)	Processing & Probe Analysis In Progress	Alberta Geological Survey *In Preparation*

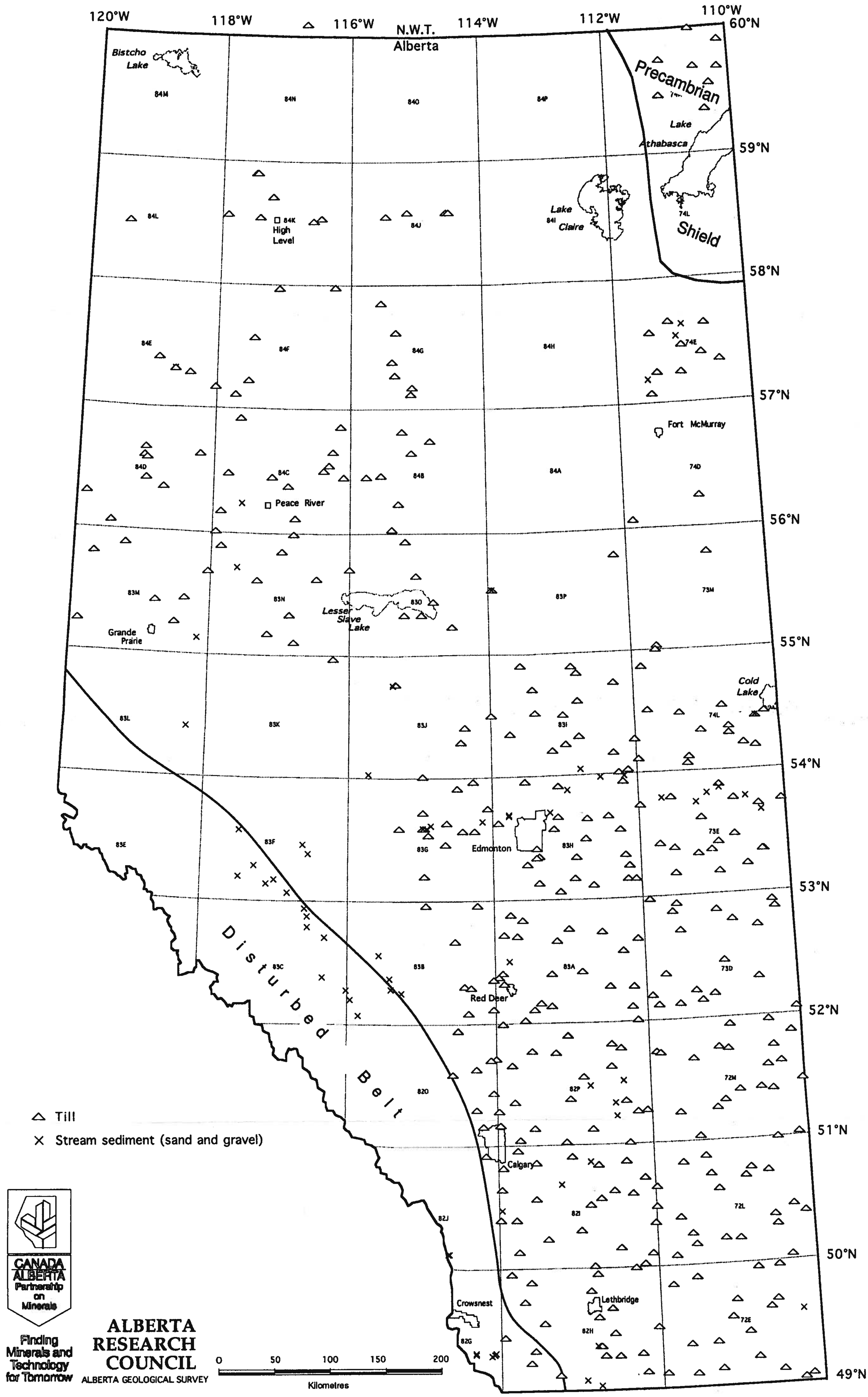


Figure 6.1. Location and sediment type of diamond indicator mineral sample sites.

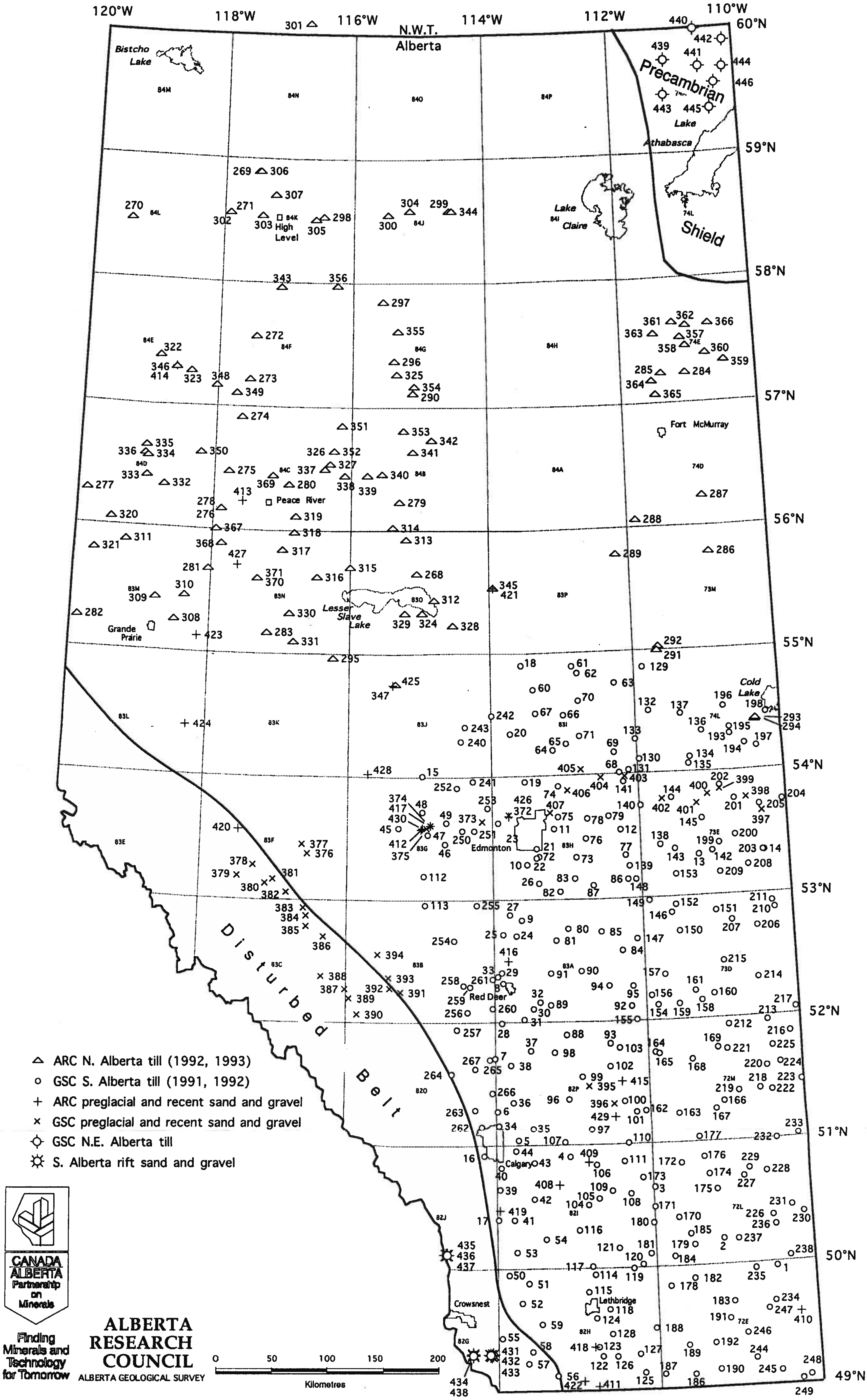


Figure 6.2. Location, sample number and data source of diamond indicator mineral sample sites.

results of all the minerals microprobed the reader is referred to Fenton and Pawlowicz (1993), Garrett and Thorliefson (1993), Thorliefson and Garrett (1993), Ballantyne and Harris (1994), Dufresne *et al.* (1994), Fenton *et al.* (1994a), Thorliefson *et al.* (1994), and Edwards *et al.* (*In Preparation*). Appendix 6.1 contains previously unreleased microprobe data for the northern Alberta tills and preglacial sand and gravel deposits from across Alberta. Processing of the AGS samples was performed at the Saskatchewan Research Council (SRC), with microprobe analyses performed at CANMET (1992 survey) and the University of Saskatchewan (1993 survey). A summary of the processing and microprobe procedures at the SRC and the University of Saskatchewan are given in Swanson and Gent (1993). All of the microprobe data that have been released to date were processed using mineral identification programs written in QBASIC and provided by the SRC (Quirt 1992a, b; Gent 1993). The results that are currently available were evaluated by using major and minor element X-Y scatter plots (Figures 6.3 to 6.19 and 6.27 to 6.43) of the sample data versus diamond inclusion compositions or compositions of minerals from other diatremes which are provided in Fipke (1990), or diamond inclusion fields illustrated on X-Y plots by Gurney (1984), McCandless and Gurney (1989), Fipke (1990), Gurney and Moore (1993), Griffin and Ryan (1993), Griffin *et al.* (*In Press*), and many others.

Based strictly on the mineral identification programs, there appear to be many samples with pyropic garnets, clinopyroxenes, chromites and picroilmenites of potential diamond exploration interest, but the anomalous samples have few discernable geographic patterns. This is well illustrated in Figure 6.20, which is a plot of the total number of potentially favourable diamond indicator minerals by site for Alberta based on the data currently available. In order to determine if any meaningful geographic patterns exist, the data were classified based on the number of indicator minerals present (Appendix 6.2), and those samples with particular indicator minerals of excellent chemistry relative to diamondiferous source rocks were compiled on a base map of Alberta (Figures 6.21 to 6.26). Because diamonds are regarded as fragments of disaggregated upper mantle peridotite or eclogite that has been incorporated into kimberlite or lamproite magmas as xenocrysts, there are essentially three types of indicator minerals that may have meaning in low density regional surveys: (a) those that are indicative of kimberlites or lamproites, (b) those that are indicative of peridotite or eclogite, and (c) those that are indicative of **diamondiferous** peridotite or eclogite source rocks. The number of indicator minerals was quantified for each sample (Appendix 6.2) after favourable grains were selected based on X-Y scatter plots (Figures 6.3 to 6.19 and 6.27 to 6.43) and other discriminating elements, such as manganese, potassium, nickel and zinc. Indicator minerals that are probably indicative of kimberlites or lamproites include: (a) high titanium G1 or G2 pyrope garnets and high magnesium ilmenites (picroilmenites) for kimberlites, and (b) high magnesium (variable chromium) P3 and P4 chromites for lamproites (Bergman 1987; Mitchell 1989; Mitchell 1991; Mitchell and Bergman 1991; Scott Smith 1992; Griffin *et al. In Press*). Indicator minerals that are indicative of peridotite source rock include: (a) chromium rich G7, G9, G10 and G11 pyrope garnets (Dawson and Stephens 1975, 1976), (b) chrome diopsides (>0.5 wt% Cr_2O_3), (Stephens and Dawson 1977), and (c) P1 xenocrystic chromites. Indicator minerals that are indicative of eclogite include: (a) low iron (<25 wt% total Fe as FeO), high magnesium (>6.5 wt% MgO) G3, G4, G5 and G6 almandine garnets (referred to as eclogitic garnets), (b) low chromium, high sodium and high aluminum diopsides, and, in some cases, (c) sodic diopside, jadeite, corundum and kyanite. Indicator minerals that are indicative of **diamondiferous peridotite** include: (a) subcalcic, high chromium G10 pyrope garnets and (b) high magnesium (≥11 wt% MgO), high chromium (≥61 wt% Cr_2O_3) P1 xenocrystic chromites. Indicator minerals that are used to identify **diamondiferous eclogite** include: (a) high sodium (>0.07 wt% Na_2O), high titanium, low iron and (b) high magnesium G3, G4, G5 and G6 eclogitic garnets, and (b) high potassium (≥0.1 wt% K_2O) eclogitic clinopyroxenes (McCandless and Gurney 1989; Fipke 1990; Gurney and Moore 1993). Other elements that are used to help determine important varieties of certain minerals versus crustal or low temperature varieties include: (a) manganese in garnets, particularly eclogitic garnets, (b) nickel in garnets and (c) zinc in chromites (Griffin *et al.* 1992; Griffin and Ryan 1993; Griffin *et al. In Press*). High manganese in garnet (>1.5 wt%) was used to eliminate crustal garnets, even if they exhibited low iron and high magnesium. Chromites from other sources, such as those from the Troodos ophiolite complex, Cyprus (Greenbaum 1977) can exhibit diamond inclusion chemistry based on major elements with high chromium and magnesium. However, the zinc content of such chromites tends to reequilibrate quite easily and increase as these types of rocks are subjected to lower temperatures with time (Griffin and Ryan 1993). Based on the aforementioned parameters, selected X-Y scatter plots were constructed for southern and northern Alberta; these include: (a) Cr_2O_3 vs CaO for high chromium (>2 wt% Cr_2O_3) G9, G10 and G11 peridotitic pyrope garnets (Figures 6.3 and 6.27), (b) FeO (total Fe) vs MgO, TiO_2 vs CaO and TiO_2 vs Na_2O for eclogitic G3, G4, G5 and G6 garnets (Figures 6.4 to 6.6 and 6.28 to 6.30), (c) Cr_2O_3 vs CaO for chrome (>0.5 wt% Cr_2O_3) diopsides (Figures 6.7 and 6.31), (d) Na_2O vs Al_2O_3 for low chromium diopsides (Figures 6.8 and 6.32), (e) FeO (total Fe) vs MgO, Cr_2O_3 vs MgO and Cr_2O_3 vs FeO (total Fe) for picroilmenites (Figures 6.9 to 6.11 and 6.33 to 6.35), and (f) Cr_2O_3 vs MgO, Cr_2O_3 vs Al_2O_3, Cr_2O_3 vs TiO_2 and TiO_2 vs Al_2O_3, Cr_2O_3 vs Ni, MgO vs Ni, TiO_2 vs Ni and Zn vs Ni for chromites (Figures 6.12 to 6.19 and 6.36 to 6.43). From these X-Y plots, anomaly maps have been prepared based on the number and types of indicator minerals present at each sample site (Figures 6.21 to 6.25). On Figure 6.20 are compiled the sites with the total number of 'anomalous' mineral grains that are reported for that site. In contrast, Figure 6.26 is a summary anomaly map, which includes the regional geology of Alberta, that depicts selected better sample sites based on: (a) the abundance of indicator minerals in Figures 6.20 to 6.25, (b) the quality of the diamond inclusion chemistry for selected minerals, such as garnets and chromites and (c) the presence of other potentially important diamond indicator minerals such as jadeite, olivine, kyanite and corundum.

On Figure 6.2 and in Appendix 6.2, all the sample sites in Alberta have been labelled with sequential numbers from 1 to 446. In the following discussion, a reference to a specific sample site will comprise the sequential number plus the sample number from the original survey source (in brackets). In the case of the AGS's northern Alberta till samples (NAT92-1 to NAT92-34, NAT93-33 to NAT93-89 and NAT93-500 to NAT93-503), the prefixes of the original sample numbers have been dropped in the following discussion.

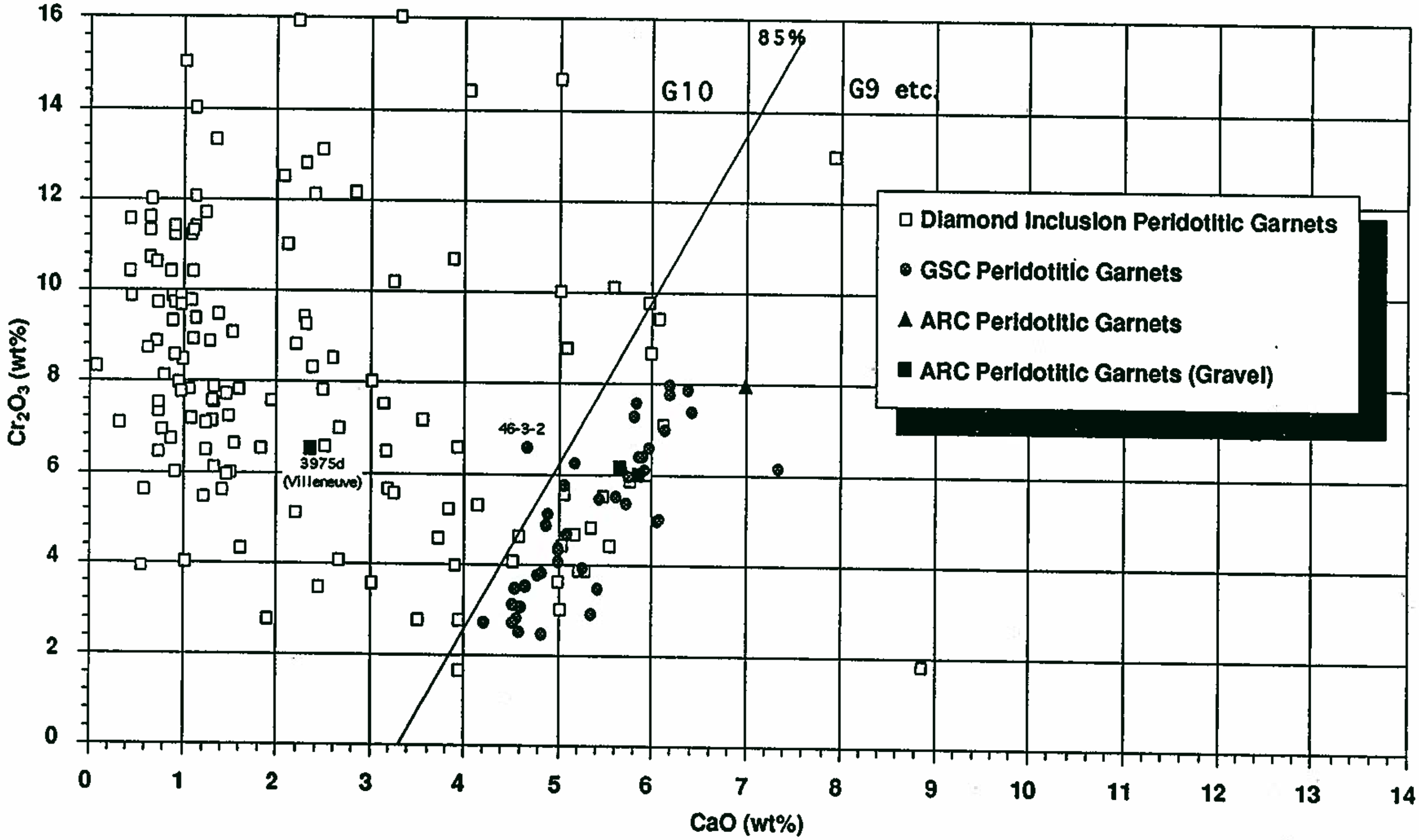


Figure 6.3: CaO vs Cr_2O_3 For Peridotitic Garnets From Southern Alberta Tills And The Villeneuve Gravel Deposit

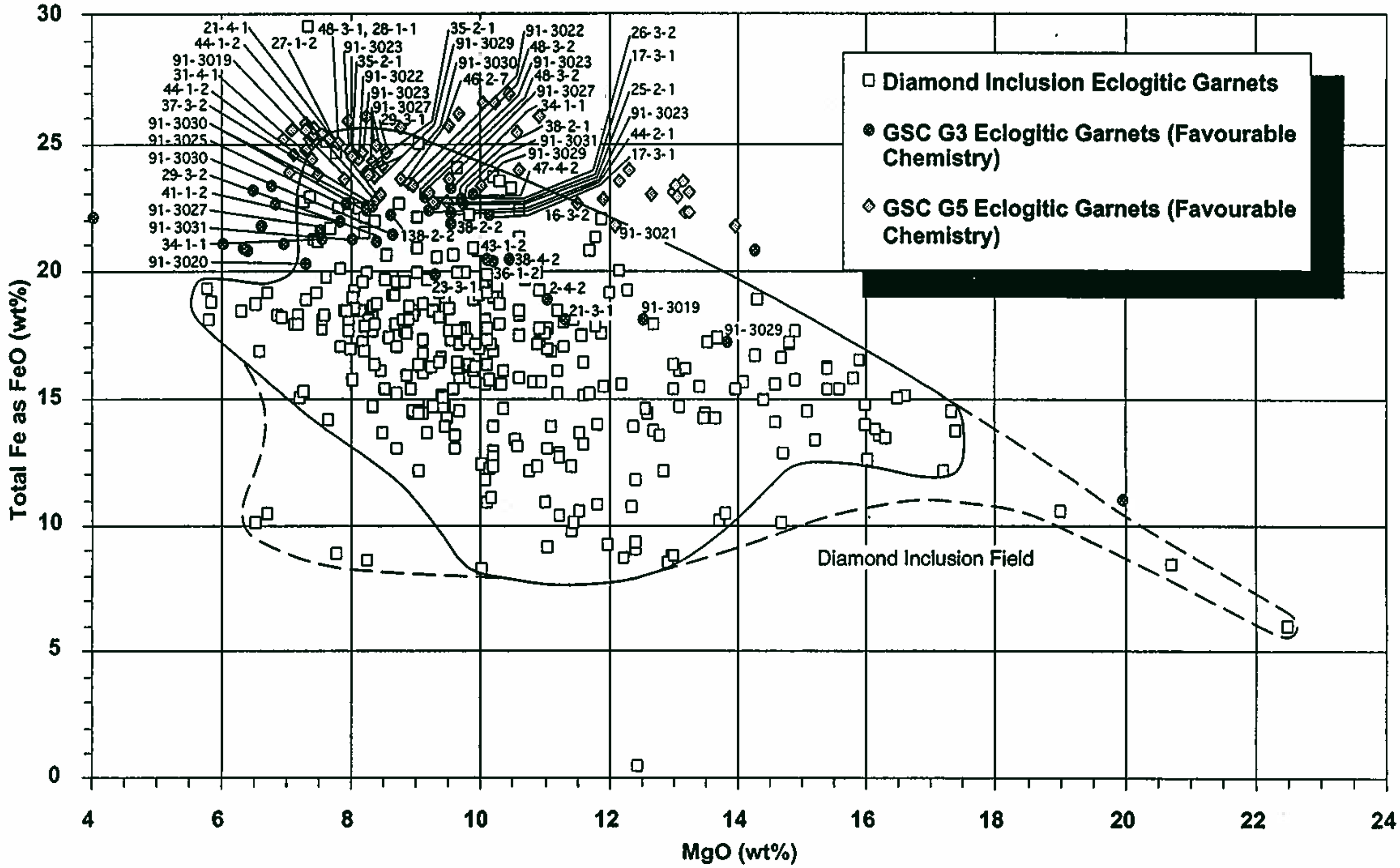


Figure 6.4: MgO vs FeO For Eclogitic Garnets From Southern Alberta Tills

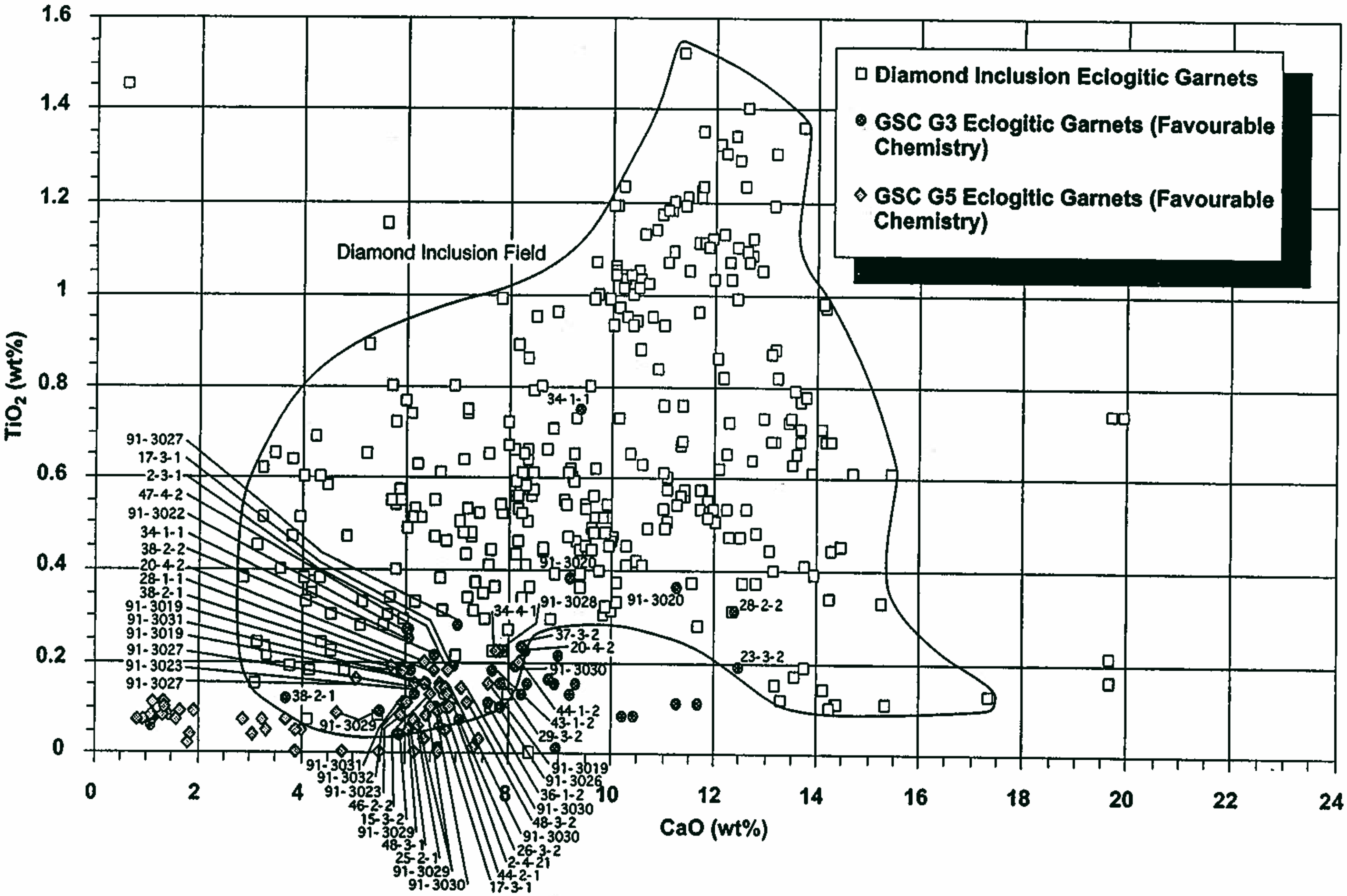


Figure 6.5: CaO vs TiO_2 For Eclogitic Garnets From Southern Alberta Tills

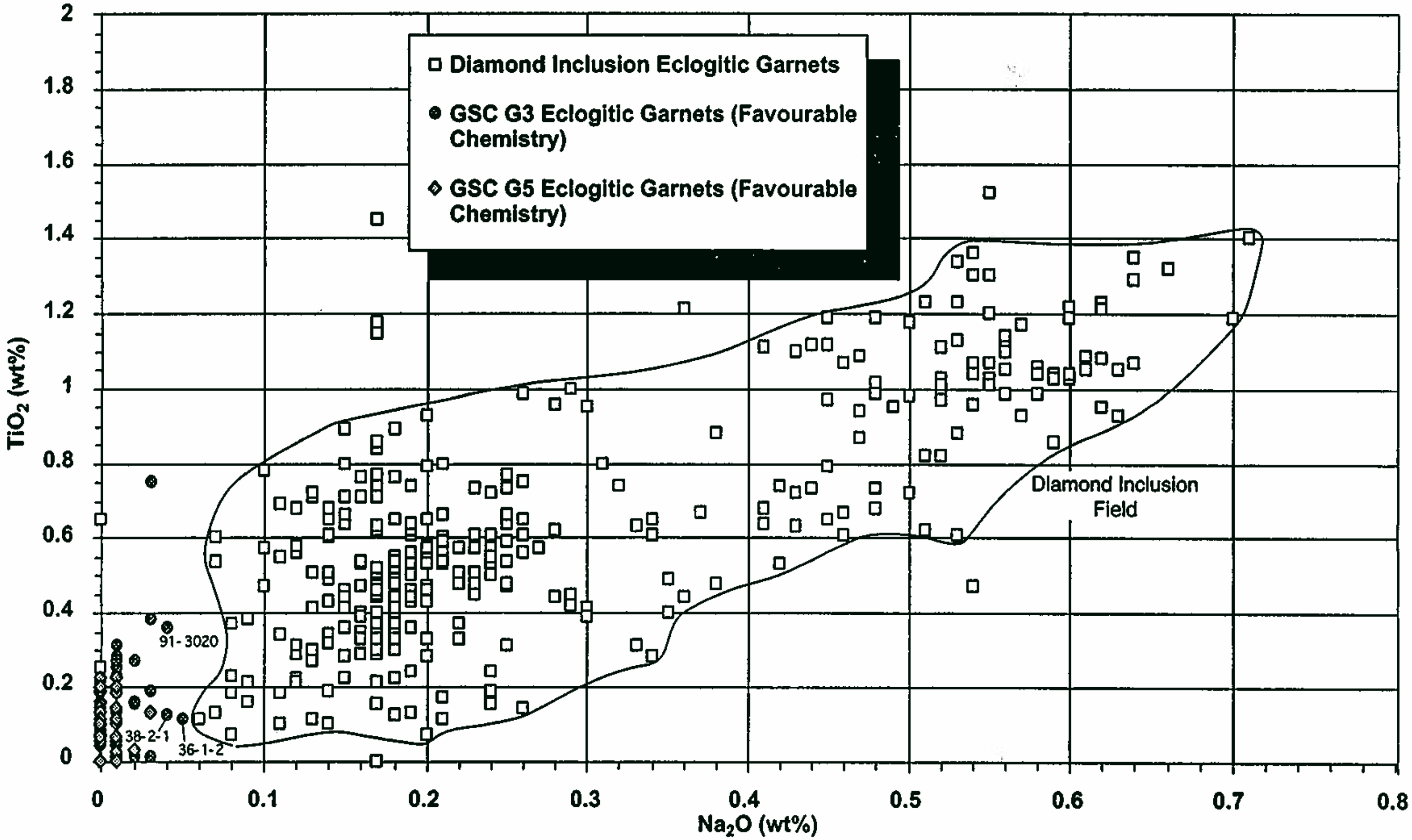


Figure 6.6: Na_2O vs TiO_2 For Eclogitic Garnets Form Southern Alberta Tills

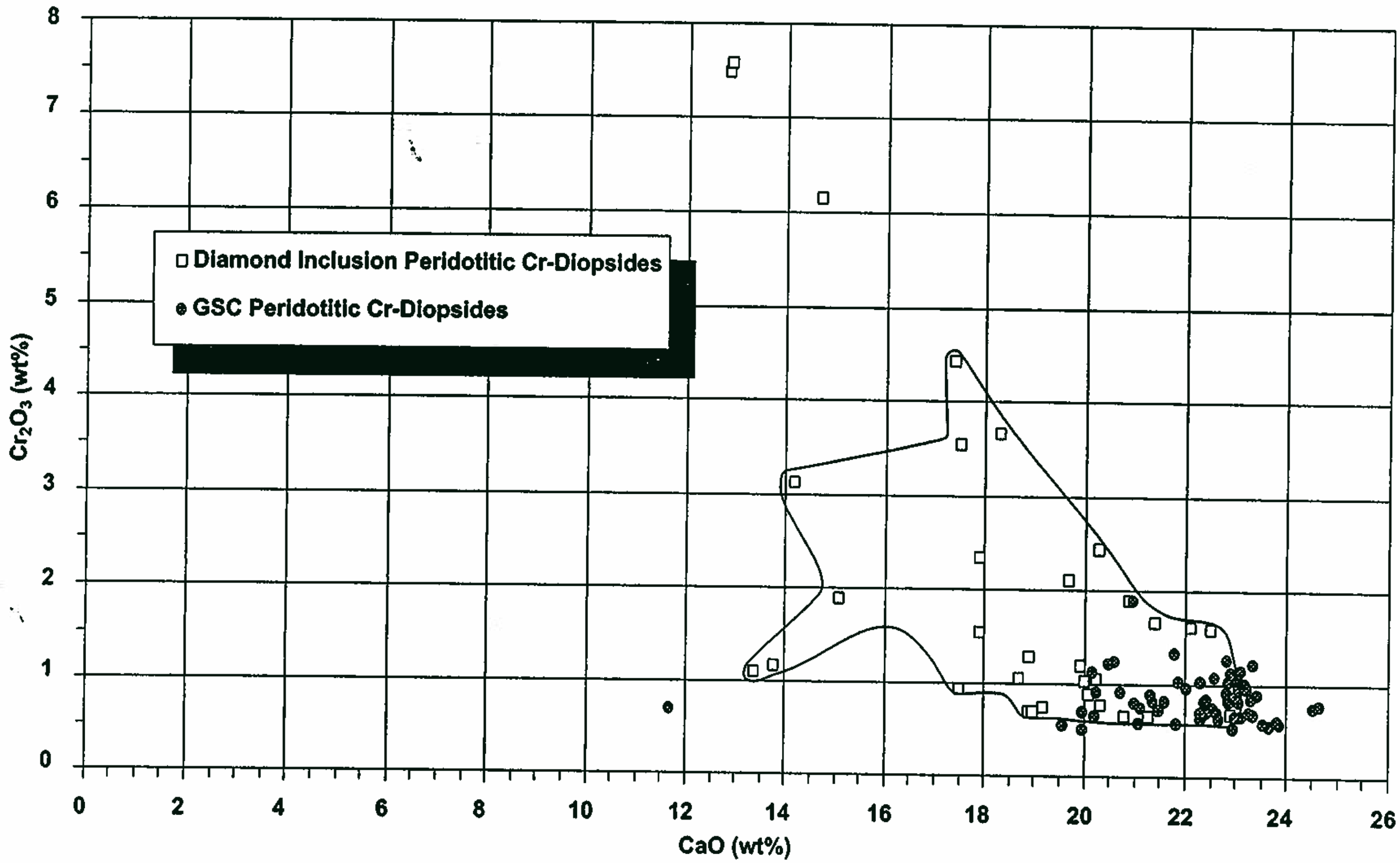


Figure 6.7: CaO vs Cr_2O_3 For Peridotitic Clinopyroxenes From Southern Alberta Tills

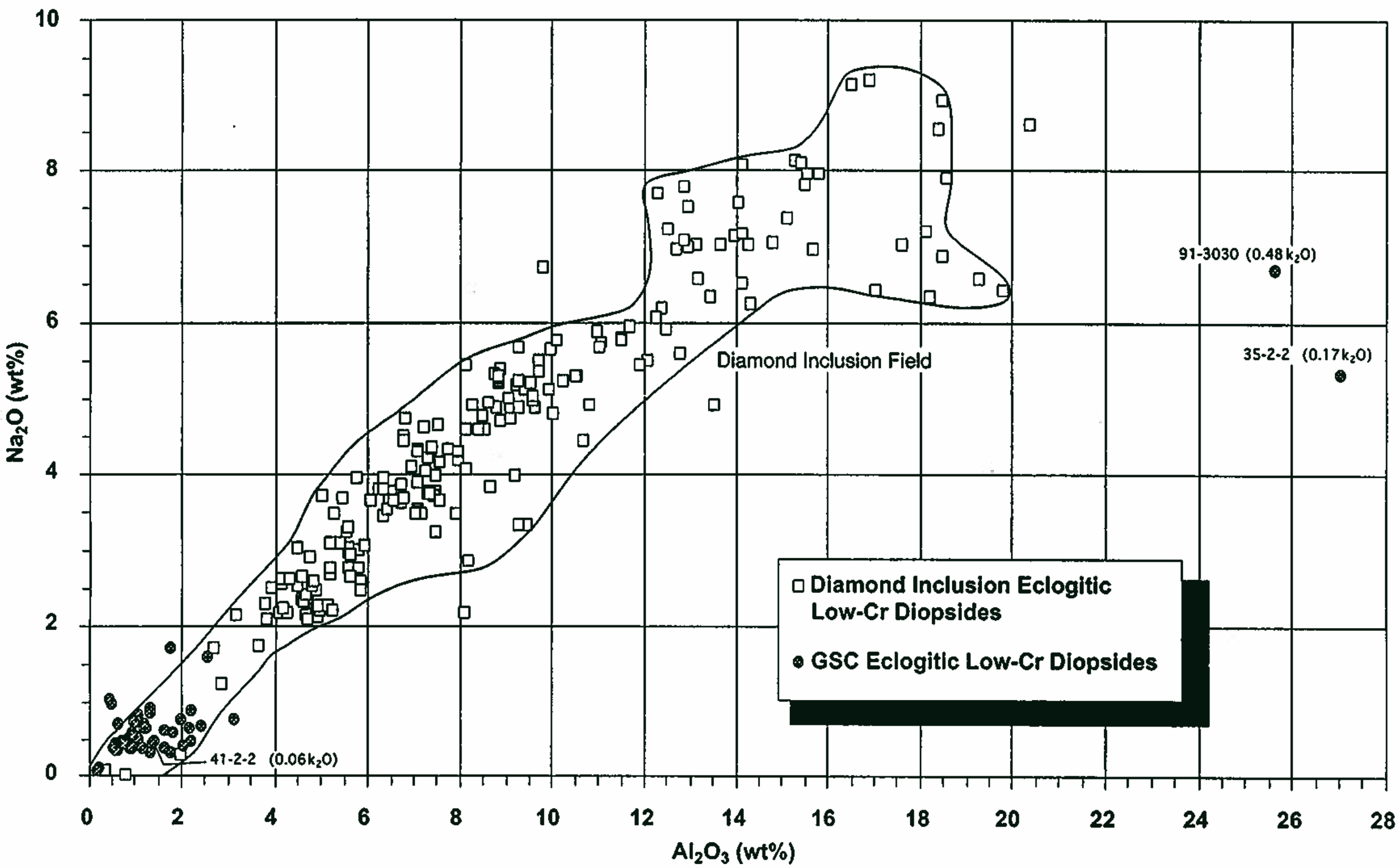


Figure 6.8: Al_2O_3 vs Na_2O For Eclogitic Clinopyroxenes From Southern Alberta Tills

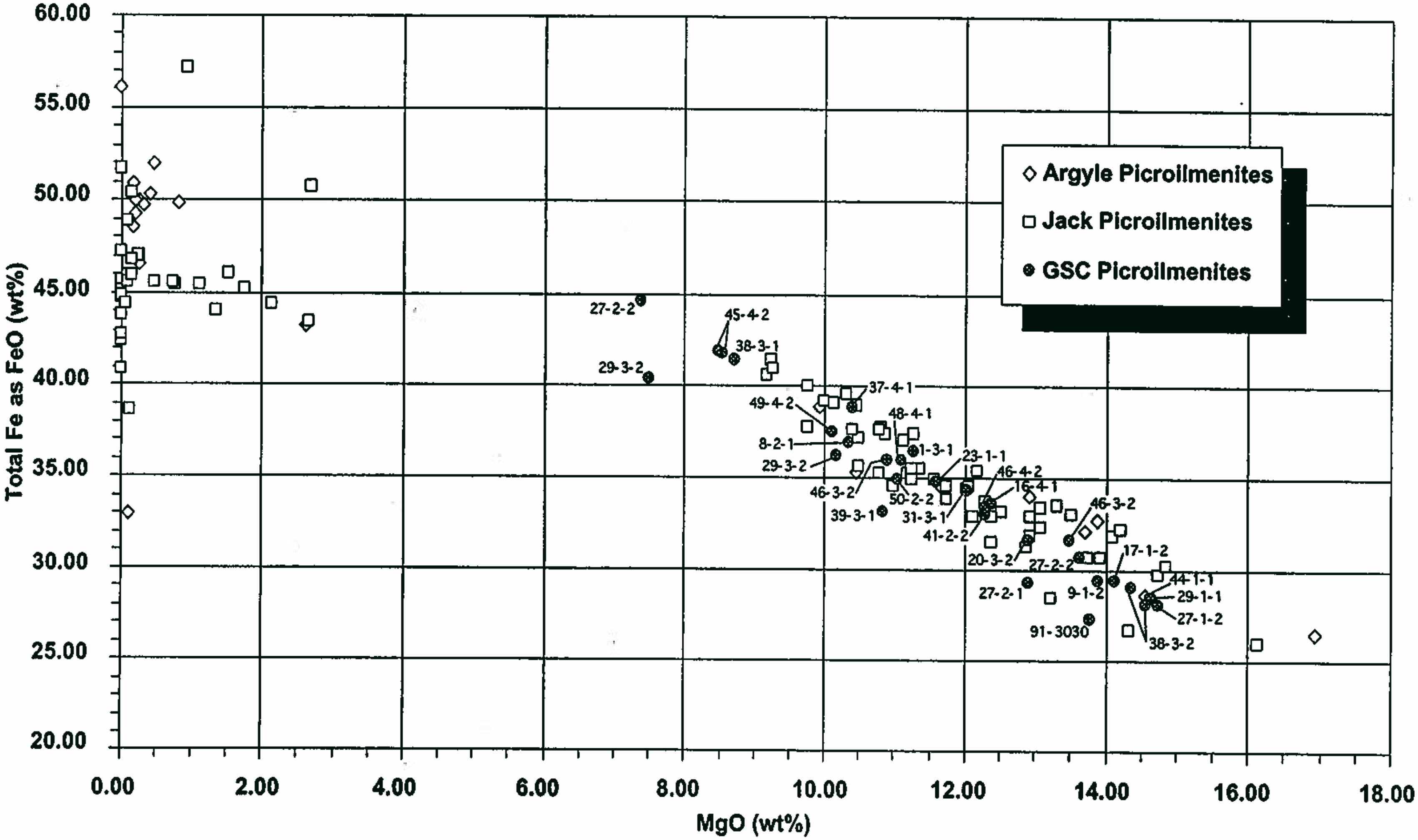


Figure 6.9: MgO vs Total Fe as FeO For Picroilmenites From Southern Alberta Tills

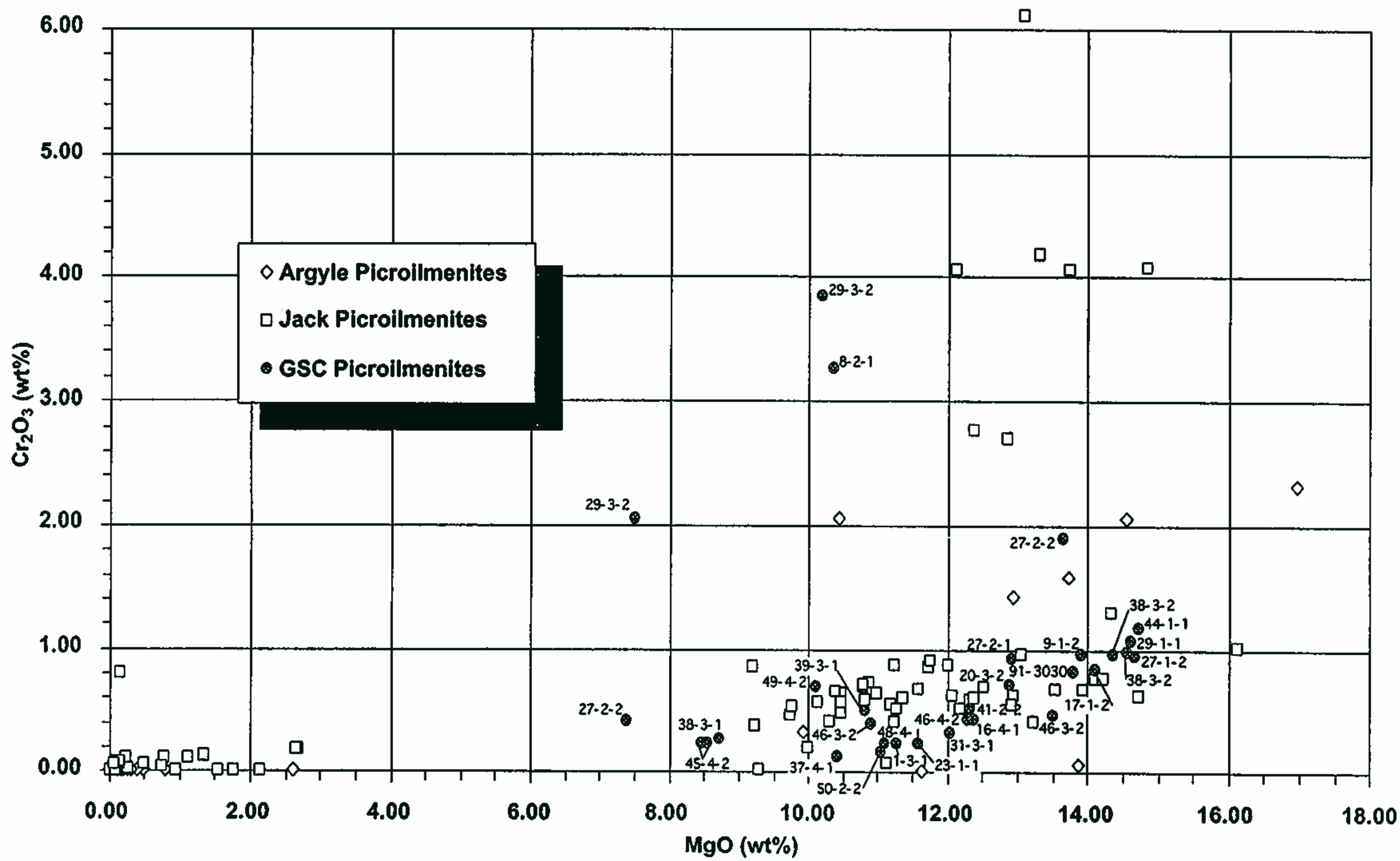


Figure 6.10: MgO vs Cr_2O_3 For Picroilmenites From Southern Alberta Tills

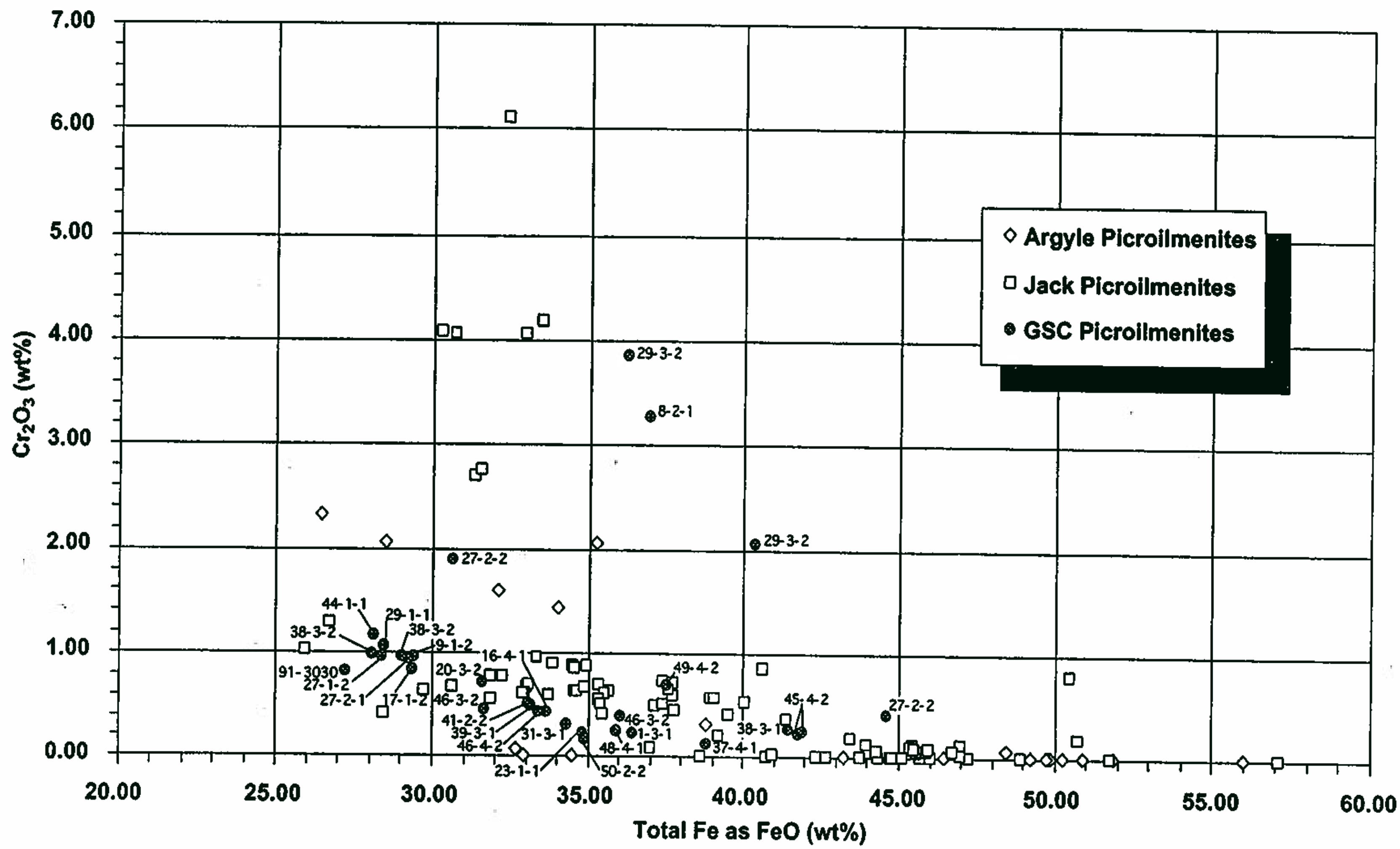


Figure 6.11: Total Fe as FeO vs Cr_2O_3 For Picroilmenites From Southern Alberta Tills

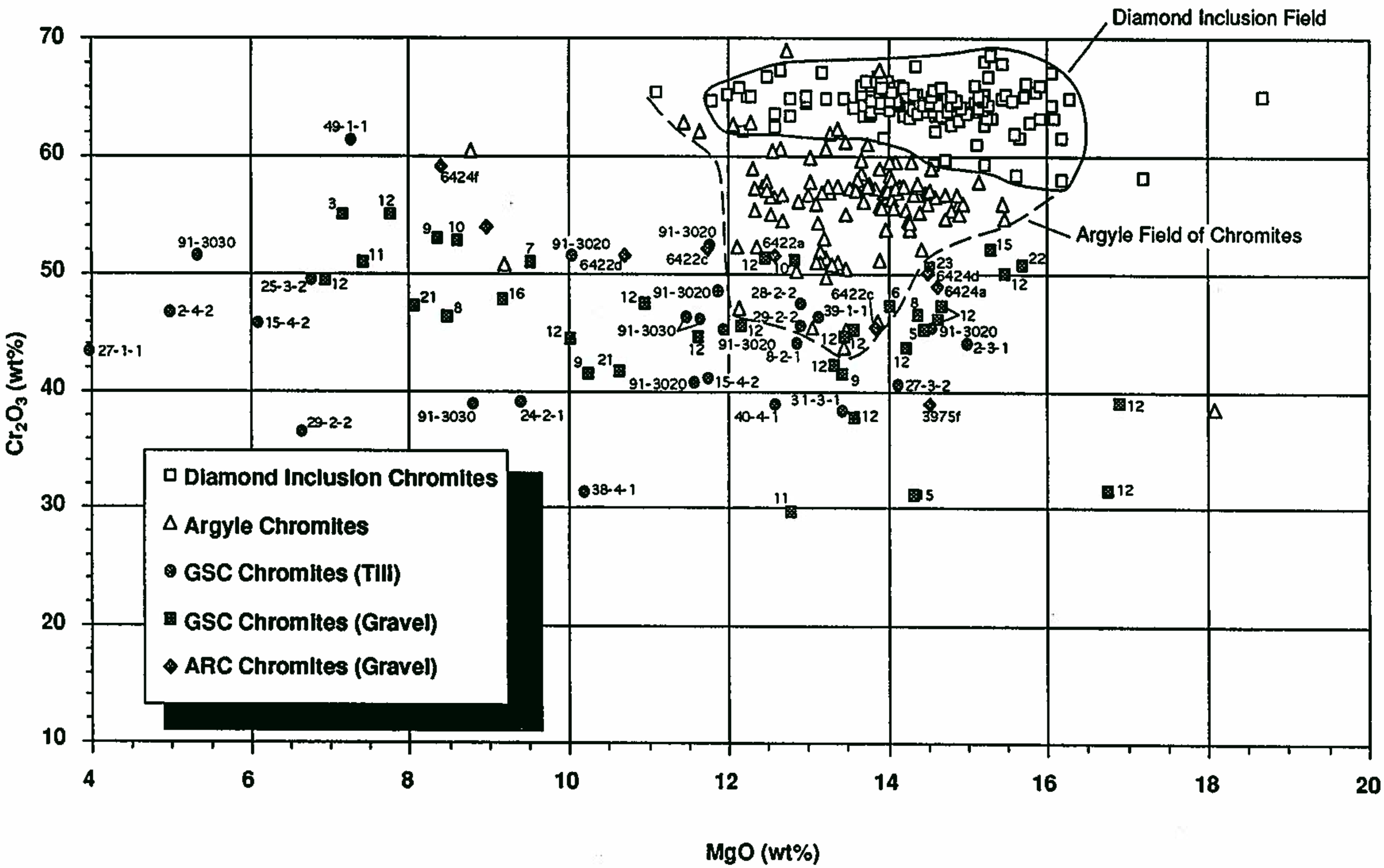


Figure 6.12: MgO vs Cr_2O_3 For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

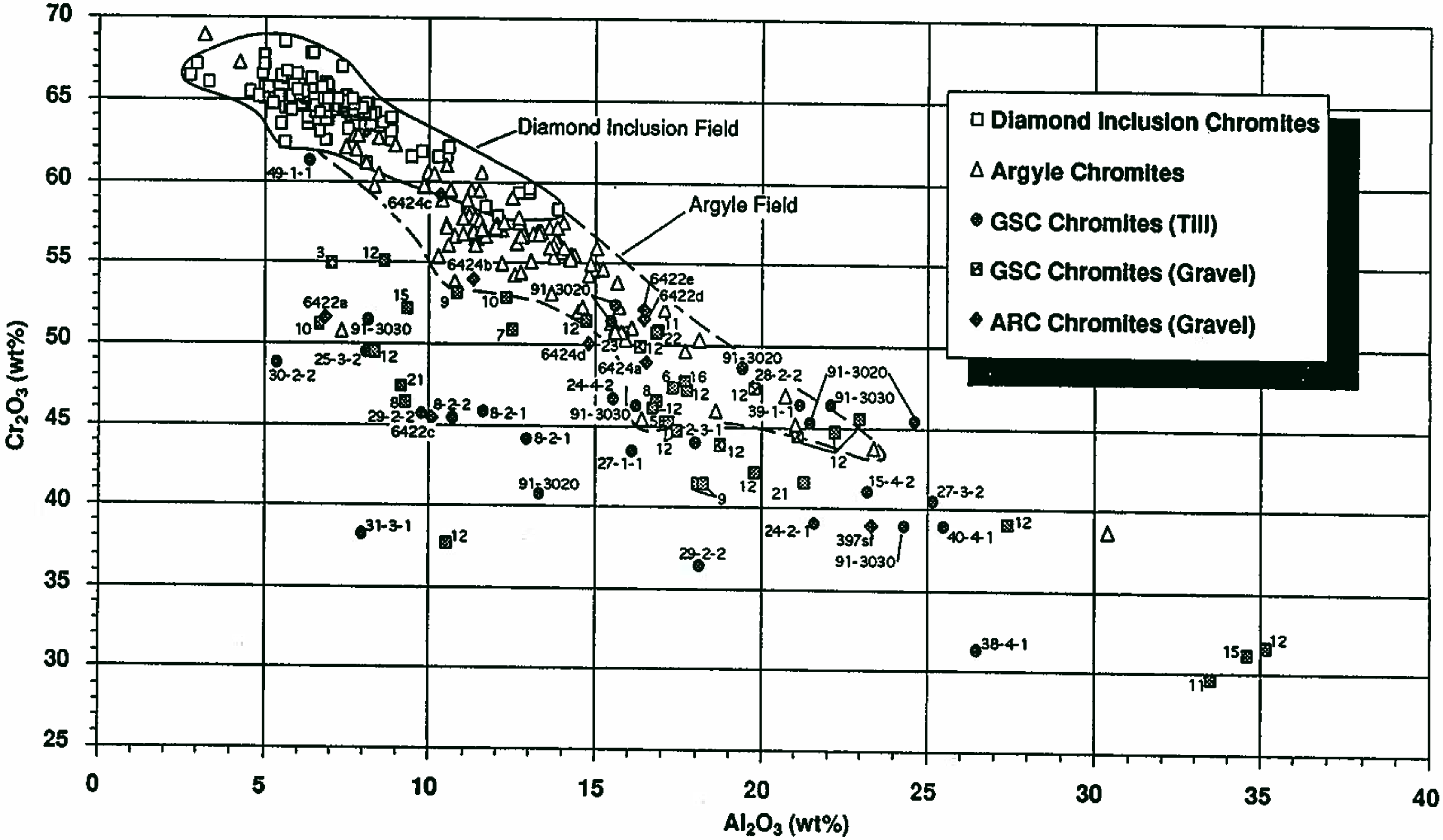


Figure 6.13: Al_2O_3 vs Cr_2O_3 For Chromites Form Southern Alberta Tills, Preglacial And Recent Gravel Deposits

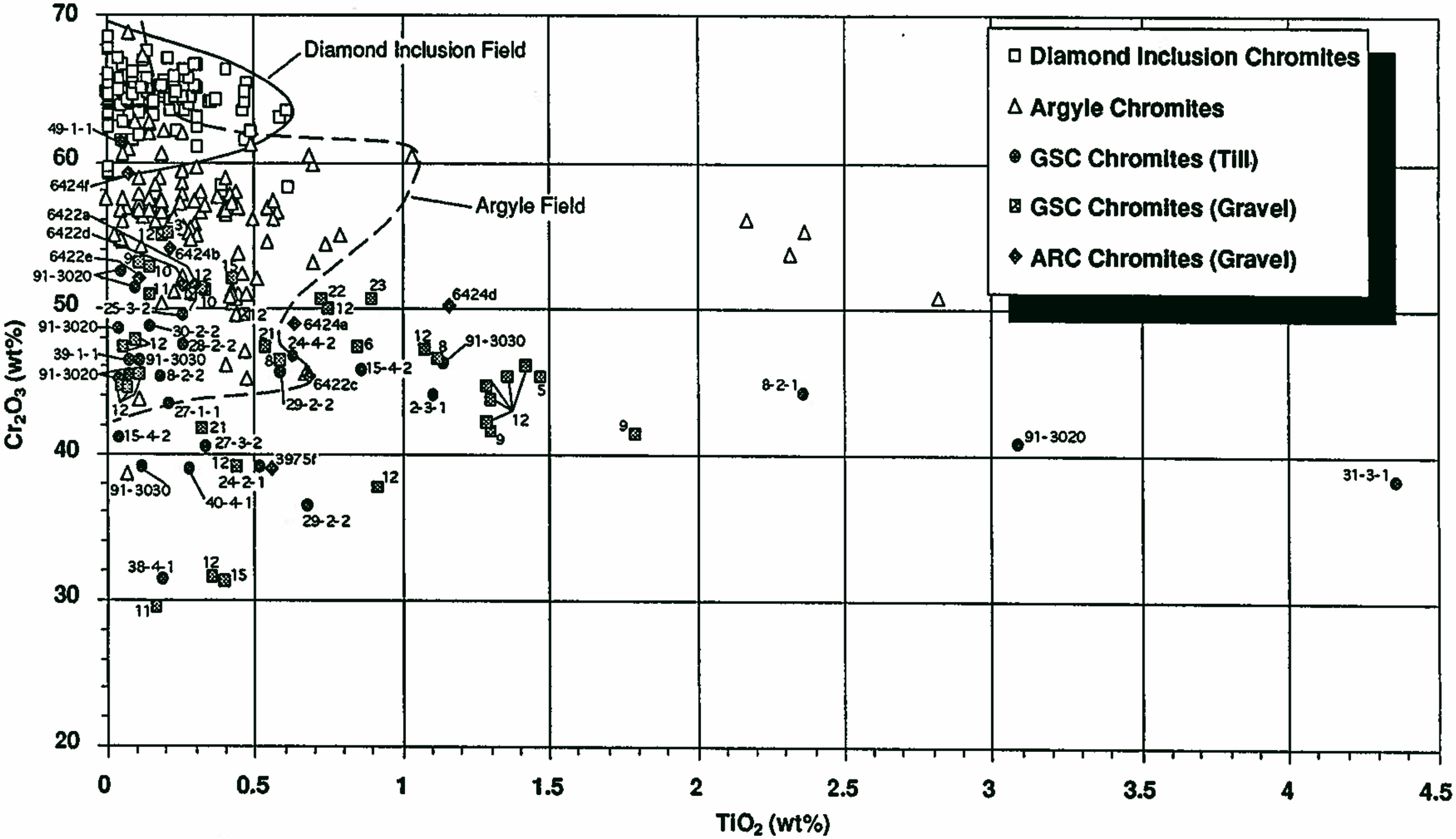


Figure 6.14: TiO_2 vs Cr_2O_3 For Chromites For Southern Alberta Tills, Preglacial And Recent Gravel Deposits

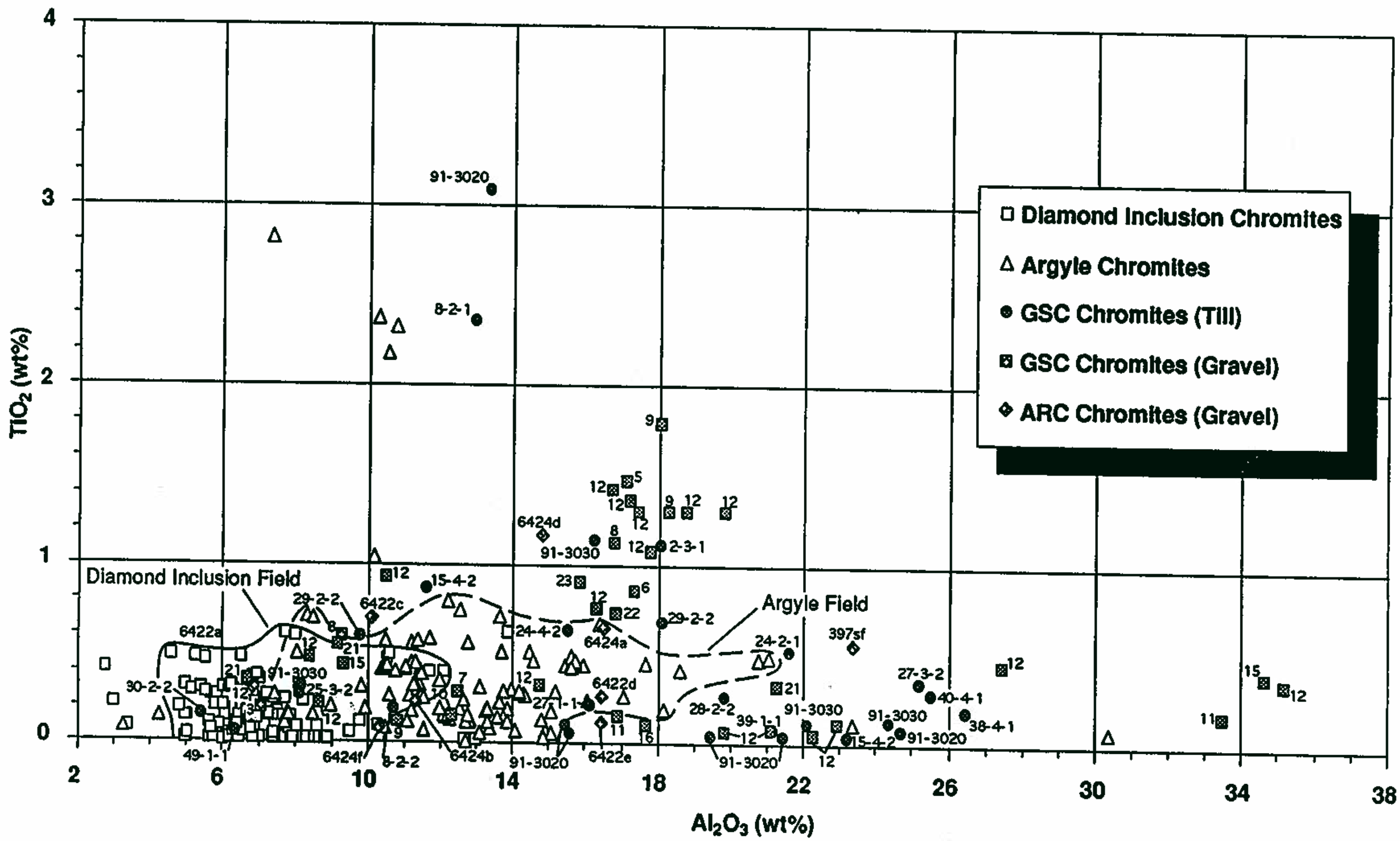


Figure 6.15: Al_2O_3 vs TiO_2 For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

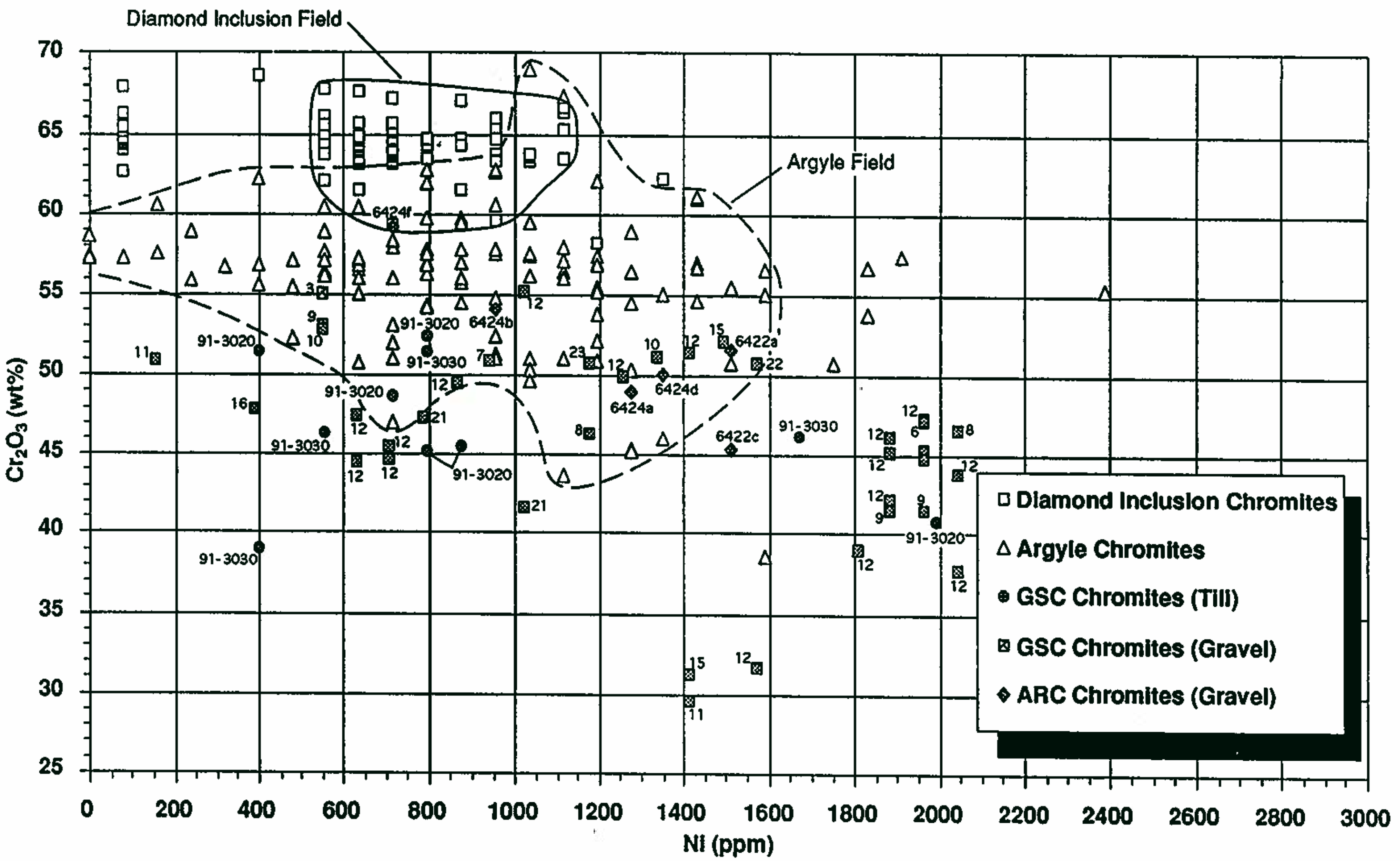


Figure 6.16: Ni vs Cr_2O_3 For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

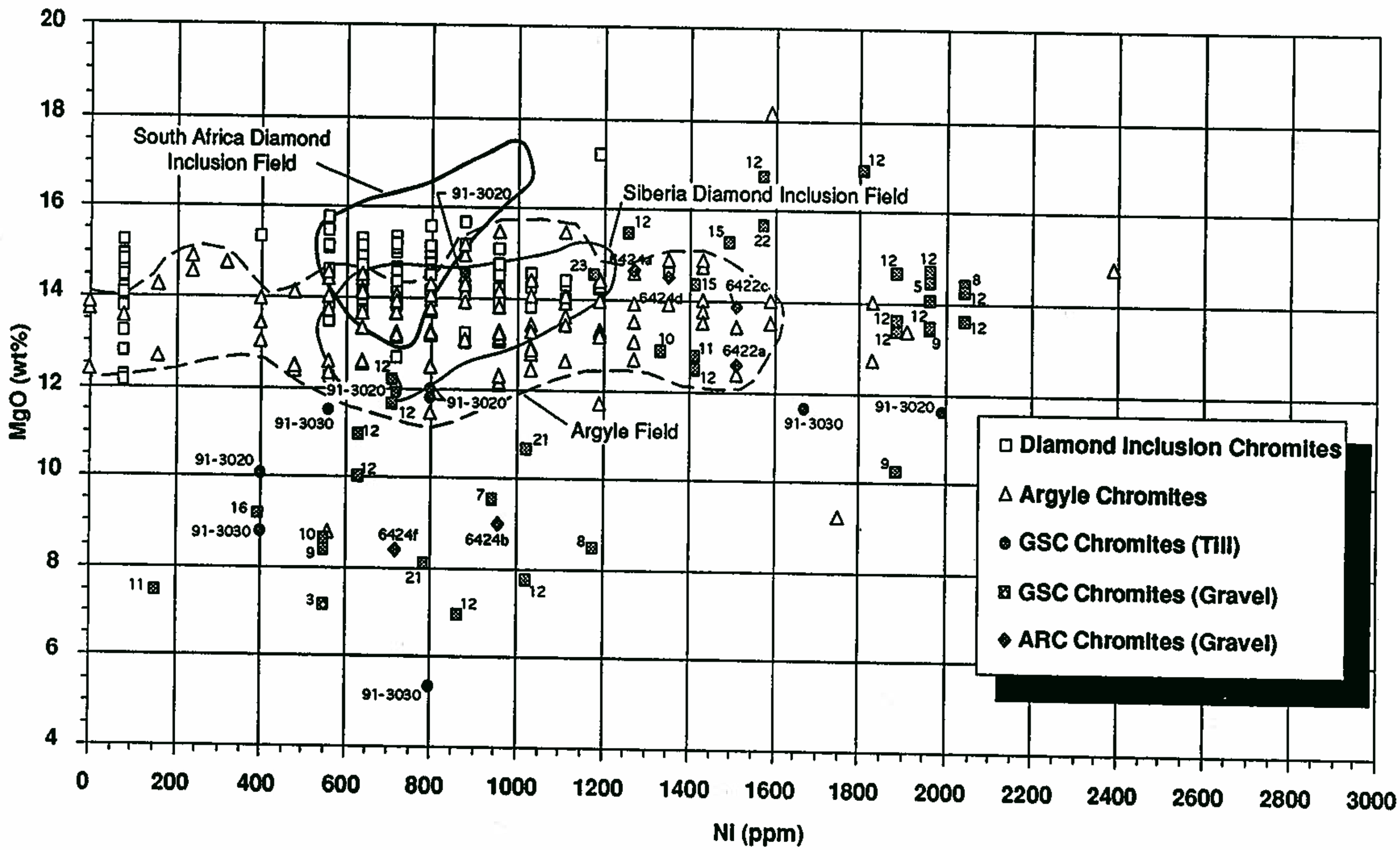


Figure 6.17: Ni vs MgO For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

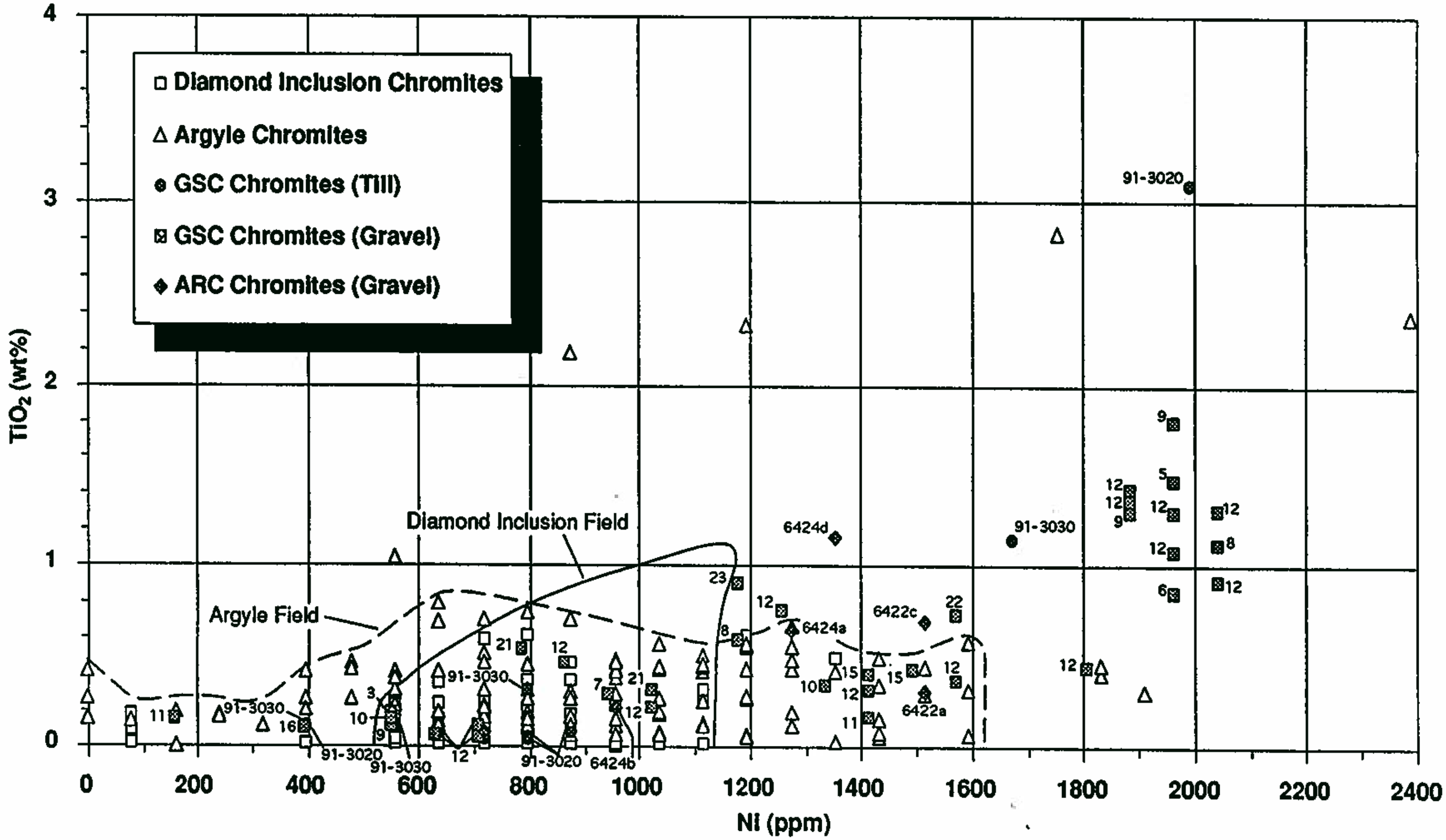


Figure 6.18: Ni vs TiO_2 For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

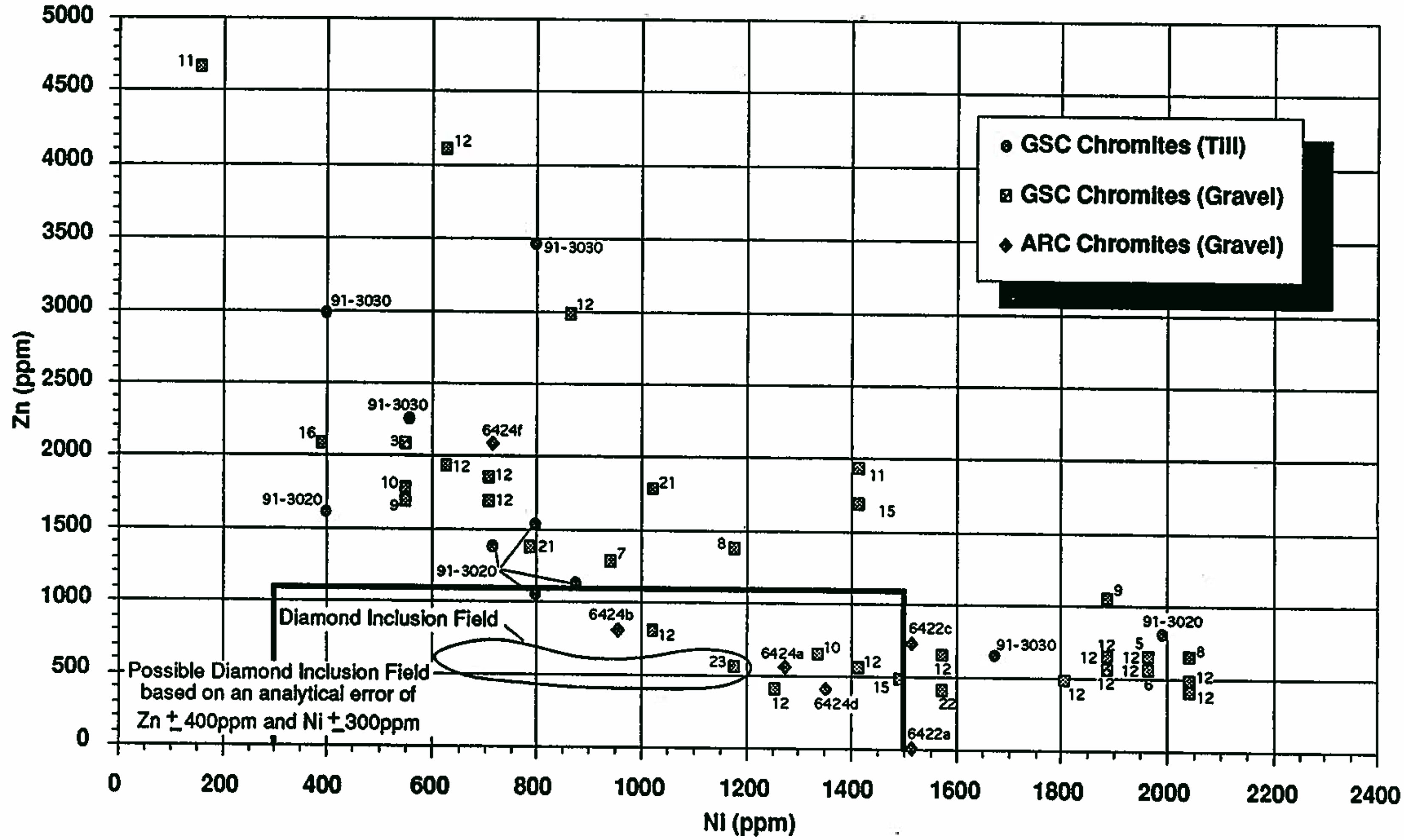


Figure 6.19: Ni vs Zn For Chromites From Southern Alberta Tills, Preglacial And Recent Gravel Deposits

6.5.2 Results for Southern to Central Alberta

In southern to central Alberta, several important trends of diamond and kimberlite or lamproite indicator minerals can be recognized. These include: (a) an arcuate east-west trend north of and parallel to the Milk River near the Alberta-Montana border, (b) an east-west trend from Brooks to the Saskatchewan border, (c) a southwesterly trend that extends from the Saskatchewan border south of Provost to southwest of Oyen, (d) a north to northwest arcuate trend that is close to and roughly parallels the exposed Cretaceous-Tertiary boundary from Gleichen to Wabamun Lake, (e) a somewhat scattered grouping southwest of Cold Lake in the vicinity of Vegreville, and (f) a southeasterly trend that is within the eastern edge of and parallel to the Foothills belt from southeast of Hinton to west of Rocky Mountain House (Figure 6.26).

The Milk River trend consists almost entirely of samples with kimberlitic garnets (G1 and G2 pyropes), G9 peridotitic garnets, chrome diopsides and one magnesium-titanium rich chromite (Figure 6.26; Appendices 6.1 and 6.2). These indicator anomalies are of exploration interest, but the indicator minerals that have been recovered to date and the work of Kjarsgaard (1994a, b), Kjarsgaard and Davis (1994), and Luth (1994) on the outcropping minettes near the Milk River, indicate low diamond potential based on the lack of deep-sourced xenoliths, sub-calcic G10 garnets, favourable eclogitic garnets or favourable high chromium chromites. Industry, however, has reported the discovery of two microdiamonds south of Legend (Edmonton Journal 1992b; Morton *et al.* 1993; Takla Star Resources Ltd. 1993a), and the presence of picroilmenites, chrome diopsides, and G9 and G10 garnets with kelphytic rims and orange peel texture (Takla Star Resources Ltd. 1993b). These results are encouraging and indicate that further work in the area of the Milk River Drainage Divide is warranted. Other than the G10 garnets reported by Takla Star and the diamonds found by a prospector (Edmonton Journal 1992b), the indicator mineralogy of the Milk River trend is similar to many of the diamond indicator mineral anomalies that exist in till and fluvial sediment in southern Saskatchewan south of Assinoboia, which consist of samples with up to 11 peridotitic garnets and 14 chrome diopsides (Simpson 1993; Swanson and Gent 1993; Thorliefson and Garrett 1993). Simpson (1993) pointed out that the anomalies in Saskatchewan are proximal to outcrops of Miocene Wood Mountain Formation, and that few anomalies are spatially associated with outcrops of the older Tertiary rock units, such as the Ravenscrag and Cypress Hills Formations. As a result, Simpson (1993) suggested that the indicator minerals in drift in southern Saskatchewan are derived from the erosion of the Wood Mountain Formation gravels, which likely carried boulders and cobbles of Eocene to Miocene age kimberlites and other associated lamprophyric volcanics from central and northern Montana to southern Saskatchewan. Swanson and Gent (1993), however, suggested that more local sources are likely responsible for the indicator anomalies in the surficial sediments of southern Saskatchewan. Leckie and Cheel (1989) demonstrated that volcanic clasts within the Oligocene Cypress Hills Formation in southeast Alberta and southwest Saskatchewan are likely derived from central and southern Montana. As a result, Kjarsgaard (1994b) suggested that the indicator minerals which are proximal to the

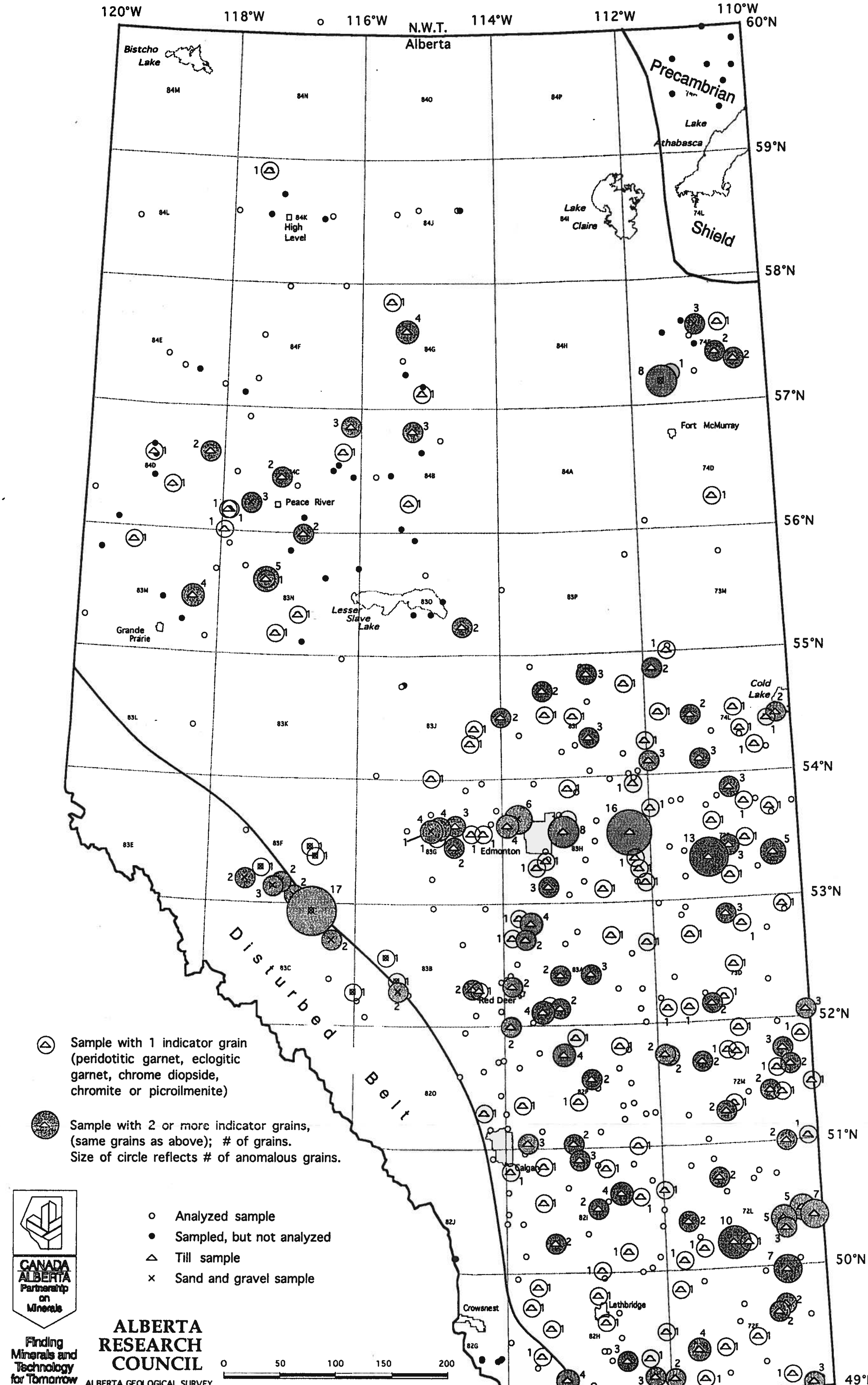


Figure 6.20. Total diamond Indicator mineral map.

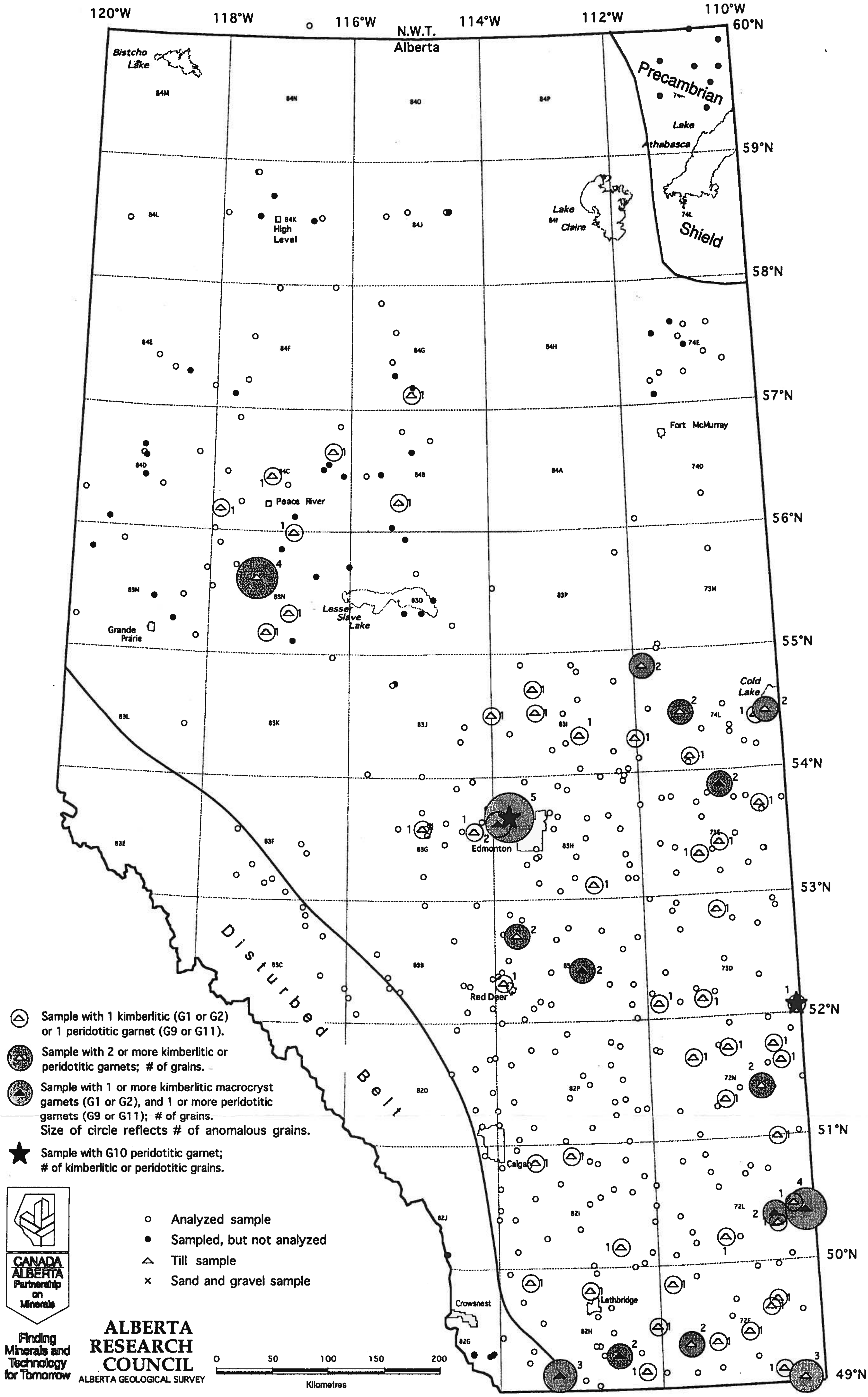


Figure 6.21. Indicator map of G1, G2, G7, G9, G10 and G11 kimberlitic garnets.

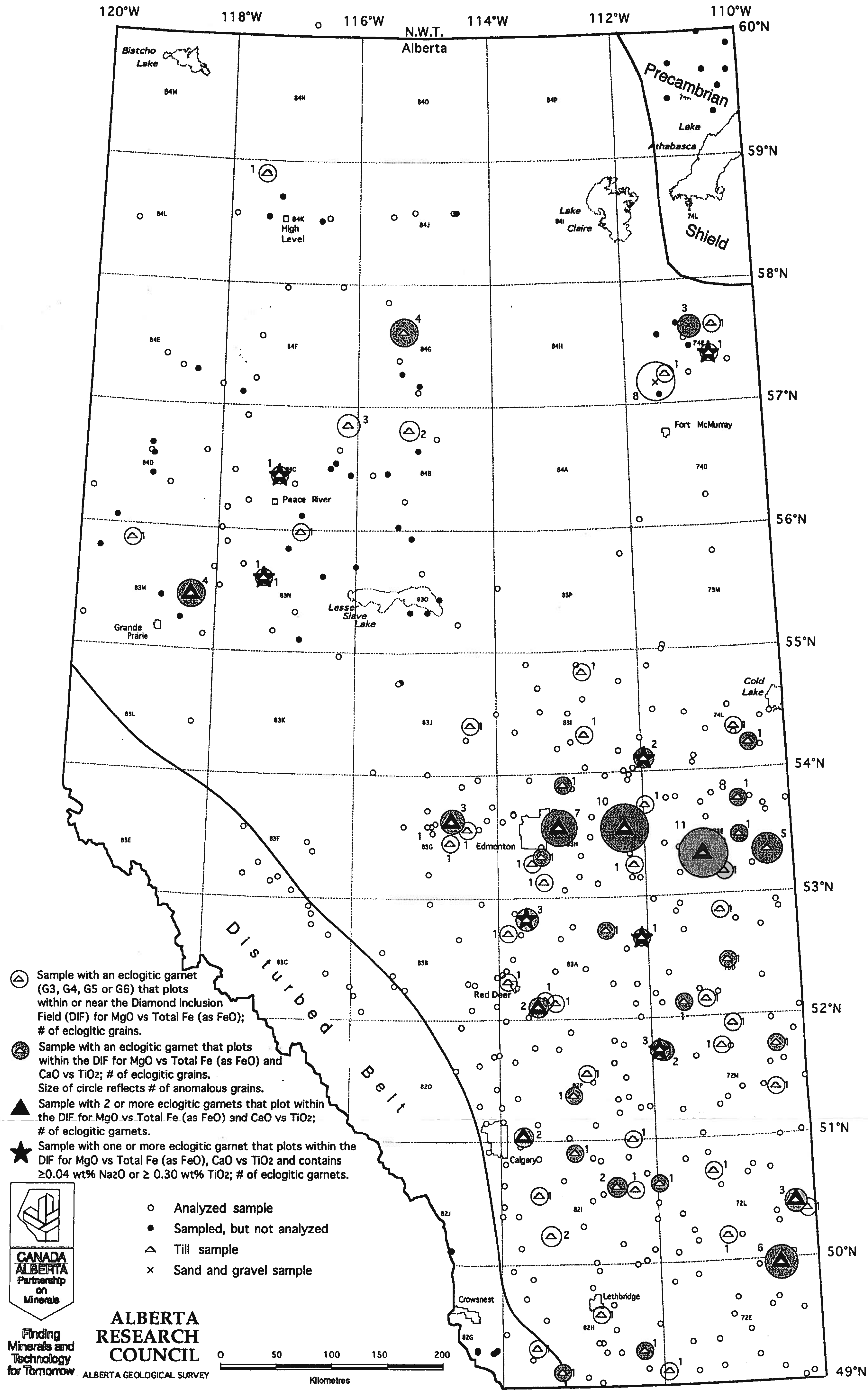


Figure 6.22. Indicator map of G3, G4, G5 and G6 eclogitic garnets.

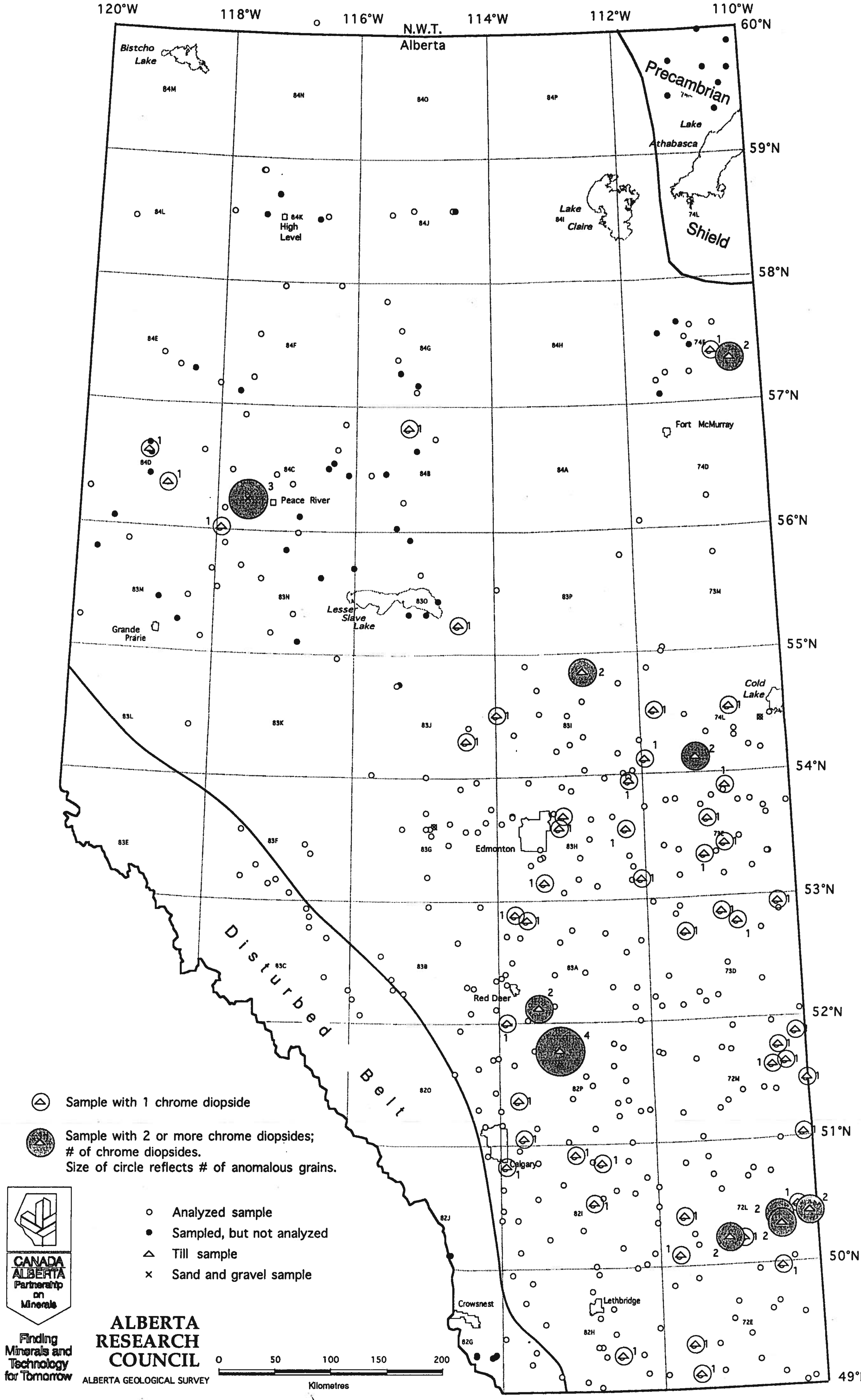


Figure 6.23. Indicator map of chrome diopsides with ≥0.5 wt% Cr_2O_3.

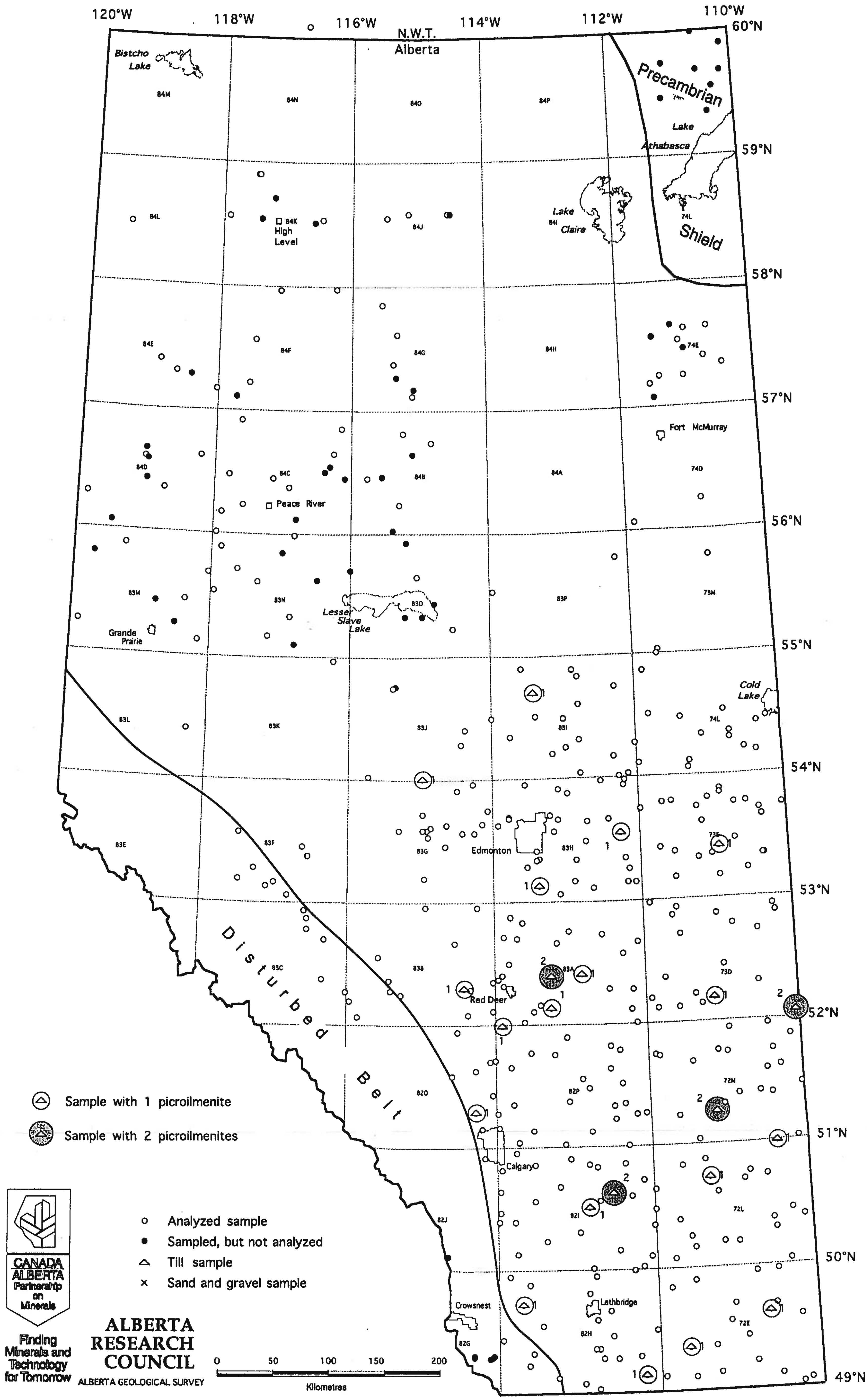


Figure 6.24. Indicator map of picroilmenites with <40 wt% total Fe as FeO and >10 wt% MgO.

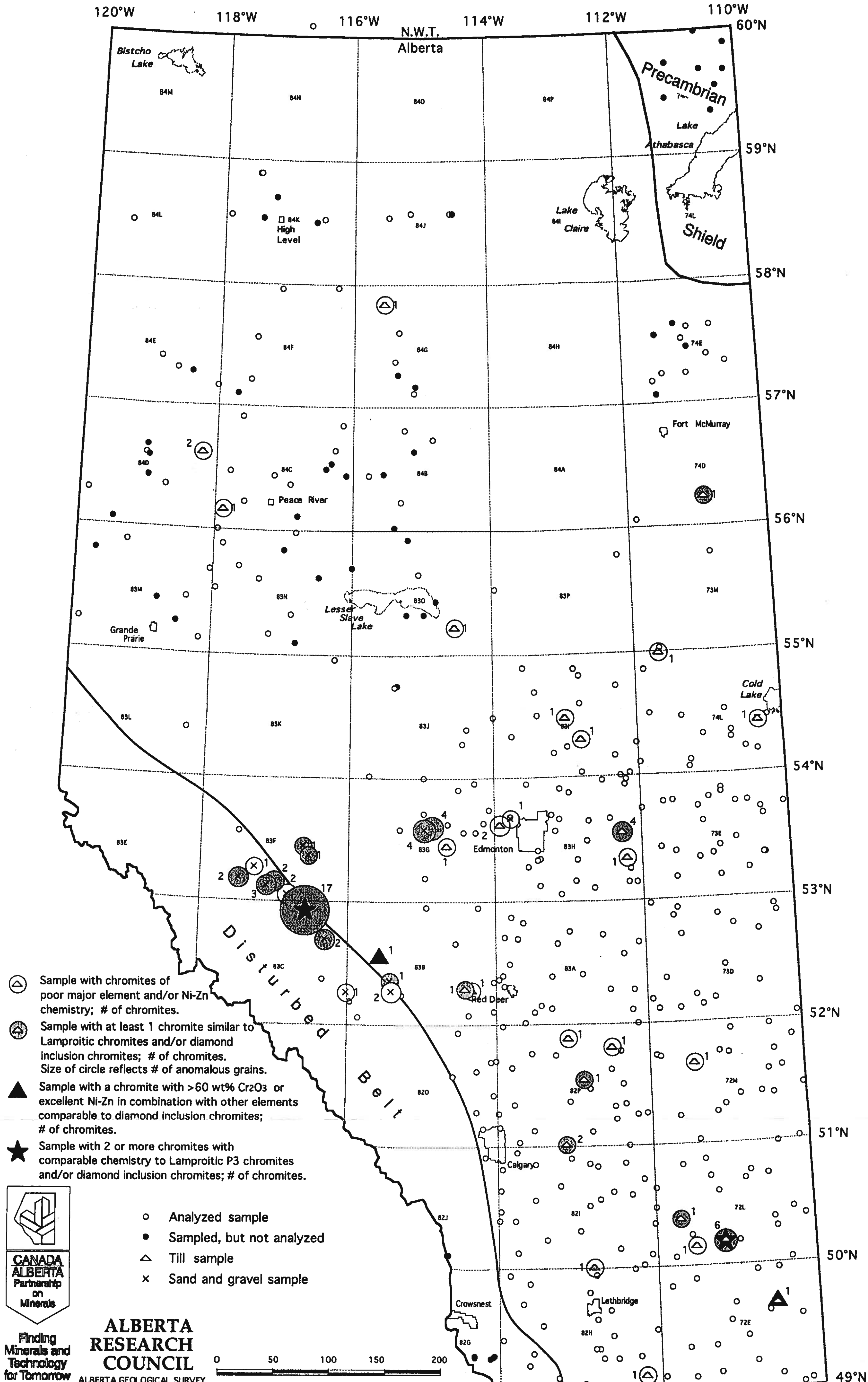


Figure 6.25. Indicator map of anomalous chromites.

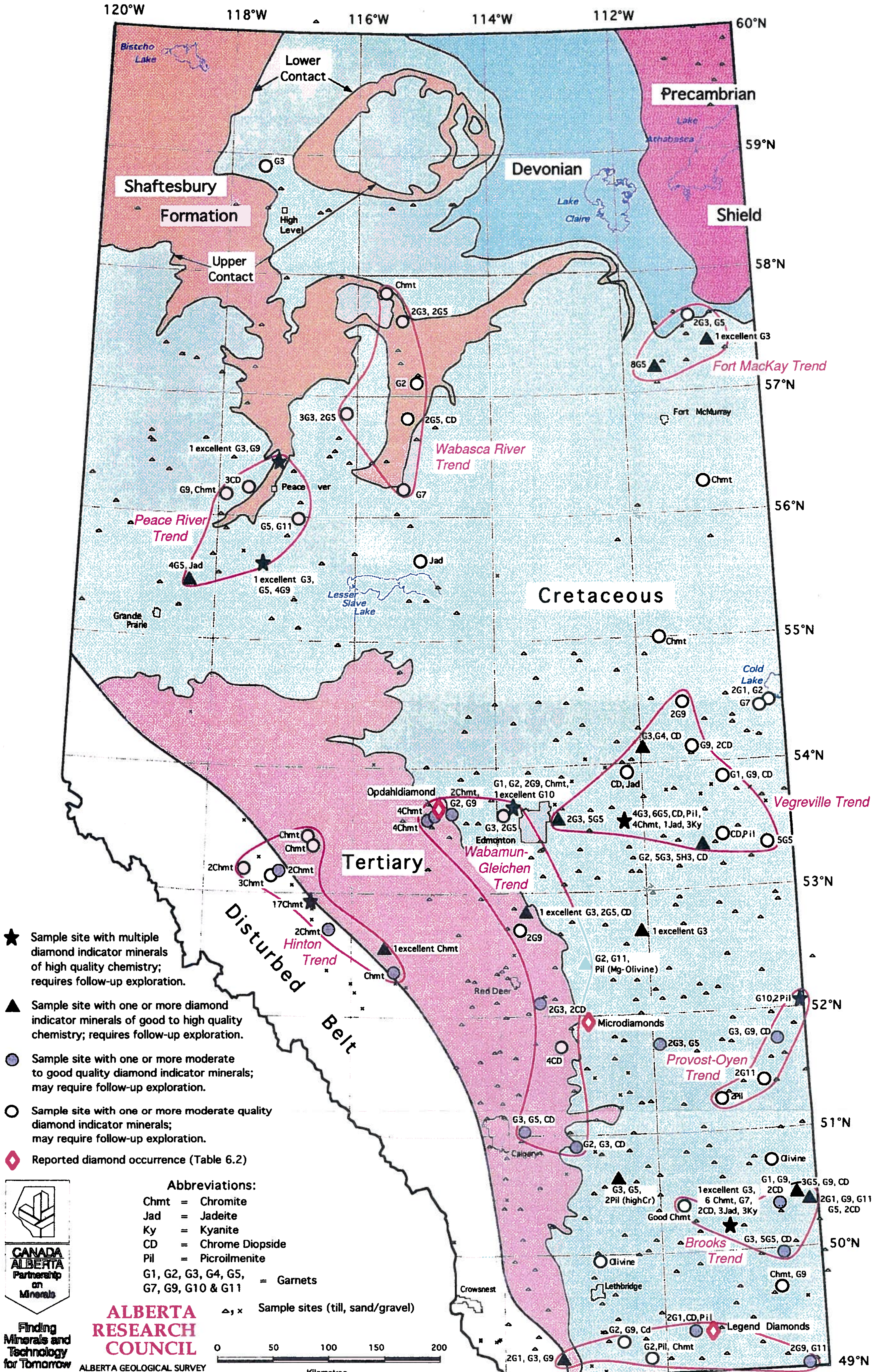


Figure 6.26. Diamond indicator mineral anomaly summary map.

Cypress Hills Formation may also be derived from volcanic clasts that have been transported in fluvial systems from Montana. Therefore, based on the current evidence it is possible that the Milk River trend of indicator mineral anomalies is not derived from the Cypress Hills Formation gravels. This conclusion is based on the extent and location of the indicator minerals in the Milk River trend, with sample sites ranging from several tens of kilometres to as many as 220 km west of the Cypress Hills. In addition, sample sites that are proximal to the Cypress Hills and down ice from the Cypress Hills do not show any significant increase in the amount of kimberlitic and peridotitic garnets or chrome diopsides as exist in the till and fluvial samples that are proximal to the Wood Mountain Formation gravels in Saskatchewan. It is probable that at one time the Cypress Hills gravels were much more laterally extensive than today. As a result, the possibility that the indicator minerals in the Milk River trend are derived from south of the Alberta-Montana border cannot be ruled out entirely. Based on the Quaternary geology, it is also possible that the indicator minerals that comprise the Milk River trend are derived from significant distances to the north or northwest. The Milk River Drainage Divide is the approximate location of the furthest extent of the Wisconsinan ice advance. Extensive and thick terminal moraines (Shetsen 1987) exist in close proximity to many of the till sites of the Milk River indicator mineral trend and the reported location near Etzikom Coulee for the Legend diamonds. If the sample sites were from till associated with the terminal moraines then it is possible that the contained indicator minerals could be derived from significant distances to the north or northwest along with much of the material in the terminal moraines (Craigie 1993).

The Brooks trend consists of at least six till sites that yielded multiple indicator minerals, some of which have chemistries comparable to certain diamond inclusion minerals (Figures 6.20 and 6.26). Northwest of Medicine Hat, site 2 (91-3020) yielded six high magnesium chromites, four of which plot near the Argyle field of chromites based on major elements and Cr_2O_3 vs Ni (Figures 6.12 to 6.16), and plot within the diamond inclusion field on MgO vs Ni and TiO_2 vs Ni (Figures 6.17 and 6.18). Griffin and Ryan (1993), Griffin *et al.* (1992) and Griffin *et al.* (*In Press*) suggested that zinc concentration exhibits a strong negative temperature dependence in chromite and, as a result, is perhaps the most critical element in determining whether a chromite was formed within the diamond stability field. The four chromites from site 2 which exhibit comparable major element chemistry to Argyle chromites, plot outside of the diamond inclusion field on a Zn vs Ni plot. However, two of the four grains plot close to the diamond inclusion field and when analytical error is considered, they may well plot within the diamond inclusion field (Figure 6.19). A fifth chromite from site 2 has low zinc (803 ppm) with high nickel (1,991 ppm) and high TiO_2 (3.09 wt%). Based on the work of Mitchell (1989), the high titanium content is characteristic of phenocrysts being formed in an evolved lamproitic or micaceous kimberlitic magma. Griffin *et al.* (In Press) suggested that high nickel in combination with low zinc is also characteristic of high temperature magmatic chromites (P3 chromites) in lamproites. The same sample also contains two chrome diopsides, a high chromium G7 almandine-grossular garnet (7.44 wt% Cr_2O_3), three jadeites (one of which has 0.35 wt% K_2O), three kyanites and an excellent G3 eclogitic garnet that plots within the diamond inclusion field for FeO (total Fe) vs MgO and TiO_2 vs CaO, and near the diamond inclusion field for TiO_2 vs Na_2O, with 0.04 wt% Na_2O (Figures 6.4 to 6.6). Elevated values of Na_2O in eclogitic garnets (usually ≥0.07 wt% Na_2O) are considered an excellent indication of formation in the diamond stability field (McCandless and Gurney 1989; Fipke 1990; Gurney and Moore 1993). In addition, high potassium in clinopyroxenes (≥0.1 wt% K_2O), particularly in sodic diopsides to jadeitic diopsides, is also considered an indication of formation in the diamond stability field. However, the use of the potassium indicator for clinopyroxenes is based on findings for a limited South African sample population (McCandless and Gurney 1989) and its applicability to jadeites from elsewhere is uncertain. In summary, the minerals in the sample from site 2 indicate that an eclogite source, which is potentially diamondiferous based on some indications of certain mineral grains from this site having been formed in the diamond stability field, probably exists to the northwest or north, that is in the up-ice direction. Furthermore, the number of eclogite indicator minerals in sample 2 may indicate that the source area is proximal rather than distal. The other five samples in the Brooks trend have multiple indicator minerals of interest, including a favourable chromite, G1, G9 and G11 garnets, (G3's and G5's) and several eclogitic garnets and several chrome diopsides (Figures 6.21 to 6.26). Till sample site 228 (48-2-1) which is near the Red Deer River, slightly north of the Brooks trend, yielded a magnesium-rich olivine (Appendix 6.2). In addition, till sample site 114 (30-1-1) which is north of Lethbridge and southwest of the Brooks trend, also yielded a magnesium-rich olivine (Appendix 6.2). Based on the low stability of olivine in the near surface environment, it is possible that the olivine grains at these two sites represent first cycle erosion and that the source is proximal rather than distal. The Brooks trend corresponds to the approximate location of the southern boundary of the Southern Alberta Rift or Vulcan Low (Kanasewich 1968; Kanasewich *et al.* 1969; Ross *et al.* 1991) and exists mostly north of the thick terminal moraine deposits mapped by Shetsen (1987). The predominant glacial transport direction in this area was southeasterly, hence the anomalous indicator minerals in the Brooks trend may have been derived from near or within the bounds of the Southern Alberta Rift (Vulcan Low on Figure 2.2). As well, local southwesterly ice flow directions are evident near the Saskatchewan border just south of the South Saskatchewan River. This may indicate that some of the indicator minerals in the samples from the Brooks trend which were collected near the Saskatchewan border, may have originated in Saskatchewan. As well, it is possible that the Cypress Hills Formation or the equivalent rocks in the Wood Mountain Formation of southern Saskatchewan existed this far north prior to uplift and erosion of the Sweetgrass Arch. These sediments, with a source area in central Montana, may also have contributed indicator minerals. To date, however, sample results from tills in the vicinity of these Tertiary formations have yielded few chromites, eclogitic garnets, olivines, jadeites or kyanites, hence it seems improbable that the anomalous indicator minerals in the Brooks trend were derived from Montana.

The Provost to Oyen trend is comprised of four till sites that trend from near the Saskatchewan border south of Provost to southwest of Oyen (Figure 6.26). Sample site 217 (46-3-2), which is closest to the Saskatchewan border, yielded a sub-calcic G10 pyrope (Figure 6.3). At present, this G10 pyrope at site 217 is the only reported G10 garnet found in the regional till surveys that have been performed by the various government agencies across Alberta, including this study and others by Fenton and Pawlowicz (1993), Fenton *et al.* (1994a), Garrett and Thorliefson (1993), Thorliefson and Garrett (1993) and Thorliefson *et al.* (1994). The same sample also contains two picroilmenites with low total Fe (< 40 wt% reported as FeO) and high MgO (> 10 wt%), which are indicative of a highly reduced deep seated intrusion such as a kimberlite or lamproite. Other indicator minerals of interest include: (a) sample site 167 (38-3-2) which produced two picroilmenites with similar compositions to those from site 217, (b) sample site 225 (47-4-2) which produced a G9 (possibly a high chromium G7) pyrope, a G3 eclogitic garnet with good diamond inclusion chemistry and a chrome diopside with the highest chrome content (1.89 wt% Cr_2O_3) of all the diopsides analysed for Alberta, and (c) sample site 218 (47-1-1) with two G11 pyropes (Figures 6.21 to 6.24 and 6.26). The glacial direction in the vicinity of Provost appears to have been southerly to southwesterly, whereas tp the southwest closer to Oyen there are indications of both southeasterly and southwesterly glacial paleoflow directions (Shetsen 1987, 1990). Based on the fairly linear nature of the southwesterly trending Provost to Oyen indicator anomalies and the fact that a few anomalous sites exist northeast of site 217 on the Saskatchewan side of the border (Thorliefson and Garrett 1993), the anomalous indicator minerals in this trend are likely derived from either near Provost or farther to the northeast, across the Saskatchewan border.

A large north-south arcuate trend of indicator mineral anomalies exists between Wabamun Lake and Gleichen (Figure 6.26). This trend consists of at least 9 anomalous till sites and 3 anomalous samples from Late Tertiary preglacial gravels. The trend is roughly centred along and parallel to the Cretaceous-Tertiary boundary. The trend can be subdivided into a southern cluster of seven sites that extends from Ponoka to Gleichen, and a northern cluster of five sites that extends from Wabamun Lake to Edmonton. Samples from the southern half of the trend contain: (a) G2, G3 and G5 garnets, (b) two G9 and one G11 pyropic garnets, (c) several chrome diopsides and (d) a picroilmenite (Figures 6.21 to 6.24 and 6.26). The northern anomalous till sites yielded G2, G3, G5 and G9 kimberlite and eclogitic garnets. As well, sample sites 412 (6424) and 417 (6422) which are from Late Tertiary preglacial gravel deposits west of Wabamun Lake at Entwistle and Magnolia, each yielded four magnesium-rich chromites (Figures 6.25 and 6.26). Sample site 426 (3975) from a similar preglacial gravel deposit northeast of Wabamun Lake at Villeneuve, yielded G1 and G2 kimberlitic garnets, two G9 pyropic garnets, a favourable chromite, and a subcalcic G10 pyrope garnet (Figures 6.21, 6.25 and 6.26). The G10 garnet plots well into the high chrome subcalcic field on Cr_2O_3 vs CaO (Figure 6.3), and as such, has comparable chemistry to many of the diamond inclusion G10's from highly diamondiferous South African kimberlites. The sources for the indicator mineral anomalies that exist in the tills and preglacial gravels of the Wabamun-Gleichen trend is difficult to ascertain. From Gleichen to about Innisfail, the transport indicators of glacial direction are predominantly southeasterly (Shetsen 1987, 1990). This would suggest that most of the indicator minerals in the anomalous sites which exist southeast of Red Deer, are derived from areas underlain by Tertiary sedimentary rocks northwest of the Cretaceous-Tertiary boundary. Whether the indicator minerals are derived from local point sources, such as diatremes and their associated volcaniclastics, or from Tertiary sedimentary rocks as second or third cycle erosional products, is not known. It is important to note that microdiamonds have been discovered southeast of Red Deer at the Cretaceous-Tertiary boundary layer by scientists looking for evidence of extraterrestial impacts (Science City News 1992; Dr. Dennis Braman, *pers comm.* 1994). However, it is also possible that Early Tertiary volcanism in the Alberta basin is responsible for the microdiamonds and the anomalous indicator minerals which exist in the Ponoka to Gleichen region. In contrast, the anomalous indicator minerals from the preglacial gravels in the vicinity of Wabamun Lake and Edmonton are derived from an easterly trending fluvial system with a source area to the west based on the paleodirection of the buried preglacial valleys (see Section 7). In Australia, it is well documented that pyropic garnets in an alluvial to fluvial setting can normally be found from a few kilometres up to about ten kilometres from their kimberlitic source (Mosig 1980 Atkinson 1989; Fipke 1990). However, in colder climates such as Yakutia in the former U.S.S.R., transport distances from a primary source of up to 50 km have been documented for pyropic garnets in a fluvial setting (Afanasev and Yanygin 1983; Afanasev *et al.* 1984). Therefore, it is quite possible that the source area for the G10 pyrope at site 426 and the other indicator minerals is local, at least from between the Foothills and Wabamun Lake, even if these grains represent second-cycle-erosion. Hence, in the Wabamun-Gleichen trend, diatremes and related volcaniclastic rocks of early Tertiary age possibly intrude or are intercalated with Tertiary sedimentary rocks of the Paskapoo Formation which is underlain at depth by the Wabamun or Thorsby basement terranes. The till sample anomalies exist southwest of the preglacial gravels in a down ice direction based on the paleoflow indicators of the Laurentide ice sheet (Shetsen 1990). Stewart and Bale (1994) also indicated that abundant eclogitic garnets, G9, G10 and G11 pyropes, and P3 and P4 chromites were found in tills on Takla Star Ltd.'s Edmonton claim block down ice from the Onoway preglacial channel. These anomalous indicator minerals may be derived from the late Tertiary preglacial gravels. In addition, the Oppdahl diamond is reported to have been discovered in or near the Pembina River about 15 km west of Wabamun Lake (Edmonton Journal 1992a; Morton *et al.* 1993). Based on the indicator minerals discovered to date, further work is warranted in the vicinity of Wabamun Lake and in the area underlain by Paskapoo Formation west and southwest of the Wabamun Lake area to search for diamondiferous diatremes or secondary diamond-bearing sedimentary deposits.

The Vegreville trend is comprised of five anomalous till sites in an easterly trend south of the North Saskatchewan River between Edmonton and the Saskatchewan border, and five anomalous till sites north of the North Saskatchewan River (Figure 6.26). Anomalous indicator minerals include: (a) G1, G2 and G9 pyrope garnets, (b) many favourable G3, G4 and G5 eclogitic garnets, (c) chrome diopsides, (d) chromites, (e) a picroilmenite and (f) two samples with jadeite (up to 0.48 wt% K_2O), one of which also yielded three kyanites (Figures 6.21 to 6.26). The glacial history of the area is complex because glacial transport indicators of ice direction indicate that the predominant ice movement was southwest in the vicinity of Cold Lake and Vegreville, except for indications of strong southeasterly flow in a linear belt that is located about half way between Cold Lake and Vegreville. The belt of southeasterly glacial transport indicators is about 20 km wide from Lac La Biche to Lloydminster. Based on these two different glacial directions, it is not clear where the source area is for the diamond indicator mineral anomalies which exist in the Vegreville trend. There are at least three possibilities: (1) the indicator minerals were dispersed to the southwest towards Vegreville from the area between Cold Lake and Winefred Lake. Indicator minerals at sites 14 (91-3032), 202 (44-2-2), 134 (34-3-1) and 137 (34-4-2) might then indicate minor southeasterly transport modification of the original southwesterly indicator mineral train (Figures 6.21 to 6.26). (2) The second possibility is that some or all of the indicator minerals originated somewhere along the Snowbird Tectonic Zone from Lac La Biche to north of Winefred Lake via southwesterly ice movement with later modification by southeasterly movement. Evidence in favour of this possibility includes the many G9, G10 and G11 pyrope garnets, eclogitic garnets and chrome diopsides that have been reported by Takla Star Ltd. on their Christina Lake block north of Winefred Lake (Stewart and Bale 1994) and some other anomalous till sites which are reported from the government surveys which have been conducted in the vicinity of Lac La Biche, where one magnesium rich chromite, two kimberlitic garnets and two chrome diopsides exist (Figures 6.21 to 6.26). (3) A third potential source area for the indicator minerals anomalies, particulary for the till sites that are south of the North Saskatchewan River, is the preglacial river gravels that exist along or near the North Saskatchewan River. Sites 11 (91-3029), 12 (91-3030), 13 (91-3031) and 14 (91-3032) south of the North Saskatchewan River all yielded G3 and G5 eclogitic garnets with good diamond inclusion chemistry. Of particular interest is site 12 (91-3030), which also yielded a high potassium jadeite (0.48 wt% K_2O), in combination with a possible P3 lamproitic chromite, three kyanites, a chrome diopside and a picroilmenite (Figure 6.26). This combination of indicator minerals is strongly suggestive of a relatively local eclogitic source, potentially diamondiferous, that is either up ice to the northeast or possibly somewhere to the west if the indicator minerals have been removed during glaciation from preglacial gravels spatially associated with the North Saskatchewan River. It should be pointed out that sites 1 to 14 are part of the GSC's original orientation survey (Garrett and Thorliefson 1993). During the orientation survey, many more mineral grains were microprobed and as a direct result sample sites 1 to 14 had a much higher chance of finding important diamond indicator minerals, especially those that are difficult to recognize visually such as eclogitic garnets, chromites and picroilmenites. This may, at least in part, explain why several of the more important sample sites, based on the number of diamond indicator minerals, are from sites 1 to 14.

Another interesting indicator mineral trend is the southeasterly chromite trend that is adjacent to and within the Foothills region between Hinton and Rocky Mountain House (Figures 6.25 and 6.26). The chromites in this trend are from modern creek and river sediment samples that were collected under a Federal MDA project (Ballantyne and Harris 1994. The chromite microprobe data along with results of sampling for gold and platinum group metals have been partially released (Ibid), and will be fully released in an upcoming publication. The complete chromite data set is in Appendix 6.1 and has been generously provided by Dr. Ballantyne of the GSC. Essentially, three groups of chromites can be discerned on Figures 6.12 to 6.19. The three groups consist of (a) those chromites that have chemistry similar to diamond inclusion chromites, (low zinc, high chromium and high magnesium), (b) those chromites that are indicative of kimberlitic or lamproitic magmas (high nickel, chromium, magnesium and titanium), and (c) other chromites of marginal chemistry. On Figure 6.25, all the chromites found and analysed by Ballantyne and Hunts (1994) are plotted regardless of their chemistry. The most important group are those chromites that might have formed in the diamond stability field, which is indicated by those chromites with zinc ≤700 ppm and nickel ≥600 ppm (Griffin *et al.* 1992; Griffin and Ryan 1993; Griffin *et al. In Press)*, and high chromium and magnesium. Only rocks that would have tapped deep upper mantle sources, such as kimberlites, lamproites and other allied volcanic rocks, or those that might represent slices of exhumed upper mantle, such as ophiolitic peridotite, should contain chromites with the high magnesium (≥11 wt% MgO) and high chromium (≥61 wt% Cr_2O_3) concentrations that characterize diamond inclusion chromites. Griffin and Ryan (1993) suggested that ophiolitic chromites should have high concentrations of zinc (>1,000 ppm) due to re-equilibration at lower temperatures upon slow exhumation and, therefore, can be distinguished from xenocrystic chromites that were formed within the diamond stability field and subsequently brought to the surface quickly in kimberlites and lamproites, which then would have low concentrations of zinc (≤700 ppm). Zinc concentrations in chromite are strongly temperature dependent, whereas nickel is only moderately temperature dependent. Only one chromite, a grain from site 394 (B-23), which is west of Rocky Mountain House at Baptiste Creek, plots in the diamond inclusion field on a plot of Ni vs Zn (Figure 6.19; note that "B-" is omitted from the sample number in the X-Y plot). However, the detection limit for zinc and nickel can vary widely depending upon the type and age of electron microprobe employed for the analyses, the types of standards used and even the daily operating conditions. For instance, the detection limits at the University of Saskatchewan electron microprobe which was used for the ARC analyses, are about ±400 ppm for zinc and ±300 ppm for nickel when the results are near the detection level. However, these levels tend to decrease with higher concentrations in the sample. As a result, any chromite grains with ≤1,100 ppm zinc can be considered of interest (Figures 6.19 and 6.43). There are seven chromites from four other sites in the Hinton trend that may have possibly formed within the diamond stability field (Figure 6.19). These four sites include: (a) one grain from site 393 (B-22) west of Rocky Mountain House on the North Saskatchewan River, (b) one of two grains from site 386 (B-15) on the Blackstone River west of Nordegg, (c) four of seventeen grains from site 383 (B-12) on the Pembina River southeast of Coalspur, and (d) one of two grains from site 381 (B-10) on the upper Embarass River near Coalspur (Figures 6.25 and 6.26). All but two of the eight chromites in the Hinton trend have >12 wt% MgO and >49 wt% Cr_2O_3, with six of the eight grains, including the grain from site 394, closely overlapping the chromite field from the highly diamondiferous Argyle lamproite (Figure 6.12). None of the grains overlap the diamond inclusion field for Cr_2O_3 vs MgO, but this field is highly biased towards South African kimberlites because the data set is comprised of 138 diamond inclusion chromites from South African kimberlites, 8 diamond inclusion chromites from Siberian kimberlites and 1 diamond inclusion chromite from the Ellendale lamproite, which is in Western Australia and is diamondiferous but uneconomic (Appendix 3.1 in Fipke 1990).

A second group of low zinc chromites with high nickel (>1,800 ppm) is evident in the chromite data for the Hinton Trend (Figure 6.19). There are thirteen chromites in this group from sites 376 (B-5), 377 (B-6), 379 (B-8), 380 (B-9) and 383 (B-12) that are all restricted to the northwestern half of the Hinton Trend between the Brazeau River and Hinton (Figure 6.25). All of these chromites have elevated titanium, with all but one of the chromites containing >0.8 wt% TiO_2. These high titanium and high nickel chromites are probably high temperature magmatic phenocrysts, perhaps a related population to Griffin's P3 chromites, based on the work of Mitchell (1989), Griffin *et al.* (1992), Griffin and Ryan (1993) and Griffin *et al.* (*In Press).* Based on the low zinc, high nickel and high titanium, these chromites are likely derived from a high temperature, possibly lamproitic melt. If this lamproitic melt originated in an area of thick crust, then it may have formed at a depth below the diamond stability field, and subsequently may have passed through the diamond stability field and acquired diamonds in conjunction with low zinc xenocrystic chromites (P1 or P4) with less nickel and titanium (less evolved chromites) from peridotitic or eclogitic rocks. Based on these data, it is possible that the Foothills region between Hinton and west of Rocky Mountain House, which is underlain by the Wabamun and Thorsby basement terranes, is prospective for deep seated lamproites that are potentially diamondiferous. This hypothesis may, in part, be confirmed by industry based on the positive comments of Mr. C. Fipke with regards to the Cameco-Dia Met joint Venture in the Foothills west of Hinton (Northern Miner 1992; Fipke 1993), and press releases by Takla Star Resources Ltd. (1994), because they both reported phenocrystic and xenocrystic chromites, some of which plot within the diamond stability field. The potential for diamondiferous lamproites southeast and northwest of the Hinton trend is unknown due to a lack of sampling rather than a lack of favourable geology. That potential for diamondiferous diatremes may exist elsewhere in Alberta's Foothills is indicated, for example, by Ecstall Mining Ltd.'s report of "*abundant chromite, as well as eclogitic G-5 garnets indicative of a lamproitic source rather than kimberlite*" in samples from the Highwood, Oldman, Crowsnest and Castle Rivers (Northern Miner 1993).

6.5.3 Results for Northern Alberta

Results to date for till samples which were collected from northern Alberta, are biased towards the Peace River and Fort McMurray areas because the existing sampling in northern Alberta has largely been based on ease of transportation access (Figure 6.1). However, during 1994 to 1995, further microprobe analysis of grains from previously collected samples as well as till sampling in some of the more remote areas of northern Alberta, are planned. Although the sample distribution in northern Alberta generally is sparse, a few trends of anomalous indicator minerals have been recognized. At present, minerals indicative of kimberlites, such as G1 or G2 garnets and picroilmenites, are rare. A few samples in the Peace River area contain G9 or G11 garnets and chrome diopsides that possibly are indicative of peridotitic source rocks. The most common and perhaps the most important group of indicator minerals which currently have been discovered in northern Alberta tills, are low iron and high magnesium G3 and G5 garnets that may be indicative of eclogitic source rocks, some of which could have been derived from the diamond stability field based on comparison with diamond inclusion eclogitic garnets from elsewhere in the world (Figures 6.28 to 6.30). Three geographic trends, based on the number and quality of eclogitic and other indicator minerals, exist in northern Alberta. These include: (a) a southwesterly trend from just north of the townsite of Peace River to the Birch Hills northeast of Grande Prairie, (b) a southerly trend from the lower Wabasca River to the Loon River, and (c) a southwesterly trend in the Marguerite River to Fort McKay area (Figures 6.20 and 6.26).

The Peace River to Birch Hills trend consists of several samples that contain eclogitic G3 and G5 garnets, peridotitic G9 and G11 garnets, chrome diopsides and a few anomalous chromites (Figures 6.21 to 6.26). Two eclogitic G3 garnets from till samples acquired by drilling at sample site 369 (93-3) north of the townsite of Peace River, and sample site 370 (93-6A) west of Winagami Lake near the Little Smoky River, may indicate that high potential exists for diamondiferous eclogitic source rocks in the Peace River area (Figures 6.22, 6.26 and 6.28 to 6.30). The composition of the garnets is well within the diamond inclusion field for eclogitic garnets on a plot of FeO (total Fe) vs MgO, near or within the diamond inclusion field for TiO_2 vs CaO, and the two garnets contain 0.07 and 0.05 wt% Na_2O, respectively (Figures 6.28 to 6.30). The till sample from site 369 (93-3) also yielded a G9 pyropic garnet. A second sample (93-6B) which was collected from a second till that is below that sampled by 93-6A, but in the same drillhole (93-6), yielded a G5 eclogitic garnet and four G9 pyropic garnets. Other indicator minerals of interest within the Peace River to Birch Hills trend include: (a) four G5 eclogitic garnets that plot within or near the diamond inclusion field for FeO (total Fe) vs MgO and TiO_2 vs CaO, coupled with a jadeitic diopside with 0.69 wt% K_2O from till site 310 (93-37) northeast of Grande Prairie near the Smoky River, (b) a G11 pyropic garnet and a high MgO eclogitic G5 garnet from till site 318 (93-45) southeast of Peace River, (c) a G9 pyropic garnet and an anomalous chromite from till site 276 (92-17) southwest of Peace River, and (d) thirty-seven chrome diopsides from the Grimshaw pre-glacial gravel deposit west of Peace River, three of which were microprobed and plot within the diamond inclusion field for Cr_2O_3 vs CaO (Figures 6.21 to 6.23, 6.25 and 6.26).

Most of the anomalous till sites in the Peace River to Birch Hills trend are on or are close to Monopros Ltd.'s Peace River Property and the Carmon Lake Property held by Consolidated Carina Resources Corp. and Currie Rose Resources Inc. Hawkins (1994) and Consolidated Carina Resources Corp. (1993) reported that abundant G9 pyropic garnets and chrome diopsides that plot within the diamond inclusion field have been obtained from till samples collected from the Carmon Lake Property, including those from a recently drilled Shell Resources Ltd. oil well. Hawkins (1994) stated that G1, G3 and

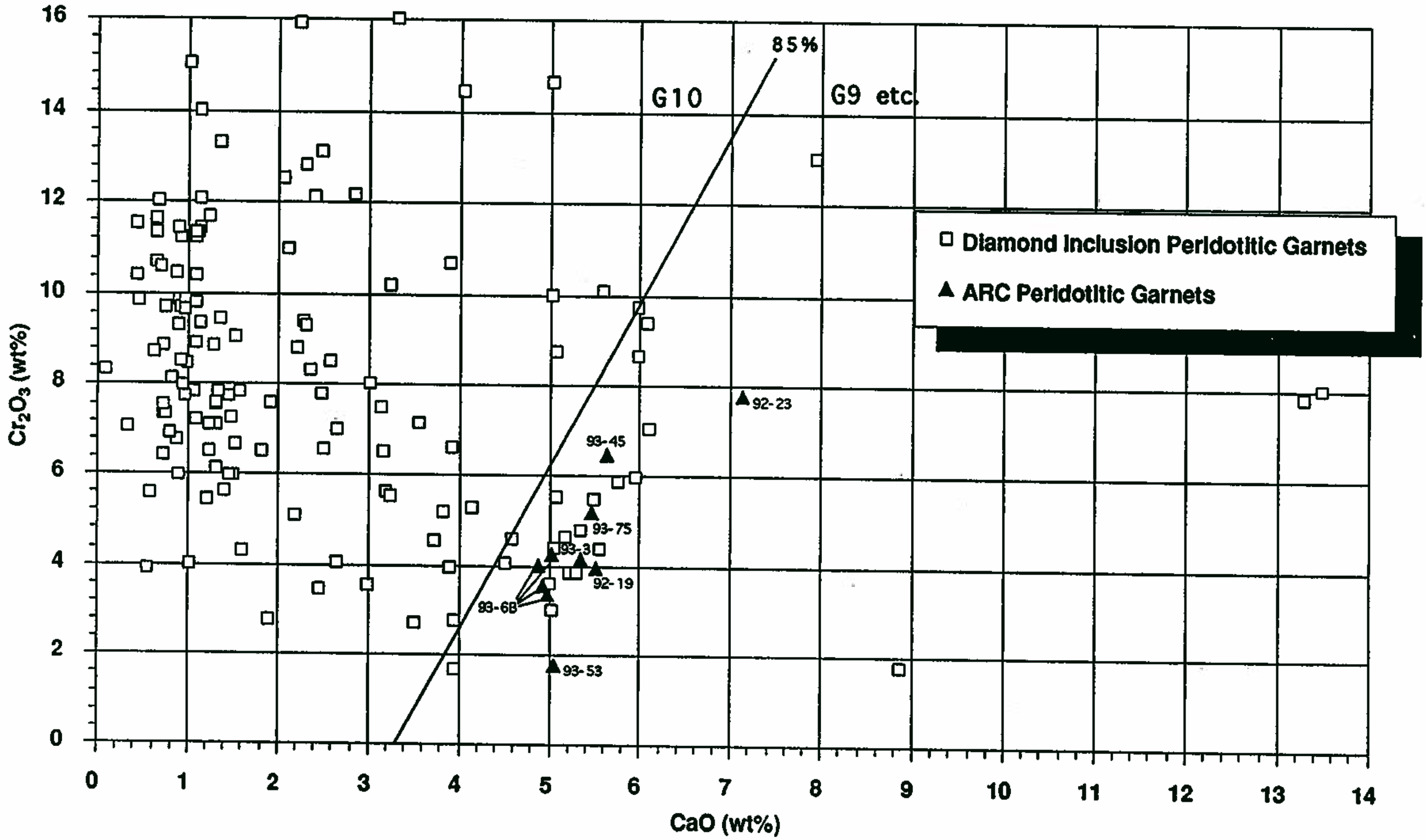


Figure 6.27: CaO vs Cr_2O_3 For Peridotitic Garnets From Northern Alberta Tills.

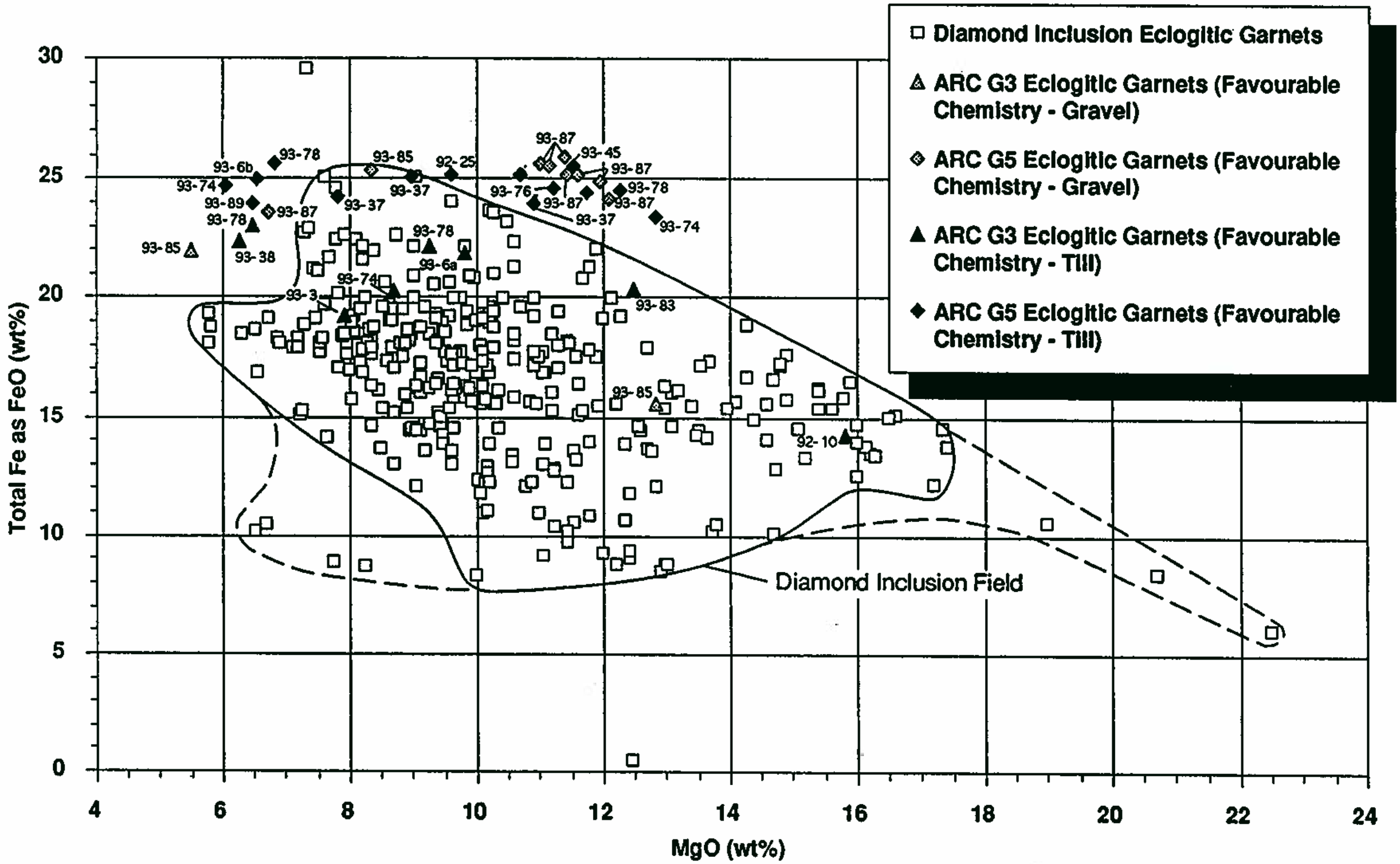


Figure 6.28: MgO vs FeO For Eclogitic Garnets From Northern Alberta Tills and Recent Gravel Deposits

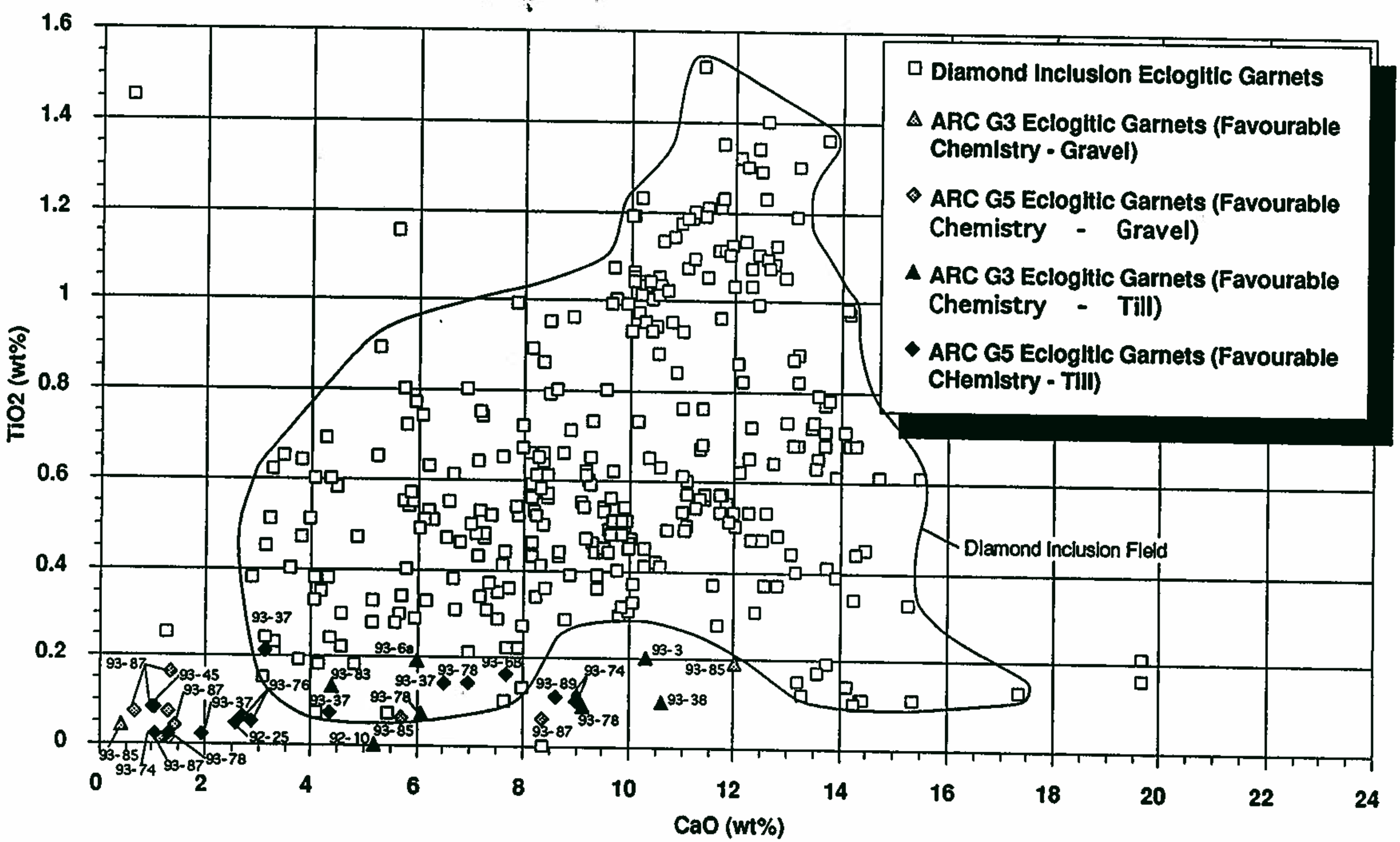


Figure 6.29: CaO vs TiO_2 For Eclogitic Garnets From Northern Alberta Tills And Recent Gravel Deposits

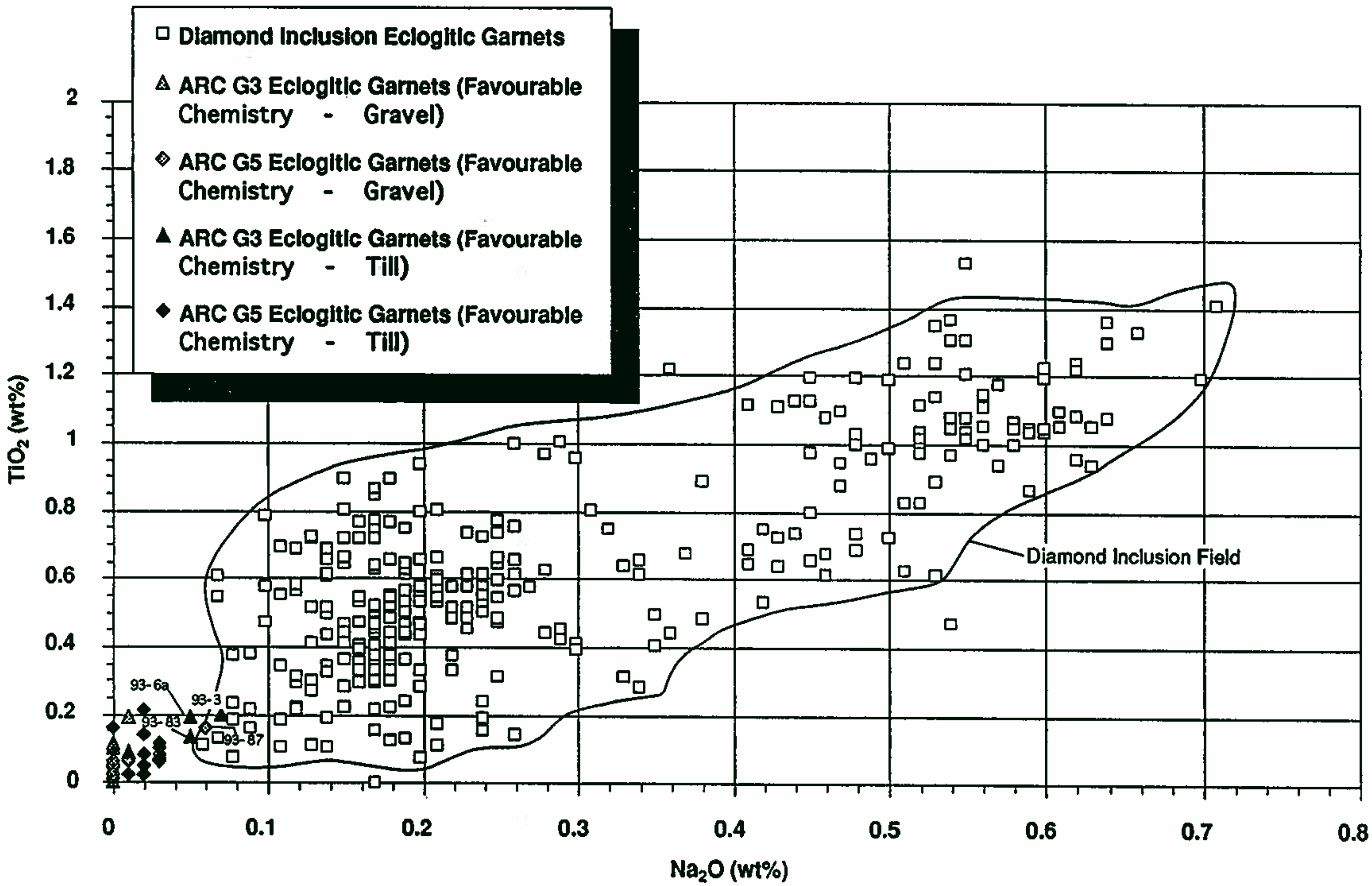


Figure 6.30: Na_2O vs TiO_2 For Eclogitic Garnets From Northern Alberta Tills And Recent Gravel Deposits

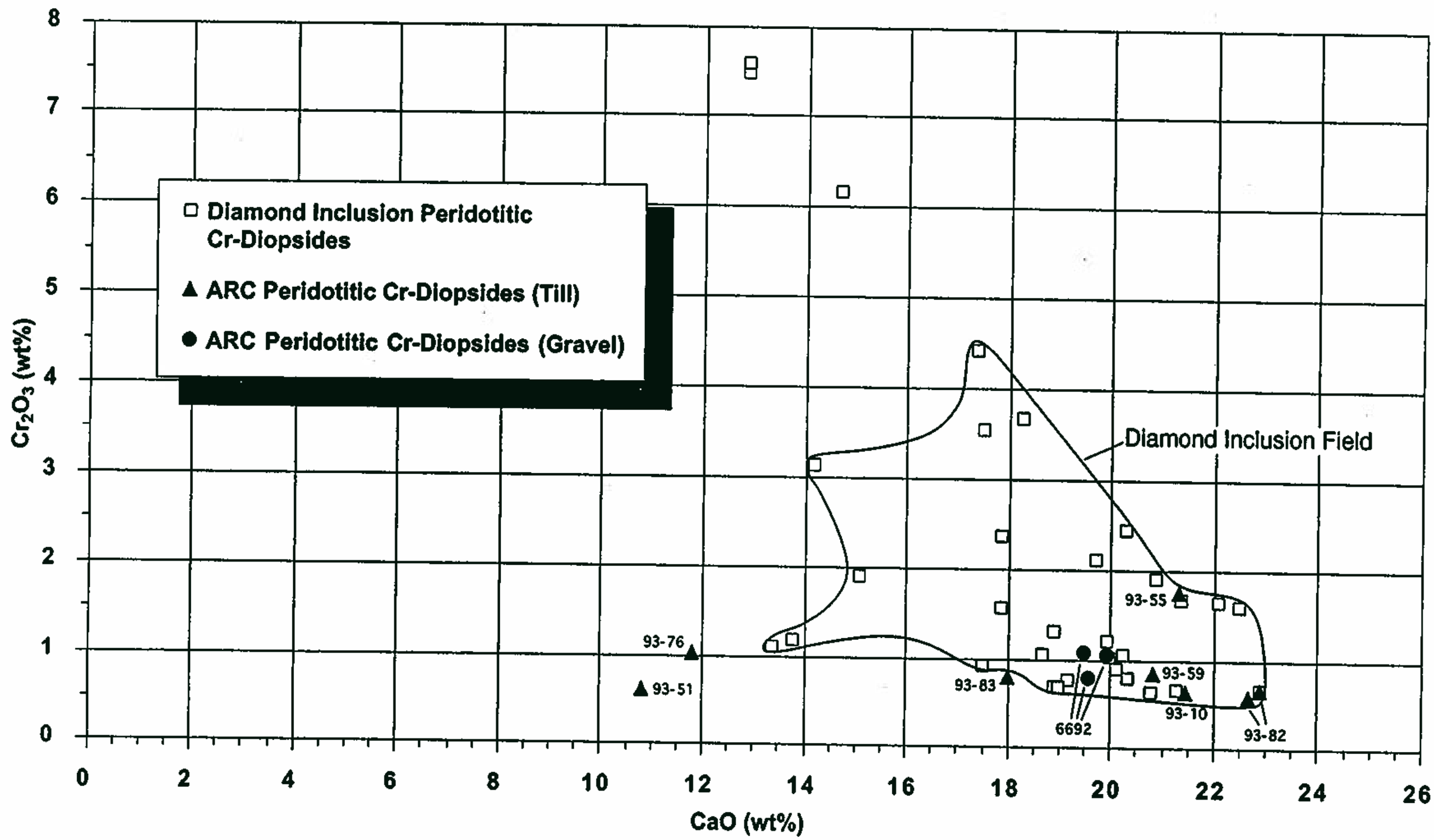


Figure 6.31: CaO vs Cr_2O_3 For Peridotitic Clinopyroxenes From Northern Alberta Tills And The Grimshaw Gravel Deposit.

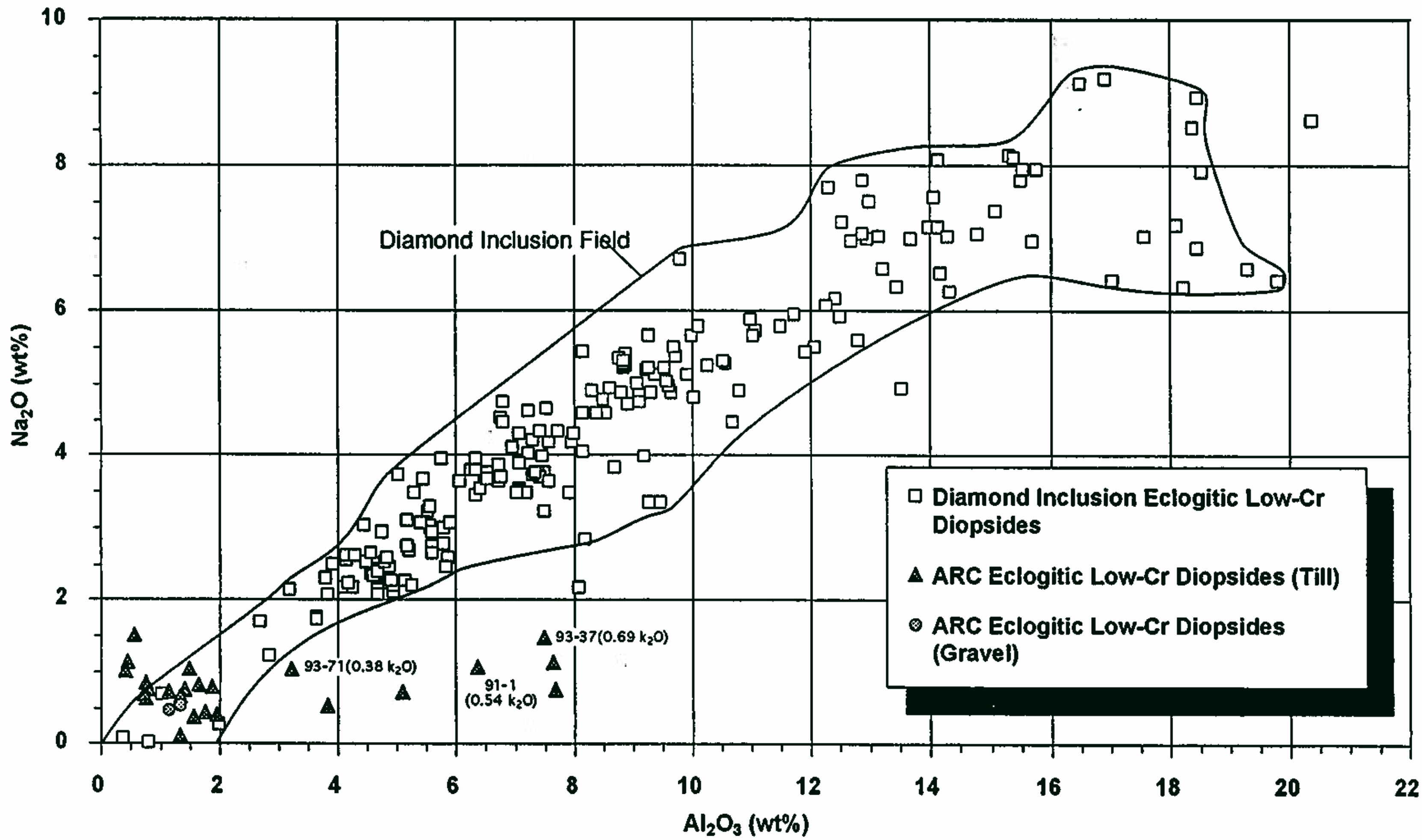


Figure 6.32: Al_2O_3 vs Na_2O for Eclogitic Clinopyroxenes From Northern Alberta Tills And Recent Gravel Deposits

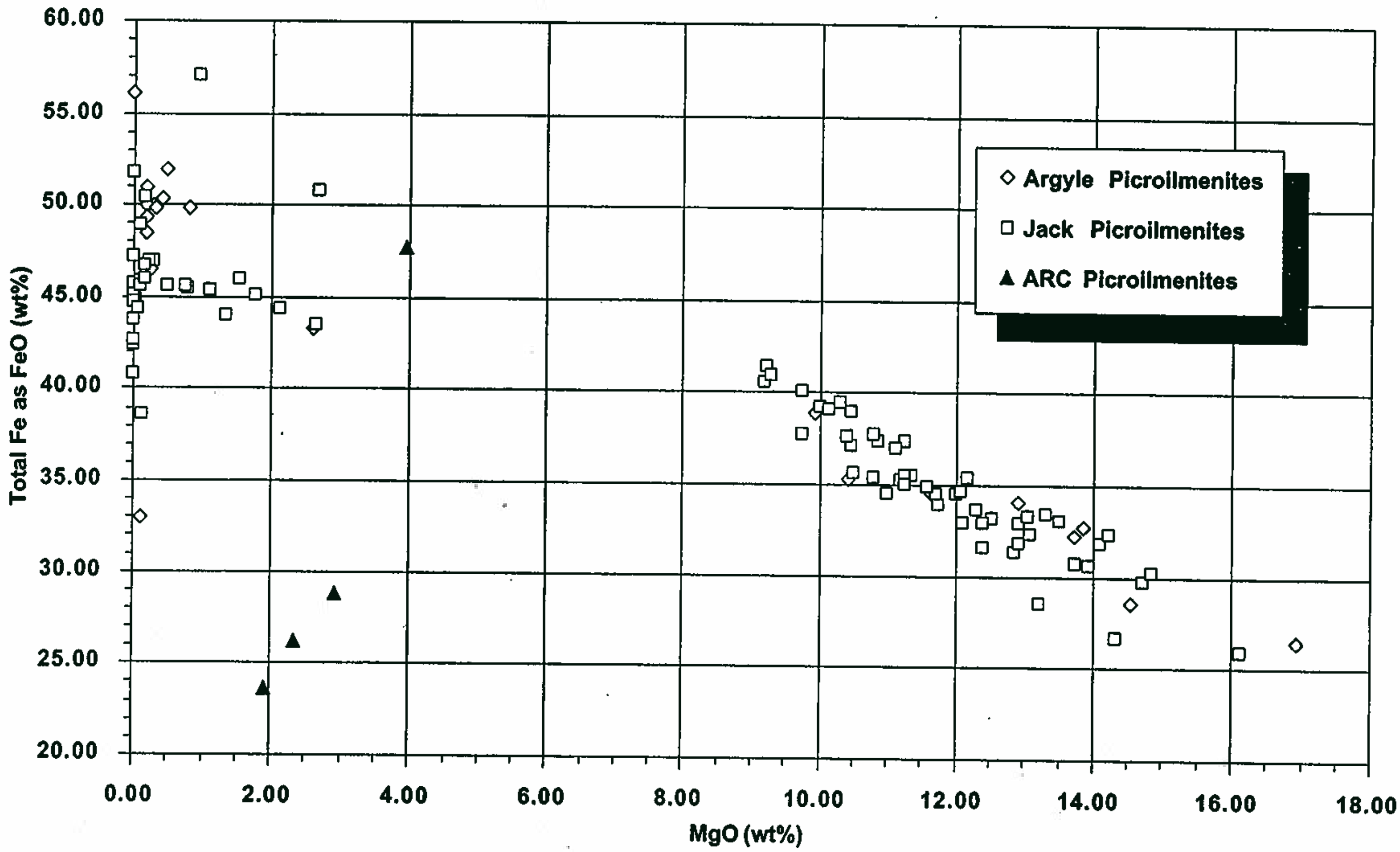


Figure 6.33: MgO vs FeO For Picroilmenites From Northern Alberta Tills

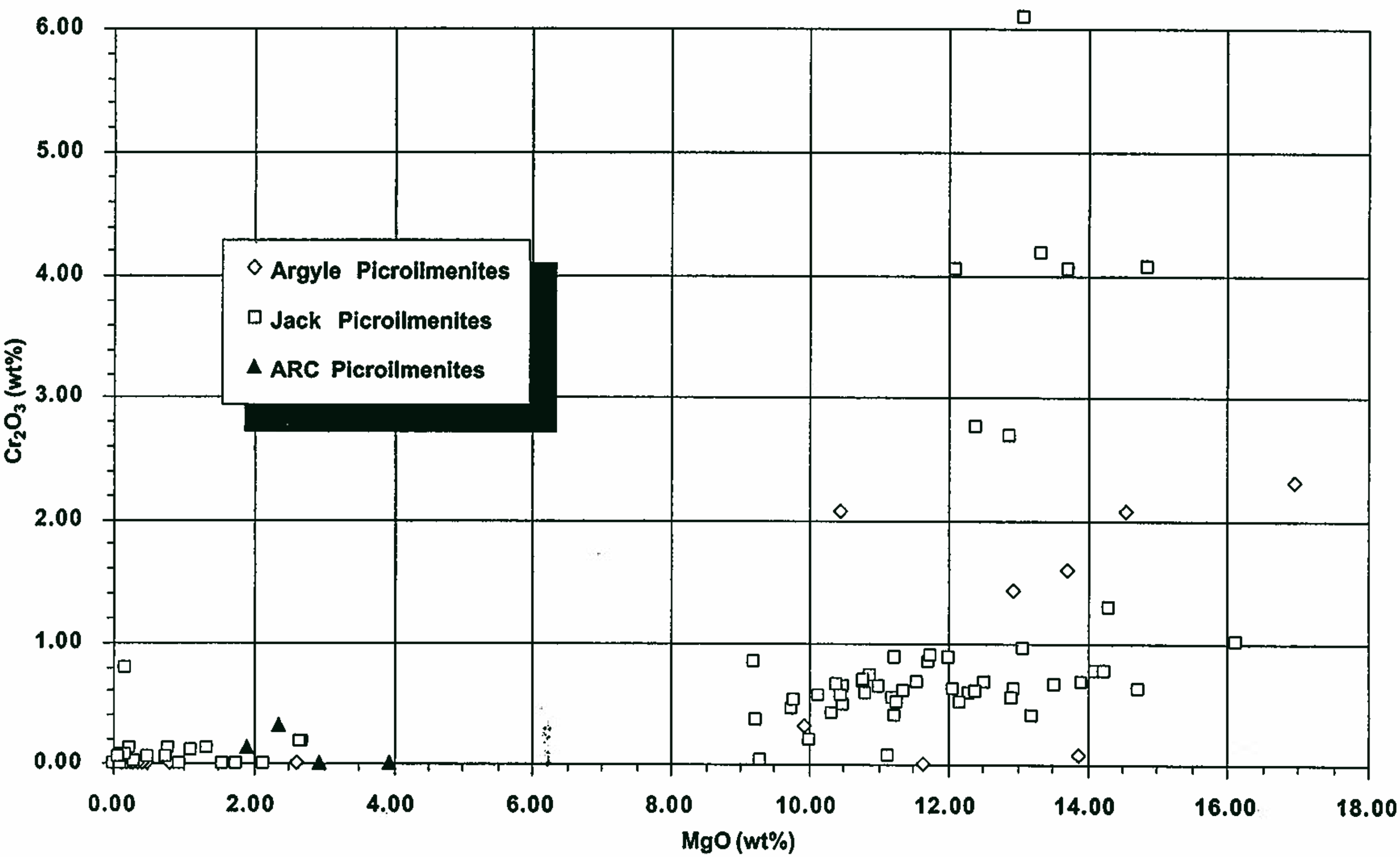


Figure 6.34: MgO vs Cr_2O_3 For Picroilmenites From Northern Alberta Tills

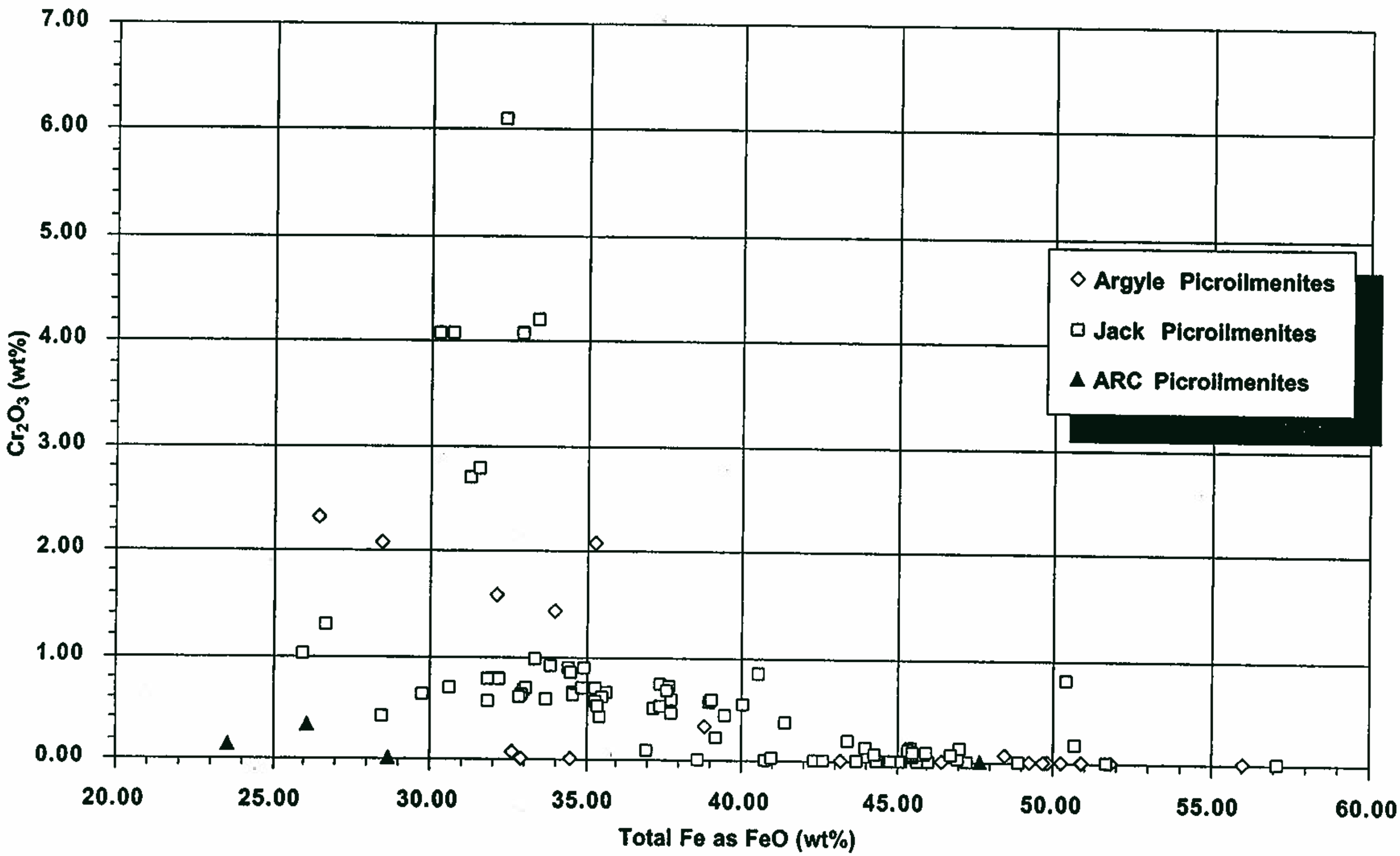


Figure 6.35: Total Fe (as FeO) vs Cr_2O_3 For Picroilmenites From Northern Alberta Tills

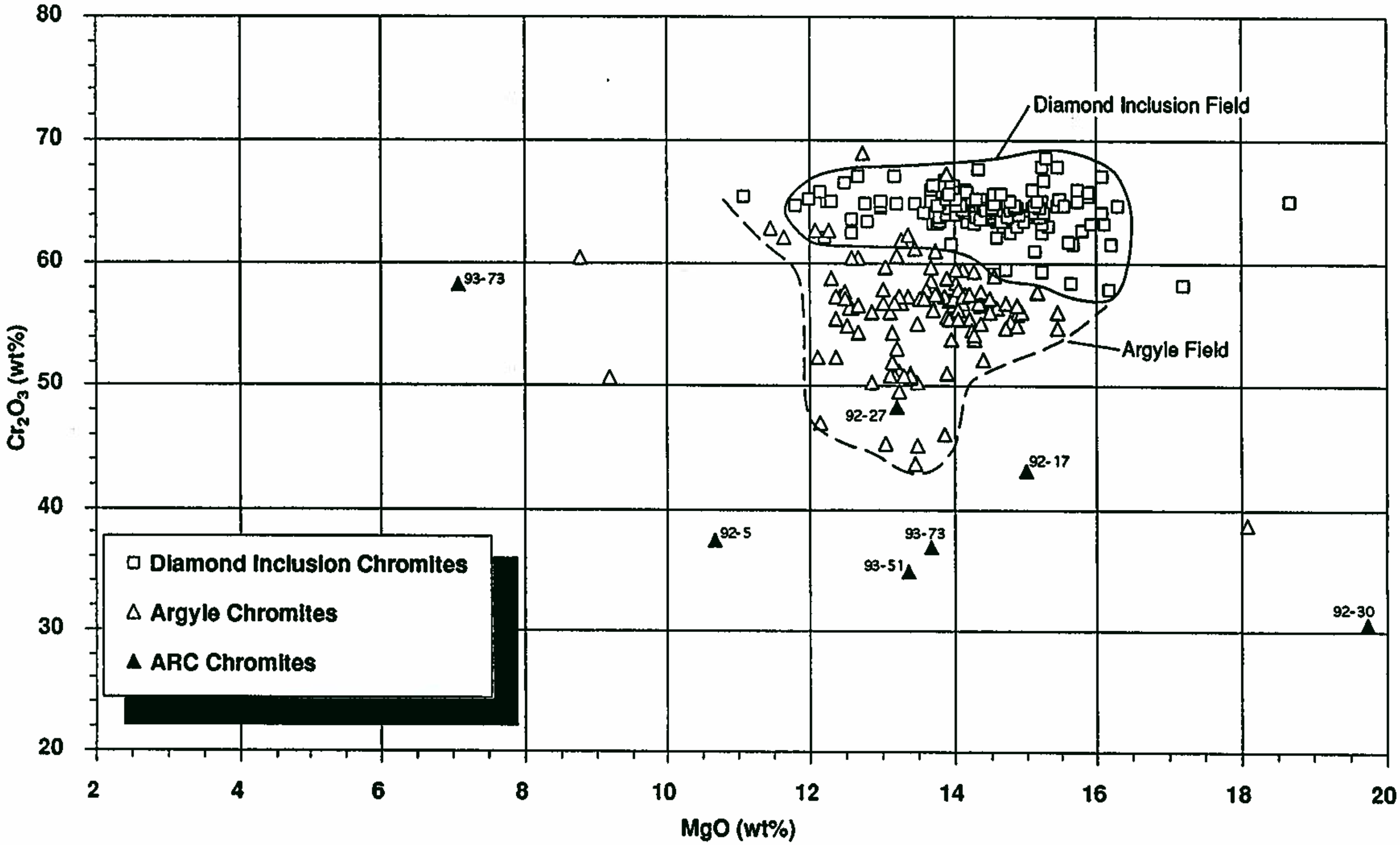


Figure 6.36: MgO vs Cr_2O_3 For Chromites From Northern Alberta Tills

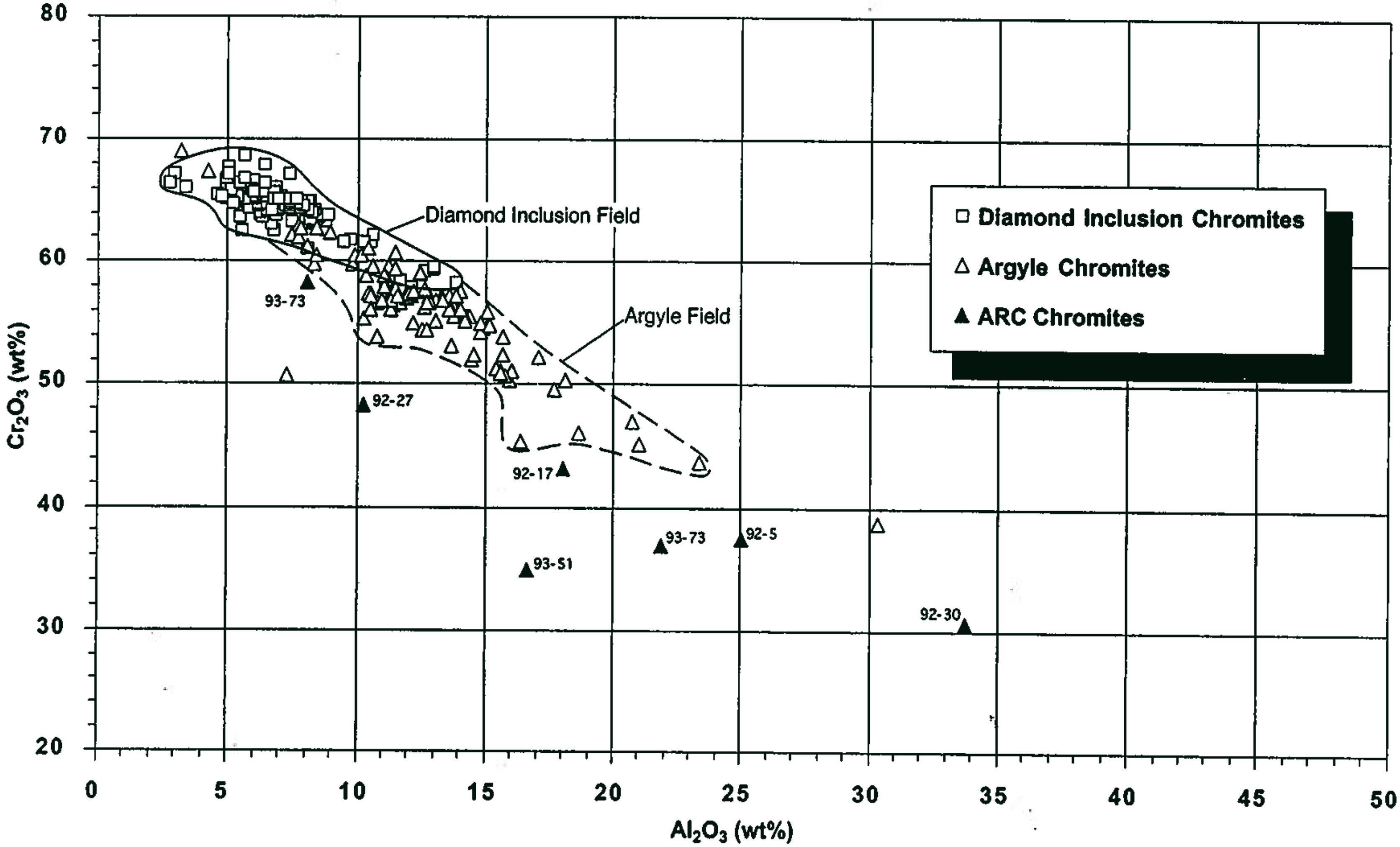


Figure 6.37: Al_2O_3 vs Cr_2O_3 For Chromites From Northern Alberta Tills

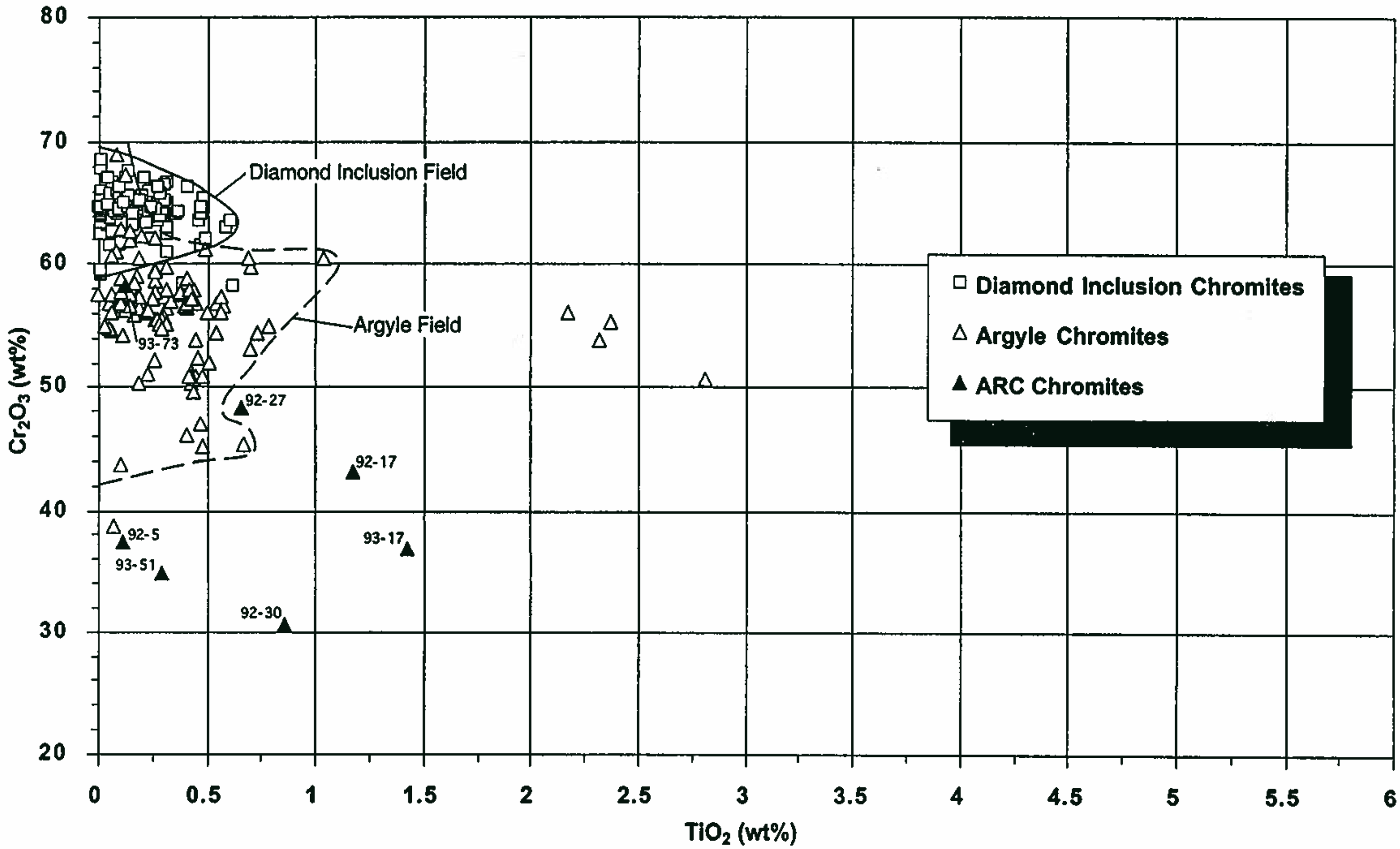


Figure 6.38: TiO_2 vs Cr_2O_3 For Chromites From Northern Alberta Tills

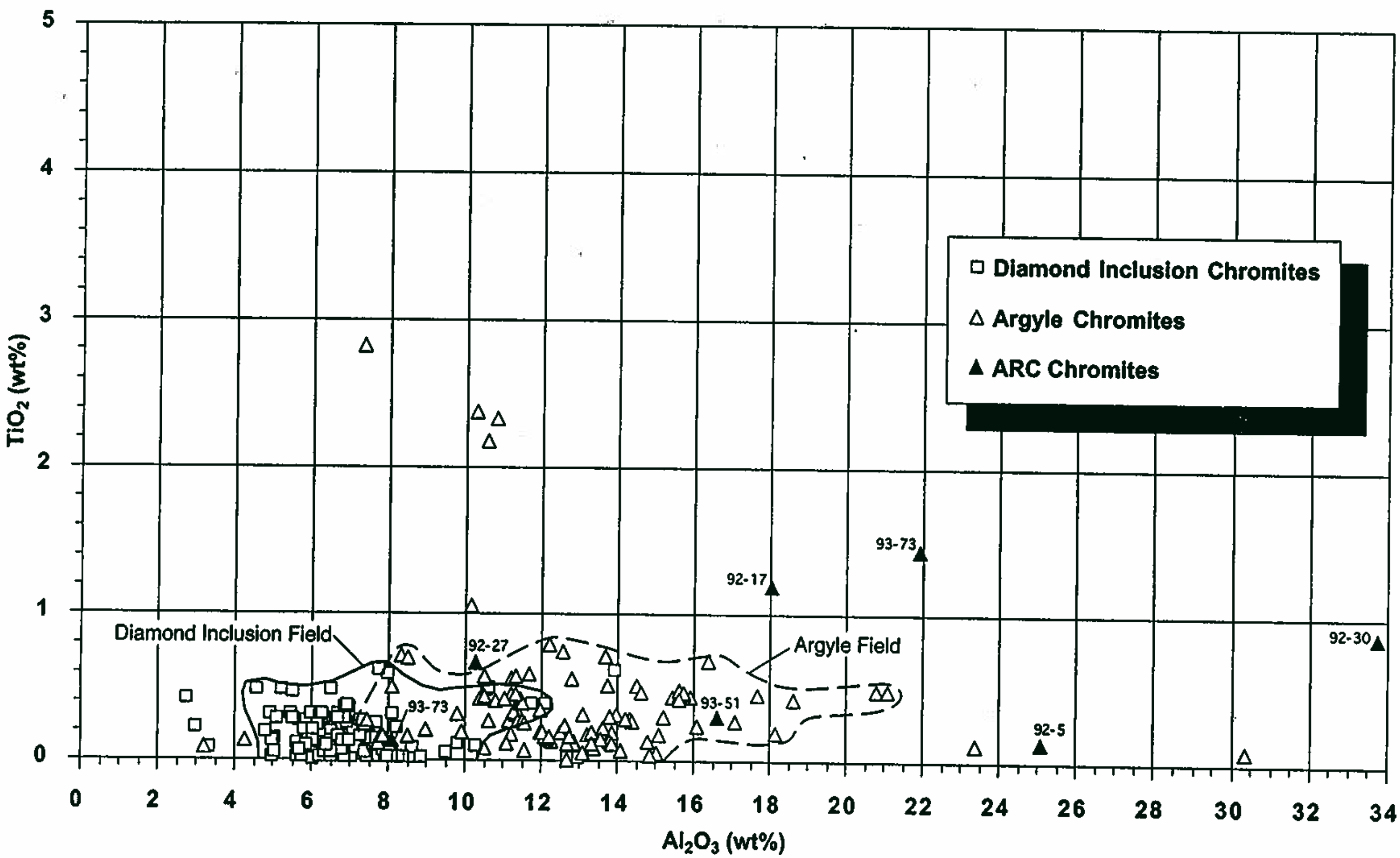


Figure 6.39: Al_2O_3 vs TiO_2 For Chromites From Northern Alberta Tills

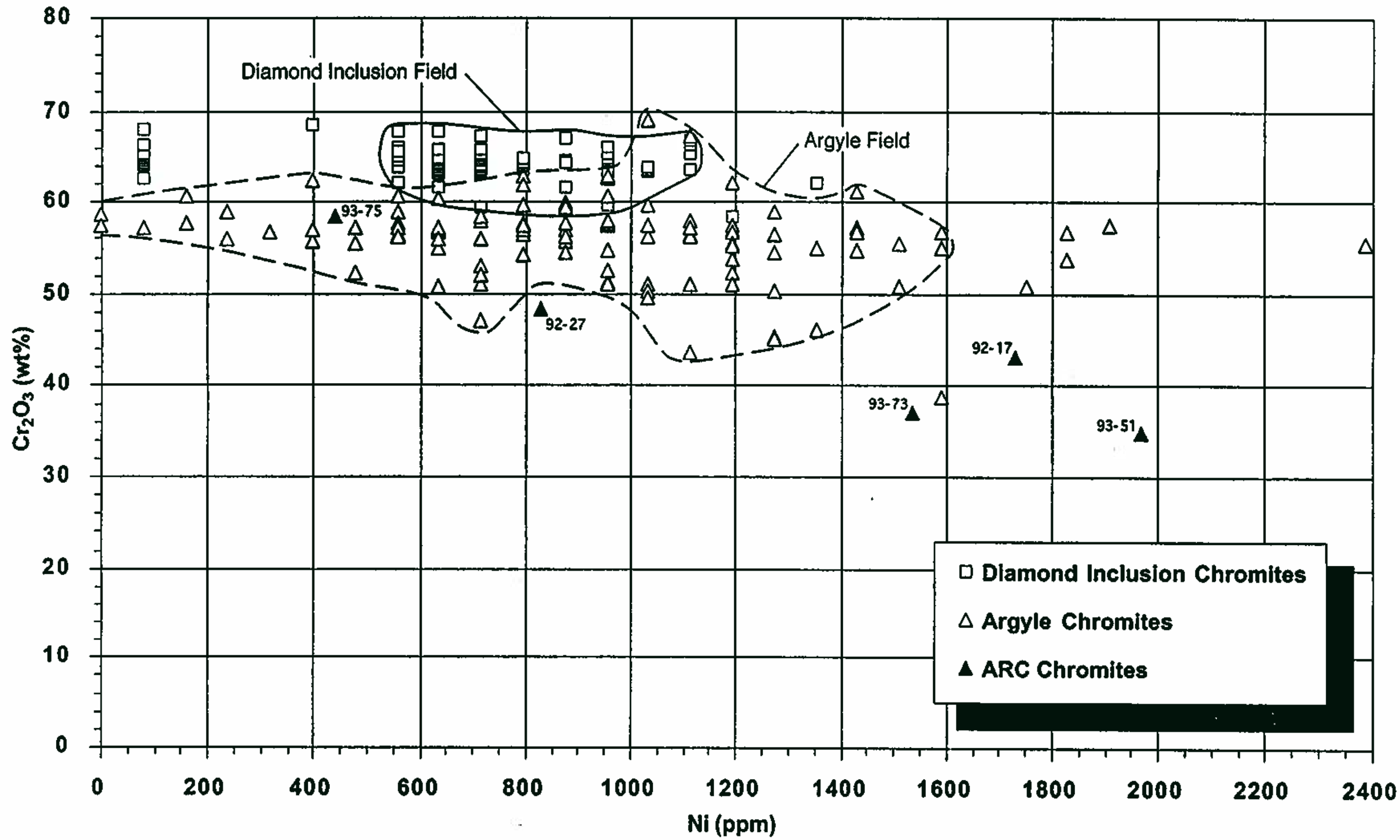


Figure 6.40: Ni vs Cr_2O_3 For Chromites From Northern Alberta Tills

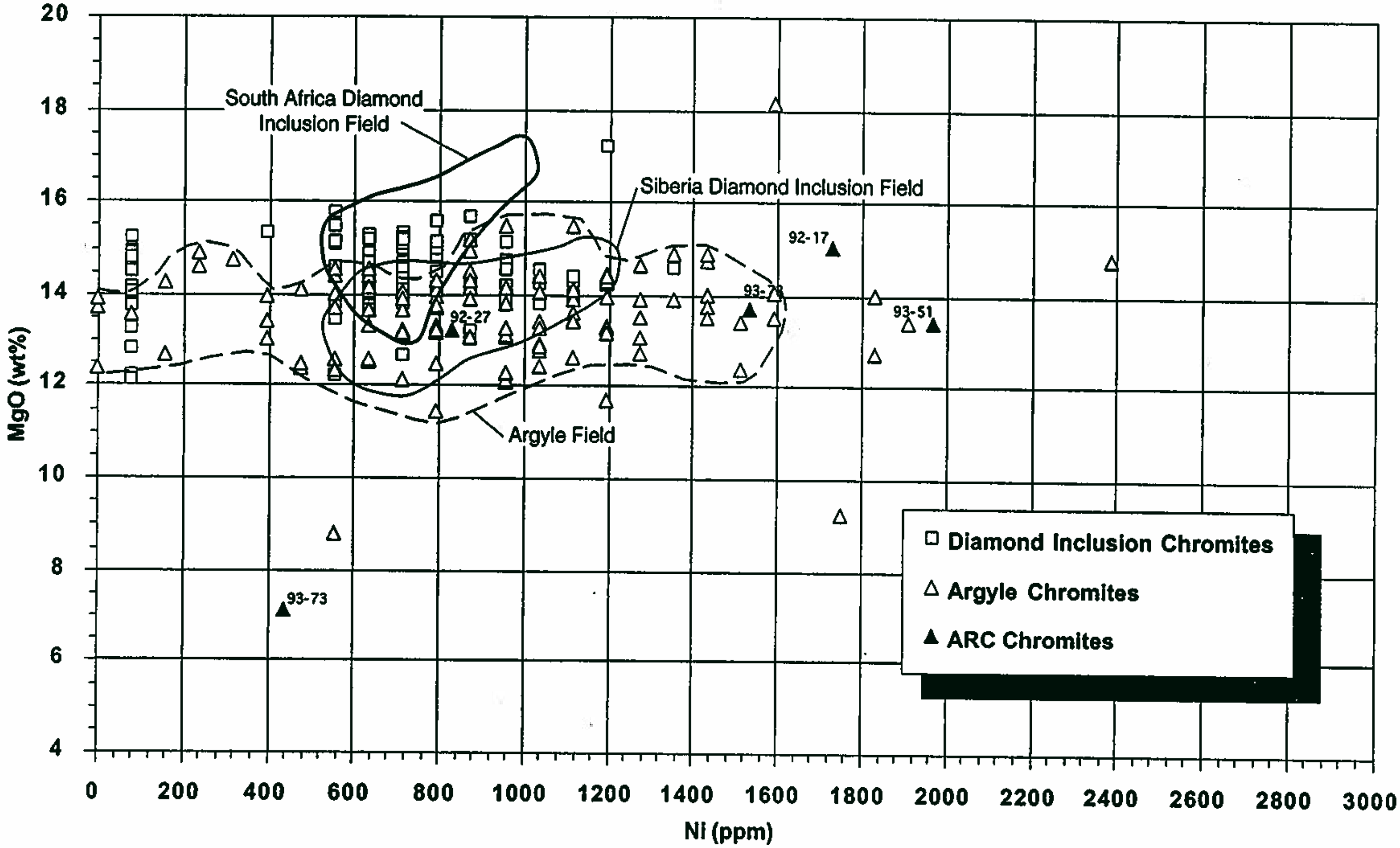


Figure 6.41: Ni vs MgO For Chromites From Northern Alberta Tills

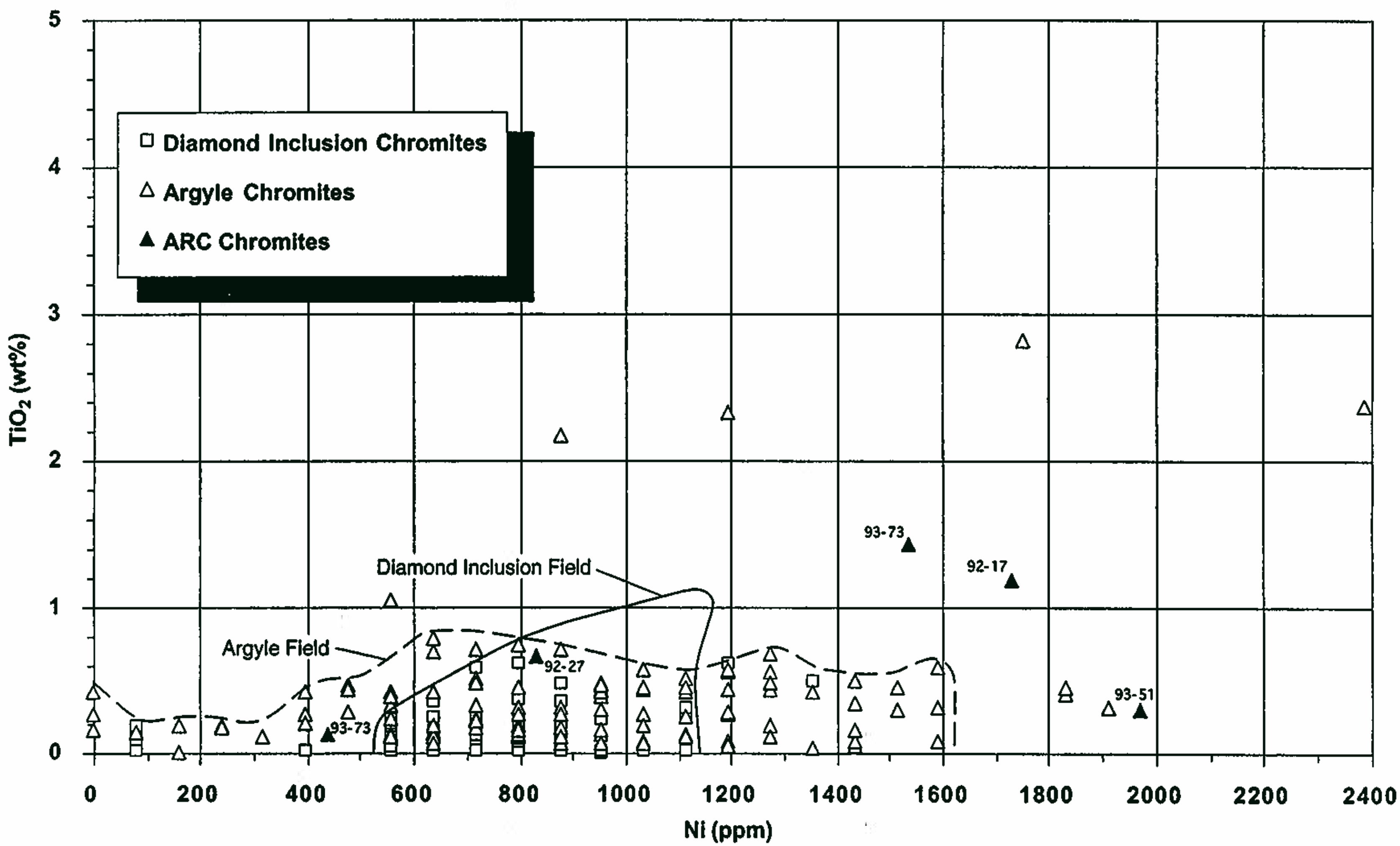


Figure 6.42: Ni vs TiO_2 For Chromites From Northern Alberta

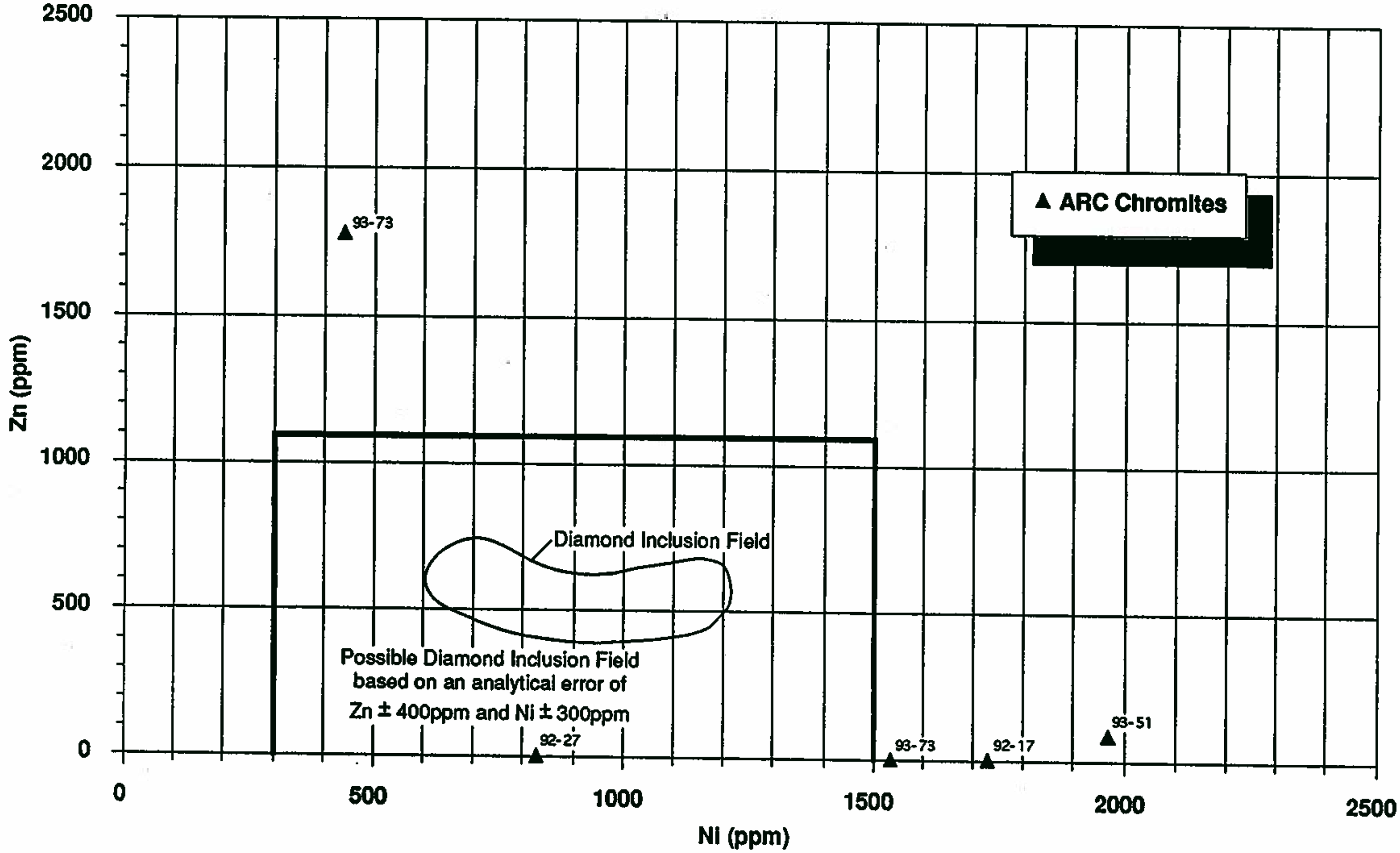


Figure 6.43: Ni vs Zn For Chromites From Northern Alberta Tills

G11 garnets were also found and that the presence of kelphytic rims on some of the garnets indicates that they are likely derived from "*a nearby kimberlite source*" and that the results "*appear to confirm the presence of unmapped kimberlitic intrusions in the Peace River area*". Based on the types of indicator minerals which have been obtained to date from the regional till surveys by government and reported on by industry, it is quite possible that alkaline intrusions with material indicative of eclogitic and peridotitic source rocks exist in the Peace River area. If such intrusions exist, it is not yet certain whether they will be kimberlitic or lamproitic in composition, because few minerals clearly indicative of kimberlite or lamproite have been found relative to the number of grains indicative of eclogite and peridotite. The sites with favourable indicator minerals tend to exist 'down-ice' from the Shaftesbury, Dunvegan and Kaskapau Formations (Figure 6.26). Based on these preliminary results, the current geographic distribution of indicator minerals in the Peace River Trend indicates that the alkaline intrusions are likely no older than Early Cretaceous and are probably time equivalent with reactivation of the Peace River Arch during the middle to Late Cretaceous. Volcanics and tuffaceous units have been described as being interbedded with the Fish Scales Horizon within the Lower Shaftesbury Formation in the vicinity of the Peace River Arch (Bloch *et al.* 1993), which in turn is approximately coeval with kimberlite intrusion in the Fort à la Corne area, Saskatchewan (Lehnert-Thiel *et al.* 1992), eruption of the alkaline Crowsnest volcanics in southwest Alberta (Folinsbee *et al.* 1957), and the approximate age of suggested meteorite impact in northern Alberta in the vicinity of the Steen River (Carrigy 1968). It is also possible that the alkaline intrusions in northern Alberta may be as young as early Tertiary, similar to the age of the Sweetgrass intrusions and the kimberlites in the Lac de Gras area, N.W.T., but this age seems less likely based on a possible spatial relationship of the indicator minerals to the mainly Upper Cretaceous (late Albian to Cenomanian) Shaftesbury Formation.

A second trend of anomalous indicator minerals in northern Alberta occurs in a north to south distribution of till sites that exist in the vicinity of the lower Wabasca River and Loon River (Figure 6.26). This trend consists predominantly of G3 and G5 eclogitic garnets from sample sites 351 (93-74), 353 (93-76) and 355 (93-78) that plot within or near the diamond inclusion field for FeO (total Fe) vs MgO and TiO_2 vs CaO (Figures 6.2, 6.22, 6.28 and 6.29). Other grains of interest include a high chrome (4.62 wt% Cr_2O_3) G7 grossular garnet from site 279 (92-2) southwest of Peerless Lake, a high titanium G2 kimberlitic garnet from site 290 (92-3) near the confluence of the Wabasca and Loon Rivers, and an anomalous chromite from site 297 (92-5) near the Wabasca River east of the Buffalo Head Hills. Although most of the sites contain some favourable indicator minerals and lie in close proximity to the Shaftesbury Formation, the interpretation of the source of these anomalous diamond indicator grains is much more difficult in this area because north-central Alberta is commonly underlain by thick drift (see Section 7).

In the Marguerite River to Fort McKay area (NTS 74E), five till samples and three river sediment samples which were collected by the AGS have been processed and analyzed for diamond indicator minerals. Preliminary results for these samples are discussed in

Dufresne *et al.* (1994). Four other AGS till samples remain to be processed and analyzed. Based on the results of the grains probed to date, there are no grains indicative of kimberlite, lamproite or peridotitic source rocks, with the possible exception of three chrome diopsides in tills from sample sites 359 (93-82) and 360 (93-83)(Figure 6.23). However, three G3 and ten G5 eclogitic garnets from till sample sites 285 (92-25), 360 (93-83) and 366 (93-89), and from river sediment sample sites 362 (93-85) and 364 (93-87), were identified as having favourable chemistry because they plot within the diamond inclusion field for eclogitic garnets on X-Y scatter plots of FeO (total Fe) vs MgO and TiO_2 vs CaO (Figures 6.22, 6.28 and 6.29). At least two of these ecologitic garnets have sufficient amounts of Na and Ti such that they border on the diamond inclusion field for eclogitic garnets on a plot of TiO_2 vs Na_2O (Figure 6.30). The lack of kimberlitic indicators in the samples which contain the eclogitic garnets indicates that they may not be derived from kimberlites. The lack of lamproitic indicators, such as chromite, does not preclude the possibility for eclogite-bearing lamproites because lamproites tend to yield few diagnostic indicator minerals (Fipke 1990). The most interesting grain is a G3 eclogitic garnet from till sample site 360 (93-83) along the Firebag River that plots well within the diamond inclusion field for FeO (total Fe) vs MgO and TiO_2 vs CaO, borders on the diamond inclusion field for TiO_2 vs Na_2O and has 0.05 wt% Na_2O (Figures 6.22, 6.26 and 6.28 to 6.30). Indicators of paleo-ice flow transport direction suggest that the last glacial event had a southwesterly transport direction, hence the eclogitic garnet and associated chrome diopside from site 360 (93-83) were likely derived from the northeast. Other eclogitic garnets of interest from sample sites in the area include: (a) a G5 from till sample site 366 (93-89), and two G3's and a G5 from fluvial sediment sample site 362 (93-85), both of which are located along the Marguerite River, (b) a G5 from till sample site 285 (92-25) east of the Muskeg River, and (c) seven G5 eclogitic garnets with greater than 11 wt% MgO and less than 26 wt% FeO (total Fe), one of which contains 0.06 wt% Na_2O, from fluvial sediment sample site 364 (93-87) along the Muskeg River (Figures 6.22 and 6.28 to 6.30). For those grains derived from tills, the interpretation of the possible source is somewhat more straightforward than for those grains derived from the fluvial samples. For the till samples, the predominant paleo-ice flow transport direction was either southwest or south, depending on which till sheet the samples were collected from. For the indicator minerals derived from the fluvial sediment samples, the interpretation is much more complicated because the indicator minerals could be derived from tills, glaciofluvial sediments or Cretaceous sedimentary strata in subcrop. Determining the possible source of origin for the anomalous indicator mineral grains in the Fort McKay trend is beyond the scope of this study, but several of the eclogitic garnets have encouraging chemistry and should be followed up by industry.

Other indicator minerals that may be of interest, especially once further sampling is conducted, include: (a) a G3 eclogitic garnet with excellent FeO-MgO chemistry from site 269 (92-10) northwest of High Level near the Hay River (Figures 6.22, 6.26, 6.28 and 6.29), (b) a jadeitic diopside with 0.54 wt% K_2O from site 268 (92-1) north of Lesser Slave Lake (Figure 6.26), (c) a chromite from site 287 (92-27) southeast of Fort McMurray that plots within the Argyle field of chomites for most of the major element plots (Figures 6.25, 6.26 and 6.36 to 6.43), (d) an extremely high MgO chromite from site 291 (92-30) northeast of Lac La Biche with otherwise poor chemistry (Figures 6.25. 6.26 and 6.36 to 6.43), and (e) a high chromium (15.87 wt% Cr_2O_3) G7 uvarovite-grossular garnet from site 293 (92-32) and two kimberlite garnets from site 198 (43-4-1-T) southwest of Cold Lake.

6.6 Selected Mineralogical and Lithogeochemical Anomalies

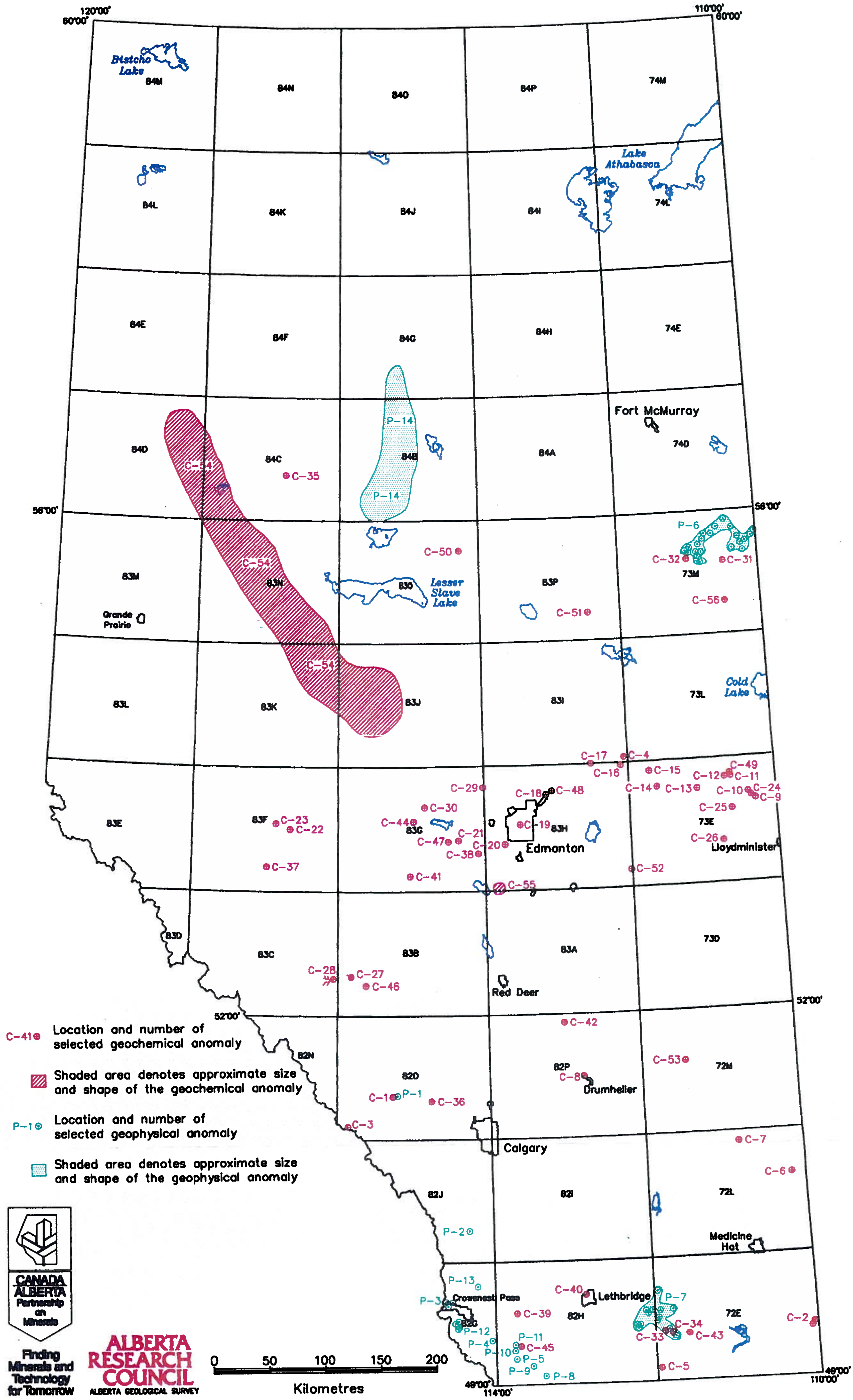
There are a number of mineralogical and lithogeochemical anomalies that occur within the Phanerozoic succession of Alberta (Figures 2.5 and 6.44, Table 2.2 and 6.2). These anomalies are diverse in nature, and include such features as anomalous fluorine (F), gas (CO_2, He) and some other element concentrations in groundwater, marl occurrences, placer and paleoplacer gold and platinum group elements in fluvial sediments, and apparent solution collapse or other subcircular structural features. Any or all of these anomalies may indirectly indicate the possible presence of diamondiferous kimberlite or lamproite activity within the immediately adjacent areas. Each of these anomalous features is discussed below.

6.6.1 Fluorine Anomalies

Two near surface regional F anomalies exist within the groundwaters of southern Alberta (Hitchon and Levinson, *In preparation*). These anomalies comprise areas within which F concentrations in groundwater are invariably greater than 1.5 parts per million (ppm). In contrast, the average F content of groundwaters for the world is approximately 0.2 ppm (Ibid). The two F anomalies occur within spatially separate areas, and within different stratigraphic horizons.

The more southerly of the two F anomalies is known as the Milk River anomaly. It is semicircular and underlies an area of about 15,000 km^2 in NTS map-areas 72E and 82H. It occurs in groundwaters of the lower member of the Milk River Formation of Late Cretaceous age, at depths ranging from 175 m to 350 m. The aquifer ranges in thickness from 60 to 75 m in the southern part, to less than 15 m at the north end of the anomaly. The F concentrations within the Milk River aquifer appear to be independent from the published chemical patterns of any ion, cation, total dissolved solids (TDS), or stable isotope content in wells of the Milk River area, and must be the result of specific local chemical conditions within the anomalous area (Hitchon and Levinson, *In preparation*).

The northern F anomaly is known as the Vulcan anomaly. It is elongated in a north-south direction and is about 200 km long and 20 to 30 km wide. It extends from about 10 km west of Vulcan to about 20 km southeast of Red Deer, in NTS map-areas 82I, 82P and 83A. It occurs in sandstone beds of the Late Cretaceous to early Tertiary Willow Creek Formation, at depths ranging from 35 m to 125 m. The Willow Creek Formation was deposited in the Sifton (Alberta) Trough, a regional northwest-trending valley. The Vulcan anomaly appears to be superimposed upon the eastern limb of this structural feature. The F content gradually decreases to the north, corresponding to a decrease in the aridity



CANADA ALBERTA Partnership on Minerals

Finding Minerals and Technology for Tomorrow

ALBERTA RESEARCH COUNCIL
ALBERTA GEOLOGICAL SURVEY

Figure 6.44: Selected geochemical and geophysical anomalies in Alberta.

of the paleodepositional environment, but this relationship may be fortuitous. The Milk River sandstone occurs at a depth of about 1,000 m in the area of the Vulcan Anomaly, and therefore the Vulcan anomaly is unrelated to the Milk River anomaly. Hitchon and Levinson (*In preparation*) suggest that the Vulcan anomaly may be related to volcanics or tuffaceous units within the Upper Cretaceous to Lower Tertiary succession.

Several authors, including Koritnig (1972), Perel'man (1977), Fuge (1988) and Fleischer and Robinson (1963), state or imply that fluorine-rich waters are associated with either volcanic activity, mineralized zones or leaching of a bentonitic source. If these two F anomalies are indeed related to a volcanic or bentonitic source, they identify at least one and possibly two unknown centres of volcanic activity that may have been active during the Late Cretaceous and early Tertiary periods. Therefore, the possibility exists that diamondiferous kimberlite or lamproite diatremes may be associated with these F anomalies.

6.6.2 Helium and Other Inert Gases

Anomalously high concentrations of inert gases, such as He and CO_2, occur in places within the Alberta Basin (McLellan and Hutcheon 1993; Hutcheon *et al.* 1994). These anomalous concentrations may indicate a possible mantle source for these gases, which in turn may provide indirect evidence for kimberlite or lamproite diatreme activity within the province.

Two intervals of anomalously high helium partial pressures occur in Alberta. The first interval is less than 500 m above the Precambrian basement, and occurs in hydrocarbon pools in Devonian in central and northern Alberta. The second occurs in Early Cretaceous and Mississippian sediments throughout the province, at an average level of about 1,000 m above the basement (McLellan and Hutcheon 1993). The shallower of the two intervals is ^3He-rich, while the deeper interval is ^3He-poor, relative to global He ratios. The enrichment of ^3He in the shallower interval is enigmatic, as it indicates a mantle source for the He. If the helium were brought to the shallower level through crustal discontinuities such as faults, one would expect localizations of anomalous P_{He} values, which is not the case. Another possible source for the ^3He is mantle-derived volcanic material, which could have been brought to the surface through diatreme activity and deposited province-wide as bentonite beds. The anomalously high helium partial pressures in the shallower interval provide indirect evidence of igneous diatreme activity, likely during the early Cretaceous. The anomalously high helium partial pressures in the deeper interval appear to be derived from a diffusive flux of He from the underlying basement, rather than from a mantle source (McLellan and Hutcheon 1993).

Anomalous concentrations of CO_2 occur in south-central Alberta in the same depth interval as the shallower of the two He anomalies. The anomalous CO_2 concentrations occur in an area about 150 km long by 70 km wide, elongated in a northwesterly direction. Within this anomalous area, CO_2 partial pressures range up to 0.22 per cent

TABLE 6.2: SUMMARY OF SELECTED GEOCHEMICAL AND GEOPHYSICAL ANOMALIES IN ALBERTA

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
P - 1 (Devil's Head Mtn)	Twp27 R9 W5	Ground magnetic - up to 60 gamma - from a limited survey.	500 m long and open to the N, E and W.	Anomalously Cr-bearing rock occurs about 3 km to the SW (C-1).	"Bag Iron" occurs in the area and may be the source of elevated magnetic intensity.	R. Renn (1956)
P - 2 (Meinsinger Lake)	Twp15 R3 W5	Aeromagnetic anomaly - circular, 30-40 gammas above background in immediate surrounding area.	800 m long and slightly elliptical - elongated in the N-S direction.	None.	The regional gradient is very smooth and increases to the north by about 20 gammas. This anomaly forms a very distinct feature. The nearest known magnetite deposits are about 20 km to the south.	R. Steiner (1958)
P - 3 (Crowsnest Pass)	Twp8 R4-5 W5	Three closely spaced aeromagnetic anomalies up to 20 gammas above local background.	The largest is about 2.5 km long x 1.2 km wide. The smallest is 800 m across and semicircular.	Intervals of Crowsnest Volcanics occur in the vicinity of these anomalies.	Moderate (up to 50 gamma) linear magnetic anomalies occur <5 km to the SE of these anomalies and may correspond to intervals of Crowsnest Volcanics. As well, the Burmis magnetite deposits occur about 20 km to the east.	R. Steiner (1958)
P - 4 (Pincher Creek)	Twp4-5 R1 W5	Aeromagnetic anomaly up to 60 gammas above regional background. Part of a positive magnetic trend that includes P -4 and P -6.	6.5 km long and 3.0 km wide elongated in the NW-SE direction.	Anomalies P - 5 and P - 6 occur along the same magnetic high which is 30 km long and up to 8 km wide.	Definitely not associated with Dungarvan magnetite deposits which occur further to the SE.	R. Steiner (1958)
P - 5	Twp3 R28-29 W4	Aeromagnetic anomaly about 30 gammas above local background and up to 80 gammas above regional background.	Up to 1.5 km long and 0.8 km wide elongated in the N-S direction.	Anomalies P - 4 and P - 5 occur along the same magnetic high.	Dungarvan magnetite deposits occur as a separate magnetic anomaly to the west.	R. Steiner (1958)
P - 6 (Christina Block of Takla Star)	Twp76-80 R1-7 W4 22 anomalies clustered in Takla Star property.	Circular positive and negative magnetic anomalies.	Most are 2 km or less in diameter.	2 diamond indicator mineral anomalies in the vicinity (C-31 and C-32).	22 magnetic anomalies identified from GSC airborne magnetic survey. Most are small and circular to ellipsoidal in shape.	Takla Star press (1993c)
P - 7 (Legend Block of Takla Star)	13 anomalies between T5-9 R14-17 W4	Aeromagnetic targets.		Diamond (kimberlite) indicator mineral anomalies C33 and C34 exist in vicinity	13 magnetic anomalies identified from GSC airborne magnetic surveys.	Takla Star Press (1993c)
P - 8 (Pincher Block of Takla Star)	S27 T1 R26 W4	Aeromagnetic anomaly ellipsoidal in shape.	1 x 0.5 km	G9 and G11 garnet indicators in Pincher Block .	Negative magnetic anomaly identified from GSC airborne magnetic survey.	Takla Star promotional material on Pincher Block - undated
P - 9 (Pincher Block)	S28 T2 R27 W4	Aeromagnetic anomaly ellipsoidal in shape.	1 x 0.75 km	Exact locations are not present in available data for anomalies P-8 to P-11	Negative magnetic anomaly.	Takla Star promotional material on Pincher Block - undated

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
P - 10 (Pincher Block)	S8 T4 R28 W4	Aeromagnetic anomaly ellipsoidal in shape.	1 x 0.5 km		Negative magnetic anomaly.	Takla Star promotional material on Pincher Block - undated
P - 11 (Pincher Block)	Center of T4 at border of R28 and R29 W4	Aeromagnetic anomaly circular in shape.	1 x 1 km		Negative magnetic anomaly.	Takla Star promotional material on Pincher Block - undated
P - 12	T6 R4 W5	Cluster of 5 anomalies - ellipsoidal to circular.	1.5 x 1 km		Numerous aeromagnetic anomalies (1-2 lines) circular to ellipsoidal in shape.	Steiner (1958)
P - 13	Center of T9 and T10 R2 W5	Aeromagnetic anomaly roughly circular.	0.5 x 0.5 km		Small, sharp aeromagnetic anomaly - (1 line).	Steiner (1958)
P - 14 (Trout Mtn Anomaly)	Approximately T1-T95 R5-R12 W5	Gravity low.	30 x 150 km (?) -25 mgal residual anomaly.		Gravity low appears to be best explained as a microcline granite pluton flanked by granulites - possible anatectic granite in a welt of deep crustal material between the Wopmay and TransHudson orogens.	Burwash and Power (1989)
C - 1 (Devil's Head Mtn.)	T27 R9-10 W5	Bog iron deposits. Also "green and brown silicate rocks" in which qualitative tests indicate Cr is present.	Area of interest is about 4 km E-W by 3 km N-S. Similar silicate rocks were also found up to 10 km to the N and W.	Weak (60 gamma) ground magnetic anomaly occurs at east end of area of interest (P-1).	Cr bearing rock had "yellow section of ore". Possibly analagous to "yellow ground" of altered kimberlites? Equivalent to Mineral Anomalies 82O-8, 82O-M9 and 82O-11 in Olson et al. (1994). Up to 63.64% Fe in bog deposits.	R. Renn (1956)
C - 2 (Battle Creek and Willow Creek)	SW-35-5-1-W4 also T5 R1 W4	"Wad" (bog maganese) First deposit about 15,000 t with assays from 6% to 16% Mn. Second deposit about 5% Mn.	Lens shaped. First deposit about 50 m in diameter, ranging from 0.67 m thick at edges to 4.7 m in centre. Second deposit ranges from 1.3 to 1.7 m thick.	None.	Recent in origin, maybe from mineral springs. Possibly leached from mafic diatremes ?	AMDO files; NMI Sheet 115060, Mineral Policy Sector, Dept. of Energy, Mines and Resources; no date
C - 3 (Redearth Pass)	3-32-24-14-W5 (Alberta-BC border)	Talc. Irregular stringers pods and beds within dolomites in Cathedral Formation.	In Alberta, thicknesses range up to 1.5 m. In B.C. 3 m talc bed is overlain by 20 m of massive talc.	None.	Possibly a result of Mg - metasomatism from mafic or ultramafic diatreme.	Govett and Byrne (1958) AMDO ARC Economic Minerals File, Mineral Policy Sector, Dept. of Energy, Mines and Resources; no date
C - 4 (Bellis Bog)	36-58-15-W4	Bog iron deposit. No tonnage defined.	Triangular shaped area about 400 m by 300 m by 100 m. Maximum thickness 0.6 m.	None.	Recent in origin, leached from surrounding area. Source may be ironstone nodules, pyrite or diatreme.	J. Godfrey (1955)

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
C - 5	13-5-2-15-W4	Platinum in Milk River.			72E-M29, S2 in Olson et al. (1994)9	Halferdahl (1965); Edwards (1990)
C - 6	5-26-19-2-W4	Platinum in South Saskatchewan River.			72L-M2, S2 in Olson et al. (1994)	As C - 5.
C - 7	5-36-22-7-W4	Platinum in Red Deer River.			72L-M1, S1 in Olson et al. (1994)	As C - 5.
C - 8	2-18-29-20-W4	Platinum in Red Deer River.			82P-M2, S2 in Olson et al. (1994)	As C - 5.
C - 9	SW1/4-14-54-3-W4	Platinum in North Saskatchewan River.			73E-M9, S9 in Olson et al. (1994)	As C - 5.
C - 10	SW1/4-22-55-4-W4	Platinum in North Saskatchewan River.			73E-M10, S1 in Olson et al. (1994)	As C - 5.
C - 11	8-22-56-5-W4	Platinum in North Saskatchewan River.			73E-M8, S8 in Olson et al. (1994)	As C - 5.
C - 12	14-19-56-6-W4	Platinum in North Saskatchewan River.			73E-M7, S7 in Olson et al. (1994)	As C - 5.
C - 13	14-16-55-8-W4	Platinum in North Saskatchewan River.			73E-M6, S6 in Olson et al. (1994)	As C - 5.
C - 14	4-32-55-11-W4	Platinum in North Saskatchewan River.			73E-M5, S5 in Olson et al. (1994)	As C - 5.
C - 15	7-18-57-12-W4	Platinum in North Saskatchewan River.			73E-M1, S1 in Olson et al. (1994)	As C - 5.
C - 16	14-34-57-15-W4	Platinum in North Saskatchewan River.			83H-M10, S1 in Olson et al. (1994)	As C - 5.
C - 17	2-12-58-18-W4	Platinum in North Saskatchewan River.			83H-M9, S9 in Olson et al. (1994)	As C - 5.
C - 18	12-14-55-22-W4	Platinum in North Saskatchewan River.		Vague reference to chromite with up to 1.2% Cr_2O_3 from Edmonton area; perhaps near where concentrator was built at Fort Saskatchewan.	83H-M8, S8 in Olson et al. (1994)	As C - 5; Reference for chromite: NMI Sheet 115100, Mineral Policy Sector, Dept. of Energy, Mines and Resources, 1981
C - 19	12-30-52-24-W4	Platinum in North Saskatchewan River.			83H-M6, S6 in Olson et al. (1994)	As C - 5.
C - 20	7-3-51-26-W4	Platinum in North Saskatchewan River.			83H-M5, S5 in Olson et al. (1994)	As C - 5.

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
C - 21	4-15-51-3-W5	Platinum in North Saskatchewan River.			83G-M3, S3 in Olson et al. (1994)	As C - 5.
C - 22		Platinum in McCleod River.			83F-M4, S4 in Olson et al. (1994)	As C - 5.
C - 23		Platinum in McCleod River.			83F-M3, S3 in Olson et al. (1994)	As C - 5.
C - 24	Vague - on the North Saskatchewan River near Lloydminster	1.4% red garnet in heavy minerals of till sample.			Study uses volume per cent of suite of heavy minerals to determine percentage of till that has Precambrian Shield source and percentage of till with Cretaceous source.	Bayrock (1962)
C - 25	Vague - NW of Lloydminster	1.2% red garnet in heavy minerals of till sample.			As above	As C - 24.
C - 26	Vague - west of Lloydminster	0.8% red garnet in heavy minerals of till sample.			As above	As C - 24.
C - 27	"Ram River Block" N of Ram River NW1/4 T38 R13 W4 NE1/4 T38 R14 W4 (Nice Creek Tributary)	Lamproitic diamond indicator heavy mineral anomaly.			Highly anomalous P4 xenocrystic and P3 phenocrystic chromites.	Takla Star, 1993a
C - 28	"Ram River Block" Kiska River drainage T38 R14-16 W4	Lamproitic diamond indicator heavy mineral anomaly.			Very high P1 harzburgite xenocrystic chromite content and diamond-inclusion-field chromites. "Excellent potential to discover 1 degree diamondiferous lamproites within 100 square km of Kiska River area".	As C - 27.
C - 29	"Edmonton Block" SW1/4 T56 R1 W5	Lamproite indicator anomaly.			P3/P4 lamproite indicator mineral diamond-inclusion-field chromite and G3 eclogitic garnet. 24 G9/G10's; 8 G11's; 8 G3's; 20 G5's; 10 P3's; 3 P4's.	Takla Star, (1993a, c) Olson et al. (1994) MEG Abstract Notes from Feb., 1994 meeting
C - 30	"Edmonton Block" centre T54 R6 W5	Lamproite indicator anomaly.			As C - 29.	As C - 29.
C - 31	"Christina Block" centre T76 R4 W4	Kimberlite indicator anomaly.			G9 and G10 pyrope garnets discovered. Also G11, 8 G3's and 3 G5's.	As C - 29
C - 32	"Christina Block" NW1/4 T76 R7 W4	Kimberlite indicator anomaly.			200 - 1,000 feet of overburden in property area.	As C - 29
C - 33	"Legend Block" SE1/4 S25 T5 R15 W4	Kimberlite indicator anomaly.			Pyrope garnets with kelphytic rim and orange peel textures; 9 G9's and G10's. Also found Cr-diopsides and picroilmenites.	Takla Star (1993a, b, c) Olson et al. (1994) MEG Abstract Notes from Feb., 1994 meeting

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
C - 34	"Legend Block" centre T5 R14 W4	Kimberlite indicator anomaly.			As C - 33.	As C - 33.
C - 35	LSD S17 T85 R18 W5 near Carmon Lake	Diamond indicator anomaly.			Consol. Carina press release: 44 pyrope garnets, 14 chrome diopsides and 2 uvarovite garnets; Marchand proposal (more recent than Consol. Carina release): 64 pyropes, 15 Cr-diopsides and 9 uvarovites, garnets have preserved kelphytic rims.	Consolidated Carina Resources Corp. (1993) M. Marchand (1994)
C - 36	T28 R4 W5 (Bow River)	Unusual chemistry in bentonite occurrence.		B-28 bentonite occurrence.	Bentonite has high K2O (4.65%), high Al2O3 (27%) and low CaO (0.85%).	Babet (1966)
C - 37	S33 T48 R21 W5 (Embarass River)	Unusual chemistry in bentonite occurrence.		B-46 bentonite occurrence.	Bentonite has K2O/Na2O ratio = 2.5	Ritchie (1957)
C - 38	SW1/4 S5 T50 R1 W5 (Strawberry Creek)	Unusual chemistry in bentonite occurrence.		B-47 bentonite occurrence.	Contains Fe-montmorillonite tuff.	Ritchie (1957)
C - 39	T17 R28 W4 (Oldman River)	Unusual chemistry in bentonite occurrence.		B-48 bentonite occurrence.	Bentonite has K2O/Na2O ratio = 1.92	Ritchie (1957)
C - 40	LSD4 S1 T9 R22 W4 (St. Mary River)	Unusual chemistry in bentonite occurrence.		B-49 bentonite occurrence.	Bentonite contains a garnet-bearing tuff.	Nascimbene (1963)
C - 41	LSD10 S1 T48 R8 W5 (Pembina River)	Unusual garnet occurrence.			Occurrence of etched spessartine in Cardium Fm. sediments. Garnets are almost pure spessartine (81% spes., 14% alm., 5% pyrope) and are unusually etched.	McMullen (1959)
C - 42	LSD 7 S11 T34 R22 W4 (Red Deer River)	Microdiamond occurrence.			Microdiamonds found in iridium-rich clay near Red Deer R. Dr. Dennis Braman (Tyrell Museum) and Dr. David Castle (Environment Canada) claim diamonds here and in Saskatchewan and USA demonstrate that meteorite impact may have caused K-T extinctions. However, possibility of diatreme source for diamonds as well.	Science City News, (1992b)
C - 43 (Etzikom Coulee)	SE edge T13 R5 W4	Diamond occurrence.			Two gem quality diamonds, weighing 0.14 and 0.17 carats, found by Tom Bryant.	Edmonton Journal, (1992b) Takla Star (1993a)
C - 44 (Pembina River)	Exact location unknown (T53 R7 W5?) 17 km S of Evansburg near Moon Lake, or 3 km S of Entwistle on the Pembina River	Diamond occurrence.			0.85 carat diamond (perfect octahedron) found by Einar Opdahl, presumably in sediment on banks of Pembina River.	Edmonton Journal, (1992a)
C - 45 (Drywood Creek)	T4 R28 W4 at confluence of Drywood Creek and Waterton River	Garnets in Belly River Formation.		Close to P-12 and P-13.	Seven varieties of garnet: colourless, colourless with inclusions, and coloured. Some garnets with distinctive pyrope signatures, eg. 49-Al, 40-Py, 11-An; 42-Py, 32-Al, 26-An	Lerbekmo (1963)

Anomaly Number (General Area)	Location	Nature of Anomaly	Approximate Size	Associated Anomalies	Comments	Source
C - 46 (Ram River)	T37-38 R12 W5	For c-46 to C-53: 0-75% of heavy minerals, non-opaque fraction. Augustus Sandstone contains apatite - its idiomorphic form shows that this mineral is pyroclastic, therefore high values may indicate increased volcanic activity in the region. As well the Augustus sandstones in these wells have relatively high amounts of volcanic material: feldspars and volcanic rock fragments with >40-50% of total detrital fraction in C-52 and C-53; 40-50% in C-47, C-48, C-49 and C-51; <40-50% in C-50.			See Nature of Anomaly column.	Mellon (1967)
C - 47 (Anglo-Can Nabamun Well No. 1)	S10 T51 R4 W5				See Nature of Anomaly column.	Mellon (1967)
C - 48 (Ft. Augustus Well No. 1)	S29 T55 R21 W4				See Nature of Anomaly column.	Mellon (1967)
C - 49 (Elk Point Well No. 1)	S26 T56 R5 W4				See Nature of Anomaly column.	Mellon (1967)
C - 50 (Wabiskaw Well No. 1)	S17 T78 R2 W5				See Nature of Anomaly column.	Mellon (1967)
C - 51 (Lyle Lake Well No. 1)	S2 T72 R17 W4				See Nature of Anomaly column.	Mellon (1967)
C - 52 (West Viking Well No. 1)	S11 T48 R15 W4				See Nature of Anomaly column.	Mellon (1967)
C - 53 (Brook Stanmore Well No. 1)	S22 T30 R11 W4	As C - 46.			See Nature of Anomaly column.	Mellon (1967)
C - 54 (Kimiwan anamaly)		Low O-18 values unexplained by age or lithology.	100 x 250 km	Peace River Arch.	O-18 values (< 5 per mil) thought to be a result of interaction between rocks and surficially derived water in crustal extension zones. This anomaly defines a new extensional zone in the Alberta basement. Possibly a meteoric core complex which straddles the Peace River Arch.	Muelenbachs et el., 1993 Lithoprobe.
C - 55	T46-47 R26-27 W4	Anomalously high Br and Mg in well water.	1,400 mg/l Br and 17,000 mg/l Mg			Govett and Byrne (1958).
C - 56	North half, T72 R4 W4	Diamond indicator anomaly.			Cr - diopside occurrence.	Morton et al. (1993); Takla Star (1993c)

or more, compared with less than 0.02 per cent for most of the province. The CO_2 may be derived from the mixing of low salinity and high salinity brines, which can catalyze bacterial sulphate reduction. Alternatively, the CO_2 may be derived from kimberlite or lamproite diatremes, which are enriched in CO_2, that may exist within the anomalous area.

6.6.3 Marl Anomalies

Unpublished assessment reports on marl occurrences (available at the AGS) and a recently published summary report (McDonald 1982) that describes most of the significant marl occurrences in Alberta, were examined to determine whether or not some of the marl occurrences might provide indirect evidence of kimberlite or lamproite diatreme activity. Kimberlites, and to a lesser extent lamproites, tend to be rich in carbonate minerals. As a result, this literature was examined in order to determine if there might be any association between marl and the weathering of kimberlites or lamproites. In total, there are more than 140 marl deposits of greater than 10,000 tonnes in Alberta. In general, marl deposits form readily in Alberta under current climatic conditions, in areas where groundwater recharges to the surface. The marl deposit data were not usable for this study because it is impossible to distinguish between marls which may have formed from the weathering of carbonate minerals in kimberlites or lamproites and marls which have formed under ordinary climatic conditions.

6.6.4 Platinum Group Elements and Gold in Fluvial Sediments

On a worldwide basis, the occurrence of placer gold and platinum group elements (PGE) is a rarity. Yet, in Alberta, significant amounts of gold and PGE are present sporadically in several widely dispersed stream drainages (Table 6.2). Many of the gold and PGE grains have primary and pristine features that indicate they are proximally sourced. The origin of these elements in Alberta streams is uncertain, but it is possible that they may be derived from kimberlite or lamproite diatremes (Ballantyne and Harris, 1994; Harris and Ballantyne, 1994).

Varying amounts of gold and PGE grains can be found at several sites in the North Saskatchewan River, at and downstream from Edmonton. Gold and PGE grains are also present in several streams in the Foothills of Alberta, including the Pembina, McLeod, Embarrass, Lovett, North Ram, Red Deer and upper North Saskatchewan Rivers, and Baptiste, Prairie and Cripple Creeks (Ballantyne and Harris, 1994; Harris and Ballantyne, 1994). Most of the PGE grains comprise Pt-Fe alloys, with minor Os-Ir-Ru alloys and rare native Pt, hongshiite (PtCu) and sperrylite ($PtAs_2$) grains (Ibid). Numerous inclusions of other PGE alloys are also present in the Pt-Fe grains, with Rh concentrations of up to 7.1 weight per cent. Gold grains range in fineness from 550 to 950, and are alloyed mainly with Ag. Some grains contain mercury, as a thin outer rim, as partial replacement or occasionally as a Au-Hg or Ag-Hg alloy. Rare gold grains appear to be alloyed with Pt and Pd as well (Ballantyne and Harris, 1994).

Primary enrichment of PGE is often associated with chrome spinel segregations in mafic-ultramafic intrusions and ophiolite-type complexes. Many of the chromites which have been recovered from heavy mineral concentrates in Alberta, have chemical compositions that indicate a potentially diamond-bearing kimberlite or lamproite source, and often they display pristine morphologies (Ballantyne and Harris, 1994; Harris and Ballantyne, 1994). In several places in the Foothills, gold or PGE occurrences are coincident with diamond indicator chromite grains. The occurrence of gold and PGE as native grains and complex alloys, often with primary and pristine features, together with the presence of potentially mantle-derived chromites in Alberta, indicates that these elements may be mantle sourced. Nekrasov *et al.* (1990) have documented the occurrence of native gold, intermetallic gold-lead compounds, nickeliferous phases and PGE from the Mir kimberlite in Siberia, and Yeremeyev *et al.* (1990) have documented the presence of native metals and associated alloys from lamproites of the central Aldan Province in the former Soviet Union. In short, it is possible that the alluvial PGE grains which exist in Alberta may act as 'indicator minerals' for kimberlite and lamproite fields, some of which may be enriched in gold, PGE, native metals or diamonds.

6.6.5 Apparent Salt Solution Collapse Features

Solution collapse structures which are commonly believed caused by salt dissolution, are a widespread phenomenon in Alberta. Most of the salt dissolution is associated with the pre-Cretaceous or post-Cretaceous erosional unconformities that exist along the northeast edge of the Alberta Basin. However, there are a number of other anomalous structural features in Alberta that resemble salt solution collapse structures, but are geographically distant from these unconformity edges. Recent work has determined that a number of similar structural features in Saskatchewan are associated with igneous diatremes, and not with salt solution collapse as was previously thought (Gent 1992). Therefore, the possibility exists that diamondiferous kimberlites or lamproites may be responsible for some of the anomalous structures in Alberta that are currently believed to be related to salt solution collapse.

One such anomalous structure exists in the Rumsey area, about 40 km north of Drumheller (site F-54 and F-55 in Figure 2.5 and Table 2.2). In one well in this area (well 3-30-33-19W4), about 77 m of evaporites from the Upper Devonian Wabamun Group have been removed (Oliver and Cowper 1983). Wells as near as 1.5 km have not experienced this salt removal. This thinning has been compensated by 65 m of thickening of Upper Cretaceous shales, with the remaining 12 m accounted for by subsequent shale compaction. The removal of salt took place during deposition of the Late Cretaceous Colorado Group and Milk River Formation. Oliver and Cowper (1983) stated that the salt solution is likely unrelated to basement control, a surface fresh water source or to an unconformity. The lack of cores from wells in the Rumsey area makes it impossible to determine the cause of the salt dissolution, but it is possible that an igneous diatreme may be responsible for this structural feature.

A second anomalous structure exists in northeast Alberta, north of the Primrose Lake Air Weapons Range. Widespread salt solution has taken place in the Lower Devonian Keg River Formation adjacent to the pre-Cretaceous unconformity edge, creating numerous paleo-lows in the area. However, two wells in the area (wells 7-34-73-4W4 and 10-16-75-6W4) show anomalously thin Devonian successions, in which there appears to have been no removal of evaporites (D. McPhee *pers comm.*, 1994). In well 7-34-73-4W4, an 'abnormally thick succession' of high conductivity was also logged (D. McPhee *pers comm.*, 1994). The cause of these anomalous successions is unknown, but it is possible that they are associated with kimberlite or lamproite diatreme activity.

6.6.6 Other Geochemical and Mineralogical Anomalies

Anomalous concentrations of the minor elements Li, Br and I are present within the formation waters associated with various stratigraphic horizons in the Alberta Basin (Hitchon *et al.* 1993). Lithium is present in concentrations of up to 140 mg/l in the vicinity of and to the southeast of the Peace River Arch, within formation waters of Cambrian through Mid Devonian (up to Woodbend Group) strata. Iodine is present in concentrations of up to 128 mg/l in aquifers of the Upper Cretaceous Viking and Belly River Formations in central and southern Alberta. Elevated concentrations of bromine (up to 2,785 mg/l) are present within formation waters of Devonian Beaverhill Lake Group in southern Alberta. The significance of elevated concentrations of these elements is not known, but it is possible that they are related to kimberlite or lamproite diatreme activity within their respective regions.

Selected mineralogical anomalies that may be pertinent to diamond exploration in Alberta are tabulated in Table 6.2. These anomalies include anomalous amounts of favourable garnets in till or other surficial sediments, anomalous chromites reported by industry, bentonites with an unusual chemistry that may indicate associated diatreme activity, and three reported occurrences of diamonds in Alberta (Figures 6.26 and 6.44).

6.7 Geophysical Anomalies

There are a number of aeromagnetic, ground magnetic and gravity anomalies present in the subsurface of Alberta (Table 6.2). These anomalies range in size from a few hundred metres across to as much as 30 km across and 150 km long. Most of the magnetic anomalies are relatively weak, generally less than 100 gammas above or below background levels. Very little is currently known about most of these anomalies, but it is possible that some of them may correspond to kimberlite or lamproite diatremes (Figure 6.44).

A cluster of thirteen circular to elliptical aeromagnetic anomalies (P-7) has been identified in the Legend area, about 50 km southeast of Lethbridge, where two small microdiamonds were found in 1992. Most of these anomalies are less than 2 km across, and may represent the magnetic expression of pipe-like intrusions (Takla Star Resources

Ltd. 1993c). Similar circular to elliptical aeromagnetic features exist in the Pincher Creek - Crowsnest Pass area of southwest Alberta (P-2 tp P-5 and P-8 to P-13), where at least fifteen separate aeromagnetic anomalies have been identified (Olson *et al.* 1994; Takla Star Resources Ltd. 1993a; Steiner 1954). As well, a cluster of twenty-two circular to elliptical aeromagnetic anomalies (P-6) has been identified in northeast Alberta, extending from near the headwaters of the Christina River to the Saskatchewan border (Takla Star Resources Ltd. 1993c). Other magnetic anomalies include an isolated aeromagnetic feature about 800 m across, 50 km south of Turner Valley (Steiner 1954), and an isolated ground magnetic anomaly (P-1) about 500 m long near the border of Banff National Park, about 30 km northeast of Banff, near which chromium-bearing "green and brown silicate rocks" (C-1) have been identified (Renn 1956).

Ross *et al.* (1994b) identified a series of linear aeromagnetic anomalies in southern Alberta, in the same general area as the Legend aeromagnetic anomalies. Some of these linear anomalies extend from known intrusive bodies in the Sweetgrass Hills, and are up to tens of kilometres long, extending from the Canada - United States border to as far north as Lethbridge. The linear anomalies generally trend in a NW-SE direction. Geophysical modelling has determined that these anomalies are relatively shallow, and follow-up ground geophysics has shown that they are not cultural features. Ross *et al.* (1994b) suggested that these aeromagnetic anomalies may correspond to igneous dyke swarms that are related to the Sweetgrass Intrusives, and may be of kimberlitic or lamproitic affinity.

The Trout mountain anomaly (P-14) is a prominent gravity low in north-central Alberta, about 30 km wide and 150 km long. It is believed to represent a microline granite pluton that is flanked by granulite terraces (Burwash and Power, 1989). The relationship, if any, of this anomaly to kimberlites and lamproites is unknown.

7. SELECTED GEOLOGICAL, GEOPHYSICAL AND OTHER ASPECTS PERTINENT TO DIAMOND EXPLORATION IN ALBERTA

7.1 Surficial Geology Pertinent to Diamond Indicator Mineral Sampling

Diamond indicator mineral sampling is an important regional to semi-detailed exploration method. Hence, it is important to have an understanding of the surficial material that is being sampled for such indicator minerals. The following sections provide supplemental data pertinent to sampling the Quaternary and Tertiary unconsolidated to poorly consolidated surficial material that exists within Alberta.

7.1.1 Quaternary Stratigraphy, Glacial Movements, Bedrock Topography and Drift Thickness

There currently exists a broad regional understanding of the Quaternary stratigraphy and history of Alberta in that workers have locally documented multiple glaciations and there is suspicion that some of them are probably early Pleistocene (Barendregt 1991a, Klassen 1989). However, what is lacking throughout much of Alberta is the definition and correlation of lithostratigraphic units on a regional basis. Till units within the Plains region, can be identified and traced or correlated over extensive areas, both on the surface and in the subsurface, on the basis of texture, mineralogy, geochemistry, petrology, stratigraphic position and geophysical log signature. Examples of such correlations of till and other surficial units include those by Andriashek and Fenton (1989), Christiansen (1992), Klassen (1979), Shetsen (1984) and Schreiner (1990). Nonetheless, this definition and correlation of tills has been done in a detailed way for only a few areas in Alberta. The reason is that throughout much of Alberta (about 95%) the major proportion of the Quaternary stratigraphic sequence is buried beneath other surficial materials and the stratigraphic data are restricted to information from 'stratigraphically poor quality' holes drilled for purposes other than the Quaternary stratigraphy; that is, for either groundwater or petroleum exploration. Subsurface correlation, when done, usually focuses primarily on the geophysical log signature of the till units. These logs, although very useful for correlation, are used primarily to differentiate till units from other stratified units, but they generally are not able to distinguish between individual till units except within specific study areas. The more expensive lithologic analyses of core or cuttings that are needed to establish the lithostratigraphic units have been done in even fewer areas. As well, the lack of dateable material from between or below the till layers has also hampered correlation efforts.

Multiple glacial advances have been interpreted from the stratigraphic sections exposed in a number of areas of Alberta. However, the age of these advances and the synchronaiety with those recognized at other sites within and without the province, are still under debate. Papers that discuss the Quaternary stratigraphy of Alberta include those by Bobrowsky and Rutter (1992), Clague (1989a), Fenton (1984), Fenton *et al.* (1994b), Jackson *et al.* (1989), Klassen (1989), Shetsen (1984), and Stalker and Vincent (1993). A review and synthesis by Fullerton and Colton (1986) that focussed on the Quaternary stratigraphy of the adjacent Montana Plain includes a discussion of the correlations with the Quaternary units in adjacent areas of Alberta and Saskatchewan. The paper by Clayton and Moran (1982) focuses on the North Dakota, Minnesota, Manitoba and Saskatchewan region.

In general, the glaciers advanced over Alberta from: (1) the northeast or north which is commonly referred to as the Laurentide source, and (2) the west, which includes Cordilleran and Rocky Mountain sources. The latter two have distinctly different source areas. That is, the Cordilleran ice flowed eastward from the interior of British Columbia, hence bringing material from west of the Rocky Mountain Trench, whereas the Rocky Mountain or Montane ice is that which originates within the Rocky Mountains and flowed eastward onto the plains. The advances of both the Cordilleran and Rocky Mountain glaciers were comparatively weak, with the ice maximum extending only to the margin of the plains.

Figure 7.1 shows the ice-flow directions indicated by the surface features in Alberta. The flow of the Laurentide glaciers was generally toward the southwest or south, but in places other flow directions exist. For example, local re-advances occurred that were transverse to this regional flow direction, such as the narrow southeastward flow east of Edmonton near the Saskatchewan boarder which is so prominent on Figure 7.1. As well, the earlier Laurentide advances did not necessarily parallel the last one. In the Cold Lake region east of Edmonton on the Alberta-Saskatchewan border, for example, the glacial advance (Early Wisconsinan?) which preceded the Late Wisconsinan advance, flowed southward and deposited a till that has a strikingly different composition (clasts, matrix and geochemistry) and clast fabric than the overlying Laurentide till (Andriashek and Fenton, 1989).

The flow of both the Cordilleran and Rocky Mountain glaciers was influenced, within the mountains, by the presence of valleys and low passes between valleys. Those valley glaciers which reached the Foothills and Plains spread out to form piedmont glaciers until they were deflected southward by intersection with the Laurentide glaciers. The interaction between the Laurentide and Cordilleran-Rocky Mountain glacial advances is complex and not well understood. The reader is referred to papers by Bobrowsky and Rutter (1992), Clague (1989a) and Jackson *et al.* (1989) to obtain the current understanding of this Continental versus Cordilleran glacial interaction (also see the proceedings from the GAC94 Special session on the "Laurentide Cordilleran overlap: The ice free corridor revisited", which is in preparation).

In general, the majority of the eastward glacial advances came from Rocky Mountain sources. Ice from Cordilleran glacial centers flowed over and east of the Rocky Mountains only a few times, and from only two or three valleys (Bobrowsky and Rutter 1992). In the area north of Jasper National Park there is a zone in which the tills and related sediments may include a mixture of montane and Laurentide materials (horizontally hachured on Figure 7.1). The most recent Cordilleran glacial event was the valley glacier that flowed out of the Athabasca Valley and was deflected southeastward by and became confluent with the Laurentide glacial ice. This flow of mixed Cordilleran and Laurentide ice along the eastward margin of the Foothills formed the Athabasca Valley erratics train and Foothills erratics train (Figure 7.1) (Roed *et al.* 1967; Roed 1975; Mountjoy 1958; Stalker 1956) The Foothills erratics train is characterized by abundant quartzite boulders and extends from the Athabasca Valley southeastward almost to the border with the United States, and perhaps on into Montana. The Athabasca erratics train is characterized by clasts of metamorphic rock (talcose schist, garnet schist, biotite-quartz schist, and hornblende gneiss) from a source west of the Rocky Mountain Trench (Roed *et al.* 1967; Roed 1975). This train was thought to be confined to a lobe that extended only eastward into the Hinton area (Figure 7.1), although it may have been a sublobe of the ice that formed the Foothills erratics train (Roed *et al.* 1967). However, Boydell (1972 and 1978) who studied the Quaternary geology of the Rocky Mountain House map-areas, southeast of the Hinton area, records a few low grade metamorphic clasts within his Athabasca Till. The Athabasca Till is a southeastward trending unit

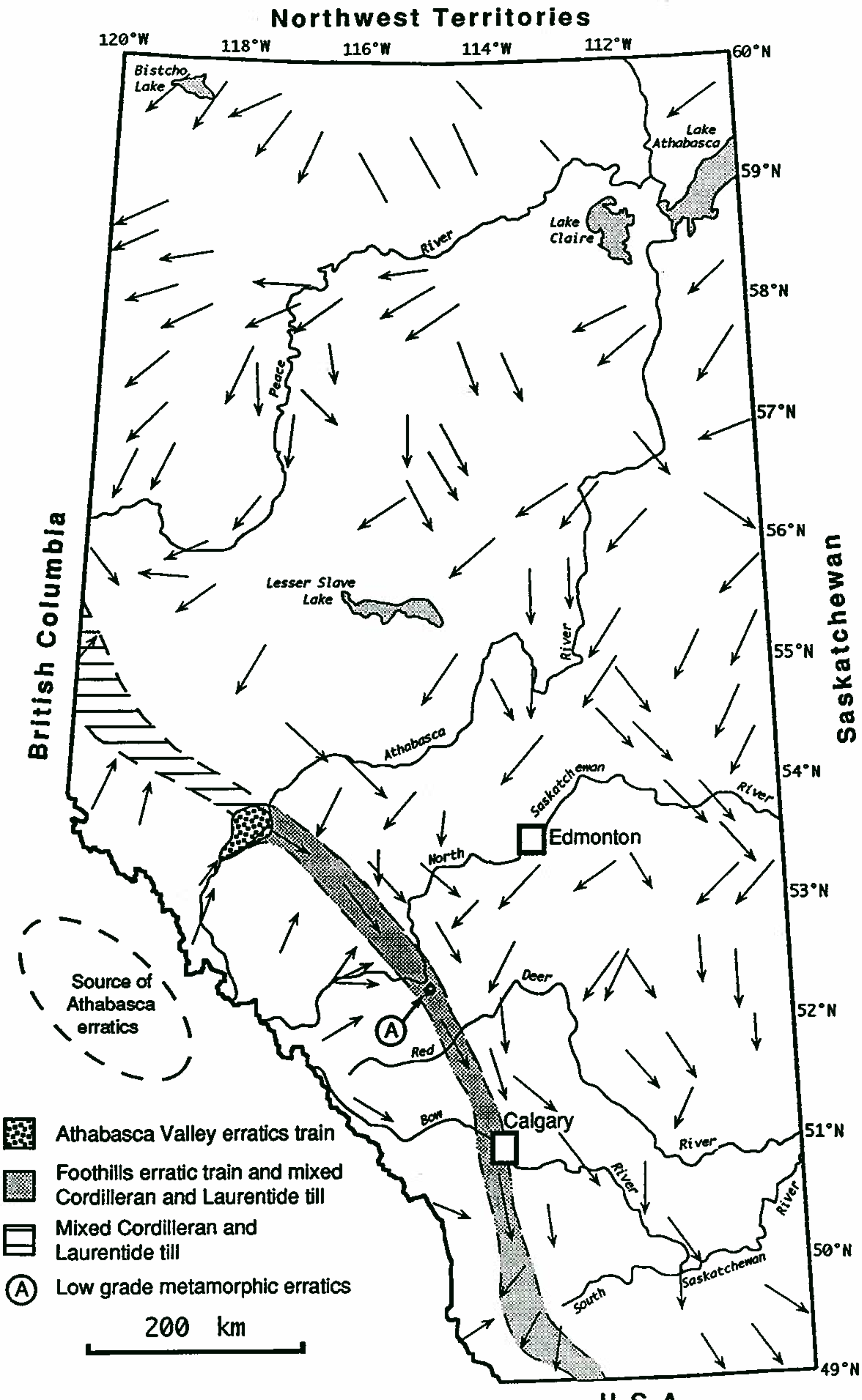


Figure 7.1. Glacial flow directions.

composed of till with a mixed Cordilleran and Laurentide provenance and including the Foothills erratics train. This suggests the low grade metamorphic clasts of the Athabasca erratics train may have been carried at least this far south.

Before discussing the bedrock topography and drift thickness maps, a few comments on the current land surface topography are required because the bedrock topography has strongly influenced the present surface topography, particularly the positive features.

The Alberta portion of the Interior Plains slopes toward the north and east from elevations of 1,200 m in the Foothills, adjacent to the Rocky Mountains, to 200 m adjacent to Lake Athabasca. Broad features such as the Alberta Plain and the Peace River Lowlands, to the north, are cut by major drainageways such as the Peace, Athabasca, North Saskatchewan, Red Deer and South Saskatchewan Rivers. Major topographic highs include the Cypress Hills, Hand Hills, Swan Hills, Pelican Mountains, Buffalo Head Hills, Clear Hills, Naylor Hills, Milligan Hills, Birch Mountains, Caribou Mountains, and the highland in northwest Alberta which comprises the Cameron, Elsa and Bootis Hills (Figure 7.2). Additional information about Alberta's present surface topography can be found in Bostock (1970 a, b) and Klassen (1989, Figure 2.16) and Pettapiece (1986).

The bedrock topography and drift thickness maps for Alberta are shown in Figures 7.3 and 7.4 (These maps have been updated and modified from similar figures in Fenton *et al.* 1994b). The maps were produced for the southern portion of the province by digitizing the contour lines from the Alberta Research Council 1:250,000 scale Bedrock Topography Series (Figure 7.3). Data for the northern portion of the province was obtained from the ARC Groundwater Map Series, where they existed, as each map includes four cross sections, and for all of northern most Alberta, from picks from a few selected water and petroleum wells. These data were then hand contoured.

The bedrock topography is drawn on the surface of the bedrock that underlies the unconsolidated sediment of Quaternary age and, mainly in the deep portions of the preglacial channels, unconsolidated sediment of Late Tertiary age. The thalwegs of the preglacial channels are shown in gray. Figure 7.3 shows, particularly in the northern half of Alberta, only the broad regional trends, hence the map is not recommended for site specific information.

The bedrock surface contours decrease from about 1,220m in the foothills to slightly more than 200 m near the margin of the Precambrian Shield (Figure 7.3). There are three basic topographic elements: (1) the broad generally northeastward and eastward trending valleys, (2) uplands formed by erosional bedrock remnants, and between these two elements, (3) broad relatively level interfluve areas. Many of the positive landforms which are shown on the surface topography map, are bedrock controlled. For example, bedrock highlands contribute significantly to Cypress Hills, Swan Hills, Pelican Mountains, Buffalo Head Hills, Clear Hills, Naylor Hills, Milligan Hills, Birch Mountains and the Caribou Mountains. However, in the vicinity of the upland that includes the Cameron, Elsa and Bootis Hills (Figure 7.2), the bedrock high is much less extensive than the upland.

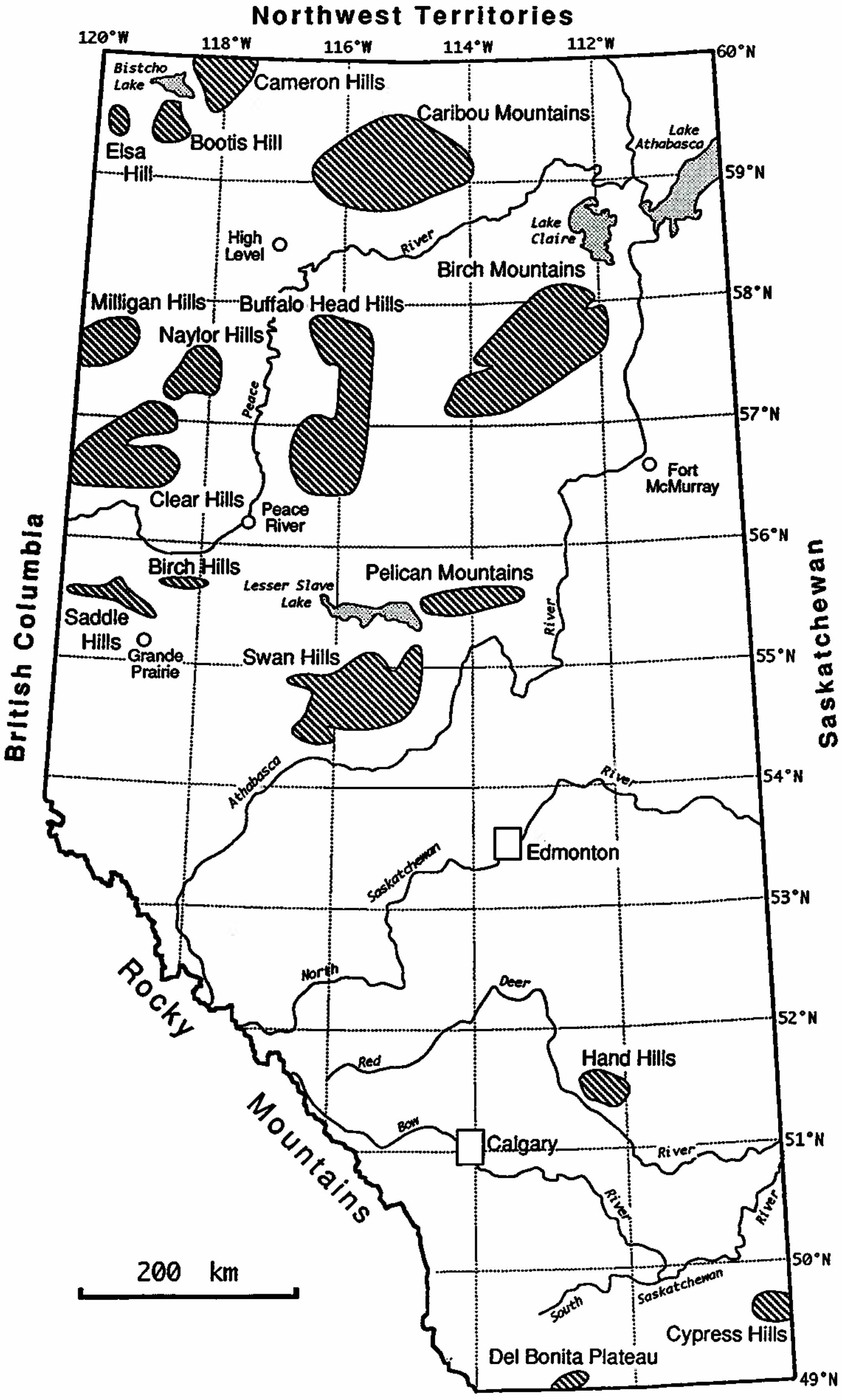


Figure 7.2. Location of major topographic features.

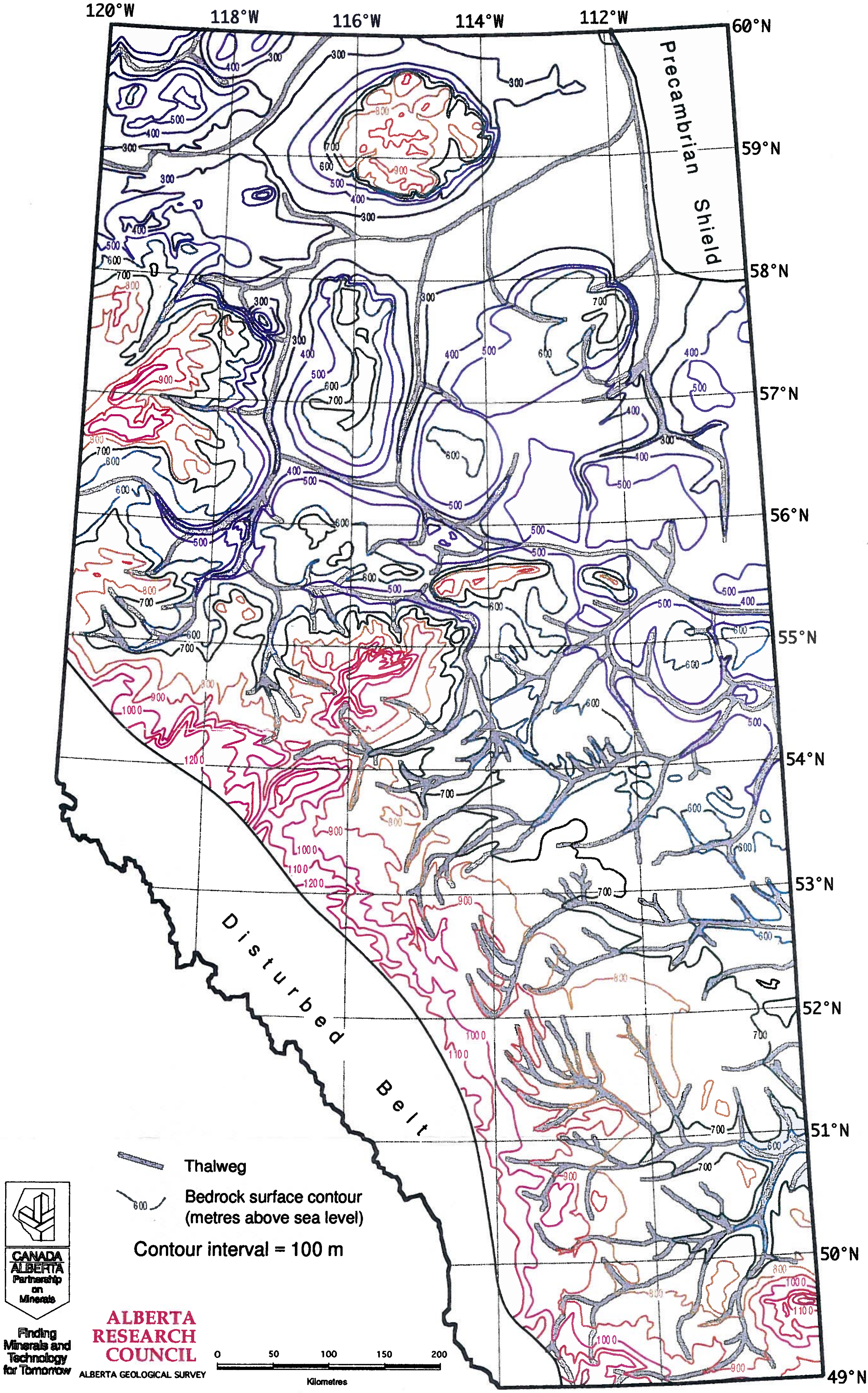


Figure 7.3. Bedrock Topography Map of Alberta

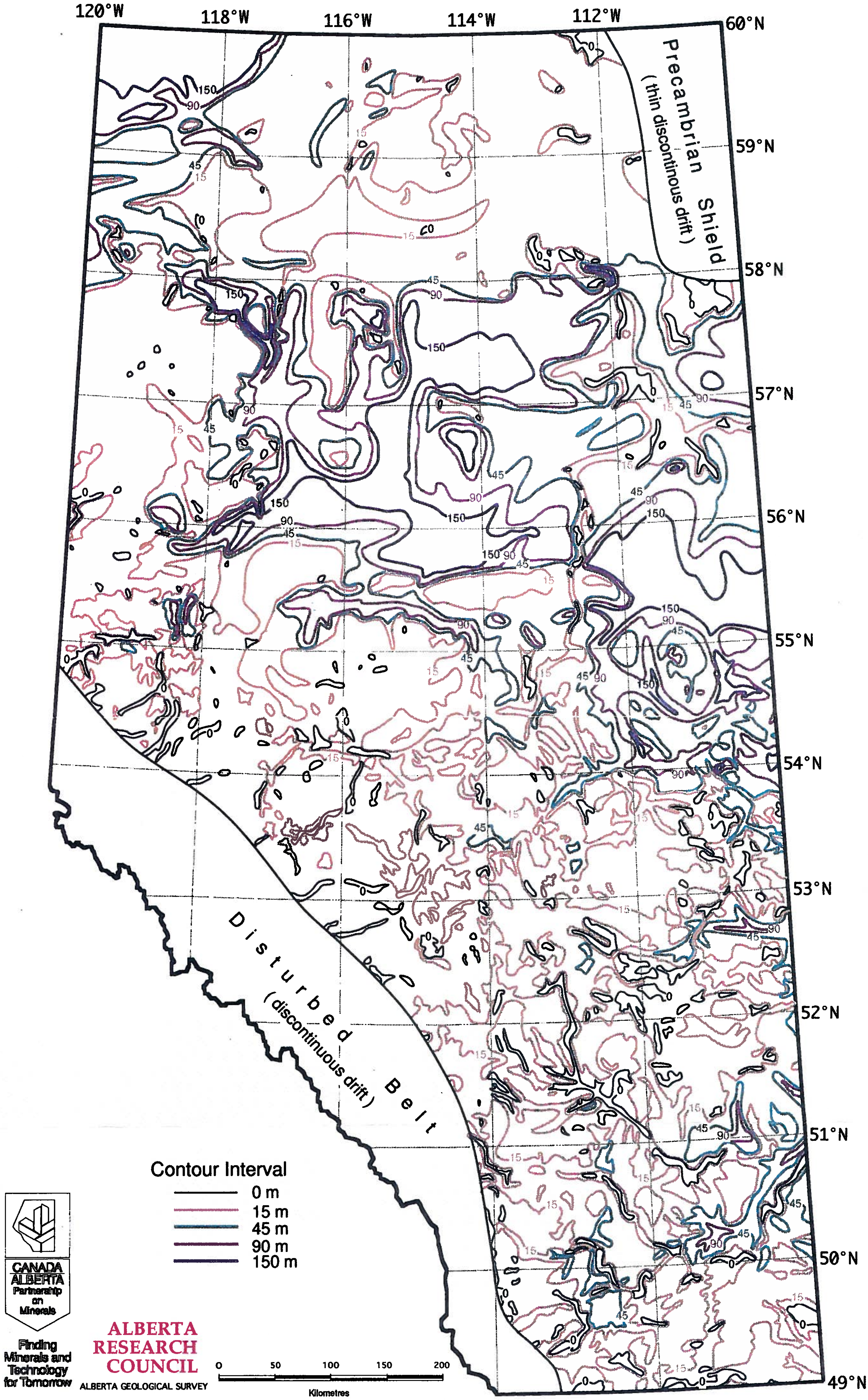


Figure 7.4. Drift Thickness Map of Alberta

The topographic lows, shown in dark shades, are primarily the major preglacial valleys. These valleys were eroded during preglacial time because they contain preglacial sediment at the base of the valley fill sediment. In some areas, deep interglacial valleys which contain sediment with clasts from the Precambrian Shield at their base, are also present. The interglacial valleys tend to be narrower than the preglacial valleys, although they are often superimposed on the broader preglacial valleys. All these valleys are deepest and, therefore, most easily recognizable on Figure 7.3 in central and northern Alberta. These features generally trend northeastward or eastward.

Figure 7.4 shows the thickness of unconsolidated sediment overlying the bedrock and includes sediment of both Late Tertiary and Quaternary Age, although Quaternary sediment comprises the major proportion of the sequence. The Tertiary sediment included in the map unit is confined largely to the lower portions of the preglacial channels. This combination of Tertiary and Quaternary map units was chosen since deposition, within the valleys, was more or less continuous from the close of the Tertiary into the Quaternary. That is, the deposition of nonglacial fluvial sediment continued until the preglacial drainageways were first blocked by the earliest glacial advance to reach a particular region. Late Tertiary sediments are also present in other areas of the province and the accompanying section on the Tertiary provides information on this. The first stratigraphic marker that positively identifies Quaternary sediment, at any particular site, is the stratigraphically lowest appearance of till and/or stratified sediment containing material transported westward and/or southward by the advancing Laurentide glaciers. This Laurentide-derived material is typically from the Precambrian Shield and/or the adjacent Paleozoic belt of carbonate outcrop.

Figure 7.4 shows only the regional trends in drift thickness in Alberta. Local areas where the sediment may be comparatively thick or thin cannot be shown and, therefore, the map is unsuitable for obtaining site specific information. The data which were used to prepare this map, indicate that sediment thickness varies from 300 m in a few preglacial valleys to zero on some of the interfluves and highlands. The most prominent feature on Figure 7.4 is a broad northwest-southeast trending band of thick sediment (>150 m) across northern Alberta. Areas where the sediment is thin or absent, however, include the Swan Hills, Clear Hills, Milligan Hills, central and eastern Alberta north of latitude 58°N, and most of the southern half of the province. As well, in many areas the preglacial channels, both shallow and deep, have been substantially infilled, thus lowering the local relief on the present land surface.

Factors influencing the location of thick accumulations of sediment are primarily: (1) the preglacial valleys, (2) bedrock highlands, (3) areas of ice marginal stillstands, and (4) bedrock contacts or scarps. An example of thick sediment accumulation in a preglacial channel is the broad east-southeast trending low shown in east-central Alberta (Figure 7.4, Long. 110 to 112°W and Lat. 55° to 56°N). These preglacial valleys influenced later sedimentary deposition in a number of ways: (a) they acted as sediment traps, accumulating thick sequences of stratified sediment as the advancing or retreating glaciers dammed the eastward flowing streams, (b) they influenced glacial dynamics, contributing to the accumulation and preservation of comparatively thick sequences of till within them, (c) during the nonglacial intervals, they formed lows favourable to the deposition of stratified sediment, and (d), because of their low position in the landscape, they tended to preserve the existing sediment from erosion during subsequent glacial advances.

Examples of the influence of bedrock highlands are the Birch Mountains, Buffalo Head Hills and the Naylor Hills. Thick accumulations of sediment were deposited on each by the southward and westward flowing glaciers. The effect of deposition at an ice marginal stillstand is shown by the Cameron-Elsa-Bootis Hills upland in northwestern Alberta, which are believed to be composed of a thick sequence of Quaternary sediment rather than the draping of a bedrock upland.

Bedrock contacts or scarps are areas where glaciers deformed the bedrock and stacked comparatively thick accumulations of thrust bedrock and glacial sediment. The Neutral Hills, Misty Hills and Mud Buttes in central eastern Alberta, as shown in Green (1972), are other examples of glaciotectonism. These three thrust masses were formed at the contact of the Belly River and Bearpaw Formations.

Areas where thick drift has accumulated are areas where multiple tills can be expected. The down cutting by the South Saskatchewan and Oldman Rivers in southern Alberta of the moderately thick drift has revealed some of the best exposures of the Quaternary stratigraphy in the province. Stratigraphic studies in the Sand River and Winifred area (Long. 110°to 112°W, Lat. 54° to 56°N) has revealed a complex stratigraphy that includes four widespread till units (Andriashek and Fenton 1989).

7.1.2 Preglacial Sand and Gravel Deposits

The three primary categories of sand and gravel deposits in Alberta are: (a) Recent fluvial (river) deposits (Figure 7.5, Unit 8), (b) Pleistocene glaciofluvial deposits (Figure 7.5, Unit 7), and (c) Tertiary/Quaternary fluvial deposits (Figure 7.5, Units 2, 3, 4 and 5). These three categories of sand and gravel can be distinguished by their different mineral and rock suites, and by their stratigraphic relationships.

The history of transport of the heavy minerals and rocks into the Recent river deposits may be quite varied and highly complex. The sources of the minerals and rocks which exist in the river deposits, include local bedrock, Laurentide glacial deposits and the Tertiary/Quaternary (preglacial) deposits. The preglacial sources includes bedrock exposed in the Foothills and Rocky Mountains.

Pleistocene glaciofluvial deposits on the Albert Plains are irregularly distributed. They may contain significant concentrations of heavy minerals, such as, for example, garnets derived from the Canadian Shield. The mineral and rock suites in Pleistocene

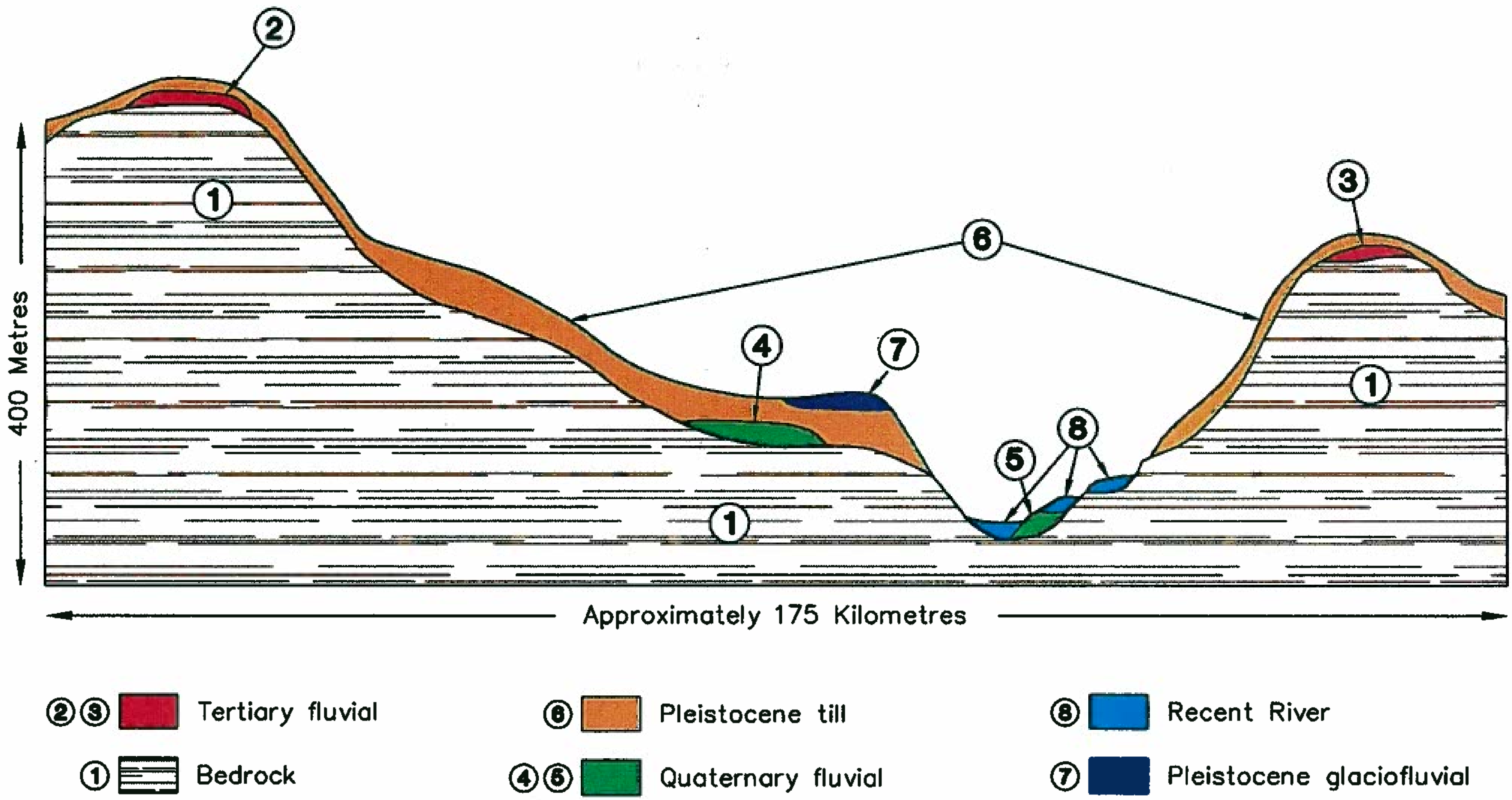


Figure 7.5: Schematic cross section of sand and gravel deposit distribution.

glaciofluvial deposits are represented by material derived from the local bedrock, from up-ice bedrock or drift, and from Tertiary/Quaternary (preglacial) deposits.

The Tertiary/Quaternary or preglacial deposits are useful in indicator mineral exploration because they tend to have a less complex transport history. That is, the source direction of the minerals is generally from the west, the result of drainage from the mountains across the plains prior to continental glaciation. To a great extent, the bedrock topography of the Alberta plains (Figure 7.3) is the result of the fluvial erosion which took place over a span of about 50 million years from the early Tertiary to the late Quaternary.

The oldest preglacial sand and gravel deposits (Unit 4 on Table 7.1; Units 2 or equivalents on Figure 7.5) are located on the highest hills on the plains (Figures 7.3 and 7.6). This phenomena is the result of uplift which exceeded the rate of erosion and carried the earliest deposits to the highest elevations. Examples of topographic highs capped by sand and gravel deposits are the: Cypress Hills, De Bonita Uplands (east), Obed Mountain and Swan Hills. The Cypress Hills Formation is believed to be Oligocene in age and the Swan Hills to be Oligocene (Dawson *et al.* 1994).

Gravel petrologies can be used to separate or group deposits. For example, the Swan Hills gravel is primarily quartzite, Obed Mountain gravel is mostly hard sandstone, and the De Bonita Uplands (east) deposits are about one-third red/green argillite. Table 7.1 shows the groupings of deposits which have similar compositions. The grouping indicate common source areas for some deposits. A unifying characteristic of all preglacial deposits is the absence of any igneous or metamorphic rocks of obvious Canadian Shield origin.

Deposits of younger age which cap hills or highlands, but with more modest elevations include: the Pelican Mountains, Halverson Ridge, Whitecourt Mountains, Hand Hills, Wintering Hills, and the Del Bonita Uplands (west)(Figures 7.3 and 7.6; Unit 3 in Table 7.1 and Unit 3 or equivalents in Figure 7.5). The Hand Hills deposits are estimated to be Pliocene in age.

The third distinctive level of preglacial deposits occurs at or slightly above plains level (in Table 7.1, Unit 2) and includes deposits at: Grimshaw, Smoky Tower, Entwistle, Magnolia, Lacombe, Nanton and Arrowwood (Figure 7.6). The age of these deposits is unknown, but is certainly younger than the Hand Hills equivalents (Miocene-Pliocene) and older than the Saskatchewan Sands and Gravels (late Pleistocene).

The youngest of the preglacial deposits (Units 4 and 5 in Figure 7.5; Unit 1 in Table 7.1) are often referred to as the Saskatchewan Sands and Gravels. Deposits belonging to this unit are seen on the Simonnette River, at Watino on the Smoky River and at Villeneuve (Figure 7.6). Dates on wood or bone found in these deposits gives ages between 35,000 and 22,000 years before present, hence they are of Pleistocene age. These deposits occur in topographically low areas and typically occur within the thalwegs of the buried valleys of the province (Figure 7.3).

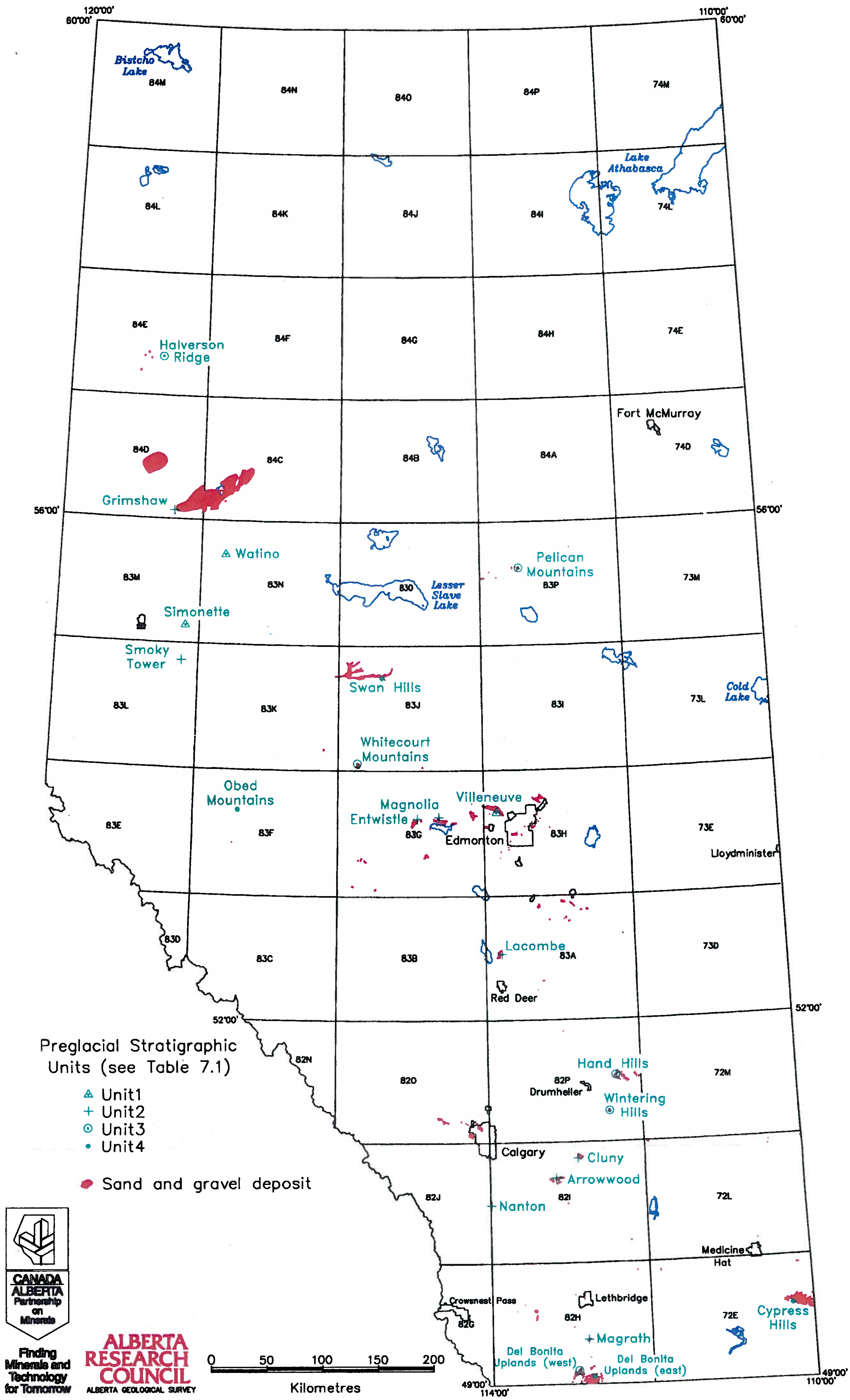


Figure 7.6: Preglacial sand and gravel deposits in Alberta.

TABLE 7.1 Preliminary stratigraphic grouping of preglacial deposits.

	Group 6	Group 5	Group 4	Group 3	Group 2	Group 1
Unit 1 Saskatchewan Sands & Gravels	Simonette Watino		Villeneuve			
Unit 2 Upland Gravels	Grimshaw	Smoky Tower	Entwistle Magnolia Wabamun Heatherdown	Wetaskiwin Lacombe	Olympic Hill Cluny Nanten	Magrath
Unit 3 Hand Hills Fm. Equivalent	Halverson	Pelican	Whitecourt		Hand Hills Wintering Hills Arrowood	Del Bonita (west)
Unit 4 Cypress Hills Fm. Equivalent		Swan Hills	Obed			Del Bonita (east)

The various preglacial (Units 2, 3, 4 and 5 in Figure 7.5) are now overlain, in whole or in part, by Pleistocene till, Pleistocene glaciofluvial deposits and Recent river gravels (Units 6, 7 and 8, respectively, in Figure 7.5).

Sand and gravel deposits are an excellent medium from which to take diamond indicator mineral samples because fluvial processes have eliminated much of the silt and clay, and concentrated the heavier minerals. However, it is important when sampling sand and gravel to determine the age and genesis of the deposit because the transport histories and sources of the minerals can vary greatly between the three ages of granular deposits (Tertiary/Quaternary, Pleistocene and Recent) that predominate in Alberta. Therefore, indicator mineral tracing which is based on sampling Recent river and Quaternary glaciofluvial deposits, requires an understanding of the river basin drainage, glacial stratigraphy and ice transport directions, and the Tertiary/Quaternary preglacial fluvial transport.

A recent (1992-1993) program which was carried out by the Alberta Geological Survey, has sampled various preglacial sand and gravel deposits throughout Alberta (Figure 7.6). The following is a preliminary discussion of the locales which were sampled that pertain to diamond exploration; results of this sampling have been discussed in Section 6. Samples from unit 4 (Table 7.1) at the Cypress Hills and Obed Mountain were processed for diamond indicator minerals, but no grains of interest were identified. Samples from Unit 4 (Table 7.1) at the Del Bonita Uplands (east) and Swan Hills are currently being analysed. Samples from unit 3 (Table 7.1) at Whitecourt Mountain's and the Wintering Hills were submitted for indicator mineral processing, but no indicator minerals were identified. Samples from Unit 3 (Table 7.1) at the Pelican Mountains, Halverson Ridge and the Hand Hills are currently being processed and analyzed. Indicator minerals were also not identified in samples collected from Unit 2 (Table 7.1) at Smoky Tower, Magrath, Lacombe or Cluny. However, 37 chrome diopside grains were picked from a sample from the Unit 2 Grimshaw deposit and 3 of these 37 grains were analyzed by Electron Microprobe (Appendix 2). Four chromite grains were picked from a sample from Unit 2 at Entwistle and a sample from Unit 2 at Magnolia Scanning Electron Micro Probe (Appendix 2). Indicator minerals were not picked from a sample from Unit 1 at Watino, but five garnets and a chromite were picked, and then microprobed from samples from Unit 1 at Villeneuve (Appendix 6.1).

7.2 Geophysical Methods

7.2.1 Introduction

The broad scale geophysical features of the crust and lithosphere which are of relevance to the explorationist in locating regions most likely to be intruded by volcanism were discussed in Section 5. Once a locale which satisfies the large scale criteria has been recognized, exploration geophysics can then play a two-fold role in both (a) the widespread detection of possible targets, and (b) in the subsequent detailed delineation and evaluation of the located prospects. This section includes a description of the bases behind the geophysical techniques that have been most commonly used in the geophysical exploration for kimberlites. Additionally, for each method a number of case studies from other locales which may be relevant to the situation in Alberta, are reviewed. It must be noted that there is surprisingly little in the way of original case history studies described in the open and easily available literature (Atkinson 1989).

An important initial point in the geophysical exploration for kimberlite and lamproite diatremes is that they are structurally complex (Macnae 1979). In general, their surface expression is broadly distinguished by conical eroded bodies or vents. With respect to the kimberlite diatremes or breccia pipes, their subsurface configuration is characterized as being 'carrot' shaped with depths of 2 to 3 km (Nixon 1980a). In contrast, the lamproite vents are not as deep and they have a vertical extent of only 500 to 1,000 m, hence their shape has been classified as that of a 'champagne glass' or 'funnel' by Mitchell and Bergman (1991). This difference in shape between kimberlites and lamproites is attributed to greater amounts of gases within the kimberlites, but other factors such as the magma viscosity may play a role. From the perspective of geophysical investigations, however, the structure must be considered in terms of the various physical properties of the materials. Hence, under this stipulation it may be useful geophysically to characterize kimberlite and lamproite diatremes in terms of (1) the deep root zones, which comprises intrusive dykes consisting of competent crystalline rock, (2)2 the diatreme or vent, which consists of heterogeneous tuffs and breccias, and (3) the surface crater which often is infilled at later times by sediments. The geophysical properties of all of these materials may further be changed by weathering processes, that across Alberta, can be highly variable, with dry semi-arid conditions in the south and wetter environments in the muskeg regions in the north. A further complication is that erosion could also have removed much of the upper parts of the conical vent material or the upper parts of the pipe-like diatreme. As a result, different exploration strategies may be called for in differing locales.

Regional searches for vents can be difficult due to the fact that often the diatremes are not large, being only a few hectares in surface area and typically having cross-sectional diameters of less than 500 m (e.g., Nixon 1980a). As a result, regional airborne geophysical surveys with a line spacing of only a few hundred metres could easily miss those portions of a vent that provide the highest signal . In such a case, the diatreme may not readily be seen in the final plotted versions of the geophysical data and could hence be missed by the explorationist.

7.2.2 Geophysical Exploration Methods - A Review

Below, the different geophysical techniques which might be employed in the direct detection of anomalies indicative of potentially diamondiferous diatremes, are briefly described. The intent is to provide an overview rather than a detailed treatise, hence the reader is referred to the listing of introductory and advanced texts in the field of geophysical exploration which is given in the references, (Dohr 1974; Dobrin and Savit 1988; Robinson and Coruh 1988; Beaumont and Foster 1989; Milsom 1989; Kearny and Brooks 1991) for more details as to the means of data acquisition, data processing, analysis and interpretation. Additionally, updated reviews of the latest trends in geophysical exploration, especially as it relates to technological developments by various contractors with special focus on the mining industry, are regularly published by the Canadian Mining Journal (Kileen 1994).

Magnetic and gravity data are available for purchase from the Geological Survey of Canada[1] at a variety of scales, although the surveys in some areas are proprietary prior to release over the next few years. Alternatively, there are a number of vendors and brokers of proprietary gravity, magnetic and seismic data for Alberta. These companies may be found under the headings of Geophysical Brokers, Geophysical Contractors or Geophysical Services in the Calgary Yellow Pages telephone directory.

[1] GSC/Geophysical Data Centre, 1 Observatory Cres., Ottawa, Ontario, (613)995-5326.

7.2.3 Magnetic Methods

Background Information

The magnetic method of geophysical prospecting is sensitive to variations in the strength of the earth's magnetic field due to the existence (or lack) of rock containing magnetic minerals. The most important rock physical property in this respect is the magnetic susceptibility, which is a measure of ability of the material to change, via its own induced field, the strength of the ambient field within which it resides. In the case of geophysical exploration this ambient field is that of the earth. In general, the higher the magnetic susceptibility of the material, the larger the increase in the final measured magnetic field strength.

Other factors to consider in magnetic exploration are the dimensions of the body and the distance away from the body the actual measurements are made. The larger the magnetic body and the closer to the body the measurement is made, the more intense is the observed signal. A corollary of this is that the magnetic anomaly mapped contours will increasingly resemble the shape of the body the nearer in proximity to the body the measurements are made (after accounting for additional affects of the magnetic field orientation and remnant magnetization). The results obtained from an aeromagnetic survey must consequently be lower in magnitude and less distinct than what would be seen in a comparative ground magnetic survey; and the higher the elevation at which the survey is obtained the more smoothed will be the final mapped contours.

For almost all purposes, the rock forming mineral magnetite has by far the highest magnetic susceptibility. As a result, the magnetic susceptibility of a given rock sample is strongly dependent on the concentration of magnetite in the rock (Telford *et al.* 1976), although ilmenite has a sufficiently high susceptibility to be important in some cases. Both magnetite and ilmenite are accessory minerals in igneous rocks, including kimberlites and lamproites. Typical mafic igneous rocks, such as gabbro, basalt and diorite have average magnetic susceptibilities near 7.5×10^{-2} (dimensionless S.I. units), which is more than 4 times that for average acidic igneous rocks and at least 50 times that for typical sediments with magnetic susceptibilities near 10^{-4}. Atkinson (1989) reported magnetic susceptibilities of kimberlite that range from 10^{-4} to 10^{-1}, but more typically lie between 1.25×10^{-4} and 1.25×10^{-1}. In contrast, lamproites have smaller, but still significant susceptibilities of 2.3×10^{-3} to 2.3×10^{-2} with an average of 8×10^{-3}. Janse *et al.* (1986), who measured susceptibilities on alkaline ultramafic cores in Ontario, found they range from approximately 10^{-3} to 2×10^{-2}. Litinskii (1963) provides a range of kimberlite susceptibilities from 1.2×10^{-3} to 7.2×10^{-2}, which corresponds to magnetite modes of 1 to 8%. Concentrations of magnetite are typically much lower in metamorphic rocks and, for most practical purposes, nonexistent in many sedimentary rocks.

Magnetic Exploration for Diatremes in Sedimentary Terranes

Dykes and sills of fresh hardebank kimberlite should provide a strong contrast of magnetic susceptibilities relative to the much lower values for sedimentary rocks. As a result, if fresh unweathered kimberlite dykes are present they should appear as a large magnitude anomaly in a contour map of the total magnetic field. The surrounding breccias and tuffs, however, are a melange of both the original igneous magma and the surrounding country rocks, and this highly heterogeneous material may not have a significant magnetic response. Furthermore, if the kimberlite has been weathered such that the magnetic minerals are destroyed, then the magnetic response also will be severely attenuated (Macnae 1979).

Since the surface of most of Alberta is covered by sedimentary rocks, studies carried out in other geologically and topographically similar locales will be of the most interest. The bulk of the published studies describe magnetic responses of kimberlites or lamproites intruding through sediments. Indeed, it is rare in any of the studies to encounter a case where the final results of a given geophysical mapping were not directly compared to the magnetic response over the same area.

Arkansas and Kansas: Gerryts (1970) summarized earlier studies at a number of locales, including reference to the earliest study of Stearn (1932) who observed a large anomaly of 2,000 nanoTeslas (nT; 1 nanoTesla equals 1 gamma) over the 30 ha Prairie Creek peridotite near Murfreesboro, Arkansas. The Prairie Creek pipe has been the site of the only commercial diamond mine in North America, but is now a state park where visitors can search for diamonds for a fee. This pipe is now considered to be a lamproite diatreme. Bolivar and Brookins (1979) characterized the geology of this area as consisting primarily of gently dipping sediments with little surface expression. They conducted a ground magnetic survey with lines spaced at intervals of 30 m to 150 m with a magnetometer accurate to $\pm$1 nT, and found two locally high regions, one of which had an anomaly of greater than 1,200 nT. The magnetic contours generally follow, but do not exactly delineate the outcropping portions of the diatreme (Figure 7.7).

Coopersmith and Mitchell (1989) described exploration procedures used in the study of two known Cretaceous diatremes, called the Rose and Hill's Pond lamproites, which are in Kansas approximately 500 km to the north of the Prairie Creek diatreme in Arkansas. These Cretaceous Kansas diatremes intrude flat-lying limestones, sandstones and shales of Pennsylvanian age. An aeromagnetic survey was carried out over a 20 km^2 area that encompassed known lamproites, with flight lines at an 800 m spacing and at an unspecified flight altitude. The success of the program was ambiguous because the Hill's Pond lamproite could not be detected and the Rose lamproite provided a weak anomaly of 10 nT; as well, no new vents or diatremes were discovered. Ground magnetic surveys were also unable to delineate any anomaly over the Hill's Pond diatreme, but did yield anomalies as high as 80 to 150 nT anomaly at the Rose lamproite over an elongate area with dimensions of approximately 500 m by 250 m.

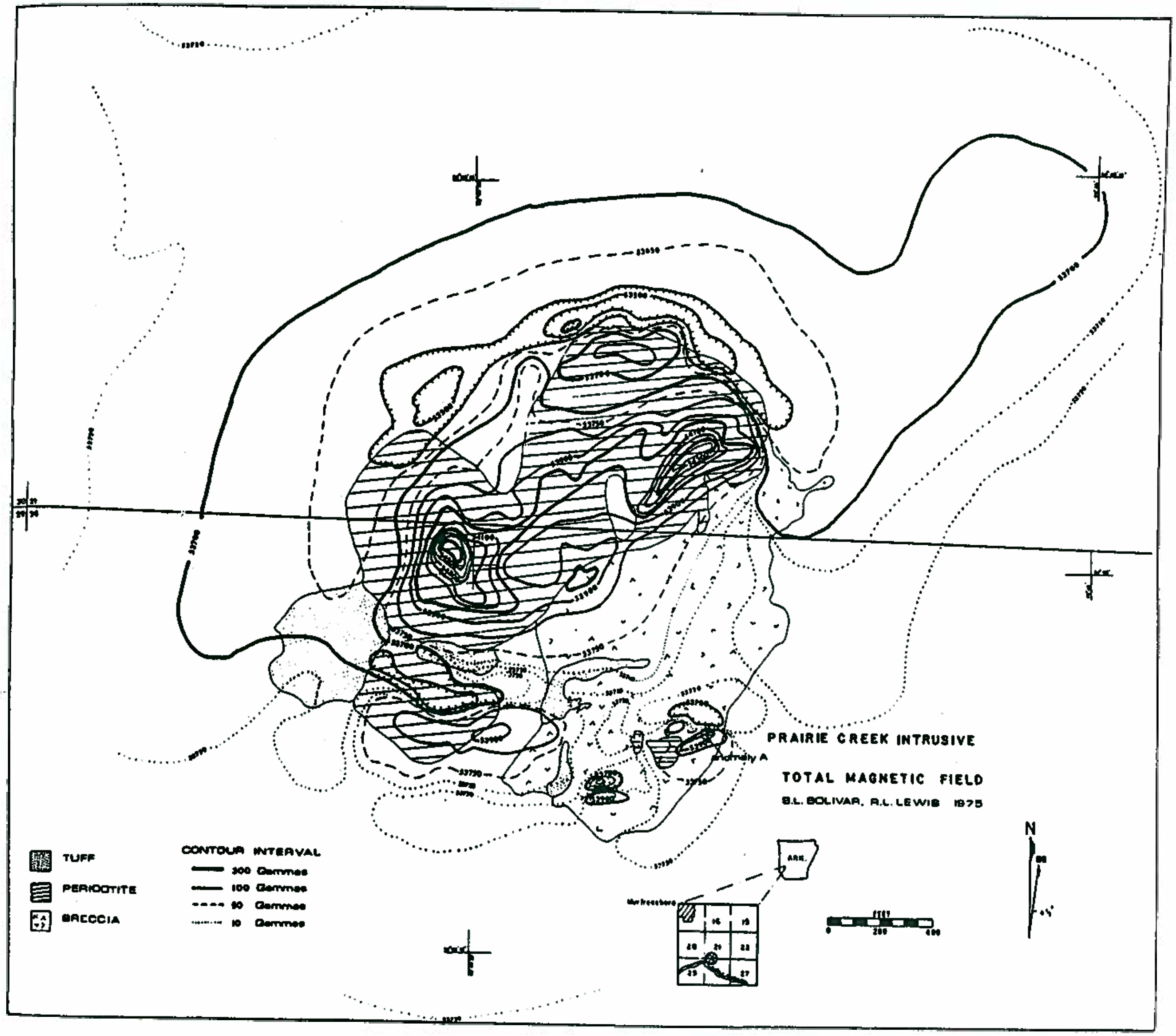


Figure 7.7: Total magnetic field of the Prairie Creek diamondiferous intrusive, Arkansas (Bolivar and Brookins 1979). Note: 1 nanotesla = 1 gamma.

U.S.S.R.: Gerryts (1970) also made reference to a large amount of magnetic surveys that were conducted during exploration for kimberlite in the U.S.S.R. and he (Ibid) suggested that in Yakutia the magnetic method was particularly suited to finding kimberlite diatremes that had intruded the flat lying calcareous sedimentary rocks. Aeromagnetic studies at a variety of altitudes showed that the anomalies could not be detected at an elevation of 600 m, whereas most pipes could be detected at an elevation of 400 m or less, although substantial variability in the magnetic responses of the pipes exist.

Lesotho: In the literature there are a large number of studies describing magnetic measurements made for kimberlite exploration in Lesotho where magnetic anomalies were found associated with nearly all known kimberlites (Paterson *et al.* 1977; Burley and Greenwood 1972; Paterson and MacFadyen 1986). In parts of Lesotho, the kimberlites intrude into sandstone and large magnetic anomalies as great as 7,000 nT in magnitude are reported. However, it must be noted that due to the 63°S inclination of the magnetic field in this region, a dipolar response with adjacent high and low areas is present (Figure 7.8) (Nixon 1980b). Macnae (1979) noted that the unweathered, hardebank, sections of kimberlite pipes contain magnetite and, consequently, he modeled the magnetic response of the pipes by assuming that buried vertical cylinders approximately described the geometry of the hardebank dykes. In order to satisfactorily fit his data, however, he was required to assume a strong remnant magnetization in the rock which correlated well with the expected Cretaceous age of the diatremes.

In places, weathering of the Lesotho kimberlite pipes has resulted in the formation of a disc-shaped layer, which although highly electrically conductive, may also be devoid of magnetite due to its decomposition to nonmagnetic iron oxides with an associated drop in the magnetic susceptibility. For weathered kimberlite, Erdmer and Downing (1993) reported magnetic susceptibilities for heavily weathered (yellow ground) and moderately weathered (blue ground) kimberlites are 2×10^{-4} to 10^{-2} nT and 10^{-5} to 2×10^{-5} nT, respectively. As a result, this weathered near surface layer would not be expected to produce a noticeable magnetic anomaly. Although the deeper unweathered material does retain substantial magnetic susceptibility because it exists at some depth below the surface, and its size tends to be constrained, the weathered material may make it difficult to distinguish magnetically the diatremes. Macnae (1979) showed examples of this where different kimberlite pipes separated at most by a few kilometres can have very different magnetic signatures (Figure 7.9). In some cases the weak or nonexistent magnetic signal was attributed to a deep weathering of some of the pipes. In other pipes, a rapidly varying signal was presumed to be produced by the differential weathering of parts of a given kimberlite. In any event, the magnetic detectability of the kimberlite pipes may be strongly related to the degree of weathering that the pipe has experienced.

Gerryts (1970) also briefly described the results of other early magnetic surveys in South Africa which indicate highly variable results, with some pipes yielding anomalies as high as 500 nT, whilst others have no signal. In Tanzania, a large known pipe could not be detected using magnetic methods, but the results may have been complicated by other

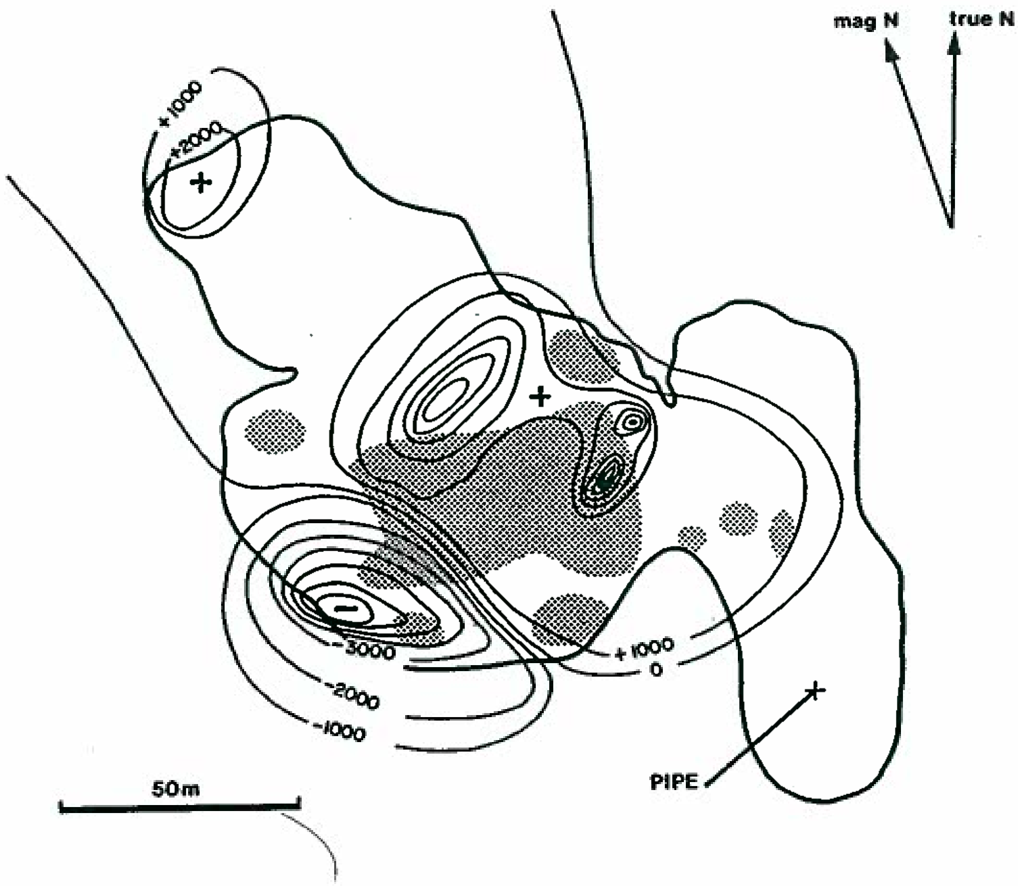


Figure 7.8: Total vertical magnetic field over a Kolo kimberlite pipe intruded into a sandstone in Lesotho. Contour values are in nT. The pipe is outlined by the heavy dark line and hardebank kimberlite exposures are represented by stipple. As published in Nixon (1980b), after Burley and Greenwood (1972).

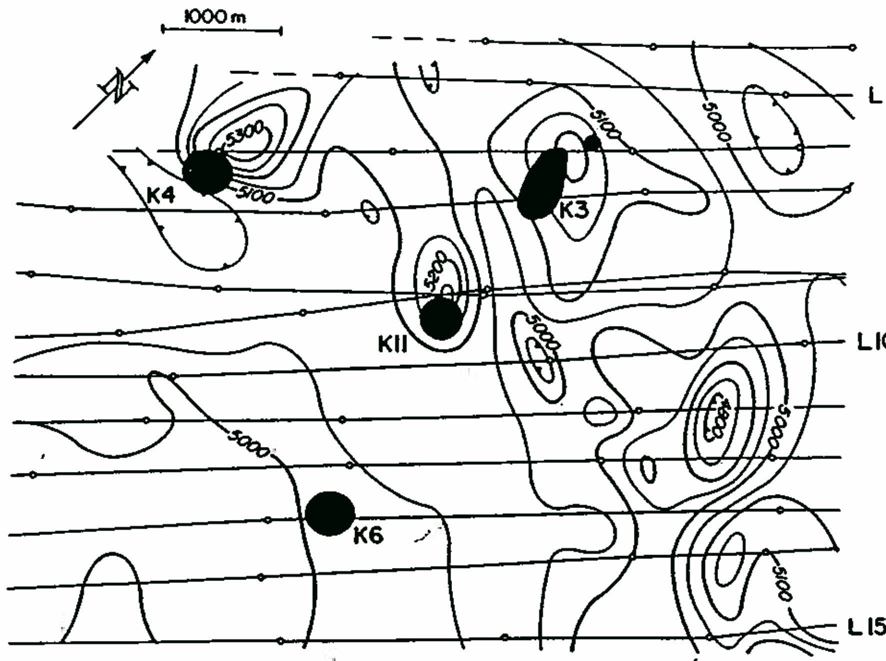


Figure 7.9: Aeromagnetic total field measured over a kimberlite field in Lesotho. Magnetic contours are at a 50 nT interval. Outcropping kimberlite pipes are highlighted in black (Macnae 1979).

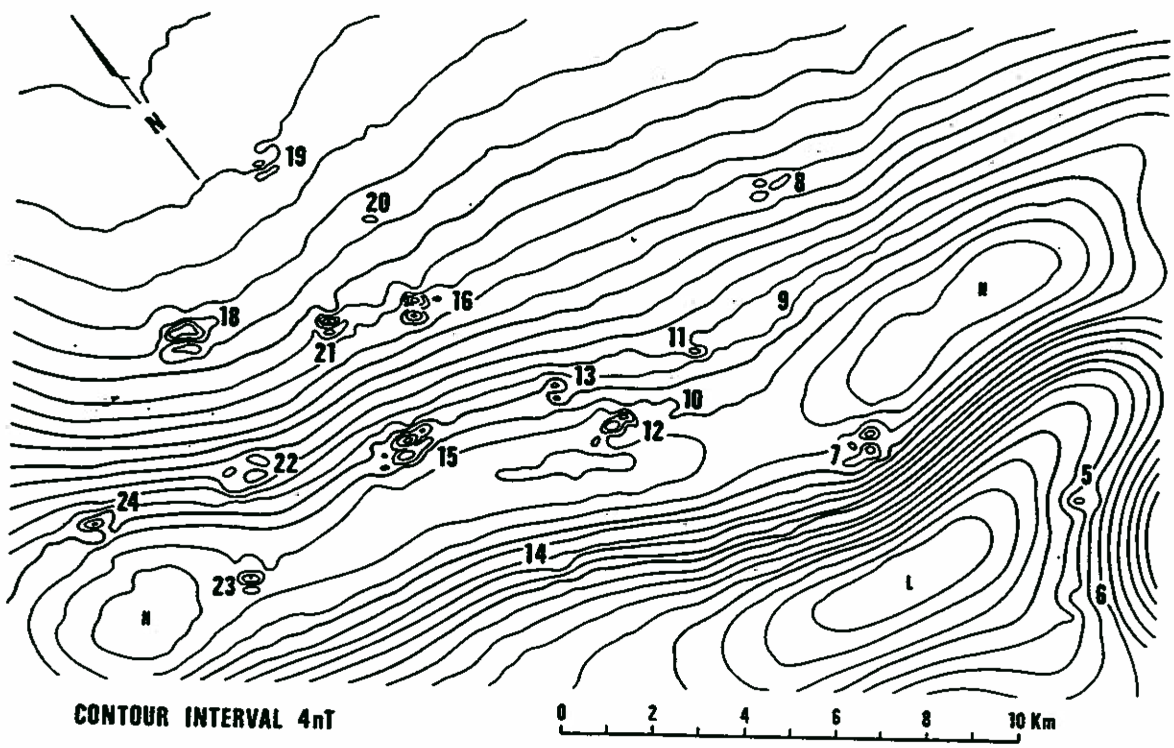


Figure 7.10: Aeromagnetic total field measured over a kimberlite/lamproite field in the Ellendale district of Western Australia. Numbers indicate locations of known vents (Smith 1985).

igneous dykes in the area. In Mali, however, good results were found over kimberlite diatremes with observed anomalies as high as 1,500 nT. This was thought to be due to the contrast in the magnetic susceptibilities of the diatreme and the surrounding sandstone.

Australia: Smith (1985) reported on aeromagnetic surveys for kimberlites and lamproites in the Ellendale province of Western Australia. An extensive survey was carried out over a region covering 3,500 km of poorly drained land where indicator mineral sampling was impractical. The survey was flown at an elevation of 80 m with line spacings of 250 m using a magnetometer sensitive to variations of 0.125 nT. The geology in this region is characterized by flat-lying Devonian and Permian limestones, sandstones and shales, and hence any igneous intrusions would be expected to produce a strong magnetic signal due to the contrasts in the magnetic susceptibility between the sediments and the intrusions. Twenty six anomalies, 24 of which were indeed found to be kimberlite or lamproite intrusions, were detected from the maps of the total magnetic field (Figure 7.10). In this figure, the known positions of vents are indicated by boldface numbers and it is worth noting that although most of the known vents are easily distinguishable, certain others such as 6, 9 or 14 could easily be missed.

Hudson Bay Lowlands: Janse *et al.* (1986) described an extensive geophysical survey over a region along the western shore of James Bay near Hearst, Ontario. The physiography of the region consists at the surface of glacial and recent deposits, with thicknesses ranging from 25 to 150 m thick. As well, there are many small lakes and swamps drained by networks of small streams, hence, indicator mineral sampling is impractical. The regional geology consists of Paleozoic clastics and limestones with thicknesses of up to 800 m; these strata are underlain by the Archean Superior Structural Province basement. In short, these geological conditions are similar to what might be expected in somes areas of northern Alberta.

Janse *et al.* (1986) carried out an aeromagnetic survey of the James Bay region at an elevation of 60 m above ground surface with a flight line interval of 250 m. The rationale for these parameters being the assumption that any economically important bodies with dimensions on the order of 200 m in diameter or greater would be detected. It is worthwhile noting that the same area had earlier been covered with a lower resolution aeromagnetic survey with a line spacing of 800 m and a terrain clearance of 300 m, but Janse *et al.* (1986) suggested that only 10% of the magnetic bodies would have been detected if these original data were used. However, Janse *et al.* (1986) also pointed out that the location of some of the anomalies correlated with basement structures that were identifiable in the lower resolution magnetics, which suggests that there was some basement controls on the emplacement of the bodies. A portion of the results are shown in Figure 7.11 and a number of circular, bulls-eye shaped anomalies are apparent. The anomalies vary from a few tens of nanoTeslas to hundreds of nanoTeslas. In general, the geophysical responses are those expected from pipe-like intrusions in the essentially nonmagnetic sedimentary rocks and buried at depths from 20 to 50 m beneath the glacial cover. The four anomalies highlighted in Figure 7.11 were discussed fully in Janse *et al.* (Ibid). As well, these and many of the other anomalies that were discovered were also followed up with ground magnetics and shallow drilling.

The follow up ground magnetic surveys were conducted in order to further detail the source structures and a few of these responses are shown in Figure 7.12. Of these, the contour plot for pipe 11-6 is perhaps one of the more interesting because the magnetic anomaly is negative. This is a consequence of the remnant magnetization of this pipe which was intruded during a period of reversal of the earth's magnetic field. In this case, the remnant magnetization acts against the earth's present day field such that a magnetic low is present. Alternatively, those pipes with a positive magnetic response indicate that they were intruded during a period in which the earth's magnetic field was normally polarized as is the situation today. Janse *et al.* (1986) suggested that 5% of the pipes which were detected in their survey, displayed this type of response. Note that this effect is different from the dipolar negative-positive response in the Kola pipe seen in Figure 7.8, which is a result of the shallower dipping magnetic field that is present in southern Africa (Nixon 1980b). In contrast, in the Hudson Bay Lowlands the magnetic field is very steeply dipping due to the proximity of the area to the north magnetic pole and the magnetic anomalies seen should well represent the outlines and positions of the source bodies. Regardless, this remnant magnetization was strong in Janse *et al.'s* (1986) study and the explorationist, when examining magnetic maps, should keep in mind the time of emplacement, and hence the ambient magnetic field polarization, of the intrusions because this will affect both the amplitude and the sign of the magnetic anomaly.

Saskatchewan: Gent (1992) described a number of cases of kimberlite magnetic exploration surveys in Saskatchewan. The two Sturgeon Lake kimberlites, which are approximately 30 km northwest of Prince Albert, were not observed in the early, low resolution, aeromagnetic data that was provided by the Geological Survey of Canada. The GSC data were acquired with a 1.14 km line spacing with the sensor at 300 m elevation above ground surface. However, both kimberlites were observed in a 120 m clearance, 120 m line spacing aeromagnetic survey. An interesting observation with these bodies is that their magnetic signature decays rapidly with elevation, which indicates that they are of limited extent in depth and suggests that they may be rootless, ice-thrust blocks.

In the Fort à la Corne area, which is 100 km to the east of Prince Albert, a number of diamondiferous kimberlite intrusives have been discovered. The Fort à la Corne kimberlites, in contrast to the Sturgeon Lake kimberlites, were originally targeted for investigation on the basis of regional Geological Survey of Canada aeromagnetic data (Lehnert-Thiel *et al.* 1992). These Fort à la Corne kimberlites contain up to 4 per cent magnetite by volume, and they form positive aeromagnetic anomalies of up to 140 nT, and positive ground magnetic anomalies of up to 1,400 nT, above background levels. By analogy to the magnetic data in this region, Gent (1992) speculated that numerous other kimberlite pipes exist in Saskatchewan. As well, Gent (1992) suggested that although

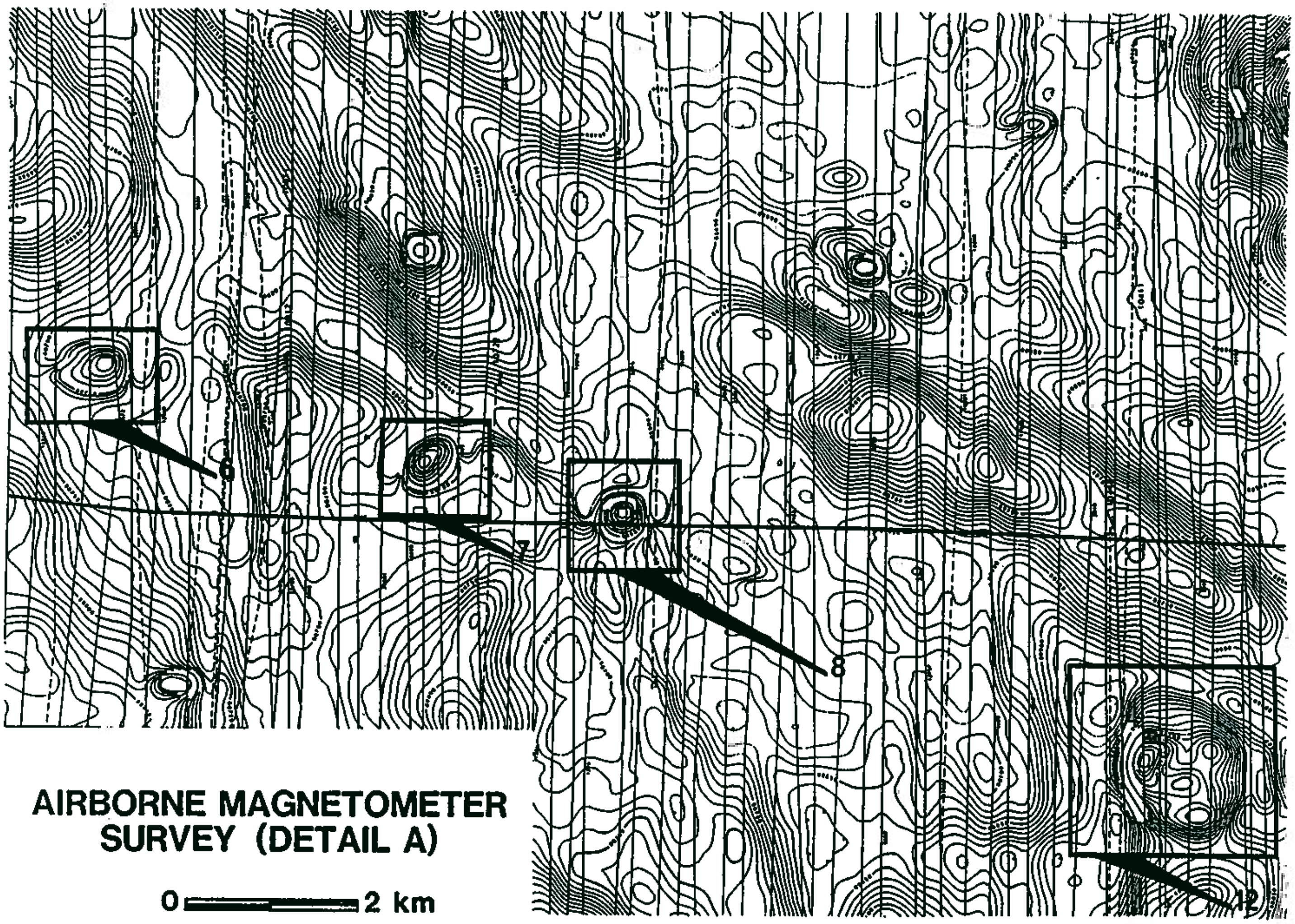


Figure 7.11: Aeromagnetic total field measured over alkaline ultramafic intrusions in the Hudson Bay Lowlands. Contour interval is 10 nT (Janse et al. 1986).

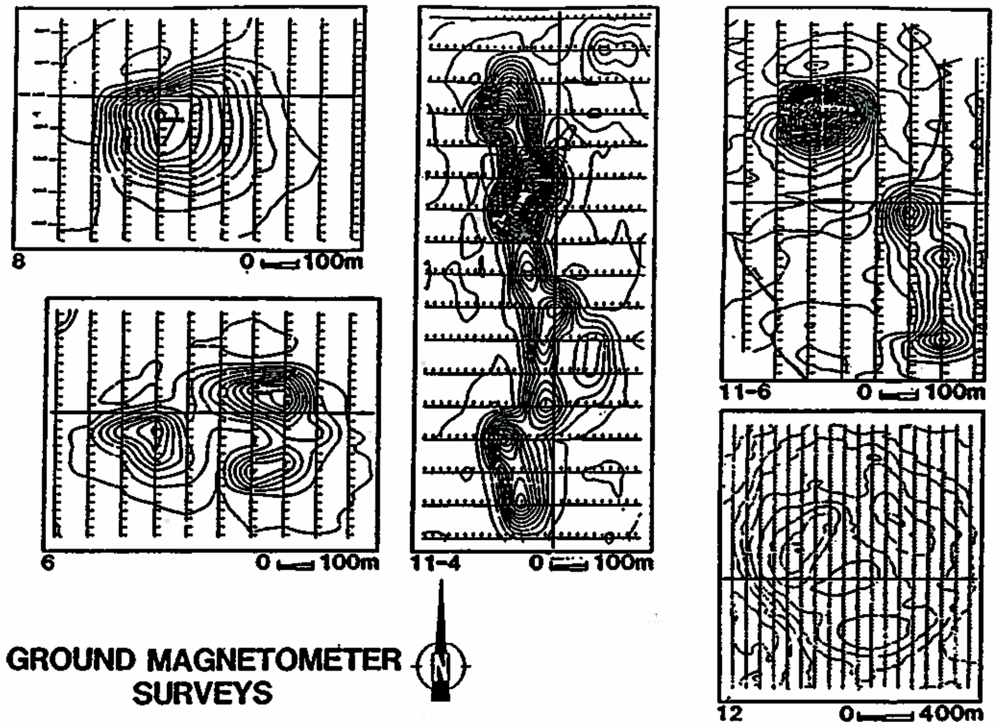


Figure 7.12: Ground magnetic total field over individual pipes in the Hudson Bay Lowlands. Numbers correspond to features seen in Figure 7.11, or elsewhere in Janse et al. (1986). Contour intervals are 100 nT for pipes 6 and 8, 50 nT for pipe 12, and 25 nT for pipes 11-4 and 11-6 (Janse et al. 1986).

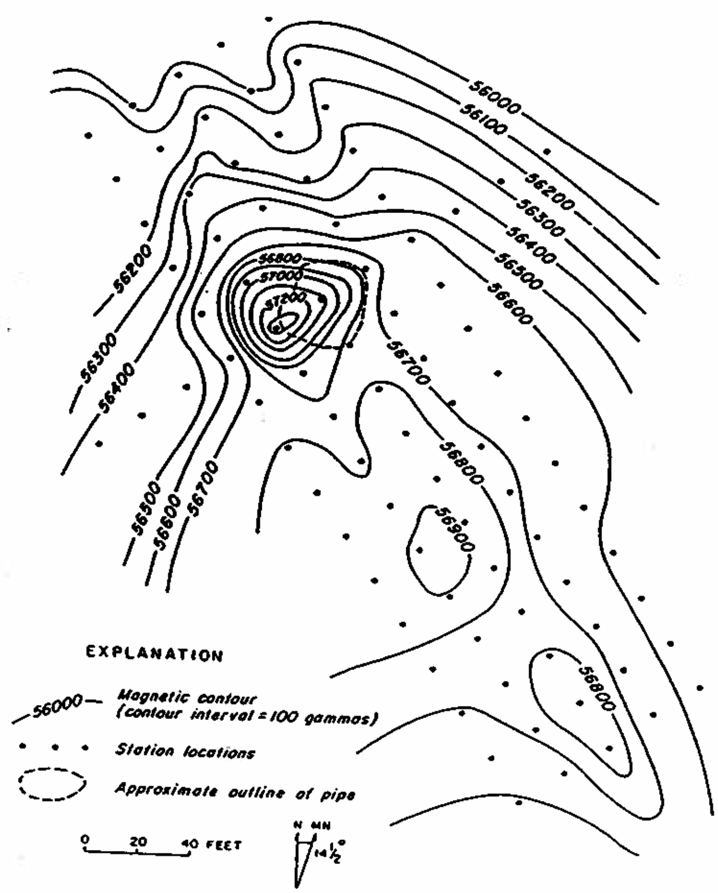


Figure 7.13: Total field magnetic measurements over a kimberlite pipe in the Iron Mountain District, Wyoming (Hausel et al. 1980).

many of the larger pipes were found using the existing regional aeromagnetic surveys, delineation of smaller features may require low altitude, high resolution, and tightly spaced aeromagetic coverage. This is in agreement with the observations of Janse *et al.* (1986).

Magnetic Exploration for Diatremes in Igneous and Metamoprhic Terranes

Kimberlite and lamproite diatremes are also found intruded into earlier igneous or metamorphic rocks and, in these cases, the contrast in magnetic susceptibilities between the diatremes and the country rock may be insufficient for the kimberlites or lamproites to be distinguished. This could be the case in the northeastern sections of Alberta where Canadian Shield rocks crop out. Some of the relevant studies are worth mentioning because it has been found that the magnetic responses of such alkaline intrusions in igneous and metamorphic terranes have mixed results.

Erdmer and Downing (1993), for example, showed positive results in the search for kimberlites in the Lac du Sauvage area of the Northwest Territories by a low level (45 m elevation), high resolution aeromagnetic survey. The total magnetic field response identified a kimberlite pipe with a magnetic high of less than 20 nT centered on a bulls-eye contour pattern of a diameter of approximately 600 m. This pipe was also apparent in a contour map of the vertical gradient of the magnetic field.

Extensive airborne and ground magnetic studies also have been carried out in Wyoming and Colorado where numerous diatremes have been detected. Hausel *et al.* (1979), for example, provided a study of the ground magnetic response of two diatremes in the State Line District of Wyoming. These two kimberlites intruded through Archean granites. The magnetic signatures were generally of low amplitude, at most 60 nT, although at localized places within the anomaly, magnitudes could reach 250 nT. Often, weak magnetic lows of up to -30 nT were also seen. This indicates that the magnetic susceptibility contrast between these diatremes and the surrounding granites is small, thereby making the diatremes difficult to locate. In a later study in the same region, Hausel *et al.* (1981) were not able to detect the dyke that connects the two pipes using ground magnetics. This was probably due to the much stronger signal of a subparallel diabasic dyke, although detection of the kimberlite dike by electrical methods was successful as will later be described. In contrast, Hausel *et al.* (1981) observed a bulls-eye positive magnetic anomaly of 700 nT associated with a kimberlite pipe further to the north within the Laramie anorthosite complex (Figure 7.13). A less distinct, positive, high magnetic trend led to the interpretation of a diatreme with the possible existence of a dyke at greater depth.

Carlson *et al.* (1984) reviewed further studies of the Colorado-Wyoming alkaline diatremes and indicates that most of them could be seen in the magnetic maps once the regional trends had been removed. They (Ibid) further noted a difference in the responses of hypabyssal kimberlite bodies which exhibit larger magnetic anomalies than do those characterized by breccia. Paterson and MacFadyen (1986), however, found that the magnetic signature of many of the diatremes in the State Line District was very weak or nonexistent, aside from a few anomalous diatremes which correlated with positive high magnitudes of over 1,000 nT. Shaver (1988) studied the Sloan 1 diatreme in detail and although he found a peak anomaly of about 200 nT, this was restricted to a very narrow region of 50 m width and 300 m length that correlated with only part of the geologic exposure and which would probably be difficult to detect in an airborne survey.

Magnetic Data in Alberta

Magnetic data for Alberta are available for purchase from the Geological Survey of Canada who also are able to provide various types of geophysical mapping services. Figure 7.14 identifies those areas in Alberta where data have been acquired and when these data will be publicly available. Note that data are not currently available over large sections of central Alberta, although these regions have recently been surveyed at a grid spacing of 400 m. Data from many of these surveys will be released between 1996 and 1998 according to the schedule shown in Figure 7.14.

The results of a high resultion aeromagnetic survey conducted in the southernmost portion of Alberta by the Geological Survey of Canada (1993) have recently been released. Ross *et al.* (1994a, b) discussed the possible interpretation of these maps at the 1994 Lithoprobe Alberta Basement Transect, and noted the existence of numerous highly linear magnetic trends which appear to radiate from portions of the Sweetgrass Hills immediately across the border in Montana. The linearity of these trends are striking and suggest that they may be due to cultural features, such as pipelines or power transmission lines. However,a search for such man-made features showed that none of the linear magnetic anomalies could be in any way correlated with human activity. Furthermore, one of the magnetic trends is spatially coincident with a known dyke that is exposed at the surface. This strongly indicates that the linear trends seen in the magnetic data show the positions of magmatic dykes at depth. These dykes may highlight potential areas for further exploration as families of diatremes are often found to be connected by such dykes.

As noted earlier, in section 7.2.2, there are also numerous brokers of private magnetic data who may be contacted for areas of coverage in Alberta. These brokers also are listed in the Calgary Yellow Pages telephone directory.

7.2.4 Electromagnetic and Resistivity Methods

Background Information

In general, electrical geophysical techniques seek to delineate the geological structure in terms of the resistivity of the earth materials. The methods can be separated into electrical and electromagnetic categories (Kearny and Brooks 1991).

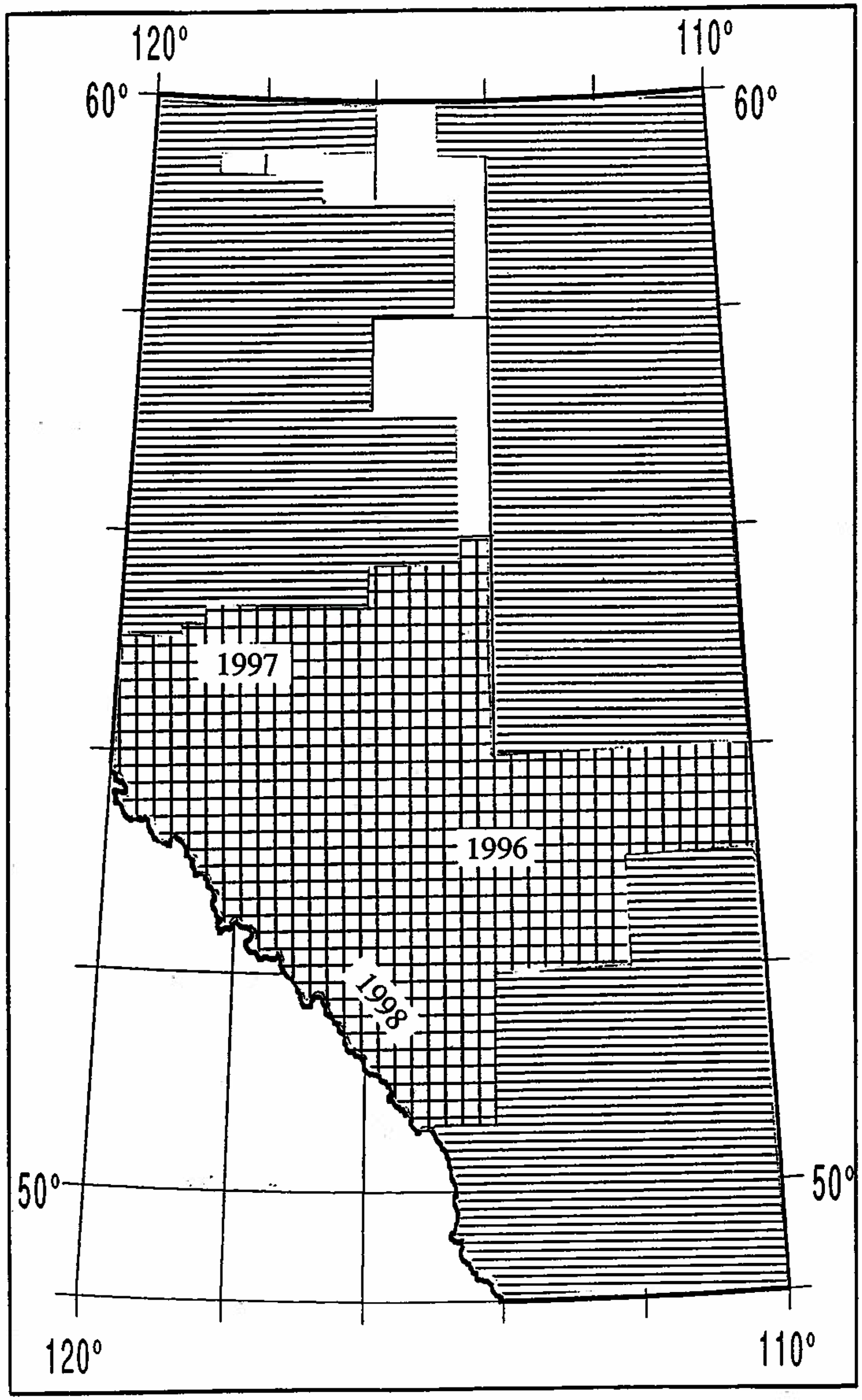


Figure 7.14: Availability of aeromagnetic data for Alberta. These data are available from the Geological Survey of Canada.

Electrical, or resistivity, techniques typically require artificially generated currents to be directly introduced into the ground using electrodes; the observations then consist of mapping out the variations in the electrical potentials at the surface. Static measurements are often referred to as electric or resistivity methods, with the Schlumberger and Wenner resistivity techniques referring to specific arrangements of the electrodes on the surface. A dynamic variation of this is called the instantaneous potential (IP) method which essentially allows a determination of the capacitance, or ability to store charge, of the ground. Since these techniques require placement of actual electrodes into the earth, they can be expensive and are usually applicable in a secondary evaluation of a potential prospect.

In contrast, electromagnetic (EM) methods rely on measuring the ground's induced response to the propagation of electromagnetic fields which is subsequently observed using a wire-wound coil or set of coils. Electromagnetic methods often do not require actual contact with the earth and as a result are amenable to airborne applications. However, their depth of penetration into the earth is typically less than that available in the resistivity methods and hence electromagnetic methods are better suited to initial regional exploration where very near surface conductivity anomalies might be expected to indicate the presence of kimberlite.

Numerous electromagnetic techniques exist, which may further be classified on whether they function passively by using external sources or actively with their own source. Passive methods include: (a) AFMAG, which uses 'sferic' radiation that is produced by lightning, and which travels between the earth's surface and ionosphere, and could be considered a variation of the magnetotelluric methods discussed in Section 5, and (b) VLF, which takes advantage of very low frequency (15 to 25 KHz) military submarine transmissions from known stations. However, the more sophisticated electromagnetic techniques employ their own transmitter. The transmissions may be continuous, such as in the Turam method, or may be pulsed for time-domain electromagnetic surveying techniques (TDEM). In the latter method, the decay of the induced field is measured at a set of fixed times after the source has been pulsed. INPUT® is an airborne adaptation of this type of time domain measurement. An overview of very recent work in the general area of airborne electromagnetic sounding is given by Smith (1994).

Essentially, however, both the electrical and electromagnetic methods attempt to map out the resistivity, which for earth materials is the most variable of all the physical properties. The sources of conductivity in earth materials are varied. Graphite and certain metallic ores are themselves conductors and the current through them is via the flow of electrons. In contrast, most rock forming minerals are essentially insulating, with high resistivities. Fluid-filled porous rock, however, will be a conductor with an electrolytic current passing through the water pathways in the rock; the conductivity being strongly dependent on the degree of salinity and amount of water present. Although many igneous rocks themselves have negligible porosity, fluid-filled fractures cutting such rocks will also act as a conductor. As a result, a measured conductivity anomaly in a given area cannot be uniquely assigned to any specific material without prior knowledge of the geologic context.

Telford *et al.* (1976) provided an extensive listing of measured earth material resistivities. This listing indicates that igneous rocks are generally the least conductive and sedimentary rock the least resistive (or most conductive), although there can be substantial overlap of values. In particular, clays, and especially wet clays, have low resistivities, typically ranging from 1 Ωm to 100 Ωm. In contrast, the resistivities of most igneous rocks of any kind range from 500 Ωm to 106 Ωm. The resistivities of sedimentary rocks are less easy to characterize and are highly dependent on concentrations of clay minerals, porosity, permeability and fluid saturation.

The heterogeneity of the kimberlite and lamproite vents again affect the electromagnetic signature that might be expected. Gerryts (1970) reported kimberlite resistivities from de Magnee (1950) that range from less than 20 Ωm to more than 150 Ωm, but does not indicate whether this is for weathered or fresh material. Resistivities for unweathered hardebank kimberlite are reported to range from 200 Ωm to 1,000 Ωm (Erdmer and Downing 1993), from 100 Ωm to more than 200 Ωm (Nixon 1980b), and to an estimated value of 500 Ωm by Macnae (1979). Near surface resistivities of weathered kimberlite range from 10 Ωm to 20 Ωm (Nixon 1980b; Smith 1985; Erdmer and Downing 1993), and more specifically from 2 Ωm to 5 Ωm and from 50 Ωm to 100 Ωm for yellow and blue ground, respectively (Macnae 1979).

As a result, the most prominent characteristic that might be detected in any electrical or electromagnetic measurement made during the exploration for diamondiferous diatremes, is the lower conductivity of the near surface yellow ground. The resistivity of which is lower due to the presence of hydrous ion-absorbing minerals such as talc-saponite, montmorillonite, vermiculite and serpentine (Nixon 1980b). A further point to consider is that magnetite is destroyed during weathering, with the result that the magnetic susceptibility is lowered. This has the interesting consequence that if a kimberlite pipe is heavily weathered, then its magnetic signature might be expected to be weak, but it may still be distinguished in airborne electromagnetic methods by highly conductive near surface anomalies. The opposite of this also may hold in that a fresh kimberlite intruding lower susceptibility rocks will have a strong magnetic signature, but a low electrical conductivity. This makes the magnetic and electromagnetic prospecting methods complementary in prospecting for kimberlite bodies. A number of case studies, almost all of which have been discussed in the context of magnetic exploration for diatremes earlier, are discussed below. Again, since most of the exploration in Alberta will be conducted in regions of substantial sedimentary cover, the case studies from geologically similar locales will first be reviewed as possible analogs to exploration strategies to be employed in Alberta. It must be kept in mind, however, that much of Alberta was recently glaciated and this may affect the degree of weathering and applicability of the electromagnetic techniques, most of which describe application for diamond exploration in warmer climates. No discussion of electrical measurements near kimberlites or lamproites within Alberta is available. Surveys will also be complicated by the possible existence of conductive near surface clays, shales and saline ground waters.

Resistivity Exploration for Kimberlites in Sedimentary Terranes

Africa: Gerryts (1970) reported on an earlier electrical resistivity surveys carried out by de Magnée (1950) in Kasai using a Wenner configuration (see Kearny and Brooks 1991). In this case the signal was primarily produced by the waterlogged and weathered kimberlite with low resistivities of 20 Ωm. Gerryts (1970) also reported on other measurements in Tanzania and Sierra Leone which indicated that the kimberlite pipes could be distinguished in both cases by their resistivities, which were substantially lower that the surrounding country rock. Atkinson (1989) commented that other authors had suggested the highest priority kimberlite targets in South Africa have both a magnetic and an electromagnetic signature, but he does not mention the local geology under which such observations were made.

Burley and Greenwood (1972) carried out a number of different types of measurements in Lesotho as described by Nixon (1980b). Their electrical soundings also used a Wenner array configuration which confirmed that the weathered kimberlite to depths of nearly 20 m was substantially less resistive than the fresh kimberlite as indicated in Figure 7.15. Macnae (1979) further confirmed these findings on other kimberlite pipes in Lesotho using both standard resistivity surveys and the related instantaneous potential (IP) technique. Burley and Greenwood (1972) also carried out preliminary electromagnetic measurements using an 'EM gun' which is probably a variation of the AFMAG method. Their (Ibid) results show low resitivities over a mapped kimberlite pipe in Lesotho (Figure 7.16).

Macnae (1979) also presented case histories for the geophysical expression of Lesotho kimberlites. They indicated that the electromagnetic methods were highly effective in delineating the presence of clays, both due to weathering of the kimberlite and due to local sedimentation of 'epiclastics' within the vent crater. In his (Ibid) study, all eight pipes which were discovered had unmistakable electromagnetic signatures, whereas only five of these same pipes were recognized from magnetic maps. These observations are most apparent in the comparisons of airborne EM (INPUT®) and magnetic field strength data that were obtained over two separate pipes shown in Figure 7.17. The better the conductor the more rapid will be the decay of the induced electromagnetic signal and, as a result, a good conductor is indicated by the existence of 'low' values which are seen on most, if not all, channels. A comparison of the mapped electromagnetic anomalies is shown in Figure 7.18, the area of which corresponds to that of the magnetic anomalies shown in Figure 7.9. When compared, these figures indicate that in this area the electromagnetic survey was more successful at delineating the kimberlite outcrops than was the magnetic survey.

Australia: Both ground and airborne electromagnetic surveys were carried out in the exploration for kimberlites and lamproites in Western Australia (Smith 1985). This study is of interest because the ground electromagnetic surveys of the kimberlites demonstrated they have a higher conductivity than a sandstone formation, but are slightly less

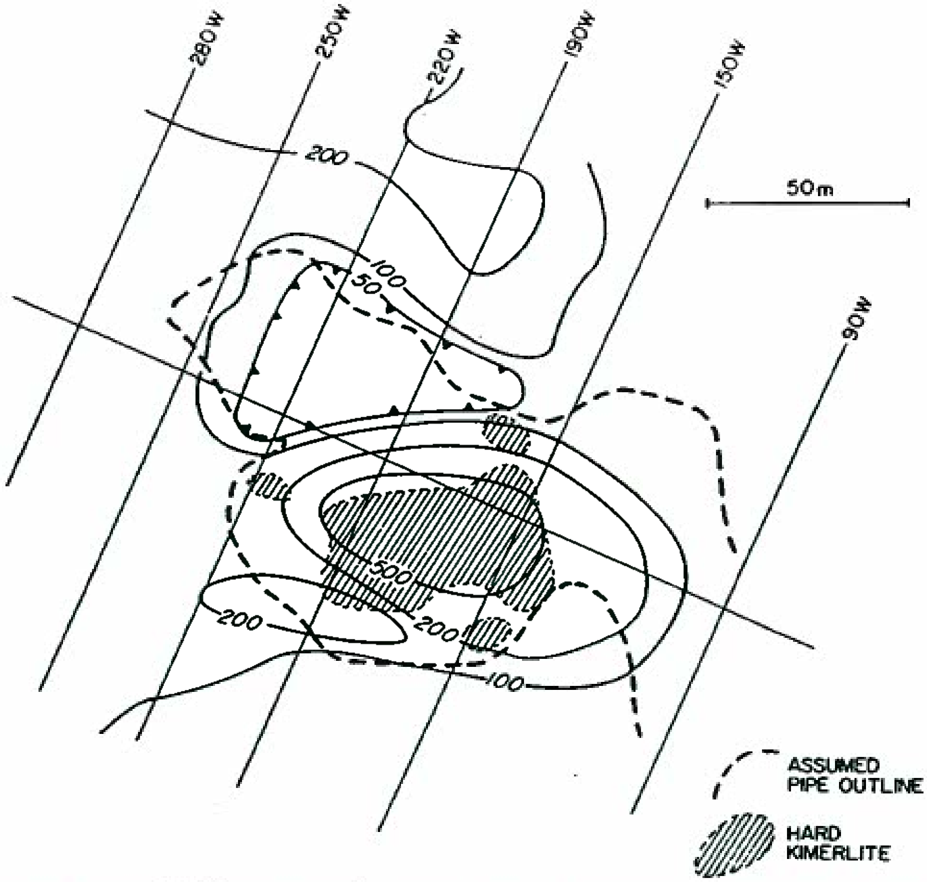


Figure 7.15: Apparent resistivity over the Kolo pipe, Lesotho. Logarithmic contours in Ωm. See Figure 7.8 for the contrasting magnetic signal. From (Macnae 1979) after (Burley and Greenwood 1972).

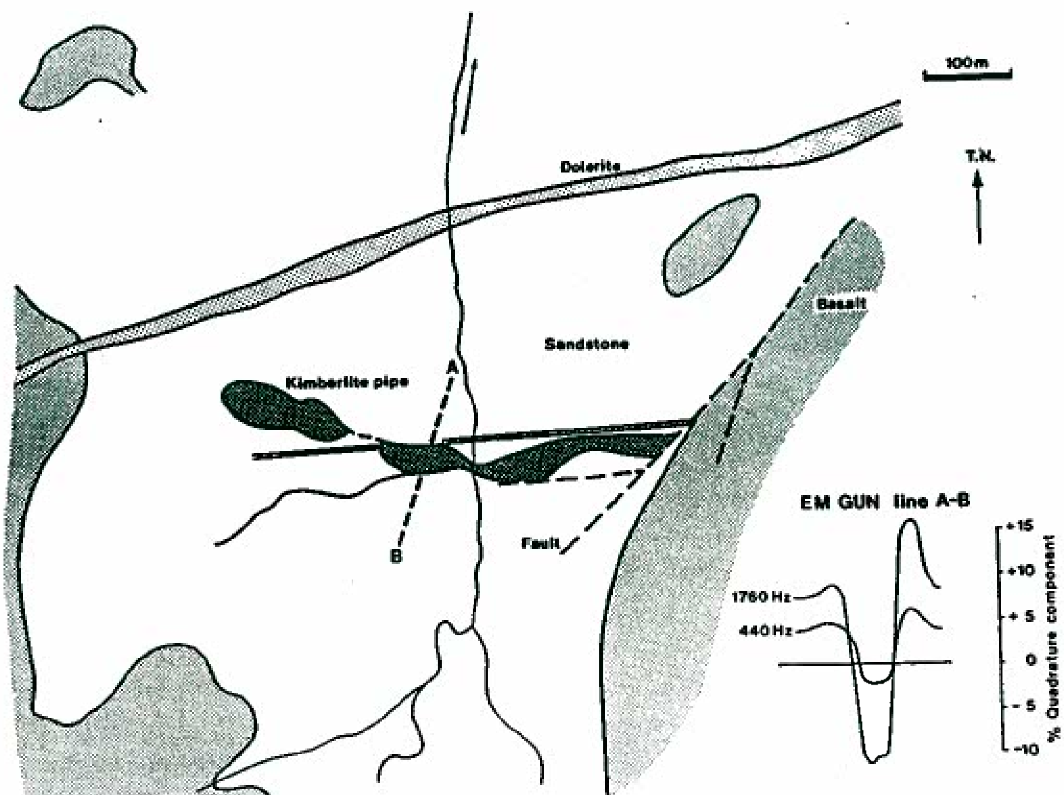


Figure 7.16: Electromagnetic profiles at 1,760 Hz and 440 Hz measured across a mapped kimberlite pipe in Lesotho (Nixon 1980b).

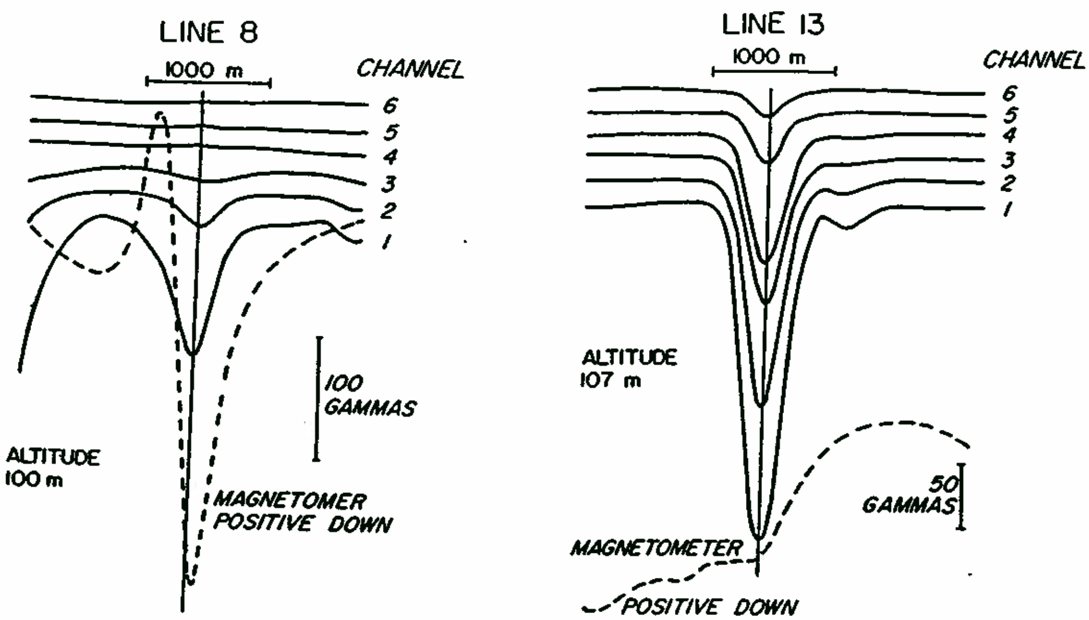


Figure 7.17: Electromagnetic INPUT® and magnetic field strength profiles across two kimberlites in Lesotho. Magnetic field strength measured in Gammas (1 Gamma = 1 nT). The six electromagnetic channels are the relative voltages taken from the observed induced response at six successive set times after a electromagnetic pulse was transmitted with the channel being the first channel measured (Macnae 1979).

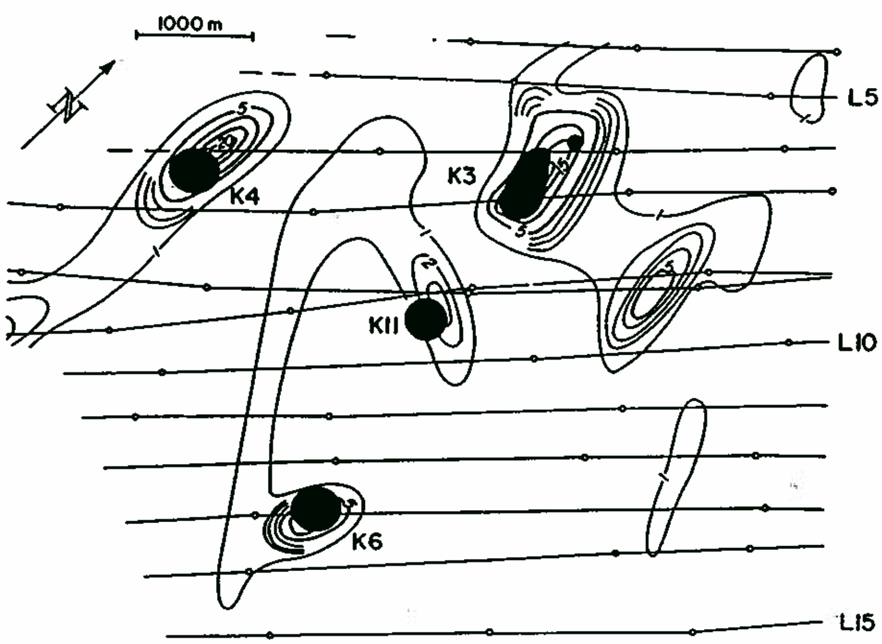


Figure 7.18: Electromagnetic amplitudes observed on the second channel over Lesotho (see Figure 7.9). Dark and light contours represent intervals of 5 and 1 arbitrary unit, respectively. Black regions correspond to the surface outlines of kimberlite pipes (Macnae 1979).

conductive than a local limestone formation. On the basis of this preliminary work, an airborne EM survey was carried out and this allowed in the upgrading of the potential of some of the weaker magnetic anomalies, one of which was later found to be a kimberlite pipe. The INPUT® and corresponding magnetic field strength results across a number of pipes are shown in Figure 7.19. In particular, the pipe labeled Ellendale 9 in Figure 7.19 has a relatively strong anomaly, but this same pipe is not distinguishable by the corresponding total magnetic field signal mapped in Figure 7.10. It is also interesting to note that pipe Ellendale 17 is more resistive than the surrounding near surface material.

Kansas and Arkansas: Coopersmith and Mitchell (1989) briefly described a ground survey over the Hill's Pond and Rose lamproites that was conducted using a Geonics EM-31 conductivity meter which provides a measure of the near surface resistivity. At Hills' Pond, there is a resistivity anomaly low of 14 Ωm to 25 Ωm in the less conductive sedimentary host material of 33 Ωm to 100 Ωm. Coopersmith and Mitchell (1989) noted, however, that other conductive anomalies are present in the area and are associated with tilled soil and clay filled creek beds.

Saskatchewan: Gent (1992) noted that airborne electromagnetic VLF-EM surveying of sediments is problematic in that signals from this type of measurement are affected by the near surface ground moisture and ground slopes. He does, however, comment on a few possible VLF-EM and IP anomalies of unknown origin.

Resistivity Exploration for Kimberlites in Crystalline Terranes

Colorado and Wyoming: The bulk of the studies in crystalline igneous terranes again come from the Colorado-Wyoming kimberlites. Hausel *et al.* (1979) conducted Wenner configuration resistivity profiling across known kimberlites in the State-Line district that indicated low resistivities for the weathered kimberlite that are from 25 Ωm to 76 Ωm lower than those in the surrounding more resistive host granites. Carlson *et al.* (1984) obtained much the same results and presented vertical resistivity profiles over a pipe that indicates increasing resistivity at depth in the unweathered kimberlite as expected.

Similar results were also seen in the nearby Schaffer kimberlites where a low resistivity lineament was seen in electromagnetic conductivity observations (unspecified technique, but probably the VLF-EM method) along the expected trend of a kimberlite dyke that connects two known pipes (Hausel *et al.* 1981)(Figure 7.20). This contrasted with magnetic measurements in the same area that highlighted the existence of a diabasic dyke subparallel to this trend. Paterson and MacFadyen (1986) carried out an airborne INPUT® survey at an average ground clearance of 50 m over this same area and were able to discriminate both the existence of the pipes and the kimberlite dyke. More sophisticated VLF-EM surveys which employed filtered data at the George Creek kimberlites (Carlson and Marsh 1986) and at the Sloan Ranch complex (Shaver 1988) in the same locale, also yielded good results. However, the electromagnetic method failed to detect a kimberlite body in the host Laramie anorthosite complex (Hausel *et al.* 1981).

Erdmer and Downing (1993) illustrated the resistivity response of a kimberlite pipe at Lac du Sauvage, N.W.T. as observed from an electromagnetic survey flown at an average sensor elevation of 30 m above ground with a line spacing of 150 m. The observed induced responses were inverted to estimate an apparent surface resistivity and, in this case, there is a nearly circular low resistivity anomaly coincident with a magnetic anomaly. However, care should be taken in the interpretation of such maps because a conductive anomaly which is not identified as being associated with kimberlites, is also present and may be due to other near surface ground features.

Resistivity and Electromagnetic Measurements in Alberta

To our knowledge there are no public domain studies or data relating to electrical or electromagnetic surveys for diatremes within Alberta and it is unknown by the authors as to what degree such electromagnetic surveys will be of use in Alberta. Certainly the studies in Lesotho and Western Australia showed that electromagnetic airborne surveys are useful in delineating diatremes, primarily because they weather to highly conductive clays at and near the surface. However, the average mean temperatures and precipitation is higher in both southern Africa and Australia, which might allow for more rapid or differential weathering, as compared to that which exists within most of Alberta. Further, these regions have not undergone recent glaciation and the diatremes there have presumably weathered in situ since they were formed. As a result, these studies may not be directly transferable to the situation in Alberta where glaciation could leave relatively unweathered material near the surface. Alternatively, most of the applications of electromagnetic methods in the State Line District of Colorado and Wyoming, where climatic conditions are not that different from the arid sections of southern Alberta, appear to generally yield positive results, as does the data mentioned by Erdmer and Downing (1993) for the N.W.T. Hence, this indicates the electromagnetic method may have application, at least in places, to the Alberta situation.

A complicating factor, however, is that the Phanerozoic sedimentary strata which forms the bedrock within much of Alberta might substantially complicate the interpretations of geophysical data as noted in the preliminary studies described by Gent (1993) in Saskatchewan. Without data from actual airborne and ground surveys conducted over known diatremes, it is difficult to speculate on the potential merits of the electromagnetic methods and it may be that, given the limited weathering expected, magnetic methods may be of more importance.

7.2.5 Gravity

Variations of the density of materials in the earth are manifest as changes in the acceleration of gravity according to Newton's law of gravitational acceleration. Essentially, the larger the mass (i.e., the higher the density) the greater the attractive force. As a result, mapping of the small changes in the earth's gravitational acceleration can be useful in delineating differences in density coincident with geologic structure within

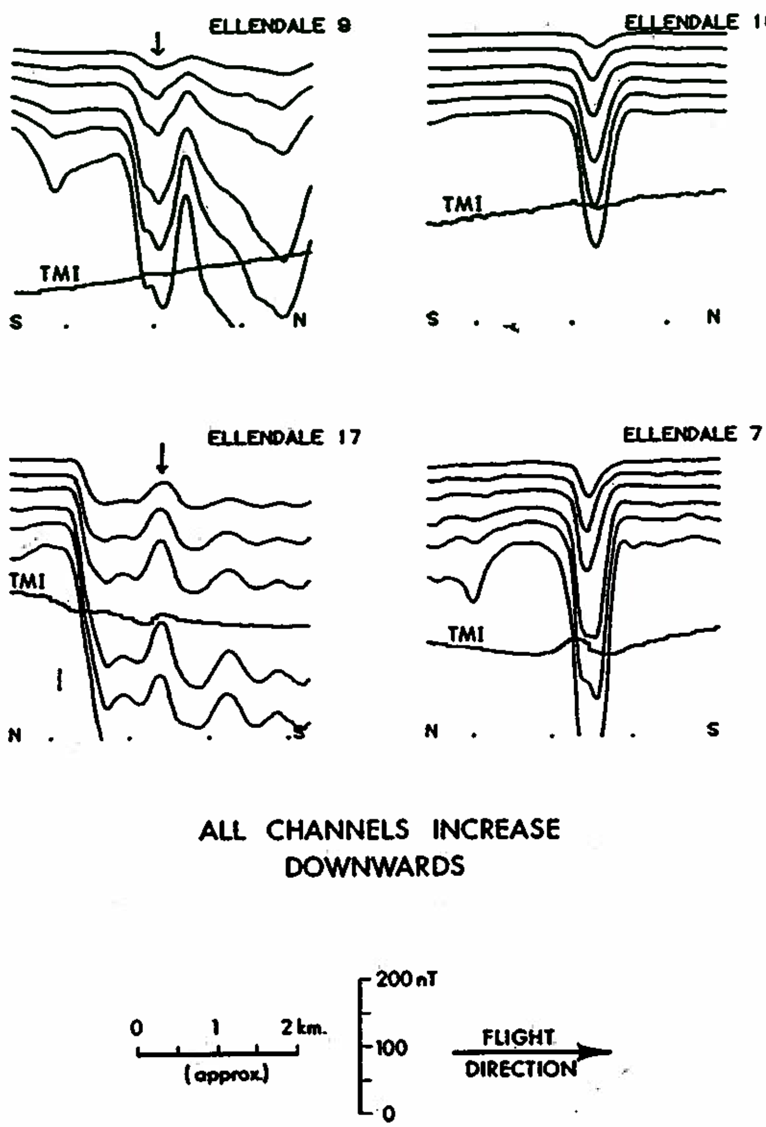


Figure 7.19: Electromagnetic INPUT® and magnetic field strength profiles across four kimberlite or lamproite pipes in Western Australia (Smith 1985).

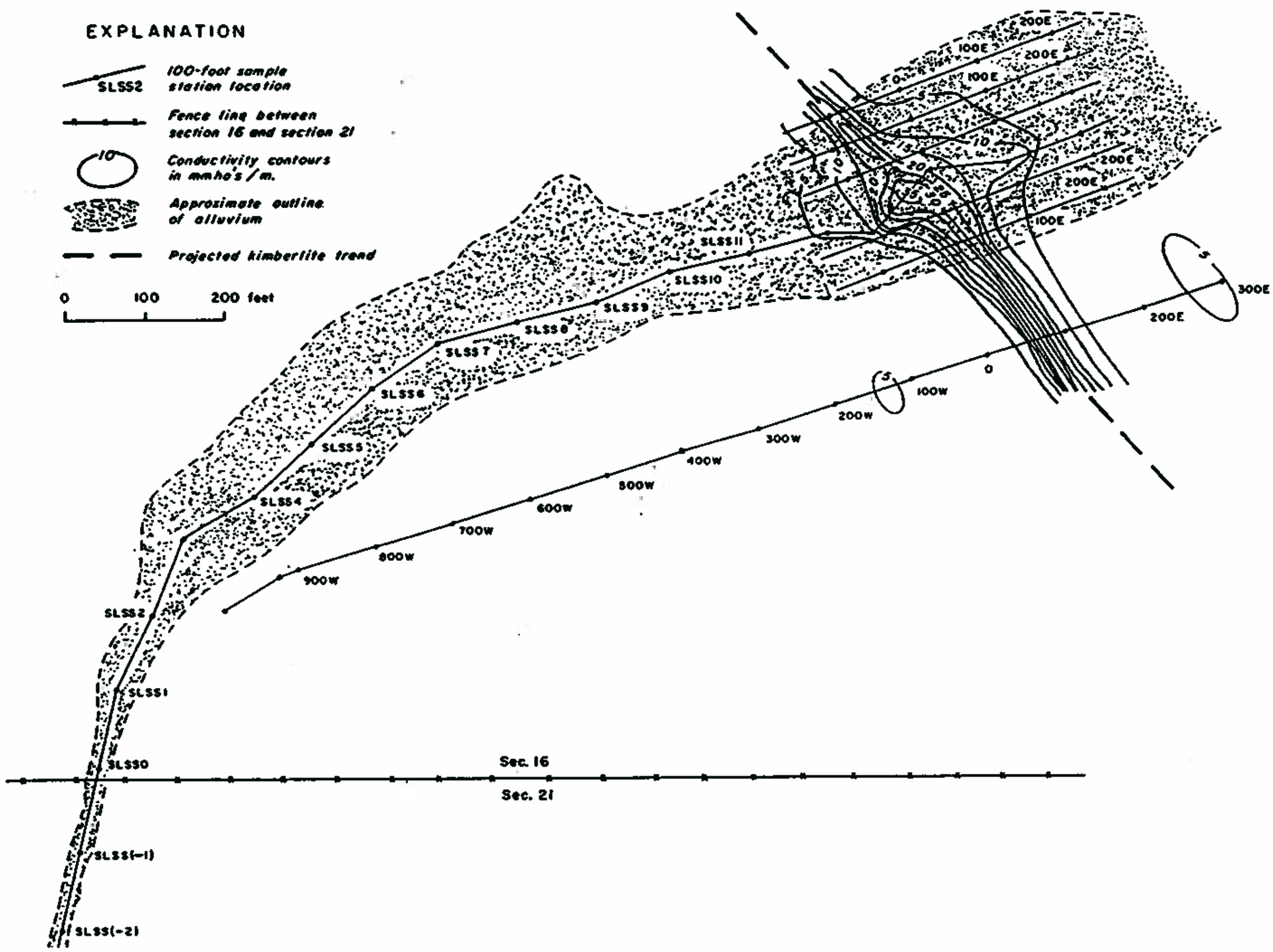


Figure 7.20: Mapped conductivity over the projected kimberlite trend at the State Line District, Wyoming indicating the existence of a kimberlite dyke connecting two known pipes. Conductivities measured in millimhos/m (note that 1 mho = Ω^{-1} and that the present name for this unit is now 1 siemens).

the earth. However, the gravitational force decays according to the reciprocal of the square of the distance away from the source body. As a result, a high density body will be undetectable if the point at which the measurements are made are sufficiently far from such body. Further, a more distant, but large object will produce the same effect as a closer and smaller object.

Gravity surveys consist of measuring small variations in the acceleration of gravity, which are of the order of 100 $\mu m/s^2$ from the normal near 9.80 m/s^2. The instruments used are typically accurate to a fraction of 1 mgal where a milligal is 10^{-3} cm/s^2. Gravity surveys are time consuming and expensive because they require a number of different corrections, one of which is the accurate determination of the station elevation needed in the calculation of the final Bouguer anomaly. As such, gravity methods are most useful during the evaluation of a prospect, rather than during the earlier stages of reconnaissance exploration. Gent (1992) suggested that the existing regional gravity surveys (see Chapter 5) might be useful in delineating targets. However, despite good coverage at over 7,000 stations in Alberta, the average spacing of these gravity data, which are available for purchase from the Geological Survey of Canada, is of the order of a few kilometres and is probably of too low a resolution for identification of alkaline diatremes.

As kimberlite is an ultramafic material, the density of nonporous crystalline kimberlite should be nearly 3 g/cm^3, but this is potentially lowered in proportion to any porosity that might be produced by processes such as vesiculation. In Lesotho, Nixon (1980b) reported that hardebank kimberlite has a specific gravity of about 2.75 g/cm^3. Gerryts (1970) suggested that densities as low as 2.3 g/cm^3 were seen in early work in the U.S.S.R., although in this latter work the character of the kimberlite is not described. In contrast, the breccias and tuffs associated with kimberlite vents will necessarily be of much lower density because they will contain substantial porosity. Furthermore, weathered kimberlite or epiclastic sediments in the vent crater would also be expected to have a lower density, with a large range of difficult to predict values. The kimberlite or lamproite vent might then be described in terms of a low density, conically shaped volume overlying a number of higher density and deeper kimberlite dykes and sills (see Figure 1.1 which illustrates the geology of the vents). In this case, the gravity signature would then be a localized Bouguer gravity negative anomaly of a fraction of a mgal. This signature would result from the low density shallow material, and would be superimposed on a broader positive gravity high due to the higher density material at depth.

Their are few published gravity surveys results that relate directly to kimberlite exploration. In general, regional gravity surveys appears to have little application towards kimberlite exploration (Atkinson 1989), although Jennings (1990) suggested that kimberlites may appear along a regional positive gravity expression indicative of the upper hinge of a crustal flexure. Burley and Greenwood (1972), as reported in Nixon (1980b), show such a gravitational response over a kimberlite pipe in Lesotho (Figure 7.21). In Figure 7.21 the increasing response to the west of the satellite kimberlite was suggestive of dense kimberlite dyke material at depth which was confirmed by drilling.

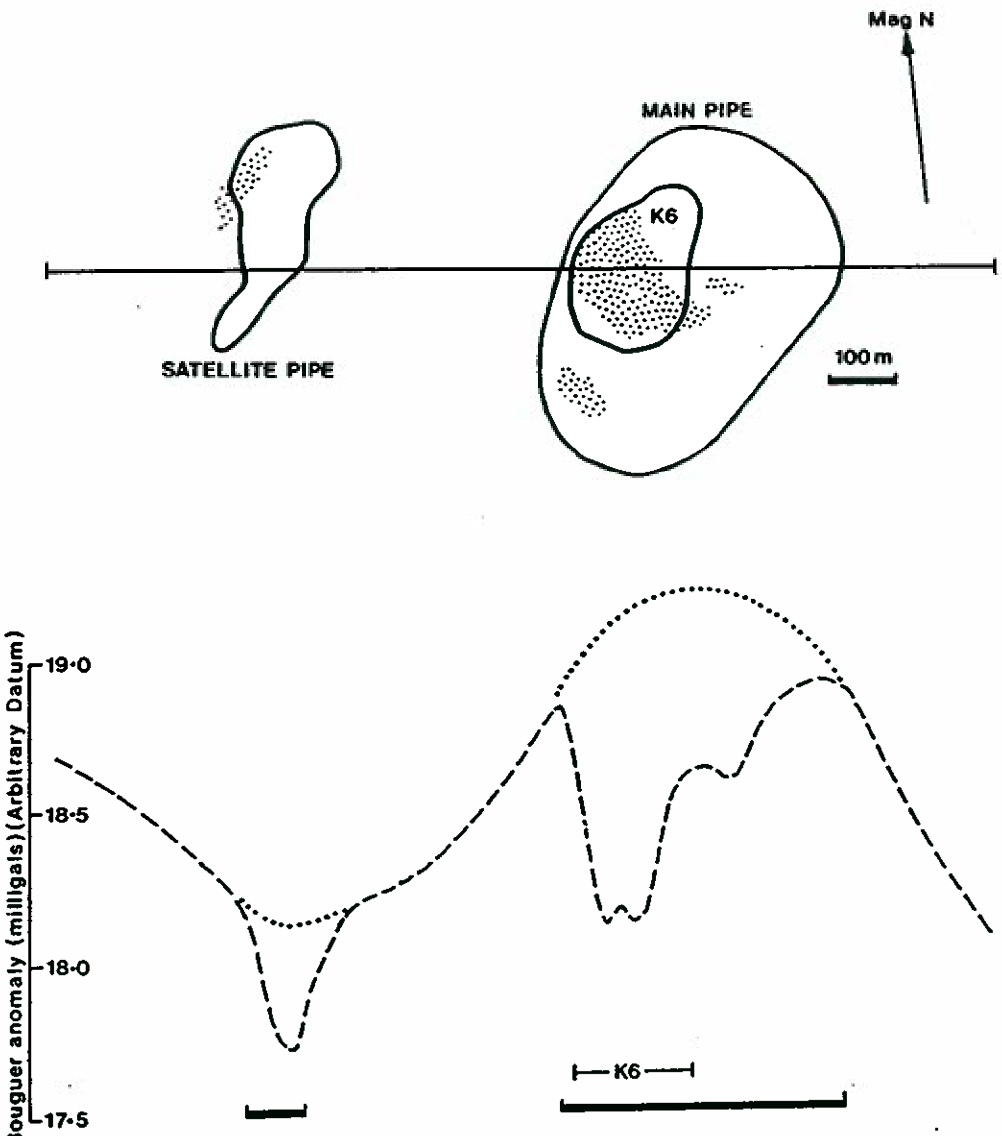


Figure 7.21: Plan view of kimberlite pipes intruded into basalt in Lesotho. Magnetic anomalies in excess of 3,000 nT are shown in stipple. Corresponding Bouguer gravity anomaly along profile. Lower values are seen where the line crosses the outcropping kimberlites (Nixon 1980b).

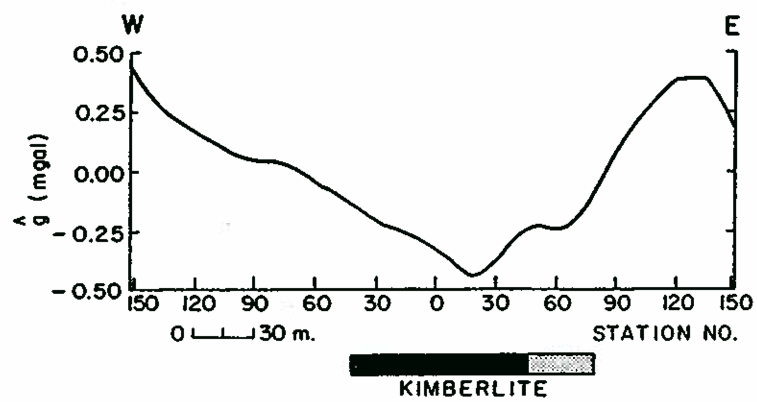


Figure 7.22: Profile of Bouguer anomaly over the Maxwell 1 kimberlite in the State Line District of Colorado and Wyoming (Carlson 1984).

Gerryts (1970) reported on studies carried out in the U.S.S.R. and in Tanzania. In the U.S.S.R., gravity measurements were able to point out the presence of blind pipes beneath trap lavas on the basis of negative Bouguer anomalies. In Tanzania, the kimberlite pipes reside in a host of metamorphic rocks. The low Bouguer values observed over the Tanzanian pipe are in very good agreement with the response expected for a contrast in densities between these metamorphic rocks and the lighter epiclastic sediments within the kimberlitic crater.

In the State Line District of Colorado and Wyoming, Hausel *et al.* (1979) indicated that gravity surveys are not expected to be successful due to the fact that the serpentinized kimberlite in the area has a density very close to that of the host granites. However, Carlson *et al.* (1984) detected a small negative Bouguer anomaly (Figure 7.22) associated with the surface expressions of the Maxwell 1 kimberlite pipe, which is located near the Schaffer pipe cluster described earlier. Despite this observation, Carlson *et al.* (1984) concluded that most of the kimberlite pipes were not distinguished in the gravity field in this area.

In Arkansas, Bolivar and Brookins (1979) commented that a small gravity anomaly of 0.5 mgal (sign not given) was observed over the Prairie Creek Intrusive, but they did not further elaborate on the possible source of the anomaly.

Finally, in Alberta there are no studies known to the author for gravity responses of alkaline diatremes.

7.2.6 Seismic Measurements

Seismic measurements are sensitive to the speed at which seismic sound energy propagates through the earth. The goal of seismic measurements are essentially to define the geologic structure in terms of the seismic velocities. As with gravity and contact resistivity methods, and in consideration of the fact that diatremes are relatively small bodies, seismic methods would most likely be used in follow-up exploration or detailed prospect evaluation.

Seismic velocities are not simple to predict and depend on a large number of factors, such as the mineralogical composition of the rock, the porosity and shape of the pores, and the fluid content. Nonporous ultramafic rocks have high seismic compressional wave velocities from 7.5 km/sec to 8.5 km/sec, which exceeds the velocities in mafic (6.5 km/sec to 7.0 km/sec) and siliceous (5.5 km/sec to 6.0 km/sec) rocks. Sedimentary rocks typically are of even lower velocities; commonly, seismic velocities range from a high of 6.5 km/sec for a well consolidated dolomite to more typical values between 2 km/sec to 3 km/sec for shales and sandstones. Unconsolidated or weakly consolidated materials typically have the slowest velocities, which range from only a few hundred metres per second to 2.0 km/sec.

The components of a kimberlite pipe will exhibit different velocities. For example, the breccias might be expected to have high porosity and low velocity, as might the epiclastic sediments that are deposited into the crater. These materials will also often be differentially weathered. An additional complication is that the hardebank kimberlite will often have a porosity and, consequently, be of lower velocity than would be expected on the basis of its mineral content only. Burley and Greenwood (1972) found that weathered kimberlite has velocities which increase with depth from 900 m/sec to 1,620 m/sec, whereas unweathered kimberlite show velocities from 2,900 m/sec to 4,200 m/sec. Hausel *et al.* (1979) stated that weathered kimberlite have velocities from 670 m/sec to 1,590 m/sec, with a velocity of 3,529 m/sec in the dense kimberlite. The low velocities indicate there is a porosity in the kimberlite rock that results either from weathering or from original primary porosity due to gas exsolution.

The kimberlite material velocities described above were determined in seismic refraction experiments (Kearny and Brooks 1991). In addition to providing a measure of the velocities, refraction measurements are useful in delineating horizontal structure and in the experiments above were used to determine the depths of the weathering layers.

In contrast, reflection seismics use the reflections of sound from differing geologic materials to produce an image of the subsurface. Reflection seismic profiles can be useful in aiding the description of the geologic structure. However, the quality of these images will depend on a number of factors, including the parameters selected in processing the seismic data. This last factor is especially crucial when a complex structure, such as a diatreme which includes many discontinuous interfaces and steeply dipping reflectors, is to be imaged.

Gent (1992) described a seismic reflection profile across a seismic anomaly that results from an as yet indeterminate structure in southwestern Saskatchewan that is known as the Maple Creek structure. This structure is associated with a broad magnetic high and a 3 mgal gravity anomaly which Gent (1992) suggested can only be associated with an intrusive body. The reflection seismic profile over these magnetic and gravity anomalies shows considerable faulting and tilting of the sedimentary horizons, and a loss of continuity in the reflections. Strong reflections are returned from lower sedimentary layers with two way travel times in excess of 1.0 seconds, but these show possible 'pull up' effects which could be a consequence of shallow material with a higher velocity than the normal sedimentary column. Shallow drilling over the anomaly was carried out in 1993 in order to test Gent's (1992) interpretation of this structure as a possible diatreme. Drilling to approximately 150 m depth showed a large uplift of the normal sedimentary sequences by 90 m (D. Gendzwil, personal communication). The uplifted sediments do not confirm the existence of a diatreme, but could be consistent with a deep intrusion.

More recently, high resolution reflection seismic profiles were conducted over a known diatreme in the Fort à la Corne area of Saskatchewan. The preliminary findings were reported at a recent public meeting of the Saskatchewan Geological Survey and will soon be published (D. Gendzwill, personal communication). The profiles are suggestive of an intrusion with breccia and crater phases; this complex structure is approximately 1 km in diameter. The structure is complex in the reflection profile, with numerous discontinuities suggested by scattered seismic energy and with velocity 'pull up' effects seen. These velocity pull up effects are a consequence of the higher velocity of 4.5 km/sec of the igneous material which is 18% porous. Cores indicate a layering of igneous rock with interbedded shales, which indicates that volcanism and sedimentary deposition were coeval; these layering effects are apparent in the seismic section. It must be noted, however, that such detail was only obtained by conducting a higher resolution reflection profile than would normally be carried out.

Regional prospecting for diatremes with reflection seismic profiles is not practical due to the diatremes relatively small size and proximity to the surface. However, one feature of the Western Canada Sedimentary Basin that is distinctive in seismic profiles and is a potential indicator for volcanic activity, are the salt solution collapse structures in which overlying sediments are disturbed by the dissolution of the deeper Prairie Evaporites. This results in the formation of a sinkhole filled with breccias of the original sedimentary layers, together with further sedimentary deposition. These features may be of interest to kimberlite exploration in Alberta, because Gent (1992) described a number of these structures in Saskatchewan and suggested a possible, but unproven, link between some of them and diatreme activity. As a result of this geologic complexity, salt solution collapse structures are typically distinguished in seismic profiles by a loss of continuity of the normal sedimentary layering. Examples of seismic profiles over salt solution collapse structures may be found in Anderson *et al.* (1989).

Seismic reflection profiles that are acquired in exploration are normally considered proprietary information and there is no formal public archive for these data in Alberta. However, there are numerous seismic data brokers in Alberta who may be able to supply seismic profiles over previously explored regions of interest.

7.2.7 Radiometric Surveying

Kimberlites are enriched in K, U and Th and, on this basis, could be expected to have a radioactive signature. Leucite bearing lamproites also have high concentrations of K. As a result, radiometric surveys may show some promise in the detection of kimberlite and lamproites. Published findings of relevant radiometric studies, however, are rare.

Nixon (1980b) indicated that laboratory radiometric measurements on approximately 100 kimberlites were disappointing. The only samples which gave a positive response were those containing phlogopite (a potassic mica) and crustal basement xenocrysts. In the field, thin layers of soil were sufficient to mask any radiometric signal. Paterson *et al.* (1977) suggested that airborne spectrometer information was a useful diagnostic as a follow-up role to magnetometer surveys for kimberlites in Lesotho.

Hausel *et al.* (1979), however, could not distinguish the kimberlites in the State Line District of Colorado and Wyoming from the surrounding granites because both produced similar scintillometer counts. In this same region, Carlson and Marsh (1986) indicated neither total count radioactivity surveys nor differentiating gamma ray spectrometer surveys (Carlson *et al.* 1984) were effective due to variations of overburden thickness and host rock radioactivity.

Atkinson (1986) indicated that the success of radiometric surveying in Australia was highly dependent on the amount of exposure or cover, in addition to the dimensions and radioactivity of the lamproite. In their study, only 6 of the 26 pipes which were detected at the Ellendale field by magnetics and electromagnetics, showed any radiometric response and all of these were large (> 7 ha) bodies that had no surface cover.

Finally, Gent (1992) suggested that an airborne radiometric survey whose intent was to search for dispersed kimberlitic material in the overburden in Saskatchewan, was unsuccessful.

7.2.8 Borehole Geophysics

Gamma-ray log information from hydrocarbon wells may be used as an aid in exploring for kimberlites and lamproites. Group I kimberlites can contain up to 2% K_2O by volume, and lamproites typically contain 6% to 8% K_2O by volume. Due to the presence of radioactive potassium-40 (K^{40}), these rocks and their associated tuffs will give strongly positive responses on a gamma-ray log. In Alberta, the presence of kimberlites or lamproites that have intruded subaqueously may be detected, indirectly, by intersecting the genetically related bedded volcaniclastics near the site of an alkaline diatreme or, more distally, by intersecting anomalously thick bentonite beds within the stratigraphic column.

7.3 Coal, Oil And Gas Well Databases

The province of Alberta has seen considerable past drilling activity, both in coal and oil/gas exploration. In these endeavours, the acquisition of downhole geophysical information has almost been a routine process, although there is considerable variation in the type and detail of geophysical information which was obtained. Alberta regulatory considerations have required the submission of these data to the Energy Resources Conservation Board (ERCB) as part of an assessment process. The downhole geophysical data are then reduced to microfiche format and compiled into separate coal and oil/gas databases. A card index is available for the oil/gas wells. This index lists key information on each particular well, including: kelly bushing elevation, coordinates, elevation tops to key horizons, and production and testing information. This information is available for public use after a suitable period of confidentiality and can be obtained at the ERCB or other government agencies such as the Alberta Geological Survey.

An additional source of information is the Alberta Geological Survey's (AGS) coal relational (INGRES) data base (Richardson *et al.* 1989). This database contains a wealth of information on past coal exploration in Alberta, including details such as coal geophysical 'picks', petrography, palynology, geophysical log type used, structural geological information and borehole coordinates. Appendices 4.1 and 4.2, and Table 4.2, contain examples of output from selective queries on this database. For those with an interest, commercial queries are conducted on a cost recovery basis with simple requests expected to cost a few tens of dollars. More complex requests can be negotiated with the Alberta Research Council.

As mentioned previously, the coal and oil/gas information can complement one another due to the different technical considerations in setting casing depths during a drilling program. Of primary concern for the explorationist is the use of gamma, density, caliper, resistivity and, to a lesser extent, sonic and neutron geophysical logs in the detection and correlation of volcanic or bentonitic horizons in the subsurface. A search of the microfiche data files can be optimized if particular attention is paid to these geophysical log types. However, care must be taken in picking top and base depths to a prospective horizon and the reader is encouraged to review some of the texts on well log interpretation that are listed in the references at the end of this report.

7.4 Bentonites as a Tool for Diatreme Exploration

Bentonites are a diagenetic product of volcanic ashfall and as such may provide a pointer mechanism to the source of volcanic activity. Their unique response to gamma log downhole geophysical surveying, and their relatively easy recognition in cuttings and core samples provide a convenient tool for identification of periods of volcanic activity in a sedimentary basin. Providing diagenesis is not extreme, the bentonites should also provide clues to the original geochemistry of the source volcanism. In particular, they should contain sufficient indicator mineralogy to reflect the somewhat unique chemistry of kimberlites and lamproites. Unlike regionally distributed and widespread thin ashfall tuffs that are genetically related to distal volcanic sources, such as, for example, the Kneehills Tuff bentonite deposit, a more proximal tuff would be areally limited, with an uneven and irregular thickness distribution. The shape of such proximal deposits may be lensoid, lobate, lenticular or various other irregular forms. In addition, the tuffs may be interconnected with numerous diatremes or volcanic vents (e.g., in Saskatchewan). However, one must evaluate thickness distribution and shape with care, because these ashfall deposits are susceptible to reworking by later sedimentary processes. Nonetheless, an association with a geologically favourable prospective horizon (e.g., the Fish Scales Horizon in Saskatchewan) or favourable indicator mineral geochemistry may allow some bentonites to be a most effective prospecting tool.

7.5 Remote Sensing

Remote sensing in the search for kimberlites has been discussed by a number of authors in the context of either delineating regional or local structures, or by directly detecting kimberlites based on their reflectance character.

Nixon (1980b) detailed a Landsat study of Lesotho by Barthelemy and Dempster (1975) that located numerous regional lineaments. In particular, kimberlite pipes were observed to exist at the intersection points of regional lineaments. He (Ibid) suggested that a few kimberlites could be detected in this manner, but that over all of southern Africa the locations of the clusters of pipes appeared to be more controlled by the deep-seated spacings of diapirs and not by the crustal framework alone. In short, the Landsat satellite images were useful as a structural mapping tool and not for direct indentification of kimberlites. Similar studies and results are described by Woodzick and McCallum (1984).

Hausel *et al.* (1979) described the use of both air photography and satellite imagery in finding lineaments in the State Line District in Wyoming. Some of the diatremes were directly apparent in the low altitude colour photographs (1:24,000 scale), and especially in the differing colours of the diatreme material which contrasted markedly with the surrounding reddish granite. Another interesting observation made by Hausel *et al.* (1979) is that the ground cover over the diatremes contains substantially more clay than the weathered products over the granites, and this results in noticeable changes in the vegetation which may easily be observed in air photography. Such observations were also made by Jones (1970) who noted that dense stands of alder and larch grew in kimberlitic soils in the Daldyn region of the former U.S.S.R.

Longman (1980), however, described a study in which multispectral Landsat data allowed detection of additional potential kimberlite targets after calibration over a known kimberlite in Australia. An additional constraint with these type of measurements is that often an extensive calibration of the ground reflectance is required in order to correlate geologic features and spectral reflectance character. Kingston (1986), for example, described preliminary measurements of the reflective properties in the optical and infrared portions of the spectrum (0.4 to 2.5 µm) of carbonatites and kimberlites and found that the former were detectable at two locations in Colorado and California. However, the associated alkaline rocks were not distinguishable on the basis of the spectral reflectance signature.

At present, the remote sensing field is advancing rapidly. This is due to the high resolution satellite images that have become commercially available from previously confidential military sources. Advances in computing speed and image processing capabilities have also been rapid, and the inclusion of such data into GIS information databases is not difficult. Although there has been little data published pertinent to diamond exploration, these recent developments will undoubtedly make remote sensing more important for future diamond exploration purposes.

8. CONCLUSIONS

The primary objectives of this study were to identify favourable geological anomalies and target areas for diamond exploration that would act to encourage industry to explore in Alberta, and to provide selected geological, geophysical and geochemical data that would assist industry in their exploration for diamonds in Alberta. We believe the foregoing text, figures, tables and appendices have provided much information and data that will be useful to industry.

Alberta is favourable for diamondiferous deposits because:

(a) Alberta is underlain by large areas of Precambrian crust that acted as 'cool roots', hence there is a good possibility that diamond-bearing source rocks exist at least locally in the mantle beneath Alberta (Figures 1.3 and 2.2).

(b) Alberta contains major faults and other tectonic features that may have acted as near surface conduits for the intrusion of diamond-bearing kimberlitic or lamproitic diatremes (Figures 2.4, 5.4 and 5.5; Table 2.2).

(c) Kimberlite and lamproite intrusions, several of which are diamondiferous, exist in several provinces, territories and states adjacent to or near Alberta (Figure 3.1). Although at present no definite kimberlite or lamproite intrusions have been definitely reported in Alberta, with the exception of the Mark 1 diatreme cluster which straddles the Alberta - British Columbia border north of Golden, B.C. (Pell 1987b, Fipke 1990), there are indications, or at least rumours, that such diatremes have been found in outcrop or intersected by drilling west of Hinton and near Peace River Alberta (Fipke 1990, Olson *et al.* 1994). In southern Alberta, although Kjarsgaard (1994a, b) suggested the region of the Sweetgrass Intrusions has low diamond potential because the intrusions which crop out in Canada are predominantly or entirely minettes, there may still be potential for diamondiferous deposits in this area because of the interpreted extensive dyke swarm that has been identified from recently published aeromagnetic data (Teskey *et al.* 1994, Ross *et al.* 1994b). As well, two diamonds were reported to have been discovered at Etzikom Coulee near Legend in southern Alberta not far north of where the Sweetgrass Intrusions crop out (Figure 6.26) (Olson *et al.* 1994). Furthermore, in the Missouri Breaks and Smoky Butte region of central Montana, age equivalents to the Sweetgrass Intrusions locally include kimberlitic and lamproitic diatremes (Hearn 1989).

(d) There is evidence of at least four, and possibly five, ages of volcanic activity in Alberta (Table 3.2). Diamondiferous diatremes of equivalent ages exist elsewhere in North America or the world. It is possible that the most important of the igneous events in Alberta occurred during the early Late Cretaceous, that is during deposition of the Shaftesbury Formation and the enclosed Fish Scales Horizon, because diamondiferous diatremes, vent facies and volcaniclastics have been found in stratigraphically equivalent successions in Saskatchewan. In addition, early Tertiary strata (Paleocene, Eocene) in Alberta should also not be ignored because the reported ages for the potentially economic diatremes that have been discovered in the Lac de Gras region of the N.W.T. are about 52 Ma.

(e) Numerous bentonites and tuffs exist in the Phanerozoic succession in Alberta, and in several places there are anomalously thick bentonitic horizons (e.g., Drumheller, Duagh and Irvine-Bullshead bentonites), some of which are localized and have a trend that crosses the major sedimentary depositional strike. This may indicate local volcanic venting as opposed to the bentonites being wind-blown debris derived entirely from outside Alberta (Figures 4.1, 4.2, 4.12 and 4.18). Interestingly, all of the above thick bentonites are of late Late Cretaceous age, which is perhaps the most extensive and voluminous period of diamondiferous magmatism in the world (Dawson 1989).

(f) There are numerous diamond indicator mineral anomalies at several places within Alberta, with some indicator grains having excellent chemistry which indicates they may have been derived from local kimberlitic or lamproitic diatremes (Figures 6.20 to 6.26). As well, diamonds have been found in drift or fluvial sediments in at least three publicized locales in southern and central Alberta (Figure 6.26).

(g) There are a large number of geological, geophysical or geochemical anomalies in Alberta, at least some of which may have been or are related to emplacement of potentially diamondiferous kimberlitic or lamproitic diatremes, or reflect erosional secondary deposits derived from such primary diamondiferous source rocks (Figures 2.4, 2.5 and 6.44; Tables 2.2 and 6.2).

(h) Lastly, although much remains to be known about the bedrock and surficial geology of Alberta, particularly in the northern half of the province, there exists an extensive geological and geophysical database of information that is available from various government agencies or from brokers of industry-generated data (e.g., Figures 2.1, 2.3, 6.1, 7.1, 7.2, 7.3, 7.4 and 7.6; Tables 2.1, 2.2, 4.2, 6.1, 6.2 and 7.1; Appendices 4.1, 4.2, 6.1A, 6.1B and 6.2).

In conclusion, the above indicates that Alberta has at least moderate to, possibly, high potential to contain diamondiferous diatremes and vent-related deposits, yet at present the province has been barely explored for such deposits, even though extensive staking has occurred (Figure 1.4). As well, if primary diamondiferous deposits are found in Alberta, then exploration should also be directed towards the discovery of secondary diamondiferous deposits in selected sedimentary strata which are geologically analogous to the setting found to contain such economically important secondary deposits in southern and western Africa, and in Russia.

9. REFERENCES

Adair, R. 1986. The pyroclastic rocks of the Crowsnest Formation, Alberta; unpublished M.Sc. thesis, University of Alberta.

Afanasev, V.P., Varlamov, V.A. and Garanin, V.K. 1984. The abrasion of minerals in kimberlites in relation to the conditions and distance of their transportation; Geol. Geofiz., vol. 25, pp. 119-125.

Afanasev, V.P. and Yanygin, Y.T. 1983. Buried primary dispersion streams of kimberlite bodies in the Malobutuobinsk region; Geol. Geofiz., vol. 24, pp. 85-90.

Aitken, J.D. and McMechan, M.E. 1992. Middle Proterozoic Assemblages, *In* H. Gabrielse and C.J. Yorath (ed's). Geology of the Cordilleran Orogen in Canada. Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada.

Alabi, A.O., Camfield, P.A. and Gough, D.I. 1975. The North American central plains conductivity anomaly. Geophys. J. R. Astr. Soc. vol. 43, pp. 815-833.

Allan, J.A. 1944. Volcanic ash or pumicite southwest of Nanton, Twp. 13, R2W5M, 82J/1, Alberta; Alberta Research Council Economic Minerals File VOL-IR-03, 1 p.

Allsopp, H.L. and Barrett, D.R. 1975*. Rb-Sr determinations on South African kimberlite pipes; Physical Chemistry, vol. 9, pp. 615-617.

Allsopp, H.L., Bristow, J.W., Smith, C.B., Brown, R., Gleadow, A.J.W., Kramers, J.D. and Garvie O.G. 1989*. A summary of radiometric dating methods applicable to kimberlites and related rocks; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement. Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 343-357.

Allenby, R.J. and Schnetzler, D.D. 1983. United States Crustal Thickness. Tectonophysics, vol. 93, pp. 13-31.

Amajor, L.C. and Lerbekmo, J.F. 1980. Subsurface correlation of bentonite beds in the Lower Cretaceous Viking Formation of south-central Alberta; Bulletin of Canadian Petroleum Geology, vol. 28, pp. 149-172.

* **References identified with an asterisk were used to compile ages of kimberlite or lamproite diatremes in Table 3.1**

Amajor, L.C. 1985. Biotite grain size distribution and source area of the Lower Cretaceous Viking bentonites, Alberta, Canada; Bulletin of Canadian Petroleum Geology, vol. 33, no. 4, pp. 471-478.

Anderson, D.L. and Dziewonski, A.M. 1984. Seismic tomography. Scientific American pp. 60-68.

Anderson, D.L. 1989. Theory of the Earth. Blackwell Scientific Publications, London.

Anderson, N.L., Hills, L.W., and Cederwall, D.A. 1989. Geophysical Atlas of Western Canadian Hydrocarbon Pools. Can. Soc. Expl. Geophys./Can. Soc. Petrol. Geol., Calgary. pp. 343.

Anderson, D.L. and Bass, J.D. 1986. Transition region of the Earth's upper mantle. Nature, vol. 320, pp. 321-328.

Andriashek, L.D. and Fenton, M.M. 1989. Quaternary Stratigraphy and Surficial Geology of the Sand River area 73L. Alberta Research Council Bulletin 57, 154 pp.

Andrichuk, J.M. 1958. Stratigraphy and facies analysis of Upper Devonian reefs in Leduc, Stettler and Redwater areas, Alberta; American Association of Petroleum Geologists Bulletin, vol. 42, pp. 1-93.

Anglin, F.M. and Beck, A.E. 1965. Regional heat flow patterns in western Canada. Canadian J. Earth Sci., vol. 2, pp. 176-182.

Apter, D.B., Harper, F.J., Wyatt, B.A. and Smith, B.H.S. 1984*. Geology of the Mayeng kimberlite sill complex, South Africa; *In* J. Kornprobst (ed.), Kimberlites, I: Kimberlites And Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, pp.43-58.

Armitage, A.E., McRae, N.D. and Miller, A.R. 1994. Diamond-bearing potential of alkaline dykes in the Gibson Lake area, District of Keetwatin, Northwest Territories; Posters session of the third Geological Survey of Canada Minerals Colloquim, Ottawa, Ontario, January 17, 1994.

Asquith, G. with Gibson, C. 1982. Basic well log analysis for geologists; In: Methods in Exploration Series, American Association of Petroleum Geologists. 216 pp.

Atkinson, W.J. 1989. Diamond exploration philosophy, practice, and promises: A review; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds and Diamond Exploration, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 1075-1107.

Atkinson, W.J., Hughes, F.E. and Smith, C.B. 1984*. A review of the kimberlitic rocks of Western Australia; *In* J. Kornprobst (ed.), Kimberlites, I: Kimberlites And Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, pp. 195-224.

Babet, P.H. 1966. Some characteristics of bentonite in Alberta. Alberta Research Council Report 66-2, 25 pp.

Bachu, S. 1988. Analysis of heat transfer processes and geothermal pattern in the Alberta basin, Canada. Journal of Geophysical Research vol. 93, pp. 7767-7781.

Ballantyne, S.B. and Harris, D.C. 1994. The exploration significance of central Alberta Modern and Tertiary alluvial platinum group minerals, chromites, ilmenites and placer gold; Unpublished Abstract and Table of Micropobe Data Provided at the The Calgary Mining Forum, February 10 & 11, 1994.

Bally, A.W., Gordey, P.L. and Stewart, G.A. 1966. Structure seismic data and orogenic evolution of southern Canadian Rocky Mountains; Canadian Journal of Earth Sciences, vol. 22. pp. 384-398.

Barclay, J.E., Krause, F.F., Campbell, R.I. and Utting, J. 1990. Dynamic casting of a Graben Complex: Basin infill and differential subsidence during the Permo - Carboniferous; Peace River Embayment, Western Canada. Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 115-145.

Barendregt, R.W., Irving, E., Karlstrom, E.T. 1991a. Paleomagnetism of Quaternary and late Tertiary sediments on Mokowan Butte, southwestern Alberta. Canadian Journal of Earth Sciences, vol. 28, pp. 1956-1964.

Barendregt, R.W., Thomas, F.F., Irving, E., Baker, J., Stalker, A. MacS., and Churcher, C.S., 1991b. Stratigraphy and paleomagnetism of the Jaw Face section, Wellsch Valley site, Saskatchewan. Canadian Journal of Earth Sciences, vol. 28, pp. 1353-1364.

Barr, K.G. 1971. Crustal refraction experiment: Yellowknife 1966. J. Geophys. Res. vol. 76, pp. 1929-1947.

Barthelemy, R. and Dempster, A.N. 1975. Geological interpretation of the ERTS-1 satellite imagery of Lesotho, and possible relations between lineaments and kimberlite pipe emplacement. *In* Proc. 10th Int. Symp. Remote Sensing Environ. Ann Arbor. II: pp. 915-921.

Barton, R.H., Christiansen, E.A., Kupsch, W.P., Mathews, W.H., Gravenor, C.P. and Bayrock, L.A. 1964. Quaternary. *In* McGrossan, R.G. and Glaister, R.P. (ed's). Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, pp. 195-200.

Basu, A.R., Rubury, E., Mehnert, H. and Tatsumoto, M. 1984*. Sm-Nd, K-Ar and petrologic study of some kimberlites from eastern United States and their implication for mantle evolution; Contributions to Mineralogy and Petrology, vol. 86, pp. 35-44.

Basu, A.R. and Tatsumoto, M. 1979*. Sm-Nd systematics in kimberlites and in the minerals of garnet lhezolite inclusions; Science, vol. 205, pp. 388-390.

Bates, R. L. and Jackson, J.A. 1987. Glossary of Geology; 3rd Edition, American Geological Institute 788 pp.

Baykal, O. 1968a. Exploration Permit 16, McGregor Telephone and Power Construction Company Limited, photogeologic mapping report; Alberta Research Council, Assessment File CU-AF-009(1).

Baykal, O. 1968b. Exploration Permit 35, McGregor Telephone and Power Construction Company Limited, geological report; Alberta Research Council, Assessment File AG-AF-001(1).

Bayrock, L.A. 1962. Heavy minerals in till of central Alberta; Alberta Society of Petroleum Geologist Journal, v. 10, pp. 171-184.

Beach, H.H. 1942. Moose Mountain, Alberta. Geological Survey of Canada Map 688A.

Beaumont, E.A. and Foster, N.H. 1989. Geophysics IV - Gravity, Magnetics, and Magnetotelluric Methods, Treatise on Petroleum Geology Reprint Series, No. 15, Amer. Assoc. Petrol. Geol., Tulsa, 255 pp.

Bednarski *et al.* In Press.

Bell, J.S. and Babcock, E.A. 1986. The stress regime of the Western Canadian Basin and implications for hydrocarbon production. Bulletin of Canadian Petroleum Geology, vol. 34, no. 3. pp. 364-378.

Benvenuto, G. and Price, R.A. 1979. Structural evolution of the Hosmer Thrust sheet, southern British Columbia; Bulletin of the Canadian Society of Petroleum Geologists, vol. 7. pp. 360-394.

Bergman, S.C. 1987*. Lamproites and other potassium-rich igneous rocks: a review of their occurrence, geochemistry and mineralogy. *In* Fitton, J.G. and Upton, B.J.G., (eds.), The Alkaline Igneous Rocks. Geol. Soc. Lond., Spec. Publ., pp. 103-109.

Berry, M.J. 1973. Structures of the crust and upper mantle in Canada. Can. J. Earth Sci. vol. 10.

Binda, P.L. 1969. Provenance of the Upper Cretaceous Kneehills Tuff, Southern Alberta; Canadian Journal of Earth Science, vol. 6, pp. 510-512.

Bingham, D.K., Gough, D.I. and Ingham, M.R. 1985. Conductive structures under the Canadian Rocky Mountains; Canadian Journal of Earth Sciences, vol. 22, pp. 84-398.

Birnie, T.A. 1961. Normal faulting in the Indianhead Creek area, Alberta; Alberta Society of Petroleum Geologists, vol. 9, pp. 331-342.

Bloch, J., Schroder-Adams, C., Leckie, D.A., McIntyre, D.J., Craig, J. and Staniland, M. 1993. Revised stratigraphy of the lower Colorado Group (Albian to Turonian), Western Canada; Bulletin of Canadian Petroleum Geology, vol. 41, pp. 325-348.

Bloy, G.R. and Hadley, M.G. 1989. The development of porosity in carbonate reservoirs; Canadian Society of Petroleum Geologists Continuing Education Short Course.

Bobrowsky P. and Rutter N.W. 1992. The Quaternary geologic history of the Canadian Rocky Mountains. Géographie physique et Quaternaire, vol. 46, pp. 5-50.

Bohor, B.F. and Triplehorn, D.M. 1993. Tonsteins: Altered volcanic-ash layers in coal-bearing sequences; Geological Society of America Special Paper 285, 44 pp.

Bolivar, S.L. and Brookins D.G. 1979. Geophysical and Rb-Sr study of the Prairie Creek, AK kimberlite, in H.O.A. Meyer and F.R. Boyd, (eds.), Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry, Proc. 2nd Int. Kimberlite Conf. Volume 1, American Geophysical Union, Washington, pp. 289-299.

Bostock, H.J. 1970a. Physiographic regions of Canada. Geological Survey of Canada Map 1254A, 1:5,000,000 scale.

Bostock, H.J. 1970b. Physiographic subdivisions of Canada. In: Geology and Economic Minerals of Canada, R.J.W. Douglas (ed.) Geological Survey of Canada, Economic Geology Report 1, Chapter II., pp. 11-30.

Boyd, F.R. 1989. Compositional distinction between oceanic and cratonic lithosphere. Earth and Planet. Sci. Lett., vol. 96, pp. 15-26.

Boydell, A.N. 1972. Multiple glaciations in the Foothills Rocky Mountain House area, Alberta, Ph.D. thesis, University of Calgary, 127 pp.

Boydell, A.N. 1978. Multiple glaciations in the Foothills Rocky Mountain House area, Alberta, Alberta Research Council Bulletin 39, 35 pp.

Brandley, R.T. and Krause, F.F. 1993. Carbonate and siliciclastic deposition on a wave-swept, cold-water, low-latitude ramp: Lower Carboniferous Mount Head Formation, southwestern Alberta, Canada; Canadian Society of Petroleum Geologists Reservoir, vol. 20, pp. 1-2.

Brandley, R.T. Thurston, J. and Krause, F.F. 1993. Basement tectonic control on carbonate ramp deposition: Lower Carboniferous Mount Head Formation, Southwest Alberta and Southeast British Columbia; *In* Ross, G.M. (ed.), *Lithoprobe Alberta Basement Transect Workshop*, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 98-118.

Brookins, D.G. 1970*. The kimberlites of Riley County, Kansas; Kansas Geological Survey Bulletin 200.

Brookins. D.G. and Naeser, C.S. 1971*. Age of emplacement of Riley County, Kansas kimberlites and a possible minimum age for the Dakota sandstone; Geological Society of America Bulletin, v.82, pp. 1723-1726.

Brummer, J.J. 1978*. Diamonds in Canada; Canadian Mining and Metallurgical Bulletin, October, 1978, pp. 64-79.

Brummer, J.J. 1984*. Diamonds in Canada; *In* Guillet, G.R. and Martin, W., eds., The Geology Of Industrial Minerals In Canada. CIM Special Publication, Volume 29, pp. 311-320.

Bullen, K.E. 1980. An introduction to the theory of seismology; 3rd edition, Cambridge University Press, Cambridge, 381 pp.

Burlet, L.A. and Trigg, C.M. 1986. Rutledge Lake, Research - 1986, LEA 1 to LEA 17, LEA 20, ENEX 3 to ENEX 5, ENEX 7, WWK 1 to WWK 10 and WWK 12 mineral claims, Mackenzie Mining District N.W.T. Unpublished report prepared by Trigg, Woollett, Olson Consulting Ltd. for a client.

Burley, A.J. and Greenwood, P.G. 1972. Geophysical surveys over kimberlite pipes in Lesotho. Spec. Pap. of the Inst. Geo. Sci.. London.

Burton E.A., and Machel H.G. 1992. Possible interactions between Devonian carbonates and basement in the western Canada sedimentary basin - clues from fluid geochemistry and dolomitization; *In* Ross, G.M. (ed.), *Lithoprobe Alberta Basement Transect Workshop,* Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #28, pp. 65-68.

Burwash, R.A. 1990. The Peace River Arch: where, when, what, why?; Edmonton Geological Society, Abstract of Talk Presented November 8, 1990, Edmonton, Alberta.

Burwash, R.A. 1993. Geological History of Basement Rocks in Alberta. *In* W.A.D. Edwards *et al.*, Diamonds in Alberta - What's It All About. Abstract from a seminar held on February 2, 1993 at the Alberta Research Council in Edmonton.

Burwash, R.A., Baadsgaard, H., and Peterman, Z.E. 1962. Precambrian K - Ar dates from the western Canada Sedimentary Basin. Journal of Geophysical Research, 67, pp. 1617-1625.

Burwash R.A. and Cumming, G.L. 1976. Uranium and thorium in the Precambrian basement of western Canada. 1. Abundance and distribution. Canadian J. Earth Sci. vol. 13, pp. 284-293.

Burwash, R.A. and Culbert, R.R. 1976. Multivariate geochemical and mineral patterns in the Precambrian basement of Western Canada. Tectonophysics. vol. 20, pp. 183-201.

Burwash, R.A., McGregor, C.R. and Wilson, J.A. 1994. Precambrian basement beneath the Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas of the Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 5, pp. 49-56.

Burwash, R.A. and Power, M.A. 1989. Trout Mountain anomaly, northern Alberta: its role in the northwest foreland of the Trans-Hudson Orogen, *In* Lewry, J.F. and Stauffer, M.R., eds., The Early Proterozoic Trans-Hudson Orogen of North America: Geological Association of Canada, Special Paper 37, pp. 301-311.

Byrne, P.J.S. 1955. Bentonite in Alberta; Alberta Research Council Report No. 71, 20 pp.

Caner, B.D., Camfield, P.A., Anderson, F. and Niblett, E.R., 1969. A large scale magnetotelluric survey in western Canada; Canadian Journal of Earth Science, vol. 6, no. 7, pp. 1245-1261.

Caner, B.D., Auld, R., Dragert, H. and Camfield, P.A., 1971. Geomagnetic depth-sounding and crustal structure in western Canada. Journal of Geophysical Research vol. 76, pp. 7181-7201.

Cant, D.J. 1988. Regional structure and development of the Peace River Arch, Alberta: A Paleozoic failed-rift system? Bulletin of Canadian Petroleum Geology, vol.36, pp. 284-295.

Cant, D.J. and Stockmal, G.S. 1989. The Alberta Foreland Basin: Relationship between Stratigraphy and Cordilleran Terrane-accretion Events. Canadian Journal of Earth Science, v. 26. pp. 1964-1975.

Carlson, J.A and Marsh, S.W. 1989*. Discovery of the George Creek kimberlite dykes, Colorado; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds And Diamond Exploration, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 1169-1178.

Carlson, J.A. and S.W. Marsh 1986. Discovery of the George Creek kimberlites, *In* J. Ross (ed) Kimberlites and Related Rocks, Geol. Soc. Australia Spec. Pap. No. 14, Proc. 4th Int. Kimberlite Conf.. Blackwell Publ. pp. 1169-1178.

Carlson, J.A., Johnson, R.B., McCallum, M.E., Campbell, D.L. and Padgett J.P. 1984. Evaluation of geophysical techniques for diatreme delineation in the Colorado-Wyoming kimberlite province, *In* Kornprobst (ed.). Kimberlites, I: Kimberlites and Related Rocks, Proc. 3rd Int. Kimberlite Conf., Elsevier. Amsterdam. pp. 21-31.

Carrigy, M.A. 1968. Evidence of shock metamorphism in rocks from the Steen River Structure, Alberta; *In* B.M. French and N.M. Short (eds.) Shock Metamorphism Of Natural Materials, Mono Book Corp., Baltimore, Maryland, pp. 367-378.

Chandra, N.N. 1966. Converted wave method for crustal structure, M.Sc. Thesis, University of Alberta, Edmonton.

Chandra, N.N. and Cumming, G.L. 1972. Seismic refraction studies in Western Canada. Can. J. Earth Science vol. 9, pp. 1099-1109.

Charlesworth, H. 1959. Some suggestions on the structural development of the Rocky Mountains of Canada; Journal of the Alberta Society of Petroleum Geologists vol. 7, no. 11, pp. 249-256.

Charlesworth, H.A.K., Weiner, J.L., Akehurst, A.J., Bielenstein, H.U., Evans, C.R., *et al.*, 1967. Precambrian geology of the Jasper region, Alberta. Alberta Research Council Bulletin 23.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. 1987. Bedrock geology, Iskwaitkan Lake area: Evidence fo Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *In* Summary of Investigation 1988, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 87-4, pp. 46-51.

Christiansen, E.A. 1992. Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada, an update. Canadian Journal of Earth Sciences, vol. 29, pp. 1776-1778.

Christiansen, E.A. 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Sciences, vol. 16, pp. 913-938.

Christopher, J.E. 1990. Notes on the Sweetgrass Arch Mesozoic tectonics and sedimentation. In Tectonic Controls on Sedimentation; National Conference on Earth Sciences, University of Alberta, Conference Notes 32 pp.

Clague, J.J. 1989a. Relationship of Cordilleran and laurentide Glaciers; *In* Chapter 1, Quaternary Geology of the Canadian Cordillera; Quaternary Geology of Canada and Greenland R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada no.1, pp. 42-43.

Clague J.H. (Compiler) 1989b. Quaternary geology of the Canadian Cordillera, section on Quaternary stratigraphy and history, *In* R.J. Fulton (ed.) Chapter 1 of Quaternary Geology of Canada and Greenland; Geological Survey of Canada no. 1, pp. 48-76.

Clayton, L. and Moran, S.R. 1982. Chronology of Late Wisconsinan Glaciations in middle North America. Quaternary Science Reviews, vol. 1, pp. 55-82.

Clifford, T.N. 1970. The structural framework of Africa. In Clifford, T.N. and Gass, I.G., eds., *Afican Magmatism and Tectonics*. Oliver and Boyd, pp. 1-26.

Clifford, T.N. 1966. Tecton-metallogenic units and metallogenic provinces of Africa. Earth and Plan. Sci. Lett., vol. 1, pp. 421-434.

Clowes, R.M. and Kanasewich, E.R. 1970. Seismic Attenuation and the Nature of Reflecting Horizons within the Crust. vol. 75, pp. 6693-6705.

Clowes, R.M., Kanasewich, E.R. and Cumming, G.L. 1968. Deep Crustal Seismic Reflections at Near-Vertical Incidence. Geophysics vol. 33, pp. 441-451.

Cochrane, N.A. and Hyndman, R.D. 1970. A new analysis of geomagnetic depth-sounding data from western Canada; Canadian Journal of Earth Science, vol. 7, no. 5, pp. 1208-1218.

Collerson, K.D., Van Schmus, R.W., Lewry, J.F. and Bickford, M.W. 1988. Buried Precambrian basement in south-central Saskatchewan: Provisional results from Sm-Nd model ages and U-Pb zircon geochronology, *In* Summary of Investigations 1988, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 88-4, pp. 142-150.

Consolidated Carina Resources Corp., 1993. Unpublished news release, April 16, 1993.

Coopersmith, H.G. 1991. Geology and exploration of the Kelsey Lake diamondiferous kimberlites, Colorado; Society of Mining and Engineering. Preprint No. pp. 91-174.

Coopersmith, H.G. 1993a*. Colorado-Wyoming Diamond Province: Continued exploration and evaluation; Proceedings of a short course presented March 27, 1993 by the Prospectors and Developers Association of Canada, pp. 43-45.

Coopersmith, H.G. 1993b*. Diamondiferous kimberlite at Kelsey Lake, Southern Wyoming Archean Province. *In* Dunne, K.P.E. and Grant, B. eds., Mid-Continent Diamonds. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 85-88.

Coopersmith, H.G. and Mitchell, R.H. 1989. Geology and exploration of the Rose lamproite, south-east Kansas, U.S.A.; *In* J. Ross (ed.), *Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds And Diamond Exploration*, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 1179-1191.

Crain, E.R. 1986. The Log Analysis Handbook Vol. 1; Pennwell Books.

Crawford, A.R. and Compston, W. 1970*. The age of Vindhyan systems of peninsular India; Geological Society of London Quarterly Journal, vol. 125, pp. 351-371.

Cumming, G.L. and Kanasewich, E.R. 1966. Crustal structure in Western Canada, Final Report Contract AF19 (628) 2835, AFCRL, Bedford.

Dahlstrom, C.D.A. 1970. Structural geology in the eastern margin of the Canadian Rocky Mountains; Bulletin of Canadian Petroleum Geology, vol. 18, pp. 332-406.

Daniels, L.R.M., Jennings, C.M.H., Lee, J.E., Blaine, J.L., Billington, F.R. and Cumming, B. *In Press**. The geology of the M1 kimberlite, Southern Botswana; *In* H.O.A. Meyer (ed.) Proceedings Volume, Fifth International Kimberlite Conference, Araxa, Brazil, 1992.

Davis, G.L. 1977a*. The ages and uranium contents of zircons from kimberlites and associated rocks; Carnegie Institute Washington, Yearbook 76, pp. 631-635.

Davis, G.L. 1977b*. The ages and uranium contents of zircons from kimberlites and associated rocks; Proceedings of the 2nd International Kimberlite Conference, Santa Fe, New Mexico, 1977, Extended Abstract Published By The American Geophysical Union, Washington, D.C.

Davis, G.L., Sobolev, N.V. and Khar'kiv, A.D. 1982*. New data on the age of Yakutian kimberlites obtained by the uranium-lead method on zircons; Doklady Akademii Nauk SSSR, 1980, vol. 254, no. 1, pp.175-179. *In* Transactions of the USSR Academy of Sciences, Earth Science Sections, 1982, vol. 254, pp. 53-57.

Davis, G.L., Krogh, J.E. and Erlank, A.J. 1976*. The ages of zircons from kimberlites from South Africa; Carnegie Institute Washington, Yearbook 75, pp. 821-824.

Dawson, F.M., Evans, C.G., Marsh R. and Richardson, R.J.H. 1994. Uppermost Cretaceous and Tertiary strata of the Western Canada Sedimentary Basin. *In* G.D. Mossop and I. Shetsen (eds.), Geological Atlas of the Western Canada Sedimentary Basin, Published jointly by the Canadian Society of Petroleum Geologists and the Alberta Research Council.

Dawson, G. 1898. Report of activities. Geological Survey of Canada, Summarial Report, Part A, vol. 11.

Dawson, G. 1875. Report on the geology and resources of the region in the vicinity of the 49th parallel from Lake of the Woods to the Rocky Mountains. British North America Boundary Commission, Montreal Quebec.

Dawson, G. 1885. Report on the country in the vicinity of the Bow and Belly Rivers. Geological Survey of Canada, Report for 1882-3-4, Part C.

Dawson, G. 1886. Preliminary report on the physical and geological feautres of the Rocky Mountains between latitudes 49° 00' and 51°30'. Geological Survey of Canada, Annual Report 1985. 169 pp.

Dawson, G. and McConnell, R.G. 1895. Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains. Geological Society of America Bulletin, vol. 7, pp. 31-66.

Dawson, J.B. 1980. *Kimberlites and their xenoliths.* Springer-Verlag, Berlin.

Dawson, J.B. and Stephens, W.E. 1976. Statistical classification of garnets from kimberlite and associated xenoliths - Addendum; Journal of Geology, vol. 84, pp. 495-496.

Dawson, J.B. and Stephens, W.E. 1975. Statistical classification of garnets from kimberlite and associated xenoliths; Journal of Geology, vol. 83, pp. 589-607.

Dawson, J.B. 1989*. Geographic and time distribution of kimberlites and lamproites: Relationships to tectonic processes. *In* Ross, J. (ed.), Kimberlites And Related Rocks, Volume 1: Their Composition, Occurrence, Origin And Emplacement. Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 323-342.

Decelles, P.G. 1986. Sedimentation in a tectonically partitioned nonmarine foreland basin: The Lower Cretaceous Kootenai Formation, southwestern Montana; Geological Society of America Bulletin vol. 97, pp. 911-931.

Demchuk, T.D. and Nelson-Glatiotis, D.A. 1993. The identification and significance of kaolinite-rich, volcanic ash horizons (tonsteins). *In* The Ardley Coal Zone, Wabamun, Alberta, Canada; Bulletin of Canadian Petroleum Geology vol. 41, pp. 464-469.

Devlin, W.J. 1989. Stratigraphy anad sedimentology of the Hamill Group in the nonrthern Selkirk Mountains, British Columbia: Evidence for the latest Proterozoic - Early Cambrian extensional tectonism; Canadian Journal of Earth Sciences, vol. 26, pp. 515-533.

Devline, W.J. and Bond, G.C. 1988. The initiation of the early Paleozoic Cordillerann miogeocline: Evidence from the uppermost Proterozoic - Lower Cambrian Hamill Group of southerwestern British Columbia; Canadian Journal of Earth Sciences, vol. 25, pp. 1 -19.

Dickinson, W.R. 1976. Sedimentary basins developed during evolution of the Mesozoic-Cenozoic arc-trench system in western North America; Canadian Journal of Earth Sciences vol. 13, pp. 1268-1287.

Dingwell, D.B. and Brearly, M. 1985. Mineral chemistry of igneous melanite garnets from analcite-bearing volcanic rocks, Alberta, Canada; Contributions to Mineralogy and Petrology, vol. 90, pp. 29-35.

Dix, G.R. 1990. Stages of platform development in the Upper Devonian (Frasnian) Leduc Formation, Peace River Arch, Alberta. Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 66-92.

Dix, G.R. 1993. Patterns of burial and tectonically controlled dolomitization in an Upper Devonian fringing reef complex: Leduc Formation, Peace River Arch area, Alberta, Canada; Journal of Sedimentary Petrology, vol. 63, pp. 628-640.

Dobrin, M.B and Savit, C.H. 1988. Introduction to Geophysical Prospecting, 4th Edition. McGraw Hill, New York, 567 pp.

Dohr, G. 1974. Applied Geophysics, Introdution to Geophysical Prospecting, John Wiley and Sons, New York, 272 pp.

Douglas, R.J.W. 1958. Mount Head map area; Geological Survey of Canada, Memoir 291.

Douglas, R.J.W. (ed.). 1970. Geology and Economic Minerals of Canada. Geological Survey of Canada, Economic Geology Report No. 1.

Douglas, R.J.W., Gabrielse, H., Wheeler, J.O., Stott, D.F. and Belyea, H.R. 1970. Geology of Western Canada. *In* R.J.W. Douglas (ed.) Geology and Economic Minerals of Canada, Geological Survey of Canada, Economic Geology Report No. 1, pp. 367-488.

Dudas, F.O. 1991. Geochemistry of igneous rocks from the Crazy Mountains, Montana, and tectonic models for the Montana Alkalic Province; Journal of Geophysical Research, vol. 96, no. B8, pp. 13,261-13,277.

Dubord, M.P. 1987. Carbonate hosted Pb-Zn potential of northeastern Alberta and the applicability of Petroleum data for mineral exploration. Alberta Research Council Open File Report 1987-07.

Dufresne, M.B., Henderson, B.A., Fenton, M.M., Pawlowicz, J.G. and Richardson, R.R. 1994. The mineral deposits potential of the Marguerite River and Fort McKay areas, Northeast Alberta; Alberta Research Council Open File Report 1994-14.

Dummett, H., Fipke, C. and Blusson, S.L. 1985. Diamondiferous diatremes of eastern British Columbia; Canadian Institute of Mining and Metallurgy Bulletin, Abstract, vol. 78, pp. 56-58.

Duskin, D.J. and Jarvis, W. 1993*. Kimberlites in Michigan; *In* Dunne, K.P.E. and Grant, B. (eds.), *Mid-Continent Diamonds*. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 105-106.

Dyke A.S. and Prest vol.K. 1986. Late Wisconsinan and Holocene Retreat of the Laurentide Ice Sheet. Geological Survey of Canada Map 1702A, 1:5,000,000 scale.

Dyke A.S. and Prest vol.K. 1987. Late Wisconsinan and Holocene history of the Laurentide Ice Sheet. Géographie Physique et Quaternaire, vol. 41, pp. 237-263.

Dziewonski, A.M. and Anderson, D.L. 1981. Preliminary reference Earth model. Phys. Earth Planet. Sci. vol. 25, pp. 297-356.

Dziewonski, A.M. and Woodhouse, J.H. 1987. Global images of the earth's interior. Science vol. 236, pp. 37-48.

Edmonton Journal, December 26, 1992a. Loner's find the stuff of lore.

Edmonton Journal, October 17, 1992b. Prospector low-key about diamond find.

Edmonton Journal, October 20, 1992c. Gem of a tip leads to diamond source.

Edmonton Journal, August 15, 1992d. Diamond fever stimulates interest in three big claims staked.

Edmonton Journal, December 15, 1992e. Pezim serious about Alberta diamond play.

Edmonton Journal, May 18, 1993. Alberta diamond hunt no waste of time, Dia Met chief says.

Edwards, W.A.D., Scafe, D., Eccles, D.R., Miller, S., Berezniuk, T. and Boisvert, D. 1994. Mapping and Reserve Exploration of the Tertiary and Preglacial Formations of Alberta; Alberta Research Council Open File Report 1994-06, 111 pp.

Edwards, D.J. and Brown, R.J. 1994. Tectonic heredity in West-Central Alberta: recognition and significance; *In* Ross, G.M. (ed.), Lithoprobe Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 164-194.

Edwards, D.J. and Brown, R.J. 1993. A geophysical investigation of basement control on reef growth; *In* Ross, G.M. (ed.), *Lithoprobe Alberta Basement Transect Workshop*, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 18-28.

Edwards, W.A.D. 1990. Placer Gold Occurrences in Alberta; Alberta Research Council Open File Report 1990-9.

Eisbacher, G.H., Carrigy, M.A. and Campbell, R.B. 1974. Paleodrainage pattern and late-orogenic basins of the Canadian Cordillera; *In* Tectonics and Sedimentation, Dickinson W.R. (ed.). Society of Economic Paleontologists and Mineralogists, Special Publication No. 22, pp. 143-166

Erdmer, P. and Downing, D. 1993. Geological, geochemical, and geophysical exploration for diamonds in Yukon. Indian and Northern Affairs Canada, Northern Affairs: Yukon Region, Open File 1993-5. 71 pp.

Fenton, M.M. 1984. Quaternary Stratigraphy of the Canadian Prairies. *In*: Quaternary Stratigraphy of Canada - A Canadian Contribution to IGCP Project 24, R.J. Fulton ed. Geological Survey of Canada, Paper 84-10, pp. 57-68.

Fenton, M.M. 1987. Metallic Mineral Exploration on the Interior Platform: Quaternary Contribution. Geoscience Canada, v. 15, no. 2, pp. 85-88.

Fenton, M.M. and Pawlowicz, J.G. 1993. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta: report for the end of fiscal year 1992-93, MDA project number M92-04-006. Environmental Research and Engineering Department, Alberta Research Council Open File Report 1993-16, 238 pp.

Fenton, M.M., Pawlowicz, J.G., and Dufresne, M.B. 1994a. Reconnaissance mineral and geochemical survey with emphasis on northern Alberta, MDA Project Number M92-04-006, report for the end fiscal year 1993-94, Alberta Geological Survey, Alberta Research Council Open File Report 1994-21, in press.

Fenton M.M., Schreiner B.T., Nielsen E., and Pawlowicz J.G. 1994b. Quaternary Geology of the Western Plains; *In* G.D. Mossop and I. Shetson (eds.), *Geological Atlas of the Western Canada Sedimentary Basin*, Published Jointly by the Canadian Society Of Petroleum Geologists and the Alberta Research Council, Chapter 26, pp. 413-420.

Fermor, P.R. and Price, R.A. 1987. Multiduplex structure along the base of the Lewis Thrust sheet in the southern Canadian Rockies; Bulletin of Canadian Petroleum Geology, vol. 35, no. 2. pp. 159-185.

Fipke, C.E. 1990. The development of advanced technology to distinguish between diamondiferous and barren diatremes; Geological Survey of Canada, Open File 2124.

Fipke, C.E. 1993. Significance of chromite, ilmenite, G5 Mg - almandine garnet, zircon and tourmaline in heavy mineral detection of diamond bearing lamproite; Talk presented at GAC-MAC Annual Meeting, Edmonton, Alberta, May 17-18, 1993.

Fitzgerald, E.L. 1962. Structure of the McConnell Thrust sheet in the Ghost River area, Alberta; Journal of the Alberta Society of Petroleum Geologists, vol. 10, no. 10, pp. 553-574.

Fleischer, M. and Robinson, W.O. 1963. Some problems of the geochemistry of fluorine. *In* Studies in Analytical Geochemistry (ed. D.M. Shaw). University of Toronto Press, pp. 58-75

Folinsbee, R.E. and Baadsgard, H. 1958. An absolute age for the Exshaw shale; *In* Eighth Annual Field Conference, Nordegg, Alberta Society of Petroleum Geologists, Calgary, pp. 69-73.

Folinsbee, R.E., Ritchie, W.D. and Stansberry, G.F. 1957*. The Crowsnest Volcanics and Cretaceous geochronology; *In* 7th Annual Field Conference and Guide Book, Alberta Society of Petroleum Geologists, pp. 20-26.

Folinsbee, R.E., Nascimbene, J., Baadsgaard, H., Shafiqullah, M. and Cumming, G.L. 1965. Late Cretaceous radiometric dates from the Cypress Hills of western Canada; *In* Zell, R.L. (ed.), Guidebook, Cypress Hills Plateau, Alberta and Saskatchewan, Part I, Alberta Society of Petroleum Geologists, Field Conference Guidebook, pp. 162-174.

Forsythe, D.A. and Berry, M.J. 1974. A Refraction Survey across the Canadian Cordillera at 54° N. Can. J. Earth Sci. vol. 11, pp. 533-548.

Fountain, D.M. and McDonough, D. 1984. Crustal structure of northern Montana and southern Alberta and British Columbia based on interpretation of gravity data; *In* J.D. McBane and P.B. Garrison (eds.), Montana Geological Society 1984 Field Conference and Symposium. pp. 253-258.

Fowler, C.M.R. 1990. The Solid Earth: An Introduction to Global Geophysics. Cambridge University Press, Cambridge.

Frost, C.D. and Burwash, R.A. 1986. Nd evidence for extensive Archean basement in the western Churchill Province, Canada: Canadian Journal of Earth Sciences, v. 23, pp. 1433-1437.

Fuge, R. 1988. Sources of halogens in the environment, influences on human and animal health. Environ. Geochem. and Health 10, pp. 51-61.

Fullerton, D.S. and Colton, R.B. 1986. Stratigraphy and correlation of the glacial deposits on the Montana Plains. *In* Glaciations in the Northern Hemisphere, vol. Sibrava, D.Q. Bowen and G.M. Richmond (eds.). Quaternary Science Reviews, Special Volume 5, Pergamon Press, Oxford U.K., pp. 69-82.

Fulton, R.J. (ed.) 1989. Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 1.

Fulton, R.J., Fenton, M.M. and Rutter, N.W. 1984. Summary of Quaternary stratigraphy and history, western Canada. *In* R.J. Fulton editor, Quaternary Stratigraphy of Canada - A Canadian Contribution to IGCP Project 24, Geological Survey of Canada, Paper 84-10, pp. 69-83.

Gabrielse, H. and Yorath, C.J. 1992. Tectonic Synthesis. *In* Gabrielse, H. and C.J. Yorath. (eds.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 679-705.

Gabrielse, H. and Campbell, R.B. 1992. Upper Proterozoic Assemblages. *In* H. Gabrielse and C.J. Yorath (eds.). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 125-150.

Gallup, W.B. 1956. Relation of Laramide movements to the Cretaceous and Tertiary sediments of western Canada; Bulletin of Canadian Petroleum Geology, vol. 4, pp. 125-126.

Ganley, D.C. and Cumming, G.L. 1974. A Seismic Reflection Model of the Crust near Edmonton, Alberta. Can. J. Earth Sci. vol. 11, pp. 101-109.

Garland, G.D. and Bower, M.E. 1959. Interpretation of aeromagnetic anomalies in northeastern Alberta; *In* 5th World Petroleum Congress, Section 1, Paper 42, pp. 787-800.

Garnett, R.H.T. 1994. Benefits of Uneroded Kimberlites at Fort à la Corne, Saskatchewan; Mineral Exploration Group, Calgary Society Program and Abstracts, 63 pp.

Garrett, R.G. and Thorleifson, H. 1993. Prairie kimberlite study - soil and till geochemistry and mineralogy, low density orientation survey traverses, Winnipeg - Calgary - Edmonton - Winnipeg 1991; Geological Survey of Canada, Open file report 2685.

Geldsetzer, H.J. and Mountjoy, E.W. 1992. Upper Devonian platform reefs and inter-platform basins, Canmore to Jasper, Alberta; American Association of Petroleum Geologists Annual Convention, Field Trip #23.

Gent, M.R. 1992. Diamonds and precious gems of the Phanerozoic basin, Saskatchewan: Preliminary investigation; Saskatchewan Energy and Mines, Open File Report 92-2.

Gent, M.R. 1993. Mineralogical and group classification program; Saskatchewan Energy Mines, Data file 18.

Geological Survey of Canada 1990a. Magnetic anomaly map of Canada, Canadian Geophysical Atlas - Map 11, 1:10,000,000 scale.

Geological Survey of Canada 1990b. Gravity anomaly maps of Canada, Canadian Geophysical Atlas - Maps 4, 5 and 6, 1:10,000,000 scale.

Geological Survey of Canada 1993. High resolution aeromagnetic total field survey of Cypress Hills Area, Alberta, Open File Report 2588, Aeromagnetic Total Field Contour Maps, 1:100,000 scale.

George Cross Newsletter 1993. Diamond discovered at Outlet Bay diatreme; No. 27, p. 1.

Gerryts, E. 1970. Diamond prospecting by geophysical methods - a review of current practice. *In* L.W. Morley (ed) Mining and Groundwater Geophysics/ 1967, Econ. Geol. Rept. No. 26, Geol. Surv. Canada. pp. 439-446.

Glass, D.J. (ed.) 1990. Lexicon of Canadian Stratigraphy. Vol. 4 Western Canada; Canadian Society of Petroleum Geologists, 772 pp.

Goble, E.O. 1974a. Geological report - Quartz mineral exploration permit #177. Unpublished assessment report prepared for Kintla Explorations Ltd.

Goble, E.O. 1974b. Geological report #S-P-1, permit area 176, southwestern Alberta. Unpublished assessment report prepared for Kintla Explorations Ltd.

Godfrey, J.D., 1955. Iron Permit 6, Varmac Mining and Exploration Company Ltd., Surface sampling and drill hole data and economic feasibility report; Alberta Research Council, Assessment File FE-AF-006(1).

Godfrey, J.D. 1986. Geology of the Precambrian Shield in Northeastern Alberta, NTS 74M and 74L N½. Alberta Research Council Map EM 180 at 1:250,000 scale.

Godwin, C.I. and Price, B.J. 1986*. Geology of the Mountain Diatreme kimberlite, north-central MacKenzie Mountains, District of MacKenzie, Northwest Territories; Canadian Institute of Mining and Metallurgy, vol. pp. 298-310.

Goff, S.P., Godfrey, J.D. and Holland, J.G. 1986. Petrology and Geochemistry of the Canadian Shield of northeastern Alberta. Alberta Research Council Bulletin No. 51.

Gogineni, S.V., Melton, C.E. and Giardini, A.A. 1978*. Some petrological aspects of the Prairie Creek diamond-bearing kimberlite diatreme, Arkansas; Contributions to Mineralogy and Petrology, vol. 66, pp. 251-161.

Gordey, S.P., Geldsetzer, H.H.J., Morrow, D.W., Bamber, E.W., Henderson, C.M., *et al.* 1992. Upper Devonian to Middle Jurassic Assemblages. Part A. Ancestral North America. *In* H. Gabrielse and C.J. Yorath. (eds.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 219-328.

Gordy, P.L. and Edwards, G. 1962. Age of the Howell Creek intrusives; Alberta Society of Petroleum Geologists Journal, vol. 10, no. 7, pp. 369-372.

Gough, D.I. 1983. Electromagnetic geophysics and global tectonics. Journal of Geophysical Research vol. 88, pp. 3367-3377.

Gough, D.I. 1986. Mantle upflow tectonics in the Canadian cordillera. Journal of Geophysical Research vol. 91, pp. 1909-1919.

Gough, D.I., Bingham, D.K. and Ingham, M.R. 1982. Conductive structures in southwestern Canada: a regional magnetometer array study. Can. J. Earth Sci. vol. 19. pp. 1680-1690.

Govett, G.J. and Byrne, P.J. 1958. Industrial Minerals of Alberta; Alberta Research Council Earth Sciences Report 58-2, 112 pp.

Grand, S.P. and Helmberger, D.V. 1984. Upper mantel shear structure of North America. Geophys. J. R. Astr. Soc. vol. 76, pp. 399-438.

Grand, S.P. 1987. Tomographic inversion for shear velocity beneath the North American plate. J. Geophys. Res. vol. 92. pp. 14065-14090.

Green, A.H., Hajnal, Z. and Weber, W. 1985a. An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States: Tectonophysics, v. 116, pp. 281-322.

Green, A.H., Weber, W. and Hajnal, Z. 1985b. Evolution of Proterozoic terrains beneath the Williston Basin: Geology, v. 13, pp. 624-628.

Green, R. 1972. Geological map of Alberta. Alberta Geological Survey Department, Alberta Research Council, 1:1 267 000 scale, reprinted 1982.

Green, R., Mellon, G.B., Carrigy, M.A. 1970. Bedrock Geology of Northern Alberta; 1:500,000 scale. Geological map published by the Alberta Research Council in two sheets (East and West Halfs).

Greenbaum, D. 1977. The chromitiferous rocks of the Troodos Ophiolite complex, Cyprus; Economic Geology, vol. 72, pp. 1175-1194.

Greenwood, H.J., Woodsworth, G.J., Read, P.B., Ghent, E.D. and Evenchick, C.A. 1992. Metamorphism. *In* H. Gabrielse and C.J. Yorath. (eds.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 535-570.

Grieve, D.A. 1982*. Petrology and chemistry of the Cross Kimberlite (82J/2); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geology in British Columbia, 1977-1981, pp. 34-41.

Griffin, W.L. and Ryan C.G. 1993. Trace elements in garnets and chromites: Evaluation of diamond exploration targets; *In* Diamonds: Exploration, Sampling And Evaluation; Proceedings of a short course presented by the Prospectors and Developers Association of Canada, March 27, 1993, Toronto, Ontario, Canada, pp. 185-212.

Griffin, W.L., Ryan, C.G., Gurney, J.J., Sobolev, N.V. and Win, T.T. *In press*. Chromite macrocrysts in kimberlites and lamproites: geochemistry and origin; *In* H.O.A. Meyer (ed.), Proceedings Volume, Fifth International Kimberlite Conference, Araxa, Brazil, 1992.

Griffin, W.L., Ryan, C.G., Fisher, N.I. and Friedman, J.H. 1992. Trace Elements in garnets and chromites: their use in diamond exploration; *In* Round Table Conference On Diamond Exploration And Mining, New Delhi, December, 1992.

Gurney, J.J. 1984. A correlation between garnet and diamond in kimberlites;

Gurney, J.J. 1990. The diamondiferous roots of our wandering continent; South African Journal of Geology, vol. 93, pp. 423-437.

Gurney, J.J. and Levinson, A.A. 1991. Marine mining of diamonds off the west coast of southern Africa. Gems & Geology, v. 27, pp. 206-219.

Gurney, J.J. and Moore, R.O. 1993. Geochemical correlations between kimberlitic indicator minerals and diamonds; *In Diamonds: Exploration, Sampling And Evaluation*; Proceedings of a short course presented by the Prospectors and Developers Association of Canada, March 27, 1993, Toronto, Ontario, Canada, pp. 147-171.

Habib, A.G.E. 1981. Geology of the Bearpaw Formation in south central Alberta: Univ. of Alberta unpublished M.Sc. Thesis 85 pp.

Hackbarth, D.A., and Nastasa, N. 1979. The hydrogeology of the Athabasca oil sands area, Alberta; Alberta Research Council Bulletin No. 38.

Haggerty, S.E. 1986. Diamond genesis in a multiply-constrained model; Nature, vol. 320, pp. 34-38.

Haggerty, S.E., Raber, E. and Naeser, C.W. 1983*. Fission track dating of kimberlitic zircons; Earth and Planetary Science Letters, vol. 63, pp. 41-50.

Haites, T.B. 1960. Transcurrent faults in Western Canada. Alberta Society of Petroleum Geologists Journal, vol. 8, no. 2, pp. 33-77.

Haites, T. B. and van Hees, H. 1962. The origin of some anomolies in the plains of western Canada; Journal of the Alberta Society of Petroleum Geologists vol.10, pp. 511-533.

Hajnal, Z., Green, A., White, Clowes, R., Lewry, J. and Luces, S. 1993. Seismic signature of the Trands-Hudson Orogene; *In* Geological Association of Canada, Mineralogical Association of Canada, Program and Abstracts from the Joint Annual Meeting, May 17-19, Edmonton, Alberta, p. A-38.

Halbertsma, H.L. 1994. Devonian Wabamun Group of the Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas of the Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 13, pp. 203-220.

Halchuk, S.C. and Mereu, R.F. 1990. A seismic investigation of the crust and Moho underlying the Peace River Arch, Canada. Tectonophysics vol. 185, pp. 1-19.

Halferdahl, L.B. 1965. The occurrence of gold in Alberta Rivers; Alberta Research Council Open File Report 1965-11.

Hall, D.H. and Brisbin, W.C. 1965. Crustal structure from converted head waves in central Western Manitoba. Geophysics vol. 30, pp. 1053-1069.

Hall, D.C., Helmstaedt, H. and Schulze, D.J. 1989. The Cross diatreme, British Columbia, Canada: A kimberlite in a young orogenic belt; *In* J. Ross (ed.) Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 97-108.

Haman, P.J. 1975. The discovery of the Caroline Arch, Alberta, by lineament analysis; *In* Proceedings, First International Conference on New Basement Tectonics, Salt Lake City.

Hamilton, W.N. and Olson, R.A. 1994. Mineral Resources of the Western Canada Sedimentary Basin. *In* G.M. Mossop and I. Shetsen (eds.). Atlas of the Western Canada Sedimentary Basin. Alberta Geological survey of the Alberta Research Council, and Canadian Society of Petroleum Geologists.

Handa, S. and Camfield, P.A. 1984. Crustal electrical conductivity in north-central Saskatchewan: the North American Central Plains anomaly and its relation to a Proterozoic plate margin. Can. J. Earth Sci. vol.21, pp. 533-543.

Harris, D.C. and Ballantyne, S.B. 1994. Characterization of gold and PGE-bearing placer concentrates from the North Saskatchewan River, Edmonton, Alberta; Geological Survey of Canada, Current Research 1994-E, pp. 133-140.

Hart, B.S. and Plint, G. 1990. Upper Cretaceous warping and fault movement on the southern flank of the Peace River Arch; Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 190-195.

Hausel, W.D., Glahn, P.R. and Woodzick, T.L. 1981. Geological and geophysical investigations of kimberlite in the Laramie Range of Southeastern Wyoming, Preliminary Report No. 18. Geol. Surv. Wyoming. 13 pp.

Hausel, W.D., McCallum, M.E. and Woodzick, T.L. 1979. Exploration for diamond-bearing kimberlite in Colorado and Wyoming: an evaluation of exploration techniques, Report of Investigations No. 19. Geol. Surv. Wyoming, 29 pp.

Hawkins, P.A. 1994. Indicator mineral geochemistry in the Peace River Diamond Play. In the Calgary Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 37 pp.

Hearn, B.C.Jr. 1989*. Alkalic ultramafic magmas in north-central Montana, USA: Genetic connections of alnoite, kimberlite, and carbonatite; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 109-119.

Helmstaedt, H.H. 1993*. Natural diamond occurrences and tectonic setting of "Primary" diamond deposits. *In* Diamonds: Exploration, Sampling And evaluation; Proceedings of a short course presented March 27, 1993 by the Prospectors and Developers Association of Canada, pp. 3-72.

Helmstaedt, H.L. 1992*. Primary diamond deposits: What controls their size, grade and location? *In* Whiting, B.H., Mason, R. and Hodgson, C.J. (eds.), Giant Ore Deposits, Proceedings of the Giant Ore Deposits Workshop, Department of Geological Sciences, Queen's University, Kingston, Ontario, Canada, pp. 15-120.

Herbaly, E.L. 1974. Petroleum geology of the Sweetgrass Arch, Alberta. American Association of Petroleum Geologists Bulletin, vol. 58, pp. 2227-2244.

Hitchon, B. 1993. Geochemistry of formation waters, northern Alberta, Canada: Their relation to the Pine Point ore deposit. Alberta Research Council Open File Report 1993-14.

Hitchon, B., Underschultz, J.R. and Bachu, S. 1993. Industrial mineral potential of Alberta formation waters; Alberta Research Council Open File Report 1993-15, 86 pp.

Hoffman, P.F. 1990. Geological constraints on the origin of the mantle root beneath the Canadian Shield. Phil. Trans. R. Soc. Lond. A vol. 331, pp. 525-532.

Hoffman, P.F. 1987. Continental transform tectonics: Great Slave Lake shear zone (ca. 1.9 Ga), northwest Canada; Geology, vol. 15, pp. 785-788.

Hoffman, P.F. 1988. United plates of America, the birth of a craton: early proterozoic assembly and growth of Laurentia. Ann. Rev. Earth Planet. Sci vol. 16, pp. 543-603.

Hopkins, J.C. 1988. Syn- and post-depositional salt-dissolution structure traps in Lower Cretaceous sandstones, Cessford Field, Alberta, Canada; Canadian Society of Petroleum Geologists Reservoir, vol. 15, no. 10.

Hopkins, J.C. 1987. Contemporaneous subsidence and fluvial channel sedimentation: Upper Mannville C Pool, Berry Field, Lower Cretaceous of Alberta; American Association of Petroleum Geologists Bulletin, vol. 71, pp. 334-345.

Hoy, T. 1989*. The age, chemistry and tectonic setting of the Middle Proterozoic Moyie Sills, Purcell Supergroup, southeastern British Columbia; Canadian Journal of Earth Sciences, vol. 26, pp. 2305-2317.

Hume, G.S. 1931. Turner Valley sheet, west of Fourth Meridian, Alberta; Geological Survey of Canada, Map 257A.

Hunt, G. 1962*. Time of Purcell eruption in southeastern British Columbia and southwestern Alberta; Journal of the Alberta Society of Petroleum Geologists, vol. 10, pp. 438-442.

Hutcheon, I., Cody, J., McLellan, S. and Abercrombie, H. 1994. Controls on the distribution of non-hydrocarbon gases in the Western Canada Sedimentary Basin; *In* Ross, G.M. (ed.), Lithoprobe Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 199-224.

Hutton, R.S., Gough, D.I., Dawes, G.J.K. and Travassos, J. 1987. Magnetotelluric soundings in the Canadian rocky mountains. Geophys. J. R. Astr. Soc. vol. 90, pp. 245-263.

Ijewliw, O.J. and Schulze, D.J. 1988. The Golden Cluster of diatremes and dykes; British Columbia Ministry of Energy, Mines and Petroleum Resources, Exploration in British Columbia, pp. B39-B46.

Ingham, M.R., Bingham, D.K. and Gough, D.I. 1983. A magnetovariational study of a geothermal anomaly. Geophys. J. R. Astr. Soc. vol. 72, pp. 597-618.

Irish, E.J.W. 1968. Foremost, Alberta; Geological Survey of Canada Map 22-1967.

Irish, E.J.W. 1971. Geology, southern plains of Alberta, west of fourth meridian; Geological Survey of Canada, Map 1286A.

Jackson, L.E. Jr., Rutter, N.W., Hughes, O.L. and Clague, J.J. 1989. Glaciated fringe (Quaternary stratigraphy and history, Canadian Cordillera; in Chapter 1, Quaternary Geology of the Canadian Cordillera; Quaternary Geology of Canada and Greenland R.J. Fulton (ed.); Geological Survey of Canada, Geology of Canada no.1, pp. 63-68.

Janse, A.J.A. 1984*. Kimberlites - where and when. *In* Glover, J.E. and Harris, P.G., eds., Kimberlite Occurrence And Origin: A Basis For Conceptual Models In Exploration. Univ. West. Aust., Dept. Geol., Publ. 8, pp. 19-61.

Janse, A.J.A., Downie, I.F. Reed, L.E. and Sinclair, I.G.L. 1986. Alkaline intrusions in the Hudson Bay Lowlands, Canada: exploration methods, petrology, and geochemistry, *In* J. Ross (ed) Kimberlites and Related Rocks, Geol. Soc. Australia Spec. Pap. No. 14, Proc. 4th Int. Kimberlite Conf.. Blackwell Publ. pp. 1192-1203.

Janse, A.J.A. 1991. Is Cifford's Rule still valid? Affirmative examples from around the world. Fifth Int. Kimb. Conf., Araxa, Brazil, Extended Abstracts, pp. 196-198.

Jaques, A.L., Ferguson, J.D. and Smith, C.B. 1984a*. Kimberlites in Australia. *In* Glover, J.E. and Harris, P.G., (eds.), Kimberlite Occurrence And Origin: A Basis For Conceptual Models In Exploration. Univ. West. Aust., Dept. Geol., Publ. 8, pp. 227-274.

Jaques, A.L., Lewis, J.D., Smith, C.B., Gregory, G.P., Ferguson, J., Chappell, B.W. and McCulloch, M.T. 1984b*. The diamond-bearing ultrapotassic (lamproitic) rocks of the West Kimberly region, Western Australia. *In* Kornprobst, J., (ed.), Kimberlites I: Kimberlites and related rocks. Elsevier, Amsterdam, pp. 225-254.

Jaques, A.L., Lewis, J.D. and Smith, C.B. 1986. The kimberlites and lamproites of Western Australia. Bull. Geol. Surv. West. Aust., Vol. 132.

Jarvis, W. and Kalliokoski, J. 1988. Michigan Kimberlite Province; *In* Klasner, J.S., Hughes, J.D., and Schultz, K.J. (eds.), Institute on Lake Superior Geology, 34th Annual Meeting, Proceedings and Abstracts, pp. 46-48.

Jeanloz, R. 1988. High-pressure experiments and the earth's deep interior. Physics Today (Jan.): S44-45.

Jennings, C.M.H. 1990. Exploration for diamondiferous kimberolites and lamproites. *In* L.S. Beck and C.T. Harper (eds.), Modern Exploration Techniques, Spec. Bull. No. 10, Sask. Geol. Soc. pp. 139-148.

Jerde, E.A., Taylor, L.A., Crozaz, G., Sobolec, N.V. and Sobolev, vol.N. 1993. Diamondiferous eclogites from Yakutia, Siberia: evidence for diversity of protoliths; Contributions to Mineralogy and Petrology, vol. 114, pp. 189-202.

Jerzykiewicz, T. and Norris, D.K. 1993a. Stratigraphy, structure and syntectonic sedimentaion of the Campanian 'Belly River' clastic wedge in the Southern Canadian Cordillera; Cretaceous Research, In Press.

Jerzykiewicz, T. and Norris, D.K. 1993b. Evolution of the Laramide foredeep and the adjacent thrust belt in southern Alberta; Geological Survey of Canada, Open File Report 2663.

Jessop, A.M. 1992. Thermal input from the basement of the western canada sedimentary basin. Bulletin of Canadian Petroleum Geology vol.40, pp. 198-206.

Jessop, A.M. 1989. Hydrological distortion of heat flow in sedimentary basins. Tectonophysics vol.164, pp. 211-218.

Jessop, A.M., Lewis, T.J., Judge, A.S., Taylor, A.E. and Drury, M.J. 1984. Terrestrial heat flow in Canada. Tectonophysics vol. 103, pp. 239-261.

Jones, F.W. and Majorowicz, J.A. 1987. Regional trends in radiogenic heat generation in the precambrian basement of the western Canadian basin. Geophysical Reaserch Letters vol. 14, pp. 268-271.

Jones, H. 1970. Prospecting by infra-red techniques. Mining Mag. Jan: 45-57.

Jones, P.B. 1971. Folded faults and sequence of thrusting in Alberta foothills; The American Association of Petroleum Geologists Bulletin, vol. 55, no. 2, pp. 292-306.

Jones, F.W., Kushigbor, C., Lam, H.L., Majorowicz, J.A. and Rahman, M. 1984. Estimates of terrestrial thermal gradients and heat flow vatiations with depth in the Hinton-Edson area of the Alberta basin derived from petroleum bottom-hole temperature data. Geophysical Prospecting vol. 32, pp. 1111-1130.

Jordan, T.H. 1981. Continents as a chemical boundary layer. Phil. Trans. R. Soc. Lond. A vol. 301, pp. 359-373.

Kaminskiy, F.V., Roman'ko, Y.F., Kolesnikov., S.K. and Salkhi, M. 1993*. Lamproites of northern Algeria; International Geology Review, vol. 35, pp. 235-252.

Kanasewich, E.R. 1968. Precambrian rift: Genesis of strata-bound ore deposits. Science, vol. 161, pp. 1002-1005.

Kanasewich, E.R., Clowes, R.M. and McCloughan, C.H. 1969. A buried precambrian rift in western Canada. Tectonophysics vol. 8, pp. 513-527.

Kanasewich, E.R., Burianyk, M., Milkereit, B., White, D. and Ross, G.M. 1993. The Central Alberta Transect 1992 Acquisition Program: Preliminary Results and Progress Report; *In* Ross, G.M. (ed.), *Lithoprobe Alberta Basement Transect Workshop*, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 1-8.

Kanasewich, E.R. 1966. Deep crustal structure under the Plains and Rocky Mountains. Can. J. Earth Sci. vol.3, pp. 937-945.

Kanasewich, E.R. and Cumming, G.L. 1965. Near-vertical-Incidence Seismic Reflections from the 'Conrad' Discontinuity. J. Geophys. Res. vol. 70, pp. 3441-3447.

Kearny, P. and Brooks, M. 1991. An Introduction to Geophysical Exploration, 2nd Ed. Blackwell Scientific Publications, London.

Kelso, J.A. 1944. Volcanic ash, analysis of volcanic glass deposit from near Stavely, Twp. 14, R27W4M, 82I/4, Alberta; Alberta Research Council Economic Minerals File VOL-IR-002, 2 pp.

Kent, D.M. 1994. Paleogeographic evolution of the cratonic platform - Cambrian to Triassic; *In* G.D. Mossop and I. Shetson (eds.), *Geological Atlas Of The Western Canada Sedimentary Basin*, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 7, pp. 69-86.

Kent, D.M. 1986. Paleotectonic controls on sedimentation in the northern Williston Basin, Saskatchewan. *In:* Williston Basin: Anatomy of a Cratonic Province (Ed.) Long, M. W. Rocky Mountain Association of Geologists, pp. 45-56.

Kent, R.W., Ghose, N.C., Paul, P.R., Hassan, M.J., and Saunders, A.D. 1992. Coal-Magma interaction: An integrated model for the emplacement of cylindrical intrusions; Geol. Mag. 129 pp. 753-762

Kileen, P.G. 1994. Emerging trends in geophysics, Can. Min. Journ. vol. 115, pp. 32-33.

King, R.H. 1969. Exploration Permit 69, geological report; Alberta Research Council, Assessment File U-AF-031(1).

Kingston, M.J. 1986. Spectral reflectance features of kimberlites and carbonatites: implications for remote sensing for exploration. *In* J. Ross (ed.) Kimberlites and Related Rocks, Geol. Soc. Australia Spec. Pap. No. 14, Proc. 4th Int. Kimberlite Conf. Blackwell Publ. pp. 1135-1145.

Kinny, P.D., Compston, W., Bristow, J.W. and Williams, I.S. 1989*. Archean mantle xenocrysts in a Permian kimberlite: Two generations of kimberlitic zircon in Jwaneng DK2, southern Botswana; *In* J. Ross (ed.), *Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds And Diamond Exploration*, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 833-842.

Kirkley, M.B., Gurney, J.J. and Levinson, A.A. 1992. Age, origin and emplacement of diamonds: a review of scientific advances in the last decade; Canada Institute of Mining and Metallurgy Bulletin, vol. 84, no. 956, pp. 48-57.

Kirkley, M.B., Gurney, J.J. and Levinson, A.A. 1991. Age, origin and emplacement of diamonds: scientific advances in the last decadel Gems & Gemology, vol. 27, no. 1, pp. 2-25.

Kjarsgaard, B.A. 1994a. Potassic magmatism in the Milk River area, southern Alberta: Petrology and economic potential; Geological Survey of Canada, Current Research 1994-B, pp. 59-68.

Kjarsgaard, B.A. 1994b. Potassic magmatism in the Sweet Grass Hills, Southern Alberta and implications for diamond exploration; The Calgary Mining Forum, Program and Abstracts, February 10 & 11, 1994, 29 pp.

Kjarsgaard, B.A. 1993*. Petrology of Somerset Island kimberlites; *In* Dunne, K.P.E. and Grant, B. (eds.), *Mid-Continent Diamonds.* GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, 147 pp.

Kjaarsgard, B.A. and Davis, W.J. 1994. Eocene magmatism, Sweetgrass Hills: Expression and tectonic significance; *In* Ross, G.M. (ed.), *Lithoprobe Alberta Basement Transect Workshop*, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 234-237.

Klassen, R.W. 1979. Pleistocene geology and geomorphology of the Riding Mountain and Duck Mountain areas, Manitoba-Saskatchewan. Geological Survey of Canada, Memoir 396, 52 pp.

Klassen, R.W. 1989. Quaternary geology of the southern Canadian Interior Plains. *In:* Chapter 2 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada, no. 1 (also Geological Society of America, The Geology of North America, vol. K-1), pp. 138-174.

Koritnig, S. 1972. Fluorine. *In* Handbook of Geochemistry (ed. K.H. Weedepohl) Vol. II/1, Chapter 9.

Koster, E.H. 1987. Vertebrate taphonomy applied to the analysis of ancient fluvial systems; Society of Economic Paleontologists and Mineralogists, Special Publication 39, pp. 159-168.

Kramers, J. D. 1979. Lead, uranium, strontium, potassium and rubidium in inclusion-bearing diamonds and mantle-derived xenoliths from Southern Africa; Earth and Planetary Science Letters, vol. 42, pp. 58-70.

Kramers, J.D. and Smith, C.B. 1983*. A feasibility study of U-Pb and Pb-Pb dating of kimberlites using groundmass mineral fractions and whole-rock samples; Isotope Geoscience, vol. 1, pp. 23-38.

Kuehner, S.M., Edgar, A.D. and Arima, M. 1981*. Petrogenesis of the ultrapotassic rocks from the Leucite Hills, Wyoming; American Mineralogist, vol. 66, pp. 663-677.

Lam, H.L., Jones, F.W. and Lambert, C. 1982. Geothermal gradients in the Hinton area of west-central Alberta. Can J. Earth Sci. vol. 19, pp. 755-766.

Langenberg, C.W. and Nielsen, P.A. 1982. Polyphase Metamorphism in the Canadian Shield of Northeastern Alberta. Alberta Research Council Bulletin No. 42.

Langenberg, C.W., Salat, H., Turner, A. and Eccles, D.R. 1993. Evaluation of the economic mineral potential in the Andrew Lake-Charles Lake area of northeast Alberta. Alberta Research Council Open File Report 1993-08.

Larsen, L.M., Rex, D.C and Secher, K. 1983*. The age of carbonatites, kimberlites and lamprophyres from southern West Greenland: recurrent alkaline magmatism during 2500 million years; Lithos, vol. 16, pp. 215-221.

Laughlin, A.W., Aldrich, M.J.Jr., Shafiqullah, M. and Husler, J. 1986*. Tectonic implications of the age, composition and orientation of lamprophyre dykes, Navajo volcanic field, Arizona; Earth and Planetary Science Letters, vol. 76, pp. 361-374.

Leckie, D.A. 1989. Upper Zuni Sequence: Upper Cretaceous to Lower Tertiary. *In* B.D. Ricketts (ed.), Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 269-284.

Leckie, D.A., Singh, C., Goodarzi, F., and Wall, J.H. 1990a. Organic-rich radioactive marine shale: A case study of a shallow-water condensed section, Cretaceous Shaftesbury Formation, Alberta, Canada; Journal of Sedimentary Petrology, vol. 60, pp. 101-117.

Leckie, D.A., Staniland, M.R. and Hayes, B.J. 1990b. Regional maps of the Albian Peace River and Lower Shaftesbury formations on the Peace River Arch, northwestern Alberta and northeastern British Columbia; Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 176-189.

Leckie, D.A., Singh, C., Bloch, J., Wilson, M. and Wall, J.H. 1992. An anoxic event at the Albian-Cenomanian boundary: the Fish Scale marker bed, northern Alberta, Canada; Paleogeography, Paleoecology, Paleoclimatology, vol. 92, pp. 139-166.

Leckie, D.A. and Cheel, R.J. 1989. The Cypress Hills Formation (Upper Eocene to Miocene: A semi-arid braidplain deposit resulting from intrusive uplift; Canadian Journal of Earth Sciences, vol. 26, pp. 1918-1931.

Leckie, D.A. and Rosenthal, L. 1986. Cretaceous depositional facies in the western interior: the southern Alberta transect. Canadian Society of Petroleum Gologists Field Trip Notes, 73 pp.

Leech, G.B. 1962. Metamorphism and granitic intrusions of Precambrian age in southeastern British Columbia; Geological Survey of Canada Paper 62-13.

Lehnert-Thiel, K., Loewer, R., Orr, R.G. and Robertshaw, P. 1992*. Diamond-bearing kimberlites in Saskatchewan, Canada: The Fort à la Corne case history; Exploration Mining Geology, Journal of the Geological Society of CIM, vol. 1, pp. 391-403.

Lerbekmo, J.F. 1963. Petrology of the Belly River Formation, Southern Alberta foothills; Sedimentology, vol.2, pp. 54-85

Levinson, A.A., Gurney, J.J. and Kirkley, M.B. 1992. Diamond sources and production: Past, present and future. Gems & Gemology, v. 28, pp. 234-254.

Levinson, A.A., Hitchon, B. and Underschultz, J.R., Submitted. Fluorine groundwater provinces, southern Alberta, Canada; Applied Geochemistry (submitted).

Levson, V.M. and Rutter, N.W. 1988. A lithofacies analysis and interpretations of depositional environments of Montane glacial diamictons, Jasper, Alberta, Canada. *In* R.P. Goldthwait and C.L. Matsch, (eds.), Genetic Classification of Glacigenic Deposits, A.A. Balkema, Rotterdam, pp. 117-140.

Lewry, J.F. 1981. Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province: Nature, v. 294, pp. 69-72.

Lewry, J.F., Thomas, D.J., MacDonald, R. and Chiarenzelli, J. 1990. Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: Telescoping in a collisional regime?; *In* the Early Proterozoic Trans-Hudson Orogen fo North America, J.F. Lewry and M. R. Stauffer (eds.), Geological Association of Canada, Special Paper 37, pp. 75-94.

Lis, M.G. and Price, R.A. 1976. Large-scale block faulting during deposition of the Windermere Supergroup (Hadrynian) in southeastern British Columbia; Geological Survey of Canada Paper 76-1A, pp. 135-136.

Litinskii, A. 1963. Measurment of magnetic susceptibility in prospecting for kimberlite pipes (Translation). Min. Mag. vol. 109, pp. 137-146.

Longman, M.J. 1980. Location of kimberlite intrusives using Landsat digital data, in J.E. Glover and D.I. Groves, (eds.), Kimberlites and Diamonds, University of Western Australia, Perth. pp. 89-95.

Lorenz, J.C. 1982. Lithospheric flexure and the history of the Sweetgrass Arch, northwestern Montana; *In* Geological Studies of the Cordilleran Thrust Belt. R. B. Powers (Ed.); Rocky Mountain Association of Geologists 1982 Symposium, pp. 77-89.

Lorenz, J.C. 1984. The function of the Lewis and Clark Fault system during the Laramide Orogeny; *In* J.D. McBane and P.B. Garrison, (eds.), Montana Geological Society 1984 Field Conference and Symposium, pp. 221-230.

Loutit, T.S., Hardenbol, J. and Vail, P.R. 1988. Condensed sections: The key to age determination and correlation of continental margin sequences; *In:* Sea-Level Changes-An Integrated Approach, SEPM Special Publication No. 42 pp. 183-213

Luth, R.W. 1994. Lower crustal xenoliths of the Sweetgrass Hills: Preliminary findings; *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 238-239.

Lyons, P.C., Outerbridge, W.F., Triplehorn, D.M., Evans, H.T. Jr., Congdon, R.D., Capiro, M., Hess, J.C., and Nsh, W.P. 1992. An Appalachian isochron: a kaolinized Carboniferous air-fall volcanic-ash deposit (tonstein); Geological Society of America Bulletin vol. 104, pp. 1515-1527.

MacDonald, R. 1987. Update on the Precambrian geology and domainal classification of northern Saskatchewan; In Summary of Investigation 1988, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 87-4, pp. 87-106.

MacDonald, R., Upton, B.G.J., Collerson, K.D., Hearn, B.C., Jr. and James D. 1992. Potassic mafic lavas of the Bearpaw Mountains Montana: mineralogy, chemistry, and origin; Journal of Petrology, vol. 33, part 2, pp. 305-346.

Machel, H.G. and Mountjoy, E.W. 1987. General constraints on extensive pervasive dolomitization and their application to the Devonian carbonates of western Canada; Canadian Society of Petroleum Geologists Bulletin, vol. 35, pp. 143-158

Machel, H.G. and Anderson, J.H. 1989. Pervasive subsurface dolomitization of the Nisku Formation in central Alberta; Journal of Sedimentary Petrology, vol. 59, pp. 891-911

Macnae, J.C. 1979. Kimberlites and exploration geophysics. Geophysics vol. 44. pp. 1395-1416.

Magnée, I. de. 1950. Délimination géo-électrique du premiere pipe de kimberlite découvert dan les champs diamantfrères du Kasai (Congo Belge). 18th Int. Geol. Congr. (Pt. 5). pp. 52-58.

Majorowicz, J.A., Jones, F.W. and Lam, H.L. 1984. A comment on 'A magnetovariational study of a geothermal anomaly' by M.R. Ingham, D. K. Bingham and D.I. Gough. Geophys. J. R. Astr. Soc. vol. 76. pp. 667-672.

Majorowicz, J.A., Jones, F.W. and Jessop, A.M. 1986. Geothermics of the Williston basin in Canada in relation to hydrodynamics and hydrocarbon occurrences. Geophysics vol. 51, pp. 767-779.

Majorowicz, J.A. and Jessop, A.M. 1993. Relation between basement heat flow and thermal state of the sedimentary succession of the Alberta Plains; Bulletin of Canadian Petroleum Geology, vol. 41, pp. 358-368.

Makhotkin, I.L., Arakelyants, M.M. and Vladykin, N.V. 1991*. Age of lamproites of the Aldan Province; Translated from Doklady Akademii Nauk SSSR, 1989, vol. 306, no. 3, pp. 703-707; *In* Transactions of the USSR Academy of Sciences, Earth Sciences Sections, February 1991, pp.163-167.

Mansker, W.L., Richards, B.D. and Cole, G.P. 1987*. A note on newly discovered kimberlites in Riley County, Kansas; *In* E.M. Morris and J.D. Pasteris (eds.), Mantle Metasomatism And Alkaline Magmatism; Geological Society of America Special Paper 215, pp. 197-204.

Marchand, M. 1994. Synopsis, current exploration activity, Horseshoe Project - Mineral Exploration Permits, Peace River area, Alberta; Press Release - Ridgeway Petroleum Corp. and Horseshoe Gold Mining Inc., 4 pp.

Martin, R. and Jamin, F.G.S. 1963. Paleogeomorphology of the buried Devonian landscape in northeastern Alberta; *In* M.A. Carrigy (ed.), The K.A. Clark Volume, A Collection Of Papers On The Athabasca Oil Sands, Research Council of Alberta, Information Series No. 45, pp. 31-42.

Marvin, R.F., Hearn, B.C., Jr., Mehnert, H.H., Naeser, C.W., Zartman, R.E. and Lindsey, D.A. 1980*. Late-Cretaceous-Paleocene-Eocene igneous activity in north-central Montana; Isochron/West, vol. 29, pp. 5-25.

Maureau, G.T. F.R. 1964. Crustal structure in Western Canada, M.Sc. Thesis, University of Alberta, Edmonton.

McCabe, P.J., Strobl, R.S., MacDonald, D.E., Nurkowski, J.R., and Bosman, A. 1986. An evaluation of the coal resources of the Horseshoe Canyon Formation and laterally equivalent strata, to a depth of 400 m, in the Alberta plains area; Alberta Research Council, 55 pp.

McCandless, T.E. and Gurney, J.J. 1989. Sodium in garnet and potassium in clinopyroxene: criteria for classifying mantle eclogites; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds and Diamond Exploration, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 827-832.

McConnell R.G. 1885. Report on the Cypress Hills, Wood Mountain and adjacent country. Geological Survey of Canada, Annual Report, 1C.

McDonald, D.E. 1982. Marl resources of Alberta; Alberta Research Council Earth Sciences Report 82-1.

McDonald, D.E., Ross, T.C., McCabe, P.J. and Bosman, A. 1987. An Evaluation of the Coal Resources of the Belly River Group to a depth of 400 m in the Alberta Plains; Alberta Research Council Open File Report 1987-8 76 pp.

McGrossan, R.G. and Glaister, R.P. 1964. Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta.

McGugan, A. 1987. "Horses" and transverse faults in the Lewis Thrust sheet, Elk Range, Kananaskis Valley, Rocky Mountain front ranges, southwest Alberta; Bulletin of Canadian Society of Petroleum Geology, vol. 35, no. 3, pp. 358-361.

McLean, J.R. 1971. Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Plains; Saskatchewan Research Council, Geological Division, Report No. 11, 96 pp.

McLellan, S. and Hutcheon, I. 1993. Controls on He anomalies in the Alberta Basin; *In* Ross, G.M. (ed.), Alberta Basement Transects Workshop (March 1-2), Lithoprobe Report #31, Lithoprobe Secretariat, University of British Columbia, pp. 146.

McMechan, M.E. 1981. The Middle Proterozoic Purcell Supergroup in the southeastern Purcell Mountains, British Columbia and the initiation of the Cordilleran miogeocline, southern Canada and adjacent United States; Bulletin of Canadian Society of Petroleum Geology, vol. 29, pp. 583-621.

McMechan, M.E. 1988. Geology of Peter Loughheed Provincial Park, Rocky Mountain Front Ranges, Alberta; Geological Survey of Canada Open File 2057.

McMechan, M.E. 1990 Upper Proterozoic to Middle Cambrian history of the Peace River Arch: evidence from the Rocky Mountains. Bulletin of Canadian Petroleum Geology, v 38A, pp. 36-44.

McMechan, M.E. and Thompson, R.I. 1989. Structural Style and History of the Rocky Mountain Fold and Thrust Belt. *In* B.D. Ricketts (ed.) Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 47-71.

McMechan, M.E., Thompson, R.I., Cook, D.G., Gabrielse, H. and Yorath, C. 1992. Structural Styles, Part E. Foreland Belt. *In* Gabrielse, H. and C.J. Yorath. (eds.) Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 634-650.

McMullen, R.M. 1959. Sedimentary petrology of the Cardium Formation, west-central Alberta; Univ of Alberta M.Sc. Unpublished Thesis 95 pp.

McWilliams, G.H., Smith, L.J. and Sawyer, D.A. 1979. Year-end report 1979 Exploration Program Richardson River project, northeastern Alberta, NTS 74 L/2, 3, 6 and 7; Alberta Research Council, Economic Mineral File Report U-AF-161(2).

Meijer-Drees, N.C. and Johnston, D.I. 1993. Geology of the Devonian-Carboniferous boundary beds in Alberta; *In* Canadian Society of Petroleum Geologists Core Workshop Guidebook, Carboniferous To Jurassic, Pangea, Calgary, Alberta August 15-19, 1993, pp.188-205.

Meissner, R. 1986. The Continental Crust: A Geophysical Approach, Academic Press, New York.

Mellon, G.B. 1967. Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville groups, Alberta foothills and plains. Alberta Research Council Bulletin 21.

Mereu, R.F. Majumdar, S.C. and White, R.E. 1976. The structure of the crust and upper mantle under the highest ranges of the Canadian Rockies from a seismic refraction survey. Can. J. Earth Sci. v 14, pp. 196-208.

Meyboom, P. 1960. Geology and groundwater resources of the Milk River Sandstone in southern Alberta; Alberta Research Council Memoir 2, 25 pp.

Meyer, H.O.A. 1976*. Kimberlites of the continental United States: a review; The Journal of Geology, vol.84, no. 4, pp.377-403.

Milanovskiy, Y.Y. and Mal'kov, B.A. 1982*. Epochs of kimberlite volcanism and global compressive and expansionary cycles of the earth; Doklady Akademii Nauk SSSR, 1980, vol.252, no. 5, pp 1203-1207. Translated in Doklady Earth Science Sections, vol. 252, pp. 62-65.

Milsom, J. 1989. Field Geophysics, Open University Press, London, 182 pp.

Mitchell, R.H. 1991. Kimberlites and lamproites: Primary sources of diamond; Geoscience Canada, vol. 18, pp. 1-16.

Mitchell, R.H. 1989. Aspects of the petrology of kimberlites and lamproites: some definitions and distinctions; *In* J. Ross (ed.) Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 7-45.

Mitchell, R.H. 1987. Megacrysts in kimberlites from the Gibean field, Namibia, Neues Jahrbuch für Mineralogic, Abhandlungen, vol. 157, pp. 267-283.

Mitchell, R.H. 1986. Kimberlite: Mineralogy, Geochemistry and Petrology; Plenum Press, New York.

Mitchell, R.H. and Bergman, S.C. 1991. Petrology of Lamproites. Plenum Press, New York, 447 pp.

Mitchell, R.H. Platt, R.G. and Downey, M. 1987*. Petrology of lamproites from Smoky Butte, Montana; Journal of Petrology, vol. 28, pp. 645-677.

Moffat, I.W. and Gardner, D.A..C. 1981. Basinal isotatic adjustment faults and their petroleum significance: Discussion. Bulletin of Canadian Petroleum Geology, vo. 30, no. 1, pp. 43-44.

Moffat, I.W. and Spang, J.H. 1984. Origin of transverse faulting, Rocky Mountain front ranges, Canmore, Alberta; Bulletin of Canadian Society of Petroleum Geologists vol. 32, no. 2, pp. 147-161.

Morel-à-l'Huissier, P., Green, A.G. and Pike, C.J. 1987. Crustal Refraction Surveys Across the Trans-Hudson Orogen/Williston Basin of South Central Canada. J. Geophys. Res. v, 92, pp. 6403-6420.

Morelli, A. and Dziewonski, A.M. 1987. Topography of the core-mantle boundary and lateral homogeneity of the liquid core. Nature vol. 325, pp. 678-683.

Morton, R.D., Stewart, J.P., Bale, W.C. and Day, R.C. 1993. A review of diamond occurrences and potentials in Alberta, Canada; *In* Dunne, K.P.E. and Grant, B. (eds.), Mid-Continent Diamonds. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 101-104.

Morris, E.M. 1987*. The Cretaceous Arkansas alkalic province; A summary of petrology and geochemistry; *In* E.M. Morris and J.D. Pasteris (eds.), Mantle Metasomatism And Alkaline Magmatism; Geological Society of America Special Paper 215, pp. 217-233.

Mosig, R.W. 1980. Morphology of indicator minerals as a guide to proximity of source; *In* J.E. Glover and D.I. Groves (eds.), Kimberlites and Diamonds; The University of Western Australia, Special Publication No. 5, pp. 81-88.

Mossop, G.D. and Shetson, I. (eds.) 1994. Geological Atlas Of The Western Canada Sedimentary Basin; Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council.

Mougeot C.M. 1991. The Quaternary Geology of the Vermilion-East, area Alberta. Unpublished M.Sc. thesis, Geology Department, University of Alberta, Edmonton, Alberta, 193 pp.

Mountjoy, E.W. 1958. Jasper area Alberta a source of the Foothills Erratics Train, Alberta Society of Petroleum Geologists, Journals, vol. 6, pp. 218-226.

Muehlenbachs, K., Burwash, R.A. and Chacko, T. 1994. The oxygen and hydrogen isotope composition of Alberta basement rocks: Possible implications for crustal and paleogeographic reconstructions of basement terrains; *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 250-253.

Muehlenbachs, K., Burwash, R.A. and Chacko, T. 1993. A major oxygen isotope anomaly in the basement rocks of Alberta; *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 120-124.

Naeser, C.W. 1971*. Geochronology of the Navajo-Hopi diatremes; Journal of Geophysical Reseach, vol. 76, pp. 4978-4985.

Nakanishi, I. and Anderson, D.L. 1984. Aspherical heterogeneity of the mantle from phase velocities of mantle waves. Nature vol. 307, pp. 117-121.

Nascimbene, G.G. 1963. Bentonites and the geochronology of the Bearpaw Sea; M.Sc. Thesis. Unversity of Alberta, 81 pp.

Nataf, H-C., Nakanishi, I., and Anderson, D.L. 1986. Measurements of mantel wave velocities and inversion for lateral heterogeneities and anisotropy, 3. Inversion. J. Geophys. Res., vol. 91, pp. 7261-7307.

Nataf, H-C., Nakanishi, I. and Anderson, D.L. 1984. Anisotropy and shear-velocity heterogeneities in the upper mantle. Geophys. Res. Lett. vol. 11, pp. 109-112.

National Geophysical Data Centre, Geophysics of North America CD-ROM, Version 1.1, United States Department of Commerce, 1990.

Nekrasov, I.Y., Yakovlev, Y.V., Pavlova, L.A. and Gotovtsev, V.V. 1990. Unusual inclusions in native gold from the Mir kimberlite pipe; Transactions (Doklady) of the USSR Academy of Sciences, Earth Sciences Sections, vol. 303, no. 6, pp. 160-164; Translated from Doklady Akademii Nauk SSSR, 1988, vol. 303, No. 5, pp. 1209-1213.

Nesbitt, B.E. and Muehlenbachs, K. 1993a. Synorogenic fluids of the Rockies and their impact on paleohydrogeology and resources of the Western Canadian Sedimentary Basin. *In* G.M. Ross (ed.), Alberta Basement Transects Workshop (March 1-2), Lithoprobe Report #31, pp. 60-62.

Nesbitt, B.E. and Muehlenbachs, K. 1993b. Crustal hydrogeology of the Rockies: Implications to the origins of brines and Pb-Zn mineralization in the Western Canadian Sedimentary Basin. *In* Geological Association of Canada Annual Meeting, May 17-19, 1993, Edmonton, Alberta, Program with Abstracts, p. A76.

Nixon, P.H. 1980a. The morphology and mineralogy of diamond pipes. *In* J.E. Glover and D.I. Groves, (eds.), Kimberlites and Diamonds, University of Western Australia, Perth. pp. 32-47.

Nixon, P.H. 1980b. Regional diamond exploration - theory and practice. in J.E. Glover and D.I. Groves (eds.), Kimberlites and Diamonds. Univ. West. Australia. Perth. pp. 64-80.

Nixon, P.H. and Condliffe, E. 1989*. Tanzania kimberlites: a preliminary heavy mineral study; *In* J.Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence, Origin And Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 407-418.

Nixon, P.H., Thirlwall, M.F., Buckley, F. and Davies, C.J. 1984*. Spanish and Western Australian lamproites: Aspects of whole rock geochemistry; *In* J. Kornprobst (ed.), Kimberlites, I: Kimberlites And Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, pp. 285-296.

Northcote, K.E. 1983a. Report on Mark property, Pangman Peak (82N/15W); British Columbia Ministry of Energy, Mines and Petroleum Resources Assessment Report 13596.

Northcote, K.E. 1983b. Report on Jack claims, Lens Mountain (82N/14E); British Columbia Ministry of Energy, Mines and Petroleum Resources Assessment Report 13597.

Northern Miner 1993. Ecstall Mining. The Northern Miner newspaper, August 30 issue. p. 11.

Northern Miner. 1992. DiaMet ponders Lac de Gras ramp, calls latest sample values 'best ever'. The Northern Miner newspaper, August 3 issue, p. 1.

Northwest Territories Government 1993. Diamonds and the Northwest Territories, Canada; Energy, Mines and Petroleum Resources.

Nurkowski, J.R. and Rahmani, R.A. 1984. An Upper Cretaceous fluvio-lacustrine coal-bearing sequence, Red Deer Area, Alberta, Canada; In: Sedimentology of coal and coal-bearing sequences: by R.A. Rahmani and R, M, Flores (eds.). Spec. Publs int Ass. Sediment. vol. 7, pp. 163-176, Blackwell Scientific Publications, Oxford.

O'Brien, H.E., Irving, A.J. and McCallum, I.S. 1991. Eocene potassic magmatism in the Highwood Mountains, Montana: petrology, geochemistry, and tectonic implications; Journal of Geophysical Research, vol. B96, pp. 13,237-13,260.

O'Connell, S.C. 1990. The development of the Lower Carboniferous Peace River Embayment as determined from Banff and Pekisko formation depositional patterns. Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 93-114.

O'Connell, S.C., Dix, G.R. and Barclay, J.E. 1990. The origin, history, and regional structural development of the Peace River Arch, Western Canada; Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 4-24.

O'Connell, S.C. 1994. Geological history of the Peace River Arch; *In* Mossop, G.D. and Shetsen, I. (compilers), Geological Atlas of the Western Canada Sedimentary Basin, Alberta Geological Survey of the Alberta Research Council and Canadian Society of Petroleum Geologists.

Olhoeft, G.R. 1980. Electrical properties of rocks, *In:* Physical properties of rocks and minerals, Thoulaikian, Y.S., Judd, W.R. and Roy, R.F. (eds.), Mcgraw Hill Book Co., New York.

Oliver, T.A. and Cowper, N.W. 1983. Wabamun salt removal and shale compaction effects. Rumsey area, Alberta; Bulletin of Canadian Petroleum Geology, vol. 31, pp.161-168.

Oldale, H.S. and Munday, R.J. 1994. Devonian Beaverhill Lake Group of the Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas Of The Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 11, pp. 149-164.

Ollerenshaw, N.C. 1975. Kananaskis Lakes, British Columbia - Alberta; Geological Survey of Canada Open File 263.

Olson, R.A., Dufresne, M.B., Eccles, D.R., Richardson, R.J.H. and Freeman, M.E 1994. Regional metallogenic evaluation of Alberta; Alberta Research Council Open File Report 1994-10.

O'Neill, J.M. anda Lopez, D.A. 1985. Character and regional significance of Great Falls tectonic zone, east-central Idaho and west-central Montana; The American Association of Petroleum Geologists Bulletin, vol. 69, pp. 437-447.

Osadetz, K.G. 1989. Basin Analysis Applied to Petroleum Geology in Western Canada. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 287-306.

Osadetz, K.G. and Haid, F.M. 1989. Tippecanoe Sequence: Middle Ordovician to Lowest Devonian Vestiges of a Great Epeiric Sea. *In* B.D. Ricketts (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 121-137.

Otter, M.L. and Gurney, J.J. 1989. Mineral inclusions in diamonds from the Sloan diatremes, Colorado-Wyoming State Line kimberlite district, North American; *In* J. Ross (ed.) kimberlites annd related rocks, Volume 2, Their Mantle/Crust setting, Diamonds and Diamond Exploration; Proceedings of the Fourth Kimberlite Conference, Perth, 1986, Geological Society of Australia Special Publication No. 14, pp. 1042-1053.

Ower, J.R. 1960. The Edmonton Formation; Journal of the Alberta Society of Petroleum Geologists, vol. 8, no. 11, pp. 309-323.

Packard, J.J., Pellegrin, G.J., Al-Aasm, I.S., Samson, I. and Gagnon, J. 1991. Diagenesis and dolomitization associated with hydrothermal karst in Famennian Upper Wabamun ramp sediments, northwestern Alberta; *In* G.R. Bloy and M.G. Hadley, (eds.), The Development of Porosity in Carbonate Reservoirs, Canadian Society of Petroleum Petrologists, Continuing Education Short Course, pp. 9-1 to 9-19.

Paterson, N.R., Macfadyen, D.A. and Turkeli, A. 1977. Geophysical exploration for kimberlites, with special reference to Lesotho, meeting abstract. Geophysics, vol. 4, 1531 pp.

Paterson, N.R. and MacFadyen, D.A. 1986. Airborne EM (INPUT)/ magnetometer survey, State Line District, Colorado-Wyoming. Soc. Min. Eng. of AIME, Trans. vol. 280, pp. 1935-1942.

Paul, D.K., Rex, D.C and Harris P.G. 1975*. Chemical characteristics and K-Ar ages of Indian kimberlite; Geological Society of America Bulletin, vol. 86, pp. 364-366.

Peace River Gazette, December 23, 1992. More diamond talk hits Peace Country.

Pearce, T.H. 1970. The analcite-bearing volcanic rocks of the Crowsnest Formation, Alberta; Canadian Journal of Earth Sciences, vol. 7, pp. 46-66.

Peeples. W.J. and Rankin, D. 1973. A magnetotelluric study in the western Canadian sedimentary basin. Pure and Appl. Geophys. 102, pp. 134-147.

Pell, J. 1987a*. Alkaline ultrabasic rocks in British Columbia: carbonatites, nepheline syenites, kimberlites, ultramafic lamprophyes and related rocks; British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Survey Branch Open File 1987-17.

Pell, J. 1987b*. Alkalic ultrabasic diatremes in British Columbia: Petrology, geochronology and tectonic significance; *In* Geological Fieldwork 1986, Minister of Energy, Mines and Petroleum Resources, Geological Survey Branch, Paper 1987-1. pp. 259-272.

Pell, J. and Atkinson, D. 1993. Northwest-Territories kimberlites and diamonds: Exploration highlights and implications; *In* Dunne, K.P.E. and Grant, B. (eds.), Mid-Continent Diamonds, GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 89-94.

Perel'man, A.I. 1977. Geochemistry of Elements in the Supergene Zone (Translated from Russian). Israel Program for Scientific Translations. Keter Publishing, Jerusalem. Also available from U.S. Dept. of Commerce, National Technical Information Service, Springfield, Virginia 22151.

Peterson, T.D. 1993. Lamproites and the diamond potential of the Churchill Province; 95th Annual General Meeting Of CIM, Calgary, Alberta, May 9-12, 1993, Paper #100.

Peterson, T.D. and Currie, K.L. 1993. Analcite-bearing igneous rocks from the Crowsnest Formation, southwestern Alberta; *In:* Current Research, Part B, Geological Survey of Canada Paper 93-1B, pp. 51-56.

Pettapiece, W.W. 1986. Physiographic subdivisions of Alberta. Land Resources Research Center, Research Branch, Agriculture Canada, 1:1,500,000 scale.

Pidgeon, R.T., Smith, C.B. and Fanning, C.M. 1989*. Kimberlite and lamproite emplacement ages in Western Australia; *In* J. Ross (ed.) Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 369-381.

Pirson, S.J. 1963. Handbook of Well Log Analysis; Prentice-Hall Inc.

Podruski, J.A. 1988. Contrasting character of the Peace River and Sweetgrass Arches, Western Canada Sedimentary Basin; Geoscience Canada, vol. 15, pp. 94-97.

Pope, A.J. and Thirlwall, M.F. 1992. Tectonic setting, age and regional correlation of ultrabasic-ultrapotassic dykes in the northern Purcell Mountains, southeast British Columbia. Canadian Journal of Earth Sciences, vol. 29, pp. 523-530.

Poulton, T.P. 1989. Upper Absaroka to Lower Zuni: The Transition to the Foreland Basin. *In* B.D. Rickettes (ed.). Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 233-247.

Prest, K. 1984. Late Wisconsinan glacial complex. Geological Survey of Canada map 1584A, 1:7,5000,000 scale. *In* Quaternary Stratigraphy of Canada - A Canadian Contribution to IGCP Project 24, R.J. Fulton (ed.). Geological Survey of Canada, Paper 84-10, 210 pp.

Prest, K. 1970. Quaternary geology of Canada. *In* Geology and Economic Minerals of Canada, R.J.W. Douglas (ed.). Geological Survey of Canada, Economic Geology Report 1, Chapter 12, pp. 676-764.

Price, R.A. 1962. Fernie map-area, east half, Alberta and British Columbia; Geological Survey of Canada Paper pp. 61-24.

Price, R.A. 1967. The tectonic significance of mesoscopic subfabrics in the southern Rocky Mountains of Alberta and British Columbia, Canada; Canadian Journal of Earth Sciences, vol. 4, pp. 39-70.

Price, R.A. 1981. The Cordilleran foreland thrust and fold belt in the southern Canadian Rocky Mountains; *In* K.R. McClay and N.J. Price, (eds.), Thrust and Nappe Tectonics, Geological Society of London Special Publication 9, pp. 427-448.

Price R.A. and Lis, M.G. 1975. Recurrent displacements on basement-controlled faults across the Cordilleran miogeocline in southern Canada; Geological Society of America Abstracts with Programs, 1234 pp.

Proudfoot D.N. 1985. A lithostratigraphic and genetic study of Quaternary Sediments in the vicinity of Medicine Hat Alberta. Unpublished Ph.D. thesis, Department of Geology, University of Alberta, Edmonton, Alberta, Canada, 248 pp.

Quirt, D. 1992a. Garclass - a program to classify garnets using the algorithm of Dawson and Stephens (1975); Saskatchewan Research Council, Publication R-1230-10-E-92.

Quirt, D. 1992b. Minclass - A program to classify garnets and pyroxenes using the discriminant functions of Dawson and Stephens (1975) and Stephens and Dawson (1977); Saskatchewan Research Council, Publication R-1230-12-E-92.

Reddy, I.K. and Rankin, D. 1971. Magnetotelluric measurements in central Alberta. Geophysics, vol. 36, pp. 739-753.

Reddy, I.K. and Rankin, D. 1972. On the interpretation of magnetotelluric data in the plains of Alberta; Canadian Journal of Earth Science, vol. 9, no. 5, pp. 514-527.

Reed, I.E. and Sinclair, I.G.L. 1991. The search for kimberlite in the James Bay Lowlands of Ontario; Canadian Institute of Mining and Metallurgy, vol. 84, pp.132-139.

Renn, R. 1956. Exploration report - Iron prospecting permit no. 12; unpublished assessment report prepared for Perfection Machine Works Ltd.

Richards, T.C. and Walker, D.J. 1959. Measurement of the thickness of the earth's crust in the Albertan Plains of western Canada. Geophysics, vol. 24, pp. 262-284.

Richards, B.C., Bamber, E.W., Henderson, C.M., Higgins, A.C., Johnston, D.I., Mamet, B. and Meijer-Drees, N.C. 1993*. Uppermost Devonian (Famennian) and Lower Carboniferous (Tournaisian) at Jura Creek and Mount Rundle, southwestern Alberta. Field Trip #7, Carboniferous to Jurassic, Pangea, Calgary, Alberta, August 15-19, 1993.

Richardson, R.J.H., Mandryk, G.B.,and Fietz, D.W. 1989. Alberta Geological Survey coal geology data base; Alberta Research Council Open File Report 1989-02A.

Richardson, S.H. 1989. Radiogenic isotope studies of diamond inclusions, Workshop on Diamonds: Extended Abstract, 28th Inemational Geological Congress, Washington, D.C., pp. 87-90.

Richardson, S.H. 1986. Latter-day origin of diamonds of eclogitic paragenesis, Nature, vol. 322, pp. 623-626.

Richardson, S.H., Erlank, A.J., Harris, J.W. and Hart, S.R. 1990. Ecologitic diamonds of Proterozoic age from Cretaceous kimberlites, Nature, vol. 346, pp. 54-56.

Richardson, S.H., Gurney, J.J., Erlank, A.J. and Harris, J.W. 1984. Origin of diamonds in old enriched mantle, Nature, vol. 310, pp. 198-202.

Ricketts, B.D. (ed.) 1989. Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta.

Ritchie, W.D. 1960*. The Kneehills Tuff; Journal of the Alberta Society of Petroleum Geologists, vol. 8, pp. 339-341.

Ritchie, W. D. 1957. The Kneehills Tuff; M.Sc. Thesis. University of Alberta, 67 pp.

Robinson, E.S. and Coruh, C. 1988. Basic exploration geophysics, John Wiley and Sons, New York, 562 pp.

Roden, M.F., Smith, D. and McDowell, F.W. 1979*. Age and extent of potassic volcanism on the Colorado Plateau; Earth and Planetary Science Letters, vol. 43, pp. 279-284.

Roed, M.A., Mountjoy, E.W. and Rutter N.W. 1967. The Athabasca Valley Erratics Train. Alberta and Pleistocene ice movements across the Continental Divide. Canadian Journal of Earth Sciences, vol. 4, pp. 625-632.

Roed, M.A. 1975. Cordilleran and Laurentide glaciations west central Alberta. Canadian Journal of Earth Sciences, vol. 12, pp. 1493-1515.

Ross, G.M. 1991. Precambrian basement in the Canadian Cordillera: an introduction. Canadian Journal of Earth Sciences, vol. 28, pp. 1133-1139.

Ross, G.M. 1990. Deep crust and basement structure of the Peace River Arch region: constraints on mechanisms of formation. Bulletin of Canadian Petroleum Geology, vol. 38A, pp. 25-35.

Ross, G.M. 1993. Tectonic Evoluation of Crystalline Basement, Western Canada: Implication for Mantle Evoluation. *In* D. Sawyer, The Calgary Mining Forum, Program and Abstracts, March 3 and 4, 1993. 12 pp.

Ross, G.M., Broome, J. and Miles, W. 1994a. Potential fields and basement structure - Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas Of The Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 4, pp. 41-48.

Ross, G.M., Mariano, J. and Dumont, R. 1994b. Was Eocene magmatism widespread in the subsurface of Southern Alberta? Evidence from new aeromagnetic anomaly data: *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia,Lithoprobe Report #37, pp. 240-249.

Ross, G.M., Milkereit, B., Eaton, D., White, D., Kanasewich, E.R. and Burianyk, J.A. 1994c. Paleoproterozoic collisional orogen beneath Western Canada Sedimentary Basin imaged by Lithoprobe crustal seismic reflection data; *In* Ross, G.M. (ed.), Lithoprobe Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #37, pp. 40-58.

Ross, G.M., Parrish, R.R., Villeneuve, M.E., and Bowring, S.A. 1991. Geophysics and geochronology of the crystalline basement of the Alberta basin, western Canada; Canadian Journal of Earth Sciences, vol. 28, pp. 512-522.

Ross, G.M. and Stephenson, R.A. 1989. Crystalline basement: the foundation of Western Canada Sedimentary Basin. *In* Ricketts, B.D. (ed.), Western Canada Sedimentary Basin, A Case History. Canadian Society of Petroleum Geologists, Calgary, Alberta, pp. 33-45.

Ross, G.M., Villeneuve, M.E., Parrish, R.R. and Theriault, R.J. 1993. Tectonic assembly of crystalline basement, Alberta Basin: Implications for mantle evolution and ancestry of Canada's Pacific margin; *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 134-143.

Russell, L.S. and Landes, R.W. 1940. Geology of the southern Alberta Plains; Geological Survey of Canada, Memoir 221. 128 pp.

Rutherford, R.L. 1943. Volcanic ash, volcanic glass on Willow Creek, southwest of Nanton, Twp. 13, R2W5M, 82J/1, Alberta; Alberta Geological Survey of the Alberta Research Council Economic Minerals File VOL-IR-001, 1 p.

Sanderson, J.O.G. 1931. Upper Cretaceous volcanic ash beds in Alberta; Transactions, Royal Society of Canada, vol. 12, pp. 61-71.

Sawatzky, H.B. 1975. Astroblemes in the Williston Basin. American Association of Petroleum Geologists, Bulletin, vol. 59, no. 4, pp. 694-710.

Sawatzky, H.B. 1976. Two probable Late Cretaceous astroblemes in western Canada-Eagle Butte, Alberta and Dumas, Saskatchewan; Geophysics, vol. 41, pp. 1261-1271.

Scafe, D.W. 1975. Alberta Bentonites; Alberta Research Council Economic Geology Report 2, 18 pp.

Schlumberger 1972. Log Interpretation Principles; Schlumberger Limited

Schreiner, B.T. 1990. Lithostratigraphic correlation of Saskatchewan tills: a mirror image of Cretaceous bedrock. Saskatchewan Research Council, publication R-1216-3-E-90, v i, ii and iii., 114 pp.

Science City News 1992. Microscopic diamonds may give clue to dinosaurs' doom; vol. 2, issue 4, Winter 1992.

Sclater, J.G., Parson, B. and Jaupart, C. 1981. Oceans and continents, Similarities and differences in the mechanisms of heat loss. J. Geophys. Res. vol. 86, pp. 11535-11552.

Scott Smith, B.H. 1992. Contrasting kimberlites and lamproites; Exploration and Mining Geology, vol. 1, no. 4, pp. 371-381.

Scott Smith, B.H., Danchin, R.V., Harris, J.W. and Stracke, K.J. 1984*. Kimberlites near Orroroo, South Australia; *In* J. Kornprobst (ed.), Kimberlites, I: Kimberlites And Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, pp. 121-142.

Scott Smith, B.H. and Skinner, E.M.W. 1984*. A new look at Prairie Creek, Arkansas; *In* J. Kornprobst (ed.), Kimberlites, I: Kimberlites And Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, pp. 255-283.

Scott Smith, B.H., Skinner, E.M.W. and Loney, P.E. 1989*. The Kapamba lamproites of the Luangwa Valley, Eastern Zambia; *In* J.Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence, Origin And Emplacement Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 189-205.

Shaver, K.C. 1988. Exploration of the Sloan Ranch complex: a diamondiferous kimberlite prospect in Northern Colorado. Min. Eng., vol. 40, pp. 45-48.

Shaw, E.W. 1963. Canadian Rockies - orientation in time and space; *In* Childs, O.E., (ed.), Backbone of the Americas, American Association of Petroleum Geologists, Memoir 2, pp. 231-242.

Shee, S.R., Bristow, J.W., Bell, D.R., Smith, C.B., Allsopp, H.L. and Shee P.B. 1989*. The petrology of kimberlites, related rocks and associated mantle xenoliths from the Kuruman Province, South Africa; *In* J.Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence, Origin And Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 60-82.

Shell Canada Limited 1978. Daugh and West Cooking Lake; unpublished exploration data with the Alberta Research Council, Alberta Geological Survey.

Shetsen, I. 1984. Application of till pebble lithology to the differentiation of glacial lobes in southern Alberta. Canadian Journal Earth Sciences, vol. 21, pp. 920-933.

Shetsen, I. 1990. Quaternary geology, Central Alberta. Terrain Sciences Department, Alberta Research Council Map, 1:500,000 scale.

Shetsen, I. 1987. Quaternary geology, Southern Alberta; Terrain Sciences Department, Alberta Research Council Map, 1:500,000 scale.

Sibbald, T.I.I., Guliov, D.F., Patterson, F.M., Haidl and P. Reeves 1991. Mineral Resources of Saskatchewan. Saskatchewan Energy and Mines, Saskatchewan Geological Survey Miscellaneous Report 91-5.

Sibbald, T.I.I. and Quirt, D.H. 1987. Uranium deposits of the Athabasca Basin. Saskatchewan Research Council, Publication #R-855-1-G-87.

Sikabonyi, L.A. and Rodgers, W.J. 1959. Paleozoic tectonics and sedimentation in the northern half of the west Canadian Basin; Journal of the Alberta Society of Petroleum Geologists, vol. 7, pp. 193-216.

Simpson, M.A. 1993. Kimberlite indicator minerals in Southwestern Saskatchewan; *In* Dunne, K.P.E. and Grant, B. (eds.), Mid-Continent Diamonds. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 53-58.

Skall, H. 1975. The paleoenvironment of the Pine Point lead-zinc district. Economic Geology, v. 70, pp. 22-47.

Skinner, E.M.W. 1989. Contrasting Group I and Group II kimberlite petrology: towards a genetic model for kimberlites; *In* J. Ross (ed.) Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence Origin and Emplacement Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 528-544.

Slater, G. 1927. Structure of the Mud Buttes and Tit Hills in Alberta: Geological Society of America, Bulletin, v. 38, no. 4, pp. 721-730.

Smith, J.Y. 1963. The Crowfoot Dike. In Edmonton Geological Society Guide book, Sunwapta Pass Area, 5th Annual Field Trip, August 1963, pp. 65-70.

Smith, C.B., Allsopp, H.L., Kramers, J.D., Hutchinson, G. and Roddick, J.C. 1985*. Emplacement ages of Jurassic-Cretaceous South African kimberlites by the Rb-Sr method on phlogopite and whole-rock samples; Transactions of the Geological Society of South Africa, vol. 88(2), pp. 249-266.

Smith, C.B., Gurney, J.J., Harris, J.W., Robinson, D.N., Shee, S.R. and Jagoutz, E. 1989. Sr and Nd isotopic systematics of diamond-bearing eclogite xenoliths and eclogitic inclusions in diamond from southern Africa; *In* J. Ross (ed.), Kimberlites And Related Rocks, Volume 2, Their Mantle/Crust Setting, Diamonds And Diamond Exploration, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 853-863.

Smith, R.J. 1985. Geophysics in Australian mineral exploration. Geophysics, vol. 50, pp. 2637-2665.

Smith, R. 1994. International workshop on AEM methods. The Leading Edge, vol. 13, pp. 198-202.

Souther, J.G. 1992. Volcanic Regines. *In* H. Gabrielse and C.J. Yorath (eds.). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 457-490.

Sprenke, K.F. and Kanasewich, E.R. 1982. Gravity modelling and isostasy in western Canada. J. Can. Soc. of Explor. Geophys. vol. 18, pp. 49-57.

St-Onge, D.A. 1972. Sequence of glacial lakes in north-central Alberta. Geological Survey of Canada Bulletin 213, 16 pp.

Stalker, A. MacS. 1956. The Erratics Train, foothills of Alberta; Geological Survey of Canada, Bulletin 37, 28 pp.

Stalker, A. MacS. and Vincent, J.S. 1993. Quaternary; subchapter 4k, *In:* D.F. Scott and J.D. Aitken, (eds.), Sedimentary Cover of the Craton in Canada., Geological Survey of Canada, Geology of Canada, No 5, pp. 466-482.

Stearn, N.H. 1932. Practical geomagnetic exploration with the Hotchkiss superdip. AIME Trans. Geophys. Prosp., 169 pp.

Steiner, R. 1958. Report on the iron nore underlying the area known as "MARASEK'S", Burmis, Alberta. Unpublished report prepared on behalf of West Canadian Collieries Ltd.

Stelck, C.R., Burwash, R.A. and Stelck, D.R. 1978. The Vreeland High; A Cordillerann expression of the Peace River River Arch; Bulletin of Canadian Petroleum Geology, v. 26, no. 1, pp. 87-104.

Stephens, W.E. and Dawson, J.B. 1977. Statistical comparison between pyroxenes from kimberlites and their associated xenoliths; Journal of Geology, vol. 85, pp. 433-449.

Stephenson, R.A., Zelt, C.A., Ellis, R.M., Hajnal, Z., Morel-à-l'Huissier, P., Mereu, R.F., Northey, D.J., West, G.F. and Kanasewich, E.R. 1989. Crust and upper mantle structure and the origin of the Peace River Arch. Bull. of Can. Pet. Geol. vol. 37, pp. 224-235.

Stewart, G.A. 1963. Geological controls on the distribution of Athabasca oil sand reserves; *In* M.A. Carrigy (ed.), *The K.A. Clark Volume, A Collection Of Papers On The Athabasca Oil Sands*, Research Council of Alberta, Information Series No. 45, pp. 15-26.

Stewart, J. 1972. Initial deposits in Cordilleran geosyncline: Evidence of a Later Precambrian (<850 m.y.) continental separation; Geological Society of America Bulletin, vol. 83, pp. 1345-1360.

Stewart, J.S. 1943. Bassano west of Fourth Meridian, Alberta; Geological Survey of Canada, Map 741A.

Stewart, J.P. and Bale, W.C. 1994. Alberta Diamond Exploration. In The Calgary Mining Forum, Program and Abstracts, 10 & 11 February, 1994; published by the Calgary Mineral Exploration Group. 34 pp.

Stokes, F. 1987. Fault controlled dolomitization of the Wabumun Group Tangent Field, Peace River Arch, Alberta. *In* Devonian lithofacies and reservoir styles in Alberta. F. F. Krause & O. G. Burrowes (eds.); Canadian Society of Petroleum Geologists, 13th Core Conference, Calgary, pp. 73-85.

Stott, D.F. and Aitken, J.D. (eds.) 1993. Sedimentary Cover of the Craton in Canada, Geology of Canada, no. 5. Decade of North American Geology (DNAG), vol. D-1, Geological Survey of Canada.

Struik, L.C. 1987. The ancient western North American margin: An alpine rift model for the east-central Canadian cordillera; Geological Survey of Canada Paper 87-15.

Swanson, F.J. and Gent, M.R. 1993. Results of reconnaissance diamond indicator mineral sampling, Saskatchewan; *In* Dunne, K.P.E. and Grant, B. (eds.), Mid-Continent Diamonds. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 113-119.

Switzer, S.B., Holland, W.G., Christie, D.S., Graf, G.C., Hedinger, A.S., McAuley, R.J., Wierzbicki, R.A. and Packard, J.J. 1994. Devonian Woodbend-Winterburn strata of the Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas of the Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 12, pp. 165-202.

Takla Star Resources Ltd. 1993a. Diamonds in Alberta; unpublished press release, January 20, 1993.

Takla Star Resources Ltd. 1993b. Kimberlite diamond indicator minerals - southern Alberta; unpublished press release, May 10, 1993.

Takla Star Resources Ltd. 1993c. Diamonds & Gold - The shining path! Corporate release dated November 17, 1993.

Taylor, R.S., Mathews, W.H. and Kupsch, W.O. 1964. Tertiary. *In* R.G. McGrossan and R.P. Glaister (eds.), Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, pp. 190-194.

Telford, W.M.,Geldart, L.P. and Sheriff, R.E. 1990. Applied Geophysics: 2nd Edition, Cambridge University Press, Cambridge.

Telford, W.M., L.P Geldart, R.E.Sheriff, and D.A. Keys 1976. Applied Geophysics. Cambridge University Press. Cambridge. 860 pp.

Thériault, R.J. and Ross, G.M. 1991. Nd isotopic evidence for crustal recycling in the ca.2.0 Ga subsurface of western Canada; Canadian Journal of Earth Sciences, vol. 28, pp. 1140-1147.

Thomas, M.D., Sharpton, L., and Grieve, R.A.F. 1987. Gravity patterns and Precambrian structure in the North American Central Plains. Geology , vol. 15, pp. 489-492.

Thorleifson, H. and Garrett, R.G. 1993. Prairie kimberlite study - till matrix geochemistry and preliminary indicator mineral data; Geological Survey of Canada, Open file Report 2745.

Thorliefson, L.H., Garrett, R.G. and Matile, G. 1994. Prairie Kimberlite Study, Indicator Mineral Geochemistry; Geological Survey of Canada, Open File 2875, 1 diskette (ASCII files).

Tilley, B.J. and Longstaffe, F.J. 1984. Controls on hydrocarbon accumulation in glauconitic sandstone, Suffield Heavy Oil Sands, southern Alberta; American Association of Petroleum Geologists Bulletin, vol. 68, pp. 1104-1023.

Tizzard, P.G. and Lerbekmo, J.F. 1975*. Depositional history of the Viking Formation, Suffield area, Alberta, Canada; Bulletin of Canadian Petroleum Geology, vol. 23, no. 4, pp. 715-752.

Tyrell, J. 1887. Report on a part of northern Alberta and portions of adjacent districts in Assiniboia and Saskatchewan. Geological Survey of Canada, Annual report for 1886, Part 2E.

U.S. Geological Survey and American Association of Pet. Geol. 1976. Geothermal gradient map of North America, scale 1: 500,000, 2 sheets, Washington, D. C.

Van Hees, H. and North, F.K. 1964. Cambrian *In* R.G. McGrossan and R.P. Glaister (eds.). Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, pp. 20-33.

Van Wagoner, J.C., Postamentier, H.W., Mitchum Jr., R.M., Vail, P.R., Sarg, J.F., Loutit, T.S., and Hardenbol, J. 1988. An overview of the Fundamentals of sequence stratigraphy and key definitions; In: Sea-Level Changes: An Integrated Approach. Society of Economic Paleontologists and Mineralogists Special Publication 42, pp. 39-46.

Varsek, J.L. and Hutton, A.N. 1992. The role of Proterozoic structure and stratigraphy on Phanerozoic sedimentation and tectonics, northeastern British Columbia; *In* Ross, G.M. (ed.), *Lithoprobe* Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #28, pp. 19-21.

Vasudevan, K., Edwards, D., vanderVelden, A., Maier, R., Geiger, H., Kelsch, L., Geis, W. and Enachescu, M. 1992. Reprocessing and post-stack processing of industry-donated deep crustal seismic data from Alberta; *In* Ross, G.M. (ed.), Lithoprobe Alberta Basement Transect Workshop, Lithoprobe Secretariat, University of British Columbia, Lithoprobe Report #31, pp. 29-45.

Verrall, P. 1968. Observations on geological structures between the Bow and North Saskatchewan Rivers; In 16th Annual Field Conference Guide Book, Alberta Society of Petroleum Geologists, pp. 107-118.

Villeneuve, M.E., Ross, G.M., Theriault, R.J., Miles, W., Parrish, R.R. and Broome, J. 1993. Tectonic subdivision and U-Pb geochronology of the crystalline basement of the Alberta basin, western Canada; Geological Survey of Canada, Bulletin 447.

Vozoff, K., and Ellis, R.M. 1966. Magnetotelluric measurements in southern Alberta; Geophysics, vol. 31, pp. 1153-1157.

Waage, K.M. 1961. Stratigraphy and refractory clayrocks of the Dakota Group along the northern Front Range, Colorado; U.S. Geological Survey Bulletin 1102, 154 pp.

Wagner, P.A. 1914. The diamond fields of Southern Africa - The Transvaal Leader, Johannesburg; 2nd edition, Gothic Printers, Capretown, 355 pp.

Walcott. R.I. 1970. Flexural rigidity, thickness, and viscosity of the lithosphere. J. Geophys. Res., vol. 73, pp. 3941-3954.

Waldman, M.A., McCandless, T.E. and Dummett H.T. 1987. Geology and petrography of the Twin Knobs #1 lamproite, Pike County, Arkansa; *In* E.M. Morris and J.D. Pasteris (eds.), Mantle Metasomatism And Alkaline Magmatism; Geological Society of America Special Paper 215, pp. 205-216.

Walker, T. 1981. Exploration Permits 6878110001 and 6878110002, SMD Mining Company, Ltd., Wood Buffalo Project, final report on exploration activities; Alberta Research Council Assessment File U-AF-171(1).

Wallace, C.A., Lidke, D.J. and Schmidt, R.G. 1990. Faults of the central part of the Lewis and Clarke line and fragmentation of the Late Cretaceous foreland basin in west-central Montana; Geological Society of America Bulletin, vol. 102, pp. 1021-1037.

Wan, G. 1989*. The distribution pattern of kimberlites and associated rocks in Shandong, China; *In* J.Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence, Origin And Emplacement Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 401-406.

Wang, K., Attrip, M. Jr. and Orth, C.J. 1993. Global iridium anomaly, mass extinction, and redox change at the Devonian-Carboniferous boundary; Geology, vol. 21, pp. 1071-1074.

Watson, K.D. 1967*. Kimberlites of Eastern North America; *In* P.J. Wyllie (ed.), Ultramafic And Related Rocks, Wiley, New York, pp. 312-323.

Weaver, D.F. 1962. Seismological determination of crustal thickness in southern Alberta. M.Sc. Thesis, University of Alberta, Edmonton.

Webb, J.B. 1964. Historical Summary. *In* R.G. McGrossan and R.P. Glaister (eds.) Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, pp. 218-232.

Wellman, P. 1973*. Early Miocene potassium-argon age for the Fitzroy lamproites of Western Australia; Journal of the Geological Society of Australia, vol. 19, pp. 471-474.

Westgate, J.A. 1968. Surficial geology of the Foremost-Cypress Hills area, Alberta. Research Council of Alberta, Bulletin 22, 122 pp.

Wickens, A.J. 1976. The upper mantle of southern British Columbia. Can. J. Earth Sci vol. 14, pp. 1100-1115.

Wickens, A.J. 1977. Variations in lithospheric thickness in Canada. Can. J. Earth Sci., vol. 8, pp. 1154-1162.

Williams, M.Y. and Dyer, W.S. 1930. Geology of Southern Alberta and Southwestern Saskatchewan; Geological Survey of Canada, Memoir 163,

Williamson, J., Dufresne, M.B. and Olson, R.A. 1993. The Southern Alberta Rift in southwest Alberta, Program to Identify Targets for Metallic Mineral Exploration. Alberta Research Council Open File Report 1993-13A and 13B.

Wilson, J.A. 1985a. Basement Geology Beneath and Around the Western Edge of the Athabasca Basin, Alberta. Alberta Research Council Map 1985-10.

Wilson, J.A. 1985b. Geology of the Athabasca Group in Alberta. Alberta Research Council Bulletin No. 49.

Wilson, J.A., Langenberg, W., Jeffries, L., Tooth, J., Grieve, R. and Berkes, Z. 1989. Proposal for scientific drilling on the Steen River Structure, northwestern Alberta; Alberta Research Council, Open File Report 1989-4.

Winzer, S.R. 1972. The Steen River Astrobleme, Alberta, Canada. 24th International Geological Congress, Section 15, pp. 148-156.

Woodzick, T.L. and McCallum, M.E. 1984. A teledetective study of kimberlite regions in North America (Colorado-Wyoming), East Africa (Mwadui) and Siberia (Mir). *In* J. Komprobst (ed.), Kimberlites, I: Kimberlites and Related Rocks, Proceedings of the 3rd International Kimberlite Conference, Amsterdam 5-12,

Workman, L.E. 1954. Possible pre-Blairmore faulting; Bulletin of Canadian Petroleum Geology, vol. 2, pp. 12-13.

Workum, R.H. 1991. Peace River Arch Wabumun Dolomite, tectonic or subaerial karst?; Canadian Society of Petroleum Geologists Bulletin, vol. 39, pp. 54-56

Wright, G.N., McMechan, M.E. and Potter, D.E.G. 1994. Structure and architecture of the Western Canada Sedimentary Basin; *In* G.D. Mossop and I. Shetson (eds.), Geological Atlas Of The Western Canada Sedimentary Basin, Published Jointly by the Canadain Society Of Petroleum Geologists and the Alberta Research Council, Chapter 3, pp. 25-40.

Wu, P. 1991. Flexure of the lithosphere beneath the Alberta Foreland Basin: Evidence of an eastward stiffening continental lithosphere. Geophy. Res. Lett. vol. 18, pp. 451-454.

Wyllie, M.R.J. 1963. The Fundamentals of Well Log Interpretation; Academic Press.

Yeremeyev, N.V., Kononova, V.A., Makhotkin, I.L., Dmitriyeva, M.T., Aleshin, V.G. and Vashchenko, A.N. 1990. Native metals in lamproites of the Central Aldan; Transactions (Doklady) of the USSR Academy of Sciences, Earth Sciences Sections, vol. 303, no. 6, pp. 167-171; Translated from Doklady Akademii Nauk SSSR, 1988, vol. 303, No. 5, pp. 1464-1467.

Yorath, C.J. 1992. Upper Jurassic to Paleogene Assemblages. *In* Gabrielse, H. and C.J. Yorath (eds.). Geology of the Cordilleran Orogen in Canada, Geology of Canada, no. 4. Decade of North American Geology (DNAG) vol. G-2. Geological Survey of Canada, pp. 329-371.

Zartman, R.E. 1977. Geochronology of some alkalic provinces in eastern and central United States; Annual Review, Earth and Planetary Sciences, vol. 5, pp. 257-286.

Zartman, R.E., Brock, M.R., Heyl, A.V., and Thomas, H.H. 1967. K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States; American Journal of Science, vol. 265, pp. 848-870.

Zelt, C.A. and Ellis, R.M. 1989a. Comparison of near-coincident crustal refraction and extended vibroseis reflection data: Peace River Region, Canada. Geophys. Res. Lett., vol. 8, pp. 843-846.

Zelt, C.A. 1989b. Seismic structure of the crust and upper mantle in the Peace River Arch region. Unpublished PhD thesis, University of British Columbia, 223 pp.

Zelt, C.A. and Ellis, R.M. 1990. Crust and upper mantle Q from seismic refraction data: Peace River region. Can. J. Earth Sci., vol. 71, pp. 1040-1047.

Zelt, C.A. and Ellis, R.M. 1989b. Seismic Structure of the Crust and Upper Mantle in the Peace River Arch Region. Canada, J. Geophys. Res., vol. 94, pp. 5729-5744.

Zhang, P., Hu, S. and Wan, G. 1989*. A review of the geology of some kimberlites in China; In J.Ross (ed.), Kimberlites And Related Rocks, Volume 1, Their Composition, Occurrence, Origin And Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth 1986, Geological Society of Australia Special Publication No. 14, pp. 392-400.

Zhao, D., Smith, D.G.W., Zhou, M., Yang, J., Deng, C. and Huang, Y. 1993*. Yinniugou lamproites in Datong, Northern Shanxi Province, China: First occurrence in the North China Craton. *In* Dunne, K.P.E. and Grant, B. (eds.), Mid-Continent Diamonds. GAC-MAC Symposium Volume, Edmonton, Alberta, May 17-18, 1993, pp. 139-144.

APPENDIX 4.1

APPENDIX 4.1: REPORTED BENTONITE OCCURRENCES IN ALBERTA					
OCCURENCE NUMBER	STRATIGRAPHIC HORIZON *	THICKNESS (Feet)	UNUSUAL FEATURES	LOCATION(s)	SOURCE
1 (Bullshead)	KBp	2		N1/2 2-8-7W4, NE 3-8-7W4, NW 14-8-7W4	Babet (1966), Scafe (1975)
2A (GrosVentre)	KBp (100' above base)	8.7		SW 25-10-5W4	Babet (1966), Scafe (1975)
2B (GrosVentre)	KBp (25' below 12A)	4.5		SW 25-10-5W4	Babet (1966), Scafe (1975)
3 (Irvine)	KBp	up to 10.9		NE 12-11-4W4, 17-11-3W4	Babet (1966), Scafe (1975)
4 (Irvine)	KBp	greater than or equal to13.0		SE 17-11-4W4	Babet (1966), Scafe (1975)
5 (Irvine)	KBp	up to 10		NW 1-11-3W4	Babet (1966), Scafe (1975)
6 (Irvine)	KBp	up to 11		E1/2 23-11-3W4, NE 25-11-3W4, 20-11-2W4, NW 30-11-2W4	Babet (1966), Scafe (1975)
7 (Irvine)	KBp	10 to 11		4-12-2W4, 15-12-2W4	Babet (1966), Scafe (1975)
8 (Dorothy-Trefoil)	KBp	up to 33	About 10 miles in extent	Sections 3-5,7-10 T27-17W4; Sections 12-14,22-24,26-27,33-34 T26-17W4; Sections 4-8,18 T26-16W4	Scafe (1975)
9 (Drumheller-Newcastle)	KHC	3 to 15		NW 2-29-20W4, NW 14-29-20W4, NE 34-28-20W4, SE 9-29-20W4	Babet (1966), Scafe (1975)
10 (Morrin)	KHC	3 to 15	Grades laterally into silty bentonite	NE 32-31-21W4	Babet (1966), Scafe (1975)
11 (Sheerness)	KHC	4.5		W1/2 13-29-13W4	Babet (1966), Scafe (1975)
12A (Rosalind)	KHC	5 to 8		Sections 31-32 T42-17W4; 25-43-18; Sections 5-8,18-19 T43-17W4	Scafe (1975)

OCCURENCE NUMBER	STRATIGRAPHIC HORIZON *	THICKNESS (Feet)	UNUSUAL FEATURES	LOCATION(s)	SOURCE
12B (Rosalind)	KHC (10' below 12A)	8 to 10.5		as above	Babet (1966), Scafe (1975)
12C (Rosalind)	KHC (80' below 12B)	6 to 8		as above	Babet (1966), Scafe (1975)
12D (Rosalind)	KHC (80' below 12C)	4 to 6		as above	Babet (1966), Scafe (1975)
13 (Onoway)	KHC	up to 22.7		6-56-2W5, 7-56-2W5, W1/2 8-56-2W5, N1/2 18-56-2W5	Babet (1966), Scafe (1975)
14 (Onoway)	KHC	0.3 to 1		NE 27 -56-2W5	Babet (1966), Scafe (1975)
15 (Onoway)	KHC	up to 31		NE 8-56-1W5, N1/2 9-56-1W5, NW 10-56-1W5, SW 15-56-1W5, E1/2 16-56-1W5	Babet (1966), Scafe (1975)
16 (Busby)	KHC	up to 52		Sections 19-22,27,29-30,36 T57-1W5; 25-57-2W5	Babet (1966), Scafe (1975)
17 (Lac la Nonne)	KHC	1.3 to 5.3		SW 11-57-2W5	Babet (1966), Scafe (1975)
18 (Lac la Nonne)	KHC	no data	Very poor quality	SW 28-57-3W5	Babet (1966), Scafe (1975)
19 (Busby)	KHC	2 to 14	Lens shaped and highly variable	NE 3-58-2W5, SE 7-58-2W5, SE 11-58-2W5	Babet (1966), Scafe (1975)
20 (Mcleod River)	TKP	6 to 8		NE 6-52-18W5	Scafe (1975)
21 (Kleskun Hills)	KWT	up to 4		Sections 15,21-23,27 T72-4W6	Babet(1966), Scafe (1975)
22 (Milk River Ridge)	KBp	1.5 to 2.0		9-4-19W4	Babet (1966)
23 (Walsh)	KBp	4 to 5		SW 28-11-1W4	Babet (1966)
24 (Little Bow River)	KBp	15		NW 14-12-20W4	Babet (1966)
25 (Rosebud)	KHC	3.5	Lens shaped deposit	SE 32-27-2-W4	Babet (1966)
26 (Rosedale)	KHC	0.5 to 1.0		SE 22-28-19W4	Babet (1966)

OCCURENCE NUMBER	STRATIGRAPHIC HORIZON *	THICKNESS (Feet)	UNUSUAL FEATURES	LOCATION(s)	SOURCE
27 (Horseshoe Canyon)	KHC	20		26-28-21W4	Babet (1966)
28 (Bow River)	KBR	no data	High K2O (~4.65%) High Al2O3 (~ 27%) ;Low CaO (~ 0.85%)	T28-4W5	Babet (1966)
29 (Nevis)	KHC	no data	Very poor quality	SW 22-39-22W4, NW 15-39-22W4	Babet (1966)
30 (Camrose)	KHC	2 to 3		SE 21-46-20W4	Babet (1966)
31 (Smokey River)	KHC	no data		SW 35-69-4W6	Babet (1966)
32 (Smokey River)	KHC	no data		SW 2-70-3W6	Babet (1966)
33 (Milk River)	KBR	up to 4		2-2-17W4	ARC Min. Comm. Files
34 (St. Mary River)	KBp	less than 1.5		T6,7 R 22W4	ARC Min. Comm. Files
35 (Standard)	KHC?	2.5		T 24 R 2W4	ARC Min. Comm. Files
36 (Black Diamond)	TKP?	no data		T 20 R2W5	ARC Min. Comm. Files
37 (Keephills)	KHC	up to 1		31-50-3W5	ARC Min. Comm. Files
38 (Camrose)	KHC	up to 2		T 47 R 20W4	ARC Min. Comm. Files
39 (Edmonton)	KHC	up to 0.7		T 53 R 24W4	ARC Min. Comm. Files
40 (Coalspur)	TKP? or KHC?	up to 16	about 20 miles in extent	33-48-21W5	Sanderson (1965)
41 (Nanton)	TKP?	up to 2	Volcanic glass or pumice	SE 36-13-2W5	Rutherford (1943) Allen (1944)
42 (Stavely)	TKP?	no data	Volcanic glass or pumice	T 14 R 27W4	Kelso (1944)
43 (Bickerdike)	TKP	100		6-52-18W5	Byrne (1955)
44 (Raley Creek)	KHC?	15		21-4-23W4	Ower (1960)

OCCURENCE NUMBER	STRATIGRAPHIC HORIZON *	THICKNESS (Feet)	UNUSUAL FEATURES	LOCATION(s)	SOURCE
45 (Well 10-20-36-16)	KBp	13		10-20-16-36	Habib (1981)
46 (Embarass River)	KC	?	K2O/Na2O = 2.5	33-48-21W5	Ritchie (1957)
47 (Strawberry Creek)	KB	?	Fe Montmorillonite Tuff	SW1/4 5-50-1W5	Ritchie (1957)
48 (Oldman River)	KB	?	K2O/Na2O = 1.92	T 7 R 28W4	Ritchie (1957)
49 (St. Mary River)	KBp	0.6	Garnet bearing Tuff	4-1-9-22W4	Nascimbene (1963)

Accompanies Figure 4.1

* Note:
KBp = Bearpaw Formation
KHC = Horseshoe Canyon Formation
TKP = Paskapoo Formation
KWt = Wapiti Formation
KBR = Belly River Formation

APPENDIX 4.2

APPENDIX 4.2

REPORTED BENTONITE MARKER BEDS GREATER THAN 3 METERS THICK

AGS COAL DATABASE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thickness (meters)	Meridian	Town-ship	Range	Section	Marker Type
1004190	419515	21-82	55.25	58.40	3.15	4	14	23	22	FIRST BENTONITE
1004269	419523	24-82	185.20	188.70	3.50	4	15	23	5	FIRST BENTONITE
1004329	419531	27-82	288.50	292.30	3.80	4	15	24	36	FIRST BENTONITE
1004565	388827	13-81	184.65	189.30	4.65	4	16	23	32	FIRST BENTONITE
1004970	419499	14-82	141.00	145.00	4.00	4	17	22	31	FIRST BENTONITE
1004971	388793	08-81	94.00	97.70	3.70	4	17	23	1	FIRST BENTONITE
1004973	419390	04-81	152.60	157.40	4.80	4	17	23	9	FIRST BENTONITE
1004975	463828	36-82	82.90	91.80	8.90	4	17	23	11	FIRST BENTONITE
1004976	419416	VU6-82	91.30	96.70	5.40	4	17	23	12	FIRST BENTONITE
1004977	463794	32-82	103.80	107.00	3.20	4	17	23	12	FIRST BENTONITE
1004978	419408	VU5-82	103.30	108.60	5.30	4	17	23	14	FIRST BENTONITE
1004979	463810	35-82	122.70	126.40	3.70	4	17	23	16	FIRST BENTONITE
1004980	463844	39-82	125.30	128.70	3.40	4	17	23	16	FIRST BENTONITE
1004982	419457	10-82	207.20	210.80	3.60	4	17	23	19	FIRST BENTONITE
1004984	419440	VU9-82	170.50	174.30	3.80	4	17	23	20	FIRST BENTONITE
1004985	463851	40-82	146.40	150.60	4.20	4	17	23	21	FIRST BENTONITE
1004987	463836	38-82	114.70	118.30	3.60	4	17	23	23	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1004988	463869	41-82	114.30	117.50	3.20	4	17	23	23	FIRST BENTONITE
1004990	463885	43-82	131.00	134.90	3.90	4	17	23	26	FIRST BENTONITE
1004992	419473	12-82	211.00	215.00	4.00	4	17	23	32	FIRST BENTONITE
1004994	463901	45-82	163.40	167.40	4.00	4	17	23	33	FIRST BENTONITE
1004995	419481	13-82	153.20	156.30	3.10	4	17	23	34	FIRST BENTONITE
1004996	463893	44-82	169.90	173.20	3.30	4	17	23	34	FIRST BENTONITE
1050001	463919	46-82	138.80	144.30	5.50	4	17	23	35	FIRST BENTONITE
1050003	388785	SH7-81	235.30	238.70	3.40	4	17	24	1	FIRST BENTONITE
1050004	463729	26-82	299.80	304.60	4.80	4	17	24	3	FIRST BENTONITE
1004997	388777	SH6-81	319.50	323.70	4.20	4	17	24	9	FIRST BENTONITE
1004998	419382	VU3-82	198.20	202.30	4.10	4	17	24	12	FIRST BENTONITE
1004999	423541	20-81	236.80	240.80	4.00	4	17	24	14	FIRST BENTONITE
1005000	463711	24-82	297.00	300.50	3.50	4	17	24	15	FIRST BENTONITE
1005001	463778	34-83	289.20	293.20	4.00	4	17	24	15	FIRST BENTONITE
1005002	463703	23-82	319.70	322.80	3.10	4	17	24	18	FIRST BENTONITE
1005003	463760	33-83	341.40	347.00	5.60	4	17	24	18	FIRST BENTONITE
1005004	463786	35-83	308.00	312.80	4.80	4	17	24	20	FIRST BENTONITE
1005005	423558	18-81	276.00	279.50	3.50	4	17	24	22	FIRST BENTONITE
1005006	463745	28-82	270.40	275.00	4.60	4	17	24	27	FIRST BENTONITE
1005007	463695	22-82	297.60	301.90	4.30	4	17	24	29	FIRST BENTONITE
1005008	388769	SH4-81	286.70	291.00	4.30	4	17	24	30	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick- ness (meters)	Merid- ian	Town- ship	Range	Section	Marker Type
1005010	463752	30-82	299.10	303.00	3.90	4	17	24	32	FIRST BENTONITE
1005011	423566	17-81	255.80	260.10	4.30	4	17	24	35	FIRST BENTONITE
1005012	423574	19-81	356.60	361.00	4.40	4	17	25	12	FIRST BENTONITE
1005013	423582	16-81	310.80	315.40	4.60	4	17	25	36	FIRST BENTONITE
1005014	463687	21-82	338.60	343.20	4.60	4	17	25	36	FIRST BENTONITE
1005136	36590	18	82.30	86.70	4.40	4	18	22	4	FIRST BENTONITE
1005137	370353	11-80	122.30	126.90	4.60	4	18	22	7	FIRST BENTONITE
1005139	36608	17	17.40	23.50	6.10	4	18	22	14	FIRST BENTONITE
1005140	36616	14	152.50	157.10	4.60	4	18	22	19	FIRST BENTONITE
1005141	370361	10A-80	130.40	133.70	3.30	4	18	22	19	FIRST BENTONITE
1005143	36582	19	91.20	94.80	3.60	4	18	22	21	FIRST BENTONITE
1005144	464198	117-82	167.10	173.60	6.50	4	18	22	30	FIRST BENTONITE
1005145	370379	09-80	145.00	149.60	4.60	4	18	22	31	FIRST BENTONITE
1005150	463935	50-82	196.40	200.50	4.10	4	18	23	5	FIRST BENTONITE
1005151	419465	11-82	201.10	208.40	7.30	4	18	23	6	FIRST BENTONITE
1005152	463943	52-82	253.00	257.60	4.60	4	18	23	7	FIRST BENTONITE
1005154	380162	81-45	193.20	197.60	4.40	4	18	23	8	FIRST BENTONITE
1005157	380147	81-35	137.00	142.00	5.00	4	18	23	14	FIRST BENTONITE
1005158	463950	53-82	186.40	190.50	4.10	4	18	23	16	FIRST BENTONITE
1005159	464172	82-84	221.20	224.70	3.50	4	18	23	16	FIRST BENTONITE
1005160	463976	57-82	193.90	197.60	3.70	4	18	23	17	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1005164	463984	58-82	219.70	224.80	5.10	4	18	23	19	FIRST BENTONITE
1005166	464149	82-70	196.20	199.80	3.60	4	18	23	21	FIRST BENTONITE
1005167	464164	82-78	174.80	180.00	5.20	4	18	23	22	FIRST BENTONITE
1005168	463968	54-82	171.40	175.60	4.20	4	18	23	23	FIRST BENTONITE
1005169	464180	82-86	186.60	191.90	5.30	4	18	23	23	FIRST BENTONITE
1005172	464123	82-65	215.80	219.10	3.30	4	18	23	27	FIRST BENTONITE
1005173	464156	82-72	190.60	195.20	4.60	4	18	23	27	FIRST BENTONITE
1005174	464131	82-68	210.40	216.40	6.00	4	18	23	28	FIRST BENTONITE
1005175	380071	81-20	246.80	250.50	3.70	4	18	23	31	FIRST BENTONITE
1005176	464024	82-43	208.20	212.00	3.80	4	18	23	33	FIRST BENTONITE
1005177	464099	82-55	224.80	229.90	5.10	4	18	23	33	FIRST BENTONITE
1005179	464032	82-45	186.00	189.20	3.20	4	18	23	34	FIRST BENTONITE
1005180	464073	82-51	189.10	193.80	4.70	4	18	23	34	FIRST BENTONITE
1005181	380097	81-23C	180.00	184.40	4.40	4	18	23	35	FIRST BENTONITE
1005183	380139	81-32	234.00	239.50	5.50	4	18	24	12	FIRST BENTONITE
1005184	388744	SH1-81	320.70	325.70	5.00	4	18	24	16	FIRST BENTONITE
1005185	380154	81-44	326.20	333.00	6.80	4	18	24	24	FIRST BENTONITE
1005186	380089	81-22	279.30	284.00	4.70	4	18	24	35	FIRST BENTONITE
1005424	38919	30-77	32.61	35.81	3.20	4	19	21	10	FIRST BENTONITE
1005446	38901	17-77	44.20	47.24	3.04	4	19	21	35	FIRST BENTONITE
1005448	39115	9	108.20	112.90	4.70	4	19	22	3	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1005449	39123	9-A	108.00	113.20	5.20	4	19	22	3	FIRST BENTONITE
1005451	370346	13-80	119.10	123.40	4.30	4	19	22	4	FIRST BENTONITE
1005452	39107	16	170.60	175.30	4.70	4	19	22	5	FIRST BENTONITE
1005454	380022	81-11	235.40	239.00	3.60	4	19	22	7	FIRST BENTONITE
1005456	370395	06-80	160.90	165.40	4.50	4	19	22	8	FIRST BENTONITE
1005457	464206	118-82	189.20	193.50	4.30	4	19	22	8	FIRST BENTONITE
1005458	39164	1	120.50	126.30	5.80	4	19	22	10	FIRST BENTONITE
1005459	380170	81-46	160.70	164.80	4.10	4	19	22	16	FIRST BENTONITE
1005460	39099	20	209.00	213.20	4.20	4	19	22	18	FIRST BENTONITE
1005461	370387	07-80	210.70	215.20	4.50	4	19	22	18	FIRST BENTONITE
1005462	370403	5A-80	164.20	167.80	3.60	4	19	22	20	FIRST BENTONITE
1005464	39024	50-76	109.42	117.65	8.23	4	19	22	21	FIRST BENTONITE
1005467	370338	3	221.60	227.00	5.40	4	19	22	30	FIRST BENTONITE
1005468	39156	2	123.70	128.00	4.30	4	19	22	33	FIRST BENTONITE
1005470	39149	3	61.40	65.80	4.40	4	19	22	35	FIRST BENTONITE
1005472	39180	BH79-3	231.50	236.00	4.50	4	19	23	3	FIRST BENTONITE
1005474	380048	81-13	282.40	286.70	4.30	4	19	23	9	FIRST BENTONITE
1005476	380220	81-17C	236.40	240.00	3.60	4	19	23	10	FIRST BENTONITE
1005477	380030	81-12	275.40	280.70	5.30	4	19	23	14	FIRST BENTONITE
1005478	464040	82-46	274.00	277.70	3.70	4	19	23	18	FIRST BENTONITE
1005480	39198	BH79-2	376.00	382.00	6.00	4	19	23	20	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1005482	379990	81-06	343.90	349.00	5.10	4	19	23	23	FIRST BENTONITE
1005483	370320	4	268.50	273.20	4.70	4	19	23	24	FIRST BENTONITE
1005484	380006	81-07	279.80	284.00	4.20	4	19	23	24	FIRST BENTONITE
1005485	379982	81-05	345.00	349.20	4.20	4	19	23	28	FIRST BENTONITE
1005487	39206	BH79-1	301.80	306.70	4.90	4	19	23	35	FIRST BENTONITE
1005491	380055	81-14	312.60	316.60	4.00	4	19	24	7	FIRST BENTONITE
1005492	380063	81-16	279.50	283.10	3.60	4	19	24	12	FIRST BENTONITE
1005493	464065	82-48	273.60	280.20	6.60	4	19	24	13	FIRST BENTONITE
1005494	380212	19-81	394.70	398.70	4.00	4	19	24	20	FIRST BENTONITE
1005566	423806	10-82	32.90	36.70	3.80	4	20	21	8	FIRST BENTONITE
1005569	423814	11-82	19.75	23.50	3.75	4	20	21	12	FIRST BENTONITE
1005571	423822	13-82	46.50	50.80	4.30	4	20	21	16	FIRST BENTONITE
1005953	424085	97-82C	75.60	79.00	3.40	4	21	21	33	FIRST BENTONITE
1005954	461657	109-83	56.24	59.40	3.16	4	21	21	33	FIRST BENTONITE
1005955	464628	134-84	63.70	68.30	4.60	4	21	21	33	FIRST BENTONITE
1005958	464602	13584C	62.00	66.20	4.20	4	21	21	34	FIRST BENTONITE
1005960	464610	136-84	64.40	69.40	5.00	4	21	21	35	FIRST BENTONITE
1005993	385054	48-80	10.00	14.00	4.00	4	22	20	7	FIRST BENTONITE
1005994	385062	48-80C	10.60	14.50	3.90	4	22	20	7	FIRST BENTONITE
1006012	423855	96-82	68.90	73.10	4.20	4	22	20	19	FIRST BENTONITE
1006013	461889	132-83	72.80	77.40	4.60	4	22	20	19	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1006014	512517	174-85	64.20	69.00	4.80	4	22	20	19	FIRST BENTONITE
1006038	464644	14084C	92.20	96.00	3.80	4	22	20	30	FIRST BENTONITE
1006041	464669	142-84	90.50	94.40	3.90	4	22	20	31	FIRST BENTONITE
1006048	512558	178-85	53.80	59.20	5.40	4	22	21	1	FIRST BENTONITE
1006049	423871	98-82	43.90	49.00	5.10	4	22	21	2	FIRST BENTONITE
1006050	464677	144-84	76.50	82.00	5.50	4	22	21	2	FIRST BENTONITE
1006051	464685	14584C	70.20	74.40	4.20	4	22	21	2	FIRST BENTONITE
1006052	464693	14684C	91.00	96.00	5.00	4	22	21	2	FIRST BENTONITE
1006053	464719	148-84	79.40	83.80	4.40	4	22	21	2	FIRST BENTONITE
1006054	423897	100-82	90.85	94.00	3.15	4	22	21	3	FIRST BENTONITE
1006055	461665	110-83	71.60	75.20	3.60	4	22	21	3	FIRST BENTONITE
1006056	512541	177-85	87.40	91.40	4.00	4	22	21	3	FIRST BENTONITE
1006057	512566	179-85	104.20	109.00	4.80	4	22	21	3	FIRST BENTONITE
1006058	461673	111-83	134.00	138.60	4.60	4	22	21	4	FIRST BENTONITE
1006059	464727	149-84	109.40	115.40	6.00	4	22	21	4	FIRST BENTONITE
1006061	423921	101-82	158.30	161.50	3.20	4	22	21	9	FIRST BENTONITE
1006062	461681	112-83	112.20	116.20	4.00	4	22	21	9	FIRST BENTONITE
1006063	464735	150-84	152.20	157.40	5.20	4	22	21	9	FIRST BENTONITE
1006064	464743	152-84	150.00	155.80	5.80	4	22	21	9	FIRST BENTONITE
1006065	461707	11483C	138.80	142.60	3.80	4	22	21	10	FIRST BENTONITE
1006066	464701	147-84	119.40	124.00	4.60	4	22	21	10	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1006067	464750	153-84	119.00	122.00	3.00	4	22	21	10	FIRST BENTONITE
1006068	464768	154-84	147.80	153.20	5.40	4	22	21	10	FIRST BENTONITE
1006069	423889	99-82	71.15	74.85	3.70	4	22	21	11	FIRST BENTONITE
1006070	423913	102-82	121.10	124.40	3.30	4	22	21	11	FIRST BENTONITE
1006072	461723	116-83	65.00	69.50	4.50	4	22	21	11	FIRST BENTONITE
1006073	464776	155-84	111.00	115.40	4.40	4	22	21	11	FIRST BENTONITE
1006074	385104	51-80	28.50	34.00	5.50	4	22	21	12	FIRST BENTONITE
1006075	385112	51-80C	29.80	33.25	3.45	4	22	21	12	FIRST BENTONITE
1006077	423905	103-82	78.59	82.50	3.91	4	22	21	12	FIRST BENTONITE
1006078	461731	117-83	66.80	70.20	3.40	4	22	21	12	FIRST BENTONITE
1006080	464792	157-84	52.60	60.80	8.20	4	22	21	12	FIRST BENTONITE
1006081	461749	11883C	75.00	80.60	5.60	4	22	21	13	FIRST BENTONITE
1006082	423830	105-82	113.90	117.25	3.35	4	22	21	14	FIRST BENTONITE
1006083	461756	11983C	129.40	133.20	3.80	4	22	21	14	FIRST BENTONITE
1006084	464800	15884C	114.20	118.00	3.80	4	22	21	14	FIRST BENTONITE
1006085	464818	159-84	92.40	97.20	4.80	4	22	21	14	FIRST BENTONITE
1006086	512574	180-85	126.00	130.00	4.00	4	22	21	14	FIRST BENTONITE
1006087	512582	181-85	144.00	148.40	4.40	4	22	21	14	FIRST BENTONITE
1006088	423954	106-82	143.60	147.50	3.90	4	22	21	15	FIRST BENTONITE
1006089	461764	120-83	153.60	158.00	4.40	4	22	21	15	FIRST BENTONITE
1006090	464826	160-84	156.80	161.20	4.40	4	22	21	15	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thickness (meters)	Meridian	Township	Range	Section	Marker Type
1006091	464834	161-84	156.40	161.00	4.60	4	22	21	15	FIRST BENTONITE
1006092	461699	113-83	162.60	167.80	5.20	4	22	21	17	FIRST BENTONITE
1006093	461772	121-83	157.40	162.00	4.60	4	22	21	17	FIRST BENTONITE
1006094	461780	122-83	141.40	146.20	4.80	4	22	21	18	FIRST BENTONITE
1006096	461798	123-83	147.20	152.00	4.80	4	22	21	22	FIRST BENTONITE
1006097	464859	164-84	149.40	153.60	4.20	4	22	21	22	FIRST BENTONITE
1006099	512590	182-85	129.20	134.80	5.60	4	22	21	23	FIRST BENTONITE
1006100	514968	183-85	140.00	144.00	4.00	4	22	21	23	FIRST BENTONITE
1006101	514976	184-85	107.40	112.20	4.80	4	22	21	23	FIRST BENTONITE
1006104	423947	107-82	82.00	85.30	3.30	4	22	21	24	FIRST BENTONITE
1006106	514984	185-85	94.20	98.20	4.00	4	22	21	24	FIRST BENTONITE
1006107	461814	125-83	125.80	131.00	5.20	4	22	21	25	FIRST BENTONITE
1006108	461830	127-83	106.40	111.00	4.60	4	22	21	25	FIRST BENTONITE
1006110	464883	167-84	98.30	104.30	6.00	4	22	21	25	FIRST BENTONITE
1006111	514992	186-85	100.60	105.80	5.20	4	22	21	25	FIRST BENTONITE
1006112	464891	169-84	123.60	129.20	5.60	4	22	21	26	FIRST BENTONITE
1006113	461806	12483C	134.60	138.80	4.20	4	22	21	27	FIRST BENTONITE
1006114	461855	129-83	140.60	144.90	4.30	4	22	21	27	FIRST BENTONITE
1006115	464842	163-84	145.80	152.20	6.40	4	22	21	27	FIRST BENTONITE
1006117	461863	130-83	140.60	145.00	4.40	4	22	21	33	FIRST BENTONITE
1006118	464917	171-84	103.60	107.20	3.60	4	22	21	34	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1006120	461848	128-83	128.40	132.90	4.50	4	22	21	35	FIRST BENTONITE
1006121	464925	172-84	108.10	111.40	3.30	4	22	21	36	FIRST BENTONITE
1006164	464933	173-84	119.00	124.20	5.20	4	23	20	6	FIRST BENTONITE
1006173	41202	065-76	35.97	41.61	5.64	4	23	20	20	FIRST BENTONITE
1006175	41236	09-77	39.01	42.06	3.05	4	23	20	20	FIRST BENTONITE
1006182	41228	H4-77	49.53	54.89	5.36	4	23	20	30	FIRST BENTONITE
1006183	41277	H4-77C	49.83	55.47	5.64	4	23	20	30	FIRST BENTONITE
1006185	41269	H12-77	42.67	48.59	5.92	4	23	20	31	FIRST BENTONITE
1006187	463398	H22-83	49.80	53.20	3.40	4	23	20	32	FIRST BENTONITE
1006190	41251	H11-77	79.25	82.30	3.05	4	23	20	34	FIRST BENTONITE
1006192	463406	H23-83	103.20	106.20	3.00	4	23	20	34	FIRST BENTONITE
1006194	41285	18-78	82.70	86.50	3.80	4	23	20	36	FIRST BENTONITE
1006202	41418	H5-77	39.47	42.67	3.20	4	23	21	24	FIRST BENTONITE
1006204	463430	H27-83	64.40	69.00	4.60	4	23	21	30	FIRST BENTONITE
1006205	463422	H26-83	71.20	76.30	5.10	4	23	21	33	FIRST BENTONITE
1006206	41434	H7-77	57.91	63.58	5.67	4	23	21	34	FIRST BENTONITE
1006208	41442	H13-77	62.79	67.67	4.88	4	23	21	35	FIRST BENTONITE
1006209	41459	21778C	56.75	61.00	4.25	4	23	21	36	FIRST BENTONITE
1006227	41749	H17-77	92.96	96.62	3.66	4	24	19	7	FIRST BENTONITE
1006243	41772	S-216	51.05	56.69	5.64	4	24	20	4	FIRST BENTONITE
1006246	41939	218C78	79.00	82.10	3.10	4	24	20	9	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1006251	41905	H3-77	63.25	67.42	4.17	4	24	20	18	FIRST BENTONITE
1006257	41855	S-220	82.30	85.34	3.04	4	24	20	30	FIRST BENTONITE
1006259	42044	H14-77	63.09	68.12	5.03	4	24	21	1	FIRST BENTONITE
1006260	42036	H-8-77	68.88	73.46	4.58	4	24	21	2	FIRST BENTONITE
1006261	463455	H29-83	70.60	76.60	6.00	4	24	21	9	FIRST BENTONITE
1006264	42051	H15-77	82.42	85.50	3.08	4	24	21	13	FIRST BENTONITE
1006294	463521	RF2-83	143.80	149.00	5.20	4	24	22	34	FIRST BENTONITE
1006297	468496	R32-84	171.50	175.10	3.60	4	24	23	14	FIRST BENTONITE
1006301	463539	RF4-83	189.20	193.20	4.00	4	24	23	23	FIRST BENTONITE
1006385	463513	RF1-83	177.50	180.50	3.00	4	25	22	5	FIRST BENTONITE
1006408	463547	R8-83C	155.00	158.80	3.80	4	25	22	12	FIRST BENTONITE
1006422	468520	R36-84	227.00	233.40	6.40	4	25	22	18	FIRST BENTONITE
1006423	468504	R38-84	219.30	224.30	5.00	4	25	22	20	FIRST BENTONITE
1006424	463554	R10-83	243.80	249.60	5.80	4	25	22	23	FIRST BENTONITE
1006426	517557	3-85C	260.80	266.90	6.10	4	25	22	27	FIRST BENTONITE
1006483	517623	16-85	147.60	150.60	3.00	4	26	21	7	FIRST BENTONITE
1006499	517755	45-85	124.80	129.80	5.00	4	26	21	31	FIRST BENTONITE
1006505	517649	23-85	140.60	144.40	3.80	4	26	22	13	FIRST BENTONITE
1006510	517664	25-85	182.20	186.80	4.60	4	26	22	21	FIRST BENTONITE
1006512	517656	24-85	183.00	186.60	3.60	4	26	22	23	FIRST BENTONITE
1006514	517631	18-85	110.00	113.80	3.80	4	26	22	24	FIRST BENTONITE

AGS Coal Database Id No.	ERCB Id No.	Company Id	Top	Base	Thick-ness (meters)	Merid-ian	Town-ship	Range	Section	Marker Type
1006517	468553	R43-84	184.20	187.20	3.00	4	26	22	27	FIRST BENTONITE
1006518	468546	R42-84	159.80	162.80	3.00	4	26	22	29	FIRST BENTONITE
1006525	463588	R19-83	171.80	178.30	6.50	4	26	23	11	FIRST BENTONITE
1006528	468561	R46-84	157.40	162.40	5.00	4	26	23	25	FIRST BENTONITE
1006829	517789	55-85	140.40	144.00	3.60	4	27	21	5	FIRST BENTONITE
1006830	468579	R47-84	87.80	92.00	4.20	4	27	21	6	FIRST BENTONITE
1006840	463596	R20-83	136.20	139.80	3.60	4	27	22	2	FIRST BENTONITE
1006841	468488	20-84C	136.70	140.50	3.80	4	27	22	2	FIRST BENTONITE
1006844	517722	40-85	161.80	164.80	3.00	4	27	22	5	FIRST BENTONITE
1006848	463604	R21-83	193.60	197.00	3.40	4	27	22	8	FIRST BENTONITE
1006849	468587	R48-84	111.00	114.60	3.60	4	27	22	9	FIRST BENTONITE
1006851	463612	R22-83	175.60	180.00	4.40	4	27	22	15	FIRST BENTONITE
1007866	463620	R26-83	183.00	188.00	5.00	4	28	22	4	FIRST BENTONITE
1025673	428011	82-46	12.19	17.13	4.94	5	46	19	13	FIRST BENTONITE
1025675	428037	82-48	64.92	68.37	3.45	5	46	19	13	FIRST BENTONITE
1025876	246298	1746	97.48	103.85	6.37	5	46	19	33	FIRST BENTONITE
1026341	448316	3039	61.26	65.38	4.12	5	47	19	3	FIRST BENTONITE
1026864	447318	2346	40.54	44.20	3.66	5	47	19	7	FIRST BENTONITE
1026888	449090	3253	51.36	54.68	3.32	5	47	19	7	FIRST BENTONITE
1027410	456871	994	69.49	70.57	3.50	5	47	19	9	FIRST BENTONITE
1028630	460840	3742	15.33	18.38	3.05	5	47	20	24	FIRST BENTONITE

APPENDIX 6.1A

APPENDIX 6.1A

MICROPROBE DATA FOR SOUTHERN ALBERTA TILL DIAMOND INDICATOR MINERALS

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
3	3		SUB_PICRO_CHROMITE	0.19	54.93	27.40	7.17	0.00	0.00	7.09	0.00	0.44	n/a	97.55	558	2089
5	9		PICRO_CHROMITE	1.47	45.26	20.60	14.45	0.00	0.00	17.11	0.00	0.21	n/a	99.43	1991	643
6	10		PICRO_CHROMITE	0.85	47.29	19.10	14.03	0.00	0.00	17.34	0.00	0.22	n/a	99.15	1991	562
7	12		PICRO_CHROMITE	0.29	50.88	25.60	9.52	0.00	0.00	12.52	0.00	0.36	n/a	99.45	956	1285
8	13		PICRO_CHROMITE	0.59	46.31	34.10	8.48	0.00	0.00	9.27	0.00	0.49	n/a	99.56	1195	1366
8	14		PICRO_CHROMITE	1.12	46.55	19.70	14.37	0.00	0.00	16.82	0.00	0.20	n/a	99.10	2071	643
9	15		PICRO_CHROMITE	1.79	41.44	24.10	13.43	0.00	0.00	18.06	0.00	0.20	n/a	99.35	1991	643
9	17		PICRO_CHROMITE	1.30	41.50	27.60	10.24	0.00	0.00	18.29	0.00	0.27	n/a	99.57	1912	1044
9	18		PICRO_CHROMITE	0.11	53.01	23.20	8.36	0.00	0.00	10.86	0.00	0.34	n/a	96.16	558	1687
10	19		PICRO_CHROMITE	0.34	51.14	27.60	12.84	0.00	0.00	6.71	0.00	0.31	n/a	99.19	1354	643
10	20		PICRO_CHROMITE	0.15	52.78	24.40	8.61	0.00	0.00	12.35	0.00	0.36	n/a	98.94	558	1767
11	21		SUB_PICRO_CHROMITE	0.15	50.84	22.80	7.43	0.00	0.00	16.89	0.00	0.28	n/a	98.99	159	4660
11	23		UNKNOWN	0.17	29.59	22.80	12.79	0.00	0.00	33.50	0.00	0.24	n/a	99.51	1434	1928
12	24		SUB_PICRO_CHROMITE	0.47	49.47	32.90	6.94	0.00	0.00	8.39	0.00	0.62	n/a	99.27	876	2972
12	25		SUB_PICRO_CHROMITE	0.44	38.99	15.00	16.92	0.00	0.00	27.45	0.00	0.20	n/a	99.29	1832	482
12	26		SUB_PICRO_CHROMITE	0.21	55.07	26.70	7.76	0.00	0.00	8.67	0.00	0.38	n/a	99.02	1035	803
12	27		PICRO_CHROMITE	0.32	51.34	20.20	12.48	0.00	0.00	14.77	0.00	0.28	n/a	99.64	1434	562
12	28		PICRO_CHROMITE	0.05	44.61	20.20	11.62	0.00	0.00	22.25	0.00	0.29	n/a	99.34	717	1848
12	29		SUB_PICRO_CHROMITE	0.92	37.71	36.80	13.59	0.00	0.00	10.52	0.00	0.25	n/a	100.10	2071	402
12	30		PICRO_CHROMITE	1.30	43.75	21.50	14.23	0.00	0.00	18.80	0.00	0.21	n/a	100.11	2071	482
12	31		PICRO_CHROMITE	1.08	47.15	19.00	14.68	0.00	0.00	17.77	0.00	0.19	n/a	100.19	1991	562
12	32		UNKNOWN	0.36	31.57	15.60	16.75	0.00	0.00	35.18	0.00	0.17	n/a	99.91	1593	643
12	33		PICRO_CHROMITE	0.11	45.49	18.10	12.18	0.00	0.00	22.96	0.00	0.25	n/a	99.39	717	1687
12	34		PICRO_CHROMITE	0.07	44.43	23.40	10.02	0.00	0.00	21.11	0.00	0.34	n/a	99.96	637	4097
12	35		PICRO_CHROMITE	0.75	49.91	16.40	15.48	0.00	0.00	16.33	0.00	0.20	n/a	99.28	1274	402
12	37		PICRO_CHROMITE	0.06	47.31	20.60	10.96	0.00	0.00	19.83	0.00	0.31	n/a	99.39	637	1928
12	38		PICRO_CHROMITE	1.29	42.19	22.40	13.35	0.00	0.00	19.85	0.00	0.21	n/a	99.61	1912	643
12	40		PICRO_CHROMITE	1.42	46.09	20.40	14.64	0.00	0.00	16.74	0.00	0.18	n/a	99.78	1912	562
12	41		PICRO_CHROMITE	1.29	44.69	21.60	13.46	0.00	0.00	17.46	0.00	0.24	n/a	99.07	1991	643
12	42		PICRO_CHROMITE	1.36	45.20	21.90	13.58	0.00	0.00	17.24	0.00	0.25	n/a	99.85	1912	643
15	43		PICRO_CHROMITE	0.43	52.04	22.10	15.30	0.00	0.00	9.35	0.00	0.22	n/a	99.69	1513	482
15	44		UNKNOWN	0.40	31.17	18.40	14.32	0.00	0.00	34.64	0.00	0.22	n/a	99.54	1434	1687
16	45		PICRO_CHROMITE	0.10	47.73	24.20	9.19	0.00	0.00	17.70	0.00	0.35	n/a	99.58	398	2089
21	46		PICRO_CHROMITE	0.54	47.27	33.80	8.07	0.00	0.00	9.18	0.00	0.40	n/a	99.53	797	1366
21	48		PICRO_CHROMITE	0.32	41.62	25.30	10.63	0.00	0.00	21.28	0.00	0.30	n/a	99.80	1035	1767
22	50		PICRO_CHROMITE	0.73	50.65	15.20	15.69	0.00	0.00	16.87	0.00	0.22	n/a	99.61	1593	402
23	52		PICRO_CHROMITE	0.90	50.63	17.50	14.54	0.00	0.00	15.86	0.00	0.22	n/a	99.87	1195	562
'91TCA-3019'	1621	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.15	0.12	18.09	12.54	6.43	39.06	22.12	0.00	0.44	0.01	98.95	n/a	n/a
'91TCA-3019'	1606	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.06	0.04	25.06	7.43	6.12	37.30	21.11	0.00	1.10	0.01	98.22	n/a	n/a
'91TCA-3019'	1614	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.15	0.03	23.59	7.89	7.61	37.58	21.28	0.00	0.39	0.01	98.52	n/a	n/a
'91TCA-3019'	1622	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.15	0.10	25.12	7.37	6.37	37.81	21.32	0.00	0.79	0.00	99.03	n/a	n/a
'91TCA-3019'	1623	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.11	0.03	23.06	13.02	1.35	38.71	22.28	0.00	0.29	0.01	98.85	n/a	n/a
'91TCA-3019'	1636	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.10	0.05	23.90	12.32	1.36	38.54	22.03	0.00	0.63	0.00	98.93	n/a	n/a
'91TCA-3019'	1641	CD1	CPX_05_UNKNOWN	0.07	0.88	2.17	17.93	23.44	52.68	0.88	0.12	0.06	0.01	98.23	n/a	n/a
'91TCA-3020'	306	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.36	0.10	20.21	7.32	11.30	37.84	21.55	0.04	0.57	0.01	99.29	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
'91TCA-3020'	325	'Cr-grossular'	UNKNOWN	0.12	7.44	20.43	0.06	33.65	34.23	0.40	0.00	0.04	n/a	96.37	n/a	n/a
'91TCA-3020'	327		CPX_02_UNKNOWN	0.06	0.74	5.65	15.47	22.54	51.60	1.72	0.64	0.17	0.00	98.59	n/a	n/a
'91TCA-3020'	328		CPX_05_UNKNOWN	0.12	0.94	3.51	16.15	23.18	51.78	2.04	0.67	0.12	0.00	98.51	n/a	n/a
'91TCA-3020'	343	'Chromite'	PICRO_CHROMITE	0.04	48.60	18.62	11.89	0.02	0.07	19.46	0.00	0.29	0.01	99.25	717	1366
'91TCA-3020'	360	'Chromite'	PICRO_CHROMITE	0.05	52.42	18.70	11.78	0.01	0.11	15.59	0.00	0.29	0.01	99.18	797	1044
'91TCA-3020'	363	'Chromite'	PICRO_CHROMITE	0.04	45.18	19.56	11.96	0.05	0.07	21.47	0.00	0.25	0.01	98.87	797	1526
'91TCA-3020'	366	'Magnesiochromite'	UNKNOWN	0.08	45.38	13.72	14.55	0.00	0.11	24.68	0.00	0.24	0.01	99.01	876	1125
'91TCA-3020'	370	'Chromite'	PICRO_CHROMITE	3.09	40.79	29.42	11.59	0.01	0.12	13.32	0.00	0.24	0.00	98.93	1991	803
'91TCA-3020'	372	'Chromite'	PICRO_CHROMITE	0.10	51.41	21.92	10.05	0.00	0.09	15.48	0.00	0.34	0.01	99.64	398	1607
'91TCA-3021'	1648	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.07	0.03	21.68	12.11	3.71	38.57	22.00	0.00	0.33	0.00	98.50	n/a	n/a
'91TCA-3022'	1673	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.27	0.09	23.35	8.94	6.10	37.21	20.96	0.02	0.58	0.00	97.52	n/a	n/a
'91TCA-3022'	1676	G1	G_02_HIGH_TITANIUM_PYROPE	0.90	1.35	7.95	21.63	4.74	40.61	20.92	0.05	0.29	0.01	98.44	n/a	n/a
'91TCA-3022'	1680	CD1	CPX_02_UNKNOWN	0.09	0.68	4.49	15.03	22.34	51.10	3.41	0.68	0.13	0.01	97.95	n/a	n/a
'91TCA-3023'	1736	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.13	0.09	22.35	9.20	6.21	37.82	21.68	0.00	0.79	0.00	98.27	n/a	n/a
'91TCA-3023'	1746	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.10	24.54	8.03	5.92	37.20	21.33	0.00	0.67	0.00	97.87	n/a	n/a
'91TCA-3023'	1744	CD1	CPX_02_UNKNOWN	0.07	0.70	3.59	16.82	22.43	52.63	1.26	0.50	0.10	0.01	98.10	n/a	n/a
'91TCA-3026'	1709	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.10	0.05	22.64	7.94	7.84	37.67	21.54	0.00	0.49	0.00	98.27	n/a	n/a
'91TCA-3026'	1712	G9	G_09_CHROME_PYROPE	0.21	5.08	7.34	20.60	4.89	40.66	19.63	0.04	0.43	0.01	98.88	n/a	n/a
'91TCA-3027'	1758	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.38	0.11	21.53	7.53	9.20	38.06	21.23	0.03	0.68	0.00	98.75	n/a	n/a
'91TCA-3027'	1753	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.15	0.05	24.57	8.18	6.21	37.89	21.40	0.00	0.55	0.00	99.00	n/a	n/a
'91TCA-3027'	1766	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.16	0.11	23.56	9.51	5.06	37.45	21.28	0.00	0.90	0.01	98.03	n/a	n/a
'91TCA-3027'	1762	CD1	CPX_02_DIOPSIDE	0.10	0.90	4.82	15.11	20.73	52.07	1.60	1.91	0.12	0.01	97.36	n/a	n/a
'91TCA-3028'	1792	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.22	0.04	23.81	7.07	7.84	37.04	21.17	0.00	0.66	0.01	97.85	n/a	n/a
'91TCA-3029'	1820	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.09	0.07	17.16	13.86	5.51	38.97	22.46	0.00	0.43	0.00	98.55	n/a	n/a
'91TCA-3029'	1844	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.11	0.04	20.87	6.36	11.30	37.51	21.45	0.00	0.52	0.00	98.16	n/a	n/a
'91TCA-3029'	1816	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.03	23.29	10.02	4.76	36.07	20.90	0.00	0.70	0.01	95.85	n/a	n/a
'91TCA-3029'	1831	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.15	0.09	23.63	8.37	6.68	37.19	21.29	0.00	0.54	0.01	97.94	n/a	n/a
'91TCA-3029'	1846	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.06	23.81	8.23	6.43	37.58	21.36	0.00	0.56	0.01	98.11	n/a	n/a
'91TCA-3029'	1857	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.11	0.08	22.87	13.06	1.38	37.12	21.81	0.00	0.65	0.01	97.08	n/a	n/a
'91TCA-3029'	1859	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.04	22.21	13.20	1.45	38.21	22.11	0.00	0.56	0.00	97.86	n/a	n/a
'91TCA-3029'	1851	CD1	CPX_02_DIOPSIDE	0.08	0.64	4.66	16.25	20.22	51.68	1.60	0.56	0.12	0.06	95.81	n/a	n/a
'91TCA-3029'	1849	'Diopside'	CPX_02_UNKNOWN	0.05	0.22	5.82	17.69	19.94	52.40	0.90	0.36	0.17	0.01	97.55	n/a	n/a
'91TCA-3029'	1850	'Diopside'	CPX_02_UNKNOWN	0.05	0.04	4.43	15.50	23.96	52.04	0.65	0.70	0.17	0.00	97.54	n/a	n/a
'91TCA-3029'	1852	'Na-diopside'	CPX_04_UNKNOWN	0.39	0.06	5.92	14.12	22.33	49.73	2.56	1.59	0.03	0.00	96.73	n/a	n/a
'91TCA-3029'	1871	'Diopside'	CPX_02_UNKNOWN	0.04	0.03	4.91	14.83	23.71	52.03	1.35	0.89	0.55	0.01	98.34	n/a	n/a
'91TCA-3030'	473	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.28	0.06	22.85	9.16	7.03	37.44	21.39	0.01	0.47	0.01	98.69	n/a	n/a
'91TCA-3030'	375	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.16	0.05	21.34	8.64	8.78	38.01	21.93	0.02	0.59	0.00	99.52	n/a	n/a
'91TCA-3030'	377	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.15	0.08	22.36	8.24	8.38	37.68	21.60	0.00	0.59	0.01	99.08	n/a	n/a
'91TCA-3030'	380	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.19	0.06	22.52	8.34	8.16	37.82	21.65	0.00	0.57	0.00	99.31	n/a	n/a
'91TCA-3030'	389	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.14	0.04	24.10	8.49	6.67	37.69	21.65	0.00	0.54	0.00	99.32	n/a	n/a
'91TCA-3030'	437	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.14	0.04	24.39	8.11	6.80	37.76	21.36	0.01	0.73	0.00	99.34	n/a	n/a
'91TCA-3030'	443	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.09	0.06	24.26	8.34	6.63	37.48	21.43	0.00	0.62	0.00	98.91	n/a	n/a
'91TCA-3030'	446	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.14	0.05	25.32	7.45	7.09	37.62	21.29	0.00	0.55	0.00	99.51	n/a	n/a
'91TCA-3030'	448	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.18	0.09	24.90	8.41	5.96	37.83	21.35	0.00	0.60	0.00	99.32	n/a	n/a
'91TCA-3030'	481	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.13	0.03	25.76	7.30	6.84	37.12	21.24	0.00	0.62	0.01	99.04	n/a	n/a
'91TCA-3030'	661		CPX_01_UNKNOWN	0.09	0.69	6.69	18.64	11.70	49.81	8.02	0.96	0.12	0.00	96.72	n/a	n/a
'91TCA-3030'	411	'Jadeite'	UNKNOWN	0.03	0.01	0.14	0.02	7.92	57.18	25.64	6.67	0.01	0.48	97.62	n/a	n/a
'91TCA-3030'	665	'Diopside'	CPX_02_UNKNOWN	0.05	0.05	5.84	15.11	23.23	51.84	1.09	0.82	0.27	0.00	98.30	n/a	n/a
'91TCA-3030'	667	'Diopside'	CPX_02_UNKNOWN	0.07	0.23	5.08	15.56	23.10	53.40	0.51	0.97	0.21	0.00	99.13	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
'91TCA-3030'	4118	'Mg-ilmenite'	UNKNOWN	51.59	0.82	27.20	13.79	0.03	0.09	0.55	0.00	0.27	0.01	94.34	n/a	n/a
'91TCA-3030'	543	'Chromite'	PICRO_CHROMITE	1.14	46.17	22.88	11.65	0.03	0.16	16.23	0.00	0.27	0.01	98.82	1673	643
'91TCA-3030'	581	'Chromite'	PICRO_CHROMITE	0.11	46.32	17.95	11.49	0.01	0.08	22.12	0.01	0.32	0.00	98.76	558	2249
'91TCA-3030'	585	'Chromite'	CHROMITE	0.31	51.41	31.96	5.35	0.02	0.08	8.16	0.03	0.48	0.01	98.33	797	3454
'91TCA-3030'	4137	'Chromite'	UNKNOWN	0.12	38.97	22.33	8.80	0.02	0.11	24.37	0.01	0.34	n/a	95.49	398	2972
'91TCA-3031'	1908	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.21	0.05	21.16	8.02	8.99	37.44	21.18	0.00	0.56	0.01	97.61	n/a	n/a
'91TCA-3031'	1913	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.18	0.06	22.60	9.73	5.92	37.42	21.22	0.00	0.50	0.01	97.63	n/a	n/a
'91TCA-3031'	1924	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.08	0.03	20.98	6.96	10.23	37.53	21.67	0.00	0.82	0.01	98.30	n/a	n/a
'91TCA-3031'	1932	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.08	0.04	21.73	6.64	10.45	37.28	21.40	0.00	0.57	0.01	98.19	n/a	n/a
'91TCA-3031'	1950	'Garnet'	G_03_CALCIC_PYROPE_ALMANDINE	0.15	0.07	22.57	6.85	9.32	37.36	21.13	0.00	0.77	0.00	98.22	n/a	n/a
'91TCA-3031'	1883	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.07	0.06	21.70	13.98	1.15	37.18	21.95	0.00	0.68	0.00	96.77	n/a	n/a
'91TCA-3031'	1917	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.09	0.04	26.56	10.05	1.94	37.47	21.57	0.00	0.43	0.00	98.15	n/a	n/a
'91TCA-3031'	1925	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.07	0.05	23.00	13.25	0.94	38.51	22.13	0.00	0.62	0.01	98.57	n/a	n/a
'91TCA-3031'	1928	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.06	23.33	13.03	1.16	38.33	21.98	0.00	0.44	0.00	98.41	n/a	n/a
'91TCA-3031'	1943	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.11	0.08	24.68	8.00	5.96	37.00	21.20	0.00	0.64	0.01	97.67	n/a	n/a
'91TCA-3031'	1947	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.19	0.04	24.40	8.03	5.73	37.34	21.49	0.00	0.81	0.00	98.03	n/a	n/a
'91TCA-3031'	1885	G2	G_02_HIGH_TITANIUM_PYROPE	0.94	2.06	8.75	20.51	4.89	39.86	20.31	0.05	0.33	0.00	97.70	n/a	n/a
'91TCA-3031'	1961	CD1	CPX_05_UNKNOWN	0.11	0.83	3.33	16.40	22.86	52.18	1.26	0.60	0.17	0.00	97.74	n/a	n/a
'91TCA-3031'	1959	'Diopside'	CPX_02_UNKNOWN	0.04	0.17	5.59	15.67	22.88	52.01	0.95	0.36	0.18	0.00	97.85	n/a	n/a
'91TCA-3031'	1960	'Diopside'	CPX_02_UNKNOWN	0.07	0.25	3.95	15.76	24.26	52.27	0.65	0.39	0.19	0.00	97.79	n/a	n/a
'91TCA-3031'	1967	'Diopside'	CPX_02_UNKNOWN	0.05	0.12	5.54	15.73	22.30	52.07	1.20	0.70	0.16	0.00	97.87	n/a	n/a
'91TCA-3032'	1984	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.08	0.05	26.90	10.46	1.09	37.34	21.73	0.00	0.64	0.00	98.29	n/a	n/a
'91TCA-3032'	1996	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.11	0.04	23.55	8.76	6.03	37.66	21.65	0.00	0.79	0.00	98.59	n/a	n/a
'91TCA-3032'	2005	'Garnet'	G_05_MAGNESIAN_ALMANDINE	0.08	0.07	22.28	13.25	1.58	38.05	22.06	0.00	0.62	0.00	97.99	n/a	n/a
'91TCA-3032'	2015	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.05	0.05	25.44	7.09	6.09	36.81	21.40	0.00	0.83	0.00	97.76	n/a	n/a
'91TCA-3032'	2034	'Almandine'	G_05_MAGNESIAN_ALMANDINE	0.05	0.03	25.98	8.24	4.02	37.18	21.41	0.00	1.40	0.01	98.31	n/a	n/a
'91TCA-3032'	2044	'Diopside'	CPX_02_UNKNOWN	0.03	0.49	5.73	15.54	22.24	51.63	1.00	0.55	0.25	0.01	97.46	n/a	n/a
'91TCA-3032'	2047	'Na-diopside'	CPX_02_UNKNOWN	0.13	0.03	5.49	16.08	21.98	54.75	1.78	1.69	0.09	0.01	102.02	n/a	n/a
'91TCA-3032'	2048	'Diopside'	CPX_02_UNKNOWN	0.06	0.06	3.99	14.71	22.89	48.81	0.86	0.49	0.02	0.04	91.89	n/a	n/a
1-3-1-T	QH	MGI	PICRO_ILMENITE	50.64	0.23	36.44	11.28	0.04	0.01	0.58	0.01	0.31	0.02	99.54	n/a	n/a
2-3-1-T	4861	Almandine	G_05_MAGNESIAN_ALMANDINE	0.18	0.01	25.60	7.42	6.56	39.59	21.03	0.01	0.89	0.00	101.29	n/a	n/a
2-3-1-T	4862	Chromite	PICRO_CHROMITE	1.11	43.99	20.03	15.00	0.01	0.06	18.05	0.00	0.28	0.01	98.53	n/a	n/a
2-4-2-T	537	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.07	0.13	18.86	11.04	7.05	38.52	21.57	0.00	0.41	0.01	97.65	n/a	n/a
2-4-2-T	536	Garnet	G_05_MAGNESIAN_ALMANDINE	0.07	0.11	22.95	8.47	6.19	37.27	21.05	0.00	0.81	0.01	96.92	n/a	n/a
2-4-2-T	538	Garnet	G_05_MAGNESIAN_ALMANDINE	0.05	0.05	23.89	10.61	3.33	38.05	21.54	0.00	0.70	0.00	98.22	n/a	n/a
5-1-1-T	QH	CD1	CPX_02_UNKNOWN	0.16	0.94	4.70	14.59	22.05	52.95	3.09	0.79	0.07	0.00	99.34	n/a	n/a
5-2-1-T	QH	CD1	CPX_05_UNKNOWN	0.11	0.82	3.43	16.39	22.86	54.81	1.22	0.58	0.14	0.00	100.36	n/a	n/a
5-2-2-T	380	Almandine	G_05_MAGNESIAN_ALMANDINE	0.07	0.03	25.63	9.52	2.89	37.38	21.22	0.00	0.70	0.00	97.44	n/a	n/a
5-2-2-T	QH	G9	G_09_CHROME_PYROPE	0.23	5.34	8.08	19.64	5.72	41.72	18.68	0.02	0.44	0.01	99.87	n/a	n/a
6-1-1-T	206	Pyrope G3?	G_05_MAGNESIAN_ALMANDINE	0.06	0.04	20.77	14.29	1.10	37.91	21.57	0.00	0.62	0.00	96.36	n/a	n/a
6-1-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.76	5.33	6.21	21.50	5.36	42.45	17.78	0.07	0.29	0.00	99.75	n/a	n/a
6-1-2-T	4870	Diopside	CPX_02_UNKNOWN	0.12	0.00	3.93	16.00	23.42	54.05	1.01	0.72	0.00	0.00	99.25	n/a	n/a
8-2-1-T	QH	MGI	PICRO_ILMENITE	48.84	3.27	36.95	10.36	0.03	0.02	0.32	0.01	0.34	0.02	100.14	n/a	n/a
8-2-1-T	6387	Chromite	PICRO_CHROMITE	2.36	44.16	25.98	12.87	0.03	0.06	12.94	0.00	0.37	0.02	98.77	n/a	n/a
8-2-2-T	5176	Chromite	CHROMITE	0.18	45.33	39.20	2.04	0.03	0.00	10.73	0.01	0.63	0.03	98.15	n/a	n/a
9-1-2-T	QH	MGI	PICRO_ILMENITE	53.88	0.96	29.40	13.91	0.03	0.03	0.47	0.03	0.27	0.01	98.98	n/a	n/a
15-3-2-T	553	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.04	0.05	21.80	9.54	5.90	36.84	20.89	0.00	1.09	0.00	96.15	n/a	n/a
15-4-2-T	GH	G2	G_02_HIGH_TITANIUM_PYROPE	0.99	3.61	7.38	21.41	5.00	40.87	19.01	0.06	0.29	0.01	98.62	n/a	n/a
15-4-2-T	QH	G9	G_09_CHROME_PYROPE	0.26	4.34	7.79	20.73	5.01	42.56	19.34	0.05	0.39	0.00	100.47	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
15-4-2-T	4840	Chromite	SUB_PICRO_CHROMITE	0.86	45.79	33.33	6.11	0.02	0.00	11.62	0.00	0.55	0.02	98.28	n/a	n/a
15-4-2-T	4842	Chromite	PICRO_CHROMITE	0.04	41.07	21.47	11.75	0.01	0.00	23.21	0.01	0.35	0.01	97.91	n/a	n/a
16-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.03	4.95	7.70	19.58	6.05	42.13	19.15	0.03	0.43	0.01	100.05	n/a	n/a
16-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.03	4.97	7.64	19.62	6.09	42.25	19.37	0.03	0.43	0.01	100.43	n/a	n/a
16-3-2-T	3152	Garnet	G_05_MAGNESIAN_ALMANDINE	0.00	0.00	22.63	11.50	3.91	39.75	21.81	0.00	0.31	0.00	99.91	n/a	n/a
16-4-1-T	6488	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.13	0.00	23.27	6.77	9.21	39.40	21.00	0.03	0.80	0.00	100.61	n/a	n/a
16-4-1-T	QH	CD1	CPX_05_UNKNOWN	0.07	0.90	3.71	16.70	22.82	54.58	1.35	0.47	0.08	0.00	100.68	n/a	n/a
16-4-1-T	QH	MGI	PICRO_ILMENITE	54.01	0.44	33.66	12.39	0.04	0.04	0.56	0.05	0.26	0.02	101.45	n/a	n/a
16-4-2-T	GH	CD1	CPX_02_UNKNOWN	0.23	0.64	3.67	15.74	23.11	52.21	3.35	0.42	0.13	0.00	99.50	n/a	n/a
17-1-2-T	QH	CD2	CPX_02_DIOPSIDE	0.26	1.23	4.70	17.39	20.61	52.13	3.09	0.17	0.12	0.00	99.70	n/a	n/a
17-1-2-T	QH	MGI	PICRO_ILMENITE	54.00	0.83	29.33	14.12	0.05	0.01	0.43	0.02	0.36	0.02	99.15	n/a	n/a
17-3-1-T	6598	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.19	0.03	22.63	9.31	6.93	39.84	21.13	0.01	0.62	0.00	100.69	n/a	n/a
17-3-1-T	6599	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.10	0.03	22.17	10.14	6.61	39.80	21.76	0.00	0.28	0.00	100.89	n/a	n/a
17-3-1-T	QH	CD1	CPX_05_UNKNOWN	0.14	0.66	2.94	16.60	23.34	53.53	2.20	0.48	0.09	0.00	99.98	n/a	n/a
17-3-1-T	QH	CD2	CPX_05_UNKNOWN	0.04	1.06	3.83	16.47	22.59	53.99	1.08	0.66	0.17	0.00	99.89	n/a	n/a
17-4-1-T	738	Almandine	G_05_MAGNESIAN_ALMANDINE	0.05	0.03	25.79	7.96	3.89	36.77	20.90	0.00	1.63	0.00	97.02	n/a	n/a
18-3-2-T	QH	CD1	CPX_02_UNKNOWN	0.20	0.69	4.72	15.69	23.25	53.64	1.62	0.32	0.16	0.00	100.29	n/a	n/a
18-4-2-T	5220	Diopside	CPX_02_UNKNOWN	0.06	0.36	4.27	15.55	23.46	54.65	1.22	0.64	0.20	0.01	100.41	n/a	n/a
19-2-2-T	GH	CD1	CPX_02_UNKNOWN	0.08	0.70	3.76	19.07	19.97	55.01	0.81	0.40	0.10	0.01	99.90	n/a	n/a
19-3-2-T	6698	Almandine	G_05_MAGNESIAN_ALMANDINE	0.10	0.03	25.45	7.32	6.48	39.11	20.76	0.00	0.88	0.00	100.13	n/a	n/a
19-4-1-T	QH	G9	G_09_CHROME_PYROPE	0.20	4.61	8.06	19.93	5.09	41.99	19.20	0.05	0.40	0.01	99.53	n/a	n/a
20-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.01	2.46	7.72	20.66	4.84	42.30	21.06	0.02	0.53	0.02	99.60	n/a	n/a
20-3-2-T	QH	MGI	PICRO_ILMENITE	52.32	0.72	31.64	12.90	0.04	0.01	0.36	0.02	0.30	0.01	98.31	n/a	n/a
20-4-2-T	782	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.22	0.02	23.16	6.51	8.33	36.90	20.83	0.00	0.63	0.00	96.60	n/a	n/a
20-4-2-T	781	Garnet	G_05_MAGNESIAN_ALMANDINE	0.20	0.09	24.52	7.13	6.40	36.92	20.84	0.00	0.73	0.00	96.83	n/a	n/a
21-3-1-T	6816	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.13	0.02	18.04	11.32	8.28	40.10	22.29	0.01	0.32	0.00	100.51	n/a	n/a
21-3-1-T	GH	G1	G_01_TITANIAN_PYROPE	0.77	2.21	8.23	20.50	4.97	42.01	20.06	0.05	0.30	0.00	99.10	n/a	n/a
21-3-1-T	QH	G1	G_01_TITANIAN_PYROPE	0.71	2.15	8.02	21.26	4.77	42.84	19.78	0.06	0.26	0.00	99.85	n/a	n/a
21-3-1-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.04	7.28	7.26	19.78	5.82	42.09	17.57	0.02	0.45	0.01	100.31	n/a	n/a
21-3-1-T	6818	Diopside	CPX_05_UNKNOWN	0.00	0.00	4.16	15.41	25.20	54.15	0.65	0.33	0.41	0.00	100.31	n/a	n/a
21-3-1-T	6819	Diopside	CPX_02_UNKNOWN	0.00	0.31	5.95	15.86	22.36	53.50	1.34	0.30	0.26	0.00	99.88	n/a	n/a
21-4-1-T	1994	Garnet	G_05_MAGNESIAN_ALMANDINE	0.01	0.00	22.79	8.40	7.31	38.73	21.51	0.01	0.77	0.00	99.53	n/a	n/a
23-1-1-T	QH	G2	G_02_HIGH_TITANIUM_PYROPE	0.96	3.04	7.45	21.60	4.86	42.57	19.57	0.09	0.25	0.00	100.39	n/a	n/a
23-1-1-T	QH	MGI	PICRO_ILMENITE	52.73	0.23	34.85	11.59	0.04	0.02	0.54	0.03	0.29	0.02	100.32	n/a	n/a
23-3-1-T	6530	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.01	0.08	19.81	9.30	8.94	39.99	21.74	0.02	0.54	0.00	100.43	n/a	n/a
23-3-1-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.28	0.73	2.53	14.70	21.11	52.17	6.52	1.46	0.00	0.00	99.50	n/a	n/a
23-3-2-T	2369	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.19	0.00	22.11	4.04	12.50	38.59	21.47	0.03	1.74	0.01	100.67	n/a	n/a
24-2-1-T	5637	Chromite	SUB_PICRO_CHROMITE	0.52	39.04	27.67	9.41	0.02	0.00	21.62	0.00	0.46	0.03	98.74	n/a	n/a
24-2-2-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.07	5.94	7.50	19.92	5.75	41.89	18.54	0.01	0.42	0.01	100.04	n/a	n/a
24-3-1-T	QH	CD1	CPX_02_UNKNOWN	0.16	0.70	4.06	15.18	22.63	53.70	2.36	0.91	0.11	0.00	99.81	n/a	n/a
24-3-2-T	4678	Diopside	CPX_02_UNKNOWN	0.04	0.48	4.48	16.29	22.97	53.66	1.76	0.32	0.16	0.00	100.16	n/a	n/a
24-4-2-T	2087	Garnet	G_05_MAGNESIAN_ALMANDINE	0.07	0.03	23.49	12.17	1.60	38.76	22.08	0.00	1.29	0.02	99.49	n/a	n/a
24-4-2-T	QH	G9	G_09_CHROME_PYROPE	0.22	5.44	6.74	20.75	5.44	42.37	18.33	0.03	0.36	0.00	99.68	n/a	n/a
24-4-2-T	5196	Diopside	CPX_02_UNKNOWN	0.07	0.38	5.34	15.42	23.04	54.03	1.40	0.44	0.15	0.01	100.27	n/a	n/a
24-4-2-T	5193	Chromite	CHROMITE	0.63	46.60	29.22	4.98	0.05	0.07	15.52	0.01	0.60	0.03	97.68	n/a	n/a
25-1-1-T	QH	G1	G_01_TITANIAN_PYROPE	0.60	4.10	6.72	21.46	5.00	42.21	18.84	0.05	0.29	0.02	99.27	n/a	n/a
25-2-1-T	1947	Garnet	G_05_MAGNESIAN_ALMANDINE	0.06	0.05	22.66	9.49	6.28	39.04	21.87	0.00	0.59	0.00	100.04	n/a	n/a
25-2-1-T	5128	Diopside	CPX_02_UNKNOWN	0.04	0.34	4.70	15.51	23.21	53.67	2.23	0.45	0.21	0.00	100.36	n/a	n/a
25-2-1-T	5130	Diopside	CPX_05_UNKNOWN	0.01	0.46	3.33	16.16	24.69	54.71	0.60	0.43	0.14	0.01	100.53	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
25-2-2-T	QH	CD2	CPX_02_UNKNOWN	0.00	1.03	4.26	14.47	22.33	52.08	3.69	0.82	0.02	0.00	98.70	n/a	n/a
25-3-2-T	4889	Chromite	SUB_PICRO_CHROMITE	0.26	49.46	32.32	6.77	0.02	0.00	8.12	0.01	0.57	0.02	97.53	n/a	n/a
26-3-2-T	5312	Garnet	G_05_MAGNESIAN_ALMANDINE	0.10	0.00	22.67	9.26	6.79	39.71	20.68	0.01	0.36	0.00	99.58	n/a	n/a
26-4-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.36	3.46	6.46	21.91	4.79	42.68	19.56	0.05	0.19	0.00	99.46	n/a	n/a
27-1-1-T	4999	Diopside	CPX_02_UNKNOWN	0.00	0.00	6.10	15.10	22.28	53.39	0.47	1.02	0.17	0.00	98.53	n/a	n/a
27-1-1-T	5000	Diopside	CPX_05_UNKNOWN	0.00	0.41	4.20	15.36	23.90	52.38	0.94	0.57	0.08	0.00	97.84	n/a	n/a
27-1-1-T	1774	Chromite	CHROMITE	0.21	43.38	33.45	3.97	0.00	0.00	16.12	0.03	0.56	0.09	97.72	n/a	n/a
27-1-2-T	7037	Almandine	G_05_MAGNESIAN_ALMANDINE	0.05	0.24	25.30	7.57	6.78	38.74	21.51	0.01	0.69	0.00	100.89	n/a	n/a
27-1-2-T	7038	Diopside	CPX_05_CHROME_DIOPSIDE	0.12	0.48	3.23	16.07	23.39	53.35	1.64	0.60	0.09	0.00	98.97	n/a	n/a
27-1-2-T	7039	Diopside	CPX_02_UNKNOWN	0.08	0.31	3.92	15.83	23.24	53.35	2.18	0.62	0.09	0.00	99.62	n/a	n/a
27-1-2-T	GH	MGI	PICRO_ILMENITE	54.14	0.95	28.41	14.66	0.01	0.00	0.53	0.03	0.26	0.00	98.99	n/a	n/a
27-2-1-T	QH	G2	G_02_HIGH_TITANIUM_PYROPE	0.94	2.15	8.26	20.71	4.89	41.69	19.36	0.05	0.26	0.00	98.31	n/a	n/a
27-2-1-T	GH	G11	G_11_UVAROVITE_PYROPE	0.45	7.99	7.76	19.01	6.20	41.26	16.42	0.07	0.42	0.00	99.58	n/a	n/a
27-2-1-T	GH	MGI	PICRO_ILMENITE	51.93	0.93	29.25	12.91	0.02	0.20	0.39	0.00	0.29	0.00	95.92	n/a	n/a
27-2-2-T	QH	MGI	PICRO_ILMENITE	54.30	1.89	30.63	13.64	0.04	0.04	0.56	0.03	0.27	0.02	101.40	n/a	n/a
27-2-2-T	GH	MGI	PICRO_ILMENITE	44.12	0.41	44.64	7.38	0.04	0.03	0.24	0.00	0.35	0.02	97.21	n/a	n/a
27-3-2-T	4476	Chromite	PICRO_CHROMITE	0.34	40.48	18.13	14.14	0.01	0.01	25.19	0.00	0.34	0.01	98.64	n/a	n/a
28-1-1-T	4510	Almandine	G_05_MAGNESIAN_ALMANDINE	0.18	0.01	25.12	7.67	6.85	39.52	21.01	0.01	0.70	0.00	101.07	n/a	n/a
28-2-1-T	QH	CD1	CPX_02_UNKNOWN	0.18	0.58	4.39	17.54	21.83	54.03	0.66	0.20	0.16	0.00	99.57	n/a	n/a
28-2-1-T	QH	CD1	CPX_02_UNKNOWN	0.04	0.81	3.94	16.52	22.41	54.41	1.82	0.66	0.14	0.00	100.75	n/a	n/a
28-2-1-T	QH	CD1	CPX_02_UNKNOWN	0.15	0.63	3.47	17.76	22.66	54.25	0.68	0.17	0.15	0.00	99.92	n/a	n/a
28-2-1-T	QH	CD2	CPX_05_UNKNOWN	0.15	1.32	3.45	15.59	21.81	53.46	1.96	1.06	0.10	0.00	98.90	n/a	n/a
28-2-2-T	QH	G6	G_03_CALCIC_PYROPE_ALMANDINE	0.31	0.03	20.73	6.42	12.43	39.60	21.17	0.01	0.45	0.01	101.15	n/a	n/a
28-2-2-T	5646	Chromite	PICRO_CHROMITE	0.26	47.40	16.98	12.91	0.02	0.02	19.82	0.02	0.70	0.02	98.13	n/a	n/a
29-1-1-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.06	1.20	2.51	16.75	23.34	54.70	1.09	0.50	0.09	0.00	100.24	n/a	n/a
29-1-1-T	QH	MGI	PICRO_ILMENITE	55.44	1.06	28.46	14.62	0.04	0.03	0.50	0.01	0.32	0.02	100.48	n/a	n/a
29-2-1-T	QH	CD1	CPX_02_DIOPSIDE	0.14	0.80	3.66	17.16	21.35	53.95	2.56	0.36	0.12	0.00	100.10	n/a	n/a
29-2-1-T	4624	Diopside	CPX_02_UNKNOWN	0.05	0.34	4.69	16.23	22.06	54.94	0.99	0.72	0.14	0.00	100.16	n/a	n/a
29-2-1-T	4625	Diopside	CPX_02_UNKNOWN	0.08	0.47	3.88	15.73	22.89	54.65	2.00	0.76	0.11	0.00	100.57	n/a	n/a
29-2-2-T	5174	Chromite	SUB_PICRO_CHROMITE	0.68	36.41	35.80	6.66	0.02	0.00	18.15	0.00	0.57	0.02	98.29	n/a	n/a
29-2-2-T	5175	Chromite	PICRO_CHROMITE	0.59	45.60	28.82	12.92	0.02	0.02	9.79	0.00	0.39	0.02	98.15	n/a	n/a
29-3-1-T	5020	Garnet	G_05_MAGNESIAN_ALMANDINE	0.00	0.03	24.57	8.57	5.53	39.21	21.46	0.01	0.56	0.00	99.94	n/a	n/a
29-3-2-T	217	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.15	0.07	21.14	8.40	7.85	37.60	21.09	0.02	0.59	0.01	96.91	n/a	n/a
29-3-2-T	219	Garnet	G_05_MAGNESIAN_ALMANDINE	0.08	0.05	22.92	12.66	1.35	37.92	21.65	0.00	0.52	0.00	97.15	n/a	n/a
29-3-2-T	GH	MGI	PICRO_ILMENITE	43.02	2.05	40.37	7.50	0.02	0.20	0.05	0.00	0.46	0.00	93.67	n/a	n/a
29-3-2-T	QH	MGI	PICRO_ILMENITE	47.22	3.85	36.22	10.18	0.04	0.01	0.34	0.00	0.34	0.02	98.20	n/a	n/a
29-4-1-T	3395	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.11	0.16	21.00	6.05	11.69	39.57	21.23	0.01	0.79	0.00	100.61	n/a	n/a
30-1-2-T	QH	G11	G_01_TITANIAN_PYROPE	0.78	6.39	6.73	20.60	5.90	42.04	16.73	0.06	0.22	0.00	99.45	n/a	n/a
30-2-2-T	6904	Chromite	CHROMITE	0.15	48.74	40.74	0.49	0.00	0.00	5.41	0.05	1.82	0.00	97.40	n/a	n/a
30-4-2-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.17	7.79	6.77	19.85	6.20	41.88	16.90	0.04	0.40	0.01	100.00	n/a	n/a
31-2-2-T	2297	Garnet	G_05_MAGNESIAN_ALMANDINE	0.10	0.06	23.46	13.15	1.39	39.87	22.47	0.01	0.56	0.04	101.07	n/a	n/a
31-3-1-T	QH	G2	G_02_HIGH_TITANIUM_PYROPE	1.04	5.12	7.26	20.69	5.61	41.98	17.58	0.06	0.32	0.01	99.66	n/a	n/a
31-3-1-T	QH	MGI	PICRO_ILMENITE	53.11	0.32	34.30	12.04	0.05	0.04	0.57	0.00	0.32	0.02	100.75	n/a	n/a
31-3-1-T	5095	Chromite	SUB_PICRO_CHROMITE	4.36	38.26	33.94	13.44	0.03	0.06	7.99	0.00	0.42	0.02	98.50	n/a	n/a
31-3-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.57	4.24	6.76	21.66	5.09	42.59	18.51	0.05	0.29	0.00	99.76	n/a	n/a
31-3-2-T	QH	G9	G_09_CHROME_PYROPE	0.03	3.43	7.85	20.33	5.42	42.55	20.38	0.01	0.49	0.00	100.49	n/a	n/a
31-3-2-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.25	0.83	3.03	15.88	23.32	53.14	2.20	0.55	0.08	0.00	99.28	n/a	n/a
31-3-2-T	4995	Diopside	CPX_05_UNKNOWN	0.05	0.47	2.84	16.74	23.68	53.82	1.07	0.48	0.07	0.00	99.22	n/a	n/a
31-4-1-T	6367	Garnet	G_05_MAGNESIAN_ALMANDINE	0.22	0.03	24.38	7.41	7.77	39.45	21.00	0.01	0.73	0.01	101.00	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
33-1-1-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.90	4.30	7.10	21.27	5.22	42.43	18.42	0.07	0.28	0.01	99.99	n/a	n/a
33-1-1-T	QH	G2	G_02_HIGH_TITANIUM_PYROPE	0.91	4.96	7.52	20.99	5.47	42.33	17.90	0.07	0.29	0.00	100.44	n/a	n/a
34-1-1-T	QH	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.25	0.02	23.22	9.56	6.09	39.62	21.39	0.01	0.60	0.00	100.76	n/a	n/a
34-1-1-T	GH	G4	G_04_TITANIAN,_CALCIC_MAGNESIAN_ALMANDINE	0.75	0.00	21.22	7.55	9.40	39.56	21.09	0.03	0.64	0.00	100.24	n/a	n/a
34-1-1-T	QH	CD1	CPX_05_UNKNOWN	0.03	0.57	2.68	17.03	23.85	54.87	1.20	0.44	0.15	0.00	100.82	n/a	n/a
34-1-1-T	6706	Diopside	CPX_02_UNKNOWN	0.02	0.18	5.40	15.77	22.95	53.60	1.66	0.37	0.15	0.00	100.10	n/a	n/a
34-1-2-T	3521	Diopside	CPX_02_UNKNOWN	0.02	0.09	4.22	15.94	24.17	54.78	0.57	0.36	0.13	0.00	100.28	n/a	n/a
34-2-1-T	QH	CD1	CPX_02_DIOPSIDE	0.13	0.56	5.63	17.24	19.56	54.37	1.95	0.73	0.12	0.00	100.29	n/a	n/a
34-2-2-T	GH	G9	G_09_CHROME_PYROPE	0.21	2.67	8.37	20.61	4.23	40.37	20.55	0.02	0.32	0.01	97.35	n/a	n/a
34-2-2-T	47	Diopside	CPX_05_UNKNOWN	0.15	0.02	2.23	16.07	24.17	51.49	2.42	0.66	0.01	0.01	97.22	n/a	n/a
34-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.25	6.08	7.33	20.12	5.69	41.85	18.02	0.05	0.42	0.01	99.81	n/a	n/a
34-3-1-T	QH	CD1	CPX_05_UNKNOWN	0.03	0.56	2.98	16.28	23.68	54.05	1.71	0.37	0.04	0.00	99.70	n/a	n/a
34-3-1-T	QH	CD1	CPX_05_UNKNOWN	0.00	0.73	3.53	15.08	24.53	54.42	1.13	0.43	0.00	0.00	99.85	n/a	n/a
34-4-2-T	QH	G9	G_09_CHROME_PYROPE	0.19	2.79	7.74	21.27	4.57	42.66	20.64	0.05	0.34	0.00	100.25	n/a	n/a
34-4-2-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.14	5.72	7.14	20.76	5.07	42.39	18.75	0.03	0.41	0.00	100.41	n/a	n/a
34-4-2-T	6930	Diopside	CPX_02_UNKNOWN	0.00	0.31	4.10	14.83	23.01	51.93	1.80	0.57	0.05	0.00	96.60	n/a	n/a
35-1-2-T	5591	Almandine	G_05_MAGNESIAN_ALMANDINE	0.03	0.00	25.14	6.96	7.42	39.69	21.17	0.02	0.93	0.00	101.36	n/a	n/a
35-2-1-T	2411	Garnet	G_05_MAGNESIAN_ALMANDINE	0.00	0.00	23.74	8.23	4.81	39.03	21.85	0.00	3.45	0.02	101.11	n/a	n/a
35-2-2-T	QH	CD2	CPX_02_DIOPSIDE	0.19	1.11	2.91	16.18	20.16	52.13	5.89	1.12	0.10	0.00	99.79	n/a	n/a
35-2-3-T	1274	Jadeite	UNKNOWN	0.02	0.02	0.13	0.01	10.82	52.89	27.04	5.34	0.03	0.17	96.30	n/a	n/a
35-4-2-T	QH	CD1	CPX_05_UNKNOWN	0.03	0.63	3.47	16.23	22.33	53.60	2.35	0.61	0.07	0.00	99.32	n/a	n/a
36-1-2-T	7030	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.11	0.02	20.33	10.21	7.62	39.44	22.23	0.05	0.43	0.00	100.44	n/a	n/a
36-2-1-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.30	0.90	2.91	15.92	20.26	51.73	6.48	1.08	0.11	0.00	99.69	n/a	n/a
36-3-1-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.28	1.20	2.38	15.38	20.48	52.03	6.37	1.31	0.04	0.01	99.47	n/a	n/a
36-3-1-T	6450	Diopside	CPX_05_UNKNOWN	0.06	0.37	3.21	16.80	23.51	54.55	1.05	0.52	0.06	0.00	100.13	n/a	n/a
36-3-2-T	5557	Garnet	G_05_MAGNESIAN_ALMANDINE	0.06	0.00	24.66	7.30	6.68	39.42	21.01	0.01	2.02	0.00	101.16	n/a	n/a
36-3-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.77	3.31	7.91	20.98	5.08	42.60	19.13	0.07	0.28	0.01	100.13	n/a	n/a
36-3-2-T	QH	CD1	CPX_02_DIOPSIDE	0.09	0.58	4.01	18.26	21.07	54.04	2.46	0.25	0.05	0.00	100.81	n/a	n/a
37-1-2-T	QH	G9	G_09_CHROME_PYROPE	0.17	4.82	8.06	20.22	4.88	42.11	19.32	0.05	0.45	0.00	100.08	n/a	n/a
37-3-1-T	1287	Almandine	G_05_MAGNESIAN_ALMANDINE	0.09	0.12	26.52	10.23	1.66	37.51	21.31	0.00	0.84	0.01	98.28	n/a	n/a
37-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.08	3.02	8.88	20.01	4.61	42.11	20.95	0.04	0.52	0.00	100.22	n/a	n/a
37-3-2-T	6595	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.23	0.03	22.54	8.25	8.28	39.77	21.27	0.01	0.52	0.00	100.90	n/a	n/a
37-4-1-T	QH	MGI	PICRO_ILMENITE	49.26	0.13	38.84	10.41	0.01	0.00	0.41	0.00	0.24	0.00	99.30	n/a	n/a
38-2-1-T	1625	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.18	0.09	22.76	9.72	6.12	39.41	21.54	0.01	0.80	0.01	100.63	n/a	n/a
38-2-1-T	1627	Pyrope G3?	G_09_CHROME_PYROPE	0.12	0.11	11.01	19.98	3.71	41.82	22.98	0.04	0.34	0.00	100.11	n/a	n/a
38-2-1-T	1626	Garnet	G_05_MAGNESIAN_ALMANDINE	0.02	0.02	23.74	8.27	1.83	38.98	21.50	0.01	6.76	0.00	101.13	n/a	n/a
38-2-2-T	710	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.21	0.07	22.17	8.63	6.57	37.26	20.73	0.00	0.49	0.01	96.13	n/a	n/a
38-2-2-T	709	Almandine	G_05_MAGNESIAN_ALMANDINE	0.07	0.05	25.59	8.78	3.26	37.10	20.89	0.00	0.59	0.00	96.33	n/a	n/a
38-3-1-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.06	7.39	6.96	19.51	6.43	41.93	17.29	0.02	0.43	0.01	100.02	n/a	n/a
38-3-1-T	6502	Diopside	CPX_02_UNKNOWN	0.00	0.20	4.86	16.34	22.82	54.25	0.58	0.34	0.08	0.00	99.47	n/a	n/a
38-3-1-T	GH	MGI	PICRO_ILMENITE	46.71	0.27	41.44	8.72	0.03	0.03	0.35	0.02	0.33	0.01	97.90	n/a	n/a
38-3-2-T	GH	MGI	PICRO_ILMENITE	55.65	0.98	28.08	14.56	0.03	0.04	0.47	0.01	0.34	0.01	100.16	n/a	n/a
38-3-2-T	GH	MGI	PICRO_ILMENITE	55.21	0.96	29.06	14.37	0.03	0.04	0.44	0.02	0.31	0.01	100.44	n/a	n/a
38-4-1-T	QH	G9	G_09_CHROME_PYROPE	0.30	2.51	7.20	21.03	4.60	42.53	20.83	0.03	0.30	0.00	99.33	n/a	n/a
38-4-1-T	4314	Chromite	UNKNOWN	0.19	31.36	28.74	10.20	0.01	0.00	26.49	0.00	0.40	0.02	97.39	n/a	n/a
38-4-2-T	4272	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.01	0.00	20.40	10.46	6.65	39.82	21.28	0.03	0.31	0.00	98.96	n/a	n/a
39-1-1-T	QH	CD1	CPX_02_UNKNOWN	0.02	0.65	4.81	15.49	23.07	52.86	1.70	0.47	0.17	0.00	99.24	n/a	n/a
39-1-1-T	6257	Chromite	PICRO_CHROMITE	0.08	46.30	18.32	13.15	0.03	0.00	21.17	0.01	0.35	0.01	99.41	n/a	n/a
39-2-1-T	4735	Diopside	CPX_02_UNKNOWN	0.05	0.29	5.40	15.29	22.50	53.82	1.25	0.62	0.26	0.00	99.48	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
39-3-1-T	507	Almandine	G_05_MAGNESIAN_ALMANDINE	0.04	0.04	25.39	10.58	1.85	37.24	21.21	0.00	0.51	0.00	96.86	n/a	n/a
39-3-1-T	GH	MGI	PICRO_ILMENITE	50.30	0.50	33.15	10.83	0.03	0.19	0.32	0.00	0.30	0.01	95.62	n/a	n/a
40-1-1-T	QH	G9	G_09_CHROME_PYROPE	0.08	3.87	7.68	19.98	5.28	41.81	19.83	0.03	0.43	0.01	98.99	n/a	n/a
40-2-1-T	QH	CD1	CPX_02_DIOPSIDE	0.17	0.82	5.62	15.17	21.62	54.38	1.48	1.07	0.15	0.01	100.48	n/a	n/a
40-2-2-T	3045	Diopside	CPX_05_UNKNOWN	0.00	0.00	2.08	17.25	25.50	54.49	0.26	0.11	0.09	0.00	99.78	n/a	n/a
40-4-1-T	6249	Chromite	SUB_PICRO_CHROMITE	0.28	38.88	21.61	12.61	0.02	0.00	25.51	0.01	0.37	0.01	99.29	n/a	n/a
41-1-1-T	QH	CD2	CPX_05_UNKNOWN	0.15	1.07	3.36	16.07	22.97	52.88	1.53	0.66	0.11	0.00	98.80	n/a	n/a
41-1-2-T	3582	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.15	0.01	21.87	7.85	8.90	39.82	21.30	0.02	0.50	0.00	100.42	n/a	n/a
41-2-1-T	QH	G9	G_09_CHROME_PYROPE	0.04	2.89	8.62	19.88	5.36	42.46	20.81	0.02	0.54	0.00	100.62	n/a	n/a
41-2-1-T	4950	Diopside	CPX_02_UNKNOWN	0.05	0.00	4.59	15.39	23.74	54.05	1.36	0.85	0.02	0.00	100.05	n/a	n/a
41-2-1-T	4951	Diopside	CPX_02_UNKNOWN	0.04	0.14	4.53	15.52	24.33	54.53	0.72	0.47	0.16	0.00	100.44	n/a	n/a
41-2-2-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.85	5.12	7.16	21.04	5.56	42.42	17.85	0.06	0.27	0.00	100.33	n/a	n/a
41-2-2-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.86	5.31	7.11	20.95	5.68	42.56	17.82	0.05	0.30	0.00	100.64	n/a	n/a
41-2-2-T	QH	CD1	CPX_02_DIOPSIDE	0.15	0.51	4.37	18.48	19.98	53.55	2.83	0.26	0.11	0.00	100.24	n/a	n/a
41-2-2-T	6654	Diopside	CPX_02_UNKNOWN	0.10	0.23	5.70	16.14	21.92	54.00	1.44	0.46	0.39	0.06	100.38	n/a	n/a
41-2-2-T	GH	MGI	PICRO_ILMENITE	52.30	0.52	33.07	12.31	0.05	0.11	0.67	0.09	0.29	0.02	99.41	n/a	n/a
41-4-2-T	QH	G9	G_09_CHROME_PYROPE	0.24	6.56	7.15	20.11	5.97	42.01	17.73	0.05	0.31	0.00	100.13	n/a	n/a
43-1-2-T	5515	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.18	0.01	20.41	10.10	7.72	40.29	21.49	0.01	0.44	0.00	100.65	n/a	n/a
43-2-1-T	5561	Almandine	G_05_MAGNESIAN_ALMANDINE	0.04	0.00	26.10	9.69	3.08	39.90	21.43	0.01	1.14	0.00	101.39	n/a	n/a
43-2-2-T	QH	CD2	CPX_02_UNKNOWN	0.14	1.02	3.16	17.47	21.89	53.11	2.35	0.42	0.11	0.01	99.67	n/a	n/a
43-4-1-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.86	1.61	9.19	19.96	4.89	41.63	20.16	0.07	0.28	0.00	98.65	n/a	n/a
43-4-1-T	QH	G2	G_02_HIGH_TITANIUM_PYROPE	1.02	5.25	7.31	20.92	5.67	42.23	17.33	0.06	0.30	0.01	100.09	n/a	n/a
44-1-1-T	QH	G9	G_09_CHROME_PYROPE	0.07	5.46	7.73	20.13	5.63	41.73	18.64	0.03	0.42	0.01	99.84	n/a	n/a
44-1-1-T	QH	CD1	CPX_03_UNKNOWN	0.55	0.71	2.60	14.65	21.48	52.29	6.59	1.36	0.07	0.01	100.30	n/a	n/a
44-1-1-T	QH	MGI	PICRO_ILMENITE	55.33	1.17	28.10	14.74	0.04	0.03	0.51	0.00	0.32	0.02	100.24	n/a	n/a
44-1-2-T	6642	Garnet	G_05_MAGNESIAN_ALMANDINE	0.20	0.03	23.72	7.49	8.23	38.85	21.00	0.01	0.65	0.01	100.18	n/a	n/a
44-2-1-T	6711	Garnet	G_03_CALCIC_PYROPE_ALMANDINE	0.10	0.05	22.27	9.56	6.80	40.01	21.31	0.00	0.53	0.00	100.63	n/a	n/a
44-2-1-T	6713	Diopside	CPX_02_UNKNOWN	0.09	0.24	4.82	14.84	22.80	53.24	3.15	0.76	0.25	0.00	100.19	n/a	n/a
44-2-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.79	4.36	7.16	20.85	5.40	41.96	18.54	0.06	0.31	0.01	99.43	n/a	n/a
44-2-2-T	QH	G9	G_09_CHROME_PYROPE	0.00	3.73	8.50	19.85	4.79	42.13	19.93	0.01	0.50	0.00	99.44	n/a	n/a
44-2-2-T	GH	CD1	CPX_05_UNKNOWN	0.11	0.85	3.50	15.15	23.00	52.20	1.96	0.58	0.11	0.00	97.46	n/a	n/a
44-3-2-T	92	Diopside	CPX_05_UNKNOWN	0.10	0.03	2.00	16.02	23.84	52.11	2.21	0.86	0.11	0.01	97.28	n/a	n/a
44-4-2-T	QH	G9	G_09_CHROME_PYROPE	0.22	2.67	7.85	20.65	4.52	42.49	20.83	0.04	0.40	0.00	99.67	n/a	n/a
45-1-2-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.08	0.99	2.51	16.34	23.12	54.23	2.25	0.67	0.07	0.00	100.26	n/a	n/a
45-2-1-T	5023	Diopside	CPX_02_UNKNOWN	0.00	0.00	4.99	14.66	24.20	53.54	0.94	0.56	0.62	0.00	99.51	n/a	n/a
45-2-2-T	749	Garnet	G_05_MAGNESIAN_ALMANDINE	0.11	0.06	22.77	11.92	1.16	37.74	21.42	0.00	1.96	0.00	97.14	n/a	n/a
45-4-1-T	QH	CD2	CPX_02_UNKNOWN	0.13	1.02	3.68	15.90	22.86	53.57	1.82	0.56	0.11	0.00	99.65	n/a	n/a
45-4-2-T	QH	MGI	PICRO_ILMENITE	46.44	0.23	41.78	8.55	0.04	0.00	0.33	0.01	0.29	0.02	97.67	n/a	n/a
45-4-2-T	QH	MGI	PICRO_ILMENITE	45.93	0.24	41.91	8.47	0.03	0.00	0.32	0.01	0.29	0.02	97.20	n/a	n/a
46-1-1-T	740	Almandine	G_05_MAGNESIAN_ALMANDINE	0.07	0.04	25.99	10.92	0.86	37.24	21.30	0.00	0.60	0.00	97.02	n/a	n/a
46-2-1-T	3092	Diopside	CPX_05_UNKNOWN	0.01	0.01	2.83	16.26	25.07	53.47	0.78	0.44	0.16	0.00	99.03	n/a	n/a
46-2-2-T	5612	Garnet	G_05_MAGNESIAN_ALMANDINE	0.13	0.03	23.38	8.89	6.50	40.01	20.92	0.03	0.63	0.00	100.52	n/a	n/a
46-3-1-T	QH	CD1	CPX_05_UNKNOWN	0.03	0.59	2.34	16.48	23.83	54.87	1.73	0.57	0.04	0.00	100.48	n/a	n/a
46-3-1-T	5627	Diopside	CPX_05_UNKNOWN	0.00	0.00	2.35	17.26	25.33	55.82	0.20	0.06	0.26	0.00	101.28	n/a	n/a
46-3-2-T	QH	G10	G_10_LOW_CALCIUM_CHROME_PYROPE	0.01	6.56	6.93	21.11	4.68	42.37	18.23	0.01	0.41	0.00	100.31	n/a	n/a
46-3-2-T	QH	MGI	PICRO_ILMENITE	50.81	0.39	36.03	10.90	0.03	0.00	0.19	0.02	0.32	0.02	98.69	n/a	n/a
46-3-2-T	QH	MGI	PICRO_ILMENITE	52.94	0.46	31.66	13.50	0.04	0.03	0.55	0.01	0.26	0.02	99.45	n/a	n/a
46-4-2-T	QH	CD1	CPX_05_UNKNOWN	0.06	0.77	4.24	14.73	24.67	53.52	1.55	0.30	0.25	0.01	100.09	n/a	n/a
46-4-2-T	QH	MGI	PICRO_ILMENITE	53.25	0.44	33.43	12.29	0.05	0.07	0.55	0.00	0.31	0.03	100.39	n/a	n/a

				%	%	%	%	%	%	%	%	%	%	%	ppm	ppm
Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	TiO2	Cr2O3	FeO	MgO	CaO	SiO2	Al2O3	Na2O	MnO	K2O	Total	Ni	Zn
47-1-1-T	QH	G11	G_02_HIGH_TITANIUM_PYROPE	0.86	6.95	7.07	20.52	6.14	41.89	16.48	0.07	0.34	0.02	100.32	n/a	n/a
47-1-1-T	QH	G11	G_02_HIGH_TITANIUM_PYROPE	0.86	6.39	6.99	20.65	5.87	41.93	16.89	0.05	0.33	0.01	99.96	n/a	n/a
47-2-1-T	QH	CD1	CPX_02_UNKNOWN	0.06	0.64	5.02	15.28	23.00	53.57	1.27	0.68	0.20	0.00	99.72	n/a	n/a
47-2-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.64	5.09	6.89	21.14	5.41	42.49	18.03	0.04	0.31	0.01	100.04	n/a	n/a
47-3-1-T	2227	Almandine	G_05_MAGNESIAN_ALMANDINE	0.00	0.08	25.50	7.10	6.64	38.63	21.71	0.00	0.68	0.00	100.34	n/a	n/a
47-3-2-T	QH	CD1	CPX_02_UNKNOWN	0.16	0.82	3.96	16.10	23.06	53.45	1.44	0.63	0.15	0.00	99.77	n/a	n/a
47-4-1-T	QH	G9	G_09_CHROME_PYROPE	0.13	4.03	8.02	20.58	5.00	42.46	19.97	0.04	0.46	0.01	100.69	n/a	n/a
47-4-1-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.02	0.99	2.70	16.02	23.18	53.92	1.77	0.83	0.01	0.00	99.44	n/a	n/a
47-4-2-T	QH	G3	G_03_CALCIC_PYROPE_ALMANDINE	0.27	0.06	22.95	9.89	6.06	39.94	21.17	0.01	0.61	0.01	100.96	n/a	n/a
47-4-2-T	QH	G7	G_09_CHROME_PYROPE	0.18	6.11	11.10	15.97	7.35	41.40	17.50	0.00	0.54	0.01	100.15	n/a	n/a
47-4-2-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.16	1.89	3.14	14.75	20.98	53.98	3.25	1.78	0.08	0.00	100.01	n/a	n/a
48-1-1-T	QH	G1	G_01_TITANIAN_PYROPE	0.68	4.36	6.81	21.43	5.21	42.82	18.73	0.06	0.28	0.01	100.38	n/a	n/a
48-1-1-T	QH	G9	G_09_CHROME_PYROPE	0.18	3.78	7.39	20.92	4.83	42.67	20.31	0.04	0.40	0.01	100.52	n/a	n/a
48-1-1-T	QH	CD1	CPX_02_DIOPSIDE	0.12	0.89	3.75	17.28	21.34	54.68	1.63	0.68	0.10	0.00	100.47	n/a	n/a
48-1-1-T	GH	CD1	CPX_05_CHROME_DIOPSIDE	0.15	0.69	2.87	15.52	22.33	53.20	1.91	0.77	0.01	0.00	97.45	n/a	n/a
48-3-1-T	6477	Garnet	G_05_MAGNESIAN_ALMANDINE	0.03	0.03	24.97	7.81	6.39	39.69	21.52	0.02	0.78	0.01	101.24	n/a	n/a
48-3-1-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.87	1.93	8.94	20.74	4.88	42.56	19.87	0.06	0.33	0.01	100.18	n/a	n/a
48-3-1-T	QH	G1	G_02_HIGH_TITANIUM_PYROPE	0.90	3.59	7.74	21.15	5.18	42.54	18.80	0.06	0.31	0.01	100.27	n/a	n/a
48-3-1-T	QH	G9	G_09_CHROME_PYROPE	0.18	3.08	7.95	20.80	4.53	42.41	20.50	0.03	0.45	0.01	99.93	n/a	n/a
48-3-1-T	QH	G11	G_02_HIGH_TITANIUM_PYROPE	0.89	6.09	7.00	20.97	5.92	42.33	16.78	0.05	0.32	0.02	100.35	n/a	n/a
48-3-1-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.07	0.94	2.75	16.25	23.22	54.50	2.16	0.76	0.05	0.00	100.70	n/a	n/a
48-3-1-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.07	1.15	3.20	16.09	23.09	53.88	1.76	0.62	0.10	0.00	99.96	n/a	n/a
48-3-2-T	2022	Garnet	G_05_MAGNESIAN_ALMANDINE	0.00	0.00	23.01	9.22	6.21	39.35	21.84	0.01	0.63	0.00	100.27	n/a	n/a
48-3-2-T	5155	Garnet	G_05_MAGNESIAN_ALMANDINE	0.11	0.03	24.08	8.48	7.23	39.38	20.78	0.01	0.48	0.01	100.58	n/a	n/a
48-3-2-T	5158	Garnet	G_05_MAGNESIAN_ALMANDINE	0.10	0.05	23.27	8.95	6.88	39.85	21.27	0.00	0.59	0.01	100.96	n/a	n/a
48-3-2-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.08	7.89	7.88	18.93	6.39	41.82	17.13	0.02	0.51	0.01	100.65	n/a	n/a
48-3-2-T	QH	CD1	CPX_05_UNKNOWN	0.00	0.84	3.75	15.71	22.42	54.20	2.14	0.76	0.04	0.00	99.86	n/a	n/a
48-4-1-T	QH	G1	G_01_TITANIAN_PYROPE	0.46	3.75	6.69	21.76	5.09	42.86	19.10	0.04	0.27	0.01	100.02	n/a	n/a
48-4-1-T	QH	MGI	PICRO_ILMENITE	52.22	0.24	35.94	11.10	0.04	0.03	0.53	0.02	0.30	0.01	100.42	n/a	n/a
48-4-2-T	QH	CD1	CPX_02_UNKNOWN	0.17	0.52	3.58	15.78	22.94	53.02	1.99	0.73	0.08	0.00	98.81	n/a	n/a
49-1-1-T	QH	G9	G_10_LOW_CALCIUM_CHROME_PYROPE	0.22	6.24	7.48	20.40	5.19	42.34	18.11	0.05	0.42	0.00	100.45	n/a	n/a
49-1-1-T	6686	Diopside	CPX_05_UNKNOWN	0.01	0.44	3.49	17.00	23.26	54.67	1.15	0.37	0.10	0.00	100.49	n/a	n/a
49-1-1-T	6687	Chromite	SUB_PICRO_CHROMITE	0.05	61.26	24.05	7.27	0.04	0.01	6.36	0.04	0.54	0.02	99.62	n/a	n/a
49-2-1-T	QH	G1	G_01_TITANIAN_PYROPE	0.43	2.09	7.29	21.80	4.45	43.16	20.26	0.05	0.26	0.00	99.79	n/a	n/a
49-2-1-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.04	1.11	2.36	16.11	23.08	54.38	1.98	0.90	0.09	0.00	100.05	n/a	n/a
49-2-1-T	QH	CD2	CPX_05_CHROME_DIOPSIDE	0.05	1.12	2.48	16.00	22.92	54.46	2.09	0.97	0.10	0.00	100.19	n/a	n/a
49-2-2-T	QH	CD1	CPX_05_CHROME_DIOPSIDE	0.07	0.96	2.20	16.30	23.07	54.66	2.39	0.82	0.07	0.01	100.54	n/a	n/a
49-2-2-T	3057	Diopside	CPX_02_UNKNOWN	0.02	0.11	5.09	15.23	23.48	53.13	2.03	0.41	0.16	0.00	99.66	n/a	n/a
49-3-1-T	QH	CD2	CPX_05_UNKNOWN	0.14	1.26	3.88	15.44	22.84	53.89	1.59	0.78	0.14	0.00	99.96	n/a	n/a
49-3-2-T	QH	CD1	CPX_05_UNKNOWN	0.08	0.57	3.08	16.49	23.53	53.83	1.81	0.33	0.10	0.00	99.82	n/a	n/a
49-3-2-T	QH	CD1	CPX_02_UNKNOWN	0.14	0.79	3.04	18.97	21.02	55.00	0.81	0.39	0.09	0.01	100.25	n/a	n/a
49-4-2-T	QH	MGI	PICRO_ILMENITE	49.34	0.70	37.50	10.12	0.04	0.01	0.14	0.01	0.31	0.02	98.17	n/a	n/a
50-1-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.59	4.61	6.94	21.41	5.13	42.37	18.46	0.06	0.29	0.00	99.86	n/a	n/a
50-2-1-T	QH	G9	G_09_CHROME_PYROPE	0.03	4.27	7.33	20.77	5.00	42.62	19.74	0.05	0.31	0.00	100.12	n/a	n/a
50-2-2-T	QH	G1	G_01_TITANIAN_PYROPE	0.72	5.61	6.64	20.75	5.62	42.17	17.64	0.07	0.35	0.00	99.57	n/a	n/a
50-2-2-T	GH	MGI	PICRO_ILMENITE	51.33	0.16	34.92	11.04	0.00	0.00	0.54	0.00	0.21	0.00	98.20	n/a	n/a
50-3-2-T	QH	G9	G_09_CHROME_PYROPE	0.22	3.46	7.80	20.88	4.55	42.54	19.89	0.05	0.38	0.01	99.77	n/a	n/a
50-3-2-T	QH	G9	G_09_CHROME_PYROPE	0.24	3.48	7.84	20.87	4.66	42.58	20.08	0.04	0.38	0.01	100.17	n/a	n/a
50-3-2-T	QH	G11	G_11_UVAROVITE_PYROPE	0.43	7.58	8.37	19.21	5.83	41.85	16.71	0.06	0.47	0.01	100.51	n/a	n/a

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
Entwistle	6424h till		G_10_LOW_CALCIUM_CHROME_PYROPE	0.00	7.96	7.03	18.66	7.00	40.74	17.89	0.05	0.43	n/a	99.76	n/a	n/a
Entwistle	6424a		PICRO_CHROMITE	0.64	48.88	18.23	14.64	0.00	0.16	16.53	0.00	0.31	n/a	99.62	1274	562
Entwistle	6424b		PICRO_CHROMITE	0.22	53.96	25.66	8.98	0.00	0.05	11.31	0.00	0.43	n/a	100.83	956	803
Entwistle	6424d		PICRO_CHROMITE	1.16	50.03	19.53	14.50	0.00	0.23	14.83	0.00	0.28	n/a	100.78	1354	402
Entwistle	6424f		PICRO_CHROMITE	0.08	59.15	22.10	8.40	0.00	0.05	10.36	0.00	0.51	n/a	101.00	717	2089
Magnolia	6422a		PICRO_CHROMITE	0.30	51.55	27.65	12.59	0.00	0.17	6.86	0.00	0.33	n/a	99.64	1513	0
Magnolia	6422c		PICRO_CHROMITE	0.69	45.35	30.08	13.87	0.00	0.15	10.11	0.00	0.23	n/a	100.76	1513	723
Magnolia	6422d		PICRO_CHROMITE	0.26	51.49	18.91.	10.72	0.03	0.00	16.46	0.00	0.31	n/a	98.18	n/a	n/a
Magnolia	6422e		PICRO_CHROMITE	0.11	52.05	18.93	11.75	0.00	0.00	16.46	0.00	0.35	n/a	99.65	n/a	n/a
Villeneuve	3975a		G_01_TITANIAN_PYROPE	0.72	4.10	7.91	21.27	5.02	42.31	19.68	0.03	0.00	n/a	101.04	n/a	n/a
Villeneuve	3975e		G_02_HIGH_TITANIUM_PYROPE	1.16	5.07	7.53	19.89	6.44	41.23	18.30	0.00	0.25	n/a	99.87	n/a	n/a
Villeneuve	3975c		G_09_CHROME_PYROPE	0.28	6.12	6.56	20.78	5.67	41.82	18.76	0.00	0.31	n/a	100.30	n/a	n/a
Villeneuve	3975b		G_10_LOW_CALCIUM_CHROME_PYROPE	0.01	5.96	7.08	20.07	5.86	41.14	19.04	0.00	0.48	n/a	99.64	n/a	n/a
Villeneuve	3975d		G_10_LOW_CALCIUM_CHROME_PYROPE	0.06	6.54	5.87	23.10	2.36	42.63	18.83	0.00	0.31	n/a	99.70	n/a	n/a
Villeneuve	3975f		SUB_PICRO_CHROMITE	0.56	38.91	21.37	14.53	0.00	0.24	23.36	0.00	0.07	n/a	99.04	n/a	n/a
n/a =	Not Analysed															
(shaded)	Those sites with indicator mineral grains of favourable chemistry															

APPENDIX 6.1B

APPENDIX 6.1B

MICROPROBE DATA FOR NORTHERN ALBERTA TILL DIAMOND INDICATOR MINERALS

Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	% TiO2	% Cr2O3	% FeO	% MgO	% CaO	% SiO2	% Al2O3	% Na2O	% MnO	% K2O	% Total	ppm Ni	ppm Zn
NAT92-1	3		CPX_04_UNKNOWN	0.40	0.21	9.82	15.74	12.10	49.64	6.38	1.07	0.15	0.54	96.05	n/a	n/a
NAT92-2	1		GROSSULAR	0.47	4.62	3.30	0.16	35.40	38.36	15.62	0.00	0.31	n/a	98.24	n/a	n/a
NAT92-3	12		G_02_HIGH_TITANIUM_PYROPE	1.02	0.96	10.30	21.41	5.03	41.24	20.86	0.01	0.30	n/a	101.12	n/a	n/a
NAT92-5	1		SUB_PICRO_CHROMITE	0.12	37.28	25.68	10.69	0.00	0.00	25.07	0.00	0.31	n/a	99.13	n/a	n/a
NAT92-10	2		G_03_CALCIC_PYROPE_ALMANDINE	0.00	0.06	14.23	15.84	5.21	40.88	22.30	0.00	0.55	0.00	99.08	n/a	n/a
NAT92-17	1		PICRO_CHROMITE	1.18	43.11	21.12	15.01	0.00	0.08	18.04	n/a	0.22	n/a	98.98	1730	0
NAT92-19	4		G_09_CHROME_PYROPE	0.01	3.94	8.04	18.72	5.52	41.29	20.55	0.00	0.62	0.00	98.69	n/a	n/a
NAT92-23	6		G_10_LOW_CALCIUM_CHROME_PYROPE	0.10	7.78	8.33	19.53	7.13	40.88	17.08	0.00	0.44	n/a	101.27	n/a	n/a
NAT92-25	9		G_05_MAGNESIAN_ALMANDINE	0.05	0.04	25.16	9.62	2.61	38.70	21.74	0.00	0.61	0.00	98.53	n/a	n/a
NAT92-27	1		PICRO_CHROMITE	0.66	48.19	26.20	13.22	0.00	0.06	10.27	n/a	0.28	n/a	98.99	830	0
NAT92-28	2		CPX_04_UNKNOWN	0.71	0.03	11.69	15.90	12.74	49.60	7.69	0.75	0.26	n/a	99.38	n/a	n/a
NAT92-34	10		CPX_04_UNKNOWN	1.15	0.08	13.34	15.82	11.18	49.44	7.64	1.14	0.18	n/a	99.96	n/a	n/a
NAT92-30	8		UNKNOWN	0.86	30.55	16.04	19.76	0.00	0.00	33.81	0.00	0.17	n/a	101.20	n/a	n/a
NAT92-32	6		G_07_FERRO-MAGNESIAN_UVAROVITE_GROSSULAR	0.42	15.87	1.31	0.54	32.79	36.97	8.04	0.00	0.76	n/a	96.71	n/a	n/a
NAT93-37	2		UNKNOWN (Jaedite?)	0.83	0.06	13.86	14.78	11.94	46.90	7.49	1.48	0.15	0.69	98.17	n/a	n/a
NAT93-37	1		G_05_MAGNESIAN_ALMANDINE	0.21	0.06	23.89	10.91	3.13	38.36	22.70	0.02	0.37	0.00	99.65	n/a	n/a
NAT93-37	2		G_05_MAGNESIAN_ALMANDINE	0.07	0.03	25.00	8.97	4.36	38.13	22.30	0.03	0.32	0.00	99.21	n/a	n/a
NAT93-37	3		G_05_MAGNESIAN_ALMANDINE	0.02	0.12	24.37	11.76	1.96	39.29	22.44	0.02	0.28	0.00	100.26	n/a	n/a
NAT93-37	3		G_05_MAGNESIAN_ALMANDINE	0.14	0.11	24.20	7.83	6.48	38.68	21.60	0.02	0.59	0.00	99.65	n/a	n/a
NAT93-38	1		G_03_CALCIC_PYROPE_ALMANDINE	0.10	0.00	22.32	6.29	10.65	39.62	21.29	0.00	0.39	0.00	100.66	n/a	n/a
NAT93-45	1		G_05_MAGNESIAN_ALMANDINE	0.08	0.14	25.51	11.53	1.08	38.50	22.21	0.02	0.47	0.00	99.54	n/a	n/a
NAT93-45	2		G_11_UVAROVITE_PYROPE	0.34	6.47	7.31	19.21	5.65	40.71	18.80	0.07	0.44	0.00	99.01	n/a	n/a
NAT93-51	1		UNKNOWN (Chromite?)	0.29	34.68	31.65	13.38	0.00	0.03	16.65	n/a	0.28	n/a	97.24	1971	84
NAT93-51	2		CPX_04_UNKNOWN	0.23	0.60	11.60	14.97	10.84	49.58	6.88	1.04	0.36	0.46	96.56	n/a	n/a
NAT93-50	1		G_09_CHROME_PYROPE	0.16	1.78	9.72	18.46	5.07	42.06	21.45	0.02	0.57	0.00	99.28	n/a	n/a
NAT93-55	1		CPX_05_CHROME_DIOPSIDE	0.05	1.73	2.42	15.60	21.32	54.65	1.35	1.72	0.11	0.00	98.94	n/a	n/a
NAT93-69	1		CPX_02_DIOPSIDE_>ONE_S.D.	0.23	0.83	4.55	17.88	20.82	53.42	2.26	0.53	0.14	0.00	100.66	n/a	n/a
NAT93-71	1		CPX_01_UNKNOWN	0.12	0.19	9.74	18.95	11.22	50.94	3.25	1.02	0.42	0.38	96.22	n/a	n/a
NAT93-73	1		SUB_PICRO_CHROMITE	1.43	36.87	22.96	13.69	0.00	0.08	21.94	n/a	0.27	n/a	97.43	1536	0
NAT93-73	2		SUB_PICRO_CHROMITE	0.13	58.27	22.64	7.09	0.00	0.03	8.09	n/a	0.38	n/a	96.90	441	1779
NAT93-74	2		G_05_MAGNESIAN_ALMANDINE	0.02	0.22	23.31	12.84	1.06	40.26	22.30	0.01	0.33	0.00	100.35	n/a	n/a
NAT93-74	6		G_05_MAGNESIAN_ALMANDINE	0.10	0.00	24.68	6.07	9.00	36.96	21.23	0.03	0.58	0.00	98.64	n/a	n/a
NAT93-74	1		G_03_CALCIC_PYROPE_ALMANDINE	0.11	0.06	20.25	8.72	9.06	40.30	21.58	0.00	0.46	0.00	100.54	n/a	n/a
NAT93-75	1		G_09_CHROME_PYROPE	0.12	5.17	8.47	18.76	5.48	41.93	18.86	0.03	0.48	0.00	99.29	n/a	n/a
NAT93-76	3		CPX_04_UNKNOWN	0.29	1.01	12.01	15.79	11.81	49.37	5.83	0.96	0.31	0.57	97.96	n/a	n/a
NAT93-76	2		G_05_MAGNESIAN_ALMANDINE	0.06	0.01	24.53	11.23	2.72	39.48	22.05	0.00	0.27	0.00	100.35	n/a	n/a
NAT93-76	3		G_05_MAGNESIAN_ALMANDINE	0.05	0.00	25.11	10.70	2.87	39.43	21.83	0.02	0.29	0.00	100.31	n/a	n/a
NAT93-78	9		G_03_CALCIC_PYROPE_ALMANDINE	0.09	0.07	22.93	6.50	9.16	38.91	21.50	0.01	0.64	0.00	99.81	n/a	n/a
NAT93-78	3		G_05_MAGNESIAN_ALMANDINE	0.02	0.09	24.42	12.29	1.33	39.37	22.32	0.00	0.28	0.00	100.12	n/a	n/a
NAT93-78	8		G_05_MAGNESIAN_ALMANDINE	0.14	0.00	25.60	6.84	7.00	38.86	21.47	0.02	0.97	0.00	100.89	n/a	n/a
NAT93-78	1		G_03_CALCIC_PYROPE_ALMANDINE	0.07	0.00	22.13	9.25	6.12	40.03	21.35	0.00	0.44	0.00	99.39	n/a	n/a
NAT93-82	3		CPX_02_UNKNOWN	0.10	0.58	3.93	16.48	22.66	53.75	1.65	0.60	0.13	0.00	99.88	n/a	n/a
NAT93-82	1		CPX_02_UNKNOWN	0.05	0.65	4.11	15.87	22.90	53.58	1.55	0.59	0.10	0.00	99.39	n/a	n/a
NAT93-83	1		CPX_04_UNKNOWN	0.11	0.77	8.17	15.71	18.01	52.39	2.65	0.77	0.04	0.00	98.63	n/a	n/a

				%	%	%	%	%	%	%	%	%	%	%	ppm	ppm
Site	Grain	Mineral (GSC ID)	Mineral (Min-ID.ASC)	TiO2	Cr2O3	FeO	MgO	CaO	SiO2	Al2O3	Na2O	MnO	K2O	Total	Ni	Zn
NAT93-83	1		G_03_CALCIC_PYROPE_ALMANDINE	0.13	0.22	20.32	12.50	4.43	39.71	21.62	0.05	0.70	0.00	99.69	n/a	n/a
NAT93-85	1		G_03_CALCIC_PYROPE_ALMANDINE	0.04	0.00	15.51	12.83	0.42	40.39	21.43	0.00	8.96	0.00	99.58	n/a	n/a
NAT93-85	4		G_03_CALCIC_PYROPE_ALMANDINE	0.19	0.00	21.91	5.51	12.01	38.48	21.00	0.01	0.69	0.00	99.80	n/a	n/a
NAT93-85	2		G_05_MAGNESIAN_ALMANDINE	0.06	0.00	25.30	8.35	5.70	39.78	21.19	0.01	0.49	0.00	100.88	n/a	n/a
NAT93-87	3		G_05_MAGNESIAN_ALMANDINE	0.08	0.00	25.88	11.39	1.04	40.52	21.86	0.03	0.46	0.00	101.26	n/a	n/a
NAT93-87	4		G_05_MAGNESIAN_ALMANDINE	0.04	0.00	25.56	11.02	1.44	40.17	21.66	0.00	0.86	0.00	100.75	n/a	n/a
NAT93-87	5		G_05_MAGNESIAN_ALMANDINE	0.01	0.04	25.11	11.45	1.30	39.99	21.70	0.00	0.48	0.00	100.09	n/a	n/a
NAT93-87	6		G_05_MAGNESIAN_ALMANDINE	0.07	0.00	24.88	11.96	1.32	40.15	21.55	0.01	0.52	0.00	100.47	n/a	n/a
NAT93-87	7		G_05_MAGNESIAN_ALMANDINE	0.01	0.00	24.11	12.10	1.15	40.07	21.79	0.00	0.87	0.00	100.10	n/a	n/a
NAT93-87	8		G_05_MAGNESIAN_ALMANDINE	0.06	0.00	23.49	6.73	8.37	39.52	21.17	0.03	0.67	0.00	100.03	n/a	n/a
NAT93-87	11		G_05_MAGNESIAN_ALMANDINE	0.16	0.00	25.49	11.15	1.38	39.58	21.74	0.06	0.94	0.00	100.50	n/a	n/a
NAT93-87	12		G_05_MAGNESIAN_ALMANDINE	0.07	0.00	25.10	11.63	0.68	40.73	21.51	0.01	1.42	0.00	101.14	n/a	n/a
NAT93-89	3		G_05_MAGNESIAN_ALMANDINE	0.11	0.00	23.90	6.50	8.65	39.01	21.88	0.03	0.72	0.00	100.80	n/a	n/a
PR93-3	1		G_09_CHROME_PYROPE	0.17	4.12	7.89	19.30	5.36	42.26	19.60	0.00	0.42	0.00	99.13	n/a	n/a
PR93-3	1		G_03_CALCIC_PYROPE_ALMANDINE	0.20	0.00	19.17	7.92	10.35	39.88	21.30	0.07	0.57	0.00	99.46	n/a	n/a
PR93-6A	1		G_03_CALCIC_PYROPE_ALMANDINE	0.19	0.00	21.83	9.84	6.01	40.05	21.25	0.05	0.54	0.00	99.76	n/a	n/a
PR93-6B	1		G_05_MAGNESIAN_ALMANDINE	0.16	0.00	24.97	6.56	7.69	39.29	20.95	0.00	0.63	0.00	100.25	n/a	n/a
PR93-6B	1		G_09_CHROME_PYROPE	0.22	3.34	8.24	19.36	4.98	42.58	20.08	0.03	0.63	0.00	99.46	n/a	n/a
PR93-6B	2		G_09_CHROME_PYROPE	0.26	4.00	8.61	19.17	4.89	42.75	19.73	0.00	0.42	0.00	99.82	n/a	n/a
PR93-6B	3		G_09_CHROME_PYROPE	0.19	4.22	8.29	19.01	5.04	42.23	19.97	0.02	0.30	0.00	99.28	n/a	n/a
PR93-6B	4		G_09_CHROME_PYROPE	0.31	3.55	8.47	19.40	4.93	41.98	19.83	0.04	0.50	0.00	99.02	n/a	n/a
PR93-10	1		CPX_02_DIOPSIDE_>ONE_S.D.	0.11	0.64	5.35	15.04	21.48	53.94	1.39	1.26	0.19	0.00	99.39	n/a	n/a
Grimshaw	6692a		CPX_03_UNKNOWN	0.55	0.78	2.99	14.93	19.59	50.99	7.09	2.08	0.06	n/a	99.06	n/a	n/a
Grimshaw	6692d		CPX_03_UNKNOWN	0.52	1.07	2.79	14.73	19.50	51.24	6.63	2.07	0.04	n/a	98.61	n/a	n/a
Grimshaw	6692h		CPX_05_CHROME_DIOPSIDE	0.14	1.03	2.30	15.18	19.94	52.39	5.85	2.11	0.06	n/a	99.00	n/a	n/a
n/a =	Not Analysed															
	Those sites with indicator mineral grains of favourable chemistry															

APPENDIX 6.2

APPENDIX 6.2: SUMMARY TABLE OF DIAMOND INDICATOR MINERAL DATA									
Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous Samples	G1, G2
1	91TCA-3019	110.482618	49.974459	72L	Medicine Hat	GSC/Thorleifson	Till	91TCA-3019	
2	91TCA-3020	111.133141	50.212083	72L	Suffield	GSC/Thorleifson	Till	91TCA-3020	
3	91TCA-3021	111.995606	50.641376	72L	Brooks	GSC/Thorleifson	Till	91TCA-3021	
4	91TCA-3022	113.072479	50.911406	82I	Gleichen	GSC/Thorleifson	Till	91TCA-3022	1
5	91TCA-3023	113.724499	51.041018	82I	Calgary	GSC/Thorleifson	Till	91TCA-3023	
6	91TCA-3024	114.000208	51.282528	82O	Airdrie	GSC/Thorleifson	Till		
7	91TCA-3025	114.020485	51.721074	82O	Olds	GSC/Thorleifson	Till		
8	91TCA-3026	113.906378	52.316490	83A	Red Deer	GSC/Thorleifson	Till	91TCA-3026	
9	91TCA-3027	113.642677	52.838858	83A	Ponoka	GSC/Thorleifson	Till	91TCA-3027	
10	91TCA-3028	113.548995	53.291394	83H	Leduc	GSC/Thorleifson	Till	91TCA-3028	
11	91TCA-3029	113.177713	53.572967	83H	Edmonton	GSC/Thorleifson	Till	91TCA-3029	
12	91TCA-3030	112.275724	53.561718	83H	Vegreville	GSC/Thorleifson	Till	91TCA-3030	
13	91TCA-3031	111.229755	53.334595	73E	Mannville	GSC/Thorleifson	Till	91TCA-3031	1
14	91TCA-3032	110.349661	53.342037	73E	Kitscoty	GSC/Thorleifson	Till	91TCA-3032	
15	1-3-1-T	114.973516	54.009835	83J	Mayerthorpe	GSC/Thorleifson	Till	1-3-1-T	
16	10-2-2-T	114.174442	50.919886	82J	Calgary	GSC/Thorleifson	Till		
17	10-3-1-T	114.003055	50.396573	82J	Nanton	GSC/Thorleifson	Till		
18	13-3-2-T	113.586360	54.910684	83I	Grosmont	GSC/Thorleifson	Till		
19	14-3-2-T	113.574480	53.961582	83H	Morinville	GSC/Thorleifson	Till		
20	14-4-1-T	113.751049	54.349667	83I	Westlock	GSC/Thorleifson	Till		
21	15-3-1-T	113.419206	53.410983	83H	Edmonton	GSC/Thorleifson	Till		
22	15-3-2-T	113.426939	53.335301	83H	Beaumont	GSC/Thorleifson	Till	15-3-2-T	
23	15-4-2-T	113.944395	53.628477	83H	Spruce Grove	GSC/Thorleifson	Till	15-4-2-T	1
24	16-3-1-T	113.710031	52.704251	83A	Ponoka	GSC/Thorleifson	Till	16-3-1-T	
25	16-3-2-T	113.897522	52.718699	83A	Gull Lake	GSC/Thorleifson	Till	16-3-2-T	
26	16-4-1-T	113.402242	53.136196	83H	Leduc	GSC/Thorleifson	Till	16-4-1-T	
27	16-4-2-T	113.798421	52.882048	83A	Ponoka	GSC/Thorleifson	Till	16-4-2-T	
28	17-1-2-T	113.931122	52.002003	83A	Innisfail	GSC/Thorleifson	Till	17-1-2-T	
29	17-2-2-T	113.976587	52.378594	83A	Gull Lake	GSC/Thorleifson	Till		
30	17-3-1-T	113.505812	52.108949	83A	Pine Lake	GSC/Thorleifson	Till	17-3-1-T	
31	17-3-2-T	113.630924	52.026182	83A	Innisfail	GSC/Thorleifson	Till		
32	17-4-1-T	113.409615	52.166709	83A	Pine Lake	GSC/Thorleifson	Till	17-4-1-T	
33	17-4-2-T	113.921387	52.410549	83A	Lacombe	GSC/Thorleifson	Till		
34	18-1-2-T	113.983408	51.162418	82P	McDonald Lake	GSC/Thorleifson	Till		
35	18-3-1-T	113.541584	51.139581	82P	Strathmore	GSC/Thorleifson	Till		
36	18-3-2-T	113.784880	51.357098	82P	Airdrie	GSC/Thorleifson	Till	18-3-2-T	
37	18-4-1-T	113.551010	51.774333	82P	Three Hills	GSC/Thorleifson	Till		
38	18-4-2-T	113.821012	51.663831	82P	Olds	GSC/Thorleifson	Till		
39	19-1-2-T	113.973555	50.651746	82I	Okotoks	GSC/Thorleifson	Till		
40	19-2-2-T	113.955918	50.821306	82I	Calgary	GSC/Thorleifson	Till	19-2-2-T	
41	19-3-1-T	113.787266	50.396394	82I	Nanton	GSC/Thorleifson	Till		
42	19-3-2-T	113.534874	50.571275	82I	Vulcan	GSC/Thorleifson	Till	19-3-2-T	
43	19-4-1-T	113.530810	50.863689	82I	Carseland	GSC/Thorleifson	Till	19-4-1-T	
44	19-4-2-T	113.761278	50.963699	82I	Calgary	GSC/Thorleifson	Till		
45	2-1-2-T	115.305178	53.583483	83G	Chip Lake	GSC/Thorleifson	Till		
46	2-3-1-T	114.676142	53.456034	83G	Wabamun Lake	GSC/Thorleifson	Till	2-3-1-T	
47	2-3-2-T	114.908833	53.533157	83G	Wabamun Lake	GSC/Thorleifson	Till		
48	2-4-1-T	114.970879	53.718523	83G	Wabamun Lake	GSC/Thorleifson	Till		
49	2-4-2-T	114.639229	53.632429	83G	Wabamun Lake	GSC/Thorleifson	Till	2-4-2-T	
50	20-1-1-T	113.870727	49.959865	82H	Claresholm	GSC/Thorleifson	Till		
51	20-3-1-T	113.618358	49.883079	82H	Ft. Macleod	GSC/Thorleifson	Till	20-3-1-T	
52	20-3-2-T	113.705464	49.722749	82H	Ft. Macleod	GSC/Thorleifson	Till	20-3-2-T	
53	20-4-1-T	113.759358	50.133490	82I	Stavely	GSC/Thorleifson	Till		
54	20-4-2-T	113.392774	50.246871	82I	Stavely	GSC/Thorleifson	Till	20-4-2-T	

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
	Garnets			Garnets	Diopsides		ilmenites	Indicators	
		1	5	6	1			7	
1	1	1		1	2	6		10	3 jadeite, 3 kyanite
			1	1				1	
	1	1		1	1			3	
		1	1	2	1			3	
1	1	1		1				2	
		1	2	3	1			4	
			1	1				1	
		2	5	7	1			8	
		4	6	10	1	4	1	16	1 jadeite; 3 kyanite
	1	5	6	11	1			13	
			5	5				5	
							1	1	
		1		1				1	
1	2					2		4	
2	2							2	
			1	1				1	
		1		1	1		1	3	
					1			1	
					1		1	2	
		2		2	2			4	
			1	1				1	
					1			1	1 corundum
					1			1	
			1	1				1	
1	1							1	
			1	1		1		2	
		1	2	3				3	
1	1							1	
							1	1	
		1	1	2				2	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
55	21-2-2-T	113.968438	49.438307	82H	Pincher Creek	GSC/Thorleifson	Till		
56	21-3-1-T	113.290555	49.129867	82H	Cardston	GSC/Thorleifson	Till	21-3-1-T	2
57	21-3-2-T	113.638861	49.234885	82H	Waterton	GSC/Thorleifson	Till		
58	21-4-1-T	113.595359	49.322239	82H	Waterton	GSC/Thorleifson	Till	21-4-1-T	
59	21-4-2-T	113.459386	49.548319	82H	Ft. Macleod	GSC/Thorleifson	Till	21-4-2-T	
60	23-1-1-T	113.433824	54.709779	83I	Athabasca	GSC/Thorleifson	Till	23-1-1-T	1
61	23-1-2-T	112.875845	54.896770	83I	Alpac	GSC/Thorleifson	Till		
62	23-3-1-T	112.803187	54.841244	83I	Grassland	GSC/Thorleifson	Till	23-3-1-T	
63	23-3-2-T	112.297317	54.751540	83I	Plamondon	GSC/Thorleifson	Till		
64	24-1-1-T	113.177236	54.207667	83I	Elbridge	GSC/Thorleifson	Till		
65	24-1-2-T	112.980632	54.264997	83I	Abee	GSC/Thorleifson	Till		
66	24-2-1-T	113.014969	54.496345	83I	Ellscott	GSC/Thorleifson	Till	24-2-1-T	
67	24-2-2-T	113.401949	54.511747	83I	Perryvale	GSC/Thorleifson	Till	24-2-2-T	
68	24-3-1-T	112.259110	54.017627	83I	Kahwin	GSC/Thorleifson	Till		
69	24-3-2-T	112.324041	54.187710	83I	Edwand	GSC/Thorleifson	Till	24-3-2-T	
70	24-4-1-T	112.794752	54.615766	83I	Boyle	GSC/Thorleifson	Till		
71	24-4-2-T	112.798801	54.320881	83I	Valley Lake	GSC/Thorleifson	Till	24-4-2-T	
72	25-1-1-T	113.385931	53.354111	83H	Beaumont	GSC/Thorleifson	Till		
73	25-1-2-T	112.877368	53.338924	83H	Cooking Lake	GSC/Thorleifson	Till		
74	25-2-1-T	113.118034	53.919257	83H	Redwater	GSC/Thorleifson	Till	25-2-1-T	
75	25-2-2-T	113.125194	53.670107	83H	Fort Sask.	GSC/Thorleifson	Till	25-2-2-T	
76	25-3-1-T	112.754627	53.495420	83H	Elk Island	GSC/Thorleifson	Till		
77	25-3-2-T	112.221350	53.351038	83H	Vegreville	GSC/Thorleifson	Till	25-3-2-T	
78	25-4-1-T	112.723489	53.656787	83H	Chipman	GSC/Thorleifson	Till		
79	25-4-2-T	112.434890	53.669583	83H	Hilliard	GSC/Thorleifson	Till		
80	26-1-1-T	113.015289	52.757665	83A	Stettler	GSC/Thorleifson	Till		
81	26-1-2-T	113.176962	52.671184	83A	Samson Lake	GSC/Thorleifson	Till		
82	26-2-1-T	113.119390	53.069640	83H	Bittern Lake	GSC/Thorleifson	Till		
83	26-2-2-T	112.911928	53.171154	83H	Miquelon Lake	GSC/Thorleifson	Till		
84	26-3-1-T	112.305981	52.576997	83A	Stettler	GSC/Thorleifson	Till		
85	26-3-2-T	112.579983	52.727400	83A	Driedmeat Lake	GSC/Thorleifson	Till	26-3-2-T	
86	26-4-1-T	112.193431	53.158046	83H	Holden	GSC/Thorleifson	Till		
87	26-4-2-T	112.656594	53.106654	83H	Camrose	GSC/Thorleifson	Till	26-4-2-T	1
88	27-1-1-T	113.078572	51.903241	82P	Trochu	GSC/Thorleifson	Till	27-1-1-T	
89	27-1-2-T	113.273845	52.142429	83A	Delburne	GSC/Thorleifson	Till	27-1-2-T	
90	27-2-1-T	112.859892	52.414040	83A	Buffalo Lake	GSC/Thorleifson	Till	27-2-1-T	1
91	27-2-2-T	113.262207	52.402528	83A	Buffalo Lake	GSC/Thorleifson	Till	27-2-2-T	
92	27-3-1-T	112.203325	52.114156	83A	Sullivan Lake	GSC/Thorleifson	Till		
93	27-3-2-T	112.500349	51.825713	82P	Farrell Lake	GSC/Thorleifson	Till	27-3-2-T	
94	27-4-1-T	112.499909	52.291482	83A	Stettler	GSC/Thorleifson	Till		
95	27-4-2-T	112.175562	52.279871	83A	Halkirk	GSC/Thorleifson	Till		
96	28-1-1-T	113.056386	51.383848	82P	Drumheller	GSC/Thorleifson	Till	28-1-1-T	
97	28-1-2-T	112.772189	51.132192	82P	Standard	GSC/Thorleifson	Till		
98	28-2-1-T	113.241396	51.757266	82P	Three Hills	GSC/Thorleifson	Till	28-2-1-T	
99	28-2-2-T	112.878453	51.565792	82P	Munson	GSC/Thorleifson	Till	28-2-2-T	
100	28-3-1-T	112.345706	51.358196	82P	Littlefish Lake	GSC/Thorleifson	Till		
101	28-3-2-T	112.186811	51.267293	82P	Littlefish Lake	GSC/Thorleifson	Till		
102	28-4-1-T	112.507201	51.639490	82P	Drumheller	GSC/Thorleifson	Till		
103	28-4-2-T	112.389057	51.792911	82P	Drumheller	GSC/Thorleifson	Till		
104	29-1-1-T	112.848941	50.510439	82I	McGregor Lake	GSC/Thorleifson	Till	29-1-1-T	
105	29-1-2-T	112.705758	50.568388	82I	Blackfoot Res.	GSC/Thorleifson	Till		
106	29-2-1-T	112.728416	50.839664	82I	Blackfoot Res.	GSC/Thorleifson	Till	29-2-1-T	
107	29-2-2-T	113.121571	51.021147	82I	Blackfoot Res.	GSC/Thorleifson	Till	29-2-2-T	
108	29-3-1-T	112.292921	50.601584	82I	Bassano/BIR	GSC/Thorleifson	Till	29-3-1-T	
109	29-3-2-T	112.535459	50.629217	82I	Blackfoot Res.	GSC/Thorleifson	Till	29-3-2-T	
110	29-4-1-T	112.309811	51.005191	82P	Wolf Lake	GSC/Thorleifson	Till	29-4-1-T	
111	29-4-2-T	112.366960	50.864244	82I	Barkenhouse L.	GSC/Thorleifson	Till		

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
1	3	1		1				4	
			1	1				1	
			1	1				1	
	1						1	2	
		1		1	2			3	
									1 corundum
						1		1	
1	1							1	
1	1		1	1		1		3	
			1	1				1	
					1			1	
						1		1	
									1 corundum
									1 corundum
			1	1				1	
	1							1	
						1		1	
			1	1			1	2	
1	2						1	3	1 olivine; MgO
							2	2	
						1		1	
			1	1				1	
					4			4	
		1		1		1		2	
					1		1	2	
					1			1	
						2		2	
			1	1				1	
		1	1	2			2	4	
		1		1				1	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
112	3-4-1-T	114.950613	53.198536	83G	Drayton Valley	GSC/Thorleifson	Till		
113	3-4-2-T	114.942338	52.964633	83B	Buck Lake	GSC/Thorleifson	Till		
114	30-1-1-T	112.782958	49.954711	82H	Keho Lake	GSC/Thorleifson	Till		
115	30-1-2-T	112.866812	49.815768	82H	Lethbridge	GSC/Thorleifson	Till	30-1-2-T	
116	30-2-1-T	112.970465	50.312366	82I	Vulcan	GSC/Thorleifson	Till		
117	30-2-2-T	112.822919	50.016155	82I	Traverse Res	GSC/Thorleifson	Till	30-2-2-T	
118	30-3-1-T	112.620021	49.668365	82H	Coaldale	GSC/Thorleifson	Till		
119	30-3-2-T	112.301606	49.991693	82H	Vauxhall	GSC/Thorleifson	Till		
120	30-4-1-T	112.183804	50.023536	82I	Vauxhall	GSC/Thorleifson	Till		
121	30-4-2-T	112.474328	50.165018	82I	Enchant	GSC/Thorleifson	Till	30-4-2-T	
122	31-1-2-T	112.714355	49.275702	82H	Raymond	GSC/Thorleifson	Till		
123	31-2-1-T	112.768061	49.354955	82H	Raymond	GSC/Thorleifson	Till		
124	31-2-2-T	112.779295	49.589565	82H	Cardston	GSC/Thorleifson	Till	31-2-2-T	
125	31-3-1-T	112.189977	49.137464	82H	Mackie Creek	GSC/Thorleifson	Till	31-3-1-T	1
126	31-3-2-T	112.542634	49.279921	82H	Raymond	GSC/Thorleifson	Till	31-3-2-T	1
127	31-4-1-T	112.252862	49.293322	82H	Warner	GSC/Thorleifson	Till	31-4-1-T	
128	31-4-2-T	112.588447	49.464609	82H	Raymond	GSC/Thorleifson	Till		
129	33-1-1-T	111.886622	54.870270	83I	Lac la Biche	GSC/Thorleifson	Till	33-1-1-T	2
130	34-1-1-T	111.973190	54.126341	73L	Vilna	GSC/Thorleifson	Till	34-1-1-T	
131	34-1-2-T	112.134626	54.042237	83I	Kahwin E	GSC/Thorleifson	Till		
132	34-2-1-T	111.829584	54.520176	73L	Grandeur L	GSC/Thorleifson	Till	34-2-1-T	
133	34-2-2-T	112.030574	54.280457	73L	Whitefish L	GSC/Thorleifson	Till	34-2-2-T	
134	34-3-1-T	111.275422	54.125466	73L	Vincent L	GSC/Thorleifson	Till	34-3-1-T	
135	34-3-2-T	111.307167	54.073263	73L	Owlseye	GSC/Thorleifson	Till		
136	34-4-1-T	111.104568	54.331550	73L	Franchere	GSC/Thorleifson	Till		
137	34-4-2-T	111.385866	54.483766	73L	Frenchman L	GSC/Thorleifson	Till	34-4-2-T	
138	35-1-1-T	111.732947	53.429653	73E	Ranfurly	GSC/Thorleifson	Till		
139	35-1-2-T	112.170876	53.263447	83H	Holden	GSC/Thorleifson	Till	35-1-2-T	
140	35-2-1-T	111.985501	53.741540	73E	Hairy Hill	GSC/Thorleifson	Till	35-2-1-T	
141	35-2-2-T	112.214320	53.947078	83H	Shandro	GSC/Thorleifson	Till	35-2-2-T	
142	35-3-1-T	111.034562	53.363578	73E	Mannville	GSC/Thorleifson	Till		
143	35-3-2-T	111.550280	53.386581	73E	Innisfree	GSC/Thorleifson	Till		
144	35-4-1-T	111.567837	53.800879	73E	Lac Sante	GSC/Thorleifson	Till		
145	35-4-2-T	111.155740	53.627752	73E	Myrnam	GSC/Thorleifson	Till	35-4-2-T	
146	36-1-1-T	111.613562	52.871186	73D	Sedgewick	GSC/Thorleifson	Till		
147	36-1-2-T	112.095838	52.671730	83A	Stettler	GSC/Thorleifson	Till	36-1-2-T	
148	36-2-1-T	112.076556	53.149272	83H	Holden	GSC/Thorleifson	Till	36-2-1-T	
149	36-2-2-T	111.911409	52.976252	73D	Killam	GSC/Thorleifson	Till		
150	36-3-1-T	111.526960	52.712483	73D	Hardisty	GSC/Thorleifson	Till	36-3-1-T	
151	36-3-2-T	111.040112	52.871870	73D	Wainwright	GSC/Thorleifson	Till	36-3-2-T	1
152	36-4-1-T	111.568275	52.929844	73D	Sedgewick	GSC/Thorleifson	Till		
153	36-4-2-T	111.540230	53.186175	73E	Birch Lake	GSC/Thorleifson	Till		
154	37-1-1-T	111.861656	52.117148	72M	Sullivan Lake	GSC/Thorleifson	Till	37-1-2-T	
155	37-1-2-T	112.142284	52.011364	83A	Sullivan Lake	GSC/Thorleifson	Till		
156	37-2-1-T	111.931993	52.198431	73D	Castor	GSC/Thorleifson	Till		
157	37-2-2-T	111.754903	52.367829	73D	Alliance	GSC/Thorleifson	Till		
158	37-3-1-T	111.279104	52.143344	73D	Coronation	GSC/Thorleifson	Till	37-3-1-T	
159	37-3-2-T	111.574074	52.126998	73D	Coronation	GSC/Thorleifson	Till	37-3-2-T	
160	37-4-1-T	111.112665	52.201167	73D	Coronation	GSC/Thorleifson	Till	37-4-1-T	
161	37-4-2-T	111.363052	52.224030	73D	Talbot	GSC/Thorleifson	Till		
162	38-1-1-T	112.066536	51.272946	82P	East Coulee	GSC/Thorleifson	Till		
163	38-1-2-T	111.643197	51.240968	72M	Drumheller	GSC/Thorleifson	Till		
164	38-2-1-T	111.913988	51.747212	72M	Hanna	GSC/Thorleifson	Till	38-2-1-T	
165	38-2-2-T	111.855834	51.735960	72M	Hanna	GSC/Thorleifson	Till	38-2-2-T	
166	38-3-1-T	111.040185	51.326353	72M	Oyen	GSC/Thorleifson	Till	38-3-1-T	
167	38-3-2-T	111.149074	51.269622	72M	Oyen	GSC/Thorleifson	Till	38-3-2-T	
168	38-4-1-T	111.430968	51.676254	72M	Hanna	GSC/Thorleifson	Till	38-4-1-T	

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
									1 olivine; MgO
1	1							1	
						1		1	
1	1							1	
			1	1				1	
	1					1	1	3	
1	2				1			3	
			1	1				1	
	2							2	
		2		2	1			3	
					1			1	
1	1							1	
1	1				2			3	
									1 kyanite
2	2							2	
			1	1				1	
			1	1				1	
					1			1	1 jadeite
					1			1	
		1		1				1	
					1			1	
					1			1	
	1		1	1	1			3	
1	1							1	
1	1		1	1				2	
		1		1				1	
							1	1	
		2	1	3				3	
		1	1	2				2	
1	1							1	
							2	2	
1	1					1		2	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
169	38-4-2-T	111.089835	51.763326	72M	Coronation	GSC/Thorleifson	Till	38-4-2-T	
170	39-1-1-T	111.696270	50.386343	72L	Tilley	GSC/Thorleifson	Till	39-1-1-T	
171	39-1-2-T	111.990791	50.479536	72L	Newell Lake W.	GSC/Thorleifson	Till		
172	39-2-1-T	111.627655	50.834595	72L	Dinosaur Park	GSC/Thorleifson	Till		
173	39-2-2-T	112.129259	50.730090	82I	Rosemary	GSC/Thorleifson	Till		
174	39-3-1-T	111.293301	50.731597	72L	Iddesleigh	GSC/Thorleifson	Till	39-3-1-T	
175	39-3-2-T	111.187954	50.607708	72L	Suffield	GSC/Thorleifson	Till		
176	39-4-1-T	111.342552	50.878943	72L	Dinosaur Park	GSC/Thorleifson	Till		
177	39-4-2-T	111.399362	51.039727	72M	Dinosaur Park	GSC/Thorleifson	Till		
178	40-1-1-T	111.844250	49.845718	72E	Purple Springs	GSC/Thorleifson	Till	40-1-1-T	
179	40-1-2-T	111.775639	50.077355	72L	Hays	GSC/Thorleifson	Till	40-2-1-T	
180	40-2-1-T	112.015006	50.359712	82I	Vauxhall North	GSC/Thorleifson	Till		
181	40-2-2-T	112.069796	50.107389	82I	Vauxhall	GSC/Thorleifson	Till		
182	40-3-1-T	111.530438	49.893458	72E	Burdett	GSC/Thorleifson	Till		
183	40-3-2-T	111.052693	49.697674	72E	Maleb	GSC/Thorleifson	Till		
184	40-4-1-T	111.518065	50.167824	72L	12 Mile Coulee	GSC/Thorleifson	Till	40-4-1-T	
185	40-4-2-T	111.558245	50.251288	72L	12 Mile Coulee	GSC/Thorleifson	Till		
186	41-1-1-T	111.564519	49.110733	72E	Writing on Stone	GSC/Thorleifson	Till	41-1-1-T	
187	41-1-2-T	111.952446	49.118978	72E	Red Creek	GSC/Thorleifson	Till	41-1-2-T	
188	41-2-1-T	112.048257	49.502250	82H	Wrentham	GSC/Thorleifson	Till	41-2-1-T	
189	41-2-2-T	111.645704	49.347784	72E	Crow Indian L.	GSC/Thorleifson	Till	41-2-2-T	2
190	41-3-1-T	111.255009	49.140621	72E	Milk River	GSC/Thorleifson	Till		
191	41-4-1-T	111.110609	49.556421	72E	North Pakowki	GSC/Thorleifson	Till		
192	41-4-2-T	111.301596	49.361796	72E	Foremost	GSC/Thorleifson	Till	41-4-2-T	
193	43-1-1-T	110.705004	54.296182	73L	Bonnyville	GSC/Thorleifson	Till		
194	43-1-2-T	110.518435	54.220993	73L	Muriel L	GSC/Thorleifson	Till	43-1-2-T	
195	43-2-1-T	110.701516	54.353695	73L	Fort Kent	GSC/Thorleifson	Till	43-2-1-T	
196	43-2-2-T	110.775965	54.526414	73L	LaCorey	GSC/Thorleifson	Till	43-2-2-T	
197	43-3-1-T	110.351797	54.186951	73L	Angling L	GSC/Thorleifson	Till		
198	43-4-1-T	110.200957	54.459270	73L	Cold L	GSC/Thorleifson	Till	43-4-1-T	2
199	44-1-1-T	110.951844	53.425594	73E	Vermilion	GSC/Thorleifson	Till	44-1-1-T	
200	44-1-2-T	110.731778	53.481935	73E	Vermilion N	GSC/Thorleifson	Till	44-1-2-T	
201	44-2-1-T	110.720834	53.771330	73E	Northern Val	GSC/Thorleifson	Till	44-2-1-T	
202	44-2-2-T	110.898081	53.881270	73E	Elk Point	GSC/Thorleifson	Till	44-2-2-T	1
203	44-3-2-T	110.348147	53.342923	73E	Kitscoty	GSC/Thorleifson	Till		
204	44-4-1-T	110.052356	53.743644	73E	John L	GSC/Thorleifson	Till		
205	44-4-2-T	110.369679	53.715176	73E	Heinsburg	GSC/Thorleifson	Till	44-4-2-T	
206	45-1-1-T	110.493503	52.735051	73D	Wainwright	GSC/Thorleifson	Till		
207	45-1-2-T	110.827970	52.795336	73D	Wainwright	GSC/Thorleifson	Till	45-1-2-T	
208	45-2-1-T	110.564018	53.236039	73E	Vermillion	GSC/Thorleifson	Till		
209	45-2-2-T	110.953609	53.187388	73E	Vermillion	GSC/Thorleifson	Till	45-2-2-T	
210	45-3-1-T	110.249710	52.874000	73D	Wainwright	GSC/Thorleifson	Till		
211	45-4-1-T	110.278453	52.932610	73D	Wainwright	GSC/Thorleifson	Till	46-1-1-T	
212	46-1-1-T	110.949088	51.939576	72M	Consort	GSC/Thorleifson	Till	45-4-1-T	
213	46-1-2-T	110.425063	51.966948	72M	Consort	GSC/Thorleifson	Till		
214	46-2-1-T	110.517388	52.314409	73D	Provost	GSC/Thorleifson	Till		
215	46-2-2-T	110.963207	52.461036	73D	Hardisty	GSC/Thorleifson	Till	46-2-2-T	
216	46-3-1-T	110.147367	51.873550	72M	Altario	GSC/Thorleifson	Till	46-3-1-T	
217	46-3-2-T	110.053335	52.062556	73D	Provost	GSC/Thorleifson	Till	46-3-2-T	
218	47-1-1-T	110.564197	51.426262	72M	Oyen	GSC/Thorleifson	Till	47-1-1-T	
219	47-1-2-T	110.847614	51.404495	72M	Oyen	GSC/Thorleifson	Till		
220	47-2-1-T	110.471513	51.605720	72M	Oyen	GSC/Thorleifson	Till	47-2-1-T	
221	47-2-2-T	110.971034	51.743577	72M	Coronation	GSC/Thorleifson	Till	47-2-2-T	1
222	47-3-1-T	110.423557	51.401377	72M	Oyen	GSC/Thorleifson	Till	47-3-1-T	
223	47-3-2-T	110.038202	51.474379	72M	Oyen	GSC/Thorleifson	Till	47-3-2-T	
224	47-4-1-T	110.290610	51.631736	72M	Oyen	GSC/Thorleifson	Till	47-4-1-T	
225	47-4-2-T	110.382793	51.759039	72M	Oyen	GSC/Thorleifson	Till	47-4-2-T	

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
		1		1				1	
					1	1		2	
			1	1			1	2	1 corundum
1	1							1	
					1			1	
						1		1	
					1			1	
		2		2				2	
1	1							1	
	2				1		1	4	
1	1							1	
		1		1				1	
			1	1				1	
					1			1	
	2							2	
1	1				1		1	3	
			1	1				1	
		1		1				1	
1	2				1			3	
1	1							1	
					1			1	
			1	1				1	
					1			1	
			1	1				1	
			1	1				1	
					1			1	
1	1						2	3	
2	2							2	
					1			1	
	1							1	
			1	1				1	
					1			1	
1	1				1			2	
1	1	1		1	1			3	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
226	48-1-1-T	110.507696	50.385578	72L	Suffield East	GSC/Thorleifson	Till	48-1-1-T	1
227	48-1-2-T	110.842810	50.705784	72L	Suffield North	GSC/Thorleifson	Till		
228	48-2-1-T	110.559235	50.742819	72L	Suffield North	GSC/Thorleifson	Till		
229	48-2-2-T	110.763202	50.765899	72L	Suffield North	GSC/Thorleifson	Till		
230	48-3-1-T	110.115049	50.396753	72L	Schuler	GSC/Thorleifson	Till	48-3-1-T	2
231	48-3-2-T	110.264585	50.461639	72L	Suffield East	GSC/Thorleifson	Till	48-3-2-T	
232	48-4-1-T	110.404223	51.007416	72L	Empress	GSC/Thorleifson	Till	48-4-1-T	1
233	48-4-2-T	110.134267	51.038108	72L	Empress	GSC/Thorleifson	Till	48-4-2-T	
234	49-1-1-T	110.530015	49.689537	72E	Cypress Hills	GSC/Thorleifson	Till	49-1-1-T	
235	49-1-2-T	110.758806	49.961868	72E	Seven Persons	GSC/Thorleifson	Till		
236	49-2-1-T	110.483269	50.303644	72L	Bowmanton	GSC/Thorleifson	Till	49-2-1-T	1
237	49-2-2-T	110.956563	50.202251	72L	Redcliff	GSC/Thorleifson	Till	49-2-2-T	
238	49-4-1-T	110.310044	50.047309	72L	Medicine Hat	GSC/Thorleifson	Till		
240	5-1-1-T	114.435861	54.289057	83J	Barrhead	GSC/Thorleifson	Till	5-1-1-T	
241	5-1-2-T	114.271288	53.965368	83G	Barrhead	GSC/Thorleifson	Till		
242	5-2-1-T	114.005257	54.504803	83J	Fawcett	GSC/Thorleifson	Till	5-2-1-T	
243	5-2-2-T	114.379163	54.407407	83J	Vega	GSC/Thorleifson	Till	5-2-2-T	
244	50-1-1-T	110.807744	49.221697	72E	Pakowki Lake	GSC/Thorleifson	Till		
245	50-1-2-T	110.498470	49.114628	72E	Onefour	GSC/Thorleifson	Till	50-1-2-T	1
246	50-2-1-T	110.902073	49.436801	72E	Pakowki Lake	GSC/Thorleifson	Till	50-2-1-T	
247	50-2-2-T	110.615029	49.633194	72E	Cypress Hills	GSC/Thorleifson	Till	50-2-2-T	1
248	50-3-1-T	110.148368	49.073893	72E	Wildhorse	GSC/Thorleifson	Till		
249	50-3-2-T	110.243283	49.044866	72E	Wildhorse	GSC/Thorleifson	Till	50-3-2-T	
250	6-1-1-T	114.430090	53.564281	83G	Wabamun	GSC/Thorleifson	Till	6-1-1-T	
251	6-1-2-T	114.267158	53.561566	83G	Wabamun	GSC/Thorleifson	Till	6-1-2-T	1
252	6-2-1-T	114.494171	53.909991	83G	Barrhead	GSC/Thorleifson	Till		
253	6-2-2-T	114.074890	53.743146	83G	Spruce Grove	GSC/Thorleifson	Till		
254	7-1-2-T	114.555356	52.670459	83B	Rimbey	GSC/Thorleifson	Till		
255	7-2-1-T	114.233837	52.959239	83B	Pigeon Lake	GSC/Thorleifson	Till		
256	8-1-1-T	114.384278	52.090373	83B	Innisfail	GSC/Thorleifson	Till		
257	8-1-2-T	114.529724	51.941531	82O	Garrington	GSC/Thorleifson	Till		
258	8-2-1-T	114.431864	52.303650	83B	Sylvan Lake	GSC/Thorleifson	Till	8-2-1-T	
259	8-2-2-T	114.347539	52.290994	83B	Sylvan Lake	GSC/Thorleifson	Till	8-2-2-T	
260	8-3-1-T	114.048572	52.111218	83B	Innisfail	GSC/Thorleifson	Till		
261	8-4-2-T	114.045513	52.355767	83B	Gull Lake	GSC/Thorleifson	Till		
262	9-1-1-T	114.208422	51.159961	82O	Bowness	GSC/Thorleifson	Till		
263	9-1-2-T	114.283447	51.294844	82O	Airdrie	GSC/Thorleifson	Till	9-1-2-T	
264	9-2-1-T	114.589260	51.590235	82O	Cremona	GSC/Thorleifson	Till		
265	9-2-2-T	114.285115	51.630358	82O	Didsbury	GSC/Thorleifson	Till		
266	9-4-1-T	114.069342	51.435388	82O	Crossfield	GSC/Thorleifson	Till		
267	9-4-2-T	114.084851	51.710997	82O	Olds	GSC/Thorleifson	Till		
268	NAT92-1	115.045494	55.655777	83O	L.Slave L	AGS/Fent	Till	92-1	
269	NAT92-10	117.482651	58.907486	84K	Meander R	AGS/Fent	Till	92-10	
270	NAT92-11	119.435425	58.494476	84L	Rainbow L	AGS/Fent	Till		
271	NAT92-12	117.922272	58.573204	84K	High Level W	AGS/Fent	Till		
272	NAT92-13	117.470474	57.573986	84F	Kemp R	AGS/Fent	Till	92-13	
273	NAT92-14	117.542633	57.226784	84F	Hawk Hills	AGS/Fent	Till		
274	NAT92-15	117.626968	56.930439	84C	Manning	AGS/Fent	Till		
275	NAT92-16	117.797569	56.479240	84C	Smithmill	AGS/Fent	Till		
276	NAT92-17	117.902939	56.179340	84C	Brownvale	AGS/Fent	Till	92-17	
277	NAT92-18	119.869659	56.300076	84D	Boundary L	AGS/Fent	Till		
278	NAT92-19	117.902969	56.179340	84C	Brownvale	AGS/Fent	Till	92-19	
279	NAT92-2	115.311295	56.241127	84B	Cranberry L	AGS/Fent	Till	92-2	
280	NAT92-20	116.914932	56.379333	84C	Peace R E	AGS/Fent	Till		
281	NAT92-21	118.050995	55.685005	83M	Birch Hills	AGS/Fent	Till		
282	NAT92-22	119.880760	55.257896	83M	Goodfare	AGS/Fent	Till		
283	NAT92-23	117.177483	55.179489	83N	Valley View	AGS/Fent	Till	92-23	

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
1	2		1	1	2			5	
									1 olivine; MgO
2	4		1	1	2			7	
1	1		3	3	1			5	
	1						1	2	
					1			1	
1	1					1		2	
	1				2			3	
					1			1	
					1			1	
1	1				1			2	
			1	1				1	
	1							1	
1	1							1	
	1						1	2	
3	3							3	
		1		1				1	
	1							1	1 corundum
						1	1	2	
						1		1	
							1	1	
									1 Na -diopside
		1		1				1	
									2 corundum
						1		1	
1	1							1	
1	1							1	
1	1							1	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
284	NAT92-24	111.057915	57.249889	74E	Kearl L E	AGS/Fent	Till		
285	NAT92-25	111.403374	57.249889	74E	Kearl L W	AGS/Fent	Till	92-25	
286	NAT92-26	110.861938	55.799088	73M	Chard	AGS/Fent	Till		
287	NAT92-27	110.903915	56.246296	74D	Cheecham	AGS/Fent	Till	92-27	
288	NAT92-28	111.877754	56.077339	74D	SW 1/4	AGS/Fent	Till	92-28	
289	NAT92-29	112.187798	55.797279	83P	Crow L	AGS/Fent	Till		
290	NAT92-3	115.104530	57.128601	84G	Wabasca R	AGS/Fent	Till	92-3	1
291	NAT92-30	111.666733	55.009575	73M	Heart L	AGS/Fent	Till	92-30	
292	NAT92-31	111.647591	55.038666	73M	Heart L	AGS/Fent	Till		
293	NAT92-32	110.329117	54.422314	73L	Cold L	AGS/Fent	Till	92-32	
294	NAT92-33	110.329137	54.422314	73L	Cold L	AGS/Fent	Till		
295	NAT92-34	116.234718	54.977757	83K	Swan Hills	AGS/Fent	Till	92-34	
296	NAT92-4	115.392570	57.388626	84G	Wabasca R	AGS/Fent	Till		
297	NAT92-5	115.552650	57.855755	84G	Wadlin L	AGS/Fent	Till	92-5	
298	NAT92-6	116.482430	58.542141	84K	High Level east	AGS/Fent	Till		
299	NAT92-7	114.554718	58.589458	84J	Wentzil R	AGS/Fent	Till		
300	NAT92-8	115.496025	58.556770	84J	Beaver Cr	AGS/Fent	Till		
301	NAT92-9	116.740000	60.100000	85A	NWT	AGS/Fent	Till		
302	HL93-10	117.914995	58.574983	84K	High Level west	AGS/Fent	Till		
303	HL93-11	117.427913	58.545908	84K	High Level west	AGS/Fent	Till		
304	HL93-4	115.159492	58.593159	84J	Lawrence Creek	AGS/Fent	Till		
305	HL93-6	116.599871	58.520458	84K	High Level east	AGS/Fent	Till		
306	HL93-8	117.469041	58.902094	84K	High Level north	AGS/Fent	Till		
307	HL93-9	117.237134	58.716729	84K	High Level north	AGS/Fent	Till		
308	NAT93-35	118.502798	55.259612	83M	Kleskun Hill	AGS/Fent	Till		
309	NAT93-36	118.791573	55.434174	83M	S. Saddle Hills	AGS/Fent	Till		
310	NAT93-37	118.380879	55.455982	83M	Teepee Creek	AGS/Fent	Till	93-37	
311	NAT93-38	119.256644	55.895966	83M	Grand Prairie	AGS/Fent	Till	93-38	
312	NAT93-39	114.797688	55.444968	83 O	Martin Mtn	AGS/Fent	Till		
313	NAT93-40	115.202941	55.943092	83 O	E. Utikuma Lake	AGS/Fent	Till		
314	NAT93-41	115.391913	56.033980	84B	N. Utikuma Lake	AGS/Fent	Till		
315	NAT93-42	116.012510	55.714038	83N	Salt Prairie	AGS/Fent	Till		
316	NAT93-43	116.477531	55.626762	83N	E. Winagami Lk	AGS/Fent	Till		
317	NAT93-44	116.981889	55.852193	83N	N. Kimiwan Lk	AGS/Fent	Till		
318	NAT93-45	116.825499	55.986723	83N	Springburn	AGS/Fent	Till	93-45	
319	NAT93-46	116.812466	56.121254	84C	Harmon Valley	AGS/Fent	Till		
320	NAT93-47	119.485239	56.074121	84D	Silver Valley	AGS/Fent	Till		
321	NAT93-48	119.700771	55.819606	83M	Saddle Hills W.	AGS/Fent	Till		
322	NAT93-49	118.883613	57.404592	84E	Chinchaga River	AGS/Fent	Till		
323	NAT93-50	118.422845	57.284647	84E	Chinchaga Rd	AGS/Fent	Till		
324	NAT93-500	114.976950	55.339521	83O	Lesser Slave Lake	AGS/Fent	Till		
325	NAT93-501	115.342733	57.273683	84G	Wabasca River	AGS/Fent	Till		
326	NAT93-502	116.266790	56.659318	84C	Haig Lake	AGS/Fent	Till		
327	NAT93-503	116.326510	56.542986	84C	Golden Lake	AGS/Fent	Till		
328	NAT93-51	114.541601	55.237706	83 O	E. Lesser Sl. Lk	AGS/Fent	Till	93-51	
329	NAT93-52	115.220233	55.339513	83 O	S.LesserSlave Lk	AGS/Fent	Till		
330	NAT93-53	116.865597	55.332242	83N	N. Snipe Lake	AGS/Fent	Till	93-53	
331	NAT93-54	116.802771	55.110438	83N	S. Snipe Lake	AGS/Fent	Till		
332	NAT93-55	118.740789	56.361331	84D	Montagneuse R.	AGS/Fent	Till	93-55	
333	NAT93-56	118.997814	56.426774	84D	Clear Hills	AGS/Fent	Till		
334	NAT93-57	119.006968	56.583099	84D	Clear Hills	AGS/Fent	Till		
335	NAT93-58	119.026920	56.670345	84D	Clear Hills	AGS/Fent	Till		
336	NAT93-59	119.046873	56.608542	84D	Clear Hills	AGS/Fent	Till	93-59	
337	NAT93-60	116.403975	56.506631	84C	Cadotte Lake	AGS/Fent	Till		
338	NAT93-61	116.101513	56.452093	84C	Little Buffalo	AGS/Fent	Till		
339	NAT93-62	115.772750	56.459370	84B	Lubicon Lake	AGS/Fent	Till		
340	NAT93-63	115.555767	56.470267	84B	Loon Lake	AGS/Fent	Till		

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
			1	1				1	
						1		1	
									1 jadeitic diopside
	1							1	
						1		1	
1	1							1	
									1 jadeitic diopside
						1		1	
			4	4				4	1 jadeite
		1		1				1	
1	1		1	1				2	
					1	1		2	
1	1							1	
					1			1	
					1			1	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	**Anomalous**	G1, G2
341	NAT93-64	115.118842	56.655675	84B	Red Earth	AGS/Fent	Till		
342	NAT93-65	114.826878	56.742928	84B	Peerless Lake	AGS/Fent	Till		
343	NAT93-66	117.105189	57.975252	84F	La Crete Ferry	AGS/Fent	Till		
344	NAT93-67	114.512365	58.585885	84J	Wentzil River	AGS/Fent	Till		
345	NAT93-68	113.973608	55.538768	83P	Pelican Mtn	AGS/Fent	Till		
346	NAT93-69	118.646443	57.306452	84E	Chinchaga Rd Pit	AGS/Fent	Till		
347	NAT93-70	115.349313	54.764969	83J	Swan Hills	AGS/Fent	Till		
348	NAT93-71	118.022858	57.171979	84E	Chinchaga Rd	AGS/Fent	Till	93-71	
349	NAT93-72	117.727772	57.121012	84F	Chinchaga Rd	AGS/Fent	Till		
350	NAT93-73	118.215513	56.633992	84D	Sulphur Lake	AGS/Fent	Till	93-73	
351	NAT93-74	116.147238	56.862901	84C	Haig Lake	AGS/Fent	Till	93-74	
352	NAT93-75	116.260155	56.659316	84C	Otter Lakes	AGS/Fent	Till	93-75	
353	NAT93-76	115.244917	56.826557	84B	Loon River	AGS/Fent	Till	93-76	
354	NAT93-77	115.089082	57.175534	84G	Wabasca River	AGS/Fent	Till		
355	NAT93-78	115.335099	57.622666	84G	Senex Creek	AGS/Fent	Till	93-78	
356	NAT93-79	116.257624	57.982514	84F	Buffalo Hd Hills	AGS/Fent	Till		
357	NAT93-80	111.096795	57.531475	74E	Firebag River	AGS/Fent	Riv sand		
358	NAT93-81	111.029191	57.462403	74E	Firebag River	AGS/Fent	Till		
359	NAT93-82	110.454578	57.338768	74E	Firebag River	AGS/Fent	Till	93-82	
360	NAT93-83	110.745265	57.404221	74E	Firebag River	AGS/Fent	Till	93-83	
361	NAT93-84	111.202795	57.647831	74E	Firebag River	AGS/Fent	Till		
362	NAT93-85	111.004878	57.622381	74E	Marguerite R	AGS/Fent	Riv sand	93-85	
363	NAT93-86	111.496257	57.564205	74E	Fort McKay	AGS/Fent	Till		
364	NAT93-87	111.562086	57.182424	74E	Muskey River	AGS/Fent	Riv sand	93-87	
365	NAT93-88	111.501796	57.076978	74E	Saline Lake	AGS/Fent	Till		
366	NAT93-89	110.677291	57.629659	74E	Johnson Lake	AGS/Fent	Till	93-89	
367	PR93-10	117.959329	56.015809	84C	Peace R south	AGS/Fent	Till	93-10	
368	PR93-13	117.881135	55.899470	83N	Winagami North	AGS/Fent	Till		
369	PR93-3	117.153553	56.452093	84C	Peace R south	AGS/Fent	Till	93-3	
370	PR93-6A	117.330067	55.615856	83N	Peavine	AGS/Fent	Till	93-6A	
371	PR93-6B	117.330097	55.615856	83N	Peavine	AGS/Fent	Till	93-6B	
372	B-1	113.800640	53.691129	83H	Villineuve	GSC/Ballintyne	Riv S&G		
373	B-2	114.163087	53.633880	83G	Eden Lake	GSC/Ballintyne	Riv S&G		
374	B-3	114.875051	53.604795	83G	Evansburg	GSC/Ballintyne	Riv S&G	3	
375	B-4	114.924141	53.590245	83G	Pembina R	GSC/Ballintyne	Riv S&G		
376	B-5	116.543000	53.381000	83F	McLeod River	GSC/Ballintyne	Riv S&G	5	
377	B-6	116.618096	53.459293	83F	Embarras River	GSC/Ballintyne	Riv S&G	6	
378	B-7	117.278713	53.284697	83F	McLeod River	GSC/Ballintyne	Riv S&G	7	
379	B-8	117.497887	53.197386	83F	Gregg River	GSC/Ballintyne	Riv S&G	8	
380	B-9	117.108255	53.139182	83F	McLeod River	GSC/Ballintyne	Riv S&G	9	
381	B-10	117.010851	53.168290	83F	Embarras River	GSC/Ballintyne	Riv S&G	10	
382	B-11	116.816040	53.066430	83F	Lovett River	GSC/Ballintyne	Riv S&G	11	
383	B-12	116.576097	52.935477	83C	Pembina River	GSC/Ballintyne	Riv S&G	12	
384	B-13	116.551941	52.877280	83C	Brazeau River	GSC/Ballintyne	Riv S&G		
385	B-14	116.547000	52.788000	83C	Cardinal River	GSC/Ballintyne	Riv S&G		
386	B-15	116.310373	52.702651	83C	Blackstone River	GSC/Ballintyne	Riv S&G	15	
387	B-16	116.012643	52.280634	83C	North Ram River	GSC/Ballintyne	Riv S&G	16	
388	B-17	116.340043	52.382510	83C	Crescent Falls	GSC/Ballintyne	Riv S&G		
389	B-18	115.965084	52.207858	83B	Cripple Creek	GSC/Ballintyne	Riv S&G		
390	B-19	115.846186	52.076873	83B	Ram River	GSC/Ballintyne	Riv S&G		
391	B-20	115.275479	52.251520	83B	Prairie Creek	GSC/Ballintyne	Riv S&G		
392	B-21	115.410000	52.280000	83B	Main Ram River	GSC/Ballintyne	Riv S&G	21	
393	B-22	115.429327	52.367953	83B	N.Saskatchewan R	GSC/Ballintyne	Riv S&G	22	
394	B-23	115.573124	52.557134	83B	Baptiste Creek	GSC/Ballintyne	Riv S&G	23	
395	B-24	112.805693	51.479347	82P	Red Deer River	GSC/Ballintyne	Riv S&G		
396	B-25	112.477858	51.333829	82P	E Coulee Beach Sd	GSC/Ballintyne	Riv S&G		
397	B-26	110.339150	53.662031	73E	N.Saskatchewan R	GSC/Ballintyne	Riv S&G		

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
									1 Na - diopside
						2		2	
		1	2	3				3	
1	1							1	
			2	2	1			3	
		2	2	4				4	
					2			2	
		1		1	1			2	
		2	1	3				3	
			8	8				8	
			1	1				1	
					1			1	
1	1	1		1				2	
		1		1				1	
4	4		1	1				5	
						1		1	
						1		1	
						1		1	
						1		1	
						2		2	
						3		3	
						2		2	
						2		2	
						17		17	
						2		2	
						1		1	
						2		2	
						1		1	
						1		1	

Sample#	Field Sample#	Longitude °	Latitude °	NTS	Location Name	DataSource	Lithology	Anomalous	G1, G2
398	B-27	110.539977	53.778430	73E	Heinsburg Bridge	GSC/Ballintyne	Riv S&G		
399	B-28	110.911260	53.851168	73E	Outwash Grvl Pit	GSC/Ballintyne	Riv S&G		
400	B-29	111.072000	53.817000	73E	N.Sask. R	GSC/Ballintyne	Riv S&G		
401	B-30	111.233038	53.749325	73E	N.Sask. R	GSC/Ballintyne	Riv S&G		
402	B-31	111.703332	53.792967	73E	N.Sask. R	GSC/Ballintyne	Riv S&G		
403	B-32	112.198378	53.982118	83H	N.Sask. R	GSC/Ballintyne	Riv S&G		
404	B-33	112.520160	53.982119	83H	N.Sask. R	GSC/Ballintyne	Riv S&G		
405	B-34	112.792437	54.054862	83I	N.Sask. R	GSC/Ballintyne	Riv S&G		
406	B-35	112.990456	53.880264	83H	Vinca Bridge	GSC/Ballintyne	Riv S&G		
407	B-36	113.236000	53.705678	83H	Ft. Saskatchewan	GSC/Ballintyne	Riv S&G		
408	5854	113.202302	50.678920	82I	Arrowwood	AGS/D.Edwards	Ter S&G		
409	3913	112.833202	50.853577	82I	Cluny	AGS/D.Edwards	Ter S&G		
410	4213	110.221554	49.587365	72E	Cypress Hills	AGS/D.Edwards	Ter S&G		
411	5570	112.777942	49.034274	82H	Del Bonita	AGS/D.Edwards	Ter S&G		
412	6424	114.973241	53.590233	83G	Entwhistle	AGS/D.Edwards	Ter S&G	6424	
413	6692	117.594093	56.237591	84C	Grimshaw	AGS/D.Edwards	Ter S&G	6692	
414	6815	118.639683	57.313717	84E	Halverson Ridge	AGS/D.Edwards	Ter S&G		
415	6808	112.360778	51.523008	82P	Hand Hills	AGS/D.Edwards	Ter S&G		
416	6106	113.830098	52.497986	83A	Lacombe	AGS/D.Edwards	Ter S&G		
417	6422	114.875041	53.604783	83G	Magnolia	AGS/D.Edwards	Ter S&G	6422	
418	5669	112.819853	49.354485	82H	Magrath	AGS/D.Edwards	Ter S&G		
419	5812	113.980350	50.475179	82I	Nanton	AGS/D.Edwards	Ter S&G		
420	3915	117.501901	53.575679	83F	Obed Mtn	AGS/D.Edwards	Ter S&G		
421	6824	113.973608	55.538768	83P	Pelican Mtn.	AGS/D.Edwards	Ter S&G		
422	5566	112.955994	49.077932	82H	Peters Ck.	AGS/D.Edwards	Ter S&G		
423	4028	118.169123	55.132343	83M	Simonette R	AGS/D.Edwards	Ter S&G		
424	3914	118.289900	54.404946	83L	Smoky Tower	AGS/D.Edwards	Ter S&G		
425	3973	115.375553	54.754055	83J	Swan Hills	AGS/D.Edwards	Ter S&G		
426	3975	113.800640	53.676584	83H	Villeneuve	AGS/D.Edwards	Ter S&G	3975	2
427	4212	117.633621	55.714031	83N	Watino	AGS/D.Edwards	Ter S&G		
428	6573	115.723903	54.026694	83J	Whitecourt Mtn	AGS/D.Edwards	Ter S&G		
429	6811	112.459265	51.231953	82P	Wintering Hills	AGS/D.Edwards	Ter S&G		
430	6424T	114.973241	53.590333	83G	Entwhistle	AGS/D.Edwards	Till	6424T	
431	3WGK001	114.128069	49.285278	82G	Pincher Creek	S AlbtaRiftProj	Fluvial		
432	3WGK004	114.104997	49.299740	82G	Pincher Creek	S AlbtaRiftProj	Fluvial		
433	3WGK005	114.082762	49.309164	82G	Pincher Creek	S AlbtaRiftProj	Fluvial		
434	3WGK006	114.340466	49.314620	82G	Grizzly Creek	S AlbtaRiftProj	Fluvial		
435	3WGK009	114.672038	50.124045	82J	Oldman R tribu	S AlbtaRiftProj	Fluvial		
436	3WGK010	114.675202	50.119949	82J	Oldman River	S AlbtaRiftProj	Fluvial		
437	3WGK011	114.662992	50.117569	82J	Oldman River	S AlbtaRiftProj	Fluvial		
438	3WGK012	114.335130	49.298765	82G	Grizzly Creek	S AlbtaRiftProj	Fluvial		
439	B1	111.101776	59.749129	74M	Shield NE Alta	GSC/Bednarsky	Till		
440	B2	110.600227	59.998906	74M	Shield NE Alta	GSC/Bednarsky	Till		
441	B3	110.563016	59.693389	74M	Shield NE Alta	GSC/Bednarsky	Till		
442	B4	110.135478	59.891433	74M	Shield NE Alta	GSC/Bednarsky	Till		
443	B5	111.143836	59.470471	74M	Shield NE Alta	GSC/Bednarsky	Till		
444	B6	110.174288	59.677470	74M	Shield NE Alta	GSC/Bednarsky	Till		
445	B7	110.414121	59.348885	74M	Shield NE Alta	GSC/Bednarsky	Till		
446	B8	110.312348	59.551247	74M	Shield NE Alta	GSC/Bednarsky	Till		

G7,9,10,11	Kimberlitic	G3, G4, G6	G5	Eclogitic	Chrome	Chromites	Picro-	Total	Other
						4		4	
					3			3	
						4		4	
3	5					1		6	
1	1							1	