EUB/AGS Special Report 20

A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data

Alberta Energy and Utilities Board

Alberta Geological Survey

EUB/AGS Special Report 20

A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data

M.B. Dufresne[1] and D.R. Eccles[2]

[1]APEX Geoscience Ltd.
[2]Alberta Geological Survey

March 2005

ISBN 0-7785-38389

When using information from this publication in other publications or presentations, due acknowledgment should be given to the EUB/AGS. The following reference format is recommended:

Dufresne, M.B. and Eccles, D.R. (2005): A guide to kimberlite-indicator mineral trends in Alberta including observations from recently compiled indicator mineral data; Alberta Energy and Utilities Board, EUB/AGS Special Report 20.

Author Address:
M.B. Dufresne
APEX Geoscience Ltd.
#200, 9797-45th Ave.
Edmonton, Alberta T6E 5V8
(780) 439-5380
Email: apexgeo@compusmart.ab.ca

Published March 2005 by:
Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca
Website: www.ags.gov.ab.ca

Contents

CONTENTS iii

ACKNOWLEDGEMENTS v

ABSTRACT vi

1 INTRODUCTION 1

2 SUMMARY OF ALBERTA'S DIAMOND POTENTIAL 1

3 KIMBERLITE-INDICATOR MINERALS DEFINED 2

4 KIMBERLITE, LAMPROITE AND DIAMOND: BACKGROUND INFORMATION 3

5 AN OVERVIEW OF KIMBERLITE-DERIVED UPPER MANTLE XENOCRYSTS AND MAGMATIC PHENOCRYSTS WITH EXAMPLES FROM SOME ALBERTA KIMBERLITIC ROCKS 10

- 5.1 PERIDOTITE MANTLE 11
  - 5.1.1 Pyrope Garnet 11
  - 5.1.2 Clinopyroxene 14
  - 5.1.3 Chromite 16
  - 5.1.4 Olivine 17
  - 5.1.5 Orthopyroxene 17
  - 5.1.6 Other Minerals 17
- 5.2 ECLOGITE MANTLE 17
  - 5.2.1 High Na_2O-TiO_2 Eclogitic Type I Garnets 18
  - 5.2.2 Ecologitic Garnet (Mg-Almandine) 19
  - 5.2.3 High Na-Al-Clinopyroxene (Omphacite or Jadeite) 20
  - 5.2.4 Cr-Corundum (Ruby) 21
- 5.3 MEGACRYSTS AND MACROCRYSTS 21
  - 5.3.1 Cr-Poor Megacrystic Pyrope Garnet 21
  - 5.3.2 Ilmenite 22
  - 5.3.3 Clinopyroxene 23
  - 5.3.4 Orthopyroxene 24
  - 5.3.5 Other 24
- 5.4 COGNATE MAGMATIC PHENOCRYSTS CRYSTALLIZED WITHIN THE KIMBERLITE MAGMA 24
  - 5.4.1 Olivine 24
  - 5.4.2 Phlogopite 25
  - 5.4.3 Spinel and Chromite 25
  - 5.4.4 Ilmenite 27
  - 5.4.5 Diopside 27

6 OBSERVATIONS ON MINERAL CHEMISTRY FROM COMPILED DATA FOR NORTHERN AND SOUTHERN ALBERTA AND SOME ALBERTA KIMBERLITIC ROCKS 27

- 6.1 PERIDOTITIC GARNET 28
- 6.2 ECLOGITIC GARNET 31
- 6.3 CR-DIOPSIDE 34
- 6.4 CHROMITE 37
- 6.5 PICROILMENITE 38
- 6.6 OLIVINE 40

7 CONCLUDING REMARKS 41

8 REFERENCES..44

Figures

Figure 1. Classification of igneous rocks..4
Figure 2. Distinctive morphological characteristics of kimberlite pipes in South Africa, Northwest Territories and Fort a la Corne, Saskatchewan..7

Appendices (At end)

Appendix 1 Selected bi-variate and ternary plots for indicator minerals from kimberlitic rocks.
Appendix 2 Selected bi-variate and ternary plots for peridotitic garnet.
Appendix 3 Selected bi-variate and ternary plots for eclogitic garnet.
Appendix 4 Selected bi-variate and ternary plots for clinopyroxene.
Appendix 5 Selected bi-variate and ternary plots for chromite.
Appendix 6 Selected bi-variate and ternary plots for ilmenite.
Appendix 7 Selected bi-variate and ternary plots for olivine.
Appendix 8 Areas with favourable indicator mineral geochemistry in Alberta.

Appendix (Data files on CD-ROM)

Appendix 9 Excel spreadsheets of compiled indicator mineral data for peridotitic and eclogitic garnet, clinopyroxene, chromite, ilmenite and olivine.

Acknowledgements

We would like to acknowledge contributions of data from a large number of companies to the Alberta government through mineral assessment filing. The scanning of these data, form the basis for the compilation by Eccles et al. (2002) and this report. We also would like to acknowledge a number of companies that have been or are exploring Alberta for diamonds and contributed data outside of the normal assessment filing process, including but not limited to, Buffalo Gold Inc. (Buffalo), Blue Diamond Mining Corp. (Blue Diamond), Cameco Inc. (Cameco), Kennecott Canada Exploration Inc. (Kennecott), Marum Resources Ltd. and Shear Minerals Ltd. In particular, the chemistry for minerals derived from concentrates from the Birch Mountain kimberlite field is published herein with permission from Buddy Doyle of Kennecott and Larry Kryska of Blue Diamond. We also would like to acknowledge the efforts of Robert Barnett of R.L. Barnett Geological Services, London, Ontario, and Tom Bonli of the University of Saskatchewan, Saskatoon, Saskatchewan, for their helpful discussions and their contributions to mineral chemistry based upon their extensive electron microprobe analyses that form the basis for the bulk of the data in this report.

Abstract

Since 1990, diamond exploration in Alberta has resulted in the discovery of 48 kimberlitic pipes and the recovery of more than 18 000 possible kimberlite-indicator minerals from surficial sampling (till, stream sediment and bedrock). The proper classification and interpretation of kimberlite-indicator mineral datasets are vital to the future discovery of kimberlites, and more importantly, diamonds in Alberta. Hence, the following review includes an updated guideline to kimberlite-indicator minerals being recovered, a synopsis of some of the important geographic and geochemical trends and their relevance to future diamond exploration in Alberta.

Of primary importance, the indicator mineral data include more than 1000 anomalous samples from across Alberta and make it clearly apparent that

- Alberta is under-explored. For example, few KIM surveys have been completed north of latitude 58ºN; and
- there are other areas of northern Alberta (i.e., besides the known kimberlite areas) with high grain counts and excellent mantle xenocryst chemistry. These anomalous data and sample sites indicate that, with continued exploration, it is likely a significant number of kimberlites remain to be discovered both in the areas where kimberlites are known to currently exist and in areas currently with no known kimberlitic pipes.

Areas that display high potential for future kimberlite discovery includes, but is not limited to, the Buffalo Head Hills, Utikuma Lake, Calling Lake and St. Paul to Cold Lake areas. A number of other regions that have seen much less exploration, such as the Birch Mountains, Mountain Lake, Caribou Mountains, Chinchaga River, Peace River to Spirit River, Kakwa-Wapiti River, Edmonton and south-central foothills areas, and much of central to southern Alberta across the Prairies, require further exploration to identify the potential for kimberlite pipes and to determine the diamond potential based upon the chemistry of the associated indicator minerals.

The data also allow for geological interpretation regarding the mantle, particularly in identification of regional characteristics and similarities or differences in the mantle beneath Alberta. For instance, garnet and chromite in northern Alberta have significantly higher Cr versus garnet and chromite recovered from southern Alberta. This is believed to represent a major fundamental difference in the mantle between northern and southern Alberta. Furthermore, pyrope garnet from northern Alberta displays a noticeable trend of increasing TiO_2 enrichment from west to east, reflecting a significant change in the composition of the upper mantle, possibly due to easterly increasing metasomatism. Finally, clusters of kimberlite-indicator minerals with unique geochemical assemblages must be related to mantle heterogeneity (e.g., Calling Lake area in northern Alberta). These observations reveal the complexity of the mantle underlying Alberta and the necessity for future kimberlite-indicator mineral sampling and compilations that will enable continued development of models required to assist in the discovery of an economic diamond deposit in Alberta.

1 Introduction

Northern Alberta (NAB) has seen tremendous amounts of exploration for diamonds in the last 10 years. This exploration has resulted in the discovery of at least 48 kimberlitic pipes with a very high likelihood of discovering many more pipes. Future kimberlite discoveries will rely more and more on the use of kimberlite-indicator mineral (KIM) sampling in combination with other exploration techniques, such as soil and biogeochemical sampling, high resolution magnetic surveys, electromagnetic surveys, existing seismic data and, possibly, gravity surveys.

It is imperative in any diamond exploration program to understand which minerals are potentially derived from kimberlites, which minerals are mantle derived and which minerals are most likely crustal derived in order to guide and focus further work. In addition, a sound understanding of the typical signature for mantle minerals indicative of high diamond potential is critical to evaluating the potential for discoveries of diamondiferous kimberlites in any exploration program.

Alberta Geological Survey (AGS) Bulletin 63, released early 1996, indicated that about 500 possible KIMs were publicly known in Alberta at that time (Dufresne et al., 1996). A preliminary guideline was provided by Dufresne et al. (1996); however, extensive work since has resulted in a much better understanding of the KIMs being recovered across Canada and their relevance to exploration, particularly for Alberta. A recently completed compilation includes analyses for more than 18 000 possible KIMs across Alberta, of which the preliminary interpretation includes several interesting geochemical and geographic trends (Eccles et al., 2002).

The following review includes an updated guideline to KIMs being recovered in Alberta, as well as a brief synopsis of some of the observations and interpretations for data derived from the recently completed KIM compilation for Alberta by Eccles et al. (2002). Observations for these important geographic and geochemical trends are outlined and their relevance to exploration discussed. A large number of geochemical analyses are present for controversial, borderline or even ‘non-KIMs.’ Geochemical analyses for borderline or ‘non-KIMs’ is often improperly interpreted and can lead to the expenditure of large sums of capital in areas where the likelihood for discovery of kimberlites and diamonds is low. Data for minerals such as eclogitic garnets, chrome diopsides and chromites are often the most difficult to assess; however, the data for these minerals can be very useful if interpreted correctly. The proper classification and resulting interpretation of KIM datasets such as these are vital to the future discovery of kimberlites, and more importantly, diamonds in Alberta.

2 Summary of Alberta’s Diamond Potential

Most of Alberta is underlain by Archean to Proterozoic crystalline basement with crustal thicknesses estimated to exceed 35 to 40 km across most of Alberta. Thick, cold crust is generally indicative of a favourable environment for the formation and preservation of diamonds in the upper mantle. These prerequisite conditions, in combination with major Proterozoic to Phanerozoic structures such as the Great Slave Lake Shear Zone, the Snowbird Tectonic Zone, the Peace River Arch, the Grosmont High and the Southern Alberta Rift that could have controlled the ascent of kimberlitic or lamproitic magma from the upper mantle to surface, are considered essential ingredients to the formation of kimberlite- or lamproite-hosted diamond deposits at surface. These favourable basement and structural characteristics, in combination with an abundance of favourable KIMs from a number of localities, indicate that Alberta is a prime target for kimberlite exploration.

The first clue to the presence of possible diamond-bearing source rocks in Alberta was the discovery of a perfect octahedral diamond, estimated at about one carat in weight, by farm worker Einar Opdahl during 1958 in the Evansburg area of west-central Alberta (Dufresne et al., 1996). 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 Department of Geology at the University of Alberta for positive identification. Since then, at least five alluvial diamond occurrences have been discovered in Alberta, including Caribou Mountains (1 diamond), Calling Lake (1), Hinton (23), Red Deer River (1) and Etzikom Coulee (2).

Coincident with the discovery of diamondiferous kimberlite in the Lac de Gras, Northwest Territories region, a staking rush was ignited in Alberta the size of which had never been seen before in Alberta (Dufresne et al., 1996). Although the 1992 and 1993 staking rush died out with not much success, an even larger staking rush was sparked by the discovery of kimberlites in the Buffalo Head Hills during early 1997 by a consortium led by Ashton Mining of Canada Inc., Alberta Energy Company Ltd. (now known as Encana Ltd.), and Pure Gold Resources Ltd. The 1997 staking rush and subsequent exploration led to the discovery of the Birch Mountains kimberlite field in the Birch Mountains during 1998.

As a result of exploration for kimberlites in Alberta since the initial staking rush in 1992, an extensive database of KIM analyses has been assembled by the AGS. Today chemistry is available for more than 18 000 possible diamond and/or KIMs from widespread samples across Alberta. The chemistry for all of these minerals, as well a number of non-indicator minerals and more than 2600 analyses for minerals from a number of Alberta kimberlites, are included in this report. These minerals, which include pyrope garnet, eclogitic garnet, clinopyroxene, orthopyroxene, olivine, chromite and ilmenite, have recently been compiled by Eccles et al. (2002) to determine if any meaningful geographic and/or geochemical patterns exist in Alberta. Preliminary observations on the geographic and geochemical patterns that are present in this dataset are presented as part of this report.

3 Kimberlite-Indicator Minerals Defined

A “kimberlite-indicator mineral” is a mineral that naturally occurs within kimberlites or closely related rocks and, therefore, can be used as a tracer to aid in finding kimberlites and, in some cases, aid in evaluating the diamond potential of a kimberlite. Kimberlite-indicator minerals must fulfill four important criteria to be useful in the search for kimberlites and diamonds in surface sampling exploration programs. The minerals must

1. be genetically linked to the kimberlite itself (i.e., crystallized from the kimberlite magma or carried by the kimberlite as a xenocryst originating from deeply sourced mantle material);
2. be abundant both in the kimberlite and in the surface environment;
3. possess chemical and physical properties such that they are resistant to weathering in the surface and sedimentary environment; and
4. have physical properties (e.g., density, colour, magnetism, etc.) to allow ease of recovery and identification.

It is generally accepted that KIMs are not restricted to those minerals that are only indicative of diamonds, but rather are defined as minerals distinctly indicative of a kimberlite or other closely related hybrid volcanic rock, such as an olivine lamproite that could be a hostrock for diamonds. There are essentially two main types of KIMs looked for in diamond exploration programs:

1. magmatic phenocrysts and/or macrocrysts associated with the kimberlite magma; and
2. xenocrysts derived from upper mantle peridotite or eclogite. Xenocrysts derived from upper mantle peridotite or eclogite may have crystallized within an area of the mantle that was within the diamond stability window within a favourable environment of pressure, temperature and oxygen fugacity.

The most important and commonly used KIMs include chromium (Cr) pyrope garnet, magnesium (Mg) ilmenite (picroilmenite), Mg-chromite and Cr-diopside as they fulfill most of the important criteria useful in the exploration of kimberlites and diamonds. Other minerals, such as eclogitic garnet, olivine, orthopyroxene, eclogitic clinopyroxene, phlogopite, zircon and diamond, can be used as KIMs; however, they fulfill fewer criteria and are found less commonly in heavy mineral concentrates. The bulk of the common phenocrystic kimberlite minerals, such as olivine and phlogopite, are often not good practical KIMs for recovery in surface exploration programs because olivine weathers easily and phlogopite is not easily recovered and can be difficult to distinguish from non-kimberlitic Mg-rich biotites from other sources. However, olivine is proving to be an important indicator mineral in colder climate areas such as Canada, where the mineral is not as easily broken down as in warm, semi-arid conditions. Chromite and ilmenite exist as common accessory phenocrysts in the groundmass of kimberlites as well as xenocrysts. Both kimberlitic chromite and ilmenite can be very useful KIMs. For example, a number of the kimberlites in the famous Premier field near Johannesburg, South Africa, may not have been found without paying close attention to the recovery of and chemistry of kimberlitic oxides (chromite and ilmenite) in the surface environment (P. Du Plessis, personal communication, 1998).

Xenoliths are foreign rock fragments incorporated into the kimberlite host magma during its ascent to surface. Xenoliths of both mantle and crustal origin are common in kimberlites. Disaggregation of mantle xenoliths results in the formation of recognizable mantle-derived minerals that are termed xenocrysts. Although mantle-derived xenocrysts are foreign minerals that are accidentally incorporated into a kimberlite magma during kimberlite ascent and, therefore, have no genetic relationship to a kimberlite, they typically form most of the important KIMs searched for in kimberlite exploration programs. Certain mantle-derived minerals, such as pyrope garnets, are so rare in the surface environment that their presence alone often indicates the presence of kimberlites, even without the recovery of actual kimberlite phenocrystic minerals, such as olivine and phlogopite. The most commonly searched for, recovered and identified minerals in diamond exploration programs include Cr-pyrope garnet, Cr-diopside, Mg-chromite and Mg-ilmenite, which are mostly derived from disaggregated xenoliths of peridotite. Less commonly, minerals such as kimberlitic chromite and ilmenite, as well as eclogitic iron-magnesium (Fe-Mg) garnet and omphacitic sodium-aluminum (Na-Al) clinopyroxene, which are derived from disaggregation of eclogite, are recovered and identified in exploration programs. Visual differentiation of some KIMs from similar minerals that are crustal derived can be difficult, especially minerals such as chromite, ilmenite, eclogitic garnet and omphacitic clinopyroxene. In these cases, it is necessary to use mineral chemistry as a tool for determining or confirming the origin of the recovered mineral.

4 Kimberlite, Lamproite and Diamond: Background Information

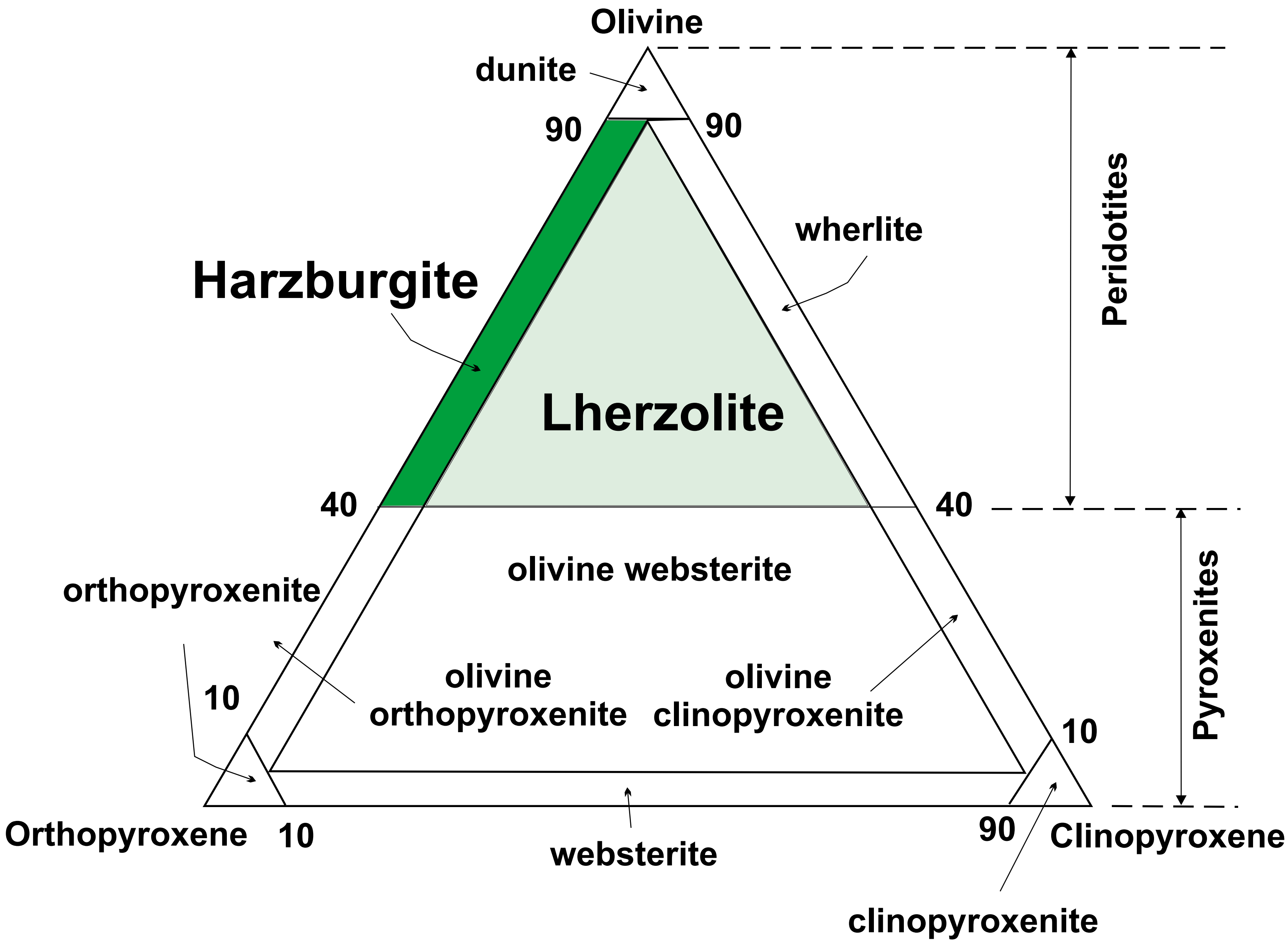
Kimberlites and lamproites are currently the only two known economic primary sources of diamonds. However, the discovery of diamondiferous lamprophyres or related dykes in the Parker Lake area of Nunavut, the Torngat area of Northern Quebec, and the Wawa area of Northwest Ontario, may change current concepts regarding favourable diamondiferous hostrocks (Northern Miner, 1995a; Pele Mountain Resources Ltd., 2000; Twin Mining Corporation, 2001). It is widely accepted that the bulk of diamonds found in kimberlite or lamproite hostrocks were not actually formed within the intrusive magmas, but are generally thought to occur as foreign crystals termed xenocrysts, which were derived from mantle material picked up during ascent of the kimberlitic or lamproitic magma. In general, diamond xenocrysts can be classified as either P-type or E-type, which represent derivation from either peridotite or eclogite mantle, respectively. Mantle peridotite is defined as a high pressure, ultramafic assemblage of varying amounts of olivine, orthopyroxene and clinopyroxene with or without accessory chromian spinel (chromite) and/or pyrope garnet. Olivine-dominant peridotite mantle can be further subdivided (Figure 1) on the proportions of its three main minerals into

- dunite (mostly olivine),
- harzburgite (mostly olivine and orthopyroxene),
- wehrlite (mostly olivine and clinopyroxene), and
- lherzolite (fairly equal proportions of olivine, orthopyroxene and clinopyroxene).

The carbon source involved in the formation of diamonds in upper mantle peridotite is generally thought to be derived from primary mantle carbon dioxide (CO_2). Eclogite is defined as a high pressure, low

Figure 1. CLASSIFICATION OF ULTRAMAFIC ROCKS

IUGS Classification For Rocks With >90%
Olivine ± Pyroxene



temperature assemblage of orange (eclogitic) garnet and green (omphacitic) clinopyroxene with or without accessory rutile, kyanite and epidote. The overall bulk chemical composition of eclogite roughly corresponds to basalt. Eclogite is generally thought to represent subducted and metamorphosed oceanic basaltic crust. As such, eclogite and its derived minerals can vary significantly in composition, particularly with respect to aluminum (Al) and sodium (Na). The carbon source for diamonds derived from eclogite is thought to be derived from either or both primary mantle CO_2 or biological carbon-related to subducted oceanic crust incorporating ocean bottom sedimentary material.

Kimberlites can be generally described as olivine-rich, potassic, ultramafic rocks with high concentrations of CO_2, often reflected by high carbonate content. Two types of kimberlites are recognized worldwide, Group I and Group II, corresponding to the original classification by Wagner (1914) of basaltic kimberlites and micaceous kimberlites (Smith et al., 1985; Skinner, 1989; Mitchell, 1989). Group I kimberlites are petrographically complex rocks often referred to as hybrid volcanic rocks, containing chemically distinct material derived from three different sources:

1. upper mantle xenoliths and associated xenocrysts;
2. the megacryst/macrocryst or discrete nodule suite (Mitchell, 1989, 1991; Skinner, 1989; Scott Smith, 1995); and
3. primary phenocrystal and groundmass mineral phases crystallizing directly from the kimberlite magma.

Distinctive, upper mantle-derived xenocrysts in Group I kimberlites include Mg-rich Cr-pyrope garnets, olivine, Cr-diopside, Cr-rich chromites and diamond (Mitchell, 1989, 1991; Skinner, 1989; Gurney and Moore, 1993). Megacrysts are large (1 to 20 cm), single crystals of titanium (Ti)-rich, Cr-poor pyrope garnets, Mg-rich (picro) ilmenite, subcalcic to calcic Cr-poor diopside, olivine, Ti-poor chromite, enstatite, phlogopite and zircon. Macrocrysts are smaller crystals that are rounded to subrounded and compositionally similar to the megacryst mineral suite, but with abundant olivine. These minerals that form the megacryst/macrocryst mineral suite are chemically distinct and represent either xenocrysts or cognate (initial mantle melt) phenocrysts, or a combination of both. They are believed to form in the upper mantle, and are highly diagnostic of kimberlite magmatism as their occurrence in even closely related volcanic rocks such as olivine lamproite is rare. Primary kimberlite phenocryst and groundmass minerals include olivine, phlogopite, perovskite, spinel, monticellite, apatite, calcite and primary serpentine.

Group I kimberlites are most typically characterized by the presence of abundant olivine, the characteristic megacryst/macrocryst suite and minor phlogopite. In comparison to other ultramafic rocks, kimberlites are characterized by being potassic ($K_2O > Na_2O$), with high concentrations of CO_2 (mostly in form of carbonate at surface) and are often heavily enriched in potassium (K), Ti, Mg, nickel (Ni), Cr, barium (Ba), niobium (Nb) and other incompatible elements. Because kimberlites represent a small partial mantle melt, they are often enriched more than 10 to greater than 100 times in incompatible elements versus normal ultramafic rocks, including most of the rare earth elements (REEs) as well as lithium (Li), fluorine (F), phosphorous (P), rubidium, (Rb), strontium (Sr), zirconium, (Zr), tin (Sn), tantalum (Ta), thallium (Tl), hafnium (Hf), cesium (Cs), lead (Pb) and uranium (U).

Group II kimberlites (sometimes referred to as micaceous kimberlites or orangeites) are comprised principally of rounded olivine macrocrysts in a matrix of abundant phlogopite and diopside, with accessory spinel, perovskite and calcite (Mitchell, 1989, 1991; Skinner, 1989; Scott Smith, 1995). Group II kimberlites lack the megacryst suite and minerals, such as monticellite and ulvöspinel. In addition, spinels and perovskite are relatively rare. To date, Group II kimberlites have been found only in southern Africa; however, phlogopite-rich dykes in the Torngat region of Quebec and along the west coast of Greenland bear some similarities to the southern African micaceous kimberlites.

There are three textural-genetic groups or facies of kimberlite recognized worldwide (Figure 2a):

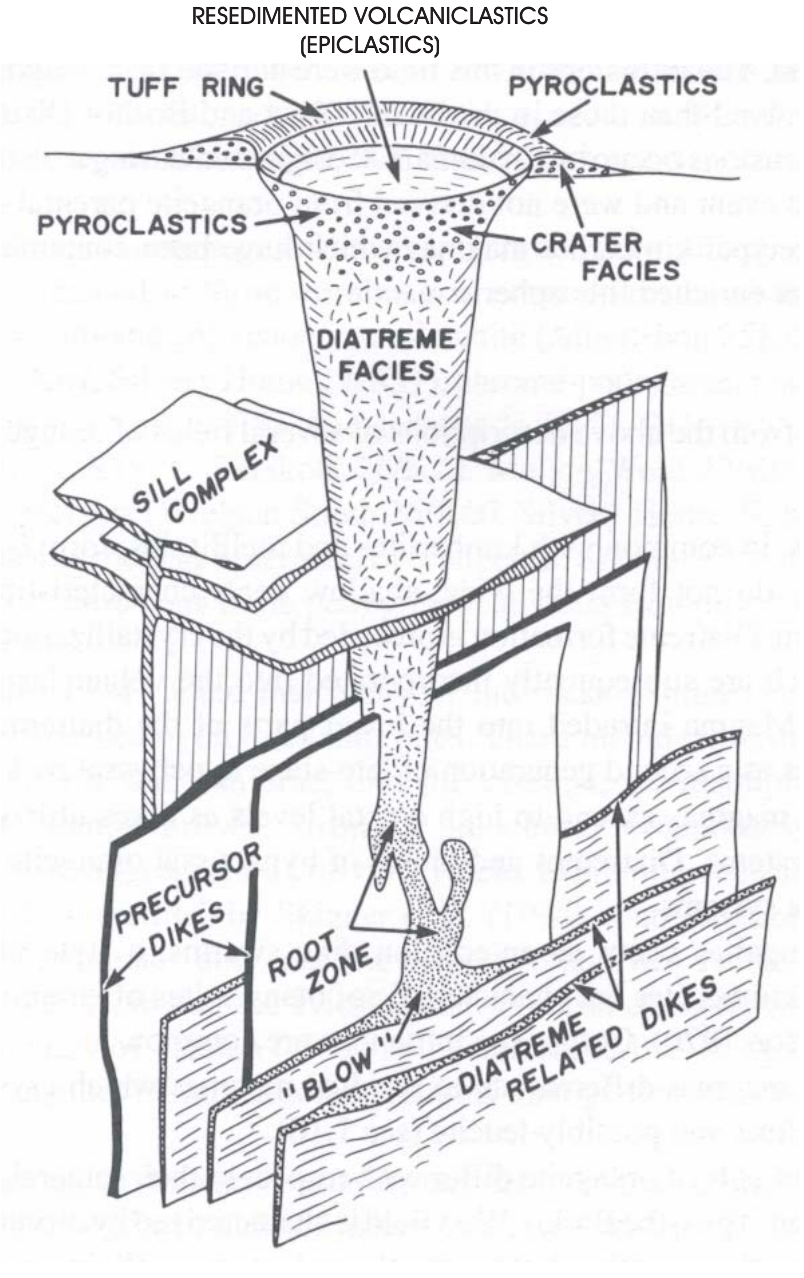
1. crater facies;
2. diatreme facies; and
3. hypabyssal facies (Mitchell, 1986, 1989, 1991).

The traditional South African kimberlite model features a pipe-like feature composed of an upright, ‘carrot-shaped’ body comprising mostly diatreme zone tuffsitic kimberlite breccia with minor volcaniclastic kimberlite breccia in the upper reaches of the diatreme (Figure 2a; Mitchell, 1986, 1989, 1991). The diatreme zone is capped or overlain by the crater zone, which includes epiclastic to volcaniclastic deposits and tuffs that form a low ring around the kimberlite vent (Figure 2a). The diatreme zone is underlain by the root zone, which is composed of hypabyssal kimberlite (Mitchell, 1991). The diatreme zone tends to grade downward into irregularly shaped root zones of hypabyssal or magmatic facies kimberlite (Figure 2a). The Lac de Gras kimberlites yield a model similar to, but with a few slight differences, to the traditional South African kimberlite model. Most of the Lac de Gras kimberlites that have been drilled intensively seem to yield a more conical shape versus the traditional carrot shape of their South African counterparts (Figure 2b; Armstrong, 2000). As well, many of the Lac de Gras kimberlites yield epiclastic kimberlite material well down into the diatreme zone of the kimberlites (Figure 2b; Armstrong, 2000). Most of the world’s diamond deposits tend to be hosted in the diatreme facies of the kimberlite. However, crater facies rocks and hypabyssal facies rocks can be significant sources of diamonds (Helmstaedt, 1992, 1993). Diamond grades can be highly variable in the crater and diatreme facies of the kimberlite.

Lamproites are petrographically complex, hybrid rocks consisting of complex mixtures of magmatic phenocrysts with upper mantle xenoliths and xenocrysts (Helmstaedt, 1993). Lamproites are referred to as ultrapotassic, peralkaline mafic to ultramafic rocks exhibiting a characteristic exotic mineralogy and distinctive geochemical signature (Scott Smith and Skinner, 1984a, b; Jaques et al., 1984; Bergman, 1987; Mitchell, 1989, 1991; Mitchell and Bergman, 1991; Scott Smith, 1992). Lamproites display a wide range of modal mineralogies making classification based on mineralogy both difficult and problematic. A revised terminology for the lamproite clan of rocks is given in Mitchell (1989). Mineralogically similar to kimberlites, olivine lamproites are distinguished from kimberlites by the presence of minerals such as leucite, amphibole (K-Ti richterite), sanidine, priderite, wadeite, armalcolite and jeppeite (Bergman, 1987; Mitchell, 1989, 1991; Scott Smith, 1992). Lamproites also differ from kimberlites by having matrix glass and a relatively low CO_2/calcite content (Mitchell, 1991). Geochemically, lamproites are classified as ultrapotassic ($K_2O/Na_2O > 3$) and typically contain 6 to 8 weight per cent (wt. %) K_2O in comparison to 2 wt. % or less for Group I kimberlites. They are peralkaline ($K_2O+Na_2O > Al_2O_3$), and they are enriched relative to kimberlites in incompatible elements such as Ba, Rb, Sr, Zr, F and light REEs, and are depleted in cobalt (Co), Cr and Ni.

Lamproites occur primarily as extrusive, subvolcanic and hypabyssal rocks, rarely forming diatremes and root zones analogous to kimberlites (Scott Smith and Skinner, 1984b; Mitchell, 1989, 1991; Mitchell and Bergman, 1991). Their vents are shallow and wide, and commonly are fluted like a champagne glass (Figure 2c). Composite craters with associated bedded volcaniclastic deposits and volcanic debris are common where the craters are preserved. The crater facies are commonly intruded by magmatic lamproite (Scott Smith and Skinner, 1984b). The crater morphology of a lamproite likely reflects the lack of volatiles and CO_2 in the erupting lamproitic magmas in comparison to the volatile and CO_2-rich kimberlitic magmas. The well studied Ellendale lamproite field in Northwestern Australia (Jacques et al., 1986) is a classic example of this type of volcanic model (Figure 2c). Most of the 72-plus kimberlites in the Fort a la Corne kimberlite field of central Saskatchewan bear a strong morphological resemblance to the Ellendale and Argyle lamproites, and therefore, a proposed model of formation for the Fort a la Corne volcaniclastic to pyroclastic dominated kimberlites could be similar to the lamproite model (Figure 2c;

Figure 2a. Traditional Kimberlite Model Terminology For Pipe Zone And Facies (After Mitchell, 1986; Field and Scott-Smith, 1998)



Pipe Zone		**Textural Interpretation**		**Facies**
CZ Crater Zone	+ VK	Volcaniclastic Kimberlite	=	Crater-facies
	+ PK	Pyroclastic Kimberlite	=	Crater-facies
	+ RVK	Epiclastic Kimberlite	=	Crater-facies
DZ Diatreme Zone	+ TK	Tuffsitic Kimberlite Breccia	=	Diatreme-facies
RZ Root Zone	+ HK	Hypabyssal Kimberlite	=	Hypabyssal-facies

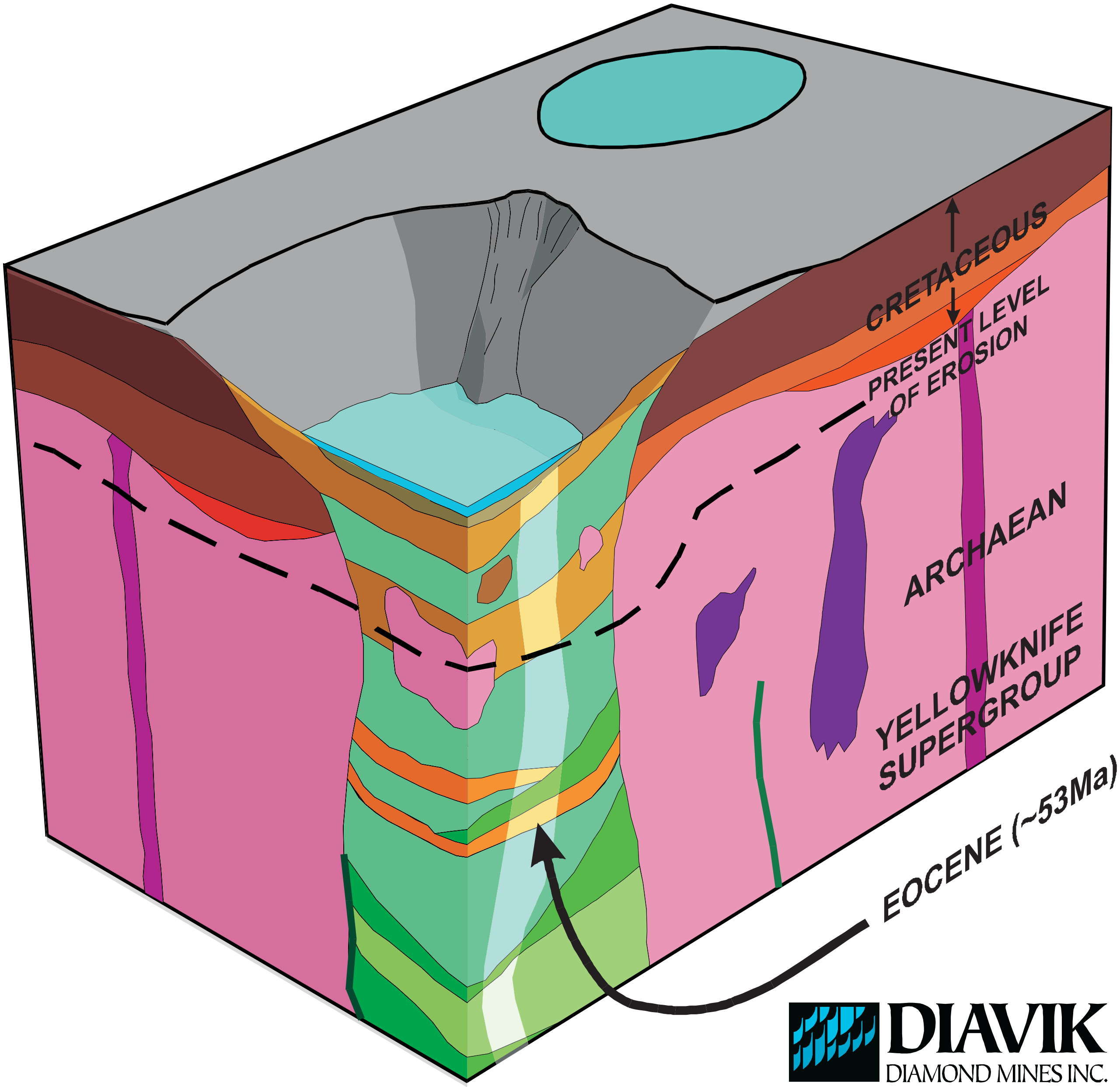


Figure 2b. Northwest Territories Pyroclastic Kimberlite Model After Diavik Kimberlites (Armstrong, 2000)

-Distinctive characteristics include cylindrical rather than classic Carrot shape pipe

-Crater facies Pyroclastic to Volcaniclastic kimberlite material Present to great depths within what appears to be the Diatreme Zone

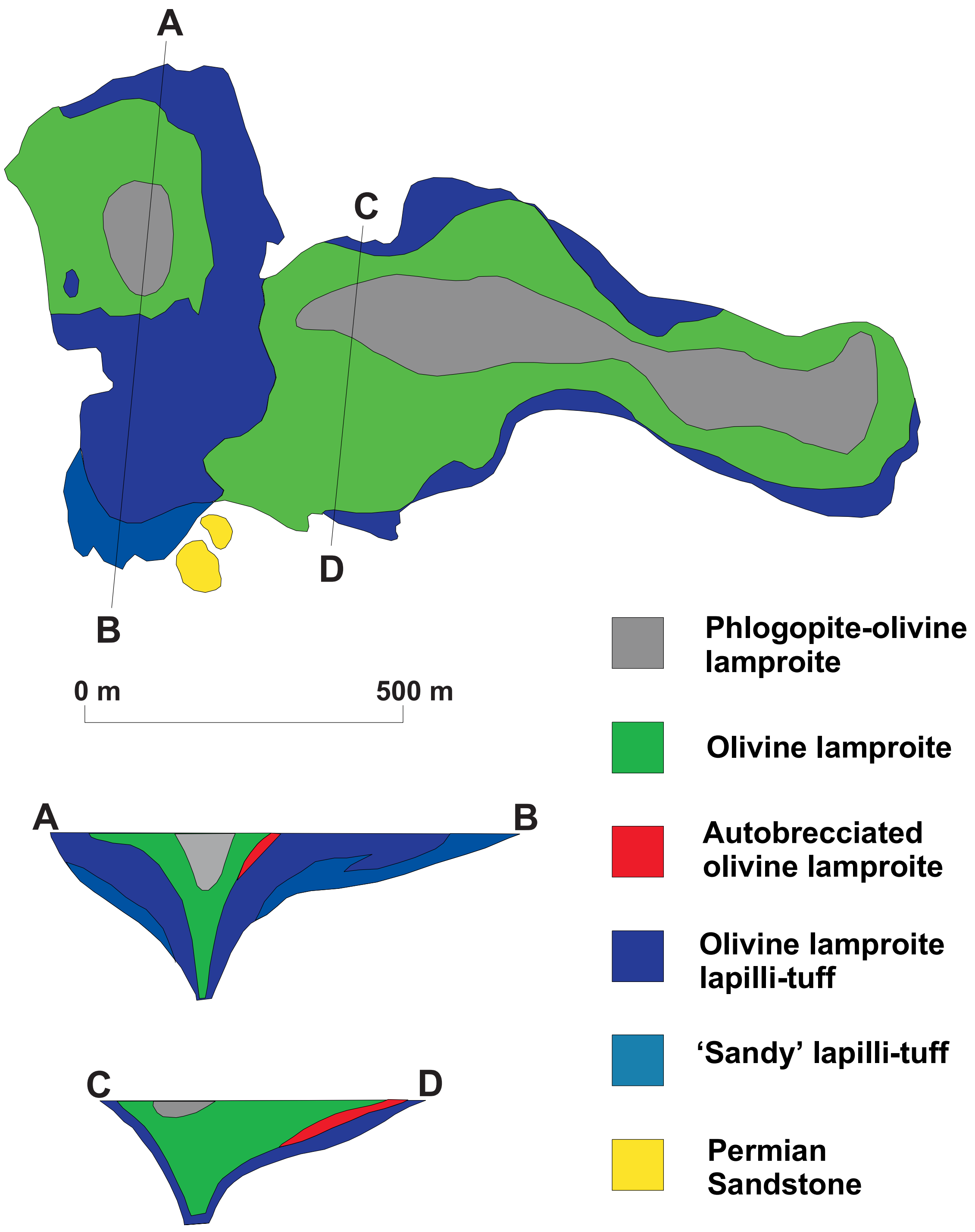


Figure 2c. Fort a la Corne Pyroclastic Kimberlite Model After The Ellendale Lamproites (modified after Jaques *et al.*, 1986)

- Distinctive characteristics include champagne glass shape with small or non-existent feeder diatreme
- Crater and diatreme zones yield mostly pyroclastic to volcaniclastic kimberlite with little or no diatreme or hypabyssal facies kimberlite
- Canadian example would be Fort a la Corne Kimberlites

Jaques et al., 1986). Diamonds tend to occur mainly in the pyroclastic crater facies rocks of these types of volcanic deposits (Scott Smith, 1995). The diamond tonnage potential of lamproites tends to be related to the volume of pyroclastic kimberlite preserved (Helmstaedt, 1992, 1993). This might also be the case for the diamondiferous Fort a la Corne kimberlites.

It is generally accepted that diamonds form at pressures equivalent to 150 to 300 km below the Earth's surface in the upper mantle, and at temperatures less than 1200 degrees Celsius (°C). These conditions occur within cool lithospheric roots, generally found below long stable Precambrian cratons, where the downward deflection of isotherms below the craton causes a corresponding upward expansion of the diamond stability field in the upper mantle (Boyd and Gurney, 1986; Haggerty, 1986; Mitchell, 1986, 1991). Macro-diamonds in kimberlite and lamproite hostrocks are derived from the disaggregation of source rocks in the lithospheric upper mantle (Boyd and Gurney, 1984; Richardson et al., 1984; Haggerty, 1986; Mitchell, 1986, 1991; Kirkley et al., 1991, 1992; Gurney and Moore, 1993). Kimberlite and lamproite magmas, which originate in the upper mantle or deeper, then provide the transport medium to move diamonds formed in the upper mantle to the surface.

Four major factors influence whether a kimberlite or lamproite may contain an economic diamond deposit:

1. the source kimberlite or lamproite magma must originate in or below the diamond stability field;
2. the ascending kimberlite or lamproite magma must sample mantle material from the diamond-bearing source region(s);
3. the host magma must ascend quickly and adiabatically for diamonds to survive the transport to the Earth's surface; and
4. there must be deep-seated structural conduits or emplacement sites that will allow the ascent of the kimberlite or lamproite magma to reach to the surface and conducive to the formation of large pipes (Helmstaedt, 1993).

Kimberlites and lamproites occur within both Archean cratons and Proterozoic mobile belts, but ‘Clifford’s Rule', which is based on empirical observation (Clifford, 1966, 1970; Janse, 1991), states that economically viable diamond deposits are confined to stable Archean cratons. However, an exception to Clifford's Rule is the Argyle deposit in Western Australia, which is hosted in a lamproite that intrudes a Proterozoic fold belt and contains mostly E-type diamonds of Proterozoic age (Jaques et al., 1986). The Argyle example illustrates that large accumulations of post-Archean, E-type diamonds can occur outside of, but adjacent to, Archean cratons (Helmstaedt, 1993).

5 An Overview of Kimberlite-Derived Upper Mantle Xenocrysts and Magmatic Phenocrysts with Examples from Some Alberta Kimberlitic Rocks

Kimberlites and closely related rocks such as olivine lamproites contain a wide variety of minerals that are derived from the disaggregation of ultramafic upper mantle including olivine-rich peridotites such as harzburgite, lherzolite, dunite and wehrlite, and the pyroxene-rich pyroxenites including olivine websterite and websterite. Disaggregation of less abundant mafic upper mantle in the form of eclogite may also yield xenocrysts in kimberlites, olivine lamproites and other closely related rocks.

Upper mantle-related populations of xenocrysts found in kimberlites and associated rock types are sourced mainly from:

1. peridotite xenoliths,
2. eclogite xenoliths,

3. megacrysts and macrocrysts which are a physically and chemically distinct population of minerals that for the most part are unique to kimberlite and whose origin is somewhat controversial, and
4. cognate magmatic phenocrysts derived from within the kimberlite magma.

The characteristics of indicator mineral assemblages from these four groups are summarized below, as recognition of these mineral assemblages is extremely important in regional prospecting programs because they can be indirect indicators of the presence of kimberlite and provide some information on diamond potential. Upper mantle xenocrysts can also be derived from glimmerite and MARID (mica, amphibole, rutile, ilmenite, diopside) xenoliths, but are not discussed in this report.

5.1 Peridotite Mantle

Worldwide, most diamonds in kimberlite or lamproite appear to be xenocrysts derived from upper mantle sources dominated by olivine-rich peridotite, typically harzburgite with subordinate contributions from Cr-pyrope-bearing lherzolite. Harzburgite of high diamond potential often contains small quantities of either subcalcic Cr-pyrope and/or high-Cr, Ti-poor, Mg-chromite. Hence, any evidence of the presence of harzburgitic mantle that can be gained during regional sampling programs is considered important.

Garnet lherzolite xenoliths are by the far the most common mantle derived xenoliths found within kimberlites worldwide, suggesting it is the most common composition of the upper mantle. Lherzolite is comprised of relatively equal amounts of olivine, orthopyroxene, clinopyroxene (Cr-diopside), Cr-pyrope garnet and/or Mg-chromite and is the main source of peridotitic Cr-pyrope garnet xenocrysts in kimberlites. The fundamental difference between lherzolitic and harzburgitic mantle is the greater concentration of Ca in lherzolitic mantle, which gives rise to more abundant clinopyroxene (Cr-diopside) and Cr-Ca–enriched pyrope garnets in lherzolite. Although it is the most common source of upper mantle xenoliths and xenocrysts, lherzolite is thought to rarely yield diamonds based upon inclusions found in diamonds.

Diamonds derived from eclogite appear to be much less common, but locally, appear to be dominant in kimberlites of great economic significance (e.g., Premier, Orapa, Letlhakane, Bellsbank and Monastery in South Africa, Argyle in Australia, Sloan in Colorado, and several of the Lac de Gras pipes).

5.1.1 Pyrope Garnet

Pyrope garnets are perhaps the most sought after indicator mineral in diamond exploration as their recovery in regional sampling programs are a strong indication of the presence of intrusions, such as kimberlite or lamproite, which have tapped the upper mantle. Cr-pyrope garnets occur as xenocrysts almost exclusively in kimberlite or lamproite and are very rarely found in any crustal rocks or in other closely related alkaline intrusions somewhat similar to kimberlites or lamproites, such as minettes, alnöites, ultramafic lamprophyres, etc. Fipke et al. (1995) conducted extensive indicator mineral sampling of more than 18 alkaline intrusions, including kimberlite, lamproite, possible lamproite and other alkaline intrusions such as alnöite and ultramafic lamprophyre. Pyropes were recovered extensively from most of the kimberlites (an average of 211 pyropes per kimberlite normalized to 50 kg). Most of the lamproites yielded a few pyropes (about 14 pyropes per lamproite normalized to 50 kg). All but one of the possible lamproites and other types of alkaline intrusions yielded no G9, G10, G11 or G12 Cr-pyrope garnets. The work of Fipke et al. (1995) demonstrates that even though pyrope garnets are not a phenocrystic mineral in kimberlite, their recovery in regional exploration programs is an indirect indication of the presence of kimberlite and, to a lesser degree, lamproite. Mantle derived pyrope garnets are resistant to resorption in a hot, ascending kimberlite magma, as well as resistant to weathering in the surficial environment. They are relatively easy to recover and concentrate with advanced laboratory processes and are easily identified by KIM pickers. There are few other sources for the distinctive mauve to lilac-purple, Cr-rich, mantle-derived pyrope garnets that are commonly found in kimberlite. Pyrope garnets are sensitive to subtle chemical variations of the upper mantle and record compositional differences between harzburgite, lherzolite and eclogite. Therefore, their discovery in any surface sampling program is a clear indication that the mantle has been sampled likely by kimberlite, lamproite or a closely related intrusion, and that the intrusion has been exposed and at least partially eroded sometime during its history.

Two common classification schemes for pyrope garnets, devised by Dawson and Stephens (1975, 1976) and Gurney (1984), are commonly used in an attempt to deal with the subtle chemical differences between different varieties of pyrope garnets recovered from kimberlites and in regional sampling programs. It is important to understand both classification schemes because both are important tools in identifying the provenance of certain varieties of pyrope garnet. In addition, Gurney's (1984) classification scheme can aid in determining the diamond potential of a particular kimberlite or a region where abundant pyrope garnets have been found during regional sampling programs but where the bulk of the kimberlites are yet to be found.

Dawson and Stephens (1975, 1976) first came out with a classification scheme for garnets in kimberlites that would chemically define coherent garnet groups with limiting chemical parameters and to determine which garnet xenocrysts found in kimberlites were likely derived from which varieties of mantle xenoliths (garnet peridotites, garnet websterites, garnet wehrlites, garnet eclogites, etc.). A total of 352 garnets from 56 kimberlite pipes, mostly South African, were used for the cluster analysis. Dawson and Stephens (1975, 1976) used the cluster analysis to identify 12 chemically distinct garnet groupings using five common oxides, CaO, MgO, FeO, Cr_2O_3 and TiO_2, which they subsequently named Groups 1 to 12 or G1 to G12. All five oxides are used in their classification scheme as variations are seen in all of these oxides, and therefore, it is deemed more appropriate to make chemical distinctions using all oxides as opposed to only two. It is important to note that garnets yield a complete solid solution series for all five of these major elements; hence, there is a certain amount of overlap between groups as there are not distinct chemical boundaries between groups. The mineral identification programs designed by Quirt (1992a, b) are based upon the algorithms of Dawson and Stephens (1975, 1976) classification scheme. The true pyrope garnets (with greater than 18 wt. % to 20 wt. % MgO) are restricted to the groups of G1, G2, G9, G10, G11 and G12. The 12 groups can be further subdivided on the basis of Ti and Cr into megacrystic garnets with high Ti and low Cr (Groups G1 and G2 ± G11), and peridotitic garnets with variable Ti but high Cr (Groups G9, G10, G12 ± G11). Groups G3, G4, G5 and G6 are essentially non-pyropic (<18 wt. % MgO) or iron-rich pyrope garnets with moderate concentrations of Fe, Mg and Ca. The bulk of these garnets is likely derived from crustal contamination from rocks such as granulite or, more importantly and certainly more rarely, derived from high-pressure mantle eclogite, which most commonly represents subducted oceanic basaltic crust. Groups G7 and G8 are essentially high Ca, moderate Fe-Ti grossular garnets that are likely sourced from crustal rocks, such as subducted and decarbonated limestone. It is important to note that the recovery of G1, G2, G9, G10, G11 or G12 pyrope garnets in regional sampling programs is strong indirect evidence of the existence of kimberlites or closely related rocks such as lamproites that have tapped the upper mantle. The presence of G3, G4, G5, G6, G7 or G8 garnets alone in regional sampling programs without other indications of kimberlites, such as pyrope garnet, Cr-diopside, Mg-chromite or picroilmenite, is not definitive evidence for the presence of kimberlites.

Gurney (1984) used Groups 9 to 12 (the peridotitic Cr-pyrope garnets) defined by Dawson and Stephens (1975, 1976) to make a distinction between the Finsch kimberlite garnets that were likely associated with diamonds with those that were not. Gurney (1984) observed that 85% of pyrope garnet inclusions in diamonds (commonly referred to as diamond inclusions) have similar low concentrations of CaO to the subcalcic pyrope garnets derived from harzburgitic mantle. Gurney (1984) concluded that the vast majority of diamonds found in kimberlites are likely derived from subcalcic harzburgitic mantle. Hence, Gurney (1984) devised a statistically based empirical line (commonly known as the Gurney 85% line) drawn on a scatter plot of CaO vs. Cr_2O_3 that effectively separated Cr-pyrope garnets derived from subcalcic harzburgite mantle versus Cr-pyrope garnets derived from the more common calcic lherzolite mantle. Gurney (1984) suggested the subcalcic pyrope garnets derived from harzburgite most closely approximated the group defined by Dawson and Stephens (1975, 1976) as G10, and that the calcic Cr-pyrope garnets derived from the lherzolite trend most closely approximated the group defined as G9. Extensive work conducted by Schulze (1995) demonstrates that Gurney's 85% line likely corresponds well with the lower CaO limit of pyrope garnets in equilibrium with lherzolitic mantle. The subtle chemical differences separating megacrystic and G9 to G12 pyrope garnets with different types of mantle was also recognized by Sobolev (1974), leading to the extensive use of the "Sobolev plot" with CaO and Cr_2O_3 on reversed axes and fields drawn for the approximate compositions expected for garnets derived from harzburgite, lherzolite and wehrlite. The use of Gurney's 85% line and the Sobolev plot (Sobolev, 1974) are demonstrated in Appendix 1, which shows that abundant pyrope garnets recovered to date from the Mountain Lake, K4, Legend and Kendu pipes of Northern Alberta (NAB) are likely derived from Ca-enriched clinopyroxene-bearing lherzolitic mantle.

Gurney (1984) indicated that subcalcic G10 Cr-pyrope garnets likely derived from harzburgite were present in most South African kimberlite pipes with diamonds. In fact, Gurney suggested it could be demonstrated that kimberlite pipes with large populations of diamonds also yielded either the largest populations of subcalcic harzburgitic G10 pyrope garnets or diamonds with large numbers of G10 pyrope garnet inclusions. It is for this reason G10 subcalcic Cr-pyropes, as defined by Gurney (1984), are commonly sought in diamond exploration programs as they are a clear indication of high diamond potential. The Gurney classification scheme can aid in determining the diamond potential of a particular kimberlite or a region where abundant pyrope garnets have been found during regional sampling programs, but where the bulk of the kimberlites are yet to be found. The discovery of the highly diamondiferous Lac de Gras pipes by Charles Fipke and Stewart Blusson is perhaps the most famous implementation of Gurney's classification scheme. The discovery of the highly diamondiferous Lac de Gras kimberlite field was due to Fipke's recognition of the importance of Gurney subcalcic G10 Cr-pyrope garnets found in regional sampling programs and his perseverance in tracing them to their source kimberlites (Fipke et al., 1995).

Fipke et al. (1995) indicate it is not only the number of subcalcic G10 garnets that is important but also the degree of Ca depletion of the pyrope garnets, inferring that the more depleted the harzburgitic mantle (indicated by the degree of Ca depletion in the garnets), the higher the diamond potential. It is for this reason Gurney's G10 subcalcic Cr-pyropes are commonly sought in diamond exploration programs, as they are a clear indication of high diamond potential. However, it should be noted that some kimberlites, like the world famous Premier and Orapa pipes, as well as the Argyle Lamproite, contain very few pyrope garnets and very few, if any, subcalcic G10 pyrope garnets, yet they are rich in diamonds.

Another more recently defined method, the Ni-garnet thermometer (Griffin et al., 1989), is employed to assess the diamond potential indicated by suites of garnets recovered from kimberlites or regional exploration programs. Griffin et al. (1989) demonstrated that the partitioning of Ni between olivine and garnet in equilibrium and under mantle pressure conditions is temperature dependent. Griffin et al. (1989) and Griffin and Ryan (1993) suggest that for a normal cratonic geothermal gradient (corresponding to a surface heat flow of about 40 mW/m^2), the temperature of the diamond stability window is from about 950^oC to about 1250^oC. As an example of the applicability of the Ni-garnet thermometer, Griffin et al. (1994b) demonstrated that few pyrope garnets from barren Tanzanian kimberlites yield diamond stability window temperatures, whereas many pyrope garnets from diamondiferous Tanzanian kimberlites yield diamond stability window temperatures. This method can be used not only on the subcalcic G10 pyrope garnets, but also on the much more abundant G9 lherzolitic garnets. However, the usefulness of this technique requires a very high precision of measuring low concentrations of Ni (5 ppm to 130 ppm) in garnet using a sophisticated proton microprobe (Kjarsgaard, 1992). The use of the Ni-garnet thermometer requires converting a temperature estimate into a depth estimate. This is accomplished by obtaining either an independent pressure estimate (using other mineralogical barometers) or by estimating the pressure from the intersection of the temperature obtained from a specific garnet with an assumed geothermal gradient (Kjarsgaard, 1992). One of the limitations of the method is it requires making an assumption for the cratonic geotherm, which can vary from region to region. Incorrect assumptions for the geothermal gradient in any particular area will lead to errors in depth estimates. In addition, a further problem with the Ni-garnet thermometer lies in the empirical calibration of the method, as discussed in detail by Kjarsgaard (1992) and Canil (1994). In the absence of Ni measurements for pyrope garnets, Grütter et al. (1999) indicate that the concentration on Mn can be used as a gross approximation of the temperature of formation for pyrope garnets.

Grütter et al. (1999) and Grütter (2002) have recently shown that the Central Slave Region yields three very distinct populations of G10 pyrope garnets, which they termed Groups G10-1, G10-2 and G10-3, ranging from the lowest concentration of Cr to the population with the highest concentrations of Cr. Grütter et al. (1999) and Grütter (2002) suggest that the low Cr population G10-1 pyropes are related to a shallow zone (at a depth ranging from 100 to 150 km) of Ca depleted mantle that likely exists within the graphite stability zone. Grütter et al. (1999) and Grütter (2002) indicate that less than half of the population of the abundant G10-1 pyrope garnets are derived from within the diamond stability field (probably those existing at the base of the Ca-depleted zone) and, based upon trace element and Ni thermometric data, that the less abundant G10-2 and G10-3 pyrope garnets, as well as a large population of lherzolitic G9 garnets, are likely derived from deeper depths and temperatures consistent with the diamond stability field. They demonstrate the usefulness of capturing trace element and thermometric data for both G9 and G10 pyrope garnets and that not all G10 garnets are associated with the diamond stability field, even in regions where the geothermal gradient is thought to be favourable. In addition, Grütter et al. (1999) and Grütter (2002) demonstrate that in some cases G9 pyrope garnets may be associated with diamonds.

Many exploration programs are continued or terminated based on the success ratio in finding subcalcic G10 pyrope garnets, even prior to the discovery of any of the kimberlite pipes. However, only one or a few pipes in any cluster of pipes may yield a significant number of G10 pyrope garnets. In a field of 50 kimberlite pipes, if only 3 or 4 of the pipes yield G10 pyrope garnets with the rest of the pipes yielding variable amounts of lherzolitic G9 pyrope garnets, the regional signature of the subcalcic G10 pyrope garnets will likely be significantly diluted and therefore very weak. It also should be noted that several of the producing South African kimberlites yield no G10 pyrope garnets; rather the evidence for a harzburgitic source for the diamonds is because the most common inclusions in the diamonds are G10 pyrope garnets. This reinforces the premise that it is important to find all the kimberlites in a cluster and use not only the mineral chemistry of the pyropes, but also all the other minerals as well as the presence or absence of microdiamonds in order to evaluate a pipe or a cluster of pipes.

It is well documented that there are a few kimberlites with a mostly lherzolitic Cr-pyrope and Cr-diopside signature that yield significant amounts of diamonds. However, there has been no distinctive chemistry identified in the Cr-pyrope garnets or Cr-diopsides that can be used to effectively discriminate between the same lherzolitic minerals that exist in a multitude of barren kimberlites dominated by a lherzolitic signature versus those that are diamondiferous (Fipke et al., 1995; Schulze, 1995). As a result, it is next to impossible to predict any kind of diamond potential either regionally or, for an individual kimberlite, on the basis of the lherzolitic mineral assemblage.

5.1.2 Clinopyroxene

Cr-diopside is probably the next most diagnostic mineral of upper mantle parentage, but is somewhat poorly understood and can be confused with Cr-diopside derived from a variety of other rocks types. Cr-diopsides found in kimberlites are generally the product of disaggregation of Ca-enriched peridotite mantle, including most commonly lherzolite and, to a lesser degree, wehrlite and websterite. Crustal greenstone or non-kimberlite–derived Cr-diopside can be very difficult to tell apart from mantle-derived Cr-diopside without multiple indicator plots utilizing chemistry. Mantle-derived Cr-diopside tends to be bright emerald green and contains high concentrations of Cr_2O_3 (>1 wt. %) and low concentrations of FeO (<4 wt. %), as illustrated in Appendices 1 and 4. A ternary displaying FeO-Cr_2O_3-Na_2O can be used as an aid to distinguish mantle-derived Cr-diopsides from Cr-diopsides derived from other crustal sources, such as alkali basalts, etc. Ramsay and Tompkins (1994) use a plot of Al_2O_3 vs. Cr_2O_3 to aid in distinguishing Cr-diopside derived from garnet or spinel peridotite versus Cr-diopside derived from other sources. Other types of alkaline intrusions, such as alkali basalts, lamprophyres, minettes, alnöites, etc., can yield Cr-diopsides with up to about 1.4 wt. % Cr_2O_3 or higher, although these high Cr_2O_3 concentrations are rare in diopsides from other types of intrusions. In general, Cr-diopsides with greater than 1.4 wt. % Cr_2O_3 derived from any rock types other than kimberlites is extremely rare; however, Cr-diopsides derived from Cordilleran alkali basalts have been found with concentrations of Cr_2O_3 of up to 2 wt. % in regions underlain by juvenile crust and mantle (Ryder and Hourican, 1997).

The most common scatter plot in use for Cr-diopside is that of CaO vs. Cr_2O_3 with a field described as the 'diamond inclusion field' derived from the chemistry of a number of Cr-diopsides found as inclusions in diamonds. This scatter plot is highly misused, as Cr-diopsides are not suitable for determination of derivation from the diamond stability field using basic chemical x-y scatter plots unless thermometric and barometric calculations are conducted on the grains using the methodols of Nimis and Taylor (2000) and Nimis (2002). In addition, there is a tremendous amount of overlap in the Ca-Cr chemistry between Cr-diopsides derived from peridotitic mantle and found in kimberlites, and Cr-diopsides found in non-kimberlitic ultramafic rocks, such as layered intrusions and basalts as well as non-kimberlitic alkaline intrusions. There is such a large field of overlap between 1 wt. % and 2 wt. % Cr_2O_3, that the recovery of Cr-diopsides alone in exploration programs is not likely a clear indication of the presence of kimberlite. However, there are other plots that can aid exploration.

Mantle peridotite-derived Cr-diopsides tend to be low in FeO (<4 wt. %), low Al_2O_3 (<3 wt. %), high in Cr_2O_3 (>1 wt. %) and high in Na_2O (>1 wt. %), as demonstrated in Appendices 1 and 4. As an example, a ternary plot of FeO, Cr_2O_3 and Na_2O for low-Cr to high-Cr diopsides from Lac de Gras does an excellent job of separating those diopsides that are likely mantle-derived versus those derived from other sources (Appendix 4). The Lac de Gras population of Cr-diopsides (Dredge et al., 1995; Kerr et al., 1995; Ward et al., 1995) shows two very distinct trends: one that can be defined as a mantle trend and another that is likely a crustal-related trend (Appendix 4). A ternary plot of the Geological Survey of Canada (GSC) kimberlite and lamproite database (Fipke et al., 1989) versus the fields defined by the Lac de Gras data (Dredge et al., 1995; Kerr et al., 1995; Ward et al., 1995) demonstrates that the vast majority of the Cr-diopsides recovered from kimberlites and lamproites yield similar compositions to the Lac de Gras mantle population (Appendix 4). A demonstration of the usefulness of this ternary plot is shown in Appendix 4. Sampling for KIMs (more than 2000 samples) in the eastern Keewatin, Nunavut, by the GSC, resulted in the recovery of a number of Cr-diopsides with between 1 wt. % and 1.4 wt. % Cr_2O_3, but few Cr-pyrope garnets (Dilabio and Knight, 1998). On the basis of the widely used scatter plots of CaO vs. Cr_2O_3 and Na_2O vs. Cr_2O_3, the Keewatin Cr-diopsides overlap the field of Cr-diopsides derived from kimberlites and the field of Cr-diopsides found as inclusions in diamonds (Appendix 4). In addition, based upon the Ramsay and Tompkins (1994) Al_2O_3 vs. Cr_2O_3 discrimination plot, it could be concluded that the Keewatin Cr-diopsides could be derived from favourable 'on-craton' peridotite. Hence, it could be wrongly concluded that these Cr-diopsides were not only likely derived from kimberlites, but that they were also formed within the diamond stability field in the upper mantle. Based upon a ternary plot of FeO, Cr_2O_3 and Na_2O (Appendix 4), it is highly likely that the majority of the Keewatin Cr-diopsides recovered in this GSC sampling program are not derived from mantle peridotite and kimberlite, but from some other upper mantle or crustal-derived ultramafic source rock that was likely pyrope-free, such as alkaline basalts, komatiites or layered peridotitic intrusions; a conclusion supported by the recovery of few pyrope garnets in the samples yielding clinopyroxene. A corollary to this conclusion is it is unlikely there are any kimberlites present in the region sampled; however, this kind of conclusion must be tempered based upon sample density for the region. For explorationists, this difference in the populations is also noticeable on a straight scatter plot of FeO vs. Cr_2O_3 (Appendix 4). Although the scatter plot of FeO vs. Cr_2O_3 is not as good at separating the populations, it certainly can be used as a first pass test to separate mantle peridotite-associated Cr-diopsides that are potentially derived from kimberlite versus Cr-diopsides derived from other source rocks with little diamond potential.

5.1.3 Chromite

High-Cr, low-Ti Mg-chromites can be quite indicative of derivation from peridotite mantle and, in some cases, from potentially diamondiferous chromite harzburgite. However, in any region where mafic to ultramafic greenstones, such as dunites or komatiites, are present or regions yielding layered peridotite complexes, one must be very careful in the interpretation of chromite data alone. Mantle-derived chromites tend to be characterized by 40 wt. % to 70 wt. % Cr_2O_3 and 10 wt. % to 16 wt. % MgO with very low concentrations of TiO_2 and relatively low concentrations of FeO, Al_2O_3, ZnO and NiO. On occasion, however, these types of chromites are known to be abundant in other alkaline intrusions, such as alnöites, minettes, ultramafic lamprophyres, etc. Discriminants such as Zr-Nb and Ni-Zn can be used to help discriminate between high pressure mantle-derived chromites from those that are not. Low concentrations of Zn are considered indicative of high pressure, mantle-derived chromites as Zn is thought to easily increase in concentration with decrease in temperature in the chromite structure (Griffin et al., 1992, 1994a; Griffin and Ryan, 1993, 1995). Griffin et al. (1992, 1994a) and Griffin and Ryan (1993, 1995) show that Zn in chromite shows a strong negative correlation with temperature. Griffin et al. (1992, 1994a) and Griffin and Ryan (1993, 1995) indicate that partitioning of Zn in chromite in equilibrium with olivine in peridotite is temperature dependent; hence, similar to the Ni-garnet thermometer, a Zn-chromite thermometer can be constructed. Chromite-Zn compositions in conjunction with an assumed regional geothermal gradient can yield information as to whether the chromites were formed within the diamond stability window. Griffin et al. (1992, 1994a) and Griffin and Ryan (1993, 1995) suggest that diamond stability window chromites are characterized by concentrations of Zn less than 700 ppm and Ni greater than 600 ppm for a normal geothermal gradient. Much like the Ni-garnet thermometer, the Zn-chromite thermometer may be useful in diamond exploration but must be used with caution, as it assumes chromite xenocrysts were in equilibrium with garnet and olivine in peridotite. In addition, regional variations in geothermal gradients and inherent errors in the Zn-chromite thermometer can limit its effectiveness for exploration. In addition, the low concentrations of Zn and Ni that are found in diamond-inclusion chromites are close to the detection limit of these elements using standard microprobe techniques. Hence, most of the Zn and Ni analyses available for large datasets represent qualitative and not quantitative data.

Grütter and Apter (1998) indicate that high-Cr and low-Ti Mg-chromites can be formed as part of an early, high pressure, phenocrystic assemblage in a kimberlitic magma. Grütter and Apter (1998) show that often these high-pressure phenocrysts are part of a population of chromites that evolve to high concentrations of Ti with decreased Cr during evolution of the kimberlite magma, but they are distinguished by chromites that contain more Cr than is found in chromites derived from mantle peridotite xenoliths.

High Cr-Mg chromites similar to garnets are also used to provide an indication of the amount of diamonds that could be potentially derived from the disaggregation of chromite harzburgite formed within the diamond stability field. Fipke et al. (1995) indicate that chromites associated with diamonds, and likely derived from diamondiferous chromite harzburgite, are characterized by greater than 60 wt. % Cr_2O_3, 10 wt. % to 16 wt. % MgO, very low concentrations of TiO_2 (<0.3 wt. %), and very low concentrations of Zn (<700 ppm). Fipke et al. (1995) display a constructed diamond inclusion field for chromites based upon their analyses for 98% of all chromite inclusions found to date in diamonds. The diamond inclusion field yields a range from 60 wt. % to 70 wt. % Cr_2O_3 and 10 wt. % to 16 wt. % MgO. The chromium content of xenocrystic chromite has been shown to be pressure dependent (Fipke et al., 1995).

5.1.4 Olivine

Olivine is used as an indication of mantle and kimberlite. Mantle-derived olivine yields an Mg range from Fo_{76} to Fo_{94}, but tends to be very high in Mg with Fo_{90} to Fo_{94} the norm. Mantle-derived olivine tends to yield low concentrations of CaO, Al_2O_3, TiO_2 (all <0.5 wt. %) and elevated NiO (>0.3 wt. % up to 0.6 wt. %) and Cr_2O_3 (0.02 wt. % to 0.2 wt. %). In most cases, however, mantle-derived macrocrystal olivine is chemically indistinguishable from phenocrystal olivine (Mitchell, 1989).

5.1.5 Orthopyroxene

Orthopyroxene can be occasionally used, as it can be a common constituent of kimberlite and lamproite; however, it is rarely picked and is usually not very abundant in the surface environment as it usually weathers chemically and mechanically very easily. Typically, mantle-derived orthopyroxene in kimberlite is characterized by Fo_{87} to Fo_{93}, with low concentrations of Al_2O_3 (<2 wt. %). Occasionally, orthopyroxene from peridotite mantle can yield high concentrations of Cr.

5.1.6 Other Minerals

Other minerals such as high-Cr corundum and high-Cr grossular garnet, although most likely crustal derived, do seem to have a very strong spatial link to those samples that yield KIMs for NAB. This could potentially indicate derivation of these minerals from kimberlites or lamproites, whether they are genetically derived from the disaggregation of crustal or mantle material.

5.2 Eclogite Mantle

Eclogite, as the high-pressure equivalent of basalt, is generally thought to represent subducted and metamorphosed oceanic crust and/or mantle (Gurney and Moore, 1993). A less favoured view held by some researchers is that eclogite is derived from high pressure cumulate segregation of partial melt of mantle garnet peridotite (Helmstaedt, 1992 and 1993). Eclogite that comes out of kimberlites tends to include orange, Cr-poor, Fe-Mg-Ca-rich garnets and blue-green omphacitic (Na-Al-rich) clinopyroxene. Eclogite by nature (being derived from a mixture of oceanic basalt and sediments) contains higher overall concentrations of Fe, Al and Na and lower concentrations of Mg and Cr relative to mantle peridotite because it is essentially derived from mafic oceanic crust and/or mantle with a minor contribution of clay-rich sedimentary material. Common accessory minerals in eclogite include corundum, kyanite, rutile and spinel.

Mantle eclogite xenoliths derived from kimberlites are classified into two distinct groups based upon texture and composition: Groups I and II (MacGregor and Carter, 1970; Hatton, 1977; McCandless and Gurney, 1989). This classification is primarily based upon data from South Africa and, to a lesser extent, Australia and, therefore, must be used with some caution when applying to North American kimberlites. Group I eclogite xenoliths are characterized by Na-enriched Mg-almandine garnets (eclogitic garnets) and K-enriched Al-Na clinopyroxenes (omphacite or jadeite). McCandless and Gurney (1989) indicate that Group I eclogitic xenoliths are characterized by eclogitic garnets with concentrations of greater than or equal to 0.09 wt. % Na_2O and clinopyroxenes with greater than or equal to 0.08 wt. % K_2O. For most exploration applications, a cut-off value of greater than or equal to 0.07 wt. % Na_2O is used to distinguish between eclogitic garnets derived from Group I and Group II eclogites (Gurney, 1984; Fipke et al., 1995; Schulze, 1997). Group II eclogites are characterized by eclogitic garnets and Na-Al clinopyroxenes with concentrations of Na and K below these enrichments. The vast majority of known, South African diamondiferous eclogites are classified as Group I eclogites (McCandless and Gurney, 1989; Schulze, 1997). Generally, only Group I eclogite xenoliths are known to contain diamonds. Typically, Group II eclogites are not known to contain diamonds (Schulze, 1997). However, a notable and important Canadian exception is a number of diamondiferous Group II eclogite nodules recovered from the Jericho Kimberlite, north of Lac de Gras (Cookenboo et al., 1998). Interestingly, a number of Group I eclogite nodules were also recovered from the Jericho Kimberlite; however, all nodules were found to be non-diamondiferous (Cookenboo et al., 1998). Ashton reports that eclogitic minerals have been found in most of the Buffalo Head Hills kimberlites. However, most of the eclogitic garnets recovered to date contain low concentrations of Na_2O and are therefore characterized as derived from Group II eclogite (Carlson et al., 1999). The Kendu Kimberlite from the Birch Mountains contains a number of eclogite xenoliths. Most of the eclogitic garnets recovered from the Kendu Kimberlite yield low concentrations of Na_2O and are therefore likely derived from Group II eclogitic mantle (Appendices 1 and 3).

Because eclogite is essentially basaltic in composition, high pressure metamorphosed rocks exposed at surface, such as granulite facies mafic volcanics, can yield Mg-rich almandines and Na-Al–rich omphacitic clinopyroxenes. The grains from these types of metamorphic rocks can be distinguished from true mantle eclogite-derived grains on the basis of chemical composition. Based upon the work of Fipke et al. (1995), only kimberlite or lamproite intrusions yield significant concentrations of true eclogite-derived minerals. Other non-kimberlitic but closely related intrusions rarely yield eclogite-derived minerals.

5.2.1 High Na_2O-TiO_2 Eclogitic Type I Garnets

High Na_2O-TiO_2 eclogitic Type I garnets are the most commonly used indicator of eclogitic mantle potentially derived from the diamond stability field. Danchin and Wyatt (1979) and Schulze (1997) demonstrate that eclogitic garnets derived from Group I diamond-bearing eclogites and as inclusions in diamond contain elevated concentrations of Na_2O (>0.07 wt. %) and TiO_2 (>0.1 wt. %). This eclogitic garnet population is useful for exploration to aid in prioritization of areas based upon the recovery of high quality eclogitic garnets, along with the more traditional indicator minerals such as pyrope garnet, Cr-diopside, picroilmenite and chromite. Schulze (1997) indicates that the two populations, eclogitic garnets from diamond-bearing Group I eclogite xenoliths, and eclogitic garnets contained as inclusions in diamonds from individual kimberlites, can be substantially different in chemistry even in the same kimberlite pipe, as aptly shown by the Roberts Victor Kimberlite from South Africa. The tendency is for the eclogitic garnets in Group I diamondiferous eclogite xenoliths to contain less Na_2O and TiO_2 versus those found as inclusions in diamond from the same kimberlite. Schulze (1997) indicates this is likely due to re-equilibration of eclogitic garnets in an open mantle system after formation of the diamonds. This tendency should be kept in mind during regional and/or detailed exploration programs where kimberlites have potentially shed eclogitic garnets derived from Group I eclogite mantle, particularly because common exploration practice is to compare the chemistry of eclogitic garnets recovered from surface versus the chemistry of diamond inclusion eclogitic garnets.

Once a garnet has been properly assessed as potentially derived from eclogite (on the basis of FeO-MgO-CaO-TiO_2), its potential for derivation from Group I eclogitic mantle and the diamond stability field can be assessed on a scatter plot of Na_2O versus TiO_2, as is demonstrated for eclogitic garnets derived from Alberta kimberlites (Appendix 1). Orange, Cr-poor, megacrystic, pyrope garnets often can have significant concentrations of Na_2O and TiO_2, and can overlap those garnets derived from Group I eclogite sourcing from kimberlite. As an example, the megacrystic garnets from the Legend Kimberlite are plotted along with the eclogitic garnets from the Kendu Kimberlite on scatter plots of MgO vs. FeO, CaO vs. TiO_2 and Na_2O vs. TiO_2 (Appendix 1). On the ternary of MgO-FeO-CaO and the scatter plot of MgO vs. FeO, there is considerable overlap between the Kendu eclogitic garnets and the Legend megacrystic garnets. However, on the scatter plots of CaO vs. TiO_2 and Na_2O vs. TiO_2, the megacrystic garnets exhibit variable but overall high concentrations of TiO_2, with a narrow window of only moderate concentrations of CaO and Na_2O that tend to separate the population from true eclogitic garnets (Appendix 1). Eclogitic garnets derived from Group I eclogite will tend to show a much higher concentration of Na_2O with the equivalent concentration of TiO_2 exhibited by megacrystic garnets. On a scatter plot of Na_2O vs. TiO_2, which is commonly used to depict those garnets of high interest for diamond potential deriving from Group I eclogite, many high Fe (>25 wt. % FeO) and/or high Mn (>2 wt. % MnO) garnets that have been recovered during surface sampling programs by a number of companies across Alberta yield from 0.1 wt. % to 0.4 wt. % Na_2O and show an overlap with eclogitic garnets derived from Group I eclogite (Appendix 3). These garnets are likely crustal metamorphic garnets based upon their major element composition. Hence, they are not likely derived from eclogite. Their Na and Ti content likely reflects their original chemical composition prior to metamorphism and not pressure conditions, such as those required for formation in the diamond stability field.

Recent work by a number of authors has shed much doubt on the use of Na as a discriminating tool for evaluating the diamond potential of eclogite in individual kimberlites or for target regions. Grütter and Quadling (1999), using numerous analyses of eclogitic garnets derived from eclogite xenoliths with either diamonds, graphite or both, show that more than half of the garnets analyzed, including those from graphite-bearing–only xenoliths, yield concentrations of Na_2O greater than 0.07 wt. %. Grütter and Quadling (1999) conclude that Na_2O in eclogitic garnet cannot be used to discriminate between diamond-bearing versus graphite-bearing eclogitic mantle. In addition, work conducted by Cookenboo et al. (1998) indicates that the diamondiferous Jericho Kimberlite, Nunavut, contains two distinct types of eclogitic xenoliths, one of which yields diamonds. The diamondiferous eclogites are characterized by Mg-rich eclogitic garnet with 0.03 wt. % to 0.06 wt. % Na_2O and Al-Fe-Na poor eclogitic clinopyroxene, similar in some respects to Group II eclogite as defined by McCandless and Gurney (1989). Interestingly, the eclogitic xenoliths characterized by high-Na eclogitic garnets and high Na-eclogitic clinopyroxenes, which would be chemically more comparable to Group I eclogite, do not appear to yield diamonds (Cookenboo et al., 1998 and H. Cookenboo, personal communication, 2000).

5.2.2 Ecologitic Garnet (Mg-Almandine)

Eclogitic garnet (Mg-Almandine) must be distinguished on the basis of FeO-MgO-CaO-TiO_2 before it can be used to assess diamond potential utilizing the concentration of Na_2O. The main reason is that regional crustal metamorphic almandine with high concentrations of Fe and/or Mn can yield high concentrations of Na. These almandines are very abundant in most surface environments across Alberta and are not likely to have seen pressures equivalent to the diamond stability field. The Na content of these crustal metamorphic almandines is likely a function of original composition and is likely due in part to a Na-rich protolith. Two main tools can be used to separate possible eclogite-derived garnets versus crustal metamorphic garnets of similar composition. The first is the use of the FeO-MgO-CaO ternary plot and comparing the garnets recovered in an exploration program to those eclogitic garnets derived from true eclogite or those existing as inclusions in diamonds. A quick assessment can also be made on the basis of total Fe (calculated as FeO) concentration based upon the work of Schulze (1997). That is, crustal metamorphic garnets, such as high-pressure granulite derived Fe garnets, tend to display concentrations of total FeO greater than 23 wt. % and TiO_2 less than about 0.15 wt. %. True eclogite-derived garnets extracted from xenoliths in kimberlites tend to yield less than 23 wt. % FeO and a range of TiO_2 from about 0.10 wt. % up to 0.8 wt. %.

Eclogitic garnets, particularly those derived from eclogite xenoliths recovered from kimberlites, also yield low concentrations of MnO (<1 wt. %). Many crustal-derived almandines (and spessartines) contain large concentrations of MnO (ranging from 2 wt. % to 25 wt. %). Hence, concentrations of MnO greater than about 2 wt. % in Fe-Mg garnets are likely indicative of a crustal-derived metamorphic garnet. It should be noted that many of the high Fe and/or high Mn garnets that have been recovered during surface sampling programs by a number of companies across Alberta yield from 0.1 wt. % to 0.4 wt. % Na_2O with elevated concentrations of TiO_2 above 0.15 wt. % (Appendix 3). These garnets are not likely derived from eclogite based upon their major element composition; rather they are likely crustal metamorphic garnets. Their Na and Ti content likely reflect their original chemical composition prior to metamorphism and not pressure conditions, such as those required for formation in the diamond stability field.

5.2.3 High Na-Al-Clinopyroxene (Omphacite or Jadeite)

High Al_2O_3-Na_2O-K_2O omphacitic to jadeitic clinopyroxene is an important constituent of the eclogite assemblage. However, eclogitic clinopyroxenes are not often looked at for diamond potential for a number of reasons. True omphacitic clinopyroxene derived from eclogite is rare in kimberlites and, therefore, even more rare in the surface environment. In addition to Na-Al eclogitic clinopyroxenes being rare, they chemically oxidize and alter easily within a kimberlite or within the surface environment, and they are not easily differentiated from other light green clinopyroxenes during picking of silicate kimberlite indicator fractions as they do not normally have distinctive colour or habit.

Work by Fipke et al. (1995) indicates that 'eclogite'-derived clinopyroxenes can be found in kimberlites as well as ultramafic lamprophyres, alnöites and a few other related rock types; however, the low abundances in all of the rock types sampled indicates they are extremely rare and/or are difficult to recognize and pick even in kimberlites. At concentrations less than 1.5 wt. % Na_2O and less than 3 wt. % Al_2O_3, there is a large overlap with Na-Al clinopyroxenes that are potentially derived from eclogite versus those from other sources, including regional metamorphic clinopyroxenes as well as clinopyroxenes derived from other alkalic to ultramafic intrusions. The Na_2O-Al_2O_3 diagram is useful for distinguishing between those clinopyroxenes that are eclogite-derived versus those derived from other rock types. In general, those clinopyroxenes that contain greater than 1.5 wt. % Na_2O and 3.0 wt. % Al_2O_3 can be distinguished as derived from eclogite or a related high pressure mantle assemblage by a comparison with diamond inclusion chemistries for low-Cr, Na-Al clinopyroxenes (Appendix 4). At concentrations of less than 1.5 wt. % Na_2O and less than 3 wt. % Al_2O_3, caution must be exercised as to the origin of these grains and therefore any samples that yield these overlap clinopyroxenes only.

The large K cation is highly unstable in the clinopyroxene structure, and its presence in any significant concentration has been shown to be pressure dependent and likely requires the co-existence of a K-rich phase (Erlank and Kushiro, 1970; McCandless and Gurney, 1989; Harlow, 1999). McCandless and Gurney (1989) show that eclogitic clinopyroxenes in both diamond inclusions and in diamond-bearing Group I eclogitic xenoliths more often then not contain elevated concentrations of K_2O. The diamond inclusion clinopyroxenes, even for diamonds from the same xenolith from which the diamond was extracted from, tend to show much higher concentrations of K_2O than the eclogitic clinopyroxenes contained within the xenolith. This phenomenon is likely due to K_2O loss and re-equilibration at lower temperatures in an open mantle system (Harlow, 1999). McCandless and Gurney (1989) demonstrate that eclogitic clinopyroxenes containing greater than 0.08 wt. % K_2O could be considered derived from Group I eclogite and, therefore, may be representative of high diamond potential. For Na-Al clinopyroxenes of greater than 1.5 wt. % Na_2O and 3 wt. % Al_2O_3, a scatter plot of Al_2O_3 versus Na_2O helps to distinguish those clinopyroxenes potentially derived from eclogite versus those from other rock types (Appendix 3). Although no clinopyroxenes derived from the Alberta kimberlites within the database show elevated concentrations of K_2O, a number of clinopyroxenes obtained from regional samples do show elevated concentrations of K_2O (Appendices 3 and 9).

5.2.4 Cr-Corundum (Ruby)

Cr-corundum (commonly known as ruby) is a mineral occasionally found in kimberlite or lamproite and not many crustal rock types. Presence of this mineral in association with other kimberlitic minerals can aid in the identification of potentially kimberlitic or lamproitic intrusions that may have sampled eclogite-related mantle. Carlson et al. (1999) indicate that Cr-corundum, both red and pink and up to 1 cm, is a common accessory of the Buffalo Head Hills kimberlite pipes. Carlson et al. (1999) suggest the Cr-corundum is mostly derived from nodules of Cr-corundum-Mg-Al spinel with or without pyrope garnet that are of unknown origin, but may be related to an eclogitic paragenesis.

5.3 Megacrysts and Macrocrysts

The megacryst/macrocryst population includes garnet, picroilmenite, diopside, chromite, phlogopite, olivine, orthopyroxene and zircon. These minerals are always keenly sought after in any regional sampling program because the chemistry of these minerals and, in some cases, the physical properties such as colour are so distinct that their discovery alone is regarded as definitive evidence of kimberlite magmatism (Mitchell, 1989). The megacryst/macrocryst population of minerals is generally absent in lamproites and other closely related intrusions. Megacrysts are large (1 to 20 cm), single crystals of either orange, low-Cr, Ti-rich pyrope garnet, Mg-ilmenite, subcalcic to calcic diopside, bronzite (orthopyroxene), phlogopite or zircon. In regional prospecting programs the megacrysts themselves are not recovered, but either fragments of the megacrysts or a population of much smaller grains (<1 mm) that are chemically equivalent to this very distinctive population of minerals can be recovered. Their recovery is considered very important as their existence alone can be definitive evidence of the existence of kimberlite in an area, even though they may not be genetically linked to the kimberlite.

Mitchell (1986, 1989) states that whether megacrysts should be considered upper mantle xenocrysts that are unrelated to kimberlite or cognate phenocrysts formed in the upper mantle early in the generation of kimberlite magma (perhaps first partial melt of the upper mantle), is one of the major unresolved problems of kimberlite petrology. From a diamond exploration perspective this doesn’t really matter as finding significant volumes of these chemically distinct minerals is usually strong evidence of the presence of local kimberlites. The megacryst population has been identified in several of the kimberlites in the Buffalo Head Hills and in the Birch Mountains. In addition, regional sampling programs have detected their presence over large portions of Alberta, likely indicating the presence of undiscovered kimberlites.

5.3.1 Cr-Poor Megacrystic Pyrope Garnet

Megacrystic pyrope garnets are typically large, fractured single crystals (1 to 20 cm) of distinctively orange to orange-red, low-Cr, Ti-enriched pyrope garnet. The concentrations of Cr, Ti and Fe in pyrope garnet can be used to differentiate between low-Cr, Ti-rich megacrystic pyrope, typical Cr-rich pyrope derived from mantle peridotite and low-Cr, Ti-Fe–enriched pyrope garnet derived from mantle eclogite. In a few rare cases, such as at Snap Lake, there can be a strong chemical overlap between low-Cr megacrystic pyrope garnets and Fe-enriched pyrope garnets derived from eclogite (McLean, 2000). Megacrystic pyrope garnets are regarded as a very important indicator mineral in the search for kimberlite as few other alkaline intrusions yield these types of pyrope garnets, and therefore, they tend to be diagnostic of kimberlite. Fipke et al. (1995) conducted extensive kimberlite-indicator sampling of more than 18 alkaline intrusions, including kimberlite, lamproite, possible lamproite and other closely related alkaline intrusions such as alnöite and ultramafic lamprophyre. Very few megacrystic pyrope garnets were recovered from any intrusions other than kimberlites.

Megacrystic pyrope is usually characterized by high Ti (0.2 wt. % to 1.5 wt. % TiO_2), variable Cr (0 wt. % to 4 wt. % Cr_2O_3), and variable Mg/(Mg+Fe) ratios of about 0.68 to 0.86 (Mitchell, 1989). This group of pyrope garnets essentially corresponds to Dawson and Stephens (1975, 1976) Group 1 (G1) and Group 2 (G2) pyrope garnets. Chemical analysis of pyrope from the Legend Kimberlite in the Birch Mountains of northeastern Alberta, as well as pyropes from regional sampling programs across Alberta, show a chemically distinct population of megacrystic pyrope garnets on a scatter plot of Cr_2O_3 vs. TiO_2 ranging from slightly less than 4 wt. % Cr_2O_3 and 1 wt. % to 1.2 wt. % TiO_2 to 2 wt. % Cr_2O_3 and about 0.6 wt. % TiO_2 (Appendices 1 and 2). The Legend Kimberlite also shows a very distinct population of megacrystic pyrope garnets with less than 1 wt. % Cr_2O_3 and 0.4 wt. % to 1.1 wt. % TiO_2 (Appendices 1 and 2). Mitchell (1989) indicates kimberlitic Ti-pyrope megacrysts can be distinguished from megacrystic garnets found in alkali basalts and other mafic alkaline intrusions by the much lower concentrations of TiO_2 (<0.5 wt. %) and Cr_2O_3 (<0.5 wt. %) in the megacrystic garnets derived from alkali basalts and other alkaline intrusions.

Megacrystic pyrope garnets are typically orange as they lack the chrome content responsible for the more red to lilac-purple colour of normal Cr-rich pyrope garnets. On the basis of habit and colour alone, megacrystic pyrope garnets can be difficult to distinguish from eclogitic garnets and some crustal garnets in regional sampling programs. A scatter plot of CaO vs. Cr_2O_3, which is normally used for pyrope garnets, is not a useful tool to distinguish these garnets in this situation as all of these garnets lack Cr; therefore, it is necessary to use other oxides (FeO, TiO_2 and Na_2O) to make the distinctions more obvious (Appendices 1 and 2). Megacrystic pyrope garnets tend to have much higher concentrations of TiO_2 (0.4 wt. % to 1.2 wt. %) and lower concentrations of FeO versus eclogitic garnets. For example, the megacrystic pyropes of the Legend Kimberlite yield concentrations of FeO ranging from 12 wt. % down to 7.5 wt. % and MgO ranging from 17 wt. % up to 20.5 wt. % (Appendices 1 and 2). Eclogitic garnets from the Kendu Kimberlite yield concentrations of FeO ranging from 20 wt. % down to 9 wt. % and MgO from 10 wt. % up to 18.5 wt. % demonstrating there is a slight overlap field between the two populations (Appendices 1 and 3). However, the Kendu eclogitic garnets all contain <0.2 wt. % TiO_2 in contrast to the Legend megacrystic garnets, which all contain >0.4 wt. % TiO_2 (Appendices 1 to 3). The difference between the Legend megacrystic pyropes and the Kendu eclogitic garnets is well illustrated on the plots of TiO_2 vs. CaO and TiO_2 vs. Na_2O (Appendices 1 and 3). The presence or absence of megacrystic pyrope garnet in kimberlites is not known to demonstrate any connection to the presence or absence of diamonds within kimberlite.

5.3.2 Ilmenite

Megacrystic ilmenites tend to occur as rounded nodules up to 10 cm in diameter. Megacrystic picroilmenite from kimberlite tends to be non-magnetic and can therefore be easily separated from paramagnetic and magnetic crustal ilmenite during heavy mineral separation. However, picroilmenite can be associated with titaniferous magnetite, either as inclusions in olivine or intergrown with olivine in relatively magnetic kimberlites. In these instances, the vast majority of picroilmenite grains will report to the magnetic fractions along with perovskite, titaniferous magnetite, chromite, rutile and olivine. Megacrystic ilmenite is characterized by high concentrations of MgO (4 wt. % to 19 wt. %) and Cr_2O_3 (1 wt. % to 11 wt. %), together with distinctive enrichments of Ni (500 to 2000 ppm), Nb (500 to 3000 ppm), Ta (65 to 440 ppm), Hf (15 to 32 ppm), Zr (385 to 1270 ppm) and V (1000 to 2000 ppm) relative to ilmenites found in other mafic igneous rocks (Mitchell, 1989). In general, megacrystic ilmenite in kimberlite is difficult to distinguish on the basis of major element chemistry from primary magmatic phenocrystal and ground mass ilmenite contained within the same kimberlite. Trace element chemistry can aid in distinguishing the two populations. Megacrystic ilmenites tend to contain lower concentrations of Cr_2O_3 than phenocrystal kimberlitic ilmenite. Kimberlitic ilmenite tends to display higher concentrations of MgO (>12 wt. %) than megacrystic ilmenites as the groundmass and phenocrystic ilmenites generally evolve to higher concentrations of MgO during the evolution of the kimberlitic magma (Appendix 1). However, there is a large overlap in composition between megacrystic and kimberlitic ilmenites. Mitchell (1989) indicates that megacrystic ilmenites are common in alkaline basalts and other closely related alkaline rocks; however, they tend to yield lower concentrations of MgO (3 wt. % to 7 wt. %), along with significantly lower concentrations of Cr (<500 ppm), Ni (<100 ppm) and Nb (<100 ppm) relative to megacrystic or phenocrystal ilmenites derived from kimberlite. Mitchell (1989) states that ilmenite containing greater than 10 wt. % MgO are primarily confined to kimberlite. Hence, the recovery and identification of high MgO picroilmenites in any sampling campaign is considered critical as they are diagnostic of kimberlite.

In the past, numerous attempts have been made to use the geochemistry of ilmenites as a predictor of diamond grades for kimberlites (see discussions by Smith et al., 1994 and Griffin et al., 1997). This primarily arose because diamondiferous kimberlites from the South African Kaapvaal Craton yield abundant ilmenites enriched in Cr and Mg (Griffin et al., 1997). However, more recent studies have shown kimberlites in a number of ‘off-craton’ settings can also yield ilmenites enriched in Cr and Mg yet few or no diamonds. The Legend pipe (Birch Mountains field) contains abundant ilmenite enriched in Cr and Mg with only a few microdiamonds (Appendix 1).

Although picroilmenites are a common constituent of kimberlites, they are only rarely encountered in mantle xenoliths (Dawson, 1980). The prevailing consensus today is that picroilmenites, in particular the megacrystic ilmenites, are likely phenocrysts related to early kimberlitic or proto-kimberlitic magma genesis and fractional crystallization (Griffin et al., 1997). Following the recognition of diamond as a xenocryst, attention has turned to the use of ilmenite as an indicator of the oxidation-reduction state of the proto-kimberlitic magma in the upper mantle and during the ascent of the kimberlite magma to surface (Gurney, 1984; Gurney and Moore, 1993; Gurney and Zweistra, 1995). Diamond is predicted to survive better under reducing magmatic conditions during the ascent of the kimberlitic magma. Picroilmenites appear to give some measure of the redox conditions of kimberlite magma. In general, picroilmenites with low Fe^{3+}/Fe^{2+} ratios (reducing conditions) are associated with higher concentrations of diamonds than those with high Fe^{3+}/Fe^{2+} ratios (oxidizing conditions) for ‘on-craton’ kimberlites (Gurney and Moore, 1993, Fipke et al., 1995; Griffin et al., 1997). Barren ‘on-craton’ kimberlites tend to contain picroilmenites with very high concentrations of total Fe (therefore high Fe^{3+}) and low concentrations of Mg (Gurney and Moore, 1993; Fipke et al., 1995). High Cr in picroilmenites can be found in conjunction with either high or low ratios of Fe^{3+}/Fe^{2+}, but is only considered important in those ilmenites with low Fe^{3+}/Fe^{2+} ratios (Gurney and Moore, 1993; Fipke et al., 1995).

5.3.3 Clinopyroxene

Mitchell (1989) indicates that megacrystic clinopyroxene (diopside) tends to contain higher concentrations of FeO than lherzolitic Cr-diopside, and they are very similar in character to magmatic kimberlitic diopsides in that they are characterized by low concentrations of Cr_2O_3 (<1 wt. %), TiO_2 (<1 wt. %), Al_2O_3 (<3 wt. %) and Na_2O (<2 wt. %). As a result, megacrystic diopside is easily distinguished from mantle-derived eclogitic or lherzolitic diopsides. Eclogitic clinopyroxene tends to yield much higher concentrations of Al_2O_3 and Na_2O tending toward omphacite and jadeite in composition. Lherzolite-derived clinopyroxene (Cr-diopside) yields much higher concentrations of Cr_2O_3 (>1 wt. %) and lower concentrations of FeO. Megacrystic diopsides range from diopside to subcalcic diopside. Megacrystic diopsides are commonly found in many other mafic alkaline rocks, such as minettes, alnöites, alkaline basalts, etc.; however, in these other intrusions, they differ in containing higher concentrations of Al_2O_3 (>4 wt. %) and FeO (>4 wt. %) tending toward augites and salites, the more Fe-rich varieties of clinopyroxene (Mitchell, 1989).

5.3.4 Orthopyroxene

Megacrysts of orthopyroxene are generally less abundant than other megacrysts. Megacrystic orthopyroxene is characterized as Ti-bronzite with low concentrations of CaO (<1.5 wt. %), Al_2O_3 (<1.5 wt. %), Cr_2O_3 (<1.5 wt. %) and Mg/(Mg+Fe) ratios ranging from 0.83 to 0.92.

5.3.5 Other

Megacrystic zircon, phlogopite and olivine are documented for kimberlites, however present literature suggests that there is really nothing chemically distinctive about these minerals that can be used in the exploration for kimberlite.

5.4 Cognate Magmatic Phenocrysts Crystallized within the Kimberlite Magma

Minerals derived as magmatic phenocrysts (and groundmass) from a kimberlite include primarily *olivine* and *phlogopite* with lesser amounts of *picrochromite*, *picroilmenite*, *spinel* and *diopside*. Although olivine and phlogopite are the most common kimberlite minerals they are the most difficult to recover in surface sampling programs. Kimberlitic chromite and ilmenite on the other hand are resistant to weathering and are commonly recovered in surface exploration programs. Kimberlitic chromite and ilmenite have distinctive and contrasting chemistry versus crustal derived chromite and ilmenite and they can yield useful information about the chemistry of the kimberlite they were derived from.

5.4.1 Olivine

Light green kimberlitic olivine is the most abundant mineral in kimberlite and is often partially to completely serpentinized, especially if the kimberlite has been exposed to formation/ground waters. Pale yellow-green olivine is derived from disaggregated mantle peridotites and the darker honey-brown olivine is most likely fragments of Fe-rich megacrysts. Megacrysts and related macrocrysts are common constituents in a kimberlite and their origin is somewhat controversial. Most people believe that they represent minerals formed in the upper mantle or they represent first melt (cognate) of the upper mantle leading to kimberlite magma formation.

Olivine in kimberlites or lamproites is typically Mg-rich ranging from Forsteritic $(Fo)_{76}$ to Fo_{94} with the bulk of the olivines at about Fo_{88} to Fo_{92} (Mitchell, 1989). The high MgO kimberlitic olivines also yield NiO concentrations ranging from 0.2 wt. % to 0.6 wt. %. Olivine derived from Alberta kimberlites typically falls well within this range (Appendix 1). Mitchell (1989), states that it is nearly impossible to distinguish between mantle-derived lherzolitic or harzburgitic olivine and true phenocrystal kimberlitic olivine. Olivine derived from other rock types such as alkali basalts, lamprophyres, alnöites etc. tend to show elevated concentrations of one or more of CaO, MnO, Al_2O_3 or TiO_2 in combination with MgO concentrations yielding less than Fo_{88} and low concentrations of NiO (< 0.3 wt. %). On occasion, olivine derived from alkali basalt can be mistaken for kimberlitic olivine based on high MgO, low CaO and high NiO; however the instances of this are rare. Cordilleran settings in California and Alaska, where oceanic crust is underplating continental or island arc terranes, are known to give rise to alkalic breccias in diatremes that do yield olivine compositionally similar to olivine derived from kimberlite (Ryder and Hourican, 1997; Dufresne, 2002). This is demonstrated in a scatter plot of NiO versus Mg number for olivine from Lac de Gras, California and Alberta kimberlites (Appendix 1).

Olivine as a guide to the discovery of kimberlites can be an excellent tool, particularly in areas where alkali basalts or komatiites are uncommon. In fact, in many non-glaciated regions the presence of olivine is an excellent indication of close proximity to a kimberlite, or a related source rock as it is a mineral that is easily decomposed in an active weathering environment. For the most part this is also likely the case in glaciated terrains, however, exceptions do occur. Olivine has been reported in several past Alberta foothills exploration programs, both in present day drainages and in Cretaceous to Tertiary sedimentary sequences (Drever and Matthews, 1996; Langenberg and Skupinski, 1996; Ball, 1998a, b, c). The original source(s) of most if not all of the foothills olivine has not yet been identified and remains an important mystery to solve. Langenberg and Skupinski (1996) propose that the source of the foothills olivine may be a number of kimberlites or closely related intrusions that were most likely emplaced during the Middle Cretaceous (110 Ma) and Late Cretaceous (70 Ma). Recent sampling conducted by Eccles et al. (2001) has yielded significant amounts of olivine in the Buffalo Head Hills area and south of the Buffalo Head Hills in the Utikuma Lake area. The source of the olivine in the Buffalo Head Hills is likely linked to known kimberlite intrusions. The source of the olivine in the Utikuma Lake area is likely linked to local kimberlites that are yet to be discovered.

Olivine as a guide to diamond potential has been used on occasion by comparing the concentrations of Cr_2O_3-MgO and NiO-MgO using data from both kimberlitic and diamond inclusion olivines. However, there is much overlap between olivine derived from diamondiferous kimberlites, non-diamondiferous kimberlites and olivine derived from non-kimberlitic rocks such as alkali basalt. As a result, any conclusion about diamond potential from olivine chemistry should be treated with extreme caution.

5.4.2 Phlogopite

Phlogopite can be partially or completely replaced by chlorite and thus have a blue-green to white colour. Phlogopite occurs as both phenocrysts and xenocrysts in the groundmass of kimberlites and as megacryst/macrocryst phases. Phlogopite is a complex and difficult mineral to use as an indicator of kimberlite particularly in regional sampling programs. However, when an intrusion is discovered the chemistry of the contained phlogopites is an important factor in the determination of whether the intrusion is a kimberlite or a closely related rock. Kimberlitic phlogopite tends to be high in MgO with typical Mg/(Mg+Fe) ratios on the order of 0.80 to 0.93 (Mitchell, 1989). However, some South African Group II micaceous kimberlites yield macrocryst phlogopite with Mg/(Mg+Fe) ratios on the order of 0.45 to 0.65. Kimberlitic micas contain substantial amounts of TiO_2 (ranging from 0.5 wt. % to 6.0 wt. %) and Cr_2O_3 (ranging from 0 to 2.0 wt. %). A scatter plot of Al_2O_3 vs. TiO_2 for phlogopite (Mitchell, 1989) is an excellent tool to determine whether the micas are kimberlitic or not. However, the concentration of FeO-MgO must be used in conjunction with Mitchell's Al_2O_3-TiO_2 diagram as there is quite often a large overlap between regional biotites (with high Fe) and kimberlitic phlogopites (with high Mg) on the basis of Al_2O_3-TiO_2 only. Phenocrystal phlogopite in kimberlites tend to show an evolution toward decreasing TiO_2 and Cr_2O_3 with increasing FeO as macrocryst mica is followed by crystallization of groundmass mica. This can also be displayed by core to rim transitions as well as chemically distinct populations of phlogopite.

Other types of closely related intrusions such as minettes and lamproites tend to exhibit trends of increasing TiO_2 with increasing FeO and either constant or decreasing Al_2O_3 from core to rims and in separate populations. However, there can be considerable overlap between the micas obtained from kimberlites versus those obtained from lamproites and minettes. Chemistry of micas in kimberlites can vary dramatically from pipe to pipe and region to region. A better discrimination of kimberlitic micas versus other micas can be obtained by employing a ternary of FeO-TiO_2-Al_2O_3. Ti enrichment is typical of the lamproite or minette trend of phlogopites in contrast to Ti depletion, which is characteristic of the kimberlite trend. To date, there is little publicly available chemistry for kimberlitic phlogopite from Alberta kimberlites.

5.4.3 Spinel and Chromite

Mg-Ti-rich chromite (a Cr-spinel) and Ti-rich Mg-Fe-Al spinel are minerals that can be very diagnostic of kimberlite. The famous kimberlite magmatic trends for spinel (Figures 1.11 to 1.13 in Mitchell, 1989) are an excellent chemical tool to distinguish for the presence of kimberlite or some other closely related alkaline ultramafic intrusion. Kimberlitic spinels (including chromites) show a substantial increase in the concentration of Ti and, to a lesser degree, Fe^{3+} with a substantial decrease in the concentration of Cr during the magmatic evolution of a kimberlite. For Trend 1 kimberlitic spinels, a relatively constant ratio of Mg^{2+} to Fe^{2+} is maintained (Mitchell, 1989). Trend 2 kimberlitic spinels show a very similar pattern to Trend 1 spinels but they tend to exhibit an early increase in Fe^{2+} followed by increasing Ti and Fe^{3+} with decreasing Cr during the evolution of the kimberlite magma. Subtle differences in the magmatic trends of the Trend 1 and Trend 2 spinels are largely a function of the precipitation of phlogopite, a common constituent of both Type 1 and Type 2 kimberlites (Mitchell, 1989). Primary magmatic phlogopite is far more abundant in Type 2 kimberlites, which are also known as micaceous kimberlites, or orangeites (Mitchell, 1989, 1991). Chromites from Alberta kimberlites show this diagnostic normal evolutionary trend (Appendix 1). However, in regional prospecting programs, kimberlitic chromites can be difficult KIMs to recover because of their high iron content and the fact that they often tend to be intergrown with magnetite or hematite. As a result, they can sometimes report to the magnetic ferromagnesian concentrate, which is not usually picked for chromites and ilmenites.

Chromites can be identified by their conchoidal fracture and their dark, vitreous to sub-metallic lustre. Chromite and spinel are ubiquitous as a groundmass phase within the matrix of a kimberlite. Macrocrystal phenocrysts of compositionally similar chromite are also common in most kimberlites. High Cr and high Mg chromites, which tend to be mantle derived, are much less common in a kimberlite but are highly sought after in exploration programs. These high Cr-Mg chromites can be indicative of the presence of diamonds, as they are compositionally similar to chromites found as inclusions in diamonds (Fipke et al., 1995). Diamond inclusion chromites have concentrations of Cr_2O_3 > 58 wt. % and concentrations of MgO between 10 and 16 wt. %, in comparison to most magmatic kimberlitic chromites, which have concentrations of Cr_2O_3 between 40 and 60 wt. % and often show increasing Ti with a decrease in Cr (Fipke et al., 1995). Recent work by Grütter and Apter (1998) indicates that high Cr (>60 wt. % Cr_2O_3), low Ti, Mg-chromites with “diamond inclusion” type chemistries can be the product of early kimberlite magmatic processes at high pressure and, therefore, may not be indicative of diamondiferous peridotite mantle.

Fipke et al. (1995) define a field of chemically distinct kimberlitic and/or lamproitic chromites that is unique to kimberlites and lamproites. The field is characterized by chromites with roughly greater than 40 wt. % Cr_2O_3 and greater than 2 wt. % TiO_2, which are unique to kimberlites and lamproites and likely represent primary phenocrystal groundmass magmatic chromites. These chromites are quite rare in Alberta, however, the Mountain Lake kimberlitic pipes and several of the kimberlites in the Birch Mountains kimberlite field yield a very distinct population of chromites with greater than 40 wt. % Cr_2O_3 and greater than 2 wt. % TiO_2, confirming the usefulness of high Ti chromites as a tool indicating the presence of kimberlite (Appendix 1).

Chromites derived from other mafic to ultramafic rock types such as komatiite, alkali basalt, ophiolitic peridotite, pyroxenites etc. generally do not yield a population of high Ti chromites with between 40 wt. % to 60 wt. % Cr_2O_3. However, Kjarsgaard (1998) showed that spinel from the Sweet Grass minette from southern Alberta plots with the unique kimberlite/lamproite field of Fipke et al. (1995), indicating that there are some exceptions that can complicate exploration work. Chromites derived from non-kimberlitic mafic to ultramafic rocks tend to yield high concentrations of Zn in comparison to low concentrations of Zn that typify kimberlitic or mantle derived chromites (Griffin et al., 1992, 1994a; Griffin and Ryan, 1993, 1995; Fipke et al., 1995). In non-kimberlitic rocks, chromite tends to incorporate high concentrations of Zn ranging from 2,000 ppm up to several percent upon slow re-equilibration at low temperatures (Griffin et al., 1992, 1994a; Griffin and Ryan, 1993, 1995; Fipke et al., 1995).

5.4.4 Ilmenite

Groundmass kimberlitic ilmenite is much less common than chromite and tends to be very similar in composition to megacrystic or mantle derived ilmenite. Groundmass ilmenite in kimberlites is often intergrown with perovskite and spinel. The chemistry of primary magmatic groundmass ilmenite is probably best characterized by the chemistry of distinct picroilmenite rims around macrocrystal ilmenite grains. In many cases, the chemistry of picroilmenite rims mimics the chemistry of true primary magmatic groundmass picroilmenites. In other cases, the chemistry of secondary picroilmenite rims is dissimilar to the chemistry of groundmass picroilmenites. In these cases, it is likely that the picroilmenite rims were likely formed as a result of progressive partial melt in the upper mantle forming the proto-kimberlitic magma or as a result of metasomatism. In almost all kimberlites world wide, ilmenite shows a distinct evolutionary trend during crystallization of the kimberlite magma from intermediate concentrations of MgO to very high concentrations of MgO on the order of 12 to 20 wt. %. Core to rim chemical analyses of picroilmenites derived from a number of the Birch Mountains kimberlites in northeast Alberta exhibit this distinct kimberlitic evolutionary trend (Appendix 1). Although not as constant as the MgO trend, kimberlitic ilmenites also tend to show a slight enrichment of Cr_2O_3 from core to rims during kimberlite magma evolution (Appendix 1). Ilmenites containing greater than 10 wt. % MgO are almost exclusively confined to kimberlites (Mitchell, 1989). However, picroilmenites yielding between 4 and 10 wt. % MgO are also commonly found in kimberlites as well as other closely related intrusions. The Birch Mountains kimberlites (in particular Dragon, Legend and Valkyrie) yield a number of picroilmenites with between 4 and 10 wt. % MgO with low concentrations of Cr_2O_3 (Appendix 1). Mitchell (1989) indicates that kimberlitic picroilmenites are also characterized by distinct enrichments in Ni (500 – 2000 ppm) and Nb (500 – 3000 ppm) versus picroilmenites derived from other closely related intrusions. As an example, a total of 722 microprobe analyses for picroilmenites derived from a number of the Birch Mountains kimberlites (including core and rim analyses), yield an average of about 1,200 ppm Ni and 1,200 ppm Nb (Appendix 9).

5.4.5 Diopside

Cr-diopside is one of the key indicator minerals in diamond exploration and the search for kimberlite. However, Cr-diopside is not usually genetically related to the kimberlite but rather is often derived from disaggregated mantle peridotite, in particular lherzolite. Magmatic diopsides in kimberlites are neither very abundant nor easy to recognize chemically, relative to other volcanic diopsides. Kimberlite magmatic diopsides tend to be Cr-poor (<0.5 wt. %) and contain very low concentrations (<1 wt. %) of TiO_2, Al_2O_3 and Na_2O (Mitchell, 1989). Lamproitic diopsides tend to be very similar to kimberlitic diopsides except they contain exceptionally low concentrations of Al_2O_3 (<0.35 wt. %). Diopsides from other regional volcanic and metamorphic rocks tend to exhibit much higher concentrations of FeO (>3 wt. %) and Al_2O_3 (>1 wt. %). Diopsides from other alkaline intrusions such as lamprophyres and alnöites display very high concentrations of TiO_2 (1 to 6 wt. %) and Al_2O_3 (1 to 13 wt. %).

6 Observations on Mineral Chemistry from Compiled Data for Northern and Southern Alberta and Some Alberta Kimberlitic Rocks

Included in this report are chemical analyses for more than 18,000 possible KIMs from Alberta surficial sampling surveys as well as a number of kimberlitic pipes from NAB that were compiled by Eccles et al. (2002). A large portion of these data has been obtained digitally from various industry and government sources. Where data could not be obtained digitally, it was scanned from publicly available assessment reports. The accuracy of this data has not been verified and it is strongly recommended that the reader check the voracity of the data prior to drawing any significant conclusions for any particular area.

More specifically, Eccles and Weiss (2003) showed that the dataset includes 18,738 analyses from 1,493 separate positive sample sites, which when compared to the total area of Alberta equates to a sample density of about one site per 437 km^2. This indicates that large parts of Alberta are still undersampled, particularly north of latitude 57º and throughout much of southern Alberta (SAB). It should be noted that negative sample sites (a site that yielded no indicator minerals) were not compiled. Of the 1,493 positive sample sites, 1,035 sites yielded three or more reported indicator minerals. To date, the top five sites based on the number of indicator grains reportedly recovered include:

1) Calling Lake, northcentral Alberta – 419 grains
2) Calling Lake, northcentral Alberta – 349 grains
3) Hinton – northwestern Alberta – 182 grains
4) Calling Lake, northcentral Alberta – 176 grains
5) Milk River/Sweet Grass, southern Alberta – 126 grains

The indicator minerals discussed within this report are evaluated using a number of x-y scatter plots and, in some cases, ternary scatter plots for a variety of elements. The scatter plots are included as Appendices 1 to 7. The indicator dataset has also been evaluated by plotting various compositions for a variety of minerals geographically across Alberta on a series of maps included as Appendix 8. Chemical analyses for the more than 18,000 KIMs as well as a large number of non-indicator or borderline-indicator minerals are included in Appendix 9.

6.1 Peridotitic Garnet

By the end of 1996, AGS Bulletin 63 indicated that chemical analyses were publicly available for 101 pyrope garnets and 174 Fe-rich garnets of possible eclogitic nature within Alberta. The population of Fe-rich garnets included 86 garnets that plot within the diamond inclusion field using a ternary of FeO-MgO-CaO (likely derived from eclogitic mantle) and another 88 garnets outside of and bordering the prospective field that may or may not be derived from eclogite. The current study contains chemical analyses for more than 2,693 pyrope garnets and 633 possible eclogitic garnets (Appendices 1 to 3, 8 and 9). If the large "possible eclogitic garnet" sample dataset from the former foothills joint venture between Cameco, Uranerz and DiaMet, and all data from actual kimberlites are excluded, the database contains chemical analyses from samples widely distributed across Alberta for about 2,042 pyrope garnets and 169 possible eclogitic garnets. The database also includes chemical analyses for 651 pyrope garnets derived from six different kimberlitic pipes including Mountain Lake near Grande Prairie and Kendu, Legend, Xena and Pegasus from the Birch Mountains. The database also contains chemical analyses for pyropes recovered from surface samples from the area directly adjacent to the K4 pipe in the Buffalo Head Hills. The database also includes chemical analyses for 79 possible eclogitic garnets from three different kimberlites with the bulk of the data from the Kendu pipe in the Birch Mountains.

To date, publicly available chemistry for the Mountain Lake pipes, the K4 pipe in the Buffalo Head Hills area, and all of the Birch Mountain pipes has failed to yield any of the much sought after Gurney G10 harzburgitic pyrope garnets (Appendices 1 and 2). In the available assessment reports, no mineral chemistry is available for the Ashton kimberlites in the Buffalo Head Hills, however, Carlson et al. (1999) and Hood and McCandless (2003) indicate that although they are not abundant, a significant number of favourable G10 pyrope garnets, some with exceptionally high chromium contents (up to 17.8 wt. % Cr_2O_3), along with abundant diamond inclusion quality chromites, have been obtained from several of the kimberlites in the central and northern portion of the Buffalo Head Hills kimberlite cluster. Carlson et al. (1999) and Hood and McCandless (2003) indicate that although Gurney G10 pyrope garnets and high chromium chromites, which are often associated with diamonds, are present in a number of kimberlites and regionally in the Buffalo Head Hills, to date, there is no direct association of these minerals in kimberlites with better diamond counts. In addition, Hood and McCandless (2003) indicate that some of the highly diamondiferous kimberlites such as K252 and K6 contain relatively few xenocrystic indicator minerals, while some kimberlites with abundant mantle xenocrysts such as K2 and K95 are only weakly diamondiferous. Carlson et al. (1999) and Hood and McCandless (2003) indicate that the northern cluster of kimberlites in the Buffalo Head Hills tend to be more diamondiferous and yield a number of G10 pyrope garnets, as well as a number of pyrope garnets and chromites that yield very high concentrations of chromium (in the case of pyrope garnets from 16 to 18 wt. % Cr_2O_3). The northern cluster of kimberlites also yields very few titanian pyrope garnets and low concentrations of picroilmenite, and when picroilmenite is present, it usually contains low concentrations of niobium. In contrast, the southern cluster of kimberlites yield lower chromium pyrope garnets often with high concentrations of calcium, in some cases likely derived from wehrlite, high titanian pyrope garnets, chromites with lower overall chromium concentrations, picroilmenites with high concentrations of niobium and few if any eclogitic garnets (Carlson et al., 1999; Hood and McCandless, 2003).

Publicly available data indicates that only a couple of regional sample sites in and down-ice from the Buffalo Head Hills have yielded subcalcic G10 pyrope garnets (Appendix 8). However, a few regional sample sites down ice from the Buffalo Head Hills yield a number of high Cr pyropes similar to the population reported by Carlson et al. (1999) and Hood and McCandless (2003) for the central and northern Buffalo Head Hills kimberlites (Appendix 8). A recent multidisciplinary government study included the collection of 338 samples in the Peerless Lake, Peace River, Bison Lake and Wadlin Lake Map areas (NTS84B, 84C, 84F and 84G) by Eccles et al. (2001) and by Friske et al. (2003). These surveys have resulted in the discovery of a number of diamond indicator mineral anomalies, a number of which include abundant pyrope garnets, from stream sediment and till samples north of the northernmost known kimberlite in the Buffalo Head Hills. The presence of significant amounts of indicator minerals, including pyrope garnets, in the northern portion of the Buffalo Head Hills well north of the existing known kimberlites are likely indicative of the presence of a number of undiscovered kimberlites. Publicly available assessment reports confirm the presence of significant numbers of indicator minerals from samples collected from the northern part of the Buffalo Head Hills, however, no chemistry is reported for these indicator minerals (Wood, 1999; Skelton and Willis, 2001).

The Mountain Lake pipes yield a distinct population of high Cr pyrope garnets separate from the more abundant population of G9 lherzolitic pyrope garnets (Appendices 1 and 2). These pyrope garnets with very high Cr (greater than 12 wt. % Cr_2O_3) are distinct from normal lherzolitic pyrope garnets and may be indicative of an ultradeep paragenesis (and derivation from well within the diamond stability field) similar to the G10-3 garnets described by Grütter et al. (1999) and Grütter (2002). The high Cr G10-3 pyropes can be found in association with diamonds in some kimberlite pipes (H. Grütter, personal communication, 2000). A relatively high knorringite ($Mg_3Cr_2Si_3O_{12}$) component in pyrope garnets can be indicative of a deep, high pressure assemblage, which is an important characteristic of the diamond stability field (Sobolev et al., 1992). Mountain Lake only contains a couple of the favourable high Cr pyropes, is a highly contaminated pipe with petrological affinities towards ultrabasic rock and alnöite (Leckie et al., 1997, Skupinski and Langenberg, 2002), and is only weakly diamondiferous (B. Wood, personal communication, 1998). The Legend kimberlite also yields a number of pyrope garnets with high Cr (10 to 11 wt. % $Cr_2O_{3)}$, however, the garnets with high concentrations of Cr occur at the high Cr end of a distinct trend of G9 lherzolitic pyrope garnets that is very similar in trend to the lherzolitic garnets recovered from the Mountain Lake pipes. The high Cr pyropes in this case, likely represent an end member of the compositional trend of lherzolitic pyropes derived from less favourable (for diamonds) lherzolitic mantle showing a Ca depletion trend (Appendices 1 and 2). The Legend kimberlite is only weakly diamondiferous.

Although publicly available data from regional sampling conducted by government agencies and industry has produced only a couple of sites with G10 pyrope garnets down-ice from the Buffalo Head Hills kimberlite cluster, G10 pyropes have been recovered from other areas of Alberta (Appendices 1, 7 and 8). Subcalcic harzburgitic G10 pyrope garnets have been recovered from five sites south of 54^o and 17 sites north of 54^o of latitude (Appendices 1, 7 and 8). Most of the sites yielding the G10 pyrope garnets identified to date in Alberta have come from sample sites east of 115^o longitude. It is unclear whether the vast majority of G10 pyrope garnets found in future will be restricted to the eastern half of Alberta, therefore indicating possibly better diamond potential for the eastern half of Alberta. Keeping in mind that the existing regional data is somewhat sparse, only two highly anomalous areas for G10 pyrope garnets have been identified to date. Multiple sites with G10 pyrope garnets, as well as sites with multiple G10 pyrope garnets have been identified in only the Calling Lake and the Cold Lake regions of NAB (Appendix 8). To date, no kimberlites have been found in these two areas, however, the morphology, size and number of indicator minerals recovered from both areas indicates that kimberlites likely exist locally in both regions. Recent work by New Claymore Resources Inc. (2002) in the St. Paul area of east-central Alberta, about 80 to 100 km southwest of Cold Lake, has yielded a number of G10 pyrope garnets (B. Ryziuk, personal communication, 2002). All three of these areas should be regarded as areas of high interest for further diamond exploration.

Regional sampling conducted by government agencies and industry has produced a number of sites with high Cr pyrope garnets and sites with multiple high Cr pyrope garnets in and down-ice of the Buffalo Head Hills area (Appendix 8). Although the high Cr pyrope garnets often plot on the G9 side of the Gurney G9/G10 plot, they tend to have much higher Cr than Ca and although they may not be considered truly subcalcic they tend to plot separate from normal lherzolitic (G9) pyrope garnets. These pyrope garnets with a high knorringitic component (greater than 12 wt. % Cr_2O_3) are likely part of the G10-3 population of pyrope garnets described by Grütter et al. (1999) and Grütter (2002) and can be considered derived from an ultradeep paragenesis. This group of pyrope garnets are sometimes found in association with diamonds in some kimberlite pipes (H. Grütter, personal communication, 2000) and, therefore, should not be ignored in regional sampling programs. The same high Cr variety of pyrope garnet is also present in the Lac de Gras region and is likely indicative of ultradeep peridotite derived from within the diamond stability field based upon regional sampling by the GSC (Appendix 1; Dredge et al., 1995; Kerr et al., 1995; Ward et al., 1995) and compilations of data by Grütter et al. (1999), Armstrong (2001) and Grütter (2002). To date, regional sampling across Alberta indicates that pyropes with high to very high concentrations of Cr (8 to 14 wt. % Cr_2O_3) form a distinct population in NAB but are almost completely absent in SAB (Appendices 2 and 8). It is unclear whether this reflects a fundamental difference in the upper mantle between NAB and SAB. Only two pyrope garnets with greater 10 wt. % Cr_2O_3 have been identified in SAB. Three areas of NAB yield a large number of samples with high Cr pyropes including the Peace River to Buffalo Head Hills region, the Calling Lake region and the Cold Lake region (Appendix 8). Of these three areas, kimberlites have only been found in the Buffalo Head Hills region.

Regional pyrope garnet data for NAB and SAB display a wide range in the concentrations of TiO_2 ranging from negligible up to 1.25 wt. % (Appendices 1 and 2). Normal low Ti (<0.4 wt. % TiO_2) lherzolitic pyrope garnets are the most widely distributed pyrope variety across Alberta (Appendices 2 and 8). Megacrystic pyrope garnets with high Ti, high Fe and low Cr are widely distributed across both NAB and SAB (Appendices 2 and 8). In addition, there is a population of high Ti (0.4 to 1.25 wt. %) lherzolitic pyrope garnets with low to modest concentrations of Cr (2 to 8 wt. % Cr_2O_3) widely distributed across NAB and SAB (Appendices 2 and 8). However, there is one noticeable difference in the pyrope populations of NAB and SAB; and that is that there is a distinct population of high Cr (8 to 12 wt. % Cr_2O_3) and high Ti (0.4 to 1.2 wt. % TiO_2) pyrope garnets in NAB that do not appear to be present in SAB (scatter plot of TiO_2 vs. Cr_2O_3 in Appendix 2). It is unclear whether this reflects a fundamental difference in the upper mantle between NAB and SAB such as a significant upper mantle metasomatic event or perhaps re-equilibration of eclogite mantle with peridotite (likely lherzolitic) mantle that took place in NAB but not SAB. Interestingly, Lac de Gras also yields a population of pyrope garnets with high Ti (>0.4 to 1.1 wt. % TiO_2) with Cr ranging from 3 up to about 12 wt. % Cr_2O_3 (Appendix 2).

Of the kimberlites in the database, only the Legend kimberlite from the Birch Mountains kimberlite field has yielded a distinct population of megacrystic pyrope garnets with high Ti, high Fe and low Cr (Appendices 1 and 2). In addition to the high Ti megacrystic pyrope garnets, a large number of the Cr rich lherzolitic G9 pyrope garnets recovered from both the Legend and Xena kimberlites yield high concentrations of Ti ranging from 0.6 to 1.1 wt. % TiO_2, with only a few grains yielding more normal lherzolitic compositions with concentrations of TiO_2 of less than 0.4 wt. %. The Legend kimberlite also yields a population of high Cr (8 to 11 wt. % Cr_2O_3) and high Ti (0.6 to 1.1 wt. % TiO_2) pyrope garnets similar in nature to the grains recovered from regional sampling across NAB but not in SAB. Eccles (2004) demonstrates that several of the Birch Mountain kimberlites display abnormally high concentrations of whole rock Ti and that these kimberlites are likely derived from a far more evolved kimberlitic magma than the kimberlites in the Buffalo Head Hills. Evolved kimberlitic magma is likely not a favourable trait for the preservation of any diamonds that may have been incorporated in the magma during ascent to surface due to the extended residence time of the diamonds at lower pressures. Alternatively, re-equilibration or re-integration of eclogitic mantle with lherzolitic mantle might also produce a similar signature. It is interesting, that the Kendu kimberlite discovered in the Birch Mountains cluster during the fall of 2000, (New Blue Ribbon Resources Ltd., 2000) yielded only low Ti (<0.4 wt. % TiO_2) lherzolitic pyrope garnets, with the exception of one grain, and a large number of eclogitic garnets and xenoliths. The eclogitic garnets are characterized as Type II low Ti and low Na eclogitic garnets (Appendices 1 and 3) and are considered of low diamond potential (McCandless and Gurney, 1989; Cookenboo et al., 1998), confirmed by a lack of any diamonds in this kimberlite.

The regional pyrope data also indicates that the bulk of the high Ti pyrope garnets (>0.4 wt. % TiO_2) found in NAB are restricted to the eastern half of NAB. A scatter plot of TiO_2 vs. Cr_2O_3 (Appendix 3) for NAB shows that the vast majority of Ti rich pyrope garnets occur between longitudes of 110^o and 114^o, with a much reduced population between 114^o and 117^o and almost no grains between 117^o and 120^o (Appendices 1, 2 and 8). A similar distribution pattern is also evident for megacrystic pyrope garnets for NAB (Appendices 1, 2 and 8). The distribution pattern for SAB is less clear, perhaps in part due to less data. However, SAB does lack a population of high Cr (>8 wt. % Cr_2O_3) pyropes with or without high Ti. Distinct populations of both high Cr pyropes with high Ti and with low Ti are present in NAB.

6.2 Eclogitic Garnet

In the case of orange coloured eclogitic garnets, surface exploration can yield a large number of orange, crustal-derived garnets that are not important but look similar to important kimberlite derived eclogitic garnets and upon cursory inspection may have overlapping major and trace element chemistry. In general, pyrope garnets are much more abundant in kimberlites and, therefore, tend to be more abundant in regional sampling programs than true eclogitic garnets. This is well borne out in the Alberta kimberlite-indicator database with the recovery of more than 2,000 pyrope garnets and 554 possible eclogitic garnets (169 eclogitic garnets if the Cameco foothills joint ventures Fe-garnets are excluded). The most common use for eclogitic garnets is in aiding the assessment of diamond potential for regions yielding indications of the presence of kimberlites. The role of eclogitic garnets in regional exploration for diamonds and kimberlites (in particular their unique chemistry) is thoroughly discussed by Schulze (1997). In addition, Grütter and Quadling (1999) suggest that the use of Na_2O in eclogitic garnets as a tool to distinguish between graphite-bearing versus diamond bearing eclogite is highly suspect.

For the purposes of this study, eclogitic garnets are defined as low Cr (<2 wt. % Cr_2O_3), low Mn (<3 wt. % MnO) garnets having less than 23 wt. % FeO, greater than 5 wt. % MgO and between 3 wt. % and 18 wt. % CaO. These cut-offs approximate the cut-offs recommended by Schulze (1997) to discriminate between Fe garnets that are likely derived from eclogitic mantle versus those that are most likely to be crustal derived. It should be noted that there are areas of the northern Canadian Shield that yield abundant orange garnets that meet all of the criteria of Schulze (1997) for being derived from eclogitie, however, the vast majority of the garnets in some of these areas can be proven to be derived from crustal granulite. A total of 554 possible eclogitic garnets that meet the above chemical criteria have been recovered from across Alberta, with 82 from NAB and 472 from SAB. The bulk of the possible eclogitic garnets (approximately 385) from SAB are from a single dataset in the central foothills region derived from a former joint venture between Cameco, Uranerz and DiaMet termed the Cameco foothills joint venture dataset. Some diamond explorationists make the mistake of trying to infer the diamond potential of certain areas on the basis of the Na and Ti chemistry for all the recovered Fe garnets in regional indicator datasets, skipping the first most important step of properly classifying the Fe garnets as potentially derived from eclogite using Fe, Mg and Ca. As discussed by Schulze (1997), it is critical that only those Fe garnets that are potentially derived from eclogitic mantle be used to evaluate diamond potential using Na and Ti, as crustal derived garnets can yield elevated concentrations of Na and Ti that overlap with eclogitic garnets considered of high diamond potential (Appendix 3). Applying the above chemical cut-offs to the publicly available Alberta low Cr non-pyropic garnets in the database, there are more than 2,100 “non-eclogitic” crustal-derived Fe (almandine), Mn (spessartine) or Ca (grossular) rich garnets that have been recovered to date. These garnets are plotted on scatter plots of MgO versus FeO and Na_2O versus TiO_2 in Appendix 3. A number of these crustal derived garnets, in particular from the central foothills region of SAB, yield elevated to highly anomalous concentrations of Na and Ti that overlap with Type I eclogitic garnets that exist as inclusions in diamonds or are derived from true eclogitic mantle (Appendix 3). It is likely that the Na and Ti composition of these non-mantle derived garnets reflect the original chemical composition of the crustal hostrock that they are derived from and not a relationship to mantle temperature and pressure gradients, confirming the suggestion by Grütter and Quadling (1999) that the use of Na_2O in eclogitic garnets as an indication of mantle pressure conditions is suspect.

Based upon scatter plots of MgO vs. FeO and the regional distribution map for Alberta (Appendices 3 and 8), possible eclogitic garnets are sparsely distributed throughout NAB and SAB with the exception of the central Foothills region. SAB appears to yield a much larger number of eclogitic garnets, however, the SAB dataset is highly skewed based upon the large central foothills dataset that resulted from a large number of samples yielding possible eclogitic garnets collected by a joint venture between Cameco, Uranerz and DiaMet (Appendix 8). The foothills joint venture dataset yields approximately 385 possible eclogitic garnets from more than 180 separate sample sites. If the foothills dataset is ignored, the plains region of NAB and SAB yield very similar numbers of sites yielding possible eclogitic garnets and total number of possible eclogitic garnets. Excluding the foothills joint venture dataset, a total of 82 possible eclogitic garnets have been recovered from 61 sites north of 54^o latitude and a total of 87 possible eclogitic garnets have been recovered from 65 sites south of 54^o (Appendix 8). A total of 10 sites yielding multiple possible eclogitic garnets exist north of 54^o and a total of 9 sites yielding multiple possible eclogitic garnets exist south of 54^o (Appendix 8). The total of 169 possible eclogitic garnets identified in this present study from the Alberta Plains region is about double the number of possible eclogitic garnets originally identified in AGS Bulletin 63 (Dufresne et al., 1996). A total of 174 possible eclogitic Fe-rich garnets were identified in AGS Bulletin 63 (Dufresne et al., 1996), however, the population included 86 garnets that plotted within the diamond inclusion field using a ternary of FeO-MgO-CaO (likely derived from eclogitic mantle) and another 88 garnets outside of and bordering the prospective field (most with unacceptably high concentrations of FeO) that may or may not be derived from eclogite.

The possible eclogitic garnet dataset is shown as a complete dataset in the x-y scatter plots of Appendix 3 and as a dataset with the Cameco foothills joint venture data removed for a couple of reasons. The Cameco foothills possible eclogitic garnet dataset should be treated with caution, firstly, because a large number (more than half) of the sample sites that yield orange possible eclogitic garnets in the foothills dataset yield no other indications of the presence of mantle peridotite or kimberlite, and even a large number of sites that do yield other indicator minerals yield only borderline clinopyroxenes (Appendices 3, 4, 8 and 9). This pattern and strong association with borderline clinopyroxenes suggests possible derivation from crustal granulite rather than eclogite for a number of the orange possible eclogitic garnets. The second reason that the Cameco foothills dataset needs to be treated with caution is that many of the garnets yield analytical totals of almost exactly 100 wt. %. Some of the analytical data appear to have been either normalized or were captured using a Scanning Electron Microscope (SEM), which may yield only semi-quantitative data. In the case of semi-quantitative data, the quality of analyses for trace elements in low concentrations such as TiO_2 and Na_2O may be suspect. The Cameco foothills possible eclogitic garnet population yields a large number of grains with highly elevated concentrations of TiO_2 and Na_2O that are suspect, which should be kept in mind for the following observations.

The scatter plots in Appendix 3 show that there are distinct chemical differences between the eclogitic garnet population of NAB versus SAB, however, there are only a couple of subtle chemical differences that are noticeable in the garnet populations from east to west for the eclogitic garnets. It is unclear whether these differences are the result of fundamental differences in the composition of eclogitic mantle beneath Late Archean to Early Proterozoic crust in NAB versus eclogitic mantle beneath the predominantly Middle Archean aged crust of the Hearne Craton of SAB.

In complete contrast to NAB, eclogitic garnets found in SAB display a wide range of concentrations of TiO_2 from negligible to more than 1.2 wt. % that is particularly well illustrated on a scatter plot of CaO vs. TiO_2 (Appendix 3). Interestingly, the high Ti (>0.4 wt. % TiO_2) eclogitic garnets found in SAB are almost exclusively restricted to west of 114^o longitude (Appendices 3 and 8). The entire population of NAB eclogitic garnets yields only one grain with greater than 0.4 wt. % TiO_2 (Appendix 3). In addition, SAB eclogitic garnets display a wide range in concentrations of Na_2O from negligible up to more than 0.4 wt. % Na_2O, which is suggestive of the presence of significant amounts of the preferred Group I eclogitic mantle (McCandless and Gurney, 1989; Schulze, 1997) beneath central to southern Alberta. As with Ti, the high Na (>0.07 wt. % Na_2O) eclogitic garnets are almost exclusively restricted to west of 114^o longitude (Appendices 3 and 8). This data likely indicates that a significant source of Group I eclogitic mantle yielding Ti and Na enriched eclogitic garnets lies proximal to the mountains and foothills of Alberta, or that these garnets are possibly sourced from crustal granulite derived from a Na and Ti enriched protolith. Although the bulk of the high Ti and high Na eclogitic garnets are derived from the central foothills region, scatter plots of CaO vs. TiO_2 and Na_2O vs. TiO_2 without the Cameco foothills data still show a similar trend of eclogitic garnets enriched in Na and Ti in the plains region of SAB (Appendix 3). Northern Alberta has yielded only a few eclogitic garnets with greater than 0.07 wt. % Na_2O and no grains with greater than 0.11 wt. % Na_2O. A large number of the eclogitic garnets found in SAB yield concentrations of Ti and Na that overlap the concentrations found in eclogitic garnets that have been found as inclusions in diamonds or as part of diamond-bearing eclogite nodules. These eclogitic garnets may indicate that the source eclogitic mantle and the intrusions that have likely transported these garnets to surface may have the potential to contain diamonds. To date, kimberlites have not been found in central to southern Alberta, however, exploration has been sparse compared to NAB. The search for kimberlite should be continued as the potential for diamondiferous Group I eclogite in the upper mantle beneath SAB is at least moderate.

To date, only the Kendu pipe from the Birch Mountains and the surficial samples in the area directly surrounding the K4 pipe from the Buffalo Head Hills have yielded any significant number of eclogitic garnets (Appendices 1 and 3). The Kendu pipe yields a large population of eclogitic xenoliths and eclogitic garnets. For the most part, the eclogitic garnets from these two kimberlites are classified as derived from Group II eclogitic mantle with low concentrations of Ti and Na and therefore of low diamond potential. However, the K4 area does yield two eclogitic garnets with elevated Na_2O (0.07 and 0.08 wt. %) and up to 0.24 wt. % TiO_2 (Appendices 1 and 3). Perhaps this indicates that Group I eclogitic mantle might exist beneath the Buffalo Head Craton although Carlson et al. (1999), indicate that all of the eclogitic garnets recovered from the Buffalo Head Hills kimberlites and analyzed to date yield low concentrations of Na_2O and are likely derived from Group II eclogitic mantle.

6.3 Cr-Diopside

By the end of 1996, AGS Bulletin 63 indicated that chemical analyses were publicly available for 141 Ca-rich clinopyroxenes, of which, a total of 83 were considered mantle derived Cr-diopsides. The current database yields analyses for more than 2,000 clinopyroxenes including 408 clinopyroxene analyses derived from NAB kimberlitic pipes such as the Mountain Lake pipes near Grande Prairie, the Legend, Dragon, Gryphon, Kendu, Roc and Xena pipes in the Birch Mountains, and surficial samples in the immediate vicinity of the K4 pipe from the Buffalo Head Hills (Appendix 9). The regional sample database yields a total of 513 Cr-diopsides for NAB and a total of 353 Cr-diopsides for SAB using a very loose definition of Cr-diopside: those clinopyroxenes containing greater than 0.5 wt. % Cr_2O_3 and less than 5 wt. % total Fe as FeO (Appendix 9). Overall, the clinopyroxene populations of NAB and SAB are quite similar chemically speaking. In general, Cr-diopsides are well distributed across both NAB and SAB with several areas with no known kimberlites yielding large numbers of Cr-diopsides similar to the concentrations seen in the Buffalo Head Hills surrounding and down-ice of a number of known kimberlites (Appendix 8). Based upon a number of scatter plots there are only a couple of subtle chemical differences between the clinopyroxene populations of NAB and SAB (Appendix 4).

In comparison to Cr-diopsides derived from known kimberlites outside of Alberta and Cr-diopsides recovered from regional samples in the Lac de Gras region, Alberta Cr-diopsides can be characterized by overall low to moderate concentrations of Cr_2O_3 ranging from negligible up 3.56 wt. % (Appendix 4). The bulk of the Cr-diopsides (with <5 wt. % FeO) derived from regional sampling across both NAB and SAB yield less than 2.30 wt. % Cr_2O_3 (Appendix 4). A total of eight SAB Cr-diopsides yield concentrations of Cr_2O_3 ranging from 2.55 to 3.56 wt. % (Appendix 4). Similarly, the bulk of the Cr-diopsides derived from NAB kimberlites in the database yield concentrations of Cr_2O_3 ranging from about 0.5 up to about 2.6 wt. % (Appendices 1, 4 and 9). Almost all of the clinopyroxenes derived from NAB kimberlitic rocks yield less than 5 wt. % total Fe as FeO (Appendices 1, 4 and 9).

The clinopyroxene database yields a large population of diopsides with high FeO and negligible to 1 wt. % Cr_2O_3 for both NAB and SAB (Appendices 1, 4 and 9). It is quite likely that most of these diopsides are crustal derived or if derived from kimberlite related intrusions represent diopsides derived from shallow depths within the upper mantle where pyrope garnets are not likely present, from metasomatized mantle or from a highly evolved magma.

Based upon a plot of Al_2O_3 versus Cr_2O_3 for peridotitic clinopyroxenes (after Ramsay and Tompkins, 1994), it appears that clinopyroxenes derived from pyrope-bearing and spinel-bearing peridotite (most likely lherzolite) appear to be represented in both NAB and SAB (Appendix 4). The Birch Mountain pipes yield clinopyroxenes that also appear to be derived from both pyrope-bearing peridotite and spinel-bearing (pyrope free) peridotite (Appendix 4). In particular, the Xena and Kendu pipes appear to yield clinopyroxenes from spinel-bearing (pyrope free) peridotite or alternatively from eclogite based upon the high concentrations of Na and Al in some of the clinopyroxenes (Appendix 4). Northern Alberta yields equally significant populations of low Al_2O_3 and high Al_2O_3 peridotitic clinopyroxenes perhaps indicating that a roughly equal mixture of pyrope-bearing peridotite and spinel-bearing (pyrope free) peridotite is the predominant upper mantle assemblage beneath NAB (Appendix 4). The data indicate that both pyrope and spinel-bearing peridotitic assemblages are well represented from east to west across NAB. However, there are a couple of distinct populations with slight compositional differences that can be seen from east to west in the peridotitic clinopyroxenes. A distinct high Cr_2O_3 (1.5 to 3 wt. %), low Al_2O_3 (<2 wt. %) “on-craton”-type population of clinopyroxenes, likely derived from pyrope-bearing peridotitic mantle, are present in north-central Alberta, spatially coincident with the Buffalo Head Craton (Appendix 4). This unique population of clinopyroxenes does not appear to be present anywhere else in NAB or in SAB. In addition, the eastern portion of NAB yields a population of clinopyroxenes with 0.5 to 1.2 wt. % Cr_2O_3 and from 6 to 9 wt. % total Fe as FeO (Appendix 4). This population also exists in SAB but does not appear to be present west of 114^o in NAB (Appendix 4). Southern Alberta yields a significantly larger population of low Al clinopyroxenes versus high Al clinopyroxenes, perhaps indicating that the upper mantle of SAB is predominantly comprised of pyrope-bearing peridotite similar to the Buffalo Head Craton of NAB (Appendix 4). Southern Alberta also yields a unique population of high Cr and high Al clinopyroxenes that do not appear to be present in NAB (Appendix 4). The potential source of these clinopyroxenes is unknown but could likely be the result of derivation from non-kimberlitic alkaline ultrabasic rocks (Grütter and Moore, 2003). The NAB database yields a very peculiar, slightly linear trend of moderate to high Na_2O-bearing (up to 7.19 wt. %) clinopyroxenes with a relatively constant concentration of about 1 wt. % Cr_2O_3 and low concentrations (<2 wt. %) of Al_2O_3 (Appendix 4). These diopsides are all derived from the Calling Lake area and they tend to have less than 4 wt. % FeO and low K_2O. These diopsides are potentially kimberlite derived and may indicate the presence of a unique mantle component underlying the Calling Lake area.

The NAB dataset also yields a few clinopyroxenes with high concentrations of Na_2O and Al_2O_3 that are comparable to omphacitic clinopyroxenes found as inclusions in diamonds (Appendix 4). A number of these omphacitic clinopyroxenes or eclogitic clinopyroxenes are found in the Calling Lake, the Buffalo Head Hills and the Peace River areas (Appendix 8). A few potentially eclogitic clinopyroxenes are also present in SAB, particularly near the Montana-Alberta border (Appendix 8).

Northern Alberta clinopyroxenes differ from SAB clinopyroxenes in their distribution pattern with respect to their overall concentration of K_2O versus other elements (Appendix 4). Clinopyroxenes from NAB tend to show a reasonable linear positive correlation of increasing K_2O with increasing Al_2O_3 or Na_2O other than for a few very high K_2O-bearing (1.2 to 1.6 wt. % K_2O) clinopyroxenes (Appendix 4). Southern Alberta K enriched clinopyroxenes display only a weak linear trend of increasing K_2O with increasing in Na_2O at an overall low concentration of Na_2O and no correlation with Al_2O_3 (Appendix 4). The NAB K enriched clinopyroxenes show concentrations of Al_2O_3 ranging from about 2 up to 8 wt. %. Southern Alberta K enriched clinopyroxenes show Al_2O_3 ranging from 2 up to 14 wt. % (Appendix 4). The concentration of K_2O in eclogite-derived clinopyroxene is generally thought to be pressure dependent with increasing concentrations of K_2O indicating derivation from higher pressures and therefore greater depths (McCandless and Gurney, 1989; B. Luth, personal communication, 1998; Harlow, 1999). The bulk of the clinopyroxenes yielding elevated concentrations of K_2O across Alberta, tend to have relatively low Na_2O and low to moderate Al_2O_3 and are not likely derived from eclogitic mantle (Appendix 4). In fact, the bulk of the clinopyroxenes that yield high concentrations of K_2O for both NAB and SAB can be classified as Cr-diopsides. A number of the NAB clinopyroxenes with high K yield from about 0.5 up to 2 wt. % Cr_2O_3 (Appendix 4). Several SAB clinopyroxene grains yield between 3 and up to 4.5 wt. % Cr_2O_3 (Appendix 4). The high K enriched clinopyroxenes from both NAB and SAB display a wide range in the concentration of FeO from about 3 up to more than 13 wt. % (Appendix 4). It is unclear whether these high Cr and high K clinopyroxenes are derived from a high-pressure peridotite or some other rock type. However, Harlow (1999) indicates that Cr-diopsides with elevated K_2O have been found in the Koffiefontein Kimberlite from South Africa. Harlow (1999) suggests that Cr-diopsides with high concentrations of K_2O are likely derived from high pressure peridotite that had to coexist with a highly enriched potassic phase, perhaps indicative of K metasomatism in the upper mantle.

One of the most recent developments in the understanding of mantle processes and lithologies, KIMs and kimberlites has been the development of single grain thermometers and thermobarometers (Doyle, 2002). The Ni in garnet thermometer, Cr in garnet barometer, and Zn in chromite thermometer (Griffin and Ryan, 1994; Canil, 1996) are good examples of the development of temperature and/or pressure dependent single grain thermometers. More recently, a robust single grain thermobarometer has been developed by Nimis and Taylor (2000) and Nimis (2002) for clinopyroxene (Cr-diopside) xenocrysts derived from pyrope-bearing peridotite. The use of this thermobarometer for clinopyroxenes derived from Lac de Gras is well demonstrated by Doyle (2002). Its predominant use is to aid in more accurately establishing the local geothermal gradient for the upper mantle in the particular exploration area that the clinopyroxenes are derived from. With establishment of the local geothermal gradient, more meaningful information concerning the temperature and pressure constraints of the upper mantle and the diamond stability field can be arrived at for a particular area. Constraining the geothermal gradient for a region allows other critical thermometers such as the Ni in garnet thermometer to be far more effective in its prediction of whether certain indicator minerals such as pyrope garnets are derived from the graphite or diamond stable portions of the mantle. Griffin et al. (1999a,b), Pearson et al. (1999) and Doyle (2002) demonstrate that Lac de Gras clinopyroxenes as well as xenoliths show a stepped conductive model geothermal gradient of about 35 mWm^{-2} for those grains and xenoliths yielding temperatures less than 900^oC, shifting to a model geotherm of between 38 to 40 mWm^{-2} between 900 and 1250^oC. Empirically, the cooler the geotherm with more grains plotting within the diamond stability field the more prospective the underlying mantle was for diamonds at the time of kimberlite volcanism. Griffin et al. (1999a, b), Pearson et al. (1999) and Grütter (2002) attribute the shift to a sharp boundary between shallow ultradepleted olivine-rich peridotite (harzburgite), which exists from a depth of about 100 to 150 km and for the most part is within the graphite stability field, to more normal less depleted peridotite beneath 150 km that is predominantly within the diamond stability field.

As an example of the use of the clinopyroxene single grain thermobarometer, calculations have been attempted for clinopyroxenes derived from a number of Alberta pipes using the equations of Nimis and Taylor (2000) and Nimis (2002). The basic assumption in order to get meaningful temperature and pressure estimates from single clinopyroxene grains is that the clinopyroxene grains are in equilibrium with and derived from garnet-bearing peridotite. In order to assess whether the clinopyroxene grains are derived from pyrope-bearing peridotite the discrimination scatter plots of Al_2O_3 vs. Cr_2O_3 (Ramsay and Tompkins, 1994) and MgO vs. Al_2O_3 (Nimis, 2002) were employed (Appendices 1 and 4). In addition, those grains yielding greater than 5 wt. % Cr_2O_3 or less than 0.5 wt. % Al_2O_3 were not used in the calculations as recommended by Nimis (2002). The temperature and pressure diagram for the clinopyroxenes that survived the filters are presented in Appendices 1 and 4. A total of 226 of 408 clinopyroxene grains passed the filter process. Similar to Lac de Gras, the clinopyroxene grains from predominantly the Kendu pipe along with a few grains from the Legend and Xena pipes define a possible low temperature ($<800^oC$) population of grains along a cool conductive model geothermal gradient of about 35 mWm^{-2} (Appendices 1 and 4). Except for a couple of the Legend clinopyroxenes, most of the grains along this cool geotherm plot within the graphite stability field. The most interesting population of clinopyroxene grains were recovered from the Legend pipe and yield a geotherm of about 40 mWm^{-2} (Appendices 1 and 4). The vast majority of 40 mWm^{-2} clinopyroxene grains that yield temperatures between 1000 and 1250^oC from the Legend pipe plot within the diamond stability field (Appendices 1 and 4). Even though only a few diamonds were recovered from the Legend pipe of northeast Alberta, the clinopyroxene data indicates that pyrope-bearing peridotite within the diamond stability field likely existed at a depth below about 150 km in the upper mantle at the time of eruption of the Legend pipe magma (Appendices 1 and 4). Even though most of the Birch Mountain pipes yield no diamonds, the clinopyroxene data for the Legend pipe indicates that peridotite within the diamond stability field did exist in the upper mantle beneath the Birch Mountains at the time of kimberlite volcanism.

Based upon the Nimis (2002) calculations, a third interesting population of clinopyroxene grains, predominantly derived from the Xena pipe yield a temperature range from 250 to 900^oC and pressure range from near surface to about 25 Kb (a depth of about 75 km) along a relatively hot geotherm of about 45 to 50 mWm^{-2} (Appendices 1 and 4). These grains exist within the graphite stability field and at these shallow depths it is unlikely that pyrope garnet is stable. It is possible because of the high Al_2O_3 content of the Xena clinopyroxenes that they may be derived from pyrope-free spinel peridotite or pyrope-bearing peridotite that has undergone some form of metasomatism and that the temperature and/or the pressure estimates are somewhat spurious. Interestingly, the Kendu and the Mountain Lake pipes also show a number of clinopyroxene grains that overlap the Xena low temperature trend of clinopyroxene grains (Appendices 1 and 4). This might suggest that a layer of spinel peridotite at a depth of about 75 km in the upper mantle exists beneath the Birch Mountains of northeast Alberta and the Mountain Lake area of northwest Alberta. Mountain Lake also displays a tight grouping of clinopyroxenes at a temperature of about 1300^{o}C and 45 Kb (within the graphite stability zone) along roughly the same hot geotherm of about 45 to 50 mWm^{-2} as indicated by the lower temperature grains (Appendices 1 and 4).

6.4 Chromite

Bulletin 63 (Dufresne et al., 1996) indicated that chemical analyses were publicly available for a total of 106 magnesium-bearing chromites with 77 from SAB and 29 from NAB. Using a cut-off of greater than 5 wt. % MgO and greater than 20 wt. % Cr_2O_3, the current compilation contains analyses for about 11,879 chromites (Appendices 1, 5 and 9). This includes a total of 908 analyses for chromites recovered from NAB and a total of 10,580 analyses for chromites from SAB (Appendix 9). The bulk of the SAB database is comprised of 9,965 chromite analyses from the central foothills region from the Cameco foothills joint venture and from the Ram River area. The SAB plains region yields analyses for about 615 chromites (Appendix 9). The distribution of chromites is somewhat more widespread for NAB than SAB (Appendix 8). The database also includes 391 analyses for chromites derived from the Mountain Lake pipes near Grande Prairie, the Dragon, Kendu, Legend, Pegasus, Phoenix, Roc, Valkyrie and Xena pipes in the Birch Mountains and from surficial samples near the K4 pipe in the Buffalo Head Hills (Appendices 1, 5 and 9).

Only a few subtle differences are noticeable in the major element chemistry of chromites for southern versus northern Alberta. The SAB chromite population displays a distinct and sizeable population of high Cr (>58 wt. % Cr_2O_3 and >8 wt. % MgO) chromites that could be derived from chromite-bearing peridotite within the diamond stability field (Appendices 5 and 8). These apparent diamond inclusions equivalent chromites derive primarily from three areas; the Cameco joint venture central foothills region, the Ram River area (also within the foothills) and the Milk River area near the Montana-Alberta border in southeast Alberta (Appendices 5 and 8). It is quite likely that the Milk River high Cr chromites are likely magmatic chromites derived from the Sweetgrass minettes based upon the work of Kjarsgaard (1994, 1998). A few high Cr diamond inclusion equivalent chromites have been obtained from NAB from northwest of Edmonton in the Westlock area, the Calling Lake area, the Buffalo Head Hills and the Kakwa River area in the northern foothills region (Appendices 5 and 8).

Only the NAB regional dataset displays a distinct population of high Ti (>2 wt. % TiO_2) and high Cr (>40 wt. % Cr_2O_3) chromites that are likely magmatic chromites derived from kimberlitic and/or lamproitic rocks (Appendix 5). Almost all of the Alberta kimberlitic rocks in the database display an excellent population of high Ti magmatic chromites with a range from 2 to 6 wt. % TiO_2 with greater than 40 wt. % Cr_2O_3 (scatter plots of TiO_2 vs. Cr_2O_3 in Appendices 1 and 5). Fipke et al. (1995) suggest that this population of chromites can only be derived from kimberlites and, to a lesser degree, olivine lamproites. The bulk of the magmatic kimberlitic chromites recovered from NAB are derived from the Calling Lake, Buffalo Head Hills, Swan Hills and the Kakwa River areas (Appendix 8). The SAB dataset displays a population with 2 to 3.5 wt. % TiO_2 and 40 to 50 wt. % Cr_2O_3 (Appendices 5 and 9), which are likely a borderline kimberlitic population of magmatic chromites that may or may not be derived from kimberlites. Almost all of these possible magmatic kimberlitic chromites are derived from either the Cameco joint venture central foothills region or the Ram River area (also in the foothills) of SAB (Appendix 8). Interestingly, this distinct population of chromites has also been noted as present in the Swan Hills (Dufresne and Kim, 2002) and the Kakwa-Wapiti area. All of these areas are characterized by the presence of young Tertiary rocks potentially indicating that the chromites could either be derived from 2nd or 3rd cycle sedimentary reworking of non-kimberlitic ultrabasic intrusions from well to the west or from more local sources of as of yet undiscovered ultrabasic intrusions that may or may not be related to kimberlite.

The SAB chromites display a distinct population of chromites characterized by 58 to 64 wt. % Cr_2O_3, 8 to 15 wt. % MgO and 0.5 to 1.4 wt. % TiO_2 (Appendix 5). These high Cr chromites with elevated Ti are restricted to the Milk River area of SAB between 110^o and 114^o longitude (Appendix 5). This population of chromites is not present in the NAB regional dataset nor are there any chromites from the known kimberlites in the database that match this population. The SAB population of chromites with high Cr and elevated Ti match the high-Cr, low-Ti Mg-chromites described by Grütter and Apter (1998) as part of an early, high pressure, phenocrystic assemblage in kimberlitic magma from a couple of South African kimberlites. Grütter and Apter (1998) also show that these types of chromites can be found in other related alkaline rock types such as alnöites. This unique population of SAB chromites is almost identical to the chromites described by Kjarsgaard (1994, 1998) from the Sweetgrass Minettes, which lie proximal to the area from which these chromites have been recovered. Therefore, it is quite likely that these chromites are derived from the Sweetgrass minettes, or similar yet undiscovered intrusions.

Griffin et al. (1992, 1994a) and Griffin and Ryan (1993, 1995) show that Zn in chromite shows a strong negative correlation with temperature. Therefore, if the geothermal gradient can be constrained for an area by clinopyroxene or orthopyroxene single grain thermometers, Zn in chromite can be used to determine whether chromite-bearing peridotite was derived from the diamond stability field. Griffin et al. (1992,1994a) and Griffin and Ryan (1993, 1995) suggest that diamond stability window chromites are characterized by concentrations of Zn less than 700 ppm and Ni greater than 600 ppm (up to about 1200 ppm) for a normal geothermal gradient. It should be noted that the Zn analyses in the vast majority of chromites in the database that have reported analyses were likely derived from microprobe analyses and are highly suspect at low concentrations of Zn. Only a limited number of chromites from the Alberta Kimberlite database presented in Appendix 9 yield concentrations of Zn and Ni that fall within a normal diamond stability field (Appendices 1 and 5). Mountain Lake is the only occurrence to yield multiple prospective chromites with concentrations of Zn and Ni characteristic of the diamond stability field. Because of the preliminary indications of a hot geotherm indicated by clinopyroxenes derived from the Mountain Lake pipes, even the low-Zn Mountain Lake chromites may not be indicative of chromite-bearing peridotite derived from the diamond stability field. This is somewhat supported by the fact that few if any chromites with favourable major element chemistry indicative of derivation from the diamond stability field have been recovered from the Mountain Lake pipes or any other kimberlitic rocks in the database. Another issue with the Zn in chromite thermometer is whether the chromites are in fact xenocrysts derived from chromite-bearing peridotitic mantle or whether the chromites are phenocrystic and derived from kimberlitic or a related alkaline magma. The application of the Zn thermometer may not be valid on phenocrystic chromites derived from kimberlitic or related alkaline magmas.

6.5 Picroilmenite

Bulletin 63 (Dufresne et al., 1996) indicated that chemical analyses were publicly available for a meagre total of only 30 picroilmenites from across Alberta, with 28 from SAB and 2 from NAB. Utilizing a cut-off of 4 wt. % MgO, the current compilation yields a total 68 picroilmenite analyses from grains derived from regional samples collected across SAB and 184 picroilmenite analyses from grains recovered from NAB (Appendices 6 and 9). Utilizing a cut-off of 8 wt. % MgO (above which picroilmenites are considered to be derived from kimberlite only as discussed by Mitchell, 1989), a total of 40 picroilmenite analyses exist for SAB and 173 analyses for NAB (Appendices 6 and 9). The database also contains 724 picroilmenite analyses (some of which yield <8 wt. % MgO) for grains derived from NAB kimberlites with the bulk of the data coming from the Dragon, Kendu, Legend, Phoenix and Valkyrie pipes in the Birch Mountains (Appendices 1, 6 and 9). The database of picroilmenite analyses from the Birch Mountain pipes includes a number of core-to-rim analyses (Appendices 1, 6 and 9). Scatter plots demonstrating the overall relationship of core to rim chemistry for these grains are included in Appendices 1 and 6.

In general, there are only subtle chemical differences between the picroilmenite populations of southern versus northern Alberta (Appendix 6). Southern Alberta picroilmenites show a large population of borderline kimberlitic picroilmenites with 2 to 6 wt. % MgO and 43 to 57 wt. % total Fe as FeO (Appendix 6). The Valkyrie and Dragon pipes from the Birch Mountains of northeast Alberta display a similar population of Fe-rich, 'oxidized' picroilmenites. The NAB picroilmenite population displays a far greater number of high Mg and high Cr picroilmenites than the SAB population. What few high Cr picroilmenites have been recovered from SAB tends to yield only intermediate concentrations of MgO in contrast to the high Mg and high Cr picroilmenites of NAB (Appendix 6). Mitchell (1989) suggests that picroilmenites with greater than 8 wt. % MgO are for the most part only found in kimberlites. However, picroilmenites with less than 8 wt. % MgO could be derived from evolved and/or 'oxidized' kimberlites or other closely related intrusions. Picroilmenite is predominantly used as an indicator of the oxidation-reduction state of the proto-kimberlitic magma in the upper mantle and during the ascent of the kimberlite magma to surface (Gurney, 1984; Gurney and Moore, 1993; Gurney and Zweistra, 1995). Diamond is predicted to survive better under reducing magmatic conditions during the ascent of the kimberlitic magma, and therefore, kimberlites with large numbers of low Fe picroilmenites are preferred to those with high Fe picroilmenites. The NAB picroilmenite population yields a far larger proportion of low Fe, high Mg picroilmenites that are favoured in diamond exploration programs versus the SAB picroilmenites (Appendix 6). In addition, the NAB high Mg picroilmenites also yield higher concentrations of Cr at higher Mg concentration, also considered a favourable indicator of diamond preservation in the upper mantle and/or during ascent of the kimberlitic magma (Appendix 6).

A number of the Birch Mountain pipes yield favourable low Fe, high Mg and high Cr picroilmenites including the Legend, Kendu, Dragon and Phoenix pipes (Appendices 1 and 6). All four of these pipes display the normal kimberlitic trend of enrichment of Mg and Cr from the core to the rim of the picroilmenite grains (Appendices 1 and 6). The Legend and the Phoenix pipes both yielded a few microdiamonds. The Valkyrie pipe yields a poor population of Fe rich, Mg and Cr poor picroilmenites, especially the cores of the grains, which is likely indicative of oxidizing conditions in the upper mantle and during kimberlite magma ascent (Appendices 1 and 6). One of the interesting features of the Birch Mountain kimberlite field is that each of the pipes that contain picroilmenite displays a chemically distinct population of grains much like a fingerprint (Appendices 1 and 6). The picroilmenite population for each of the kimberlites can be easily distinguished based on both major elements and trace elements (Appendices 1 and 6). Picroilmenites derived from the Legend, Kendu, Phoenix, Dragon and Valkyrie pipes all show high concentrations of Nb and Ni (Appendices 1 and 6) consistent with normal kimberlite values as described by Mitchell (1989). Picroilmenites from the Valkyrie pipe yield the lowest overall concentrations of Ni and, to a lesser degree, Nb but both are well within the normal concentrations for kimberlite. Only a few regionally derived picroilmenites have been analyzed for both Nb and Ni. For those picroilmenite grains that have been analyzed for Nb and Ni, particularly for those grains with greater than 4 wt. % MgO from NAB, the concentrations obtained are consistent with the concentrations expected for kimberlite (Appendix 6).

Using a of 4 wt. % MgO, picroilmenites are well distributed across both NAB and SAB (Appendix 8). However, using a cut-off of 8 wt. % MgO, followed by a cut-off of 8 wt. % MgO combined with greater than 1.5 wt. % Cr_2O_3, the number sites yielding unequivocal kimberlitic picroilmenites greatly decreases (Appendix 8). Multiple sites with multiple grains are really found in only three locations, the Buffalo Head Hills and immediately south, the Calling Lake area and the Cold Lake area. Kimberlites have not yet been found in the Calling Lake or Cold Lake areas, however, they most likely exist, and therefore, these areas represent strong exploration targets. Only a few well-separated single grain sites occur in SAB, with a few sites congregated in the Milk River area near the southern border of the province. It should be noted that the central foothills region has yielded only one or two picroilmenites that could be considered of unequivocal kimberlitic origin shedding doubt on whether the other abundant indicator minerals, in particular chromites and olivine (with only very minor amounts of pyrope garnet) are derived from true kimberlitic rocks in the area.

6.6 Olivine

Exploration by government and industry prior to 1996 had only netted a total of three grains of olivine (Dufresne et al., 1996). The first significant amounts of olivine were identified in the foothills region of central Alberta by the Cameco-Uranerz-DiaMet joint venture during exploration programs conducted from 1992 to 1994 (Drever and Matthews, 1996; Langenberg and Skupinski, 1996). Olivine was found both in present day drainages and in Cretaceous to Tertiary sedimentary sequences (Drever and Matthews, 1996; Langenberg and Skupinski, 1996). In one case, olivine along with a number of microdiamonds was found at Pinto Creek (Ball, 1998a, b, c). The source of the Pinto Creek diamonds and olivine has yet to be pinpointed. Similarly, the original source(s) of most if not all of the foothills olivine has not yet been identified. Langenberg and Skupinski (1996) propose that the source of the foothills olivine may be a number of kimberlites or closely related intrusions that were most likely emplaced during the Middle Cretaceous (110 Ma) and Late Cretaceous (70 Ma).

The present study includes analyses for more than 915 olivines, with 163 olivines from three areas of NAB, 350 olivines predominantly from the Cameco foothills area of south-central Alberta, and 402 olivines from Alberta kimberlites (Appendices 1, 7 and 8). The NAB olivines have been mainly recovered from the Buffalo Head Hills, the Utikuma Lake area and the Calling Lake area (Appendix 8).

Olivine from the Birch Mountain kimberlite field is characterized by normal high Mg with compositions ranging from Mg# of 87 to 93 (Appendices 1 and 7). Concentrations of NiO range from about 0.2 wt. % up to 0.46 wt. %, typical of normal kimberlites (Appendices 1 and 7). A number of the Birch Mountain pipes show a distinct bimodal distribution of olivine on a scatter plot of Mg# versus NiO (Appendices 1 and 7). In particular, the Dragon, Legend and Phoenix pipes show a strong bimodal population of olivines, with the Gryphon, Pegasus and Xena pipes displaying somewhat more subtle bimodal distributions (Appendices 1 and 7). A bimodal distribution for olivine in kimberlites is not unusual and is often a result of the presence of one or more of mantle xenocrysts, megacrystic olivine and magmatic olivine (Appendices 1 and 7).

Olivines recovered by industry and government are chemically similar for the most part between NAB and SAB with a couple of subtle differences. The NAB olivines recovered from regional samples in the areas of the Buffalo Head Hills and Calling Lake overlaps the compositions displayed by the Birch Mountain kimberlite field olivines (Appendix 7). In contrast to the Birch Mountain pipes, the NAB regional samples show a significant number of low Mg (Mg# 75 to 85) and high Ca (0.1 to 0.43 wt. % CaO) olivines (Appendix 7). It is unclear whether these olivines are derived from kimberlite or closely related alkaline intrusions. The SAB olivines show a similar low Mg# population of olivines, however, not quite as many grains with as high a concentration of CaO or as low in Mg# (Appendix 7). The SAB olivines, most of which are from the foothills region, yield an overall higher Mg# in comparison to the NAB samples ranging from 90 to 94 with a few grains as high as Mg# 96 (Appendix 7). Most strikingly, the foothills olivines yield concentrations of Ni ranging from 0.2 wt. % up to 0.54 wt. % with a sizeable population of olivines with concentrations of Ni from 0.46 to 0.54 wt. %, well above the concentrations of Ni in the Alberta Kimberlite olivines and in olivines from NAB regional samples (Appendix 7). Kimberlitic olivines with exceptionally high concentrations of Ni, in some cases up to 0.7 wt. % Ni, are known, hence the concentrations demonstrated by the foothills olivines are not unusual but they are different to the NAB olivines as well as those derived from the known kimberlites. The foothills olivines also show unusually high enrichment in Cr with a population of high Mg olivines yielding 0.2 to 0.5 wt. % Cr_2O_3 (Appendix 7). The olivines from the Alberta kimberlitic pipes in the database and the NAB samples typically display concentrations of below 0.2 wt. % Cr_2O_3 (Appendix 7). The olivines recovered from the south-central foothills region of Alberta are quite chemically distinct from the olivines recovered either from the Birch Mountain pipes or in regional samples from NAB.

Recent sampling conducted by Eccles et al. (2001) has yielded significant amounts of olivine in the Buffalo Head Hills and south of the Buffalo Head Hills in the Utikuma Lake area (Appendix 8). Chemically, the olivines are indistinguishable from the two areas, although Eccles et al. (2001) do not report concentrations of Ni for the olivines. The source of the olivine in the Buffalo Head Hills is likely directly linked to one or more of the known Buffalo Head Hills kimberlite intrusions (Appendix 8). A number of samples, which yield abundant olivine south of Utikuma Lake in the Utikuma upland, lie a minimum of 30 km southwest of the nearest known kimberlite (Ashton's LL07 pipe which is under more than 100 m of overburden) and more than 60 km south of the nearest kimberlite (Ashton's K1 pipe) in the main Buffalo Head Hills cluster of kimberlites (Appendix 8). The source of the olivine in the Utikuma Lake area is likely linked to that of a local kimberlite cluster yet to be identified based upon the strong association with a number of other indicator minerals such as abundant pyrope garnet, Cr-diopside and picroilmenite.

7 Concluding Remarks

Extensive research on and exploration for kimberlites across North America over the last ten years, since the discovery of diamondiferous kimberlites in the Lac de Gras region, has resulted in a much better understanding of the KIMs being recovered across Canada, their chemistry and distribution in glaciated terrains, and their relevance to finding economic diamondiferous kimberlites. The Prairie Provinces, in particular Alberta, present significant challenges to finding kimberlites of which thick and varied glacial overburden is considered the largest obstacle. As a result, ongoing knowledge through the compilation and interpretation of Alberta KIMs is considered extremely important in order to determine those areas of the Province that are considered of high potential for the discovery of diamondiferous kimberlites and therefore maximize exploration expenditures in order to find potential economic kimberlite pipes.

A summary of some of the observations for garnet, clinopyroxene, chromite and ilmenite recovered from across Alberta include the following;

Garnet

- In general, garnets from KIM samples collected to date from across Alberta are dominated by G9 (Gurney, 1984) calcic lherzolitic garnets (considered of low or indeterminate diamond potential) on a scatter plot of Cr_2O_3 versus CaO. Mantle underlying much of Alberta is likely composed of garnet lherzolite.
- G10 subcalcic harzburgitic garnets (considered of high diamond potential) are rare, but are most abundant in NAB where there currently are 17 sites with G10 garnets versus 5 G10 sites in SAB. The G10 sites are mostly in the east half (longitudes 110ºW to 115ºW) of the province. Two regions of high interest include the Calling Lake and Cold Lake-St. Paul areas of northeast-central and northeastern Alberta, respectively. Although mineral chemistry is not yet publicly available for the Ashton kimberlites in the Buffalo Head Hills, Carlson et al. (1999) and Hood and McCandless (2003) indicate that a significant number of favourable G10 pyrope garnets, some with exceptionally high chromium contents (up to 17.8 wt. % Cr_2O_3) have been obtained from several of the kimberlites in the central and northern portion of the Buffalo Head Hills kimberlite field.
- Recent research by Grütter et al. (1999) and Grütter (2002) indicate that high Cr pyrope garnets (both G10 and G9 varieties) are considered of high interest for diamonds. NAB garnets have

significantly higher Cr (in the 8 to 14 wt. % range) and moderately higher Ti content versus garnets recovered from SAB. This is believed to represent a major fundamental difference in the mantle between NAB and SAB. Areas of high Cr pyropes in NAB include: Peace River to Buffalo Head Hills, Calling Lake and the Cold Lake-St. Paul areas.

- In NAB, the pyrope garnets display a noticeable trend of increasing TiO_2 enrichment from west to east, likely reflecting a significant change in the composition of the upper mantle from west to east, possibly due to increased metasomatism from west to east.
- Lastly, NAB possible eclogitic garnets display low concentrations of Na and Ti in comparison to SAB possible eclogitic garnets. Likely indicates a fundamental difference between NAB and SAB eclogitic mantle and may indicate stronger potential for eclogite derived diamonds exists in SAB.

Clinopyroxene

- A large population of Alberta clinopyroxenes fall within the low-Cr suite (<0.5 wt. %) and are likely suspect in terms of being derived from mantle peridotite and kimberlite.
- The majority of the Alberta clinopyroxenes plot in the garnet peridotite paragenetic field of Ramsay and Tompkins (1994) based on discrimination of Al_2O_3 versus Cr_2O_3.
- There is a huge scatter in data and only a few subtly distinct clusters or populations of clinopyroxenes; as an example a unique and distinct high Cr_2O_3 (1.5 to 3 wt. %) and low Al_2O_3 (<2 wt. %) “on-craton”-type population of clinopyroxenes, likely derived from pyrope-bearing peridotitic mantle, are present in north-central Alberta, spatially coincident with the Buffalo Head Craton.
- The NAB database yields a very peculiar, slightly linear trend of moderate to high Na_2O-bearing (up to 7.19 wt. %) clinopyroxenes with a relatively constant concentration of about 1 wt. % Cr_2O_3 and low concentrations (<2 wt. %) of Al_2O_3 in samples derived from the Calling Lake area. These diopsides are potentially kimberlite derived and may indicate the presence of a unique mantle component underlying the Calling Lake area.
- Lastly, a subset population of Cr rich clinopyroxenes for both SAB and NAB have high K_2O (between 0.25 and 0.8 wt. %), which is most often attributed to high-pressure mantle peridotite coexisting with a highly enriched potassic phase, perhaps indicative of K metasomatism in the upper mantle (Harlow, 1999).
- Clinopyroxenes derived from NAB kimberlites yield at least three distinct populations on a plot of temperature versus pressure using the Nimis and Taylor (2000) and Nimis (2002) single grain thermobarometric equations. The Legend kimberlite yields a number of clinopyroxene grains that plot within the diamond stability field for garnet peridotite and indicate a favourably cool geotherm of between 37 and 41 mW/m^2.

Chromite

- Abundant anomalous magmatic chromites exist in western Alberta at the edge of the deformed belt and in the Swan Hills region, both areas with abundant Tertiary rocks. The chromites are distinct and are only marginally kimberlitic based upon Cr, Mg and Ti. The chromites could either be derived from 2nd or 3rd cycle sedimentary reworking of non-kimberlitic ultrabasic intrusions from well to the west or from more local sources of as of yet undiscovered ultrabasic intrusions that may or may not be related to kimberlite.
- High Cr (58 to 70 wt. % Cr_2O_3 and 10 to 16 wt. % MgO) peridotite derived xenocrystic chromites with diamond inclusion like chemistry are rare in Alberta and have been noted in only a few locations in NAB and SAB.
- High Cr_2O_3 (>40 wt. %) and TiO_2 (>1.5 wt. %) chromites are restricted to samples from NAB. Thus, only NAB to date displays the high Ti-Cr magmatic chromite trend characteristic of kimberlite, and clearly present in many of the NAB kimberlites.

Ilmenite

- Abundant true kimberlitic picroilmenites found consistently in NAB in the Buffalo Head Hills, the Chinchaga River area, the Calling Lake area and the Cold Lake area. Kimberlites have not been found to date in the latter three areas. Other areas such as the Kakwa-Wapiti area, the Chain Lakes area and the Milk River area also yield a number of potentially kimberlitic picroilmenites.
- NAB picroilmenites contain lower FeO and higher MgO in comparison to SAB; for example, picroilmenites from NAB form a distinct cluster between 27 to 40 wt. % FeO, and 8 to 16 wt. % MgO.
- NAB picroilmenites tend to have higher Cr (1 to 5.5 wt. % Cr_2O_3) content than SAB picroilmenites, but this could be related to a sample density issue rather than real differences in chrome content between NAB and SAB.

Based upon the data herein, a number of areas display high potential for the future discovery kimberlites, some of which, have high potential to be diamondiferous, including but not limited to the Buffalo Head Hills, Utikuma Lake, Calling Lake and St. Paul to Cold Lake areas. The identification of these areas is based in part due to the discovery of either diamondiferous kimberlite, as is the case for the Buffalo Head Hills, or favourable chemistry of KIMs that has resulted in a number of larger exploration programs in each of these areas.

A number of other areas that have seen much less attention from industry and require further exploration in order to identify the potential for kimberlite pipes and to determine the diamond potential based upon the chemistry of the associated indicator minerals. These areas include the Birch Mountains, the Mountain Lake area, the Caribou Mountains, the Chinchaga River area, the Peace River to Spirit River area, the Kakwa-Wapiti River area, the Edmonton area, the south-central foothills region and much of central to SAB across the Prairies where little diamond exploration has occurred historically.

8 References

Armstrong, J. P. (2000): The diamond fields of Northern Canada: An exploration and development history for the Northwest Territories and Nunavut, Canada. A presentation made to Alaska Geoscience Group.

Armstrong, J. P. (2001): A preliminary digital compilation of kimberlite indicator mineral chemistry (KIMC) extracted from publicly available archived assessment filings, Slave Craton and environs, Northwest Territories and Nunavut, Canada. EGS Open File Report 2001-02.

Ball, S. (1998a): Metallic and Industrial Mineral Assessment Report on the Geological, Geophysical, Geochemical and Drilling for the Masumeka-Troymin Claim Block. Unpublished Assessment Report Prepared on behalf of Kennecott Canada Exploration Inc., Alberta Geological Survey Mineral Assessment Report 9707.

Ball, S. (1998b): Metallic and Industrial Mineral Assessment Report on the Geological, Geophysical, Geochemical and Drilling for the New Claymore Claim Block. Unpublished Assessment Report Prepared on behalf of Kennecott Canada Exploration Inc., Alberta Geological Survey Mineral Assessment Report 9708.

Ball, S. (1998c): Metallic and Industrial Mineral Assessment Report for the Geological, Geophysical, and Geochemical on the Rich Claim Block. Unpublished Assessment Report Prepared on behalf of Kennecott Canada Exploration Inc., Alberta Geological Survey Mineral Assessment Report 9709.

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., (editors), Alkaline Igneous Rocks. Geol. Soc. Lond., Spec. Publ., p. 103-109.

Boyd, F.R. and Gurney, J.J. (1986): Diamonds and he African lithosphere. Science, v. 232, p. 472-477.

Canil D. (1994): An experimental calibration of the 'Nickel in garnet' geothermometer with applications. Contributions to Mineralogy and Petrology, v. 117, p. 410-420.

Canil D. (1996): An experimental calibration of the nickel in garnet geothermometer with applications: reply. Contributions to Mineralogy and Petrology, v. 124, p. 219-223.

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999): The Buffalo Hills Kimberlites: A newly discovered diamondiferous kimberlite province in north-central Alberta, Canada, *In*: The J.B. Dawson volume, Proceedings of the VIIth International Kimberlite Conference, v. 1, p. 109-116.

Clifford, T.N. (1970): The structural framework of Africa. *In:* Clifford, T.N. and Gass, I.G. (editors), African Magmatism and Tectonics. Oliver and Boyd, p. 1-26.

Clifford, T.N. (1966): Tecton-metallogenic units and metallogenic provinces of Africa, Earth and Plan. Sci. Lett., v. 1, p. 421-434.

Cookenboo, H.O., Kopylova, M.G. and Daoud, D.K. (1998): A chemically and texturally distinct layer of diamondiferous eclogite beneath the central Slave Craton, northern Canada, Extended Abstracts, Seventh International Kimberlite Conference, Capetown, South Africa, 1998, p. 164-166.

Danchin, R.V and Wyatt, B.A. (1979): Statistical cluster analysis of garnets from kimberlites and their xenoliths. Kimberlite Symposium II, Cambridge, p. 22-27.

Dawson, J.B. (1980): Kimberlites and their xenoliths. Springer-Verlag, Berlin.

Dawson, J.B. and Stephens, W.E. (1975): Statistical classification of garnets from kimberlite and associated xenoliths. Journal of Geology, v. 83, p. 589-607.

Dawson, J.B. and Stephens, W.E. (1976): Statistical classification of garnets from kimberlite and associated xenoliths - Addendum. Journal of Geology, v. 84, p. 495-496.

Dilabio, R.N.W. and Knight, R.D. (1998): Kimberlite-indicator minerals in Geological Survey of Canada archived till samples: results of analysis of samples from the Baker Lake area and Northern Baffin Island, Northwest Territories, Geological Survey of Canada, Open File Report 3643.

Doyle, B. (2002): A comparison of single grain geothermbarometers from the Slave Craton: Implications for diamond exploration and kimberlite emplacement. Abstract and talk presented at the January 21st, 2002 Diamond Short Course, Vancouver, B.C., Hosted by the BC and Yukon Chamber of Mines, 4 p.

Dredge, L.A., Kjarsgaard, I.M., Ward, B.C., Kerr, D.E. and Stirling, J.A.R. (1995): Distribution and chemistry of kimberlite indicator minerals, Aylmer Lake map area, NWT (NTS 76C), Geological Survey of Canada, Open File Report 3080.

Drever, G. and Matthews, R. (1996): Alberta Diamond Project Hinton Area, 1992-94 Exploration Activities. Unpublished Assessment Report Prepared on Behalf of Cameco Inc. and the Foothills Joint Venture. Alberta Geological Survey, Mineral Assessment Report 9505.

Dufresne, M.B. (2002): Exploration for diamonds in Yukon and the Cordillera. Presentation made at a Diamond Short Course at the 2002 Annual Yukon Geoscience Forum.

Dufresne, M.B., Eccles, D.R., McKinstry, B., Schmitt, D.R., Fenton, M.M., Pawlowicz, J.G. and Edwards, W.A.D. (1996): The Diamond Potential of Alberta; Alberta Geological Survey, Bulletin No. 63, 158 p.

Dufresne, M.B. and Kim, H. (2002): Assessment report for the Swan Hills property, north-central Alberta, Permits 9300070001 to 9300070008, 9300180001 to 9300180022 and 9397120049. Assessment File 20020012, Alberta Geological Survey.

Eccles, D.R. (2004): Petrogenesis of the northern Alberta kimberlite province, M.Sc. Thesis, University of Alberta, Edmonton, Canada, 179 p.

Eccles, D.R., Haynes, M. and Csanyi, W. (2001): Diamond and metallic-mineral potential of the Peerless Lake map area, North-Central Alberta. Alberta Energy and Utilities Board, Alberta Geological Survey, Earth Science Report 2000-08, 67 p.

Eccles, D.R., Dufresne, M.B., Copeland, D., Csanyi, W. and Creighton, S. (2002): Alberta Kimberlite-Indicator Mineral Geochemical Compilation. Alberta Energy and Utilities Board, Alberta Geological Survey, Earth Science Report 2001-20.

Eccles, D.R. and Weiss, J. (2003): Alberta indicator minerals: compilation and observations. Calgary Mineral Exploration Group Short Course, April (2003):

Erlank A.J. and Kushiro I. (1970): Potassium contents of synthetic pyroxenes at high temperatures and pressures. Carnegie Inst. Wash. Yearb., v. 68:23, p. 236

Fipke, C.E., Moore, R.O. and Gurney, J.J. (1989): The development of advanced technology to distinguish between diamondiferous and barren diatremes, Geological Survey of Canada, Open File Report 2124, 1094 p.

Fipke, C.E., Gurney, J.J. and Moore, R.O. (1995): Diamond exploration techniques emphasizing indicator mineral geochemistry and Canadian examples, Geological Survey of Canada Bulletin 423, 86 p.

Friske P.W.B., Prior G.J, McNeil R.J., McCurdy M.W., Day S.J.A. (2003): National geochemical reconnaissance (ngr) stream sediment and water survey in the Buffalo Head Hills area, northern Alberta (parts of NTS 84B, 84C, 84F, and 84G) including analytical, mineralogical and kimberlite indicator mineral data from silts, heavy mineral concentrates and waters; Alberta Energy and

Utilities Board - Alberta Geological Survey, Special Report 66 / Geological Survey of Canada, Open File 1790.

Griffin, W.L., Cousens, D.R., Ryan C.G., Sie, S.H. and Suter, G.F. (1989): Ni in chrome pyrope garnets: a new geothermometer. Contributions to Mineralogy and Petrology, v. 103, p. 199-202.

Griffin, W.L., Doyle, B.J., Ryan, C.G., Pearson, N.K., O'Reilly, S.Y., Davies, R., Kivi, K., Van Achterbergh, E. and Natapov, L.M. (1999a): Layerd mantle lithosphere in the Lac de Gras area, Slave Craton: Composition, Structure and Origin. Journal of Petrology, v. 40, No. 5, p. 705-727.

Griffin, W.L., Doyle, B.J., Ryan, C.G., Pearson, N.K., O'Reilly, S.Y., Natapov, L., Kivi, K., Kretschmar, U. and Ward, J. (1999b): Lithosphere structure and mantle terranes: Slave Craton, Canada. *In:* J.J. Gurney, J.L Gurney, Pascoe, M.D. and Richardson, S.H. (editors), The J.B Dawson vume, Proceedings of the Seventh International Kimberlite Conference, Capetown, South Africa, vume 1, p. 299-306.

Griffin, W.L., Moore, R.O., Ryan, C.G., Gurney, J.J. and Win T.T. (1997): Geochemistry of magnesian ilmenite megacrysts from southern African kimberlites. *In:* Diamonds: Characterization, Genesis and Exploration, vume 2, Proceedings of the Sixth International Kimberlite Conference, Russian Geology and Geophysics, v. 38, p. 421-443.

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, p. 185-212.

Griffin, W.L. and Ryan C.G. (1995): Trace elements in indicator minerals: Area selection and target evaluation in diamond exploration. Journal of Geochemical Exploration, v. 53, p. 311-337.

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):

Griffin, W.L., Ryan, C.G., Gurney, J.J., Sobolev, N.V. and Win, T.T. (1994a): Chromite macrocrysts in kimberlites and lamproites: geochemistry and origin. *In:* H.O.A. Meyer and O.H. Leonardos (editors), Kimberlites, Related Rocks and Mantle Xenoliths, Proceedings of the Fifth International Kimberlite Conference, vume 1, Araxa, Brazil, 1991, CPRM Special Publication 1A, p. 142-144.

Griffin, W.L., Ryan, C.G., O'Reilly, S.Y., Nixon, P.H. and Win, T.T. (1994b): Trace elements in garnets from Tanzanian kimberlites: Relation to diamond content and tectonic setting. *In:* H.O.A. Meyer and O.H. Leonardos (editors), Diamonds: Characterization, Genesis and Exploration, vume 2, Proceedings of the Fifth International Kimberlite Conference, Araxa, Brazil, 1991, CPRM Special Publication 1B, p. 346-356.

Grütter, H.S. (2002): Regional mapping of the Slave Craton Root. Abstract and talk presented at the January 21st, 2002 Diamond Short Course, Vancouver, B.C., Hosted by the BC and Yukon Chamber of Mines.

Grütter, H.S. and Moore, R.O. (2003): Pyroxene geotherms revisited - an empirical approach based on Canadian xenoliths. 8th International Kimberlite Conference, Extended Abstracts.

Grütter, H.S. and Apter, D.B. (1998): Kimberlite- and lamproite-borne chromite phenocrysts with "diamond inclusion"–type chemistries. Proceedings of the Seventh International Kimberlite Conference, Capetown, SA, April, 1998, Extended Abstracts, p. 280 – 282.

Grütter, H.S., Apter, D.B. and Kong, J. (1999): Crust-Mantle coupling: Evidence from mantle-derived xenocrystic garnets. *In:* J.J. Gurney, J.L Gurney, Pascoe, M.D. and Richardson, S.H. (editors), The

J.B Dawson vume, Proceedings of the Seventh International Kimberlite Conference, Capetown, South Africa, vume 1, p. 307-313.

Grütter, H.S. and Quadling, K.E. (1999): Can sodium in garnet be used to monitor eclogitic diamond potential? *In:* J.J. Gurney, J.L Gurney, Pascoe, M.D. and Richardson, S.H. (editors), The J.B Dawson vume, Proceedings of the Seventh International Kimberlite Conference, Capetown, South Africa, vume 1, p. 314-320.

Gurney, J.J. (1984): A correlation between garnets and diamonds in kimberlites. *In:* Kimberlite Occurrence and Origin: A basis for conceptual models in exploration, J.E. Glover and P.G. Harris (editors), Geology Department and University Extension, University of Western Australia, Publication No. 8, p. 143-166.

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, p. 147-171.

Gurney, J.J. and Zweistra, P. (1995): The interpretation of major element compositions of mantle minerals in diamond exploration. Journal of Geochemical Exploration, v. 53, p. 293.

Haggerty, S.E. (1986): Diamond genesis in a multiply-constrained model. Nature, v. 320, p. 34-38.

Hatton, C.J. (1977): The geochemistry and origin of xenoliths from the Roberts Victor mine, Ph.D. thesis, University of Cape Town.

Harlow, G.E. (1999): Interpretation of Kcpx and CaEs components in clinopyroxene from diamond inclusions and mantle samples. *In:* J.J. Gurney, J.L Gurney, Pascoe, M.D. and Richardson, S.H. (editors), The J.B Dawson vume, Proceedings of the Seventh International Kimberlite Conference, Capetown, South Africa, vume 1, p.321-331.

Helmstaedt, H.H. (1992): Primary diamond deposits: What controls their size, grade and location? *In:* Whiting, B.H., Mason, R. and Hodgson, C.J. (editors), Giant Ore Deposits, Proceedings of the Giant Ore Deposits Workshop, Department of Geological Sciences, Queen’s University, Kingston, Ontario, Canada, p. 15-120.

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, p. 3-72.

Hood, C.T. and McCandless, T.E. (2003): Systematic Variations in Xenocryst Mineral Composition at the Province Scale, Buffalo Hills Kimberlites, Alberta, Canada. 8th International Kimberlite Conference Extended Abstracts, Canada.

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, p. 196-198.

Jaques, A.L., Lewis, J.D. and Smith, C.B. (1986): The kimberlites and lamproites of Western Australia, Geological Survey of Western Australia, Bulletin 132, 268 p.

Jaques, A.L., Lewis, J.D., Smith, C.B., Gregory, G.P., Ferguson, J., Chappell, B.W. and McCulloch, M.T. (1984): The diamond-bearing ultrapotassic (lamproitic) rocks of the West Kimberley region, Western Australia. In Kimberlites I: Kimberlites and Related Rocks, J. Kornprobst (editor), Elsevier, p. 225-254.

Kerr, D.E., Kjarsgaard, I.M., Ward, B.C., Dredge, L.A. and Stirling, J.A.R. (1995): Distribution and chemistry of kimberlite indicator minerals, Winter Lake map area (86 A), Northwest Territories, Geological Survey of Canada, Open File Report 3081, 75 p.

Kirkley, M.B., Gurney, J.J. and Levinson, A.A. (1991): Age, origin and emplacement of diamonds: scientific advances in the last decade. Gems & Gemology, v. 27, No. 1, p. 2-25.

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, v. 84, No. 956, p. 48-57.

Kjarsgaard, B.A. (1992): Is Ni in chrome pyrope garnet a valid diamond exploration tool? Geological Survey of Canada, Current Research, Part E, Paper 92-1E, p. 315-322.

Kjarsgaard, B.A. (1994): Potassic magmatism in the Milk River area, southern Alberta: Petrology and economic potential. Geological Survey of Canada, Current Research, Pat B, Paper 1994-B, p. 59-68.

Kjarsgaard, B.A. (1998): Compositional trends of spinel and mica in alkali minettes, southern Alberta, Canada. Proceedings of the Seventh International Kimberlite Conference, Capetown, SA, April, 1998, Extended Abstracts, p. 435-437.

Langenberg, C.W and Skupinski, A. (1996): The Provenance of KIMs in Bedrock of the Hinton Area, Alberta Foothills. Alberta Geological Survey Open File Report 96-09.

Leckie, D.A., Kjarsgaard, B.A., Peirce, J.W., Grist, A.M., Collins, M., Sweet, A., Stasiuk, L., Tomica, M.A., Eccles, R., Dufresne, M.B., Fenton, M.M., Pawlowicz, J.G., Balzer, S.A., McIntyre, D.J. and McNeil, D.H. (1997): Geology of a Late Cretaceous Possible Kimberlite at Mountain Lake, Alberta – Chemistry, Petrology, Indicator Minerals, Aeromagnetic Signature, Age, Stratigraphic Position and Setting; Geological Survey of Canada, Open file 3441, 202 p.

MacGregor, I.D. and Carter, J.L. (1970): The chemistry of clinopyroxenes and garnets of eclogite and peridotite xenoliths from the Roberts Victor Mine, South Africa. Phys. Earth Plant Interiors, v. 3, p. 391-397.

McCandless, T.E. and Gurney, J.J. (1989): Sodium in garnet and potassium in clinopyroxene: criteria for classifying mantle eclogites. *In:* J. Ross (editor), Kimberlites And Related Rocks, v. 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, p. 827-832.

McLean, R.C. (2000): Kimberlite indicator mineral analysis: Comparison of the northwest and south peninsulas Snap Lake, NWT. Unpublished undergraduate honours thesis, University of Alberta.

Mitchell, R.H. (1986): Kimberlites: Mineralogy, Geochemistry and Petrology. Plenum Press, New York.

Mitchell, R.H. (1989): Aspects of the petrology of kimberlites and lamproites: some definitions and distinctions. *In:* J. Ross (editor) Kimberlites And Related Rocks, v. 1, Their Composition, Occurrence Origin and Emplacement, Proceedings of the Fourth Kimberlite Conference, Perth, 1986, Geological Society of Australia Special Publication No. 14, p. 7-45.

Mitchell, R.H. (1991): Kimberlites and lamproites: Primary sources of diamond. Geoscience Canada, v. 18, p. 1-16.

Mitchell, R.H. and Bergman, S.C. (1991): Petrology of Lamproites. Plenum Press, New York, 447 p.

New Claymore Resources Inc. (2002): Exploration Update. Unpublished corporate news release dated April 16 (2002):

Nimis, P. (2002): The pressures and temperatures of formation of diamond based on thermobarometry of chromian diopside inclusions. The Canadian Mineralogist, v., 40, p. 871-884.

Nimis, P and Taylor, W.R. (2000): Single clinopyroxene thermobarometry for garnets peridotites. Part I, Calibration and testing of a Cr-in-Cpx barometer and an enstatite-in-Cpx thermometer. Contributions to Mineralogy and Petrology, v. 139, p. 541-554.

Pearson, N.J., Griffin, W.L., Doyle, B.L., O'Reilly, S.Y., Van Achterbergh, E. and Kivi, K. (1999): Xenoliths from kimberlite pipes of the Lac de Gras area, Slave Craton, Canada. *In:* J.J. Gurney, J.L Gurney, Pascoe, M.D. and Richardson, S.H. (editors), The P.H. Nixon vume, Proceedings of the Seventh International Kimberlite Conference, Capetown, South Africa, vume 2, p.644-658.

Pele Mountain Resources Ltd. (2000): Unpublished corporate news release, dated 2000

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.

Ramsay, R.R. and Tompkins, L.A. (1994): The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of the Boa Esperanca and Cana Verde pipes, Corrego D'anta, Minas Gerais, Brazil. *In:* H.O.A. Meyer and O.H. Leonardos (editors), Diamonds: Characterization, Genesis and Exploration, vume 2, Proceedings of the Fifth International Kimberlite Conference, Araxa, Brazil, 1991, CPRM Special Publication 1B, p. 329-345.

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, v. 84, p. 132-139.

Richardson, S.H., Gurney, J.J., Erlank, A.J. and Harris, J.W. (1984): Origin of diamonds in old enriched mantle, Nature, v. 310, p. 198-202.

Ryder, J. and Hourican, P.C. (1997): Report on the 1996 diamond activities and data derived from the programme conducted on the Leek Springs Property, Eldorado, California, USA. Unpublished Assessment Report prepared on behalf of Diadem Resources Ltd., 53 p.

Schulze, D.J. (1995): A guide to the recognition and significance of kimberlite indicator minerals. *In:* Diamonds – Theory and Exploration, a Hands-on Short Course, Geological Association of Canada, Cordilleran Section Short Course 20, 39 p.

Schulze, D.J. (1997): The significance of eclogite and Cr-poor megacryst garnets in diamond exploration. Exploration and Mining Geology, v. 6, No. 4, p. 349-366.

Scott Smith, B.H. (1992): Contrasting kimberlites and lamproites. Exploration and Mining Geology, v. 1, No. 4, p. 371-381.

Scott Smith, B.H. (1995): Petrology and diamonds. Exploration and Mining Geology, v. 4, No. 2, p. 127-140.

Scott Smith, B.H. and Skinner, E.M.W. (1984a): A new look at Prairie Creek, Arkansas. *In:* J. Kornprobst (editor), Kimberlites, I: Kimberlites and Related Rocks. Proceedings of the Third International Kimberlite Conference, Elsevier, Amsterdam, p. 255-283.

Scott Smith, B.H. and Skinner, E.M.W. (1984b): Diamondiferous lamproites. Journal of Geology, vol. 92, p. 433-438.

Shaver, K.C. (1988): Exploration of the Sloan Ranch complex: a diamondiferous kimberlite prospect in Northern Colourado. Min. Eng., v. 40, p. 45-48.

Simpson, M.A. (1993): Kimberlite indicator minerals in Southwestern Saskatchewan. *In:* Dunne, K.P.E. and Grant, B. (editors), Mid-Continent Diamonds. GAC-MAC Joint Annual Meeting, Edmonton, Alberta, May 17-18, 1993, unpublished Program with Abstracts, p. 53-58.

Skelton, D. and Willis, D. (2001): Assessment Report for the Loon Lake, Birch Mountain, Rabbit Lake, and Muddy River Properties. Assessment File 20010007, Alberta Geological Survey.

Skinner, E.M.W. (1989): Contrasting Group I and Group II kimberlite petrology: towards a genetic model for kimberlites. *In:* J. Ross (editor) Kimberlites And Related Rocks, v. 1, Their Composition, Occurrence Origin and Emplacement, Proceedings of the Fourth International Kimberlite Conference, Perth, 1986, Geological Society of Australia Special Publication No. 14, p. 528-544.

Skupinski, A. and Langenberg, C.W. (2002): Petrography of the Mountain Lake Pipe; Alberta Energy and Utilities Board, Alberta Geological Survey, Earth Sciences Report 2000-13.

Smith, C.B., Gurney, J.J., Skinner, E.M.W., Clement, C.R. and Ebrahim, N. (1985): Geochemical character of Southern African kimberlites: a new approach based on isotopic constraints; Transactions Geological Society South Africa, v. 88, p. 267–281.

Smith, C.B., Lucas, H., Hall, A.E. and Ramsay, R.R. (1994): Diamond prospectivity and indicator mineral chemistry: A western Australian prospective. *In:* H.O.A. Meyer and O.H. Leonardos (editors), Diamonds: Characterization, Genesis and Exploration, vume 2, Proceedings of the Fifth International Kimberlite Conference, Araxa, Brazil, 1991, CPRM Special Publication 1B, p. 312-318.

Sobolev, N.V. (1974): Deep-seated inclusions in kimberlites and the problem of the composition of the upper mantle. Izdatel'stvo Nauka, SSSR, English Translation by D.A. Brown, 1977, American Geophysical Union, Washington, D.C., 279 p.

Sobolev, N.V., Pokhilenko, N.P., Grib, V.P., Skripnichenko, V.A., Titova, V.E. (1992): Specific composition and conditions of formation of deep-seated minerals in exploration pipes of the Onega peninsula and kimberlites of Zimnii Coast in the Arkhangelsk province. Russ. Geol. Geophys., v. 33 (10), p. 71–78.

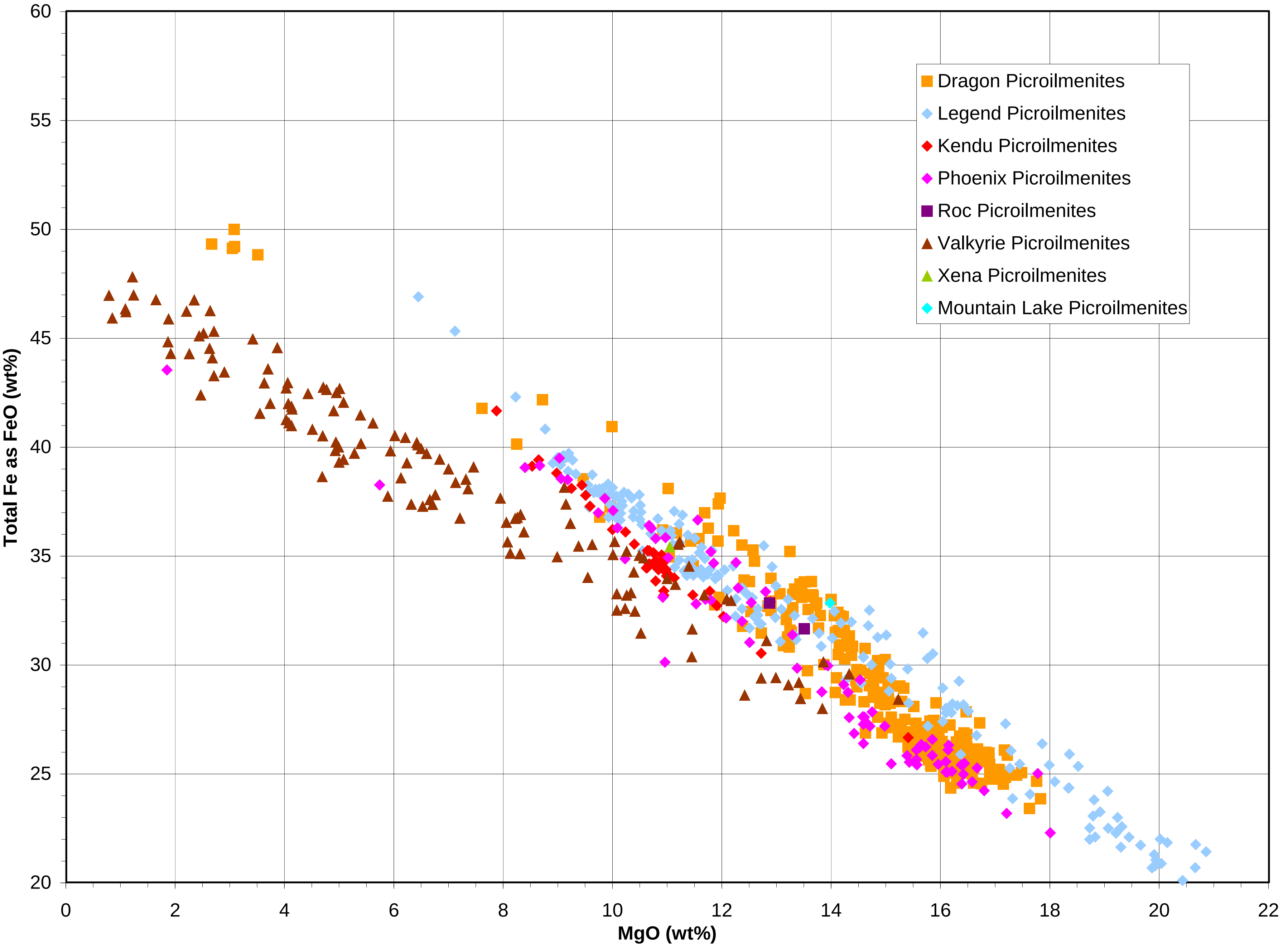
Twin Mining Corporation (2001): Unpublished corporate news release, April 2001.

Wagner, P.A. (1914): The Diamond Fields of Southern Africa, Transvaal Leader, Johannesburg, South Africa.

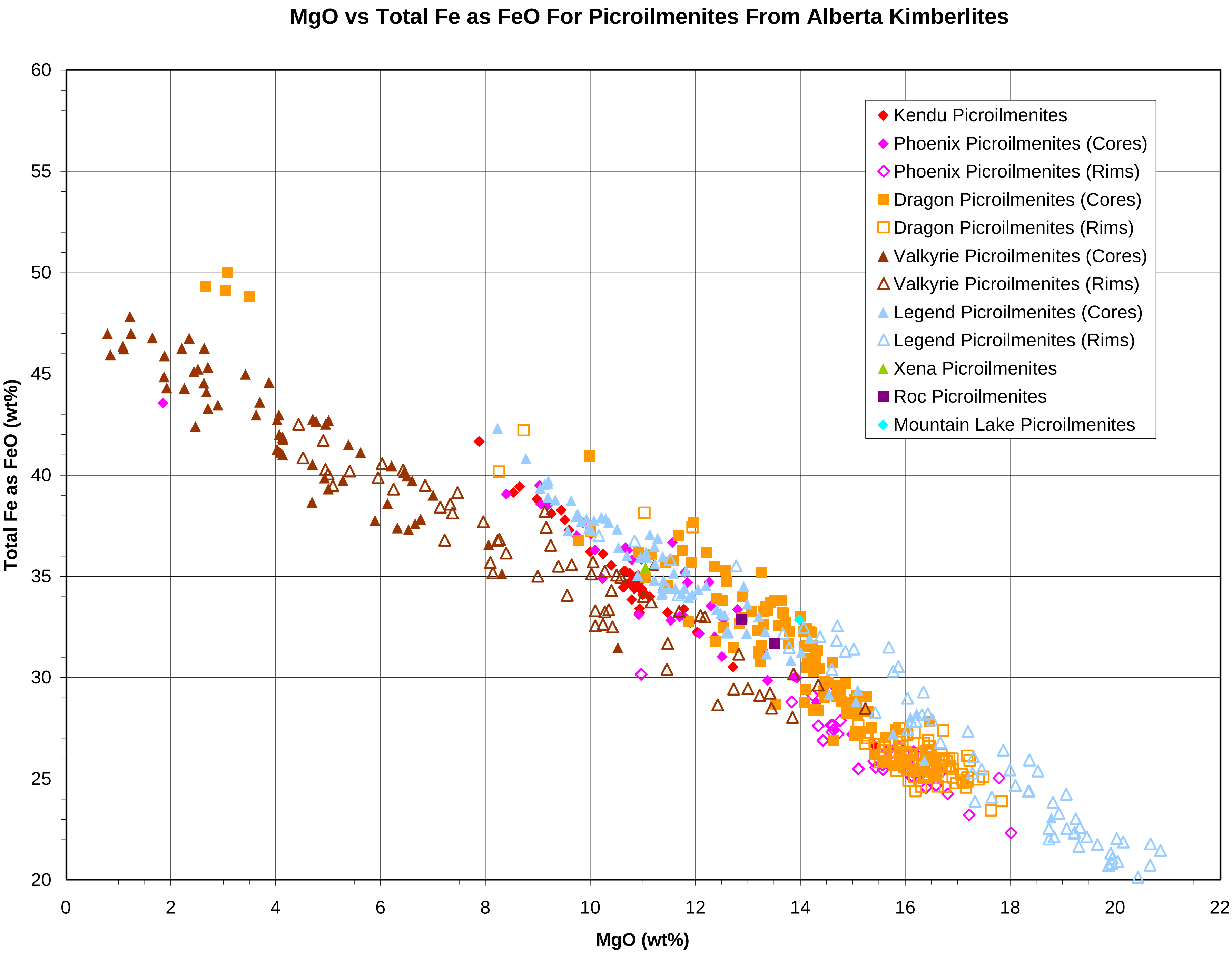
Ward, B.C., Kjarsgaard, I.M., Dredge, L.A., Kerr, D.E. and Stirling, J.A.R. (1995): Distribution and chemistry of kimberlite indicator minerals, Lac de Gras map area (76D), Northwest Territories, Geological Survey of Canada, Open File Report 3079, 95 p.

Wood, B.D. (1999): Geological assessment report, Troymin prospect: sediment sampling, geophysics and exploration drilling. EUB/AGS Assessment File 19990017.

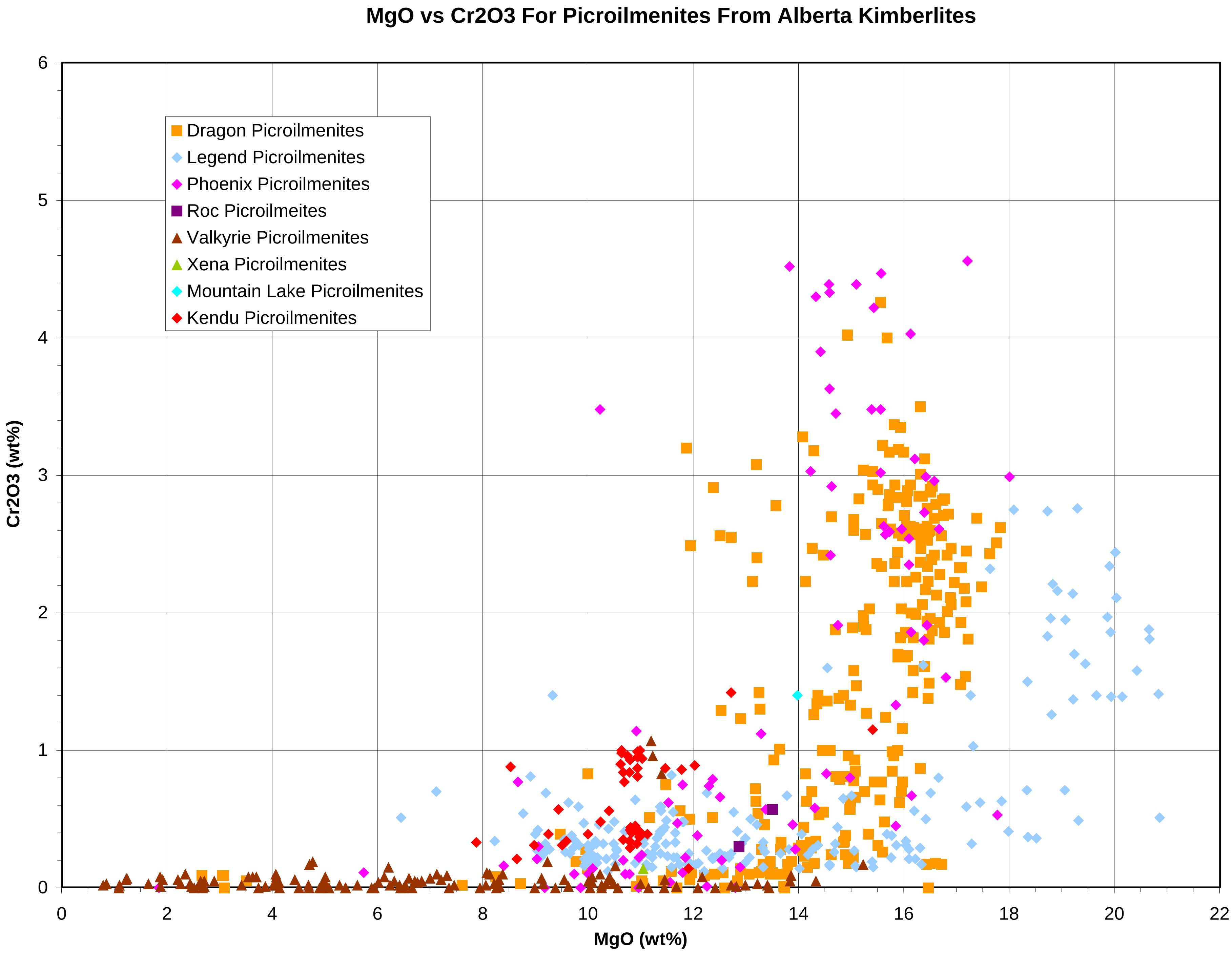
MgO vs Total Fe as FeO For Picroilmenites From Alberta Kimberlites



Appendix 1

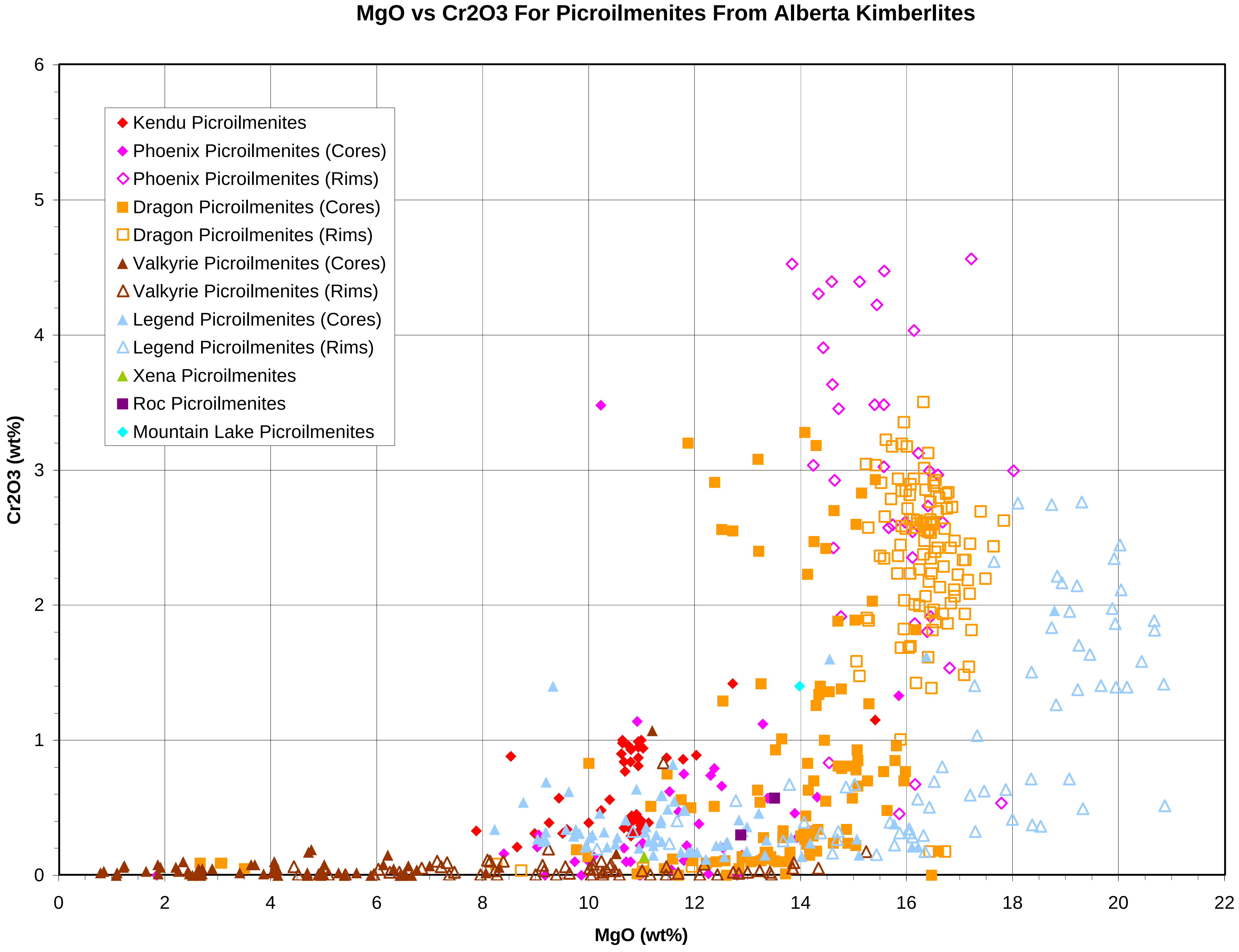

MgO vs Total Fe as FeO For Picroilmenites From Alberta Kimberlites
Total Fe as FeO (wt%)
MgO (wt%)
60
55
50
45
40
35
30
25
20
0
2
4
6
8
10
12
14
16
18
20
22
Kendu Picroilmenites
Phoenix Picroilmenites (Cores)
Phoenix Picroilmenites (Rims)
Dragon Picroilmenites (Cores)
Dragon Picroilmenites (Rims)
Valkyrie Picroilmenites (Cores)
Valkyrie Picroilmenites (Rims)
Legend Picroilmenites (Cores)
Legend Picroilmenites (Rims)
Xena Picroilmenites
Roc Picroilmenites
Mountain Lake Picroilmenites

Appendix 1

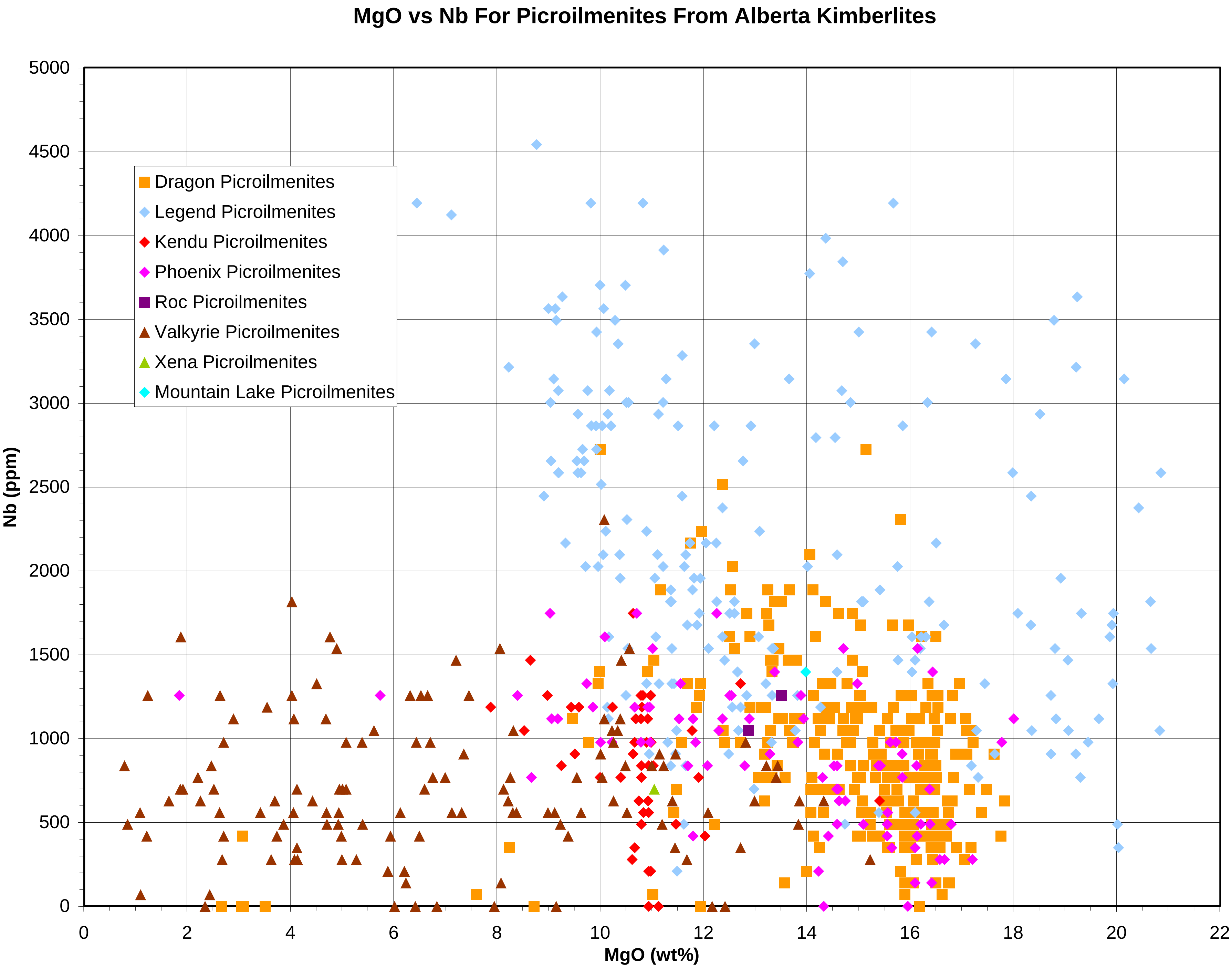


MgO vs Cr2O3 For Picroilmenites From Alberta Kimberlites
Dragon Picroilmenites
Legend Picroilmenites
Phoenix Picroilmenites
Roc Picroilmeites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites
Kendu Picroilmenites
Cr2O3 (wt%)
0
1
2
3
4
5
6
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22

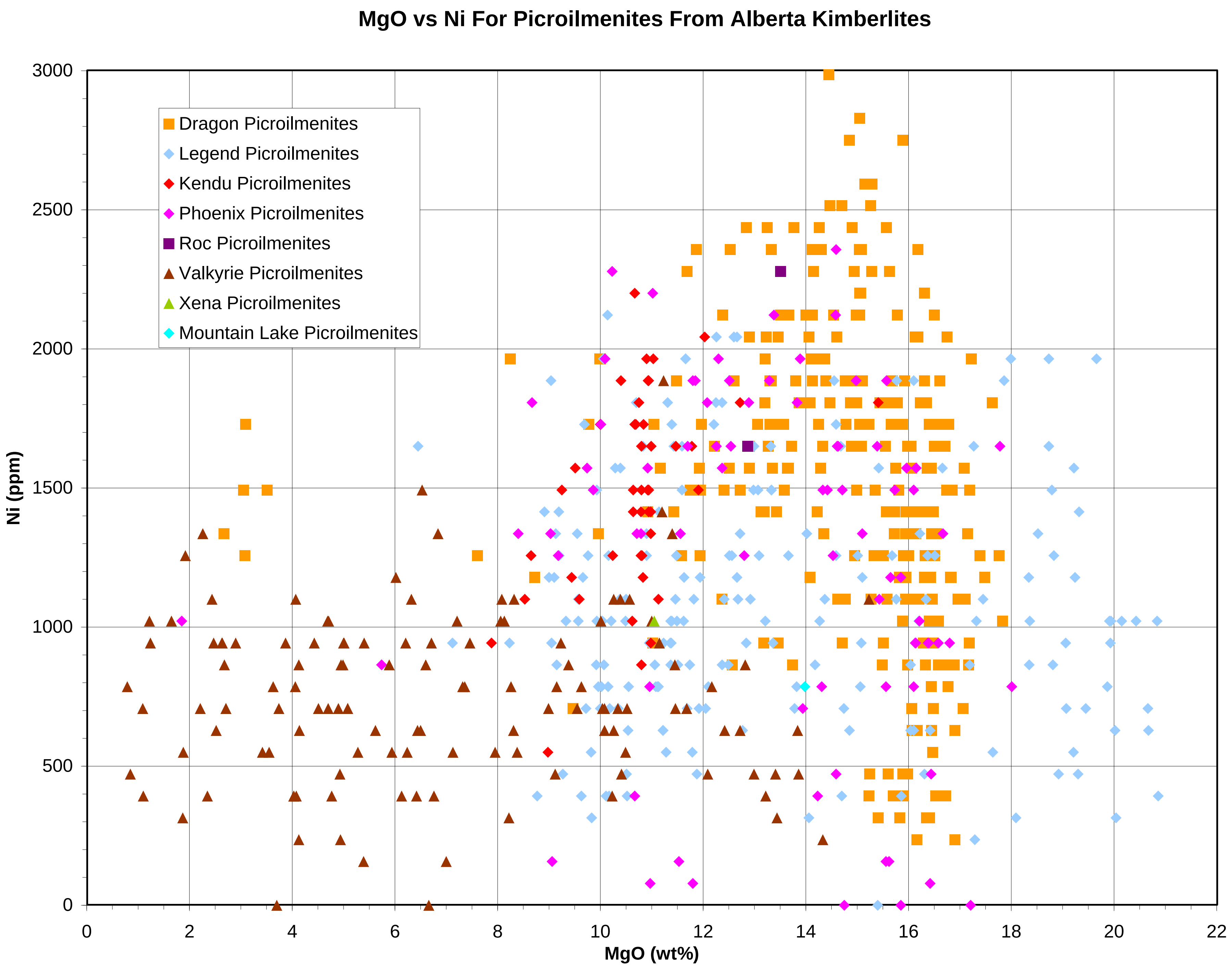
Appendix 1


MgO vs Cr2O3 For Picroilmenites From Alberta Kimberlites
Cr2O3 (wt%)
6
5
4
3
2
1
0
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
Kendu Picroilmenites
Phoenix Picroilmenites (Cores)
Phoenix Picroilmenites (Rims)
Dragon Picroilmenites (Cores)
Dragon Picroilmenites (Rims)
Valkyrie Picroilmenites (Cores)
Valkyrie Picroilmenites (Rims)
Legend Picroilmenites (Cores)
Legend Picroilmenites (Rims)
Xena Picroilmenites
Roc Picroilmenites
Mountain Lake Picroilmenites

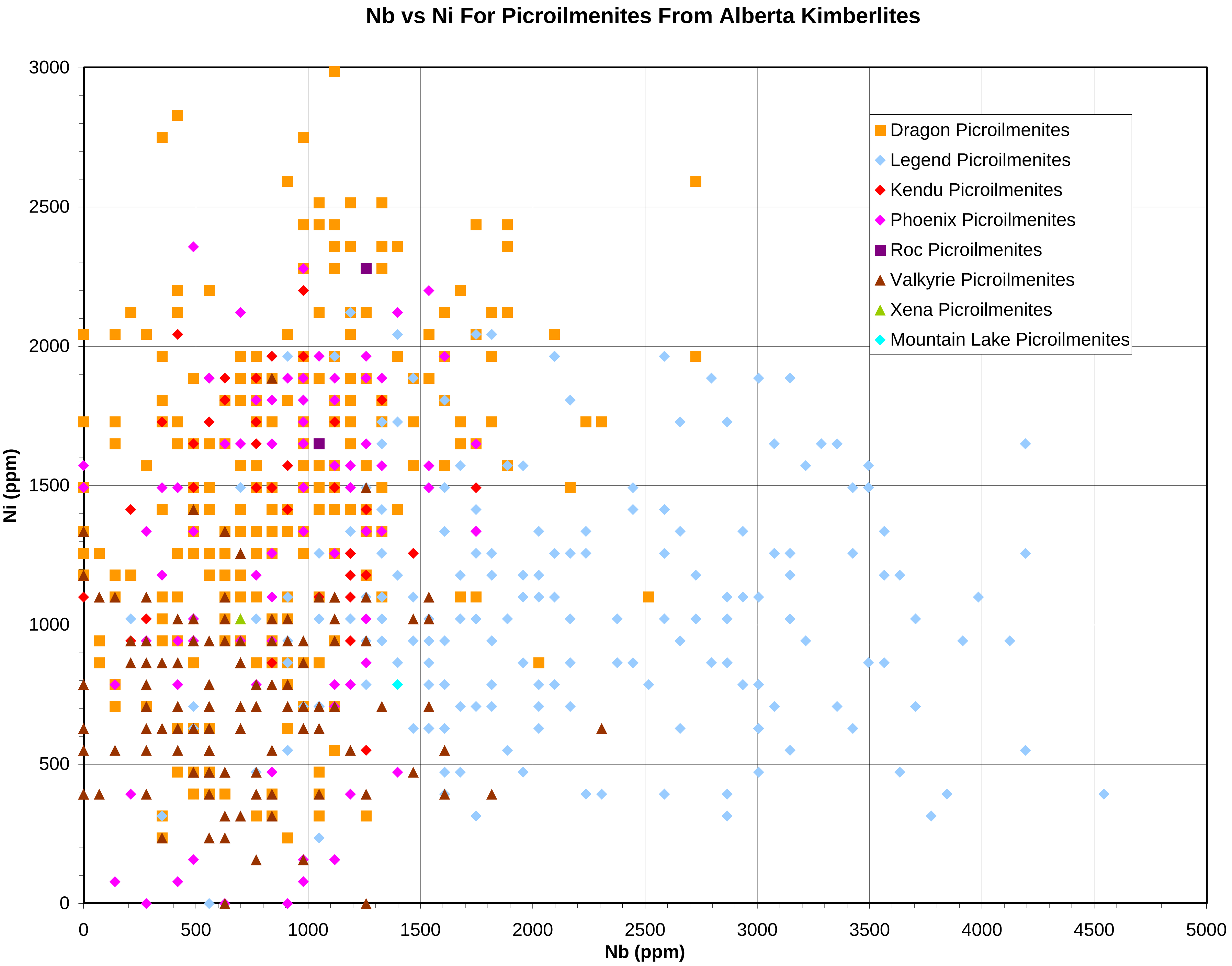
Appendix 1


MgO vs Nb For Picroilmenites From Alberta Kimberlites
Dragon Picroilmenites
Legend Picroilmenites
Kendu Picroilmenites
Phoenix Picroilmenites
Roc Picroilmenites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites
Nb (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22

Appendix 1


MgO vs Ni For Picroilmenites From Alberta Kimberlites
Dragon Picroilmenites
Legend Picroilmenites
Kendu Picroilmenites
Phoenix Picroilmenites
Roc Picroilmenites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites
Ni (ppm)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
18
20
22
MgO (wt%)

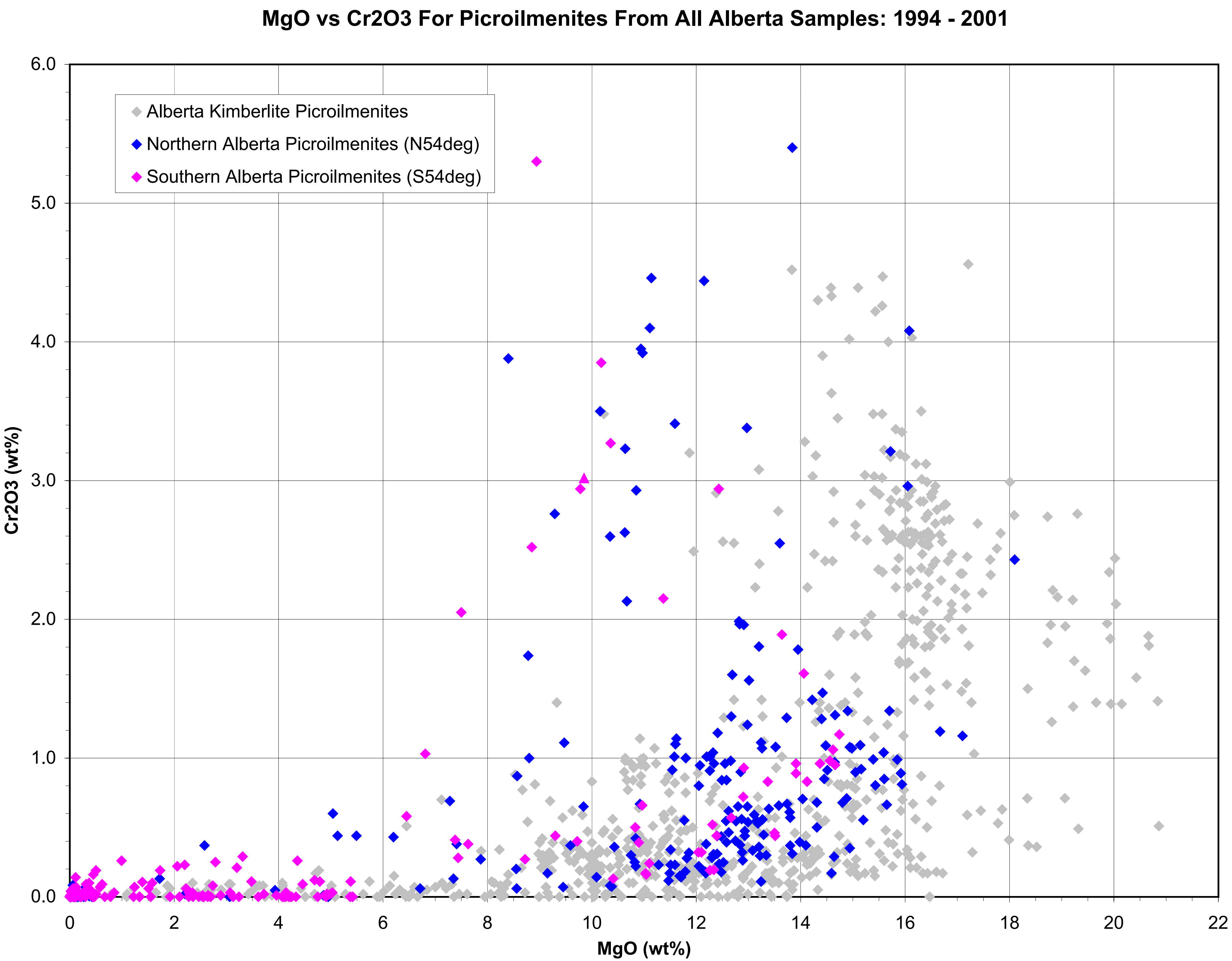
Appendix 1


Nb vs Ni For Picroilmenites From Alberta Kimberlites
Ni (ppm)
Nb (ppm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Dragon Picroilmenites
Legend Picroilmenites
Kendu Picroilmenites
Phoenix Picroilmenites
Roc Picroilmenites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites

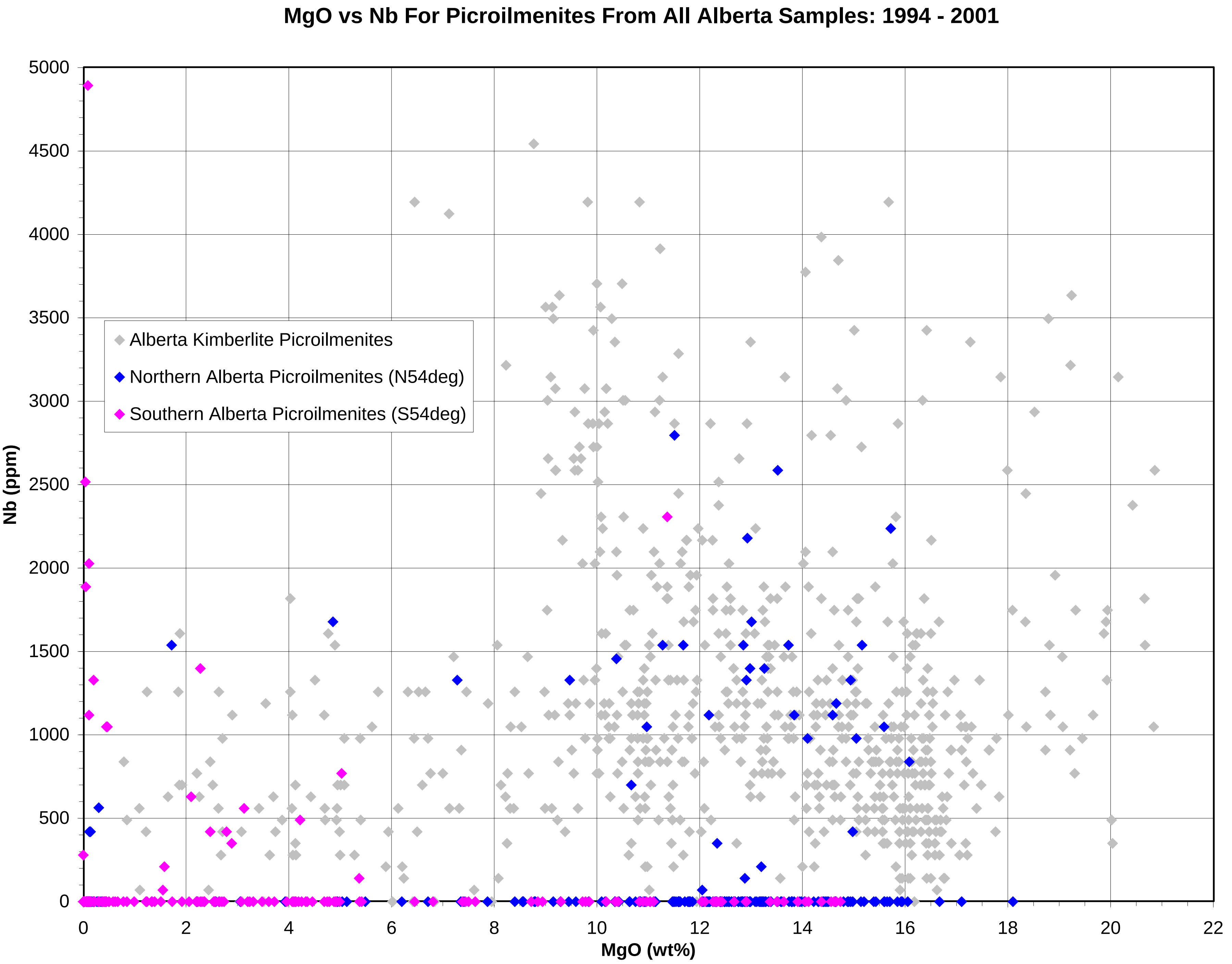
Appendix 1


MgO vs Total Fe as FeO For Picroilmenites From All Alberta Samples: 1994 - 2001
Alberta Kimberlite Picroilmenites
Northern Alberta Picroilmenites (N54deg)
Southern Alberta Picroilmenites (S54deg)
Total Fe as FeO (wt%)
MgO (wt%)
60
55
50
45
40
35
30
25
20
0
2
4
6
8
10
12
14
16
18
20
22

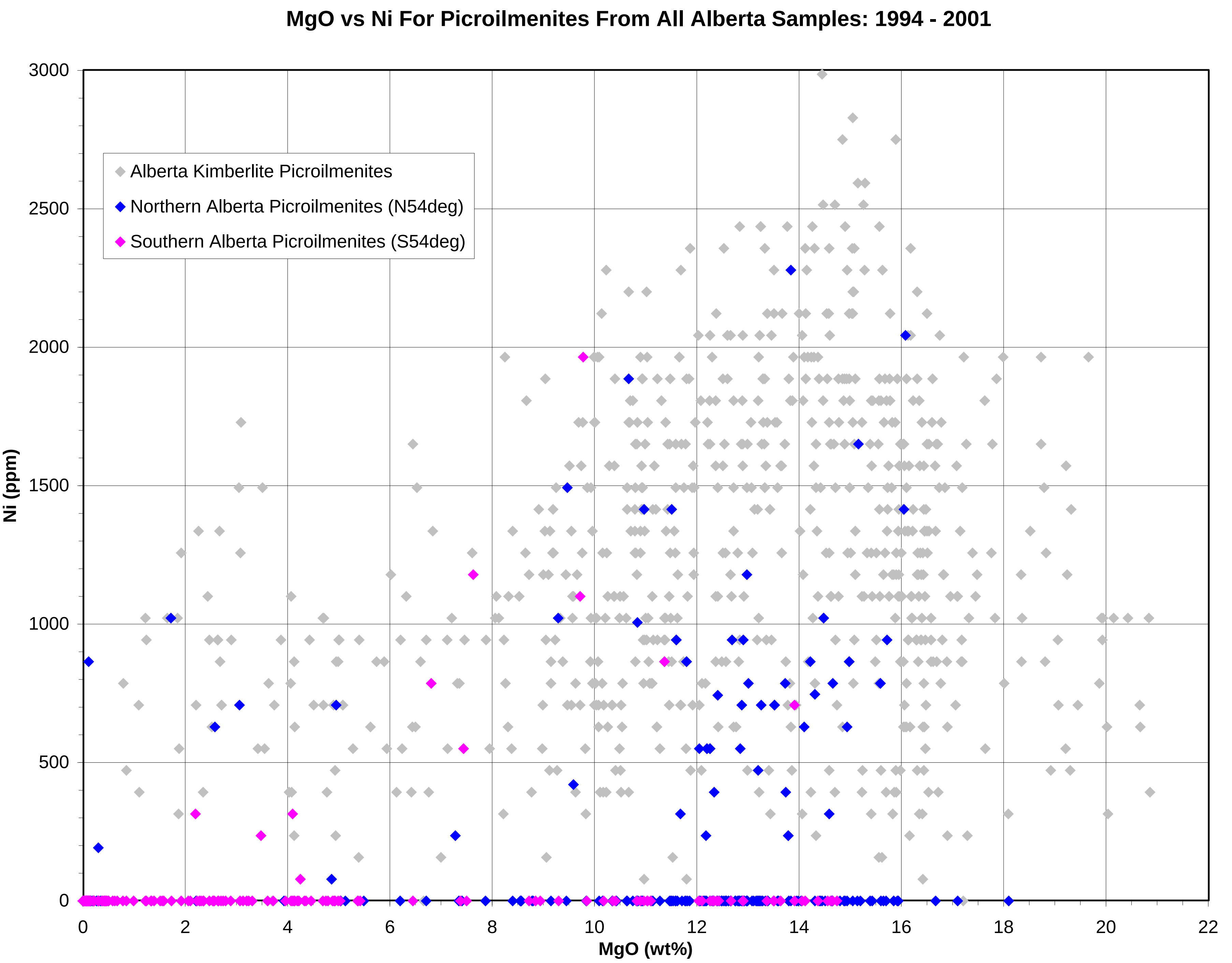
Appendix 1


MgO vs Cr2O3 For Picroilmenites From All Alberta Samples: 1994 - 2001
◆ Alberta Kimberlite Picroilmenites
◆ Northern Alberta Picroilmenites (N54deg)
◆ Southern Alberta Picroilmenites (S54deg)
Cr2O3 (wt%)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2
4
6
8
10
12
14
16
18
20
22
MgO (wt%)

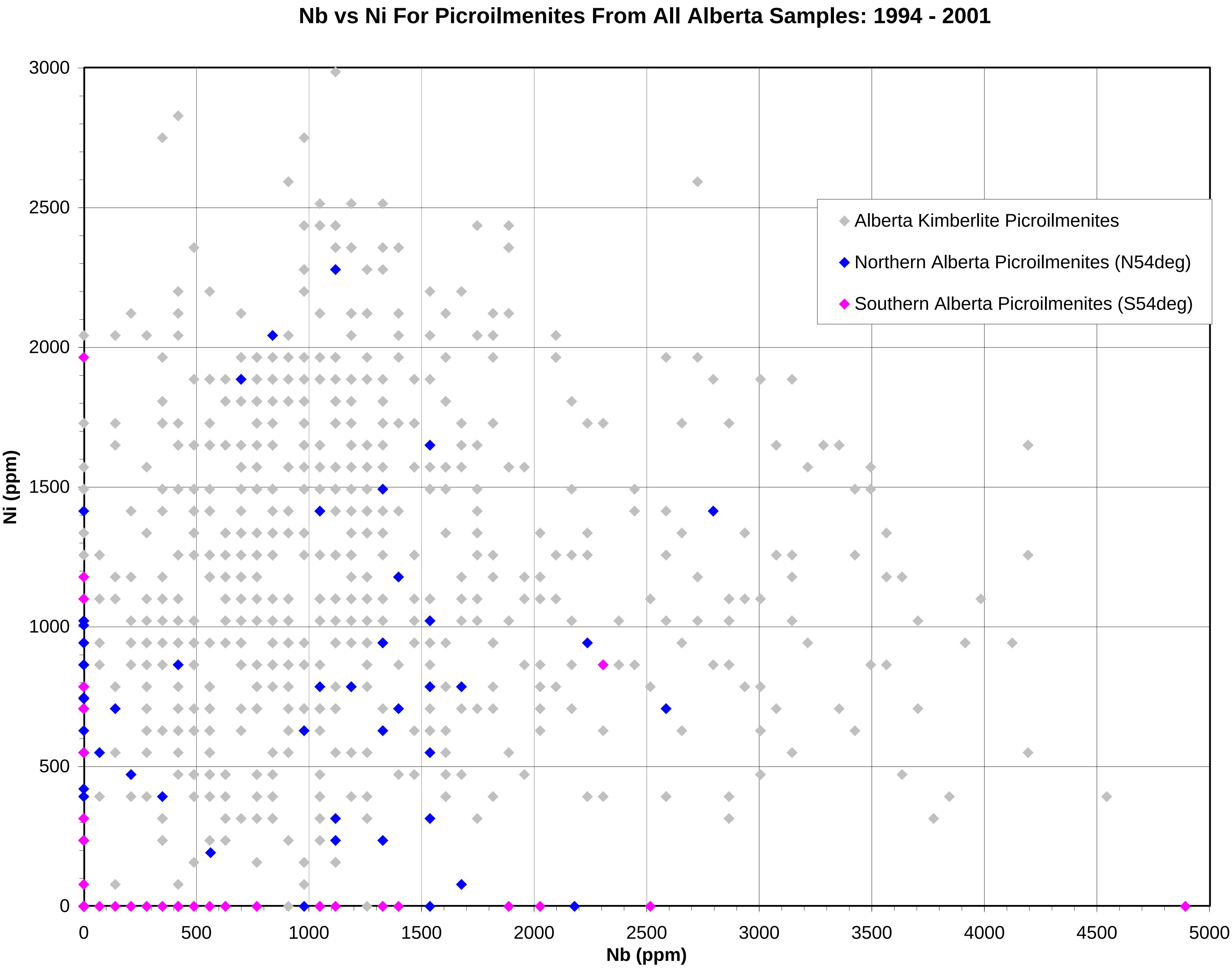
Appendix 1


MgO vs Nb For Picroilmenites From All Alberta Samples: 1994 - 2001
Nb (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
◆ Alberta Kimberlite Picroilmenites
◆ Northern Alberta Picroilmenites (N54deg)
◆ Southern Alberta Picroilmenites (S54deg)

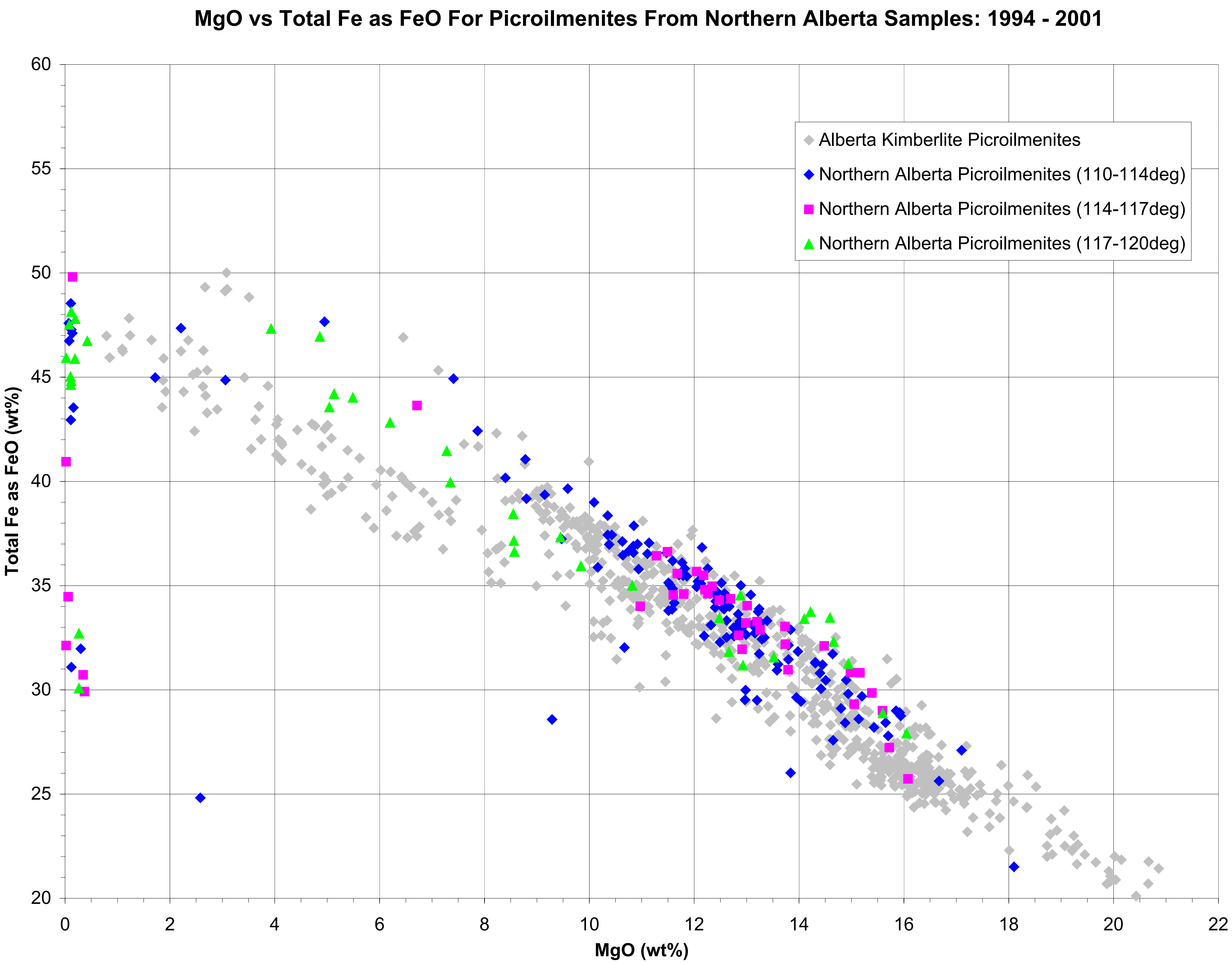
Appendix 1


MgO vs Ni For Picroilmenites From All Alberta Samples: 1994 - 2001
Alberta Kimberlite Picroilmenites
Northern Alberta Picroilmenites (N54deg)
Southern Alberta Picroilmenites (S54deg)
Ni (ppm)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
18
20
22
MgO (wt%)

Appendix 1

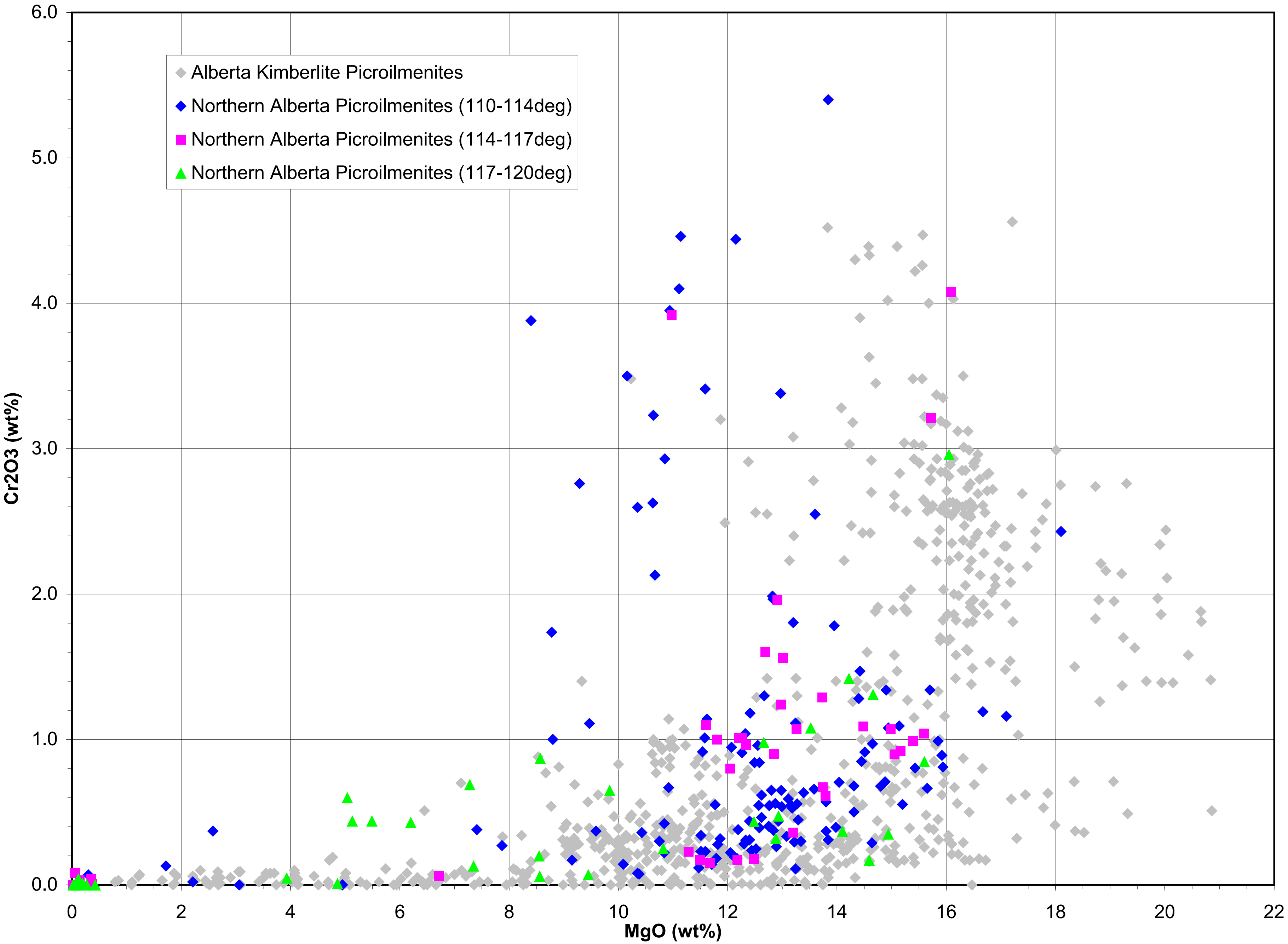

Nb vs Ni For Picroilmenites From All Alberta Samples: 1994 - 2001
Ni (ppm)
Nb (ppm)
0
500
1000
1500
2000
2500
3000
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
◆ Alberta Kimberlite Picroilmenites
◆ Northern Alberta Picroilmenites (N54deg)
◆ Southern Alberta Picroilmenites (S54deg)

Appendix 1

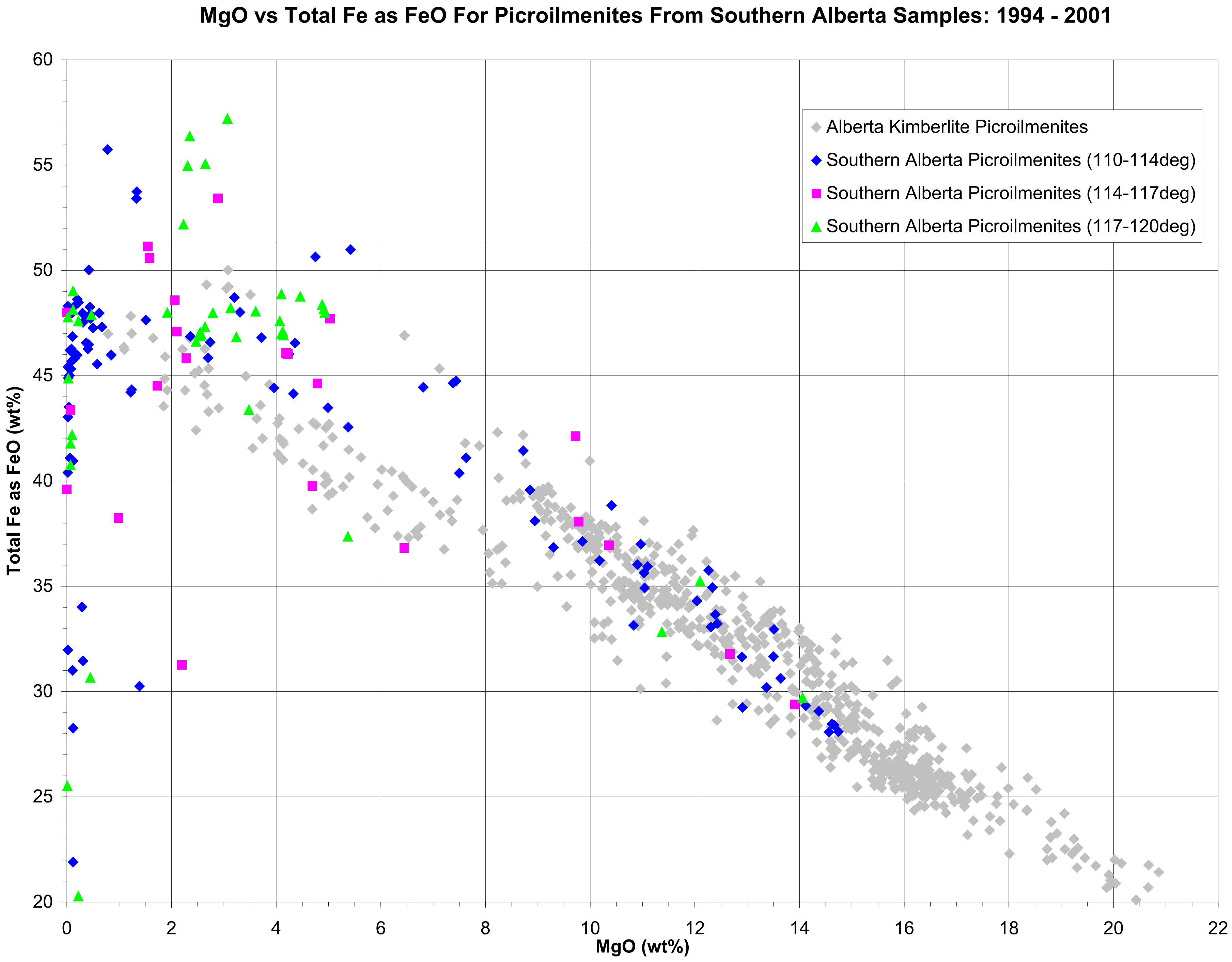

MgO vs Total Fe as FeO For Picroilmenites From Northern Alberta Samples: 1994 - 2001
Total Fe as FeO (wt%)
60
55
50
45
40
35
30
25
20
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
◆ Alberta Kimberlite Picroilmenites
◆ Northern Alberta Picroilmenites (110-114deg)
■ Northern Alberta Picroilmenites (114-117deg)
▲ Northern Alberta Picroilmenites (117-120deg)

Appendix 1

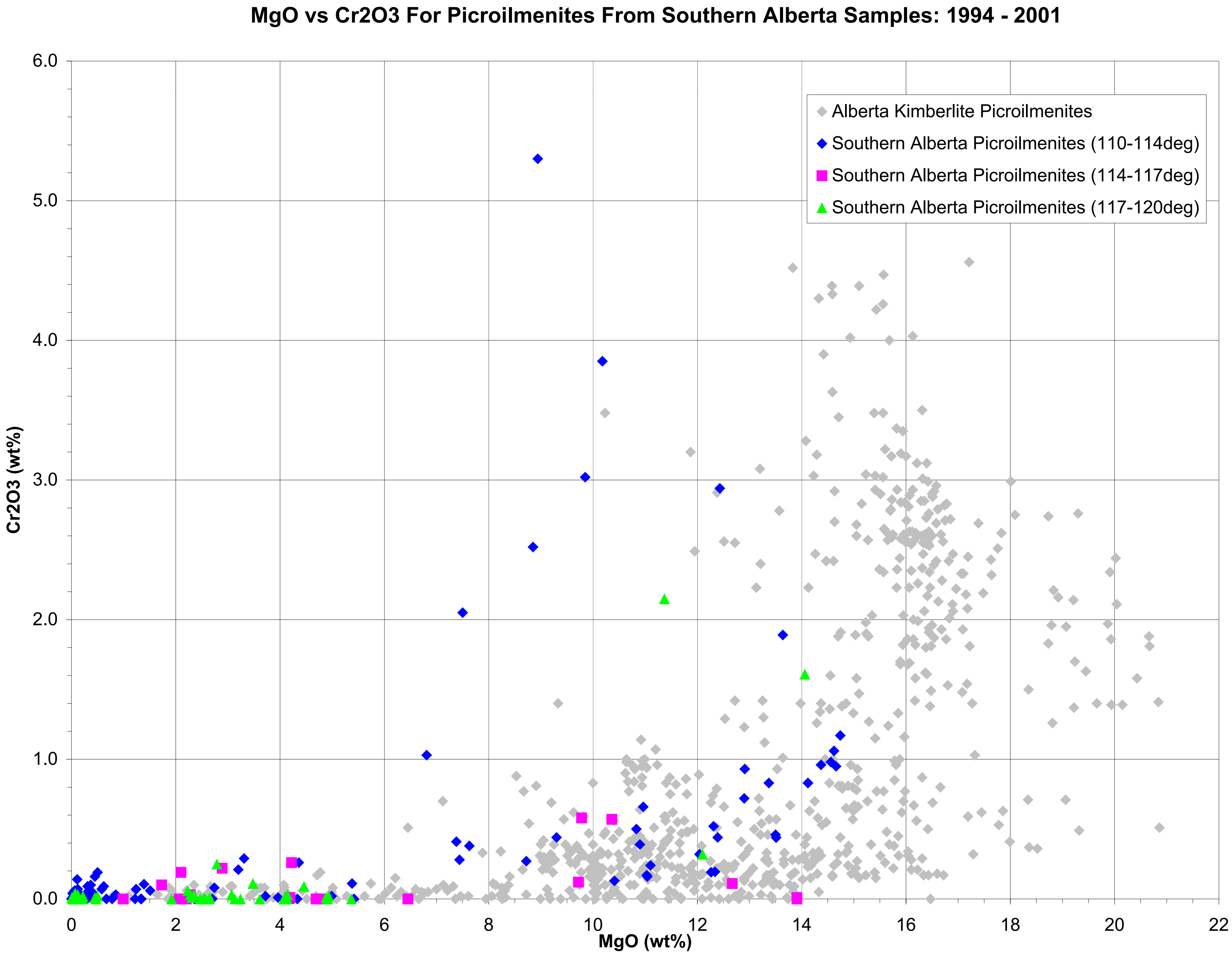
MgO vs Cr2O3 For Picroilmenites From Northern Alberta Samples: 1994 - 2001



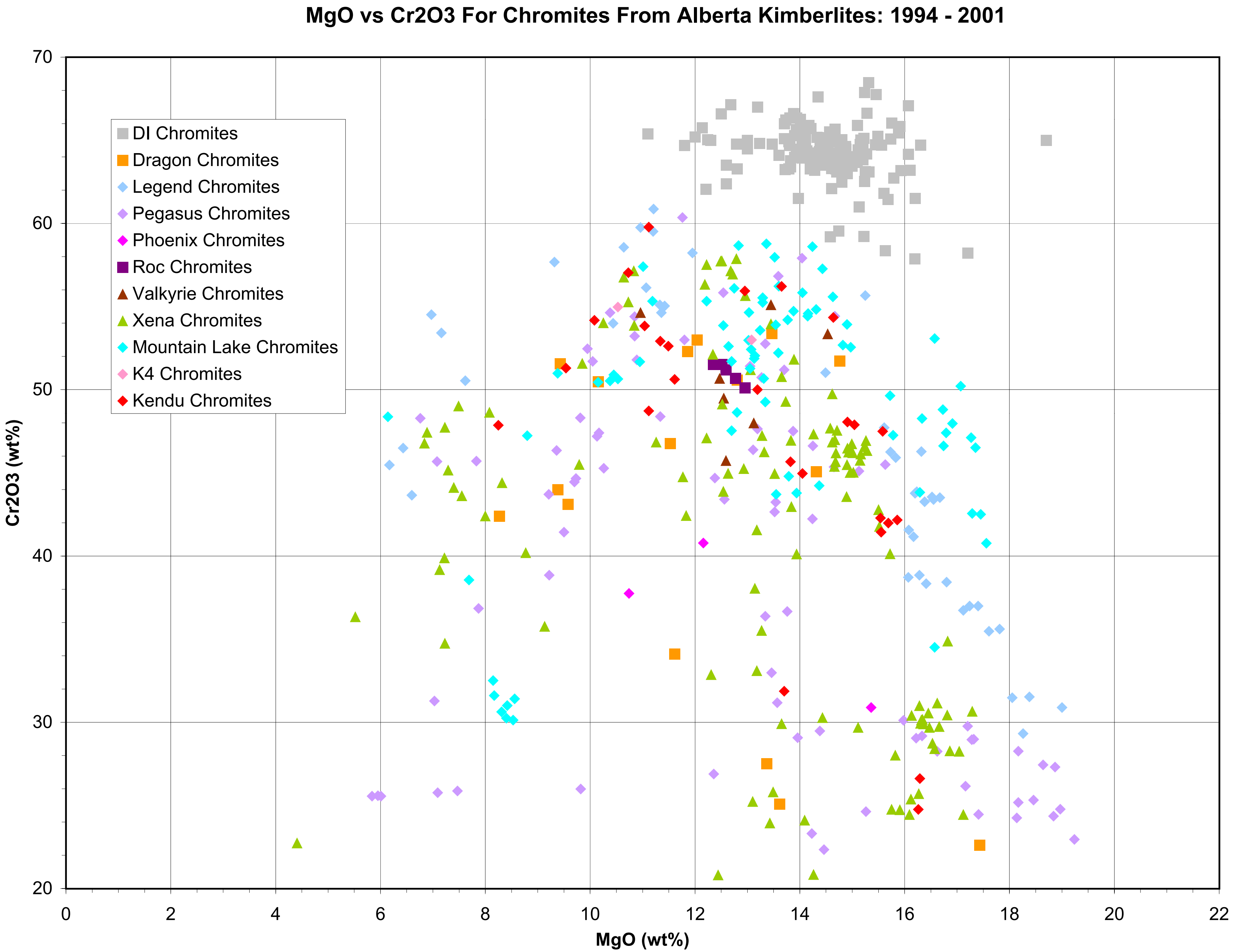
Appendix 1


MgO vs Total Fe as FeO For Picroilmenites From Southern Alberta Samples: 1994 - 2001
Total Fe as FeO (wt%)
MgO (wt%)
60
55
50
45
40
35
30
25
20
0
2
4
6
8
10
12
14
16
18
20
22
◆ Alberta Kimberlite Picroilmenites
◆ Southern Alberta Picroilmenites (110-114deg)
■ Southern Alberta Picroilmenites (114-117deg)
▲ Southern Alberta Picroilmenites (117-120deg)

Appendix 1

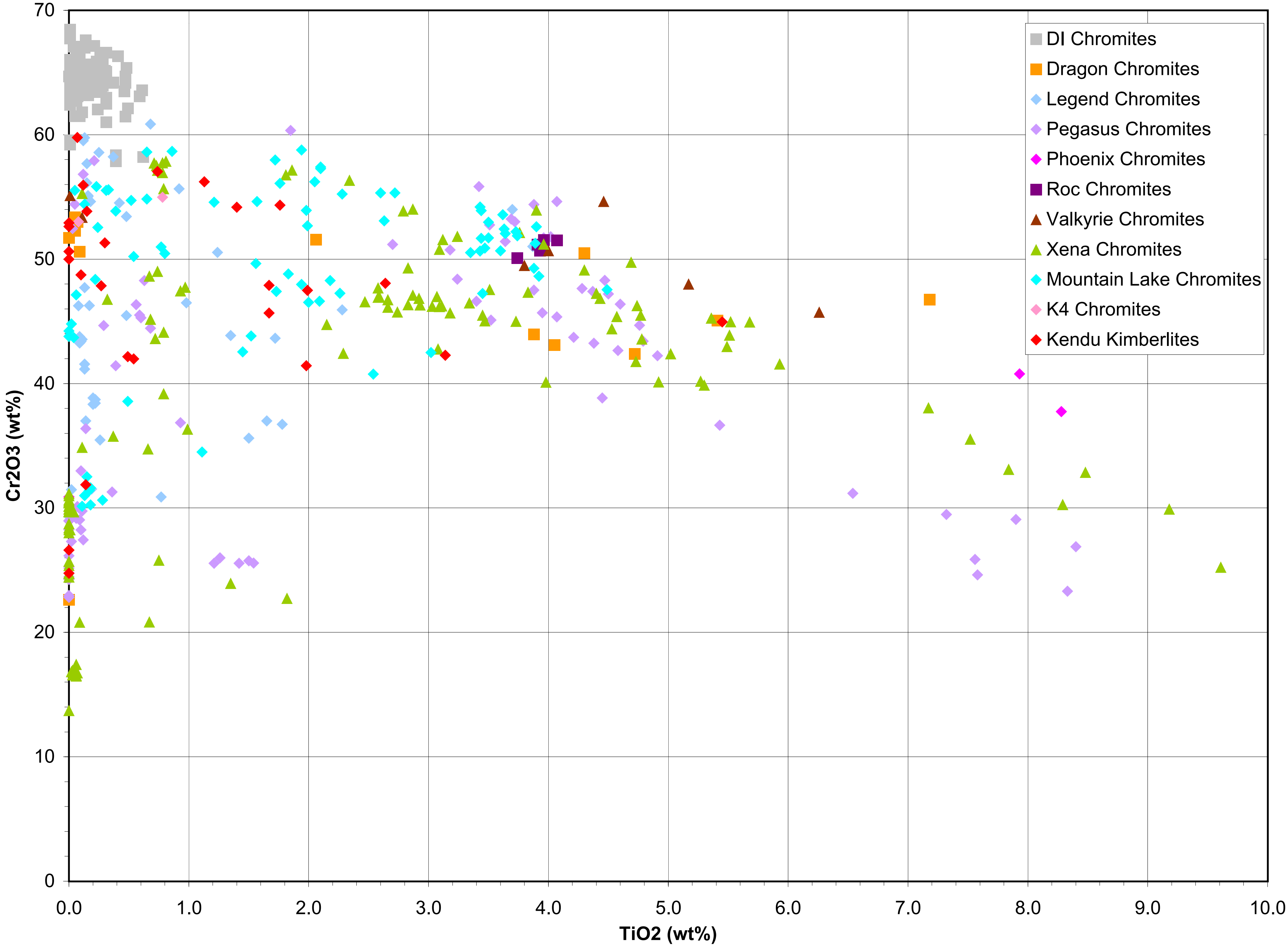

MgO vs Cr2O3 For Picroilmenites From Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
MgO (wt%)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2
4
6
8
10
12
14
16
18
20
22
Alberta Kimberlite Picroilmenites
Southern Alberta Picroilmenites (110-114deg)
Southern Alberta Picroilmenites (114-117deg)
Southern Alberta Picroilmenites (117-120deg)

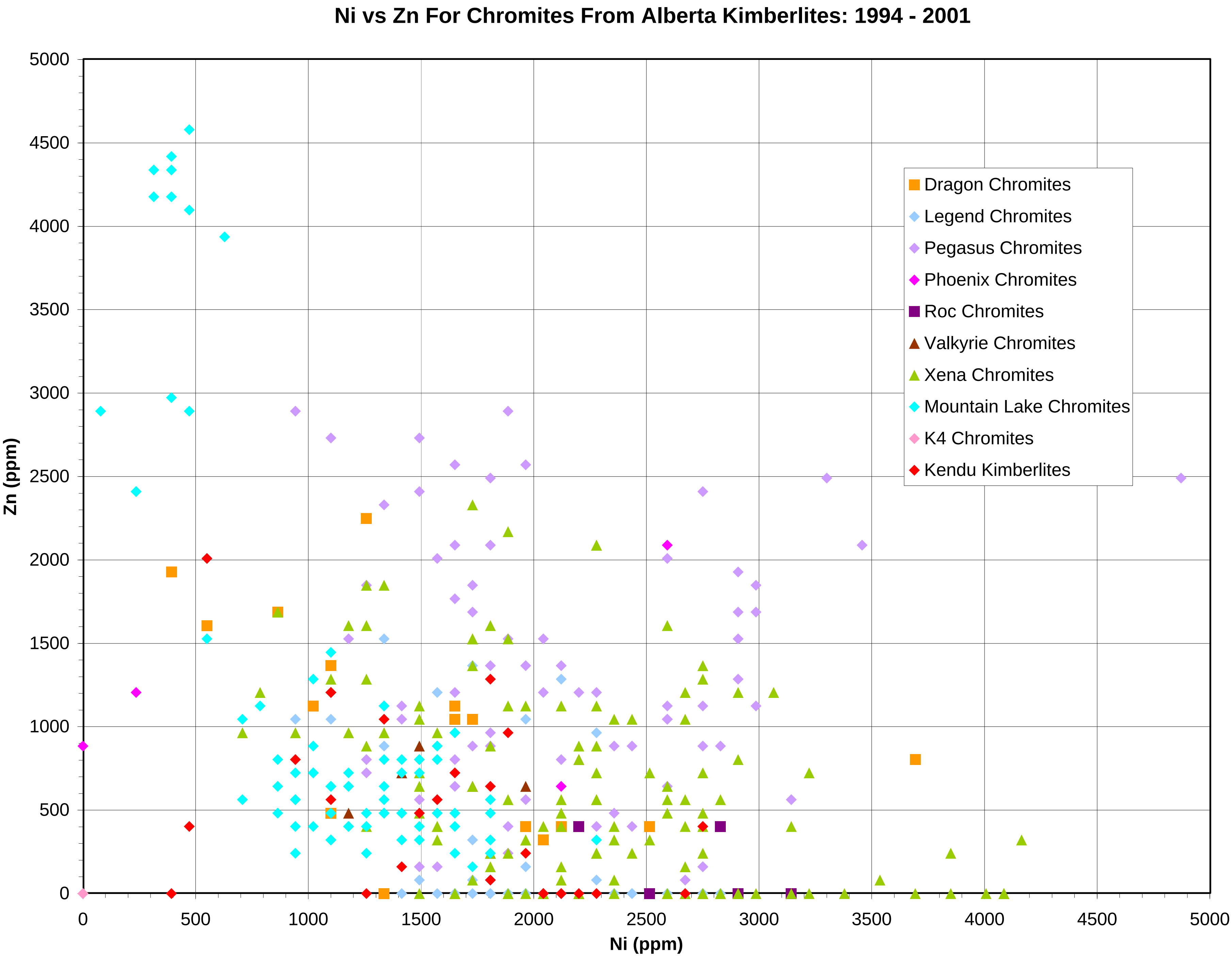
Appendix 1


MgO vs Cr2O3 For Chromites From Alberta Kimberlites: 1994 - 2001
DI Chromites
Dragon Chromites
Legend Chromites
Pegasus Chromites
Phoenix Chromites
Roc Chromites
Valkyrie Chromites
Xena Chromites
Mountain Lake Chromites
K4 Chromites
Kendu Chromites
Cr2O3 (wt%)
70
60
50
40
30
20
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22

Appendix 1

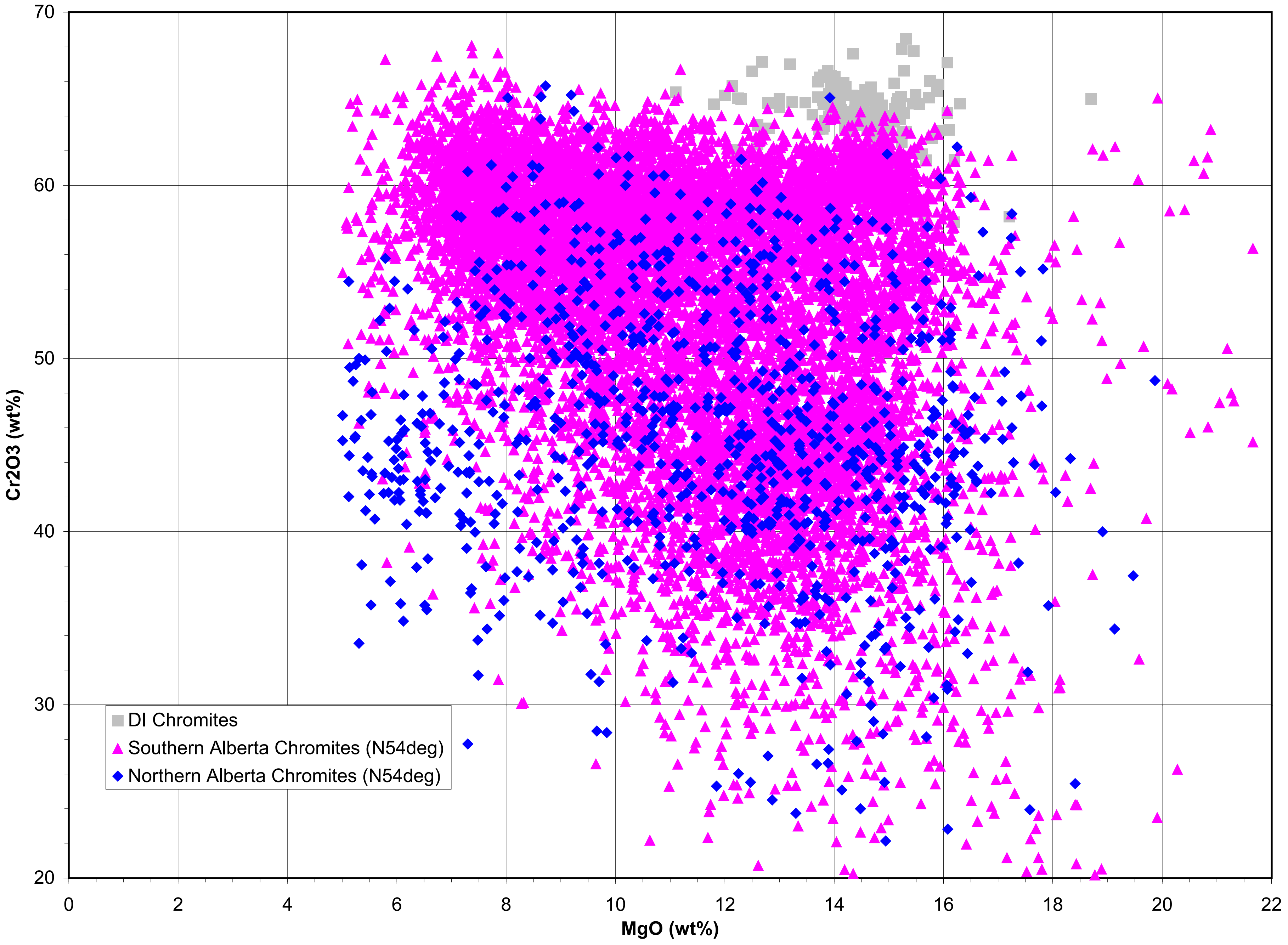
TiO2 vs Cr2O3 For Chromites From Alberta Kimberlites: 1994 - 2001



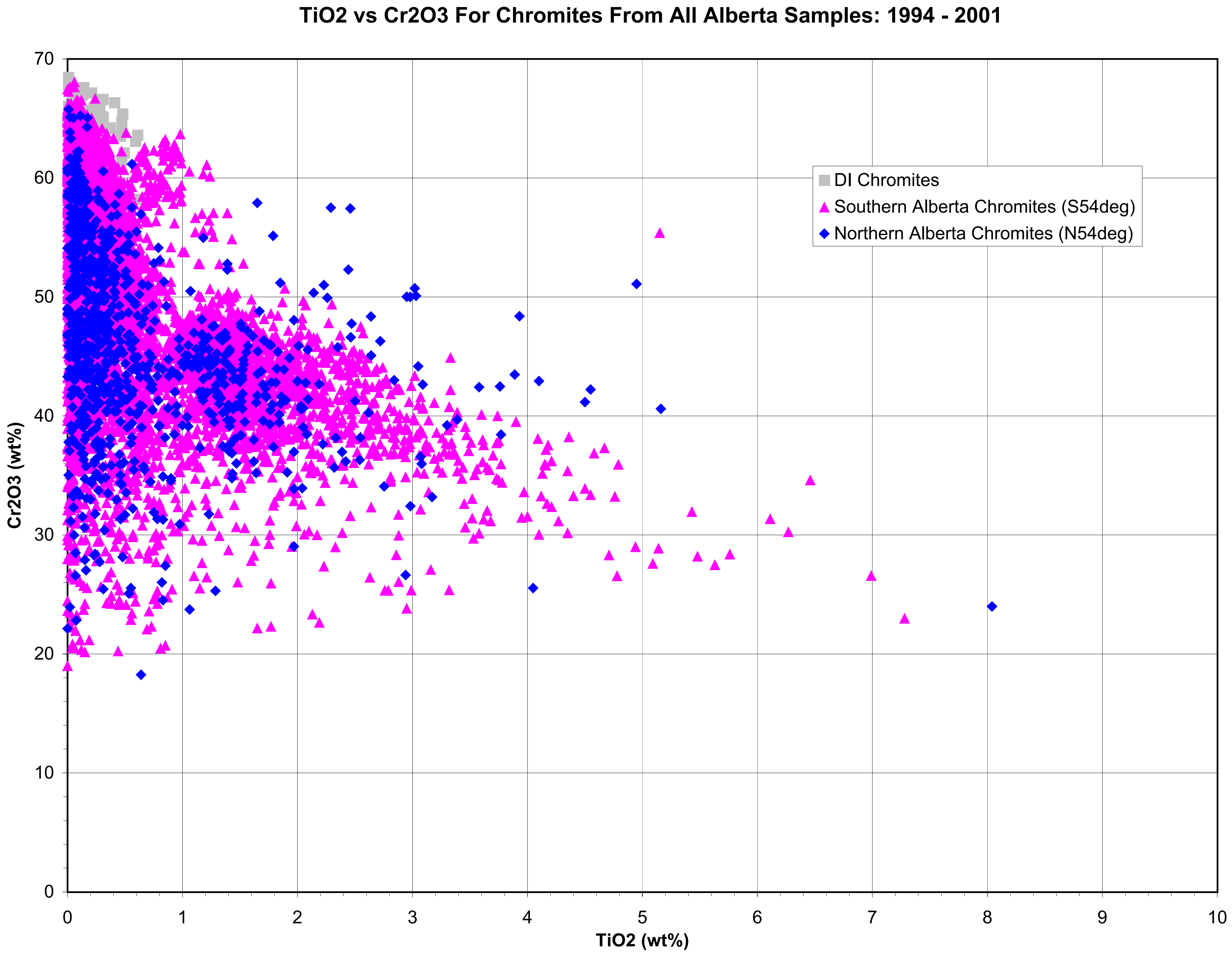

Ni vs Zn For Chromites From Alberta Kimberlites: 1994 - 2001
Zn (ppm)
Ni (ppm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Dragon Chromites
Legend Chromites
Pegasus Chromites
Phoenix Chromites
Roc Chromites
Valkyrie Chromites
Xena Chromites
Mountain Lake Chromites
K4 Chromites
Kendu Kimberlites

Appendix 1

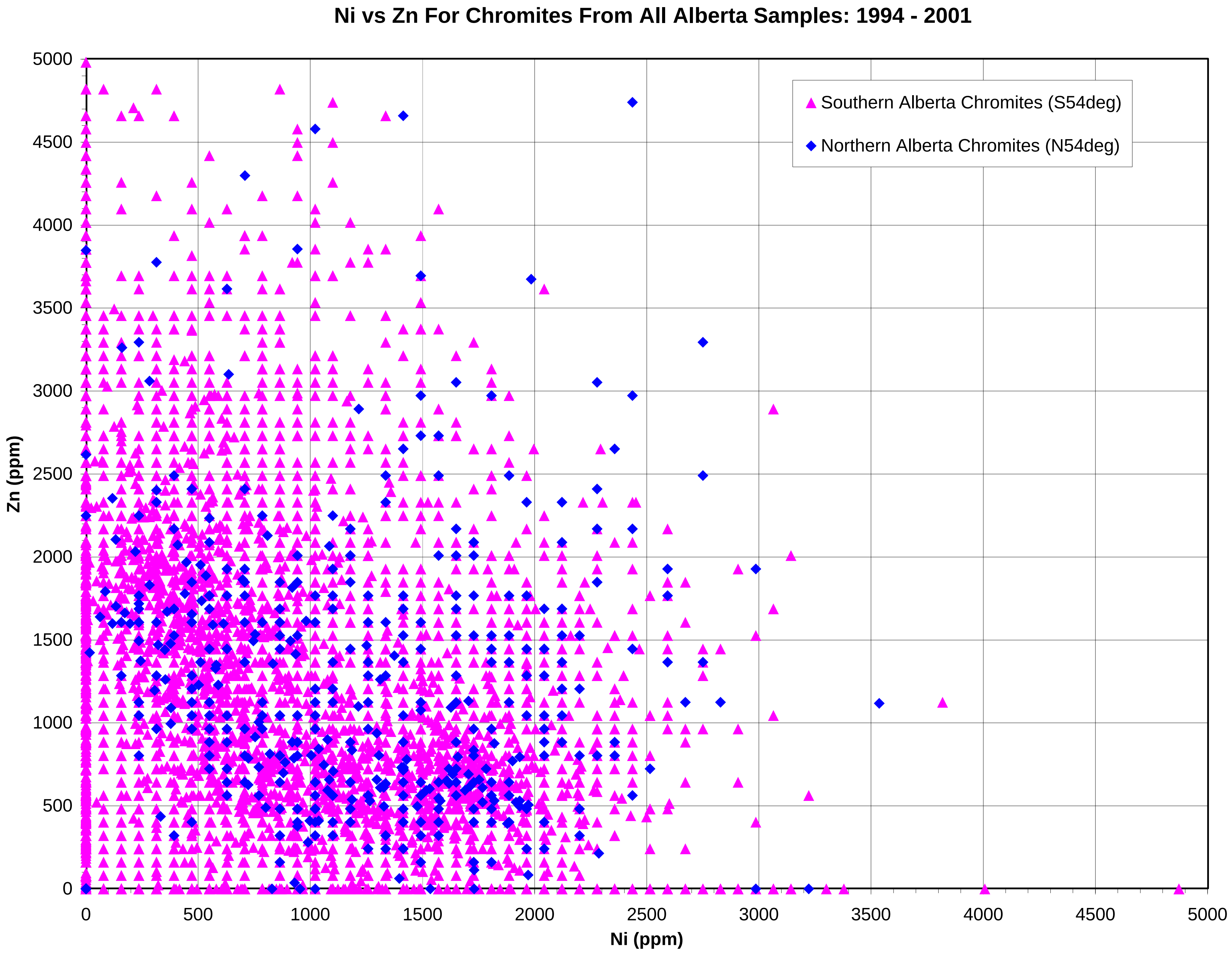
MgO vs Cr2O3 For Chromites From All Alberta Samples: 1994 - 2001

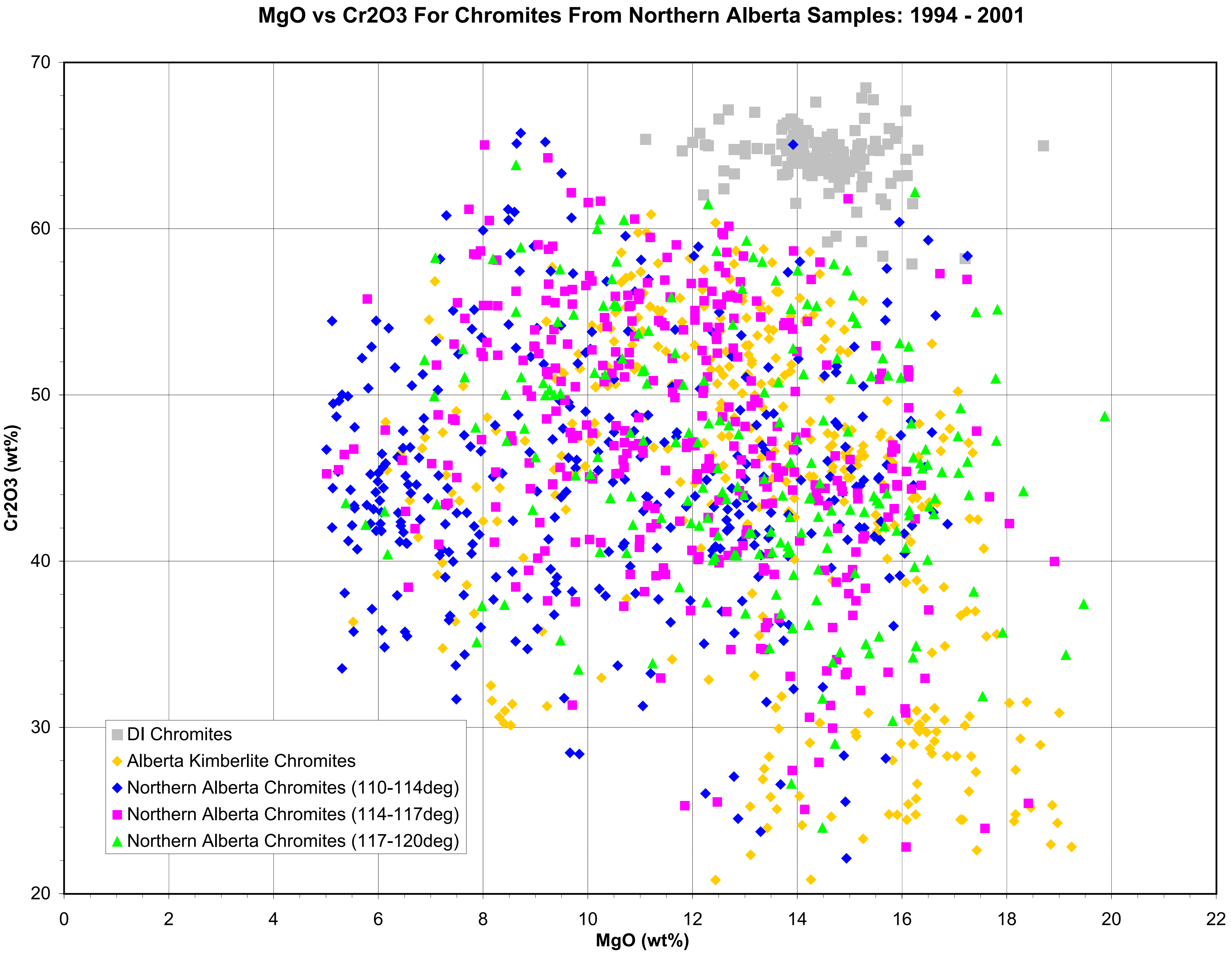


Appendix 1

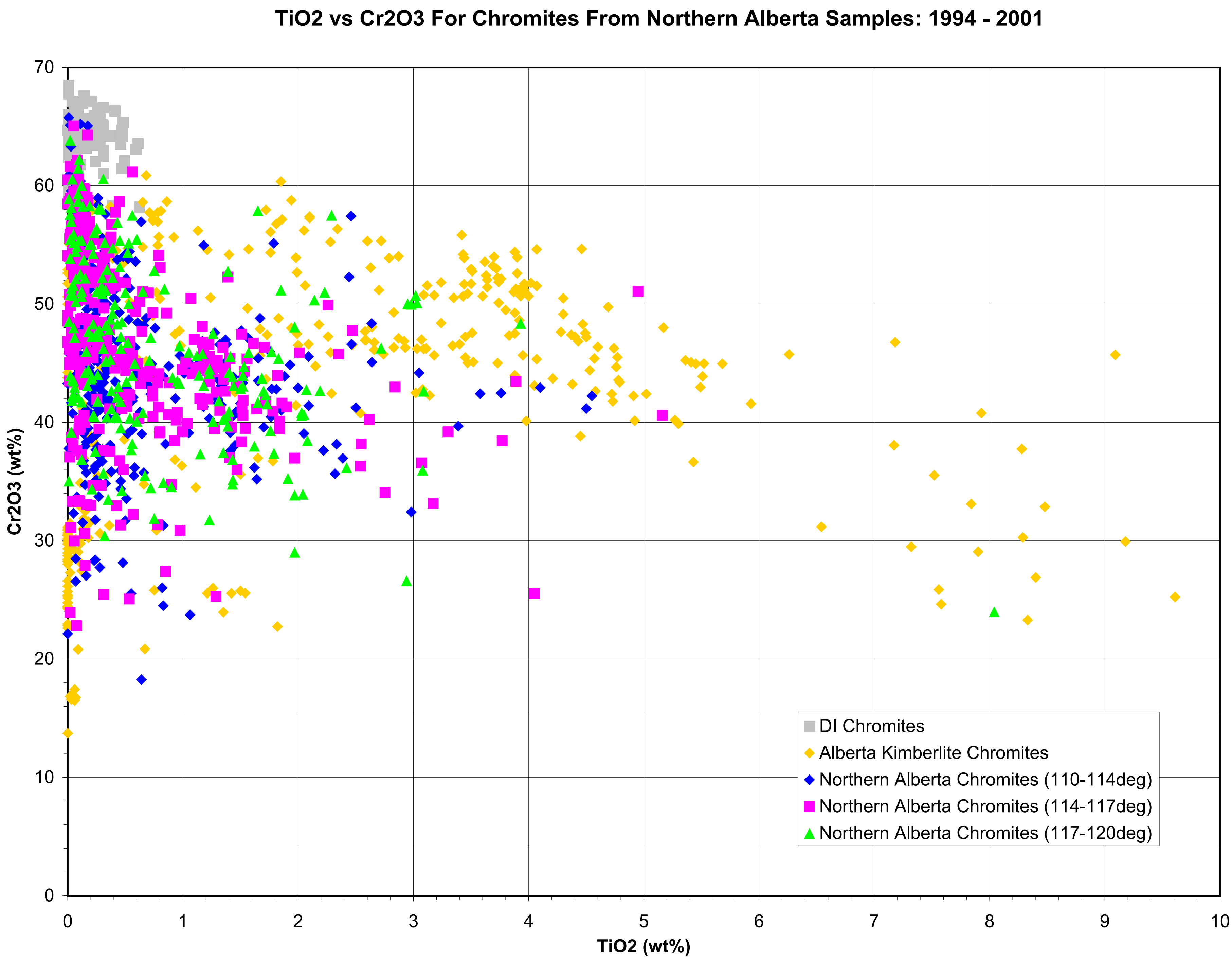

TiO2 vs Cr2O3 For Chromites From All Alberta Samples: 1994 - 2001
■ DI Chromites
▲ Southern Alberta Chromites (S54deg)
◆ Northern Alberta Chromites (N54deg)
Cr2O3 (wt%)
TiO2 (wt%)
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10

Appendix 1


Ni vs Zn For Chromites From All Alberta Samples: 1994 - 2001
Zn (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Ni (ppm)
▲ Southern Alberta Chromites (S54deg)
◆ Northern Alberta Chromites (N54deg)

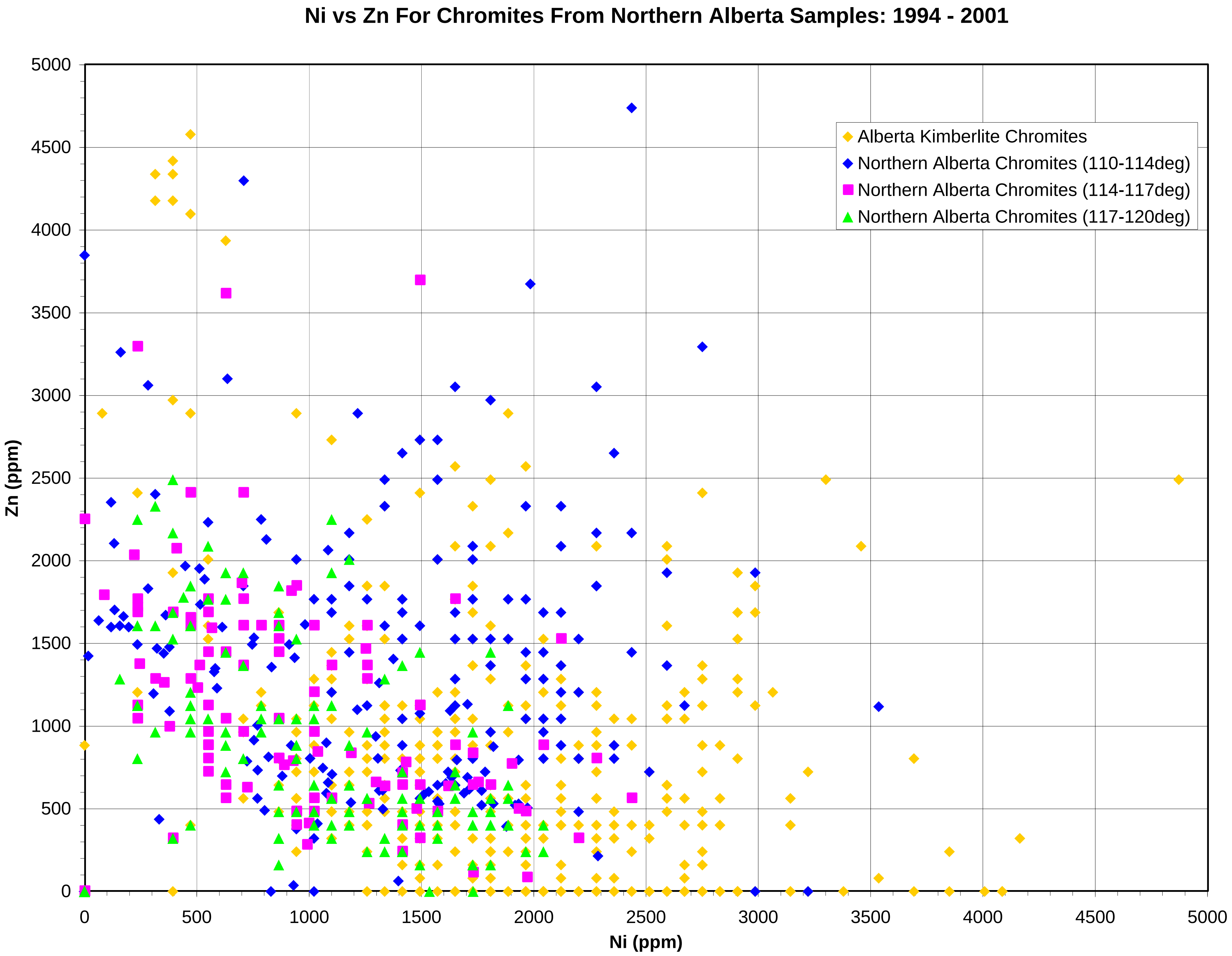

MgO vs Cr2O3 For Chromites From Northern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
70
60
50
40
30
20
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
■ DI Chromites
◆ Alberta Kimberlite Chromites
◆ Northern Alberta Chromites (110-114deg)
■ Northern Alberta Chromites (114-117deg)
▲ Northern Alberta Chromites (117-120deg)

Appendix 1



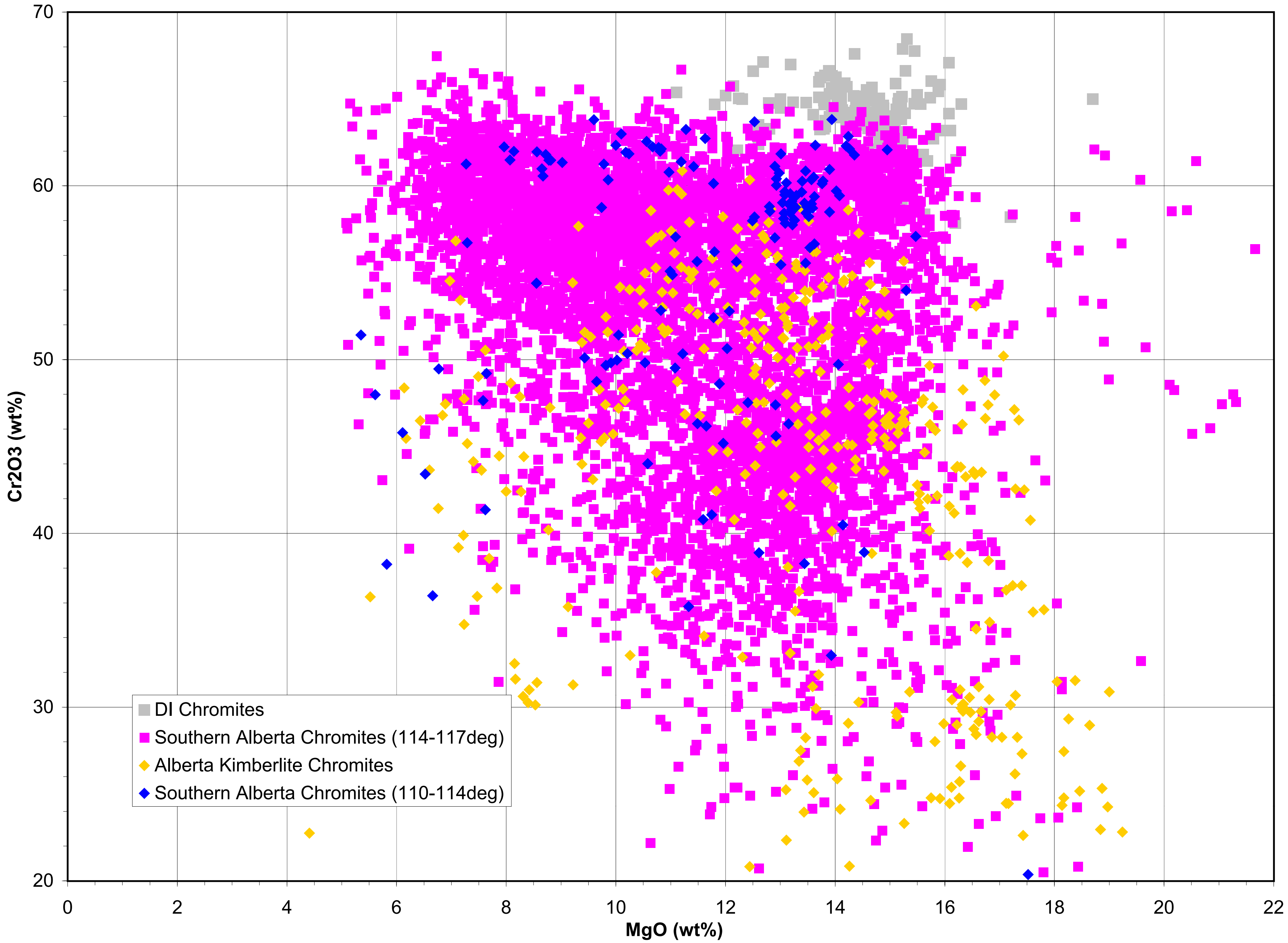
TiO2 vs Cr2O3 For Chromites From Northern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
0
10
20
30
40
50
60
70
TiO2 (wt%)
0
1
2
3
4
5
6
7
8
9
10
■ DI Chromites
◆ Alberta Kimberlite Chromites
◆ Northern Alberta Chromites (110-114deg)
■ Northern Alberta Chromites (114-117deg)
▲ Northern Alberta Chromites (117-120deg)

Appendix 1

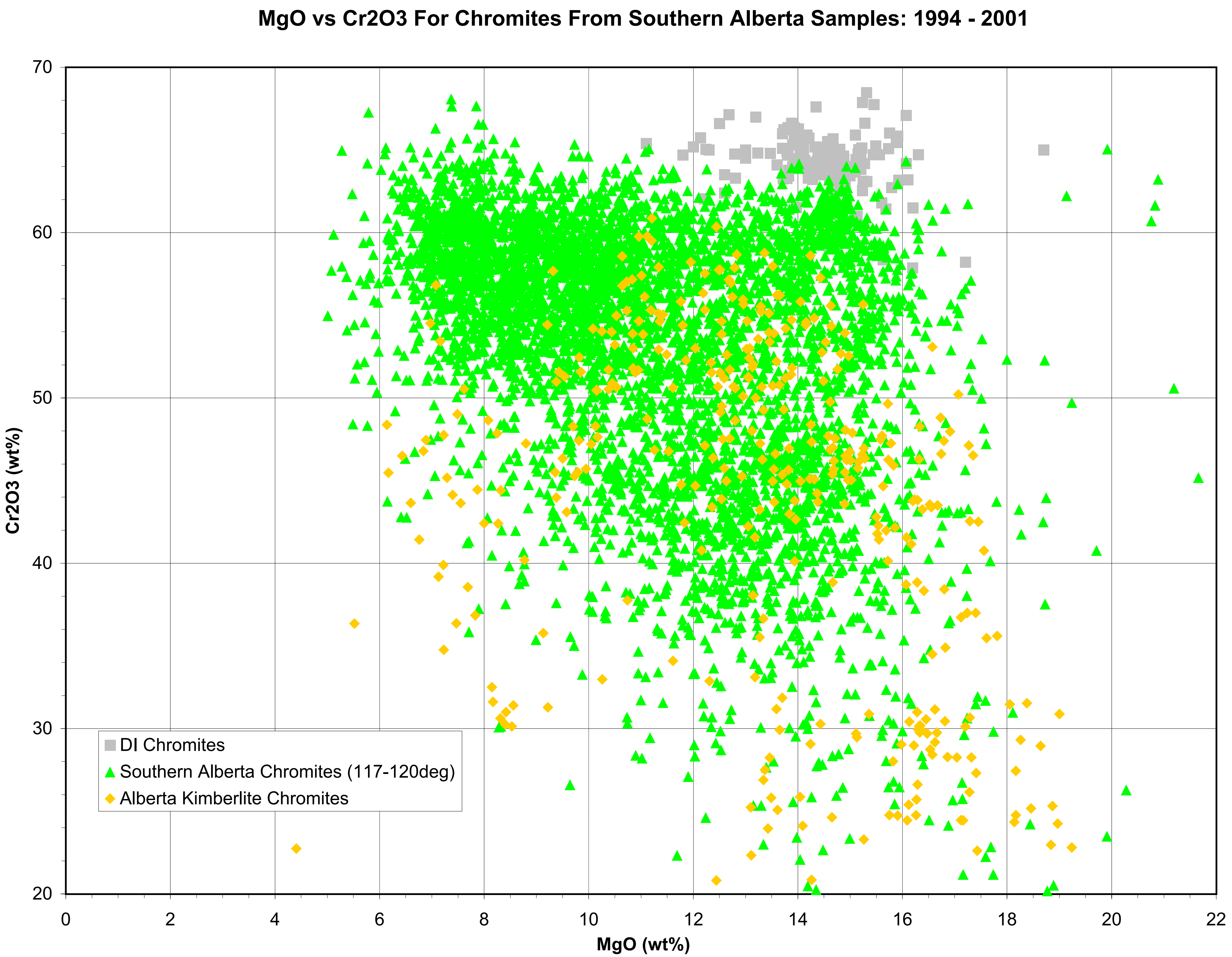

Ni vs Zn For Chromites From Northern Alberta Samples: 1994 - 2001
Zn (ppm)
Ni (ppm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
◆ Alberta Kimberlite Chromites
◆ Northern Alberta Chromites (110-114deg)
■ Northern Alberta Chromites (114-117deg)
▲ Northern Alberta Chromites (117-120deg)

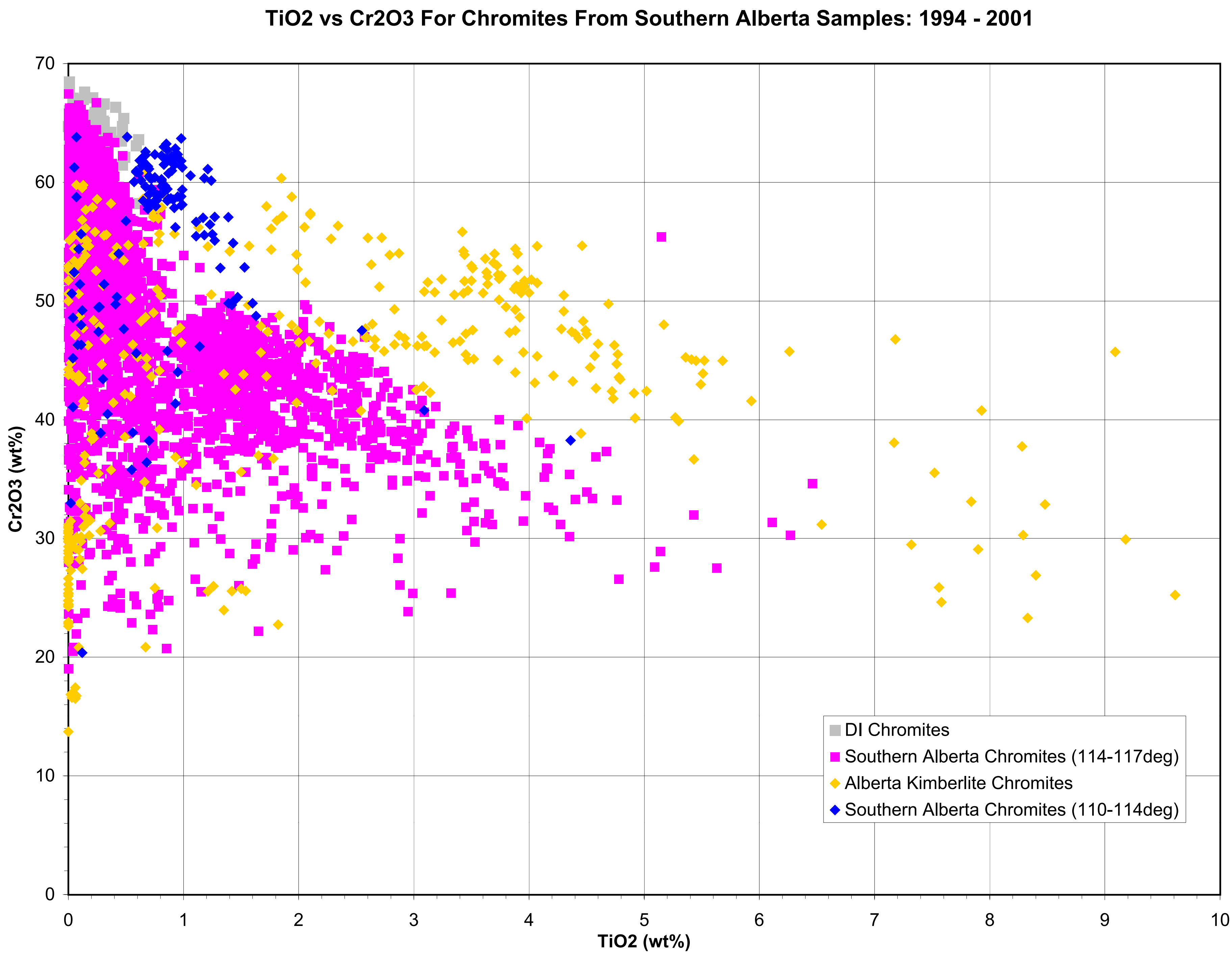
Appendix 1

MgO vs Cr2O3 For Chromites From Southern Alberta Samples: 1994 - 2001

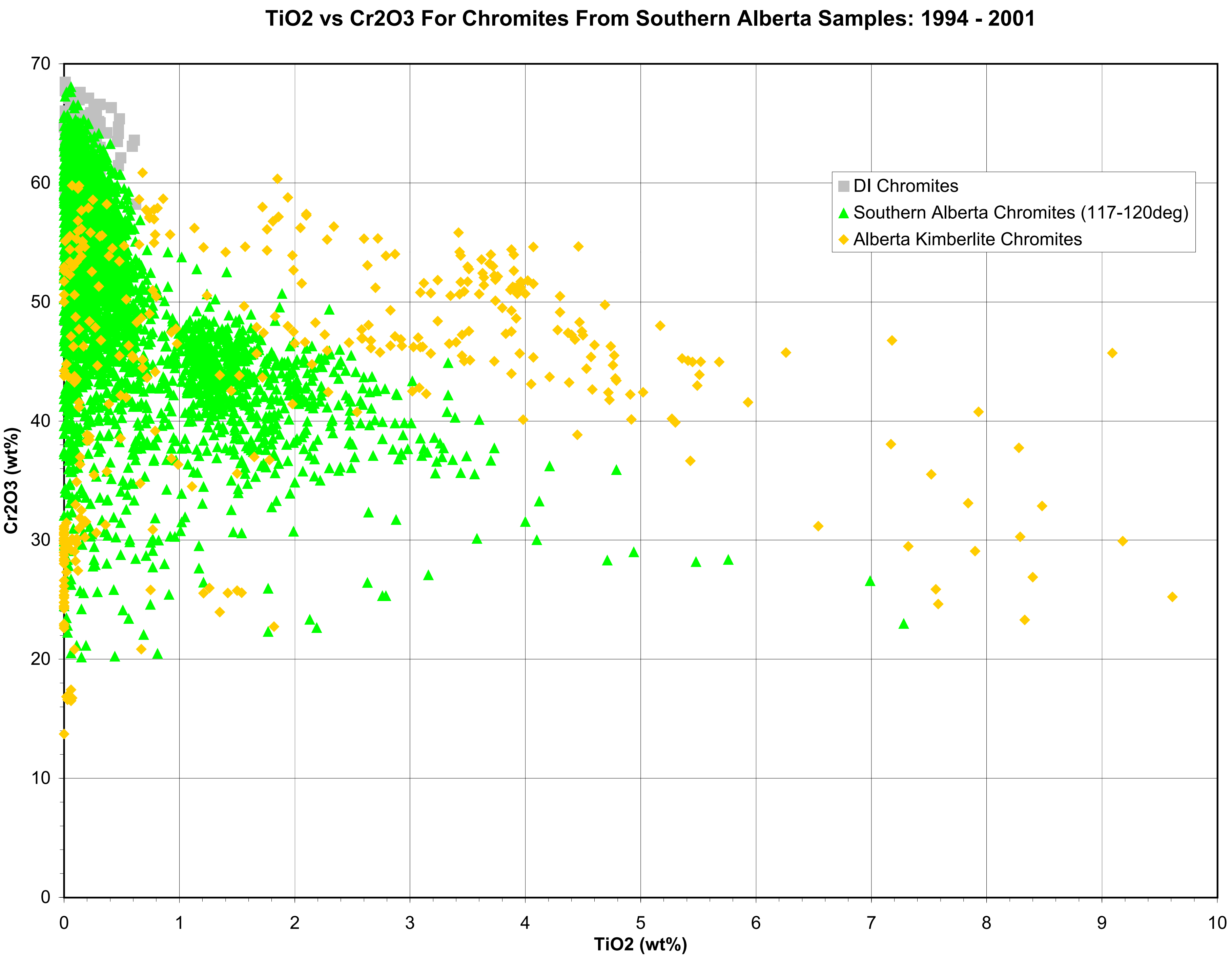


Appendix 1

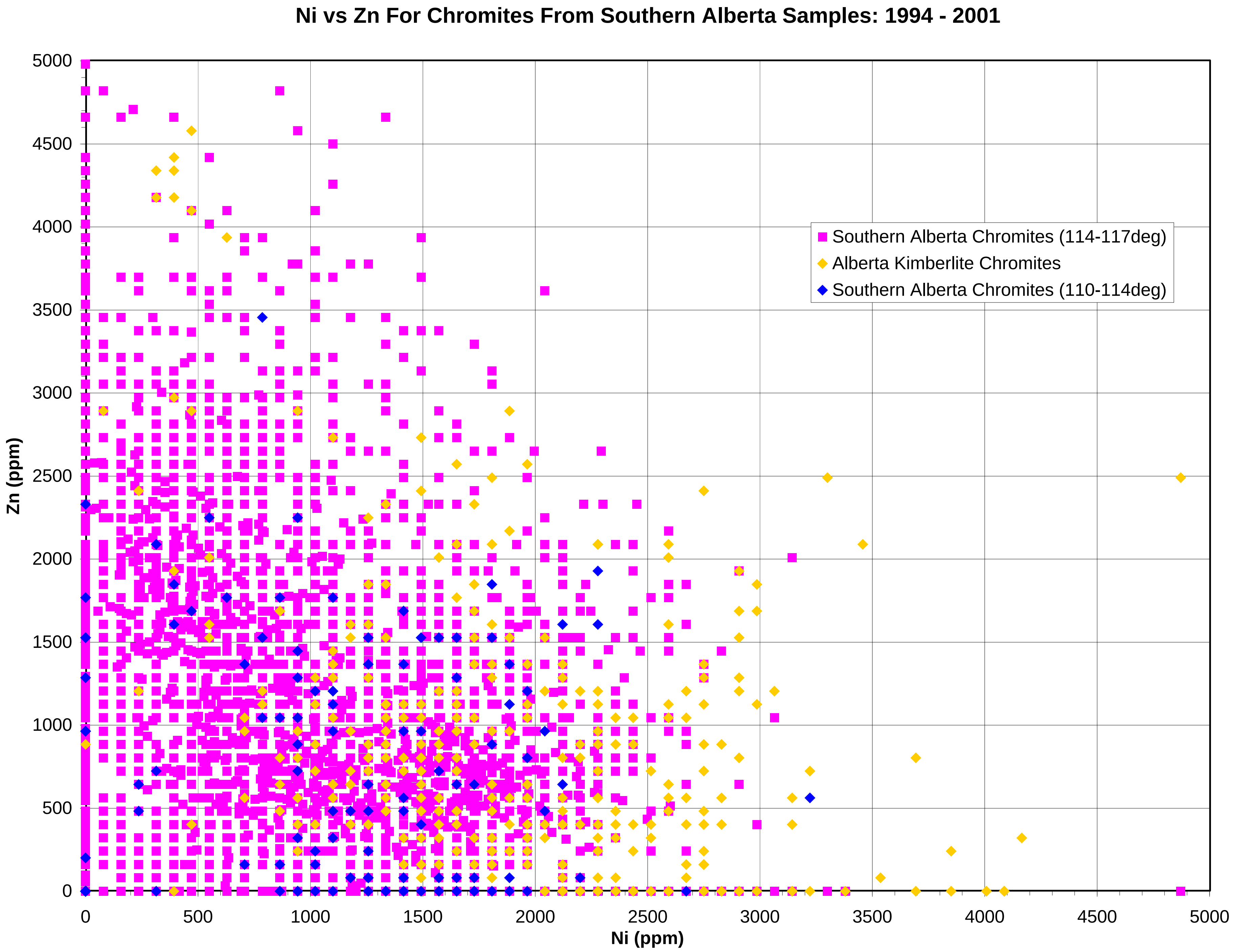

MgO vs Cr2O3 For Chromites From Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
70
60
50
40
30
20
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
DI Chromites
Southern Alberta Chromites (117-120deg)
Alberta Kimberlite Chromites


TiO2 vs Cr2O3 For Chromites From Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
70
60
50
40
30
20
10
0
TiO2 (wt%)
0
1
2
3
4
5
6
7
8
9
10
■ DI Chromites
■ Southern Alberta Chromites (114-117deg)
◆ Alberta Kimberlite Chromites
◆ Southern Alberta Chromites (110-114deg)

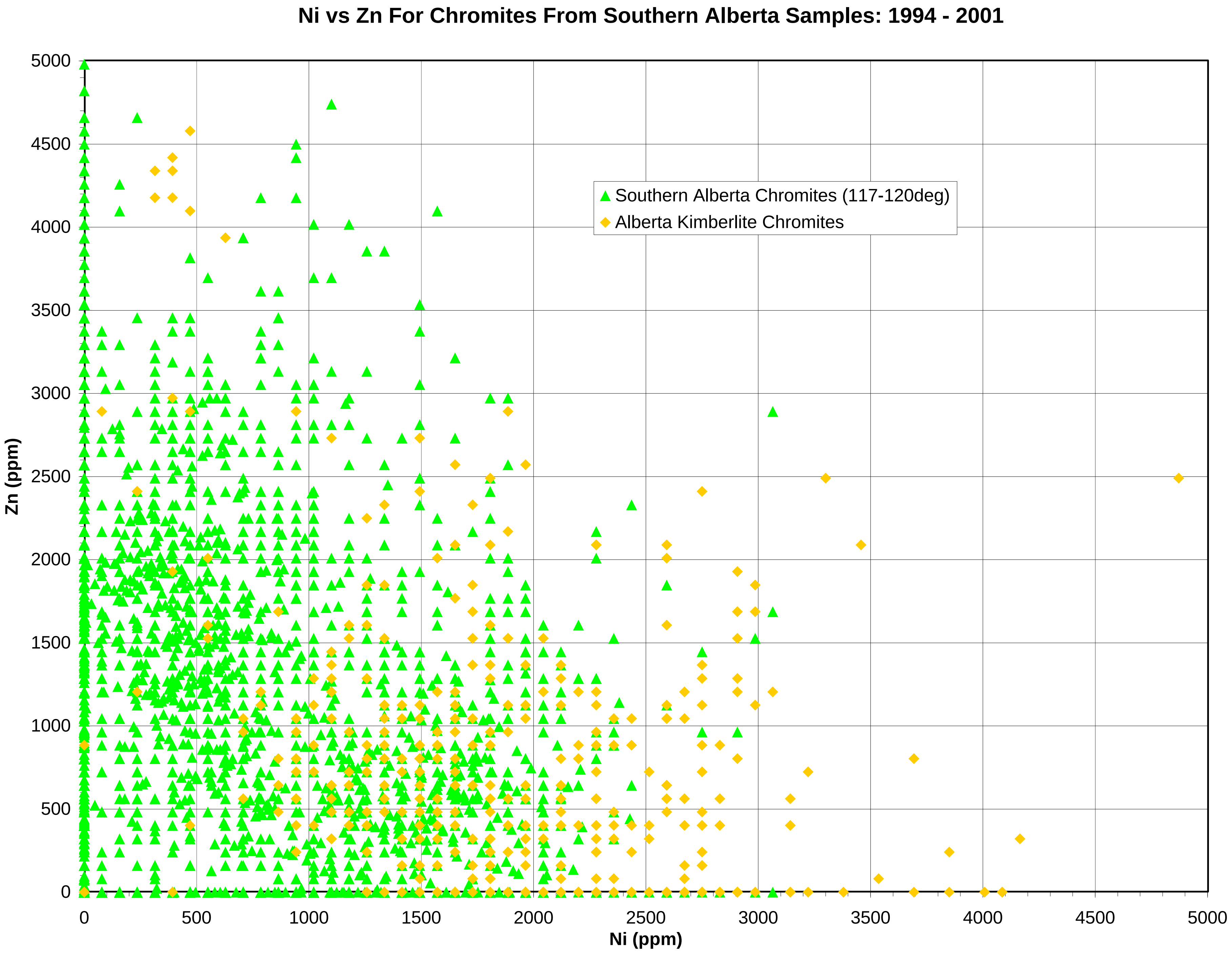
Appendix 1


TiO2 vs Cr2O3 For Chromites From Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
TiO2 (wt%)
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10
DI Chromites
Southern Alberta Chromites (117-120deg)
Alberta Kimberlite Chromites

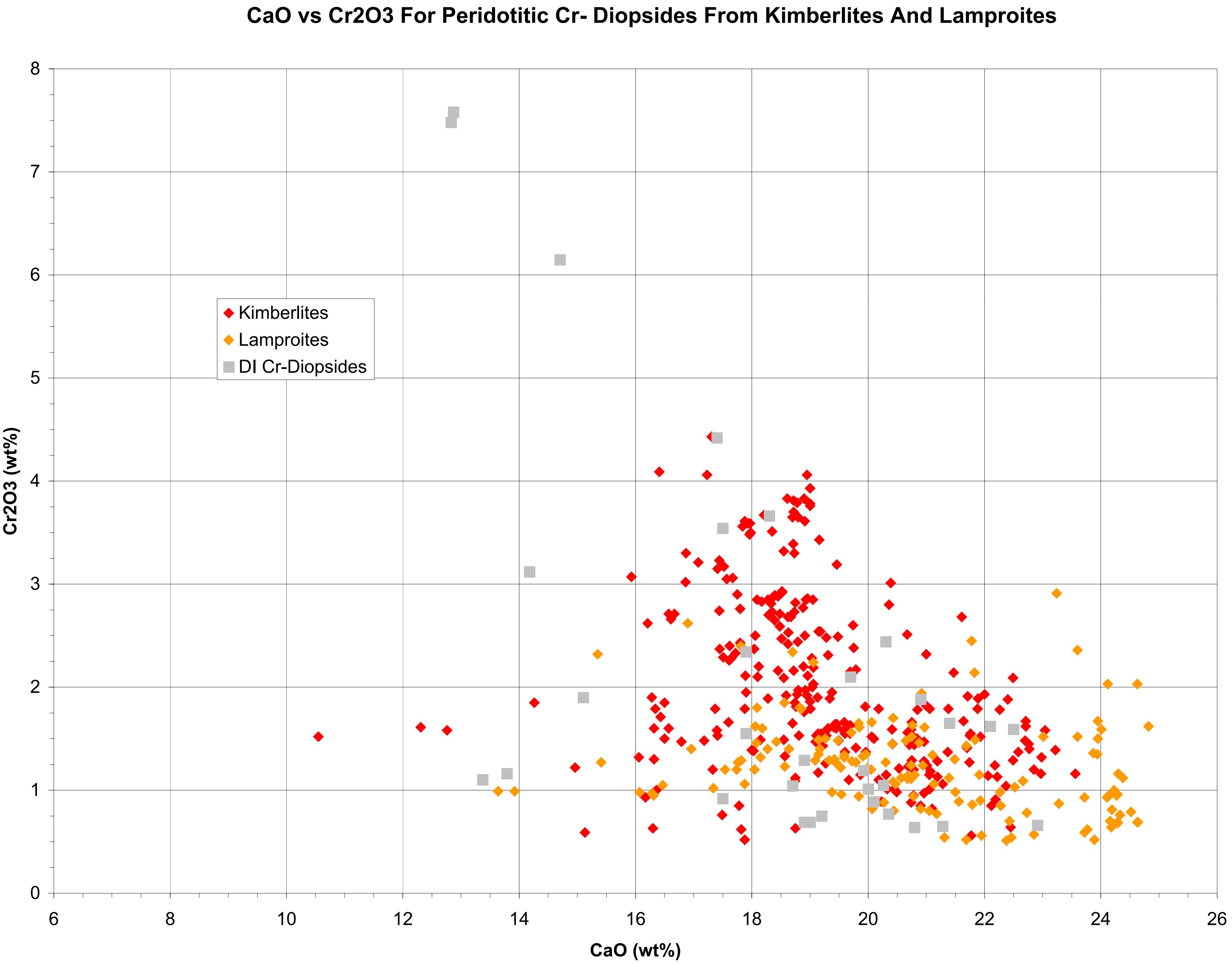
Appendix 1


Ni vs Zn For Chromites From Southern Alberta Samples: 1994 - 2001
Zn (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Ni (ppm)
■ Southern Alberta Chromites (114-117deg)
◆ Alberta Kimberlite Chromites
◆ Southern Alberta Chromites (110-114deg)

Appendix 1

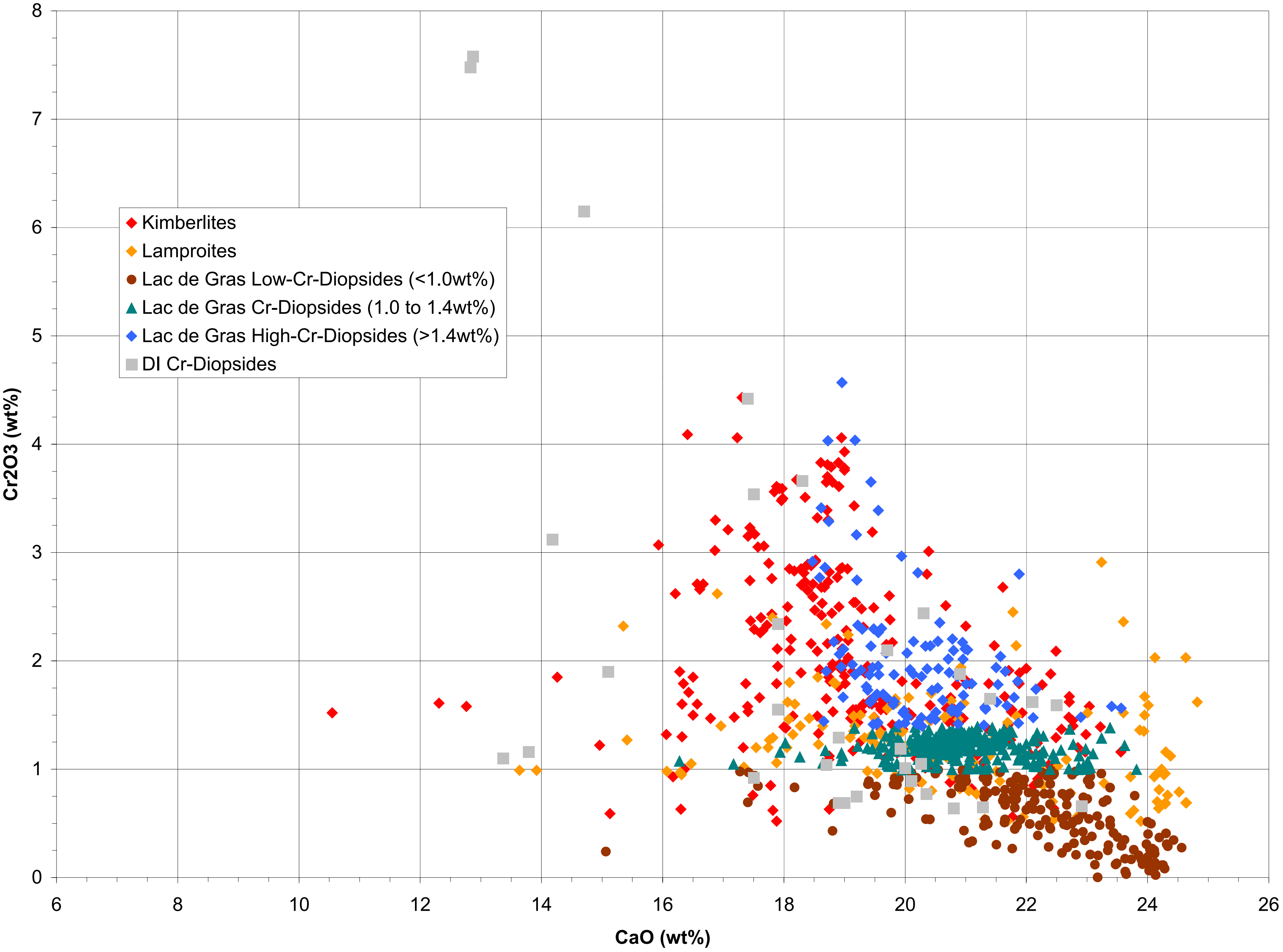

Ni vs Zn For Chromites From Southern Alberta Samples: 1994 - 2001
▲ Southern Alberta Chromites (117-120deg)
◆ Alberta Kimberlite Chromites
Zn (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Ni (ppm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Appendix 1

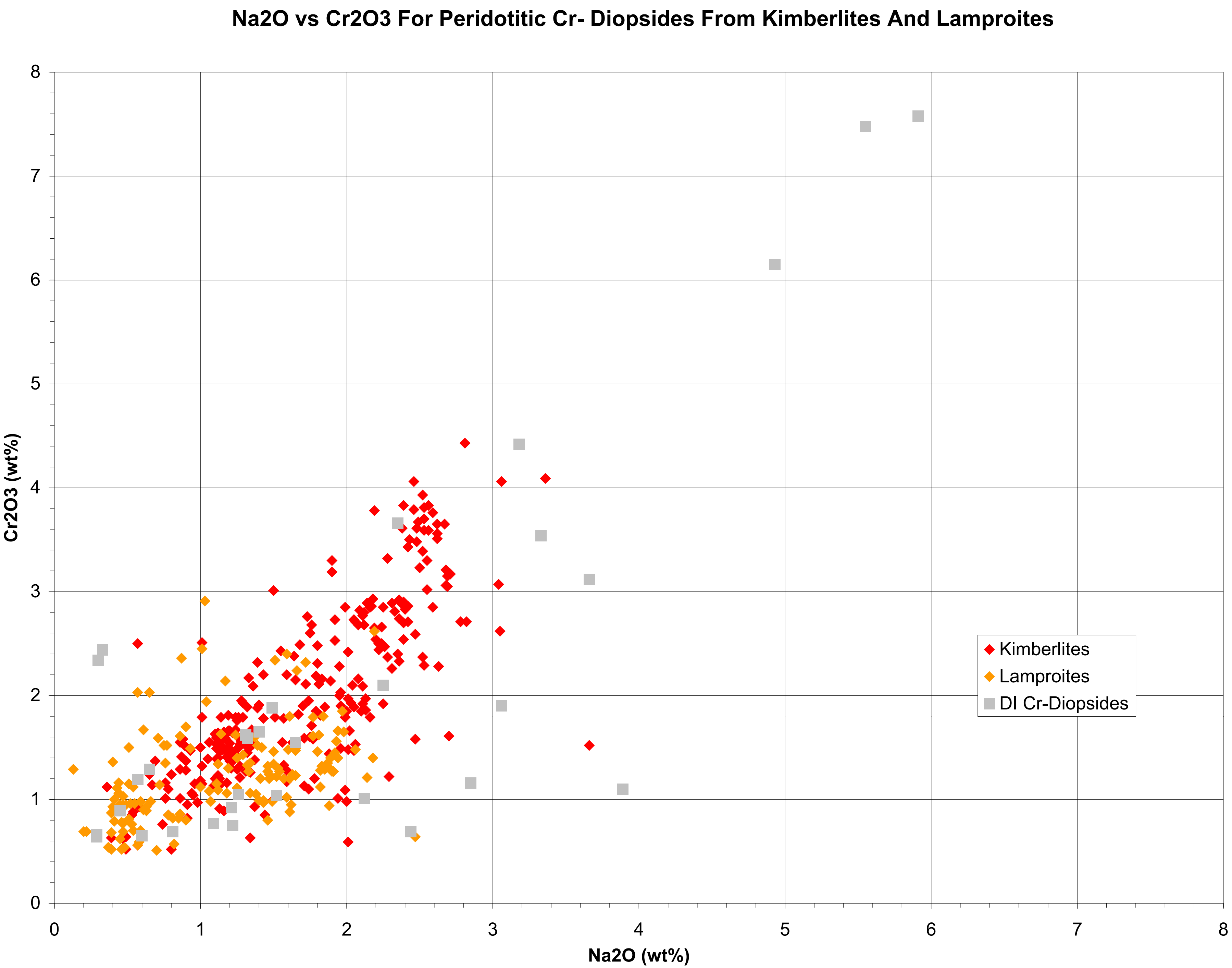

CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites And Lamproites
Kimberlites
Lamproites
DI Cr-Diopsides
Cr2O3 (wt%)
0
1
2
3
4
5
6
7
8
CaO (wt%)
6
8
10
12
14
16
18
20
22
24
26

Appendix 1

CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Various Lac de Gras And Kimberlites/Lamproites

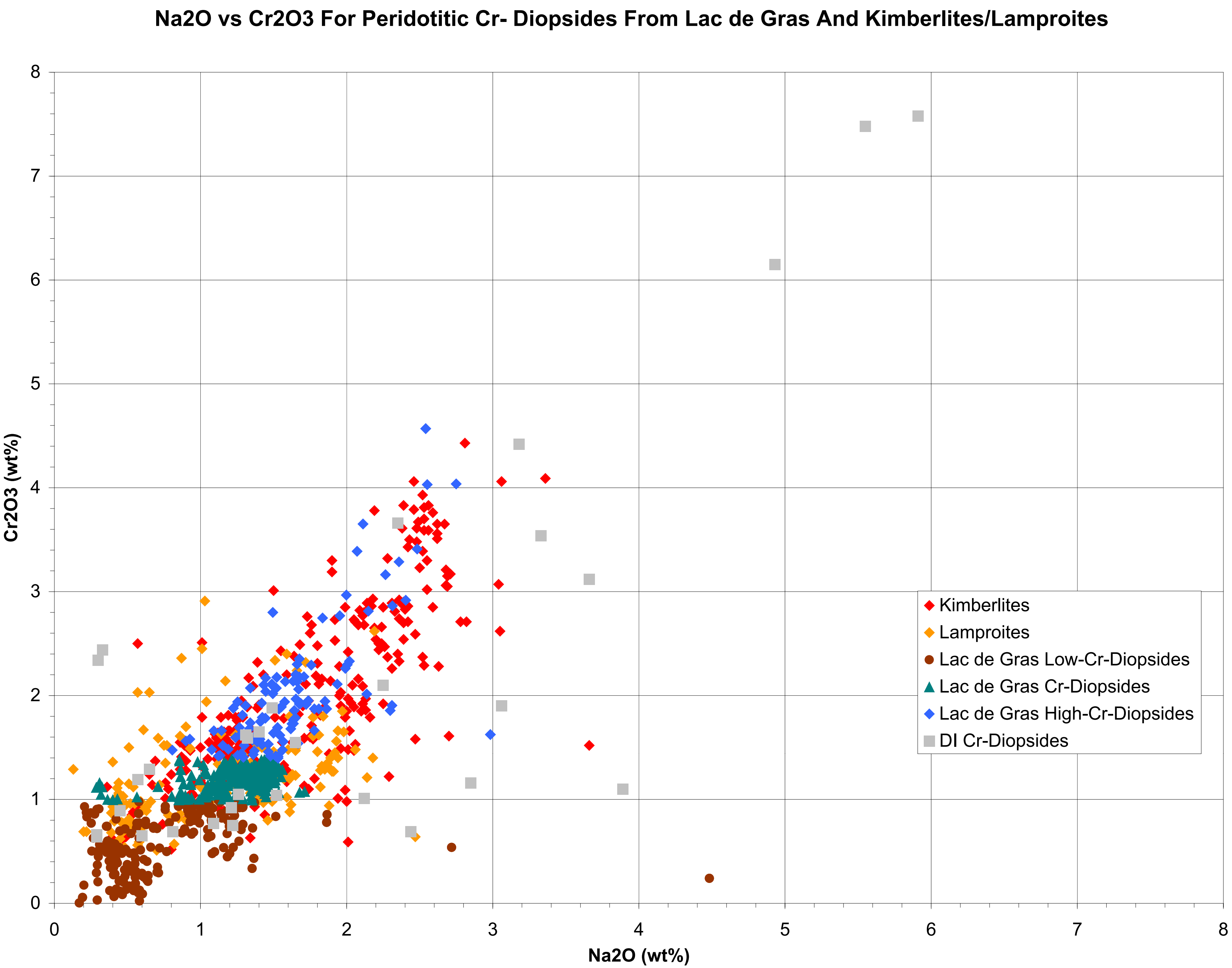


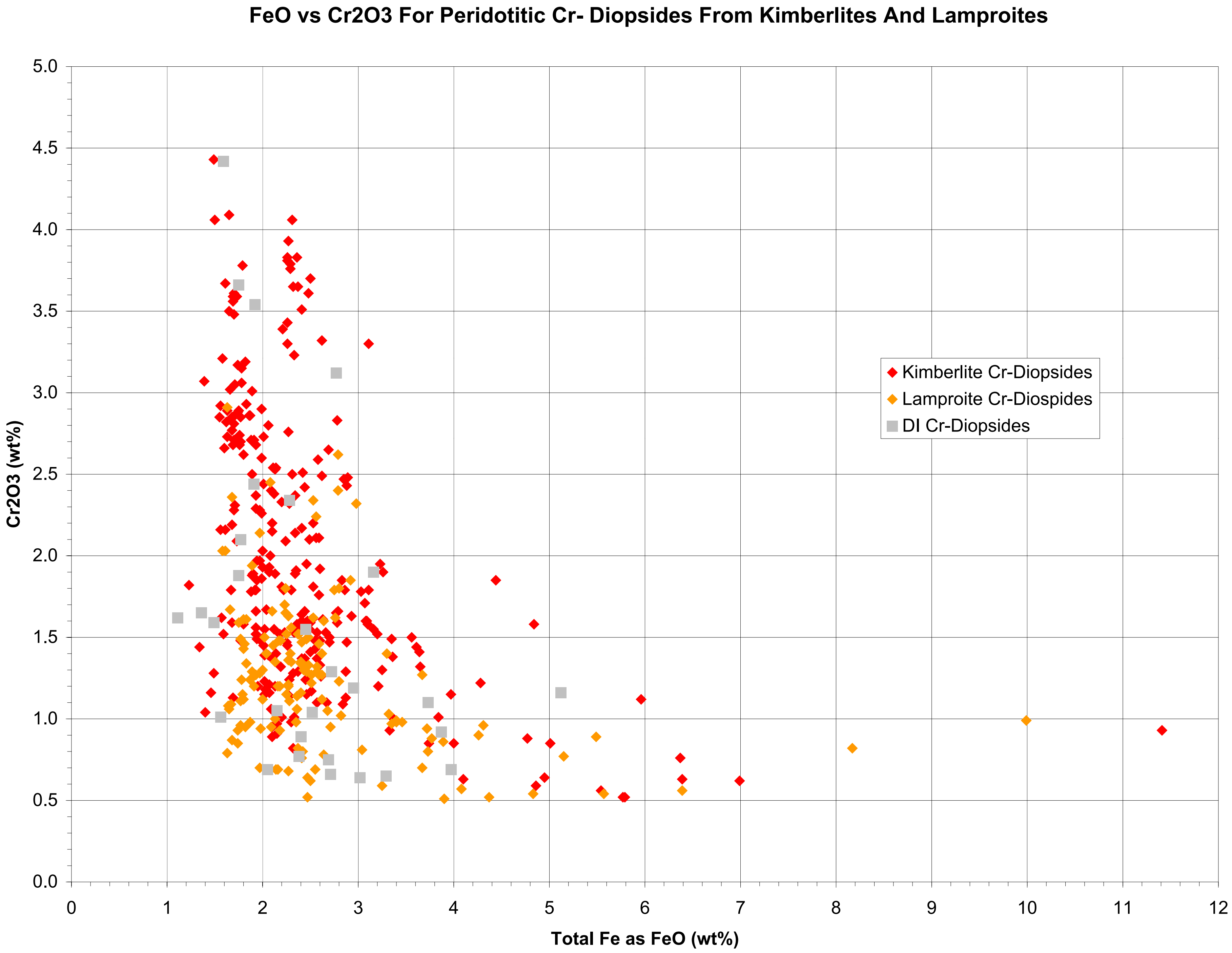
Appendix 1



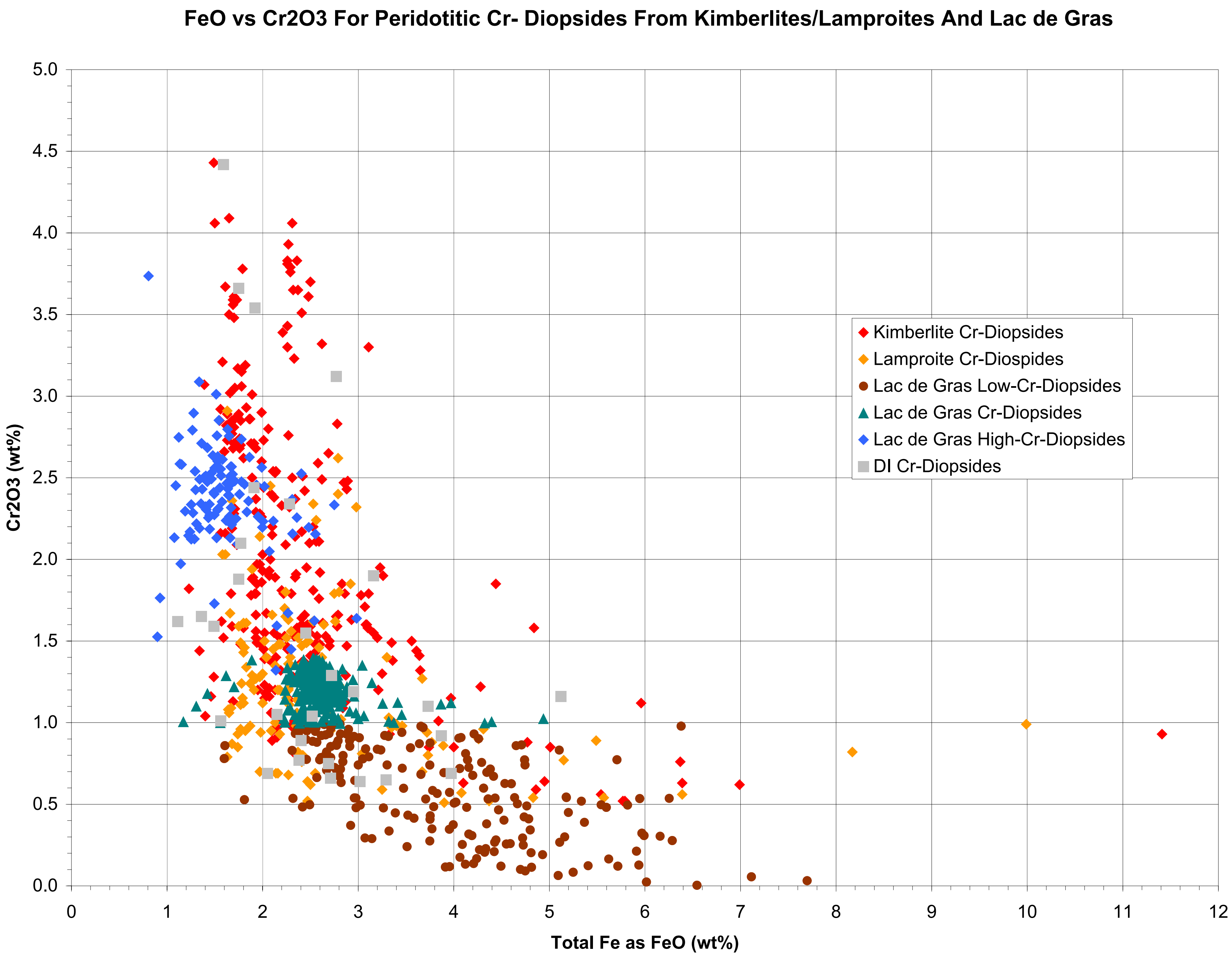
Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites And Lamproites
Cr2O3 (wt%)
0
1
2
3
4
5
6
7
8
Na2O (wt%)
0
1
2
3
4
5
6
7
8
◆ Kimberlites
◆ Lamproites
■ DI Cr-Diopsides

Appendix 1

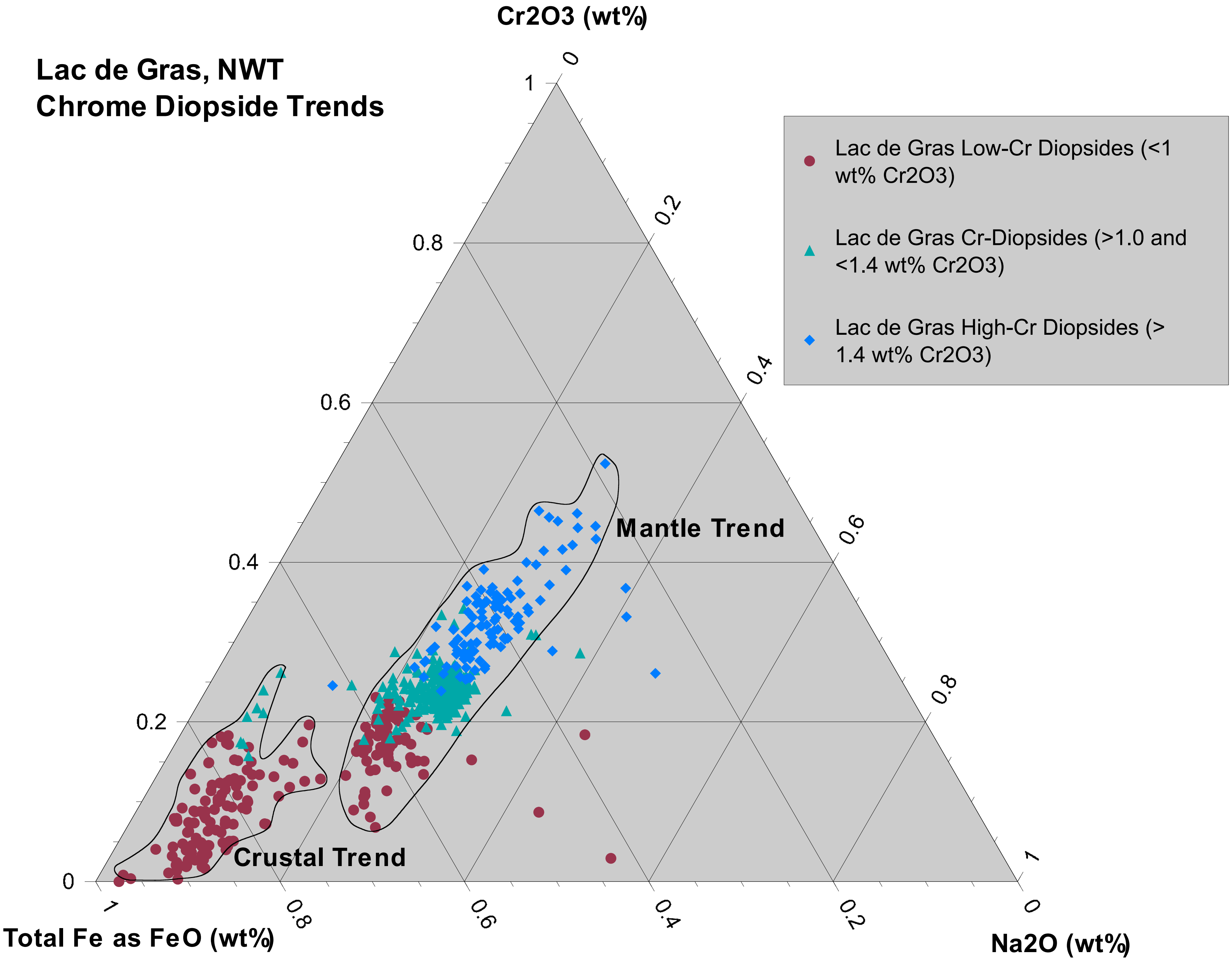

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Kimberlites/Lamproites
Cr2O3 (wt%)
8
7
6
5
4
3
2
1
0
Na2O (wt%)
0
1
2
3
4
5
6
7
8
◆ Kimberlites
◆ Lamproites
● Lac de Gras Low-Cr-Diopsides
▲ Lac de Gras Cr-Diopsides
◆ Lac de Gras High-Cr-Diopsides
■ DI Cr-Diopsides


FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites And Lamproites
Cr2O3 (wt%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Total Fe as FeO (wt%)
0
1
2
3
4
5
6
7
8
9
10
11
12
Kimberlite Cr-Diopsides
Lamproite Cr-Diospides
DI Cr-Diopsides

Appendix 1

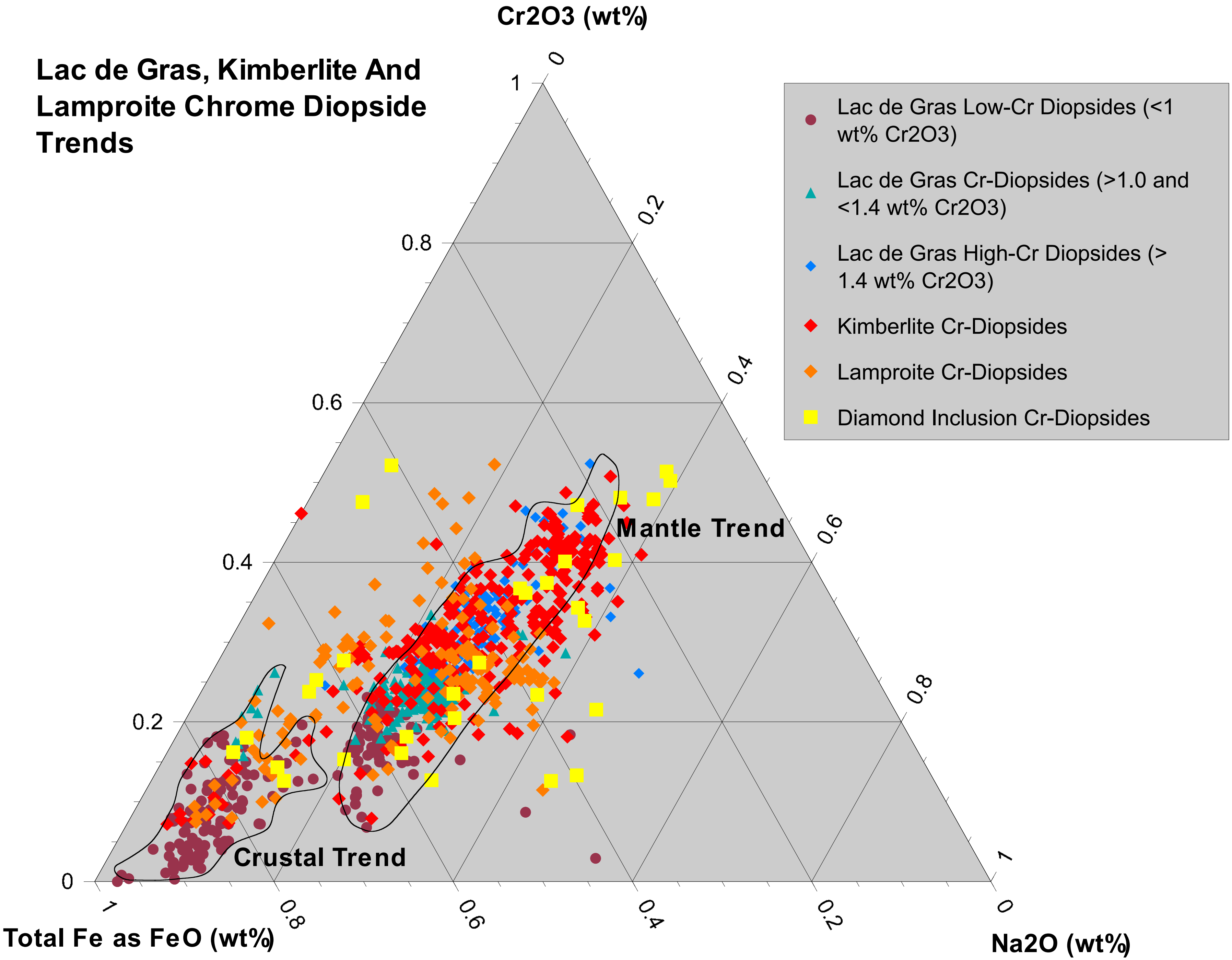

FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites/Lamproites And Lac de Gras
Cr2O3 (wt%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Fe as FeO (wt%)
Kimberlite Cr-Diopsides
Lamproite Cr-Diospides
Lac de Gras Low-Cr-Diopsides
Lac de Gras Cr-Diopsides
Lac de Gras High-Cr-Diopsides
DI Cr-Diopsides

Appendix 1

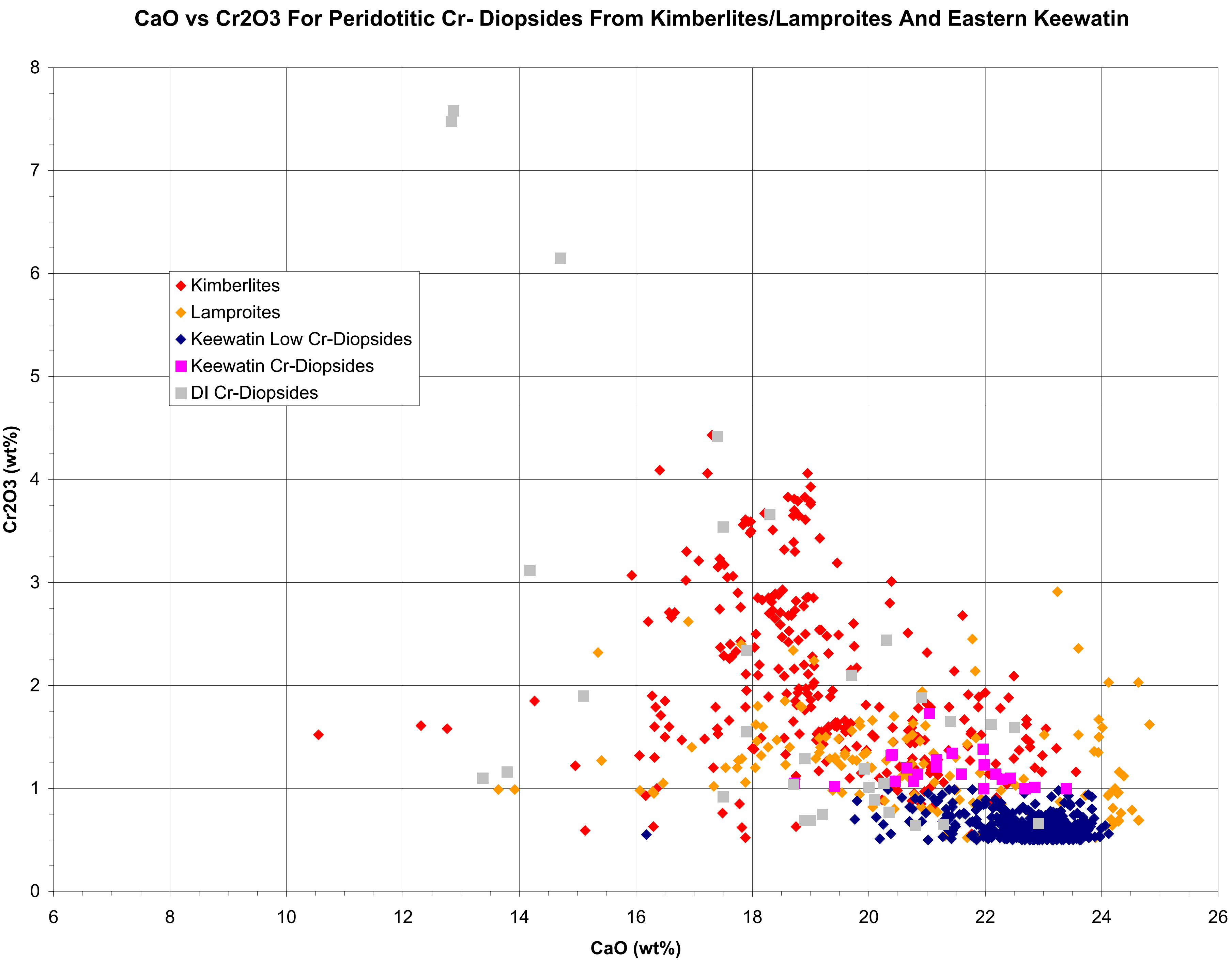


Lac de Gras, NWT
Chrome Diopside Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
0
0.2
0.4
0.6
0.8
1
Mantle Trend
Crustal Trend
● Lac de Gras Low-Cr Diopsides (<1 wt% Cr2O3)
▲ Lac de Gras Cr-Diopsides (>1.0 and <1.4 wt% Cr2O3)
◆ Lac de Gras High-Cr Diopsides (> 1.4 wt% Cr2O3)

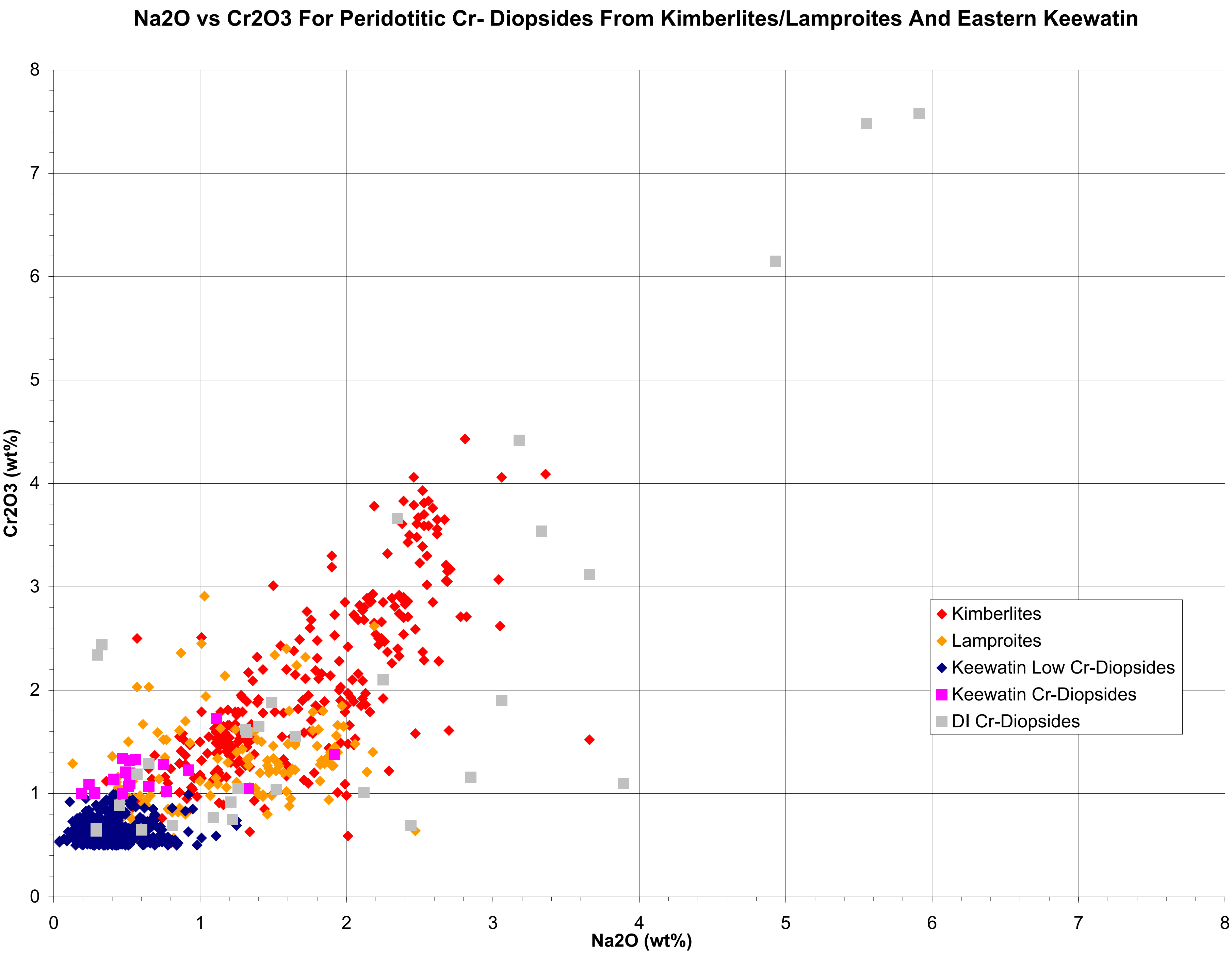
Appendix 1

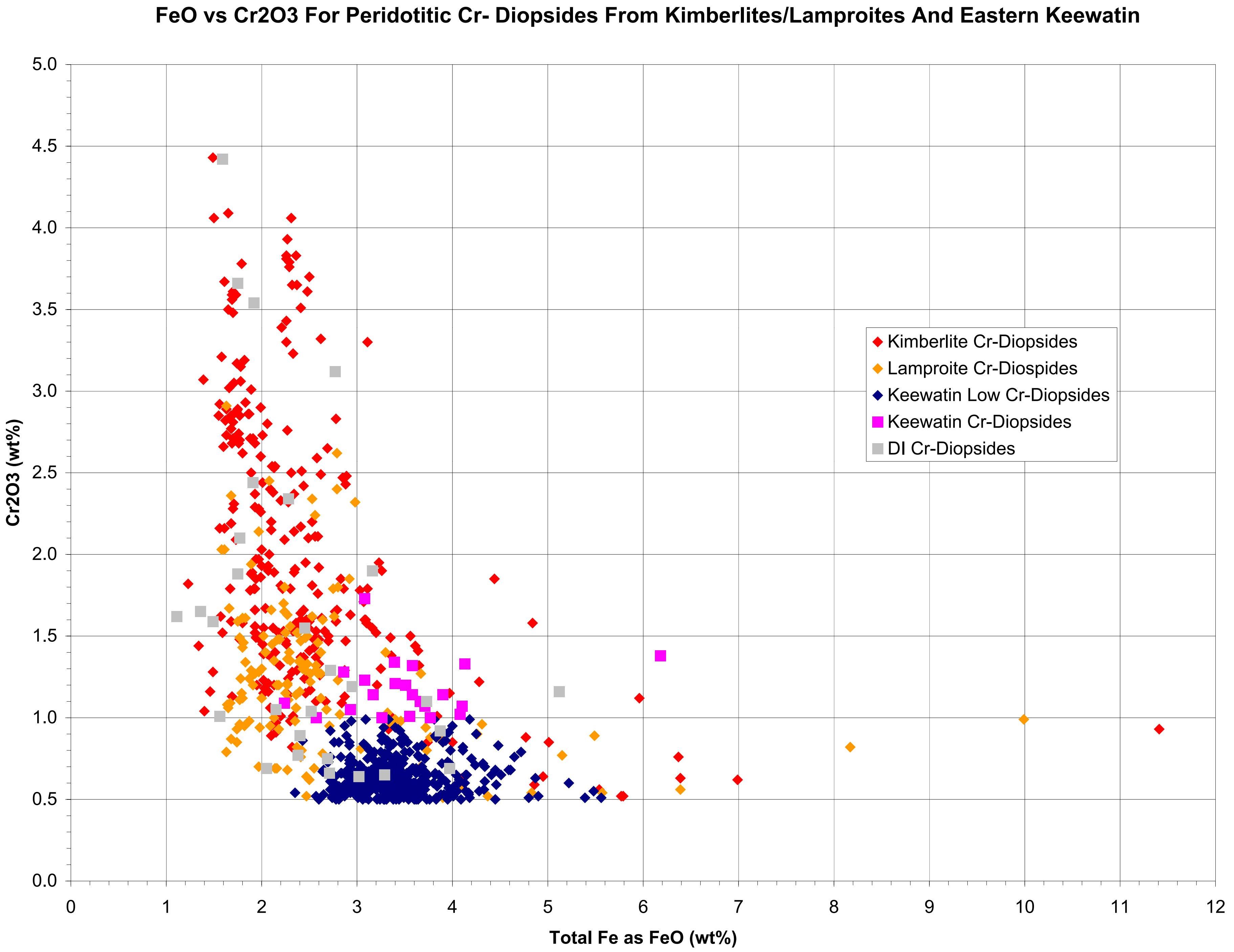

Lac de Gras, Kimberlite And Lamproite Chrome Diopside Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
0
0.2
0.4
0.6
0.8
1
Mantle Trend
Crustal Trend
● Lac de Gras Low-Cr Diopsides (<1 wt% Cr2O3)
▲ Lac de Gras Cr-Diopsides (>1.0 and <1.4 wt% Cr2O3)
◆ Lac de Gras High-Cr Diopsides (> 1.4 wt% Cr2O3)
◆ Kimberlite Cr-Diopsides
◆ Lamproite Cr-Diopsides
■ Diamond Inclusion Cr-Diopsides

Appendix 1


CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites/Lamproites And Eastern Keewatin
Kimberlites
Lamproites
Keewatin Low Cr-Diopsides
Keewatin Cr-Diopsides
DI Cr-Diopsides
Cr2O3 (wt%)
CaO (wt%)
0
1
2
3
4
5
6
7
8
6
8
10
12
14
16
18
20
22
24
26

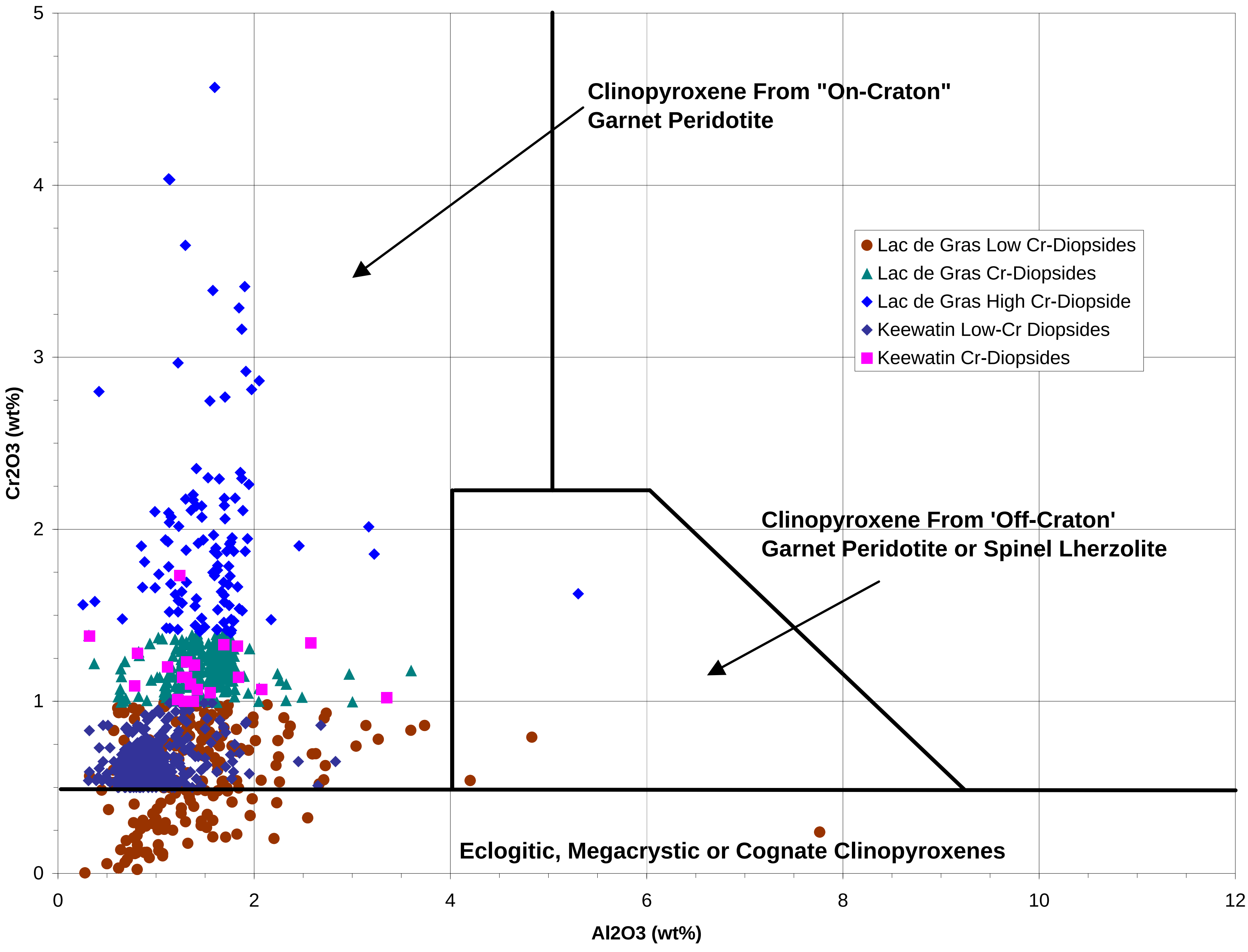
Appendix 2

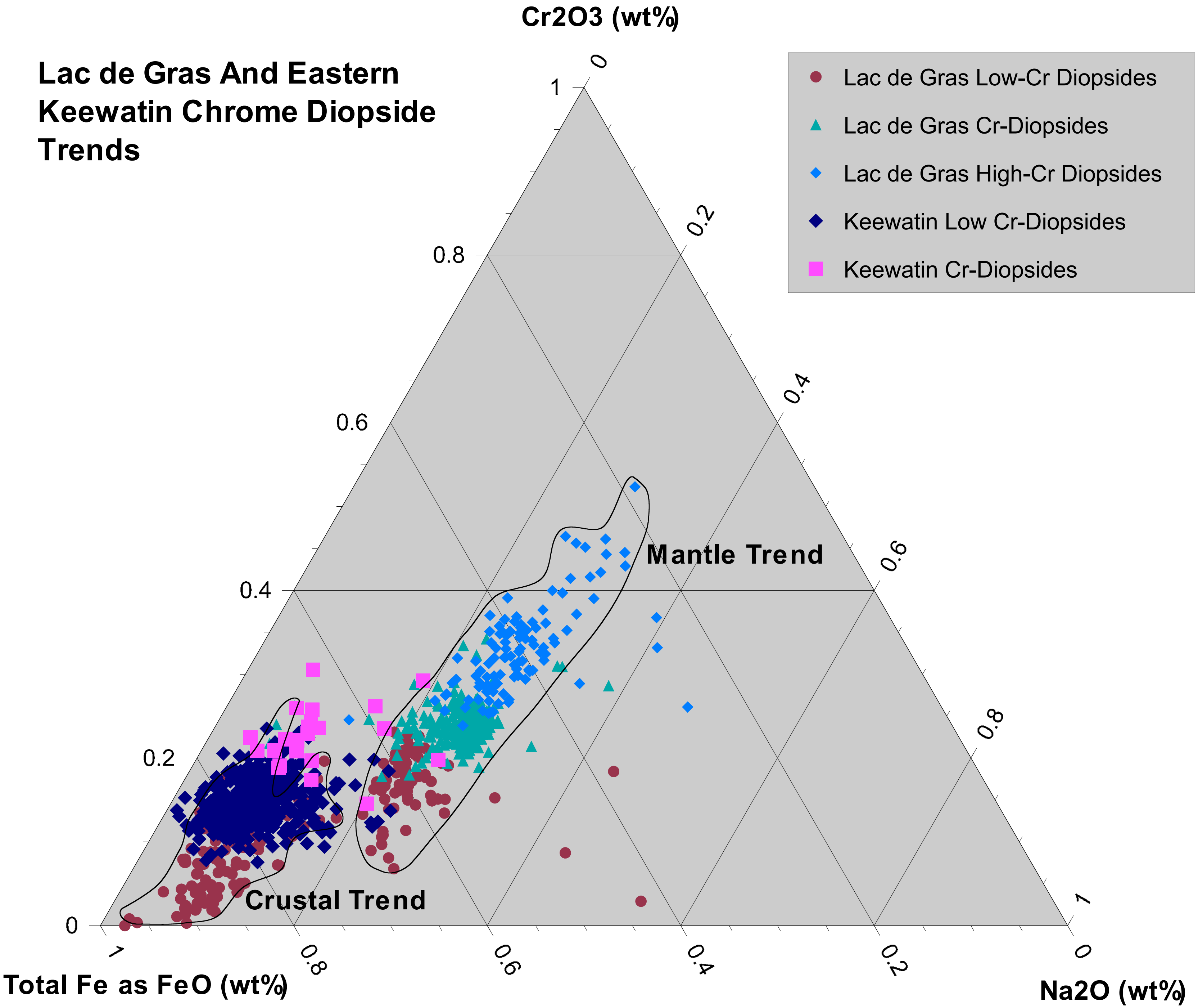

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites/Lamproites And Eastern Keewatin
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
8
◆ Kimberlites
◆ Lamproites
◆ Keewatin Low Cr-Diopsides
■ Keewatin Cr-Diopsides
■ DI Cr-Diopsides


FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Kimberlites/Lamproites And Eastern Keewatin
Cr2O3 (wt%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Fe as FeO (wt%)
◆ Kimberlite Cr-Diopsides
◆ Lamproite Cr-Diospides
◆ Keewatin Low Cr-Diopsides
■ Keewatin Cr-Diopsides
■ DI Cr-Diopsides

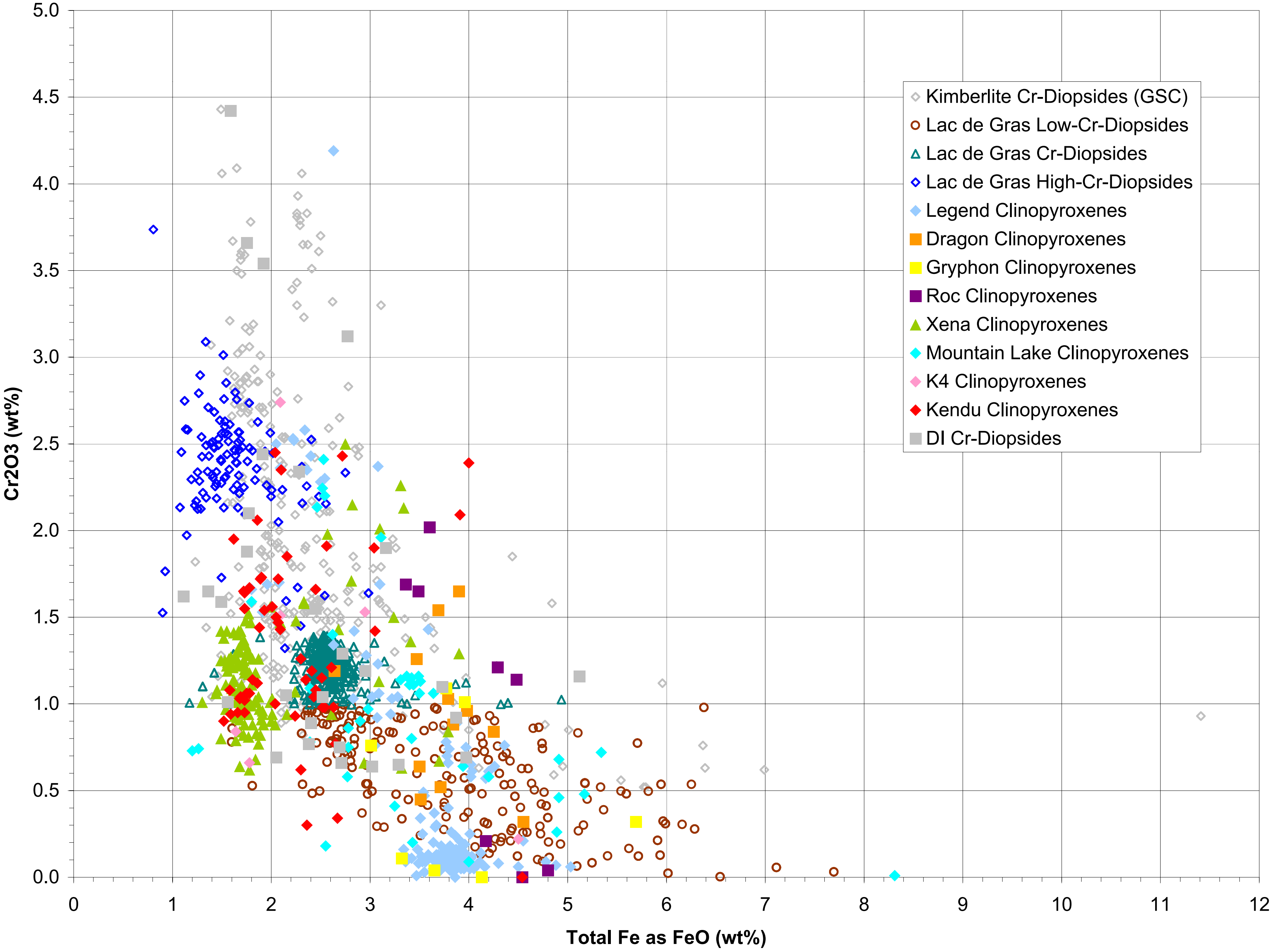
Appendix 2

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Eastern Keewatin

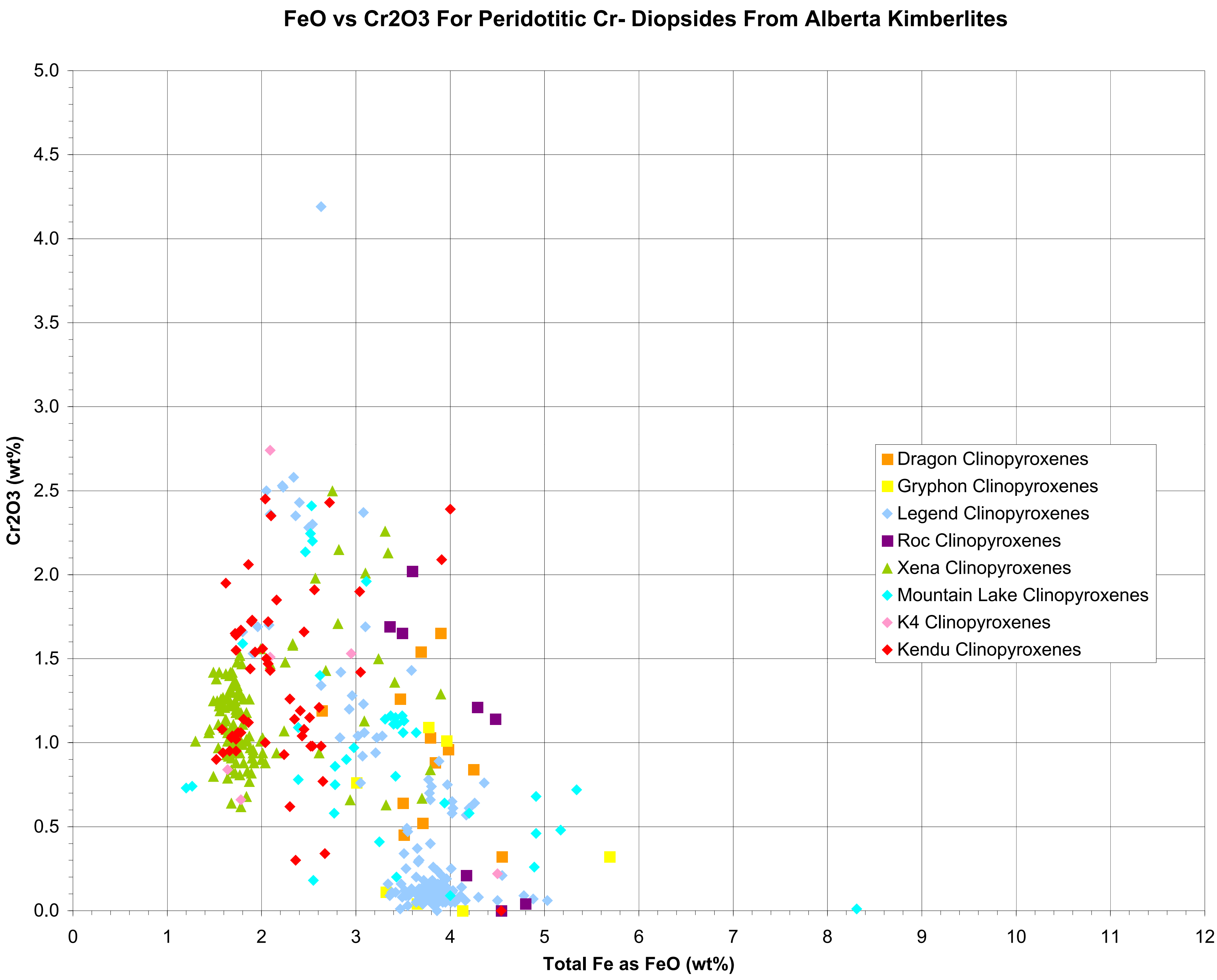



Lac de Gras And Eastern Keewatin Chrome Diopside Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
Lac de Gras Low-Cr Diopsides
Lac de Gras Cr-Diopsides
Lac de Gras High-Cr Diopsides
Keewatin Low Cr-Diopsides
Keewatin Cr-Diopsides
Mantle Trend
Crustal Trend
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1
1
0.8
0.6
0.4
0.2
0

FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites

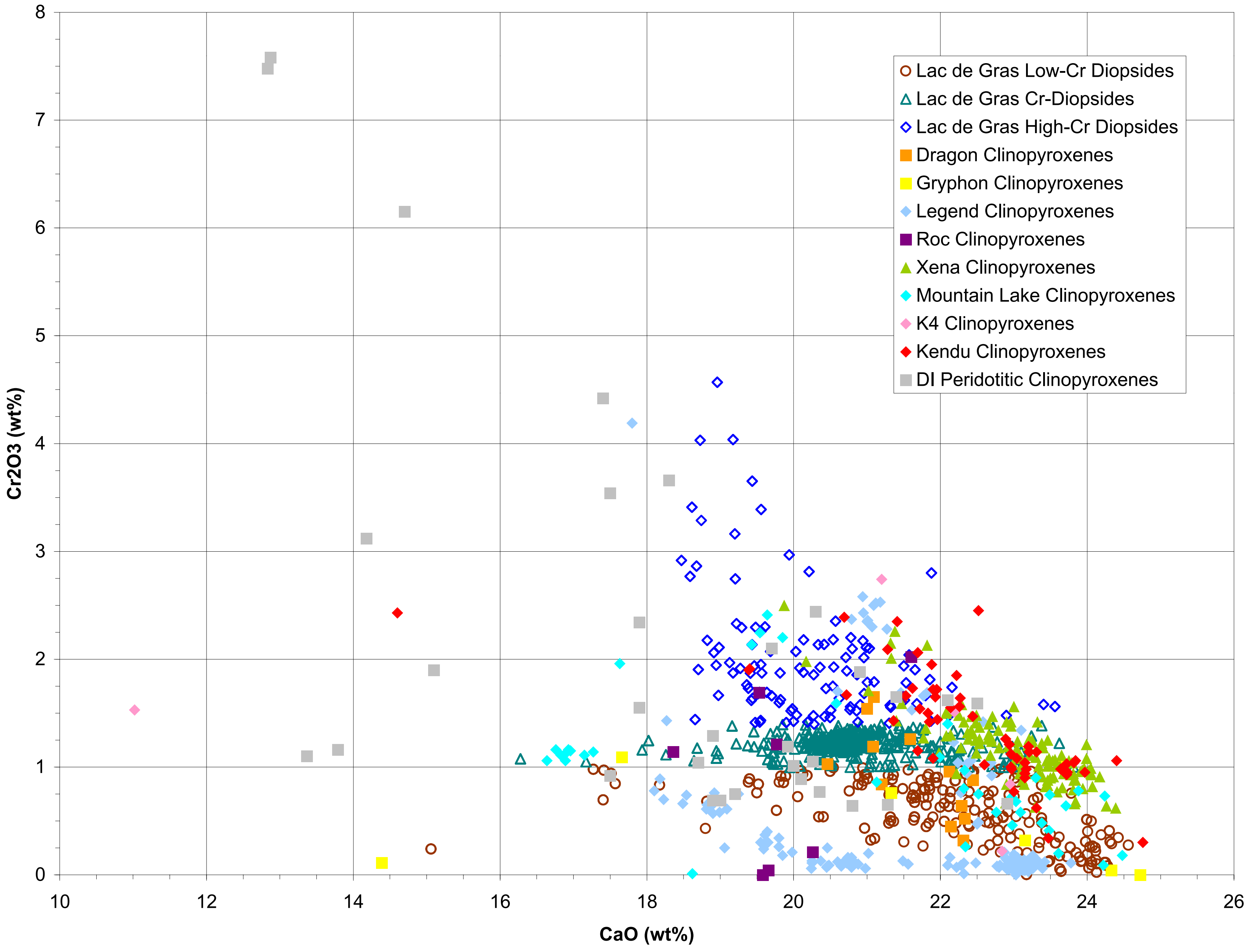


Appendix 2

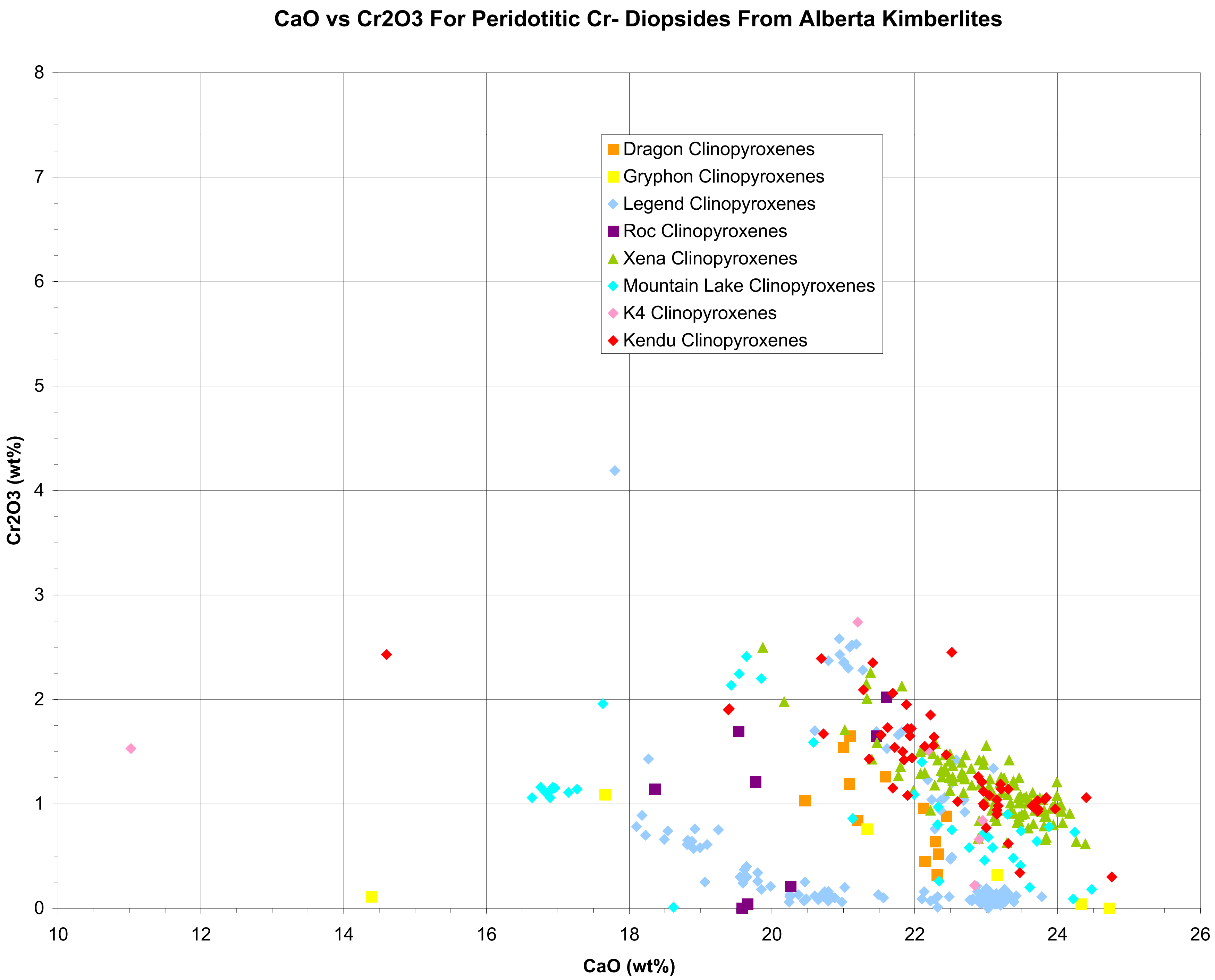

FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Cr2O3 (wt%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Fe as FeO (wt%)
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes

Appendix 2

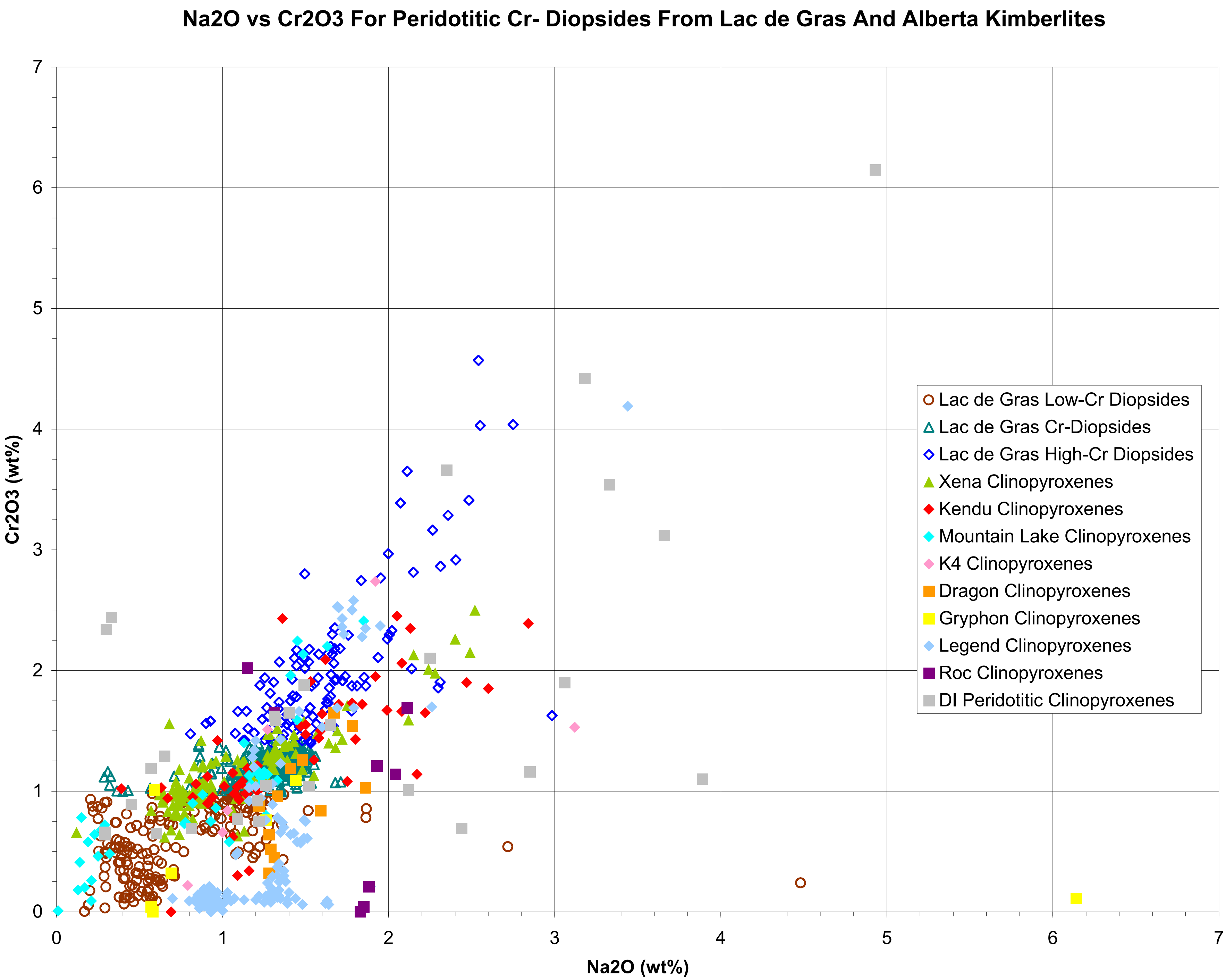
CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites



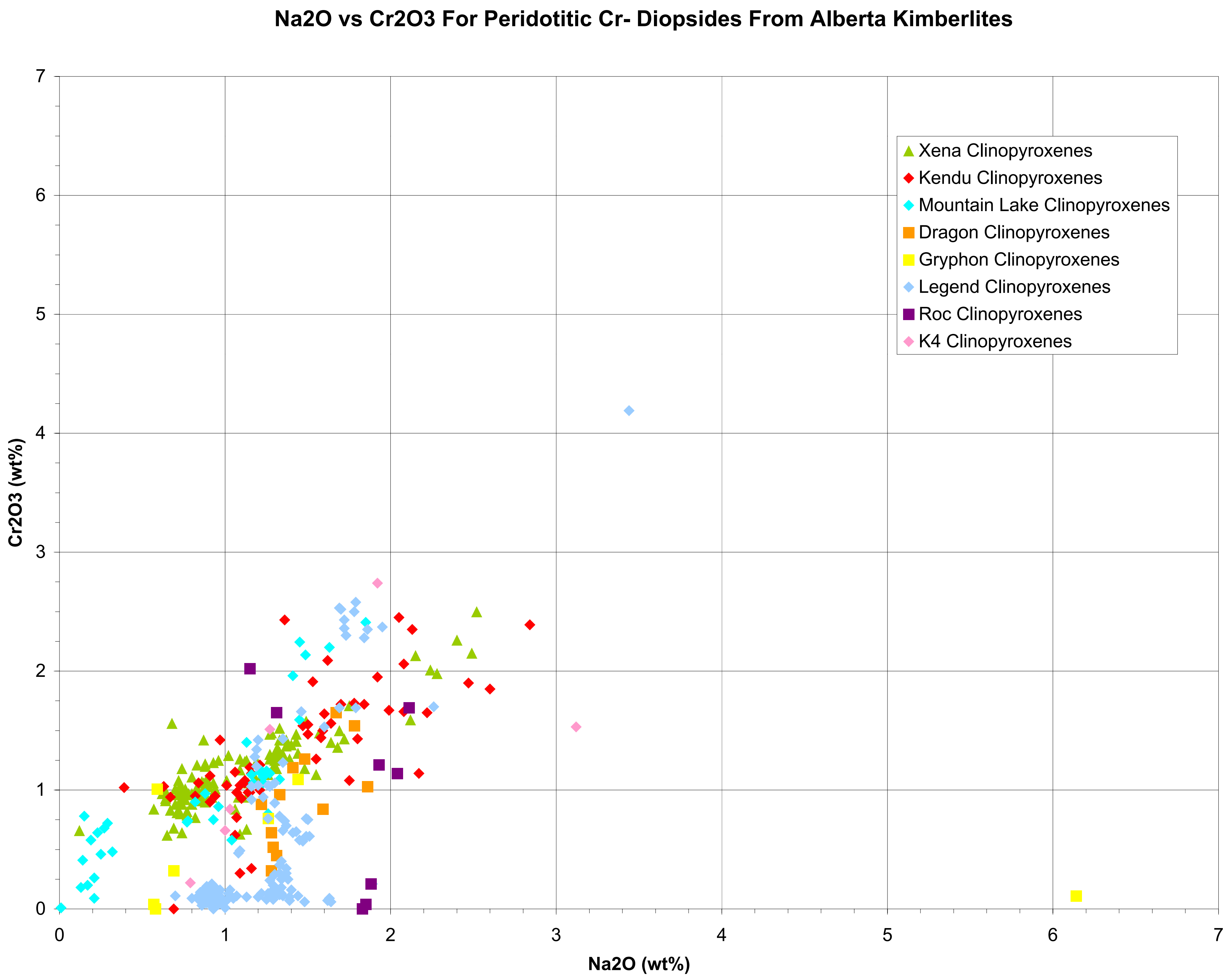
Appendix 2


CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Cr2O3 (wt%)
CaO (wt%)
0
1
2
3
4
5
6
7
8
10
12
14
16
18
20
22
24
26
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes

Appendix 2

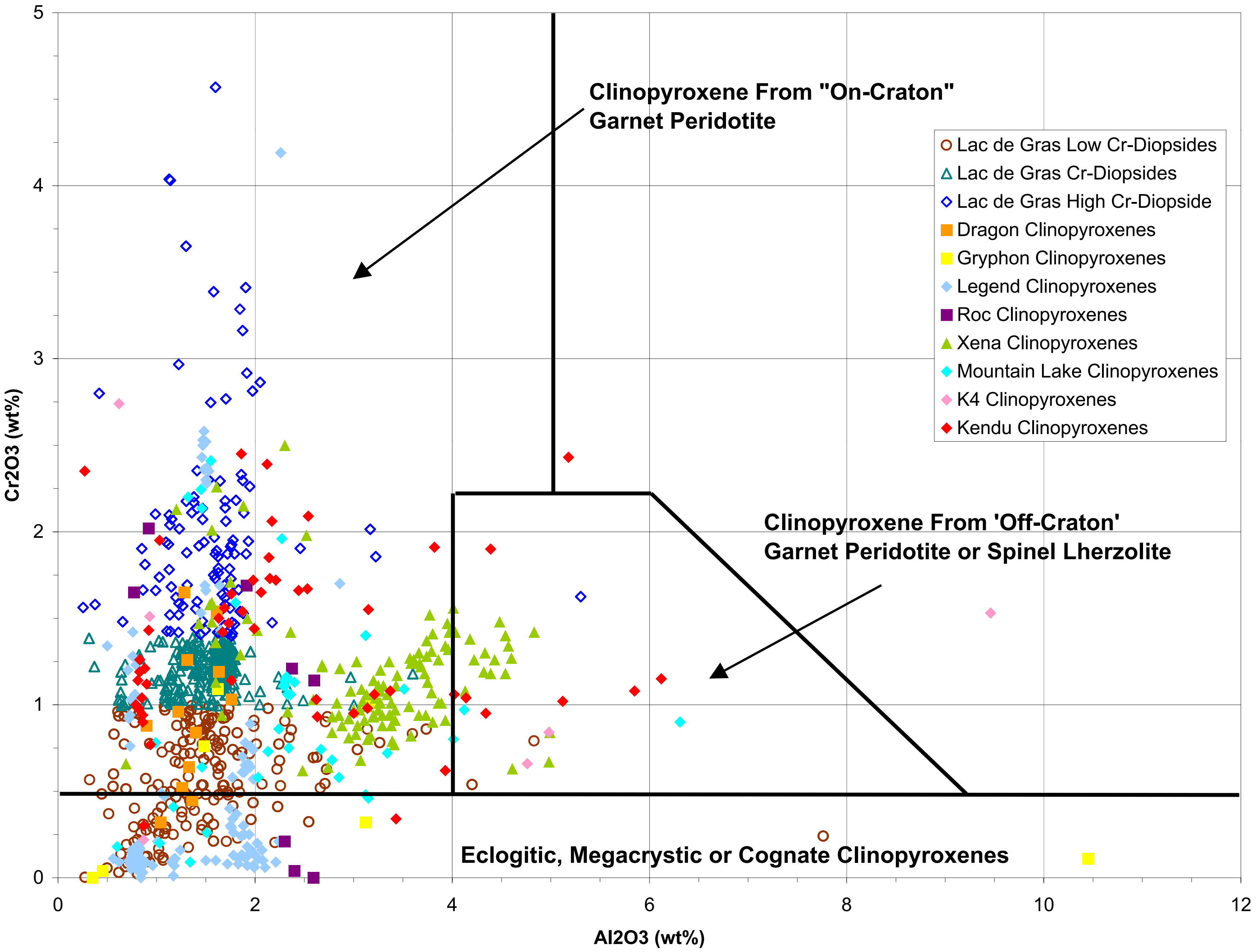

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
Lac de Gras Low-Cr Diopsides
Lac de Gras Cr-Diopsides
Lac de Gras High-Cr Diopsides
Xena Clinopyroxenes
Kendu Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
DI Peridotitic Clinopyroxenes

Appendix 2

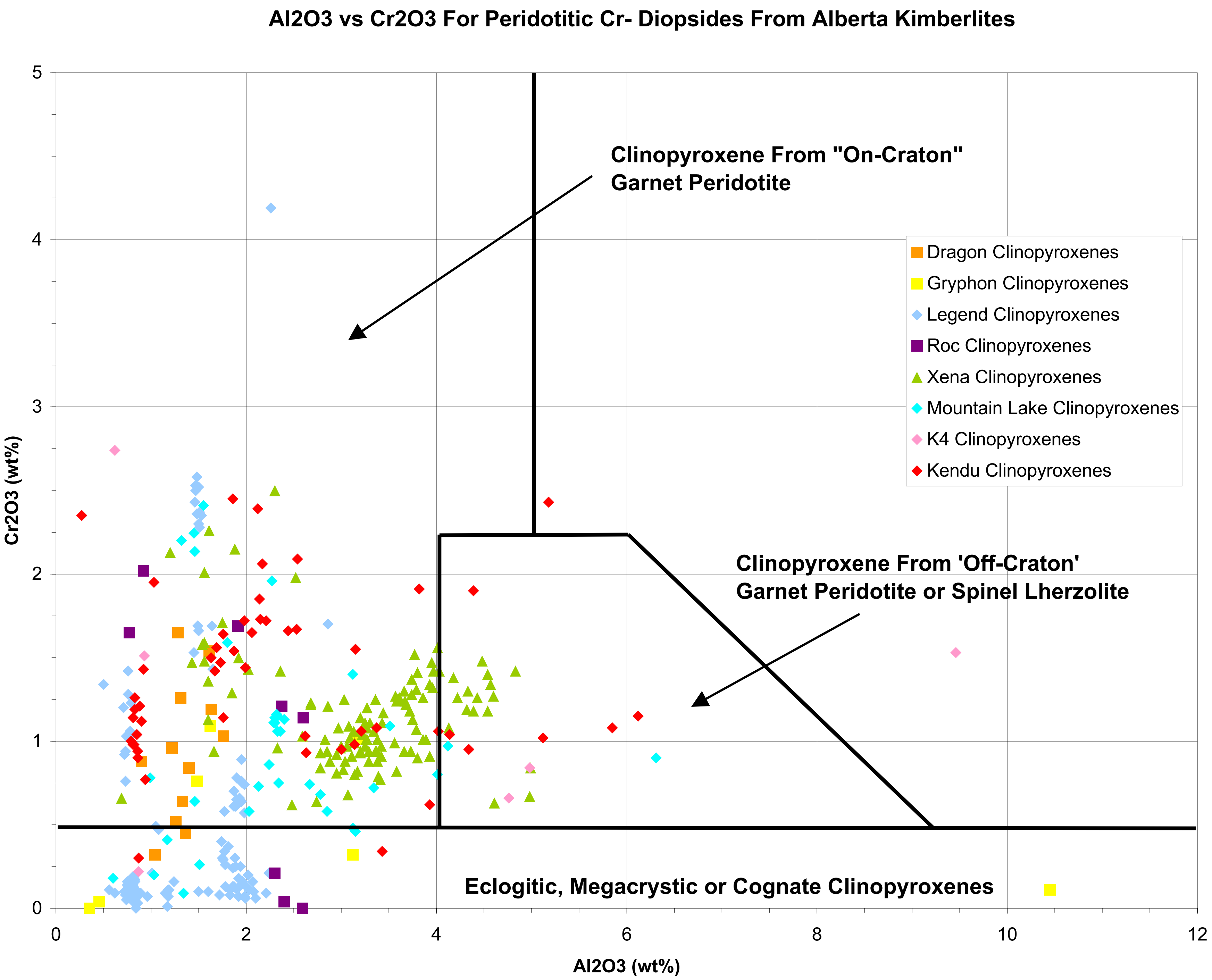


Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
Xena Clinopyroxenes
Kendu Clinopyroxenes
Mountain Lake Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
K4 Clinopyroxenes

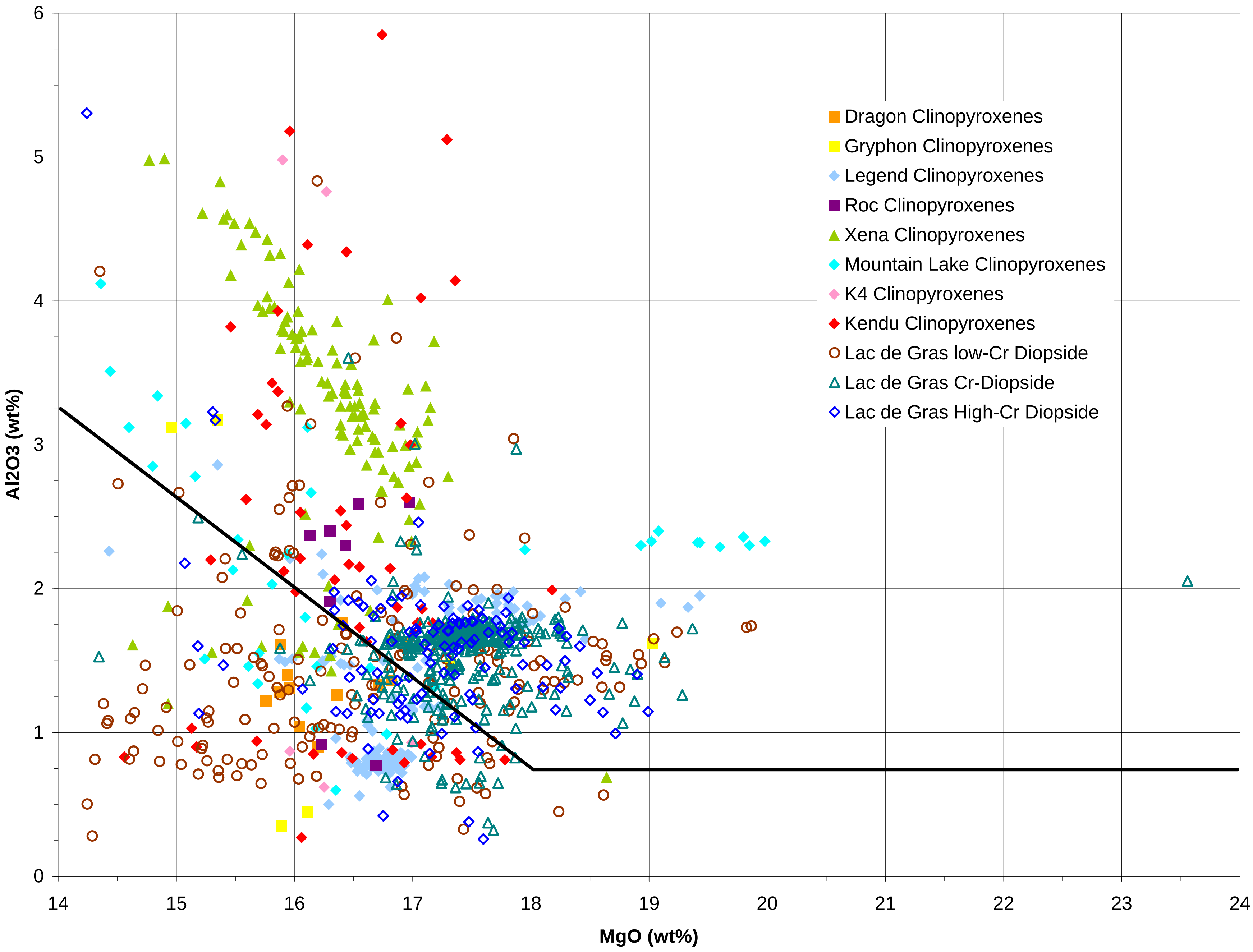
Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites



Appendix 2

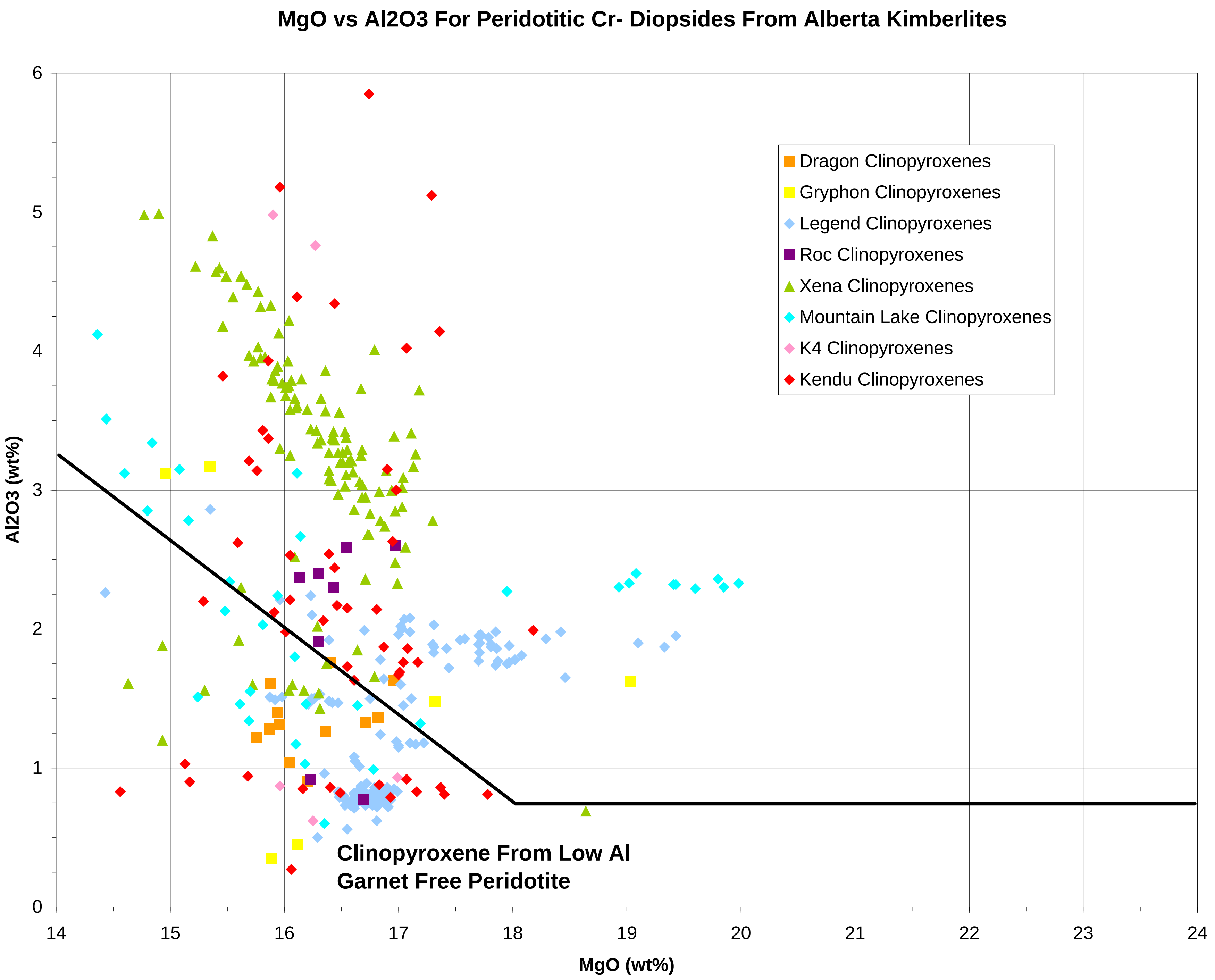

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Clinopyroxene From "On-Craton" Garnet Peridotite
Clinopyroxene From 'Off-Craton' Garnet Peridotite or Spinel Lherzolite
Eclogitic, Megacrystic or Cognate Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes
Cr2O3 (wt%)
Al2O3 (wt%)
0
1
2
3
4
5
0
2
4
6
8
10
12

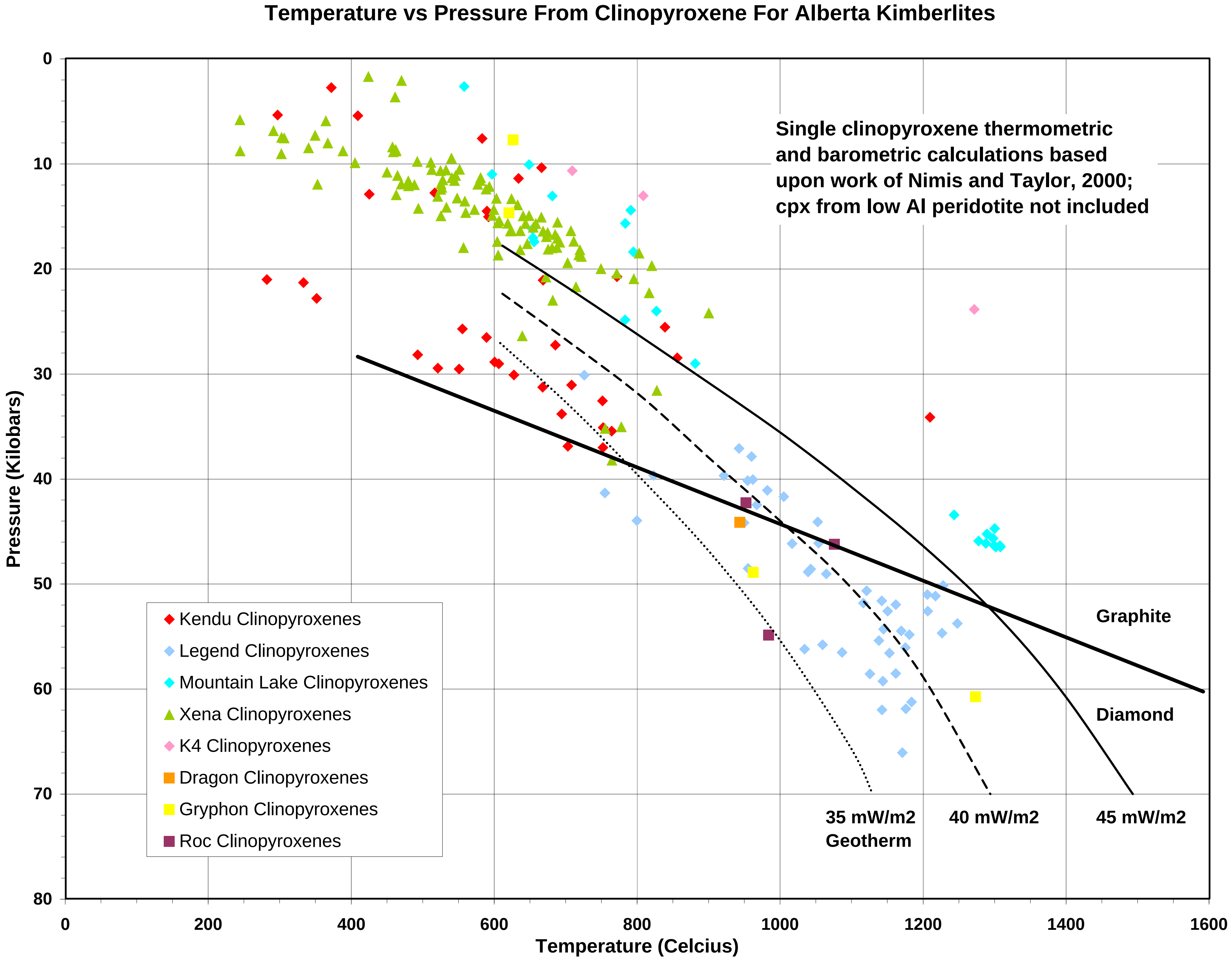
Appendix 2



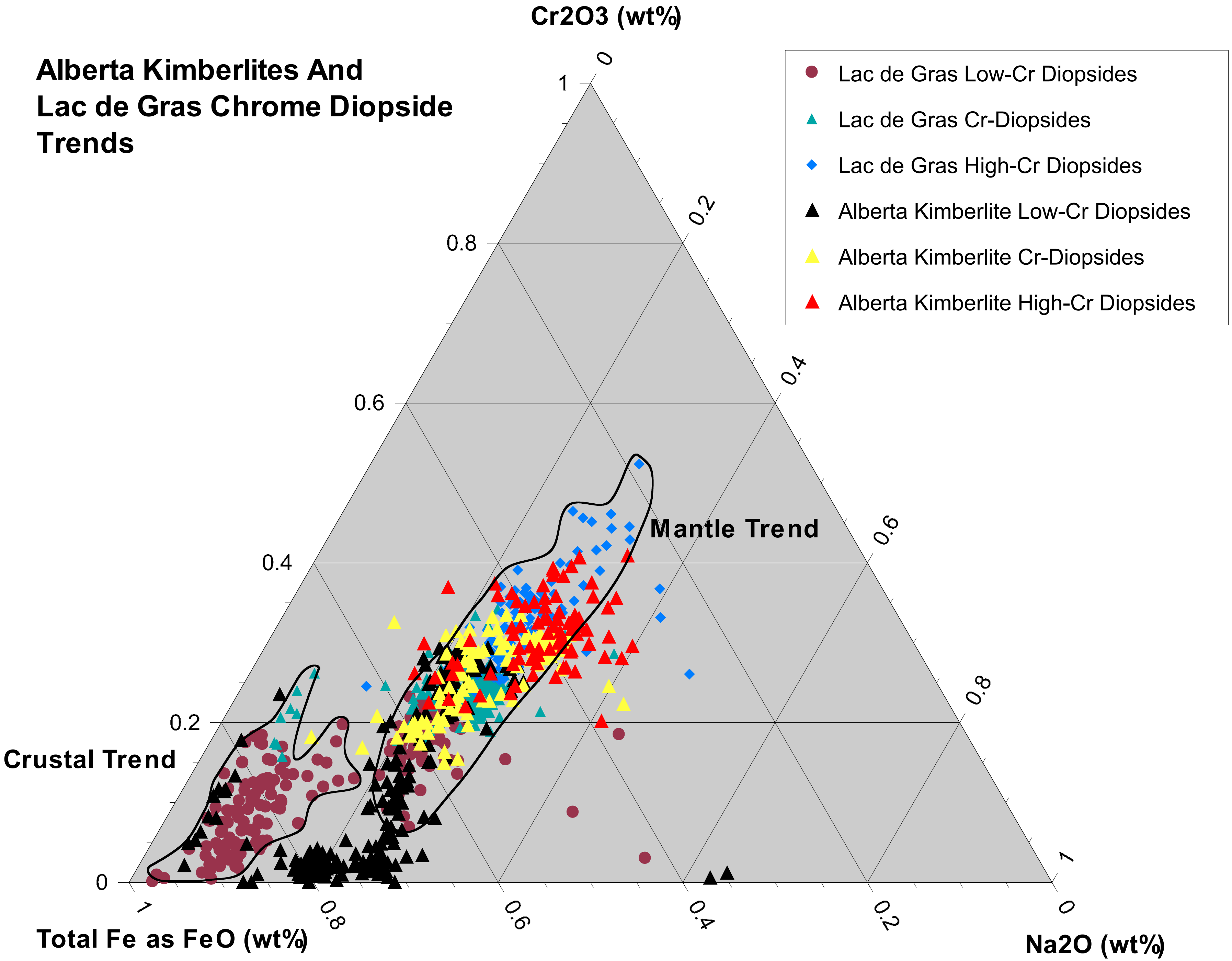
MgO vs Al2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites

Appendix 2

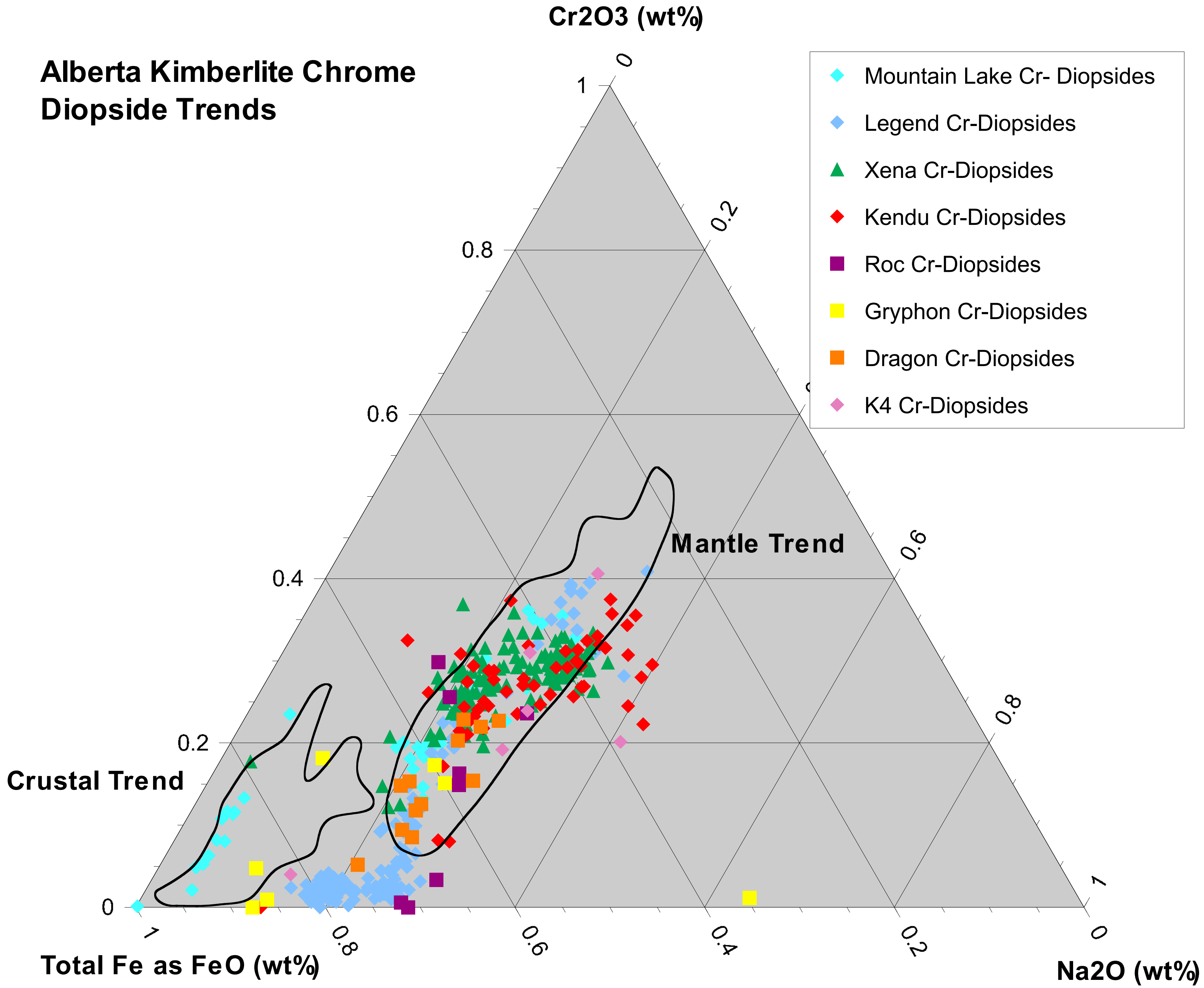

MgO vs Al2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Al2O3 (wt%)
MgO (wt%)
0
1
2
3
4
5
6
14
15
16
17
18
19
20
21
22
23
24
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes
Clinopyroxene From Low Al
Garnet Free Peridotite


Temperature vs Pressure From Clinopyroxene For Alberta Kimberlites
Single clinopyroxene thermometric and barometric calculations based upon work of Nimis and Taylor, 2000; cpx from low Al peridotite not included
Pressure (Kilobars)
Temperature (Celcius)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
Kendu Clinopyroxenes
Legend Clinopyroxenes
Mountain Lake Clinopyroxenes
Xena Clinopyroxenes
K4 Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Roc Clinopyroxenes
Graphite
Diamond
35 mW/m2
Geotherm
40 mW/m2
45 mW/m2

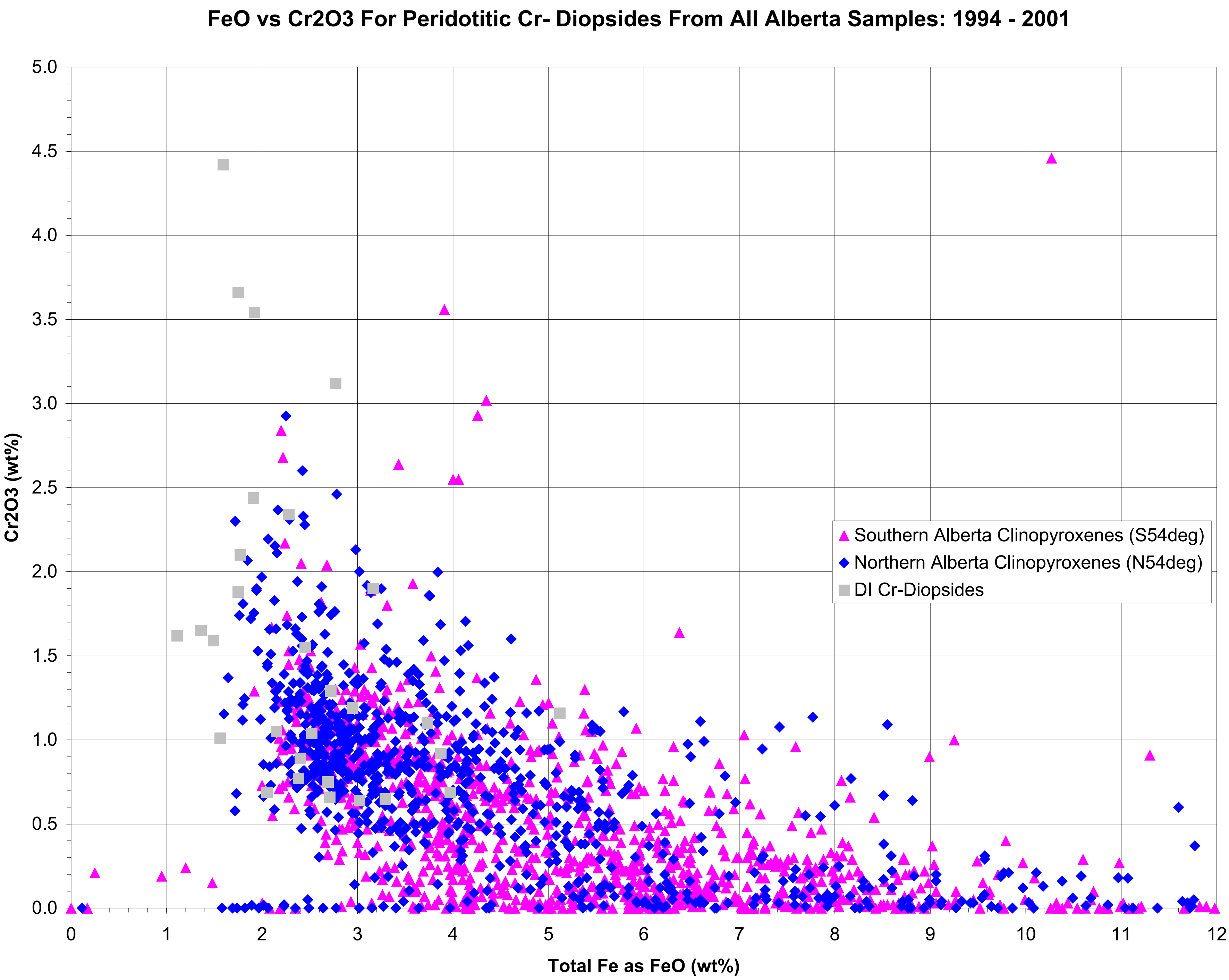
Appendix 2


Alberta Kimberlites And
Lac de Gras Chrome Diopside
Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
Mantle Trend
Crustal Trend
0
0.2
0.4
0.6
0.8
1
● Lac de Gras Low-Cr Diopsides
▲ Lac de Gras Cr-Diopsides
◆ Lac de Gras High-Cr Diopsides
▲ Alberta Kimberlite Low-Cr Diopsides
▲ Alberta Kimberlite Cr-Diopsides
▲ Alberta Kimberlite High-Cr Diopsides

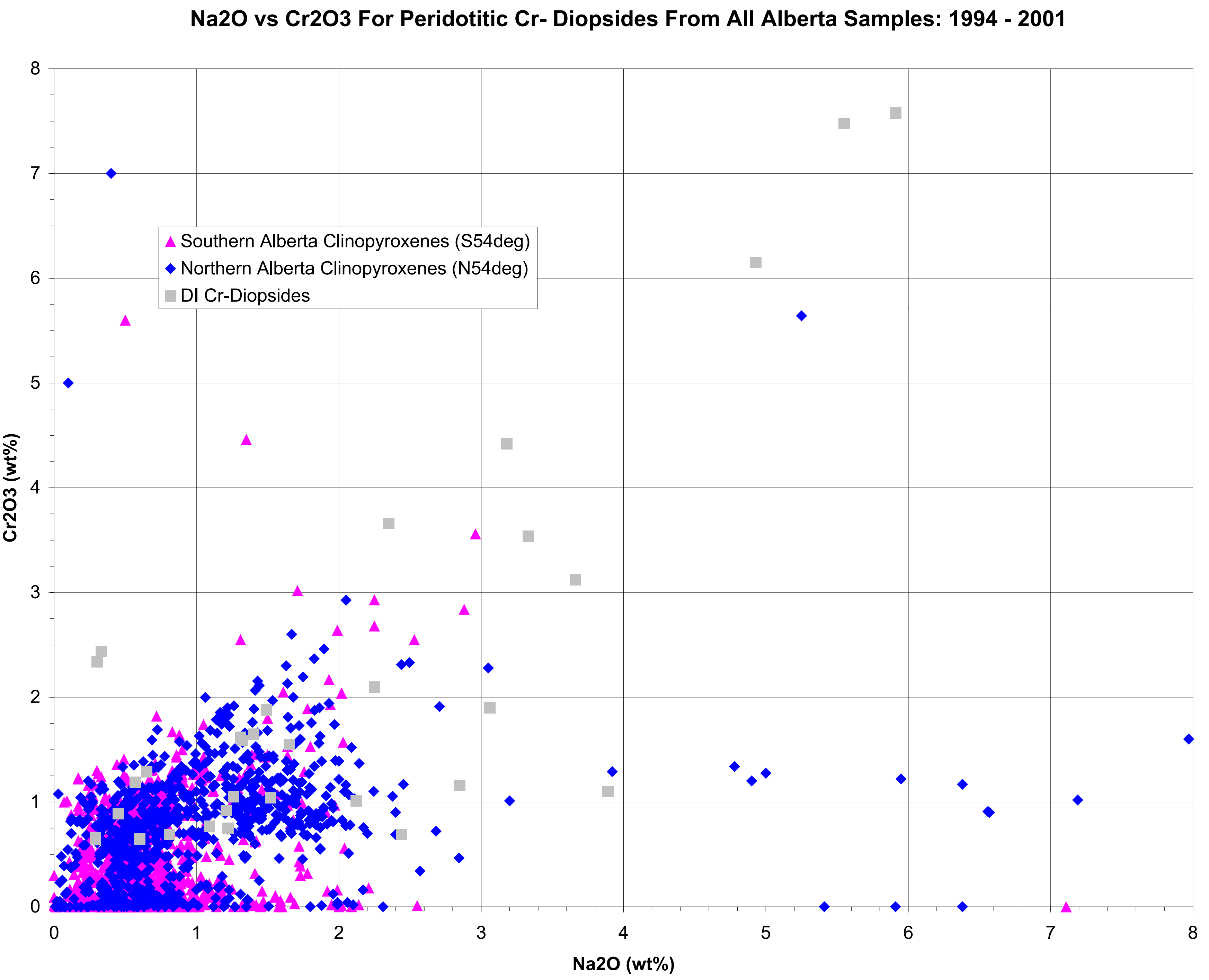
Appendix 2


Alberta Kimberlite Chrome Diopside Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
Mantle Trend
Crustal Trend
◆ Mountain Lake Cr- Diopsides
◆ Legend Cr-Diopsides
▲ Xena Cr-Diopsides
◆ Kendu Cr-Diopsides
■ Roc Cr-Diopsides
■ Gryphon Cr-Diopsides
■ Dragon Cr-Diopsides
◆ K4 Cr-Diopsides
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1
0.8
0.6
0.4
0.2
0

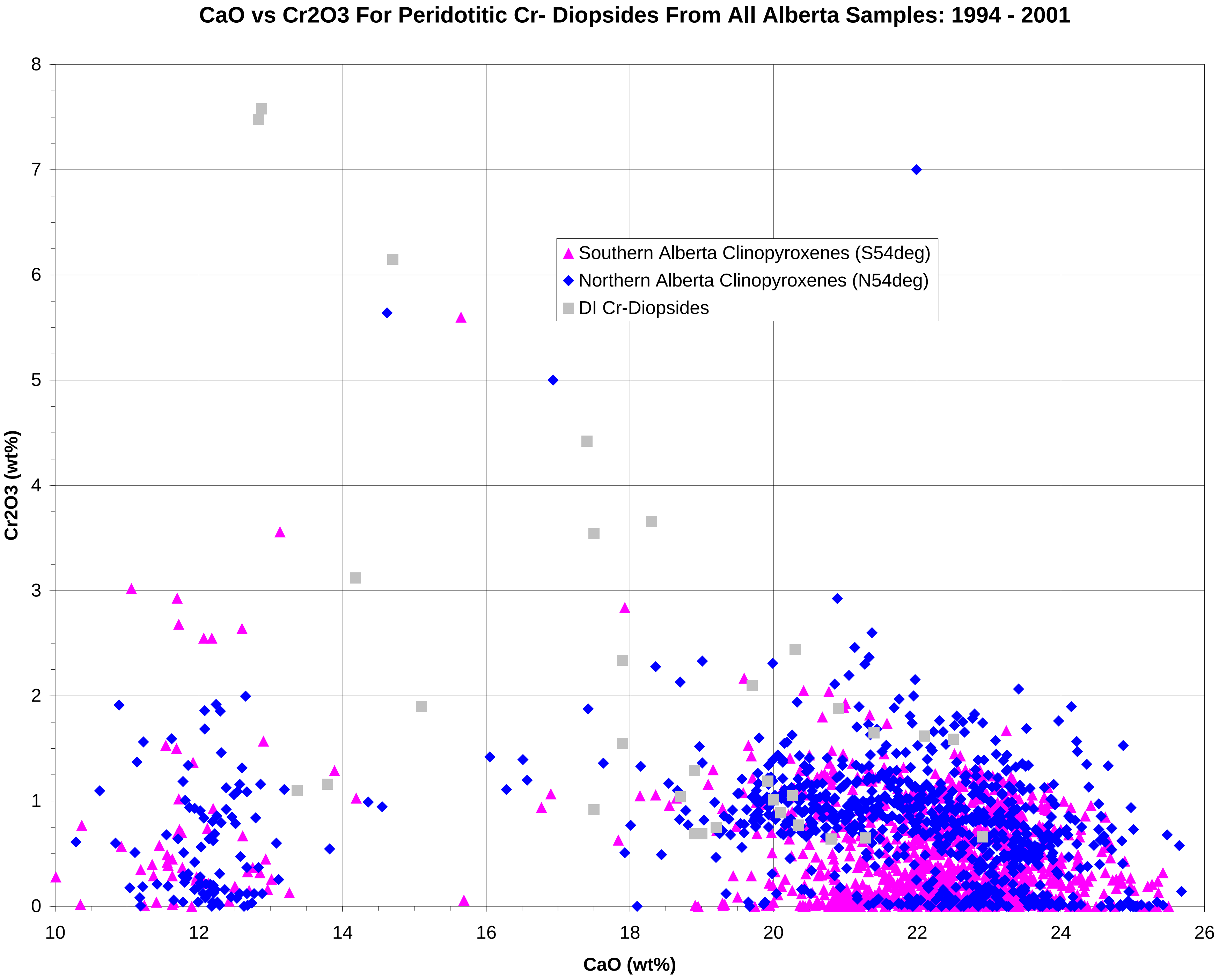
Appendix 2


FeO vs Cr2O3 For Peridotitic Cr- Diopsides From All Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Fe as FeO (wt%)
▲ Southern Alberta Clinopyroxenes (S54deg)
◆ Northern Alberta Clinopyroxenes (N54deg)
■ DI Cr-Diopsides

Appendix 2

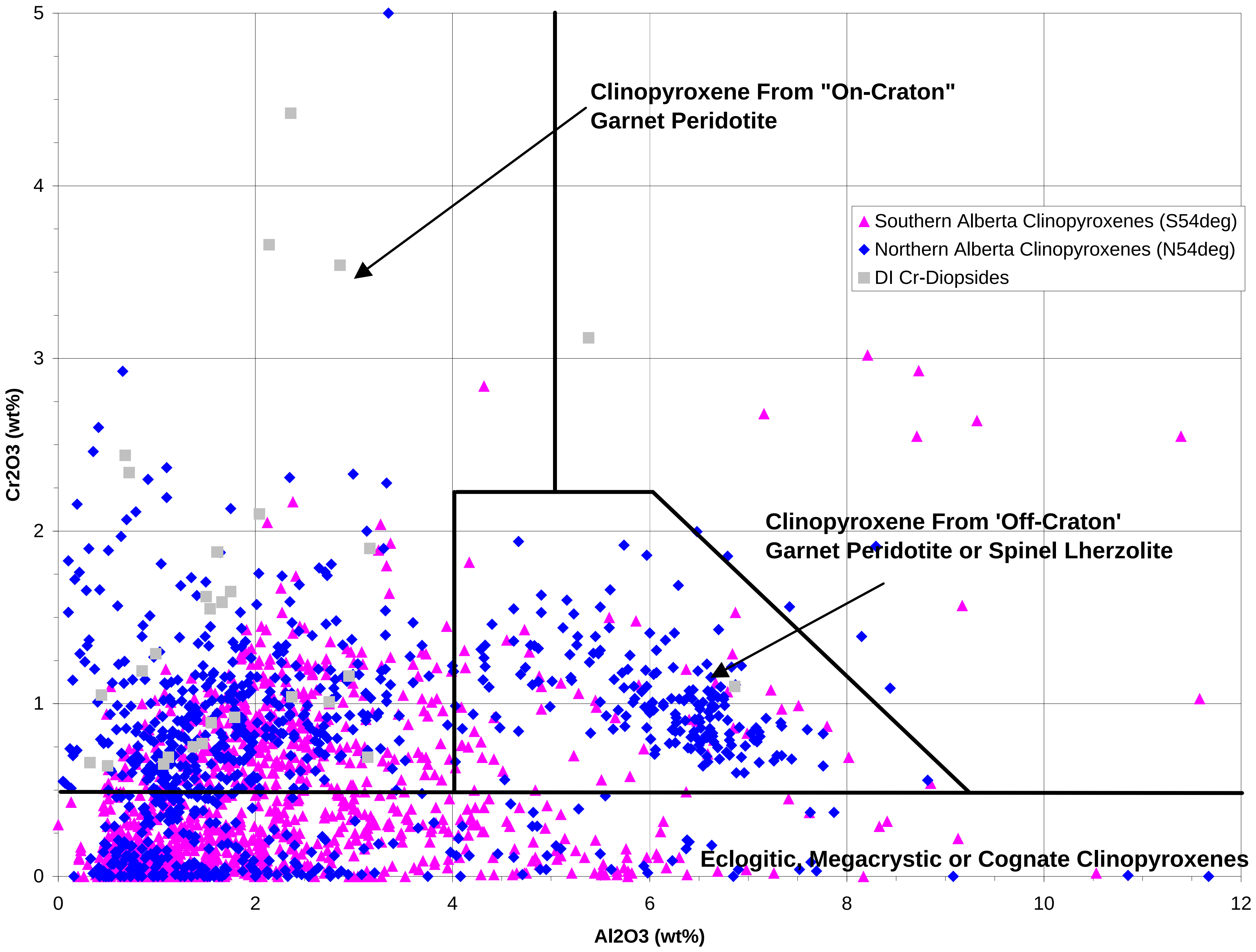

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From All Alberta Samples: 1994 - 2001
▲ Southern Alberta Clinopyroxenes (S54deg)
◆ Northern Alberta Clinopyroxenes (N54deg)
■ DI Cr-Diopsides
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
8

Appendix 2



CaO vs Cr2O3 For Peridotitic Cr- Diopsides From All Alberta Samples: 1994 - 2001
▲ Southern Alberta Clinopyroxenes (S54deg)
◆ Northern Alberta Clinopyroxenes (N54deg)
■ DI Cr-Diopsides
Cr2O3 (wt%)
0
1
2
3
4
5
6
7
8
CaO (wt%)
10
12
14
16
18
20
22
24
26

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From All Alberta Samples: 1994 - 2001



Appendix 2


Al2O3 vs Na2O For Low-Cr Diopsides From All Alberta Samples: 1994 - 2001
Na2O (wt%)
Al2O3 (wt%)
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
Southern Alberta Clinopyroxenes (S54deg)
Northern Alberta Clinopyroxenes (N54deg)

Appendix 2

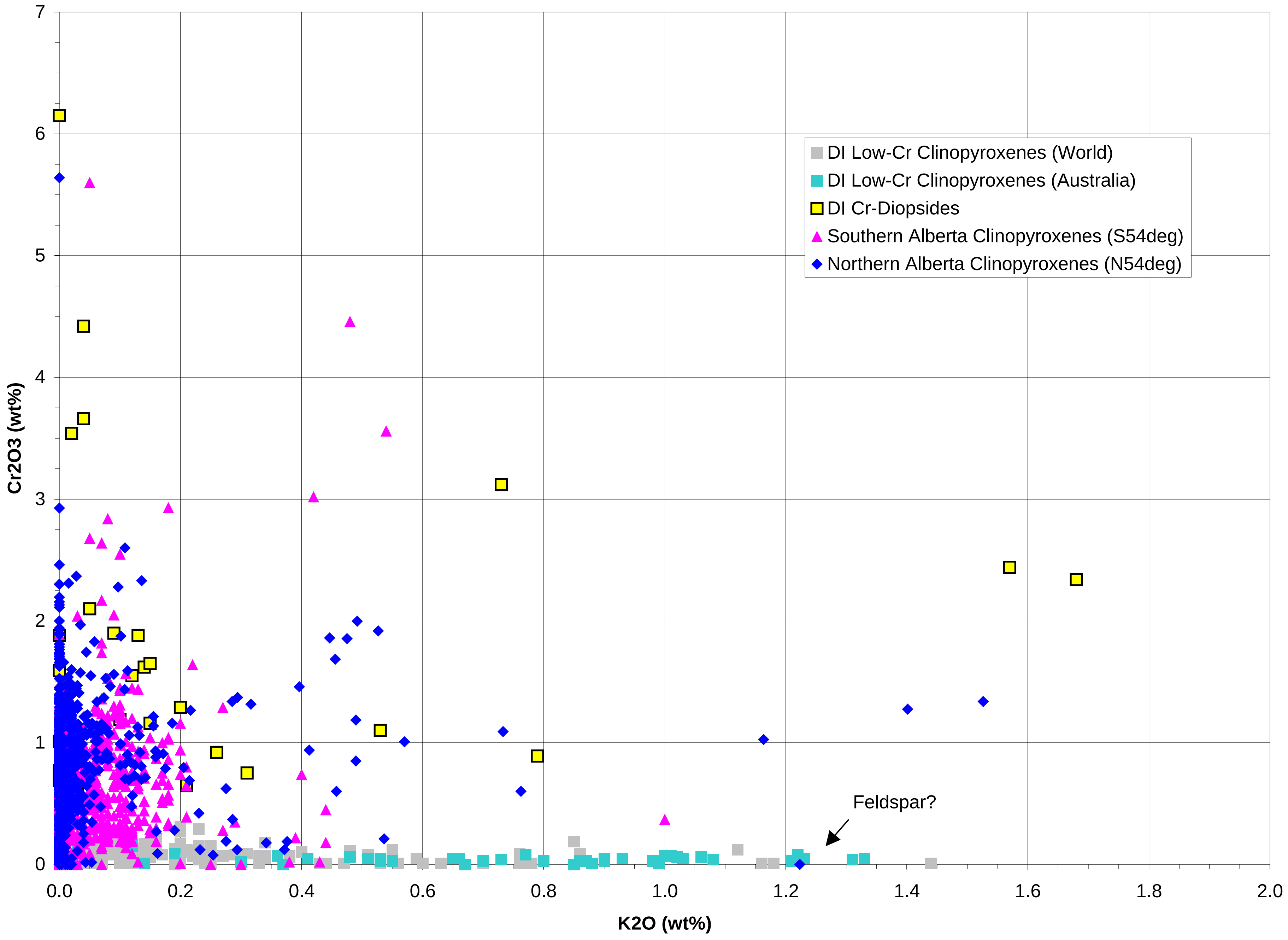

K2O vs Na2O For Low-Cr Diopsides From All Alberta Samples: 1994 - 2001
Na2O (wt%)
0
1
2
3
4
5
6
7
8
9
10
K2O (wt%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Southern Alberta Clinopyroxenes (S54deg)
Northern Alberta Clinopyroxenes (N54deg)
Feldspar?

Appendix 2

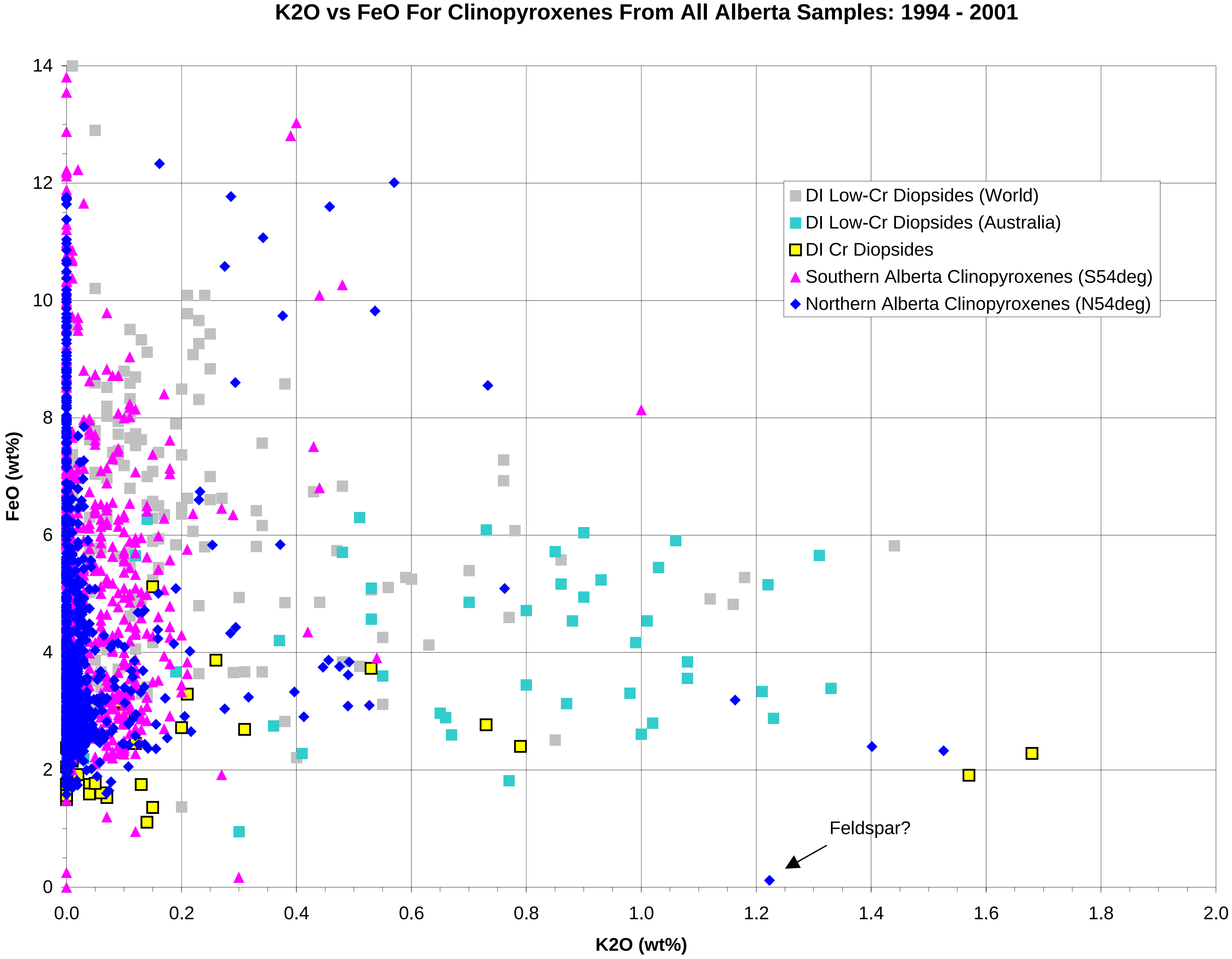

K2O vs Al2O3 For Clinopyroxenes From All Alberta Samples: 1994 - 2001
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Southern Alberta Clinopyroxenes (S54deg)
Northern Alberta Clinopyroxenes (N54deg)
Al2O3 (wt%)
20
18
16
14
12
10
8
6
4
2
0
K2O (wt%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

Appendix 3

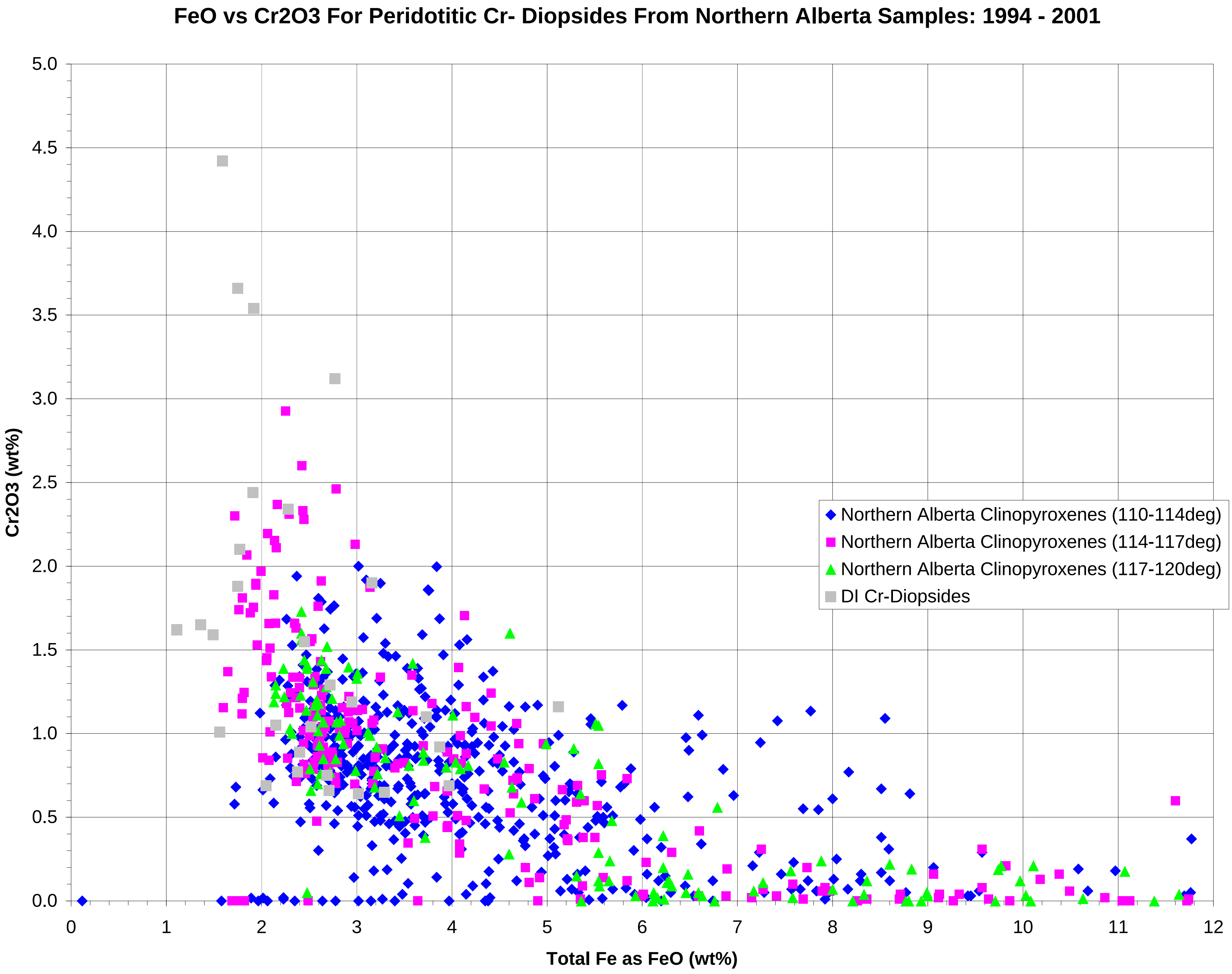
K2O vs Cr2O3 For Clinopyroxenes From All Alberta Samples: 1994 - 2001



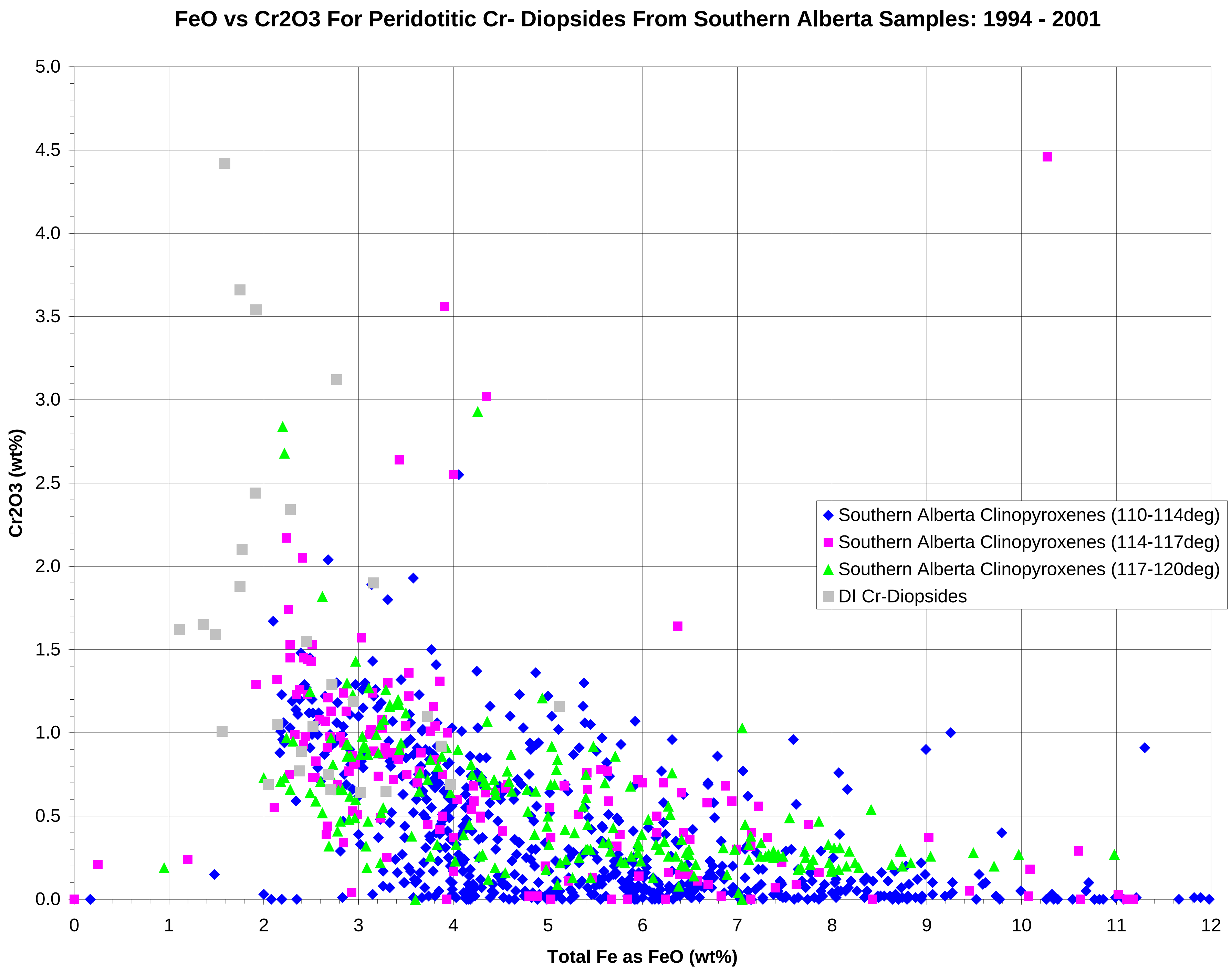
Appendix 3


K2O vs FeO For Clinopyroxenes From All Alberta Samples: 1994 - 2001
FeO (wt%)
K2O (wt%)
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Southern Alberta Clinopyroxenes (S54deg)
Northern Alberta Clinopyroxenes (N54deg)
Feldspar?

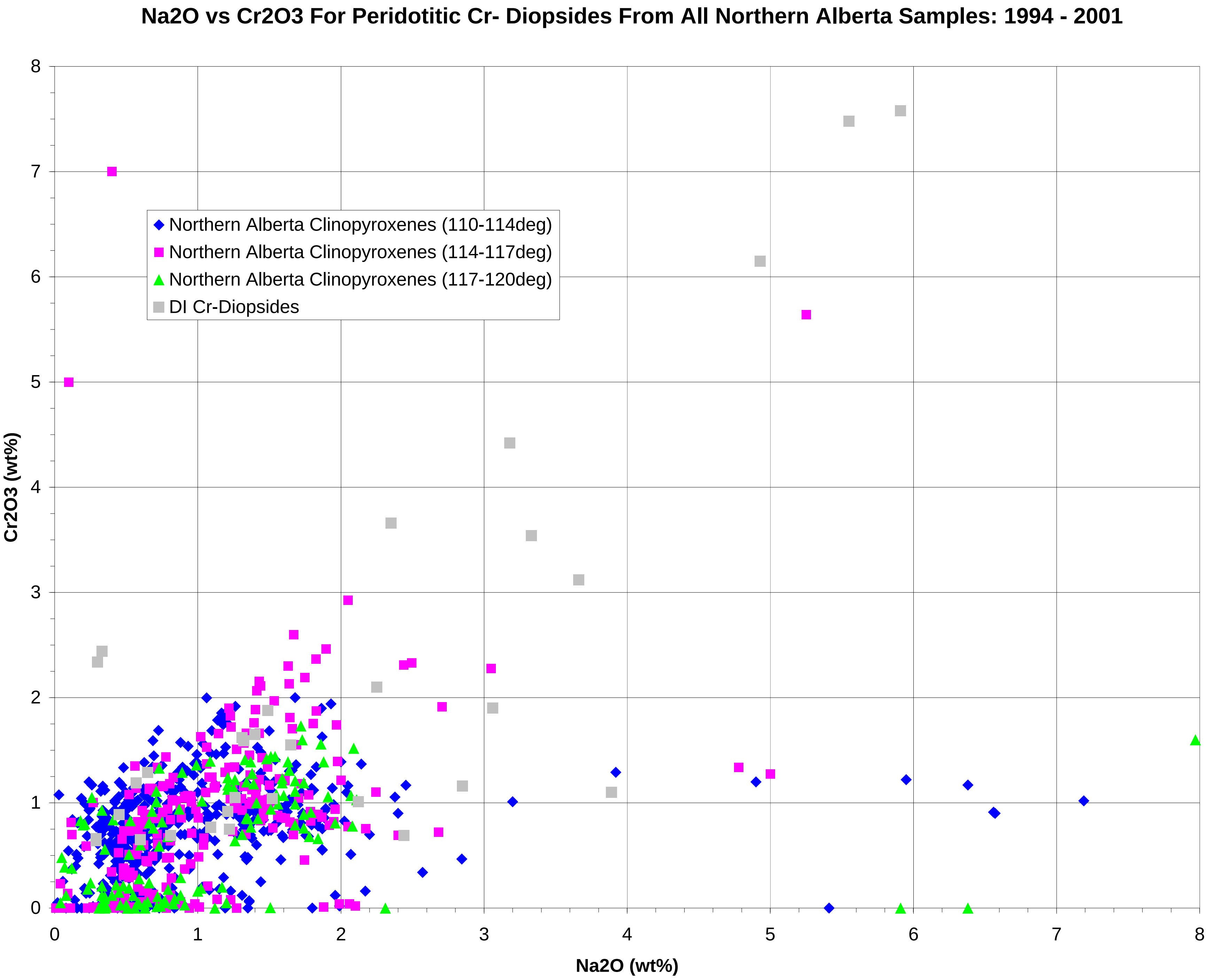
Appendix 3


FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Northern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
Total Fe as FeO (wt%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0
1
2
3
4
5
6
7
8
9
10
11
12
◆ Northern Alberta Clinopyroxenes (110-114deg)
■ Northern Alberta Clinopyroxenes (114-117deg)
▲ Northern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides

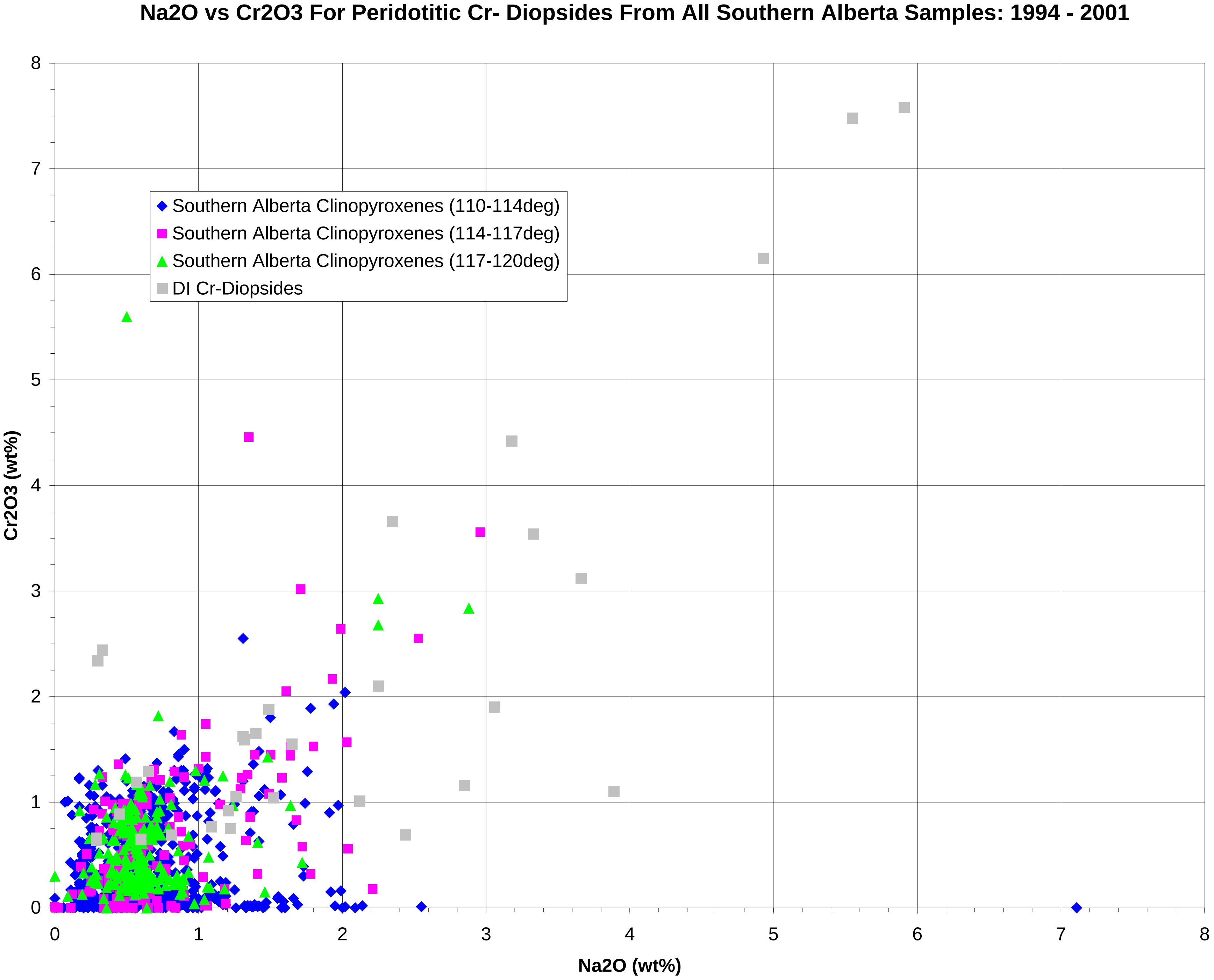
Appendix 3


FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Fe as FeO (wt%)
◆ Southern Alberta Clinopyroxenes (110-114deg)
■ Southern Alberta Clinopyroxenes (114-117deg)
▲ Southern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides

Appendix 3

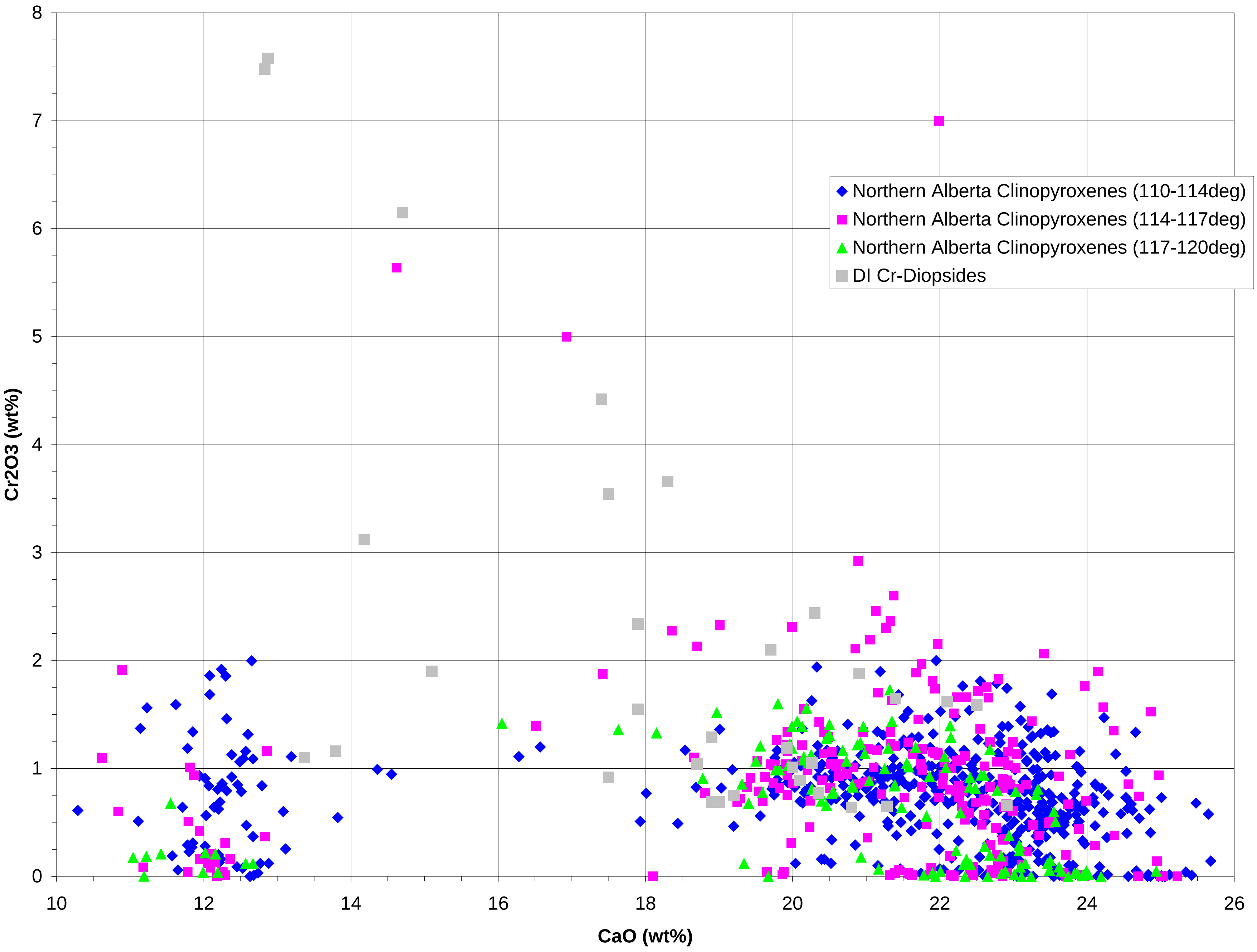

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From All Northern Alberta Samples: 1994 - 2001
◆ Northern Alberta Clinopyroxenes (110-114deg)
■ Northern Alberta Clinopyroxenes (114-117deg)
▲ Northern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides
Cr2O3 (wt%)
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
Na2O (wt%)

Appendix 3

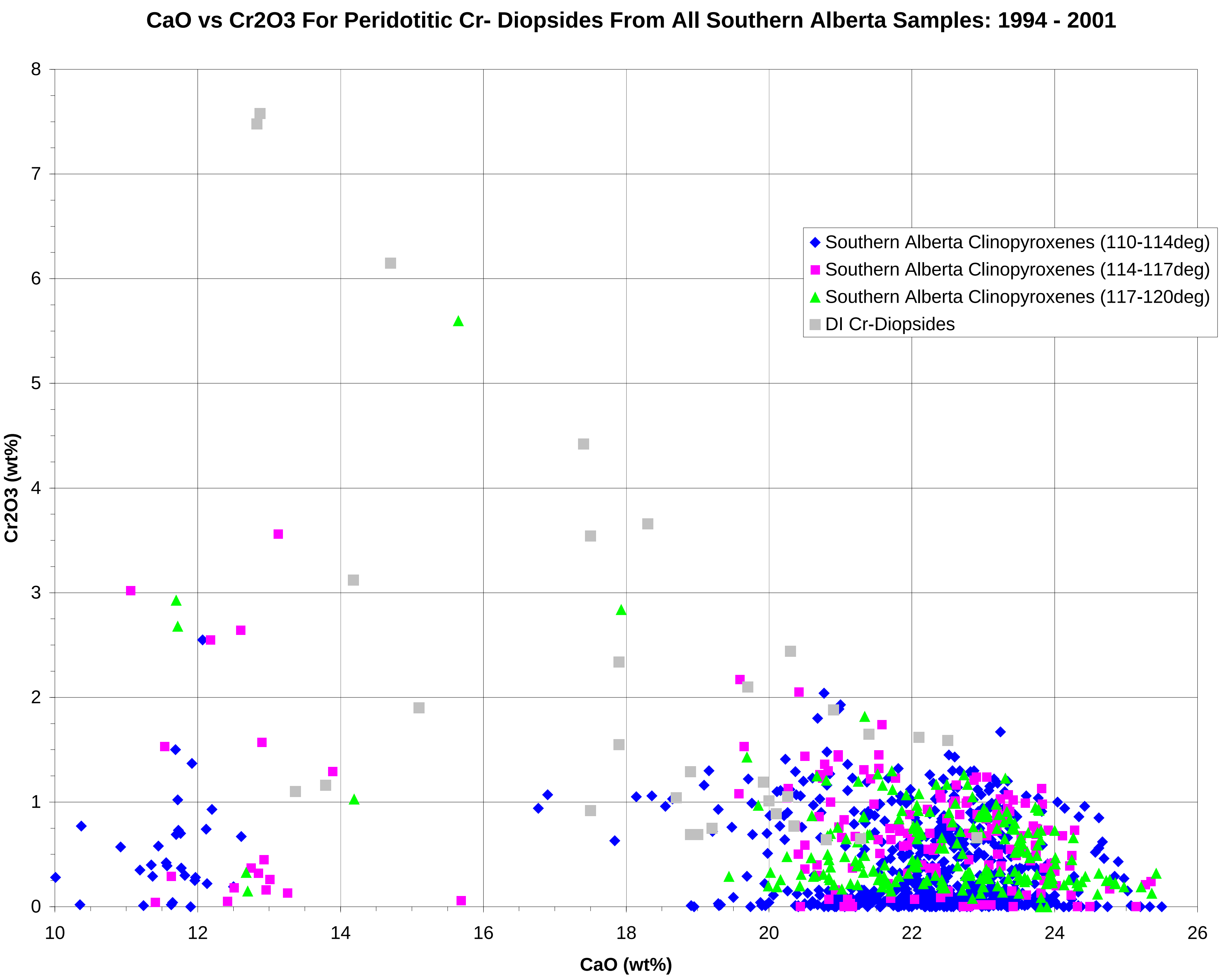

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From All Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
8
◆ Southern Alberta Clinopyroxenes (110-114deg)
■ Southern Alberta Clinopyroxenes (114-117deg)
▲ Southern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides

Appendix 3

CaO vs Cr2O3 For Peridotitic Cr- Diopsides From All Northern Alberta Samples: 1994 - 2001

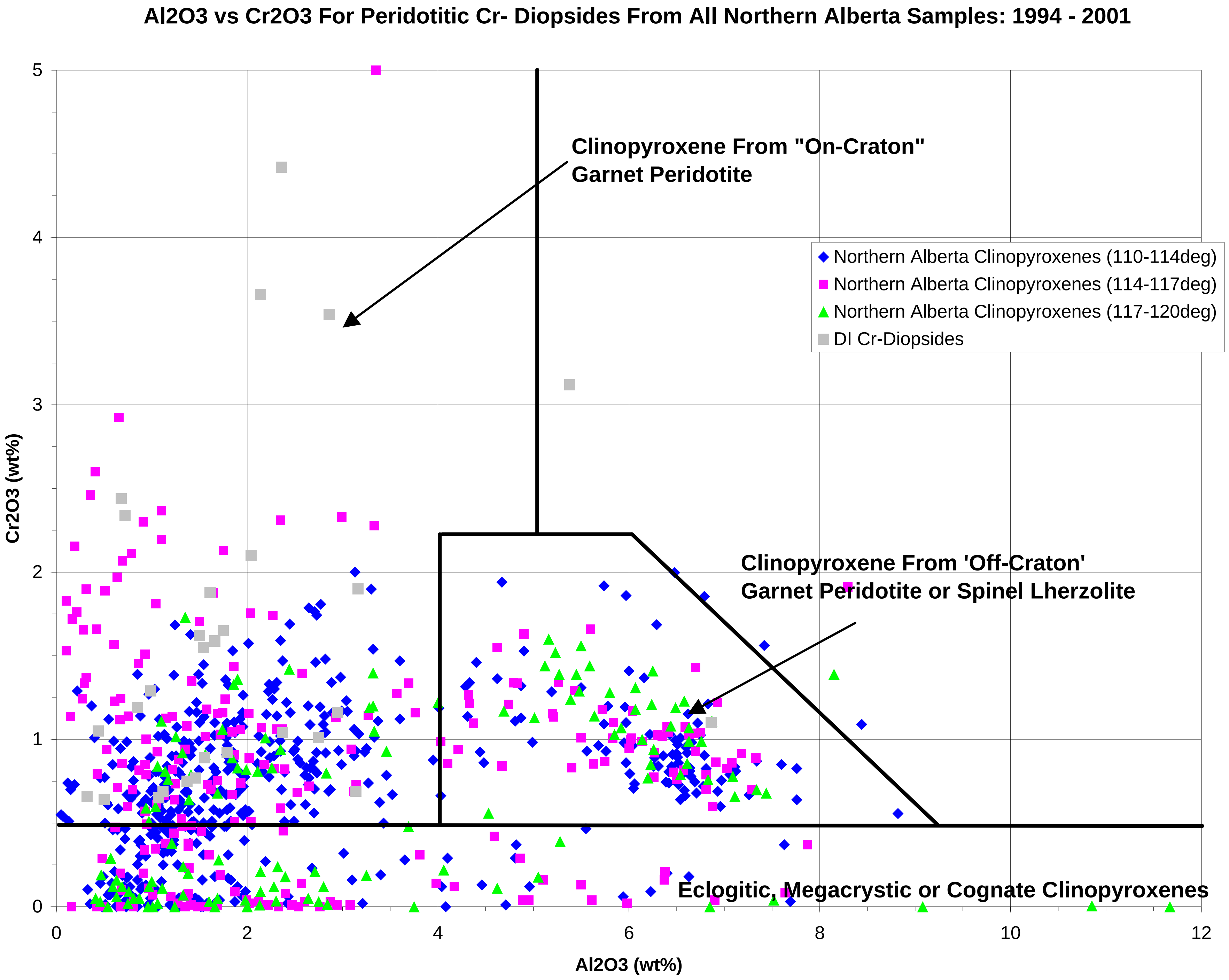


Appendix 3

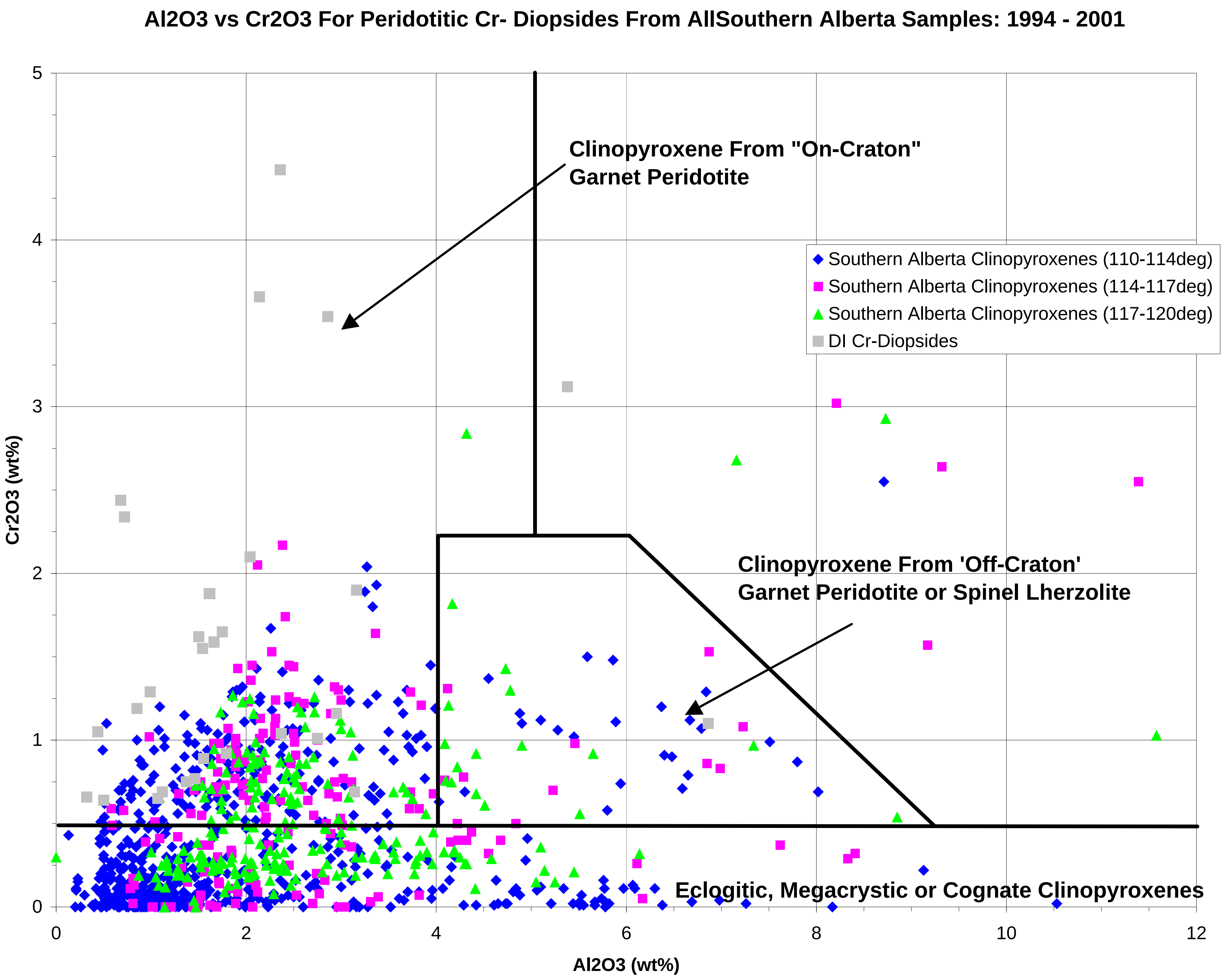


CaO vs Cr2O3 For Peridotitic Cr- Diopsides From All Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
0
1
2
3
4
5
6
7
8
CaO (wt%)
10
12
14
16
18
20
22
24
26
◆ Southern Alberta Clinopyroxenes (110-114deg)
■ Southern Alberta Clinopyroxenes (114-117deg)
▲ Southern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides

Appendix 3

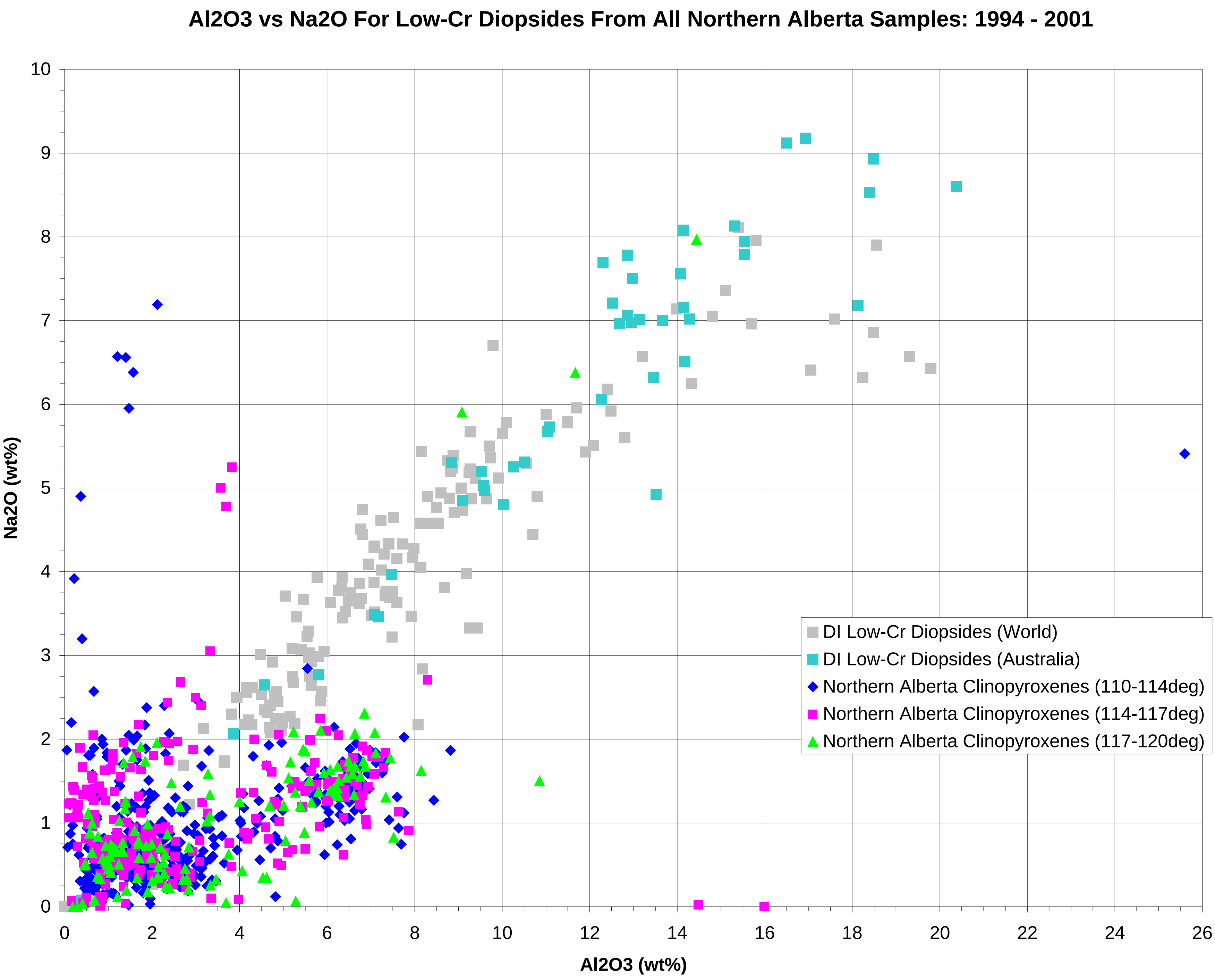

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From All Northern Alberta Samples: 1994 - 2001
Clinopyroxene From "On-Craton" Garnet Peridotite
Clinopyroxene From 'Off-Craton' Garnet Peridotite or Spinel Lherzolite
Eclogitic, Megacrystic or Cognate Clinopyroxenes
◆ Northern Alberta Clinopyroxenes (110-114deg)
■ Northern Alberta Clinopyroxenes (114-117deg)
▲ Northern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides
Cr2O3 (wt%)
0
1
2
3
4
5
Al2O3 (wt%)
0
2
4
6
8
10
12

Appendix 3



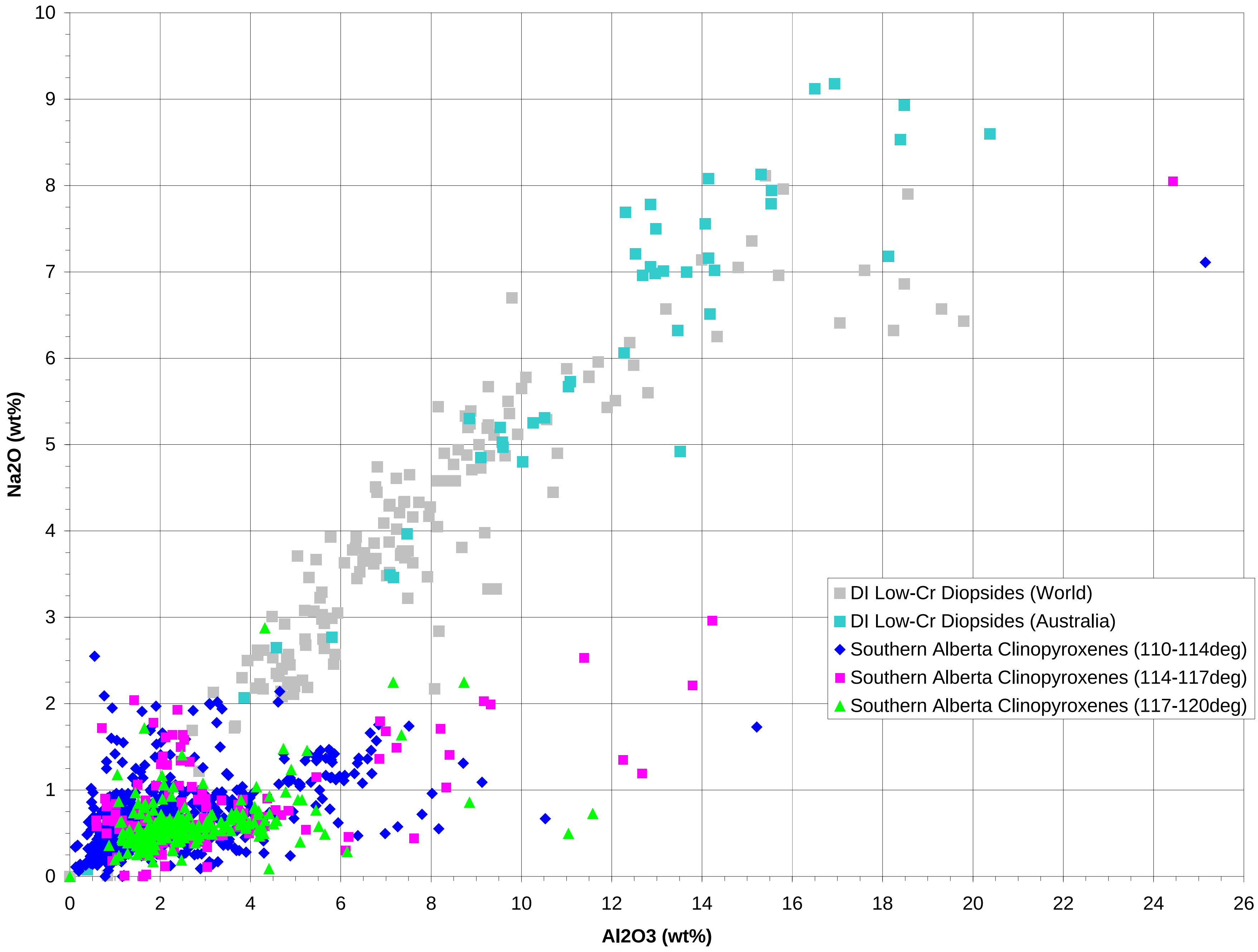
Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From AllSouthern Alberta Samples: 1994 - 2001
Clinopyroxene From "On-Craton" Garnet Peridotite
Clinopyroxene From 'Off-Craton' Garnet Peridotite or Spinel Lherzolite
Eclogitic, Megacrystic or Cognate Clinopyroxenes
◆ Southern Alberta Clinopyroxenes (110-114deg)
■ Southern Alberta Clinopyroxenes (114-117deg)
▲ Southern Alberta Clinopyroxenes (117-120deg)
■ DI Cr-Diopsides
Cr2O3 (wt%)
Al2O3 (wt%)
0
1
2
3
4
5
0
2
4
6
8
10
12

Appendix 3

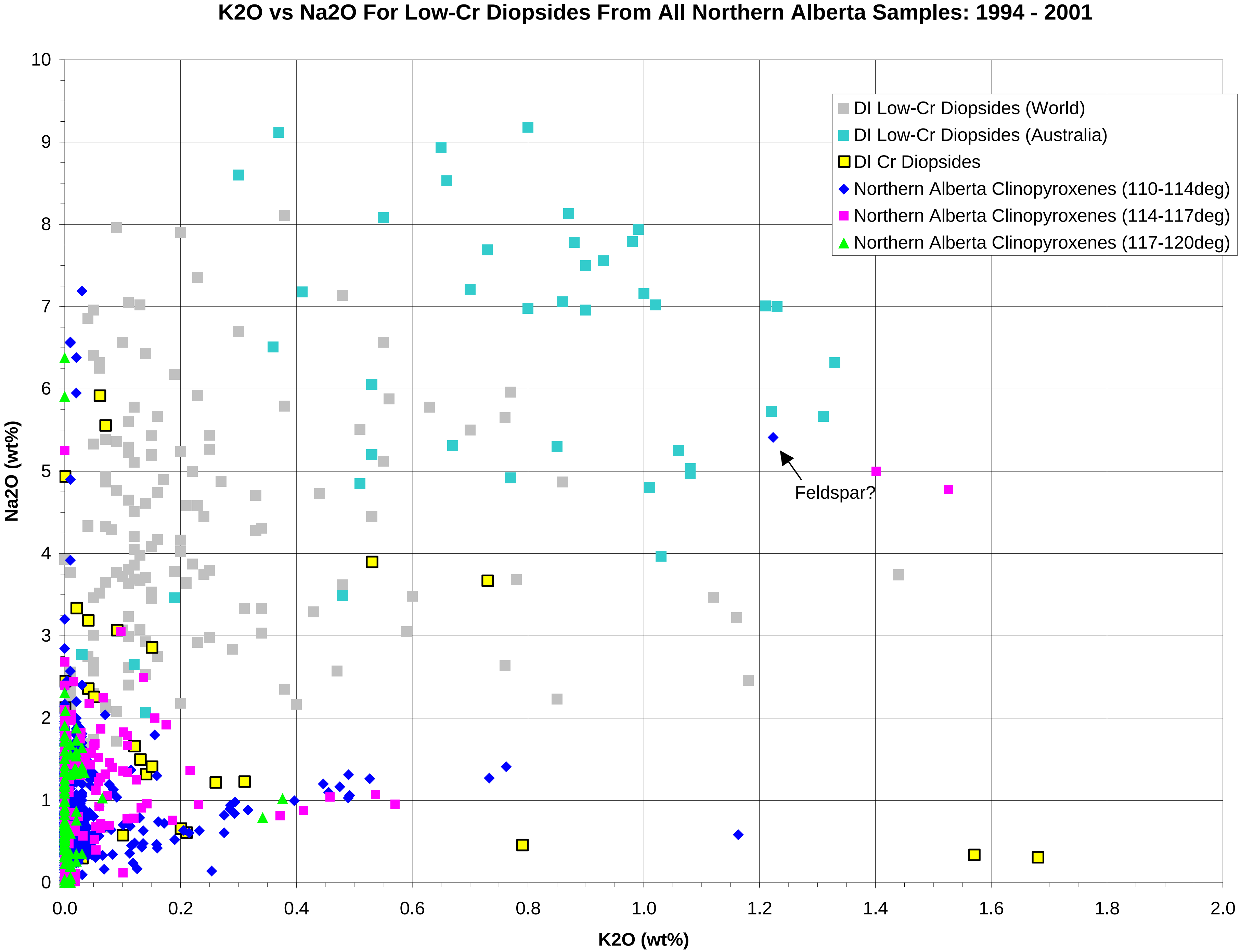

Al2O3 vs Na2O For Low-Cr Diopsides From All Northern Alberta Samples: 1994 - 2001
Na2O (wt%)
Al2O3 (wt%)
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
Northern Alberta Clinopyroxenes (110-114deg)
Northern Alberta Clinopyroxenes (114-117deg)
Northern Alberta Clinopyroxenes (117-120deg)

Appendix 3

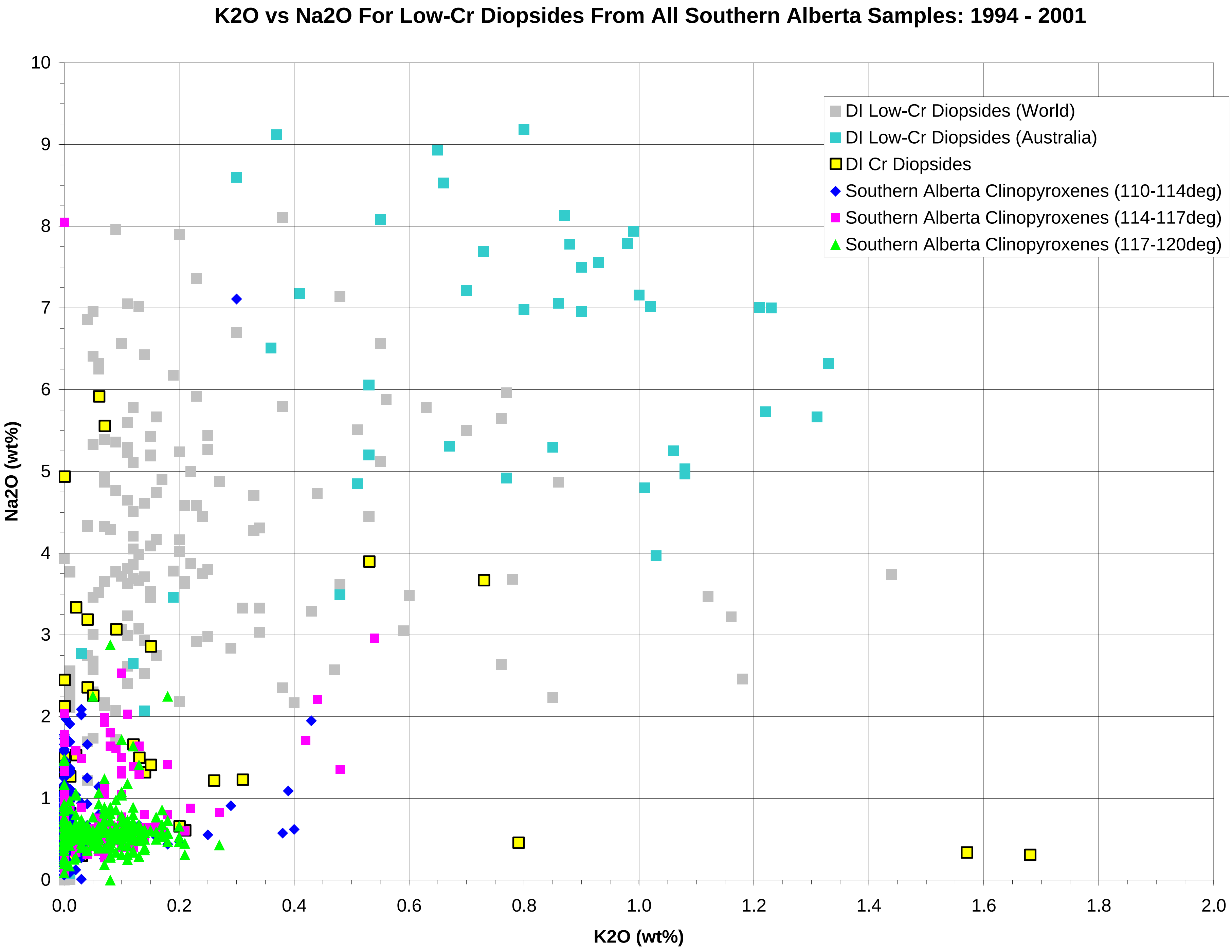
Al2O3 vs Na2O For Low-Cr Diopsides From All Southern Alberta Samples: 1994 - 2001



Appendix 3

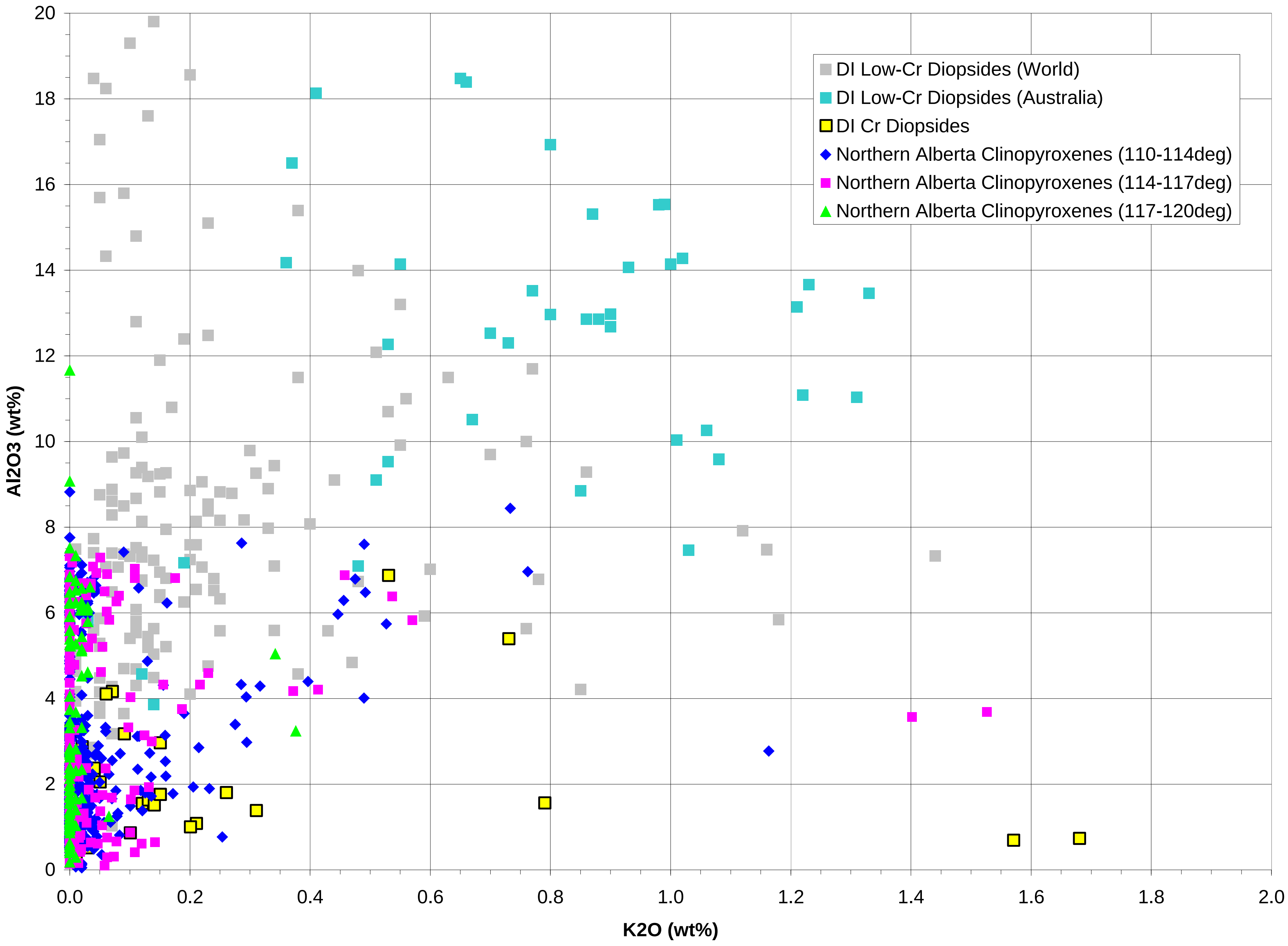

K2O vs Na2O For Low-Cr Diopsides From All Northern Alberta Samples: 1994 - 2001
Na2O (wt%)
K2O (wt%)
0
1
2
3
4
5
6
7
8
9
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Northern Alberta Clinopyroxenes (110-114deg)
Northern Alberta Clinopyroxenes (114-117deg)
Northern Alberta Clinopyroxenes (117-120deg)
Feldspar?

Appendix 3


K2O vs Na2O For Low-Cr Diopsides From All Southern Alberta Samples: 1994 - 2001
Na2O (wt%)
K2O (wt%)
0
1
2
3
4
5
6
7
8
9
10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Southern Alberta Clinopyroxenes (110-114deg)
Southern Alberta Clinopyroxenes (114-117deg)
Southern Alberta Clinopyroxenes (117-120deg)

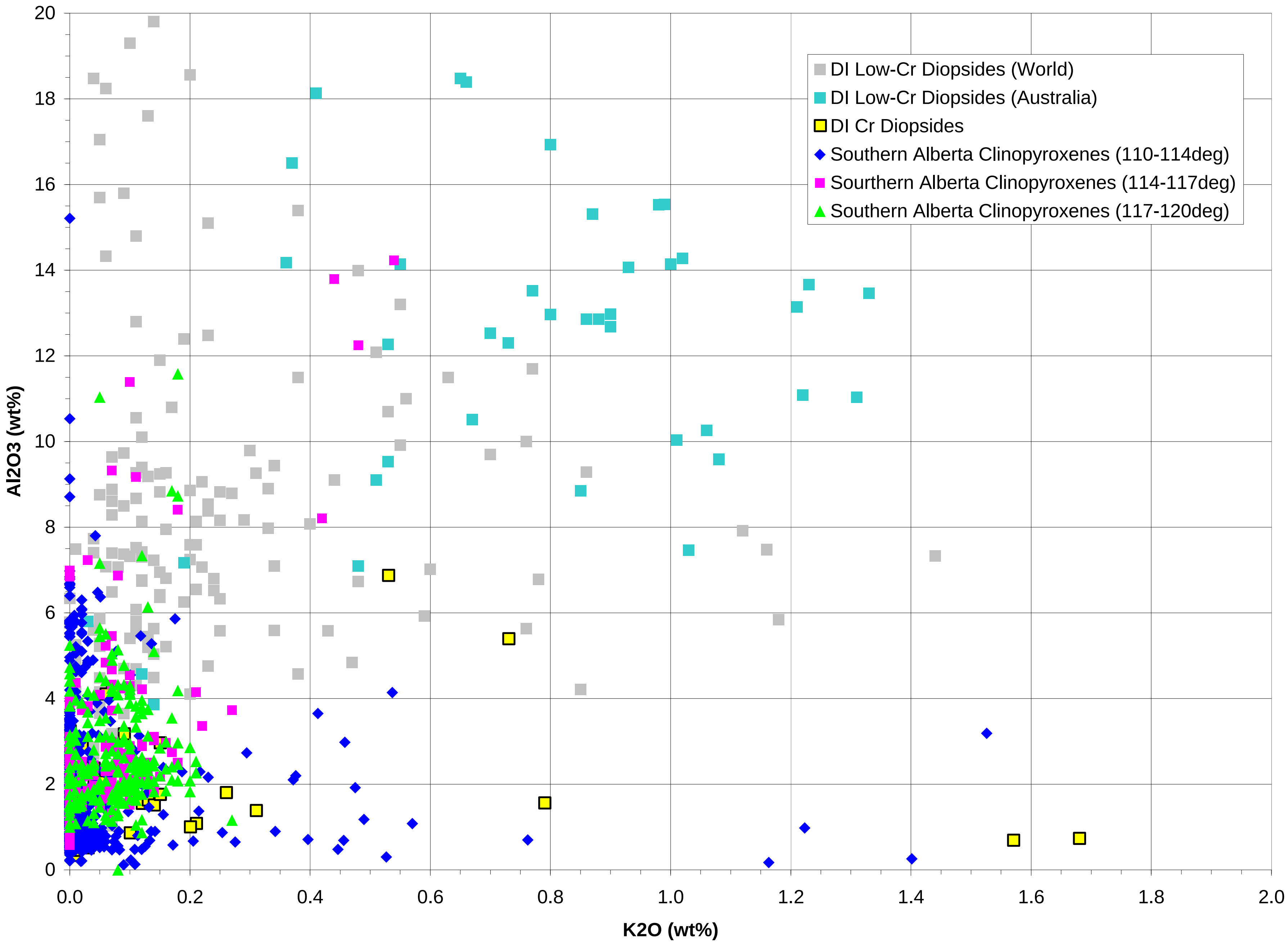
Appendix 3

K2O vs Al2O3 For Clinopyroxenes From All Northern Alberta Samples: 1994 - 2001

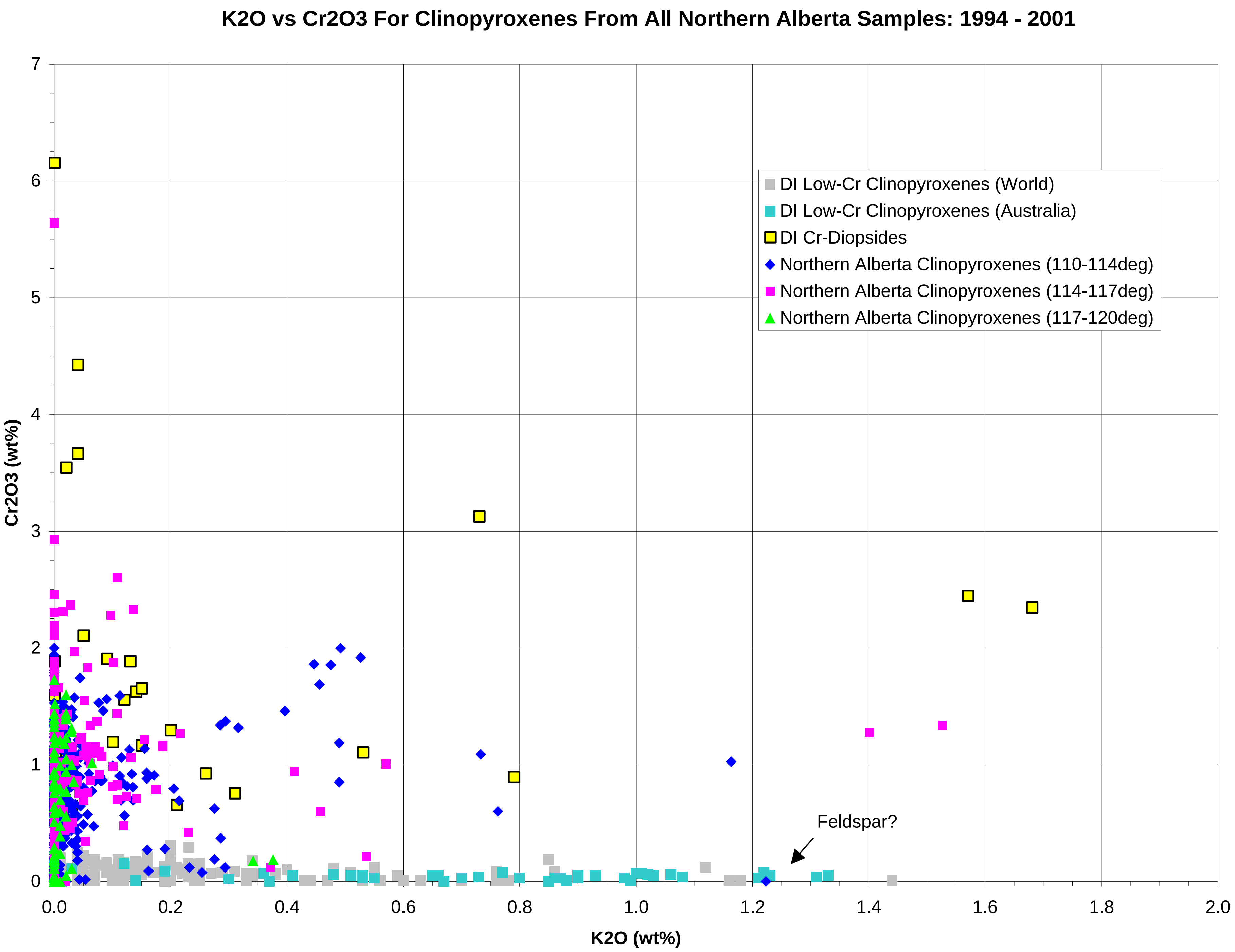


Appendix 3

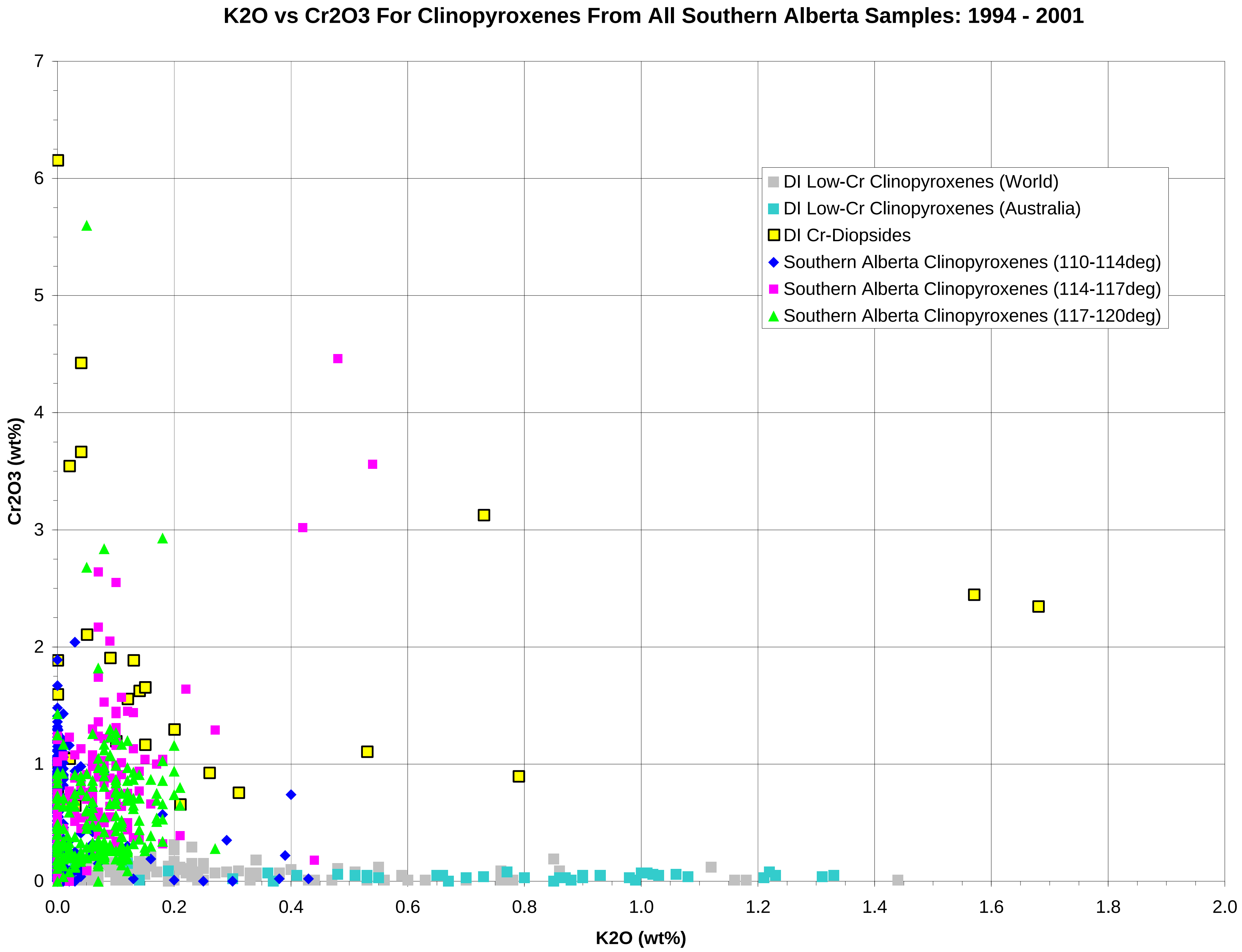
K2O vs Al2O3 For Clinopyroxenes From All Southern Alberta Samples: 1994 - 2001



Appendix 3

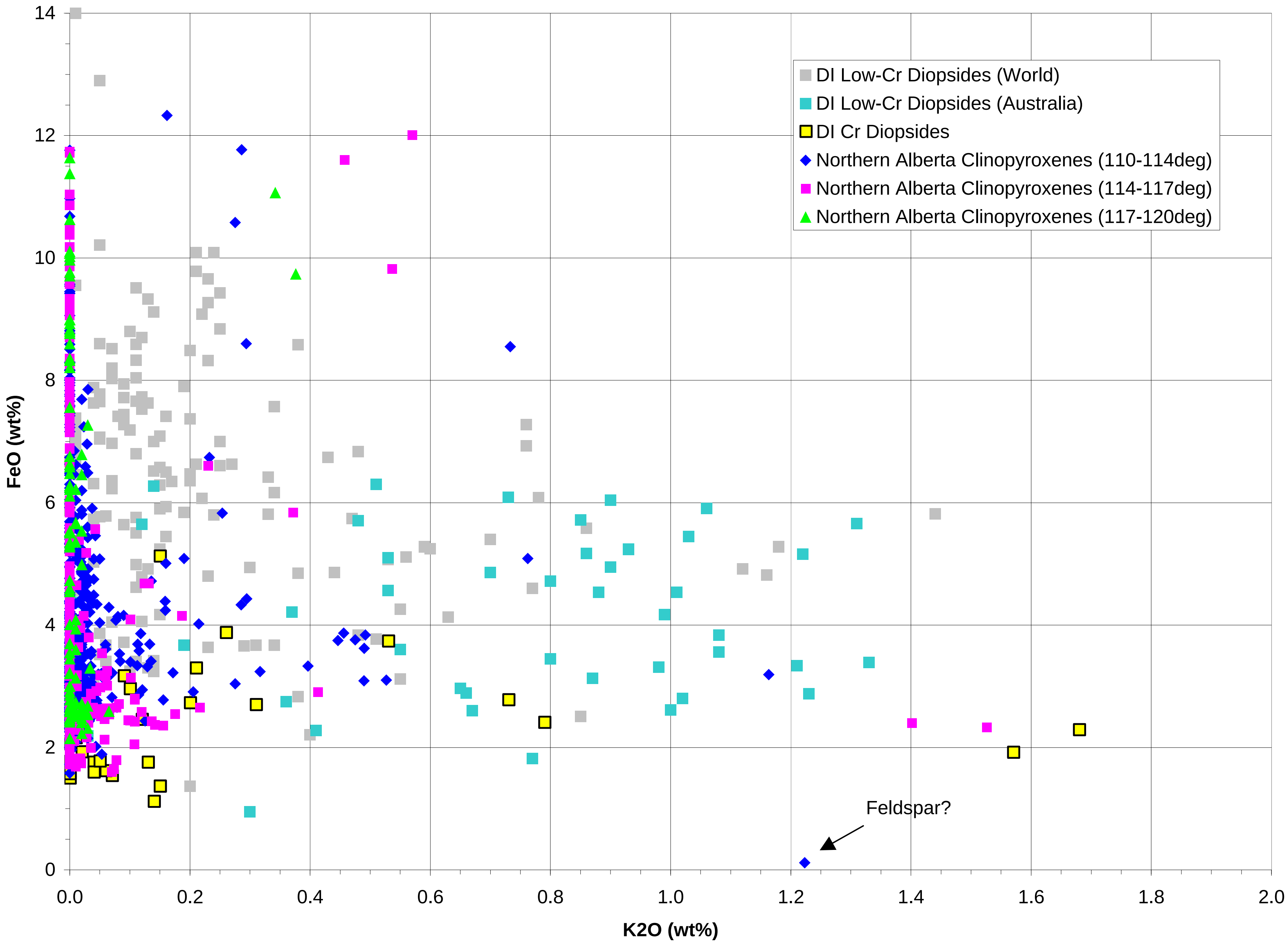

K2O vs Cr2O3 For Clinopyroxenes From All Northern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
K2O (wt%)
0
1
2
3
4
5
6
7
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Clinopyroxenes (World)
DI Low-Cr Clinopyroxenes (Australia)
DI Cr-Diopsides
Northern Alberta Clinopyroxenes (110-114deg)
Northern Alberta Clinopyroxenes (114-117deg)
Northern Alberta Clinopyroxenes (117-120deg)
Feldspar?

Appendix 3

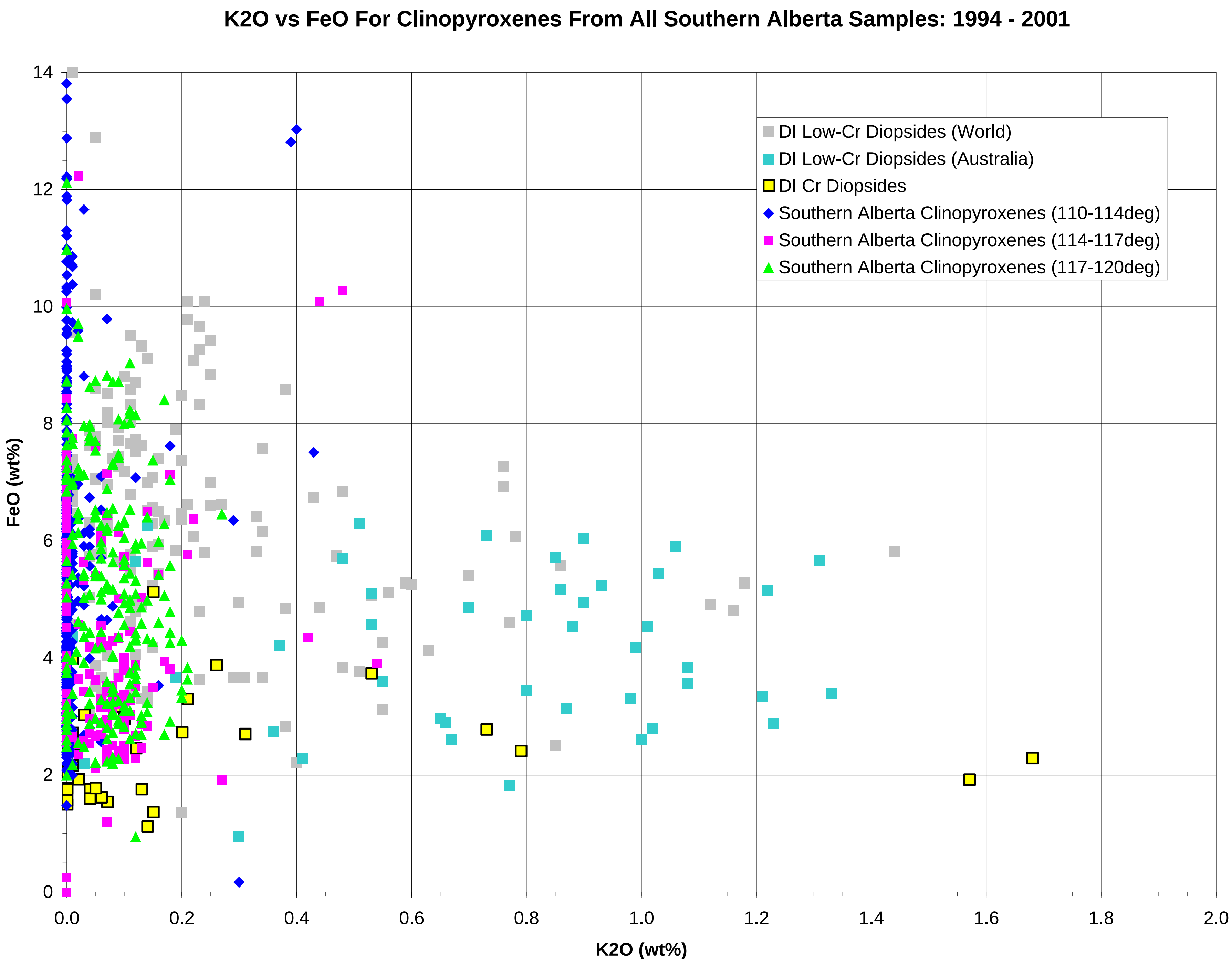

K2O vs Cr2O3 For Clinopyroxenes From All Southern Alberta Samples: 1994 - 2001
Cr2O3 (wt%)
K2O (wt%)
0
1
2
3
4
5
6
7
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Clinopyroxenes (World)
DI Low-Cr Clinopyroxenes (Australia)
DI Cr-Diopsides
Southern Alberta Clinopyroxenes (110-114deg)
Southern Alberta Clinopyroxenes (114-117deg)
Southern Alberta Clinopyroxenes (117-120deg)

Appendix 3

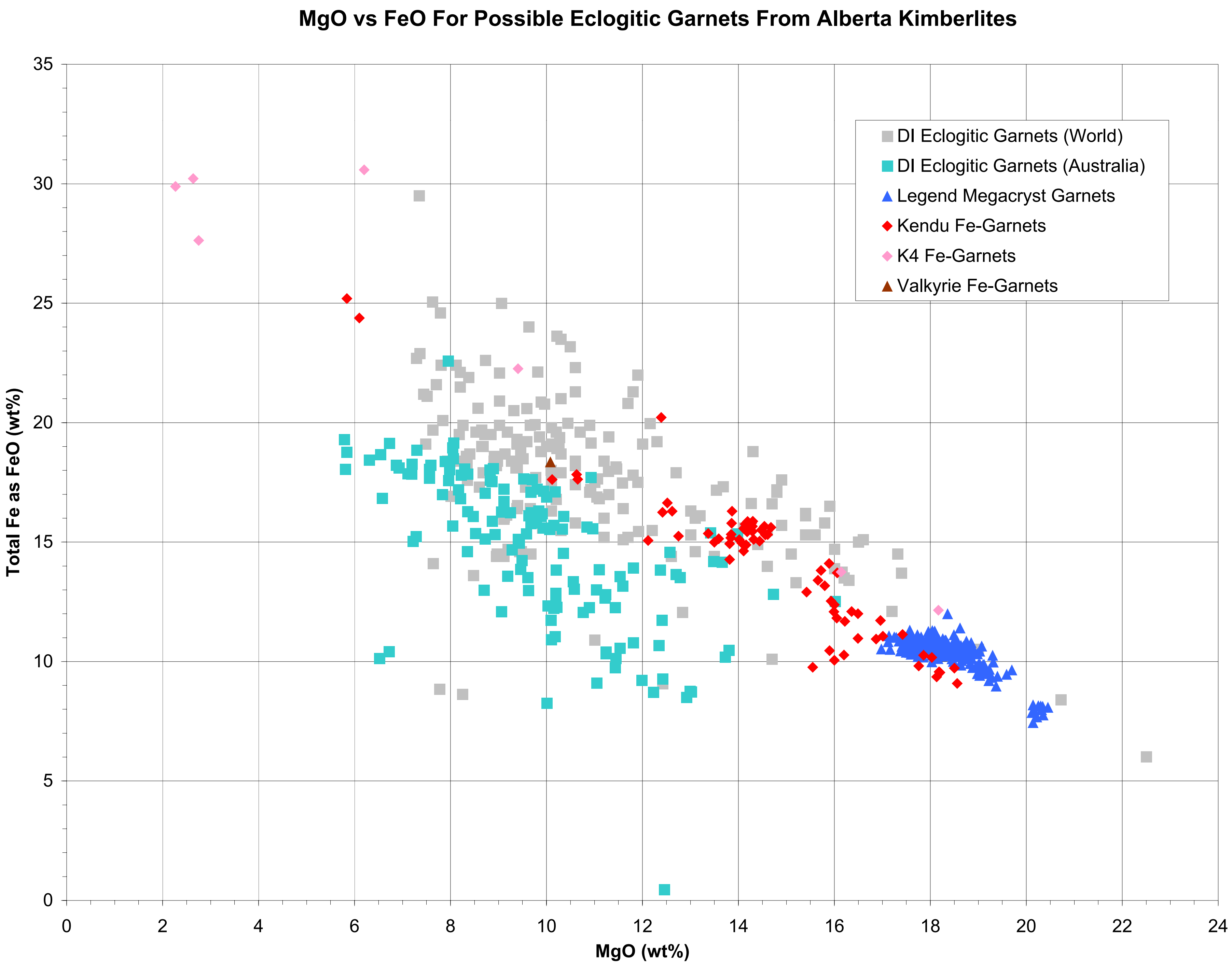
K2O vs FeO For Clinopyroxenes From All Northern Alberta Samples: 1994 - 2001



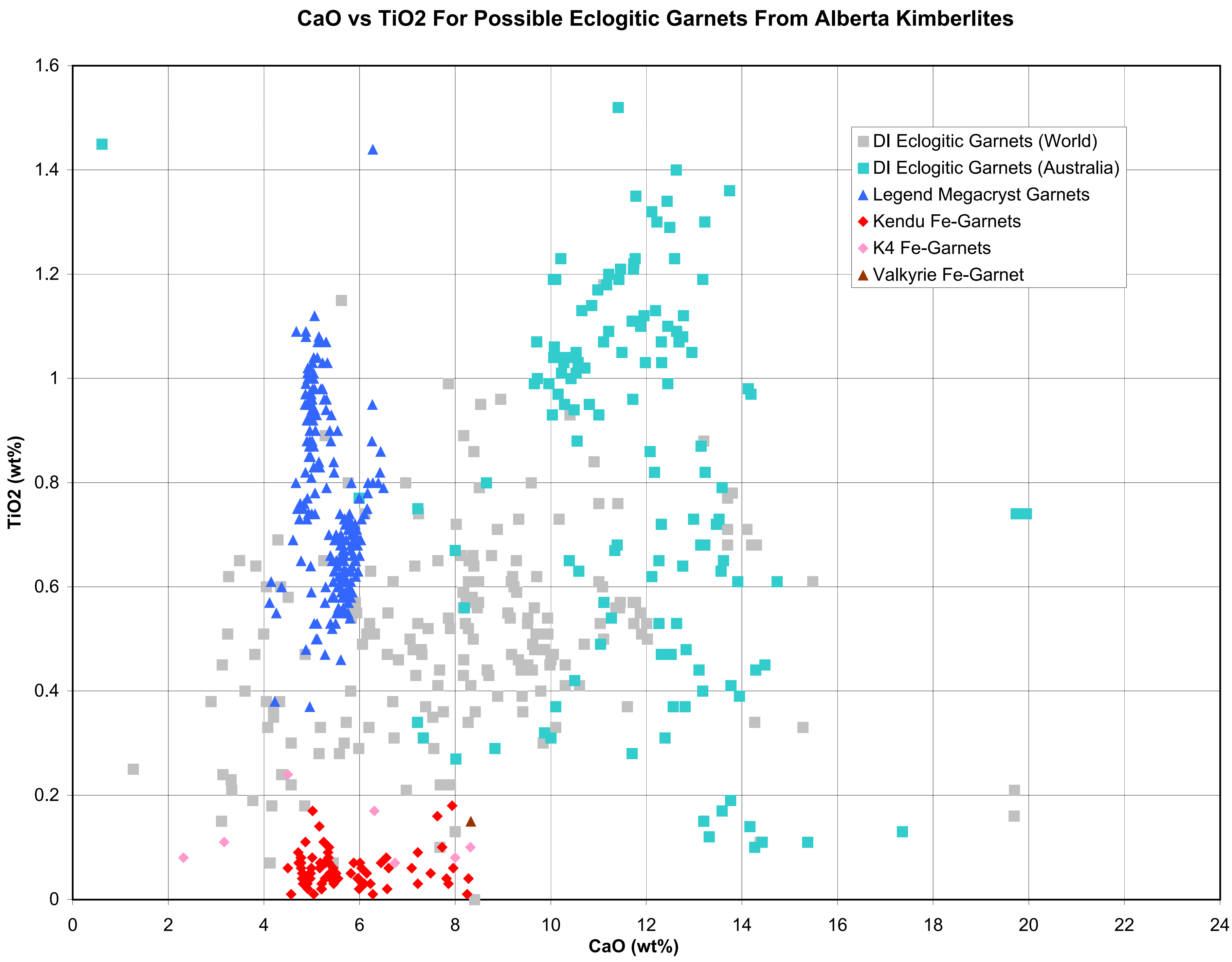
Appendix 3


K2O vs FeO For Clinopyroxenes From All Southern Alberta Samples: 1994 - 2001
FeO (wt%)
K2O (wt%)
0
2
4
6
8
10
12
14
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DI Low-Cr Diopsides (World)
DI Low-Cr Diopsides (Australia)
DI Cr Diopsides
Southern Alberta Clinopyroxenes (110-114deg)
Southern Alberta Clinopyroxenes (114-117deg)
Southern Alberta Clinopyroxenes (117-120deg)

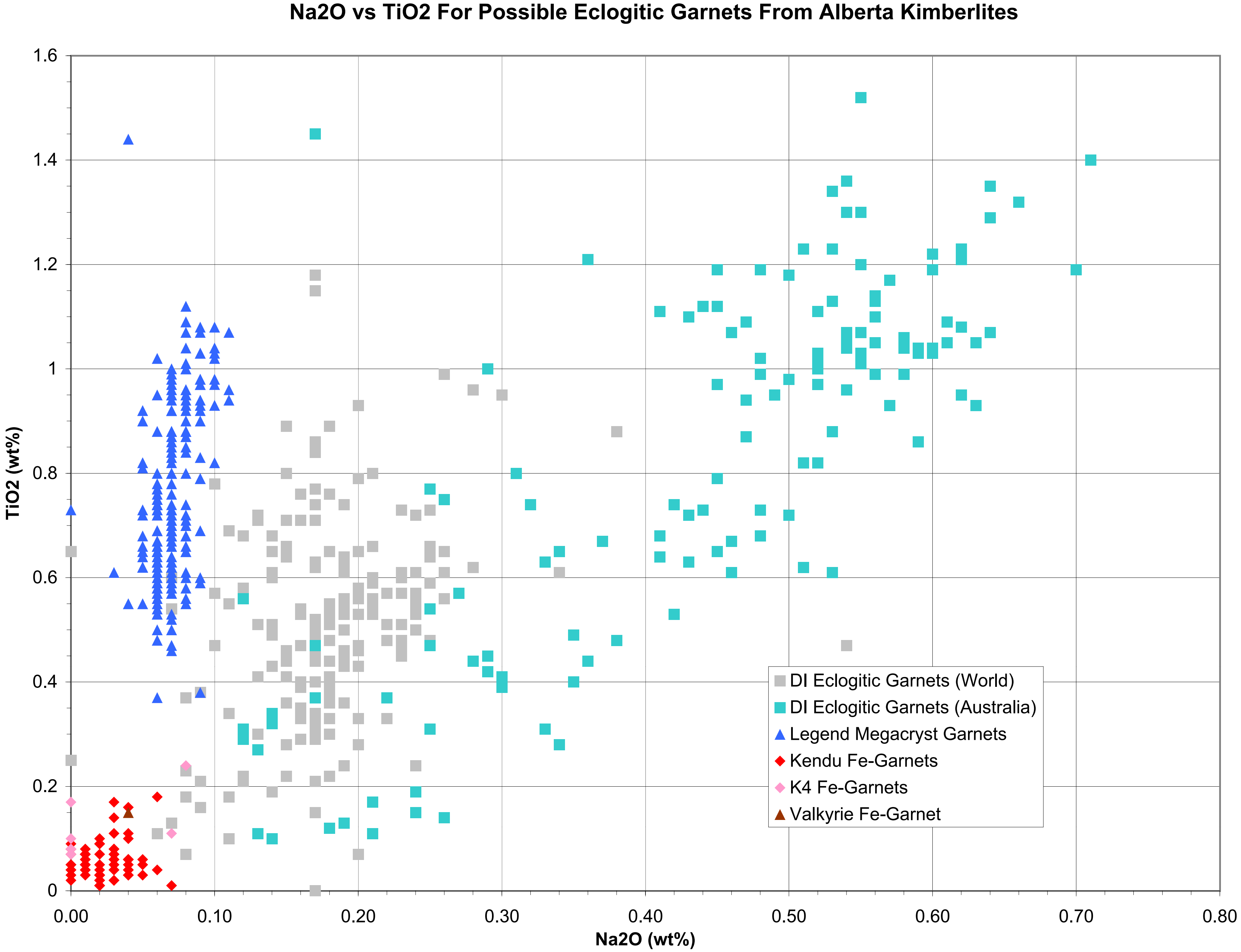
Appendix 3


MgO vs FeO For Possible Eclogitic Garnets From Alberta Kimberlites
Total Fe as FeO (wt%)
MgO (wt%)
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Legend Megacryst Garnets
Kendu Fe-Garnets
K4 Fe-Garnets
Valkyrie Fe-Garnets

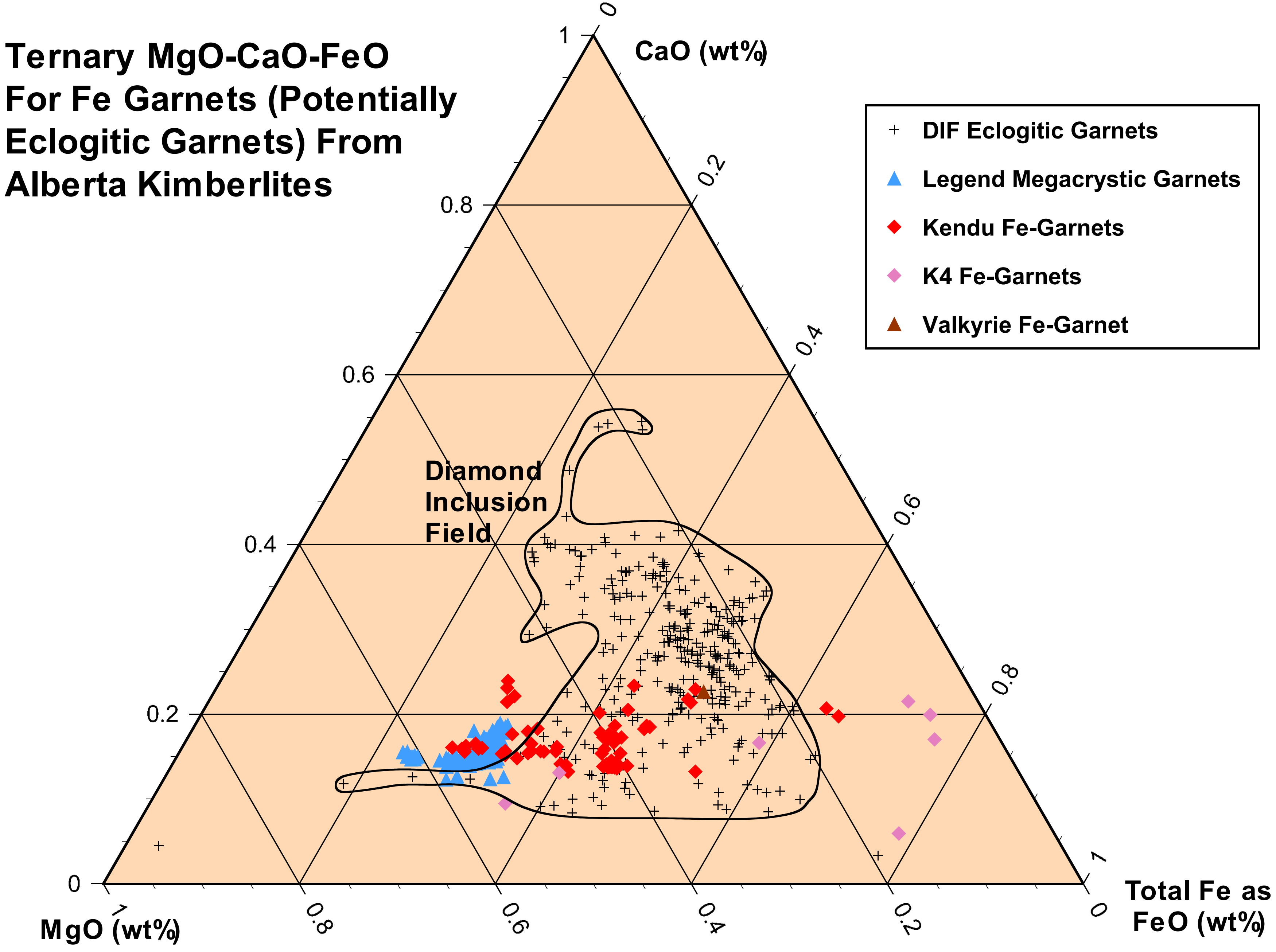
Appendix 3


CaO vs TiO2 For Possible Eclogitic Garnets From Alberta Kimberlites
TiO2 (wt%)
CaO (wt%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Legend Megacryst Garnets
Kendu Fe-Garnets
K4 Fe-Garnets
Valkyrie Fe-Garnet

Appendix 3


Na2O vs TiO2 For Possible Eclogitic Garnets From Alberta Kimberlites
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Legend Megacryst Garnets
Kendu Fe-Garnets
K4 Fe-Garnets
Valkyrie Fe-Garnet

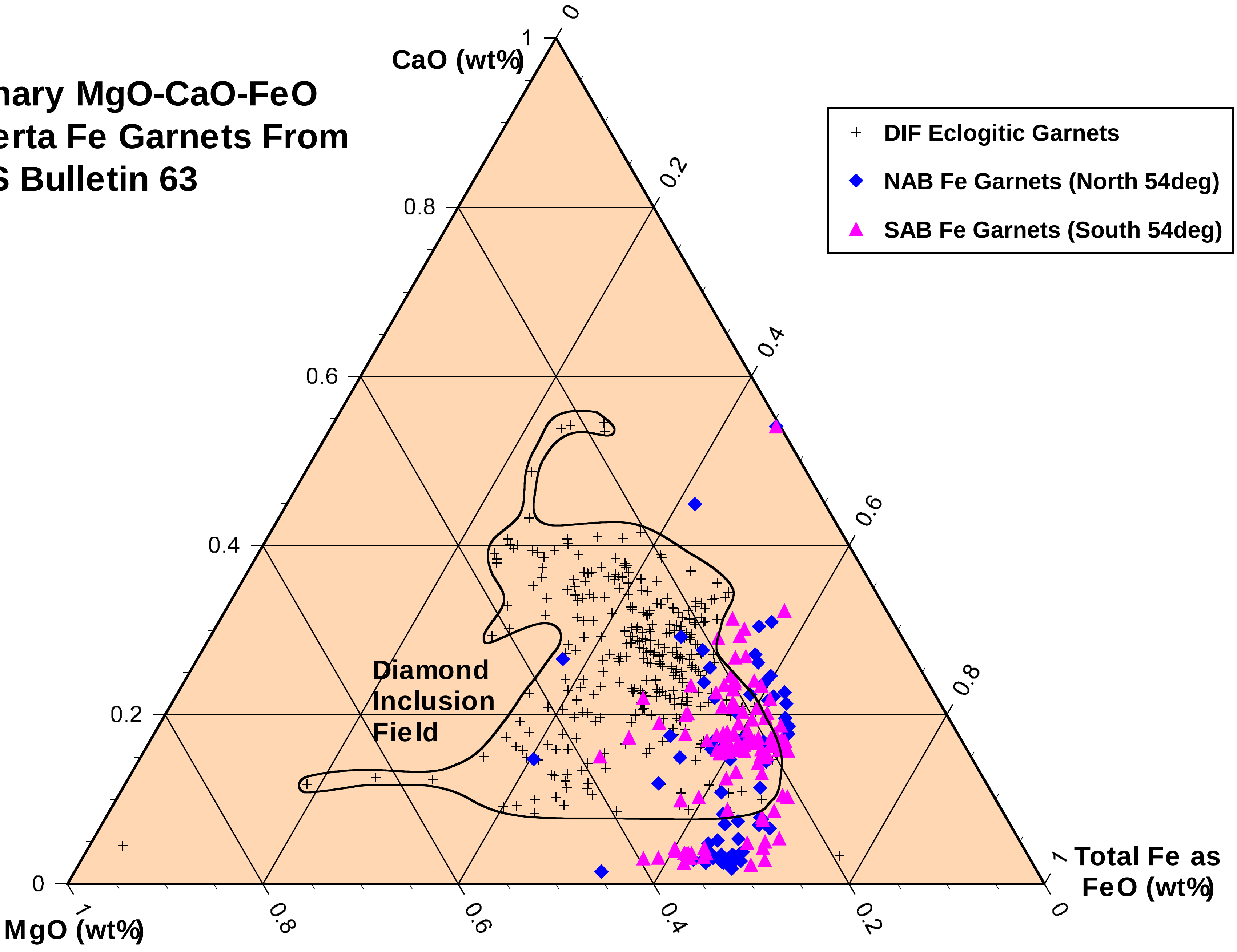
Appendix 3



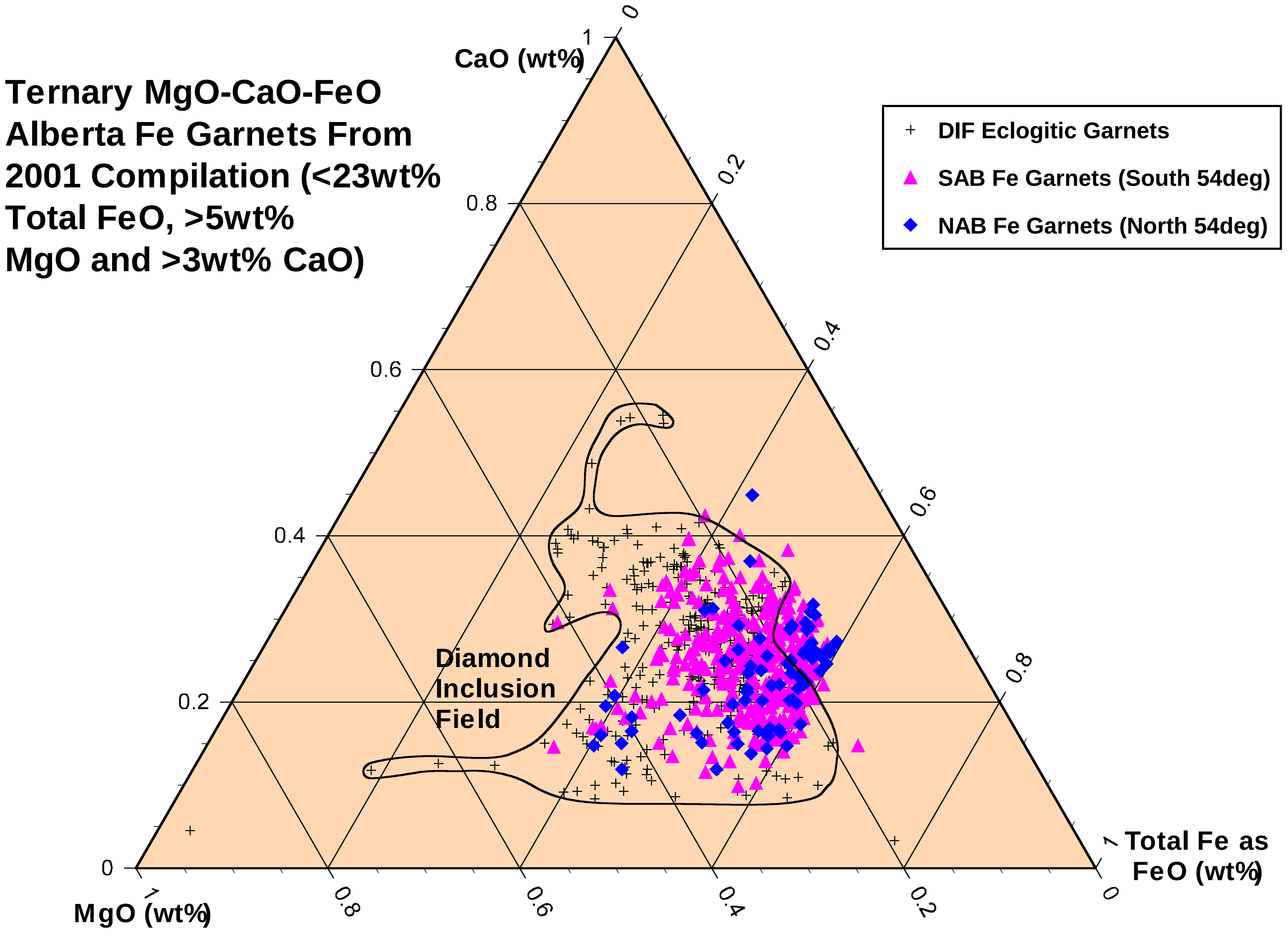
Ternary MgO-CaO-FeO For Fe Garnets (Potentially Eclogitic Garnets) From Alberta Kimberlites

Appendix 3

Ternary MgO-CaO-FeO Alberta Fe Garnets From AGS Bulletin 63

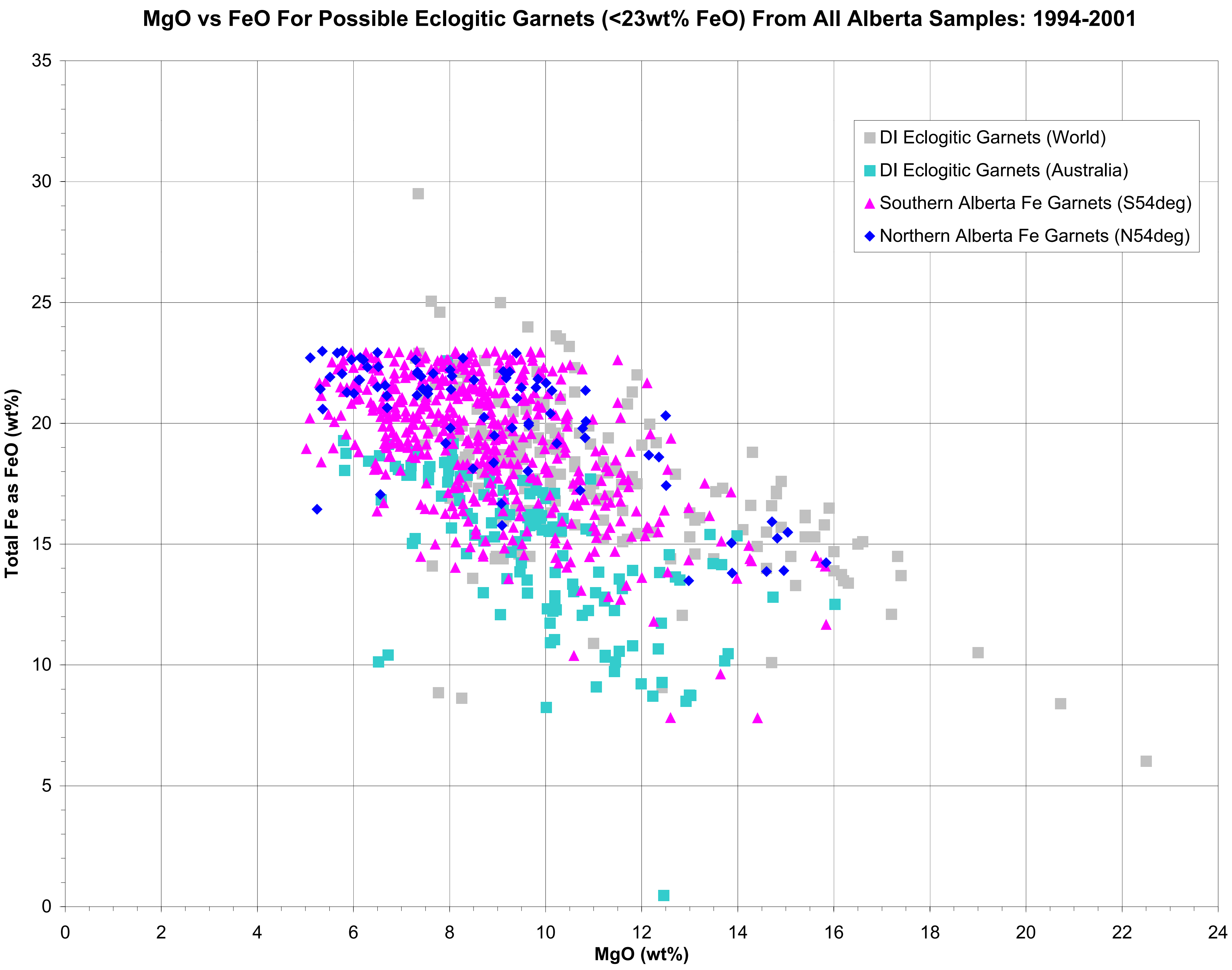


Appendix 4



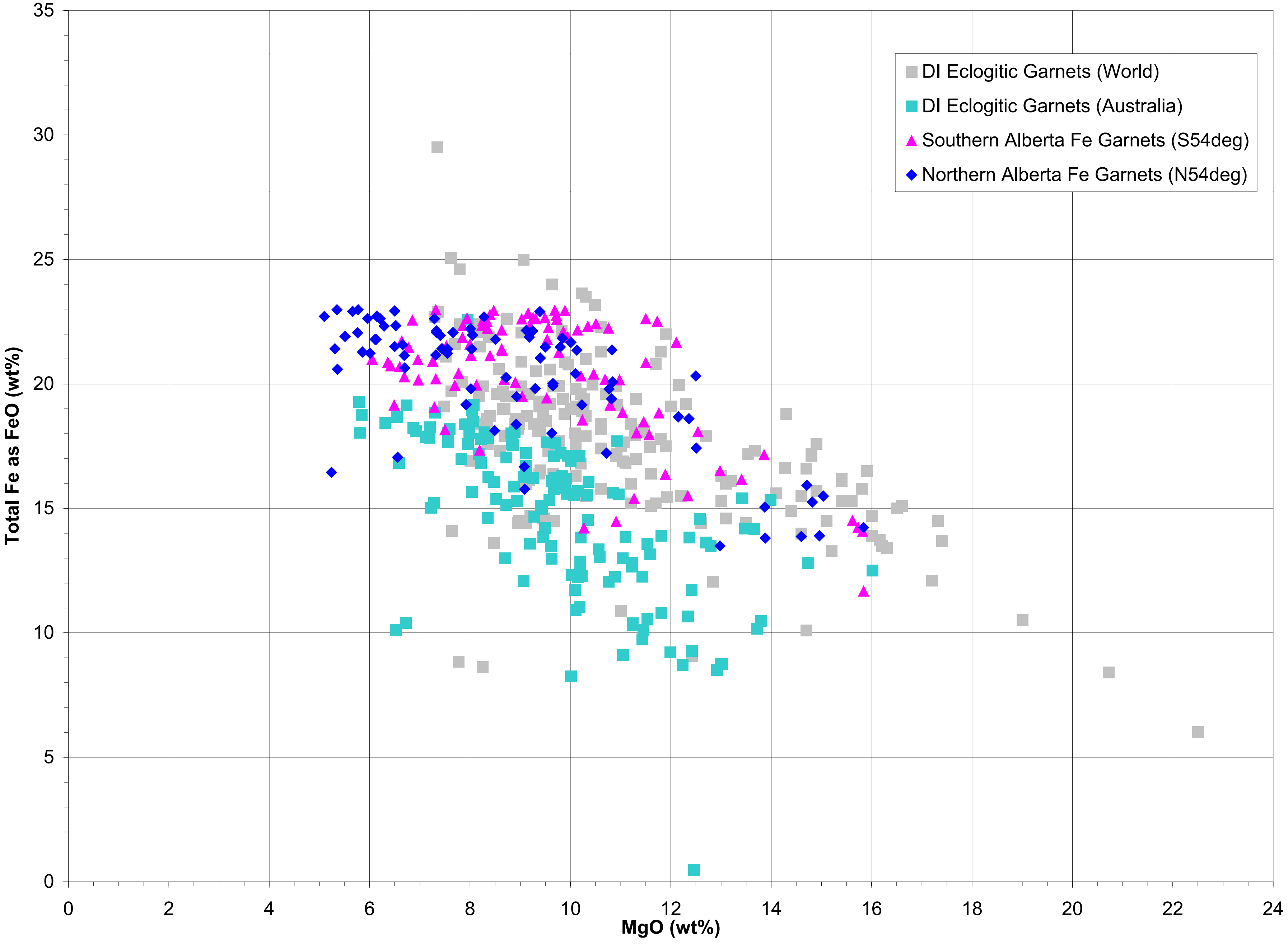
Ternary MgO-CaO-FeO Alberta Fe Garnets From 2001 Compilation (<23wt% Total FeO, >5wt% MgO and >3wt% CaO)

Appendix 4


MgO vs FeO For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001
Total Fe as FeO (wt%)
MgO (wt%)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (S54deg)
Northern Alberta Fe Garnets (N54deg)

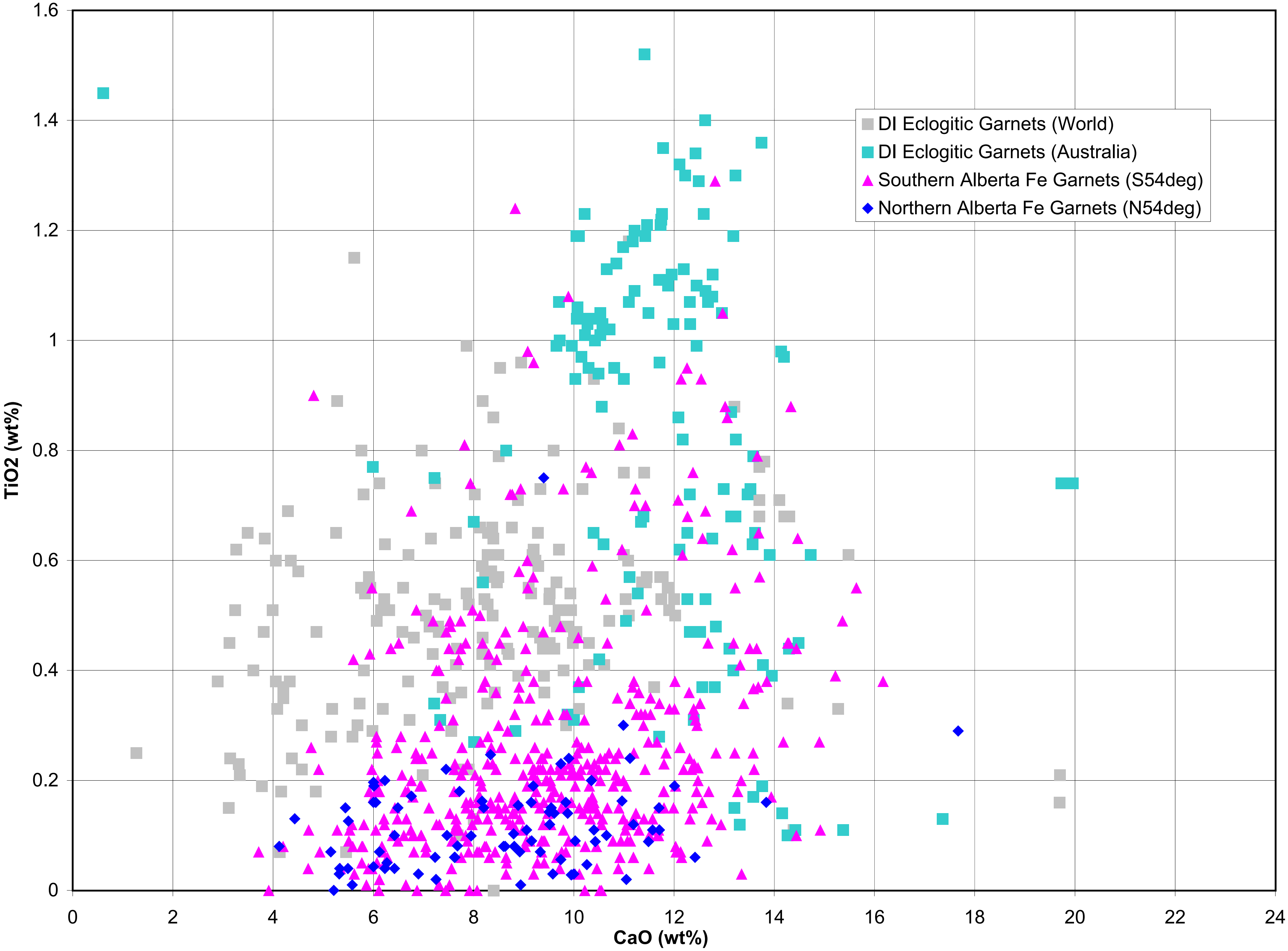
Appendix 4

MgO vs FeO For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001 Excluding Cameco Foothills Data

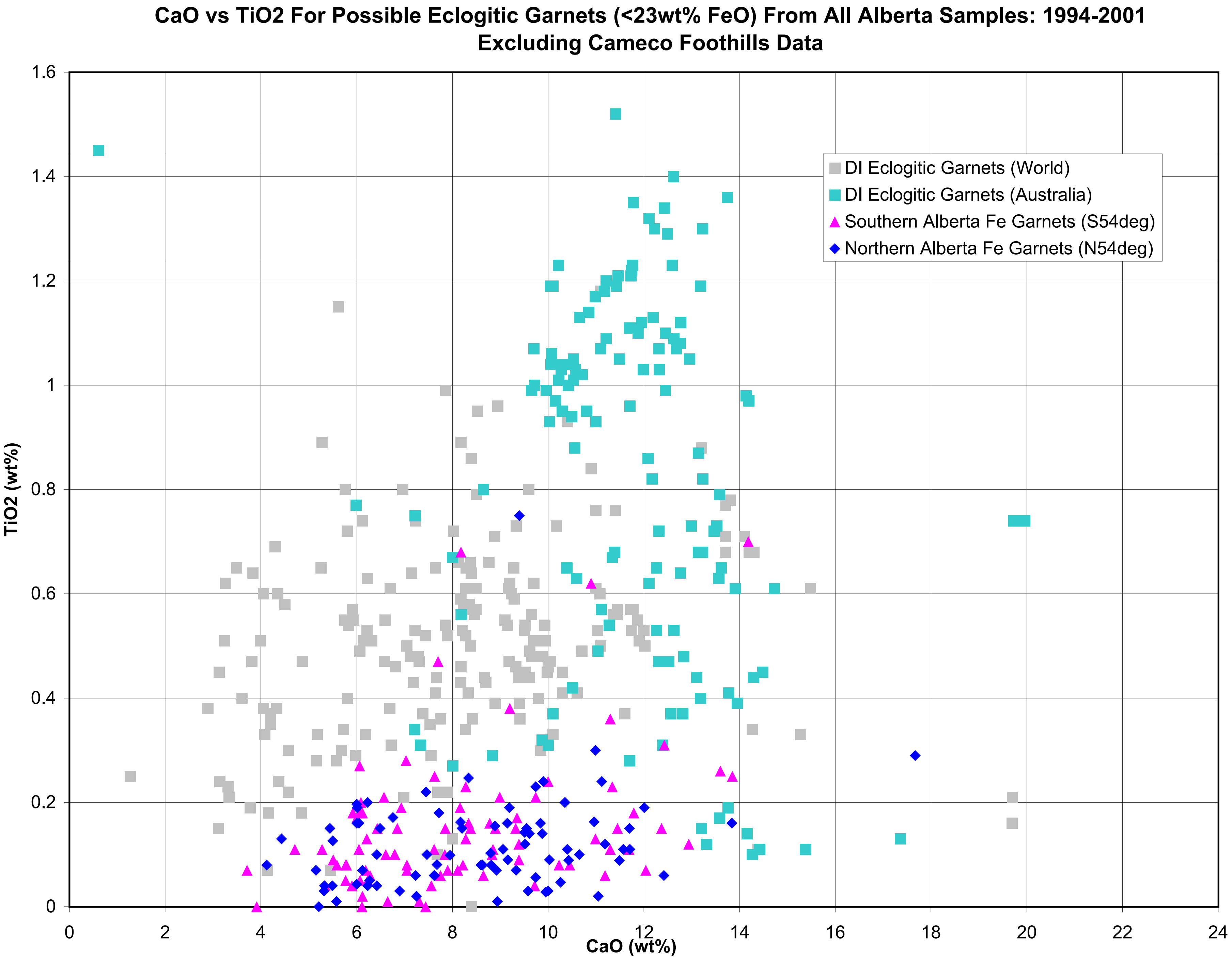


Appendix 4

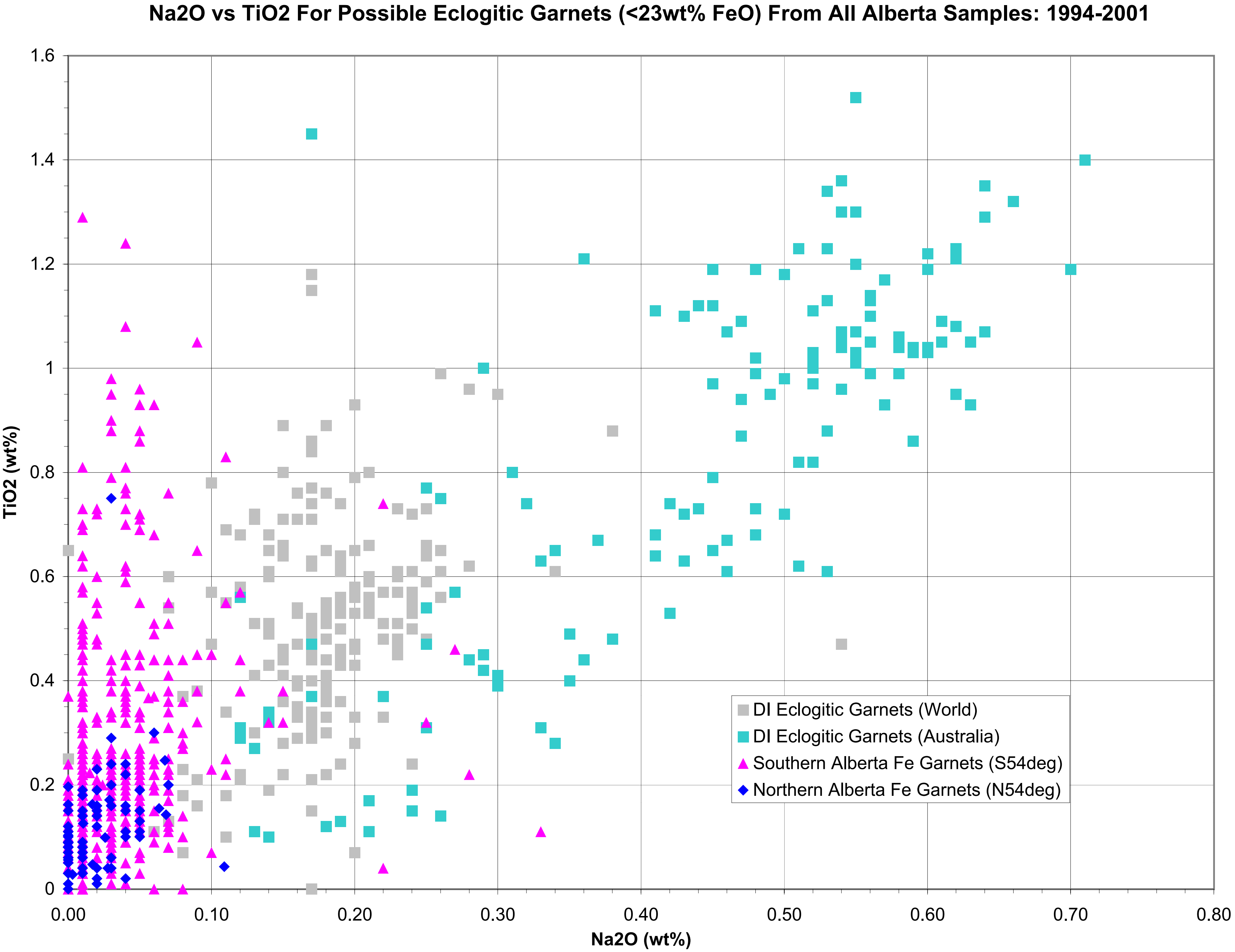
CaO vs TiO2 For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001



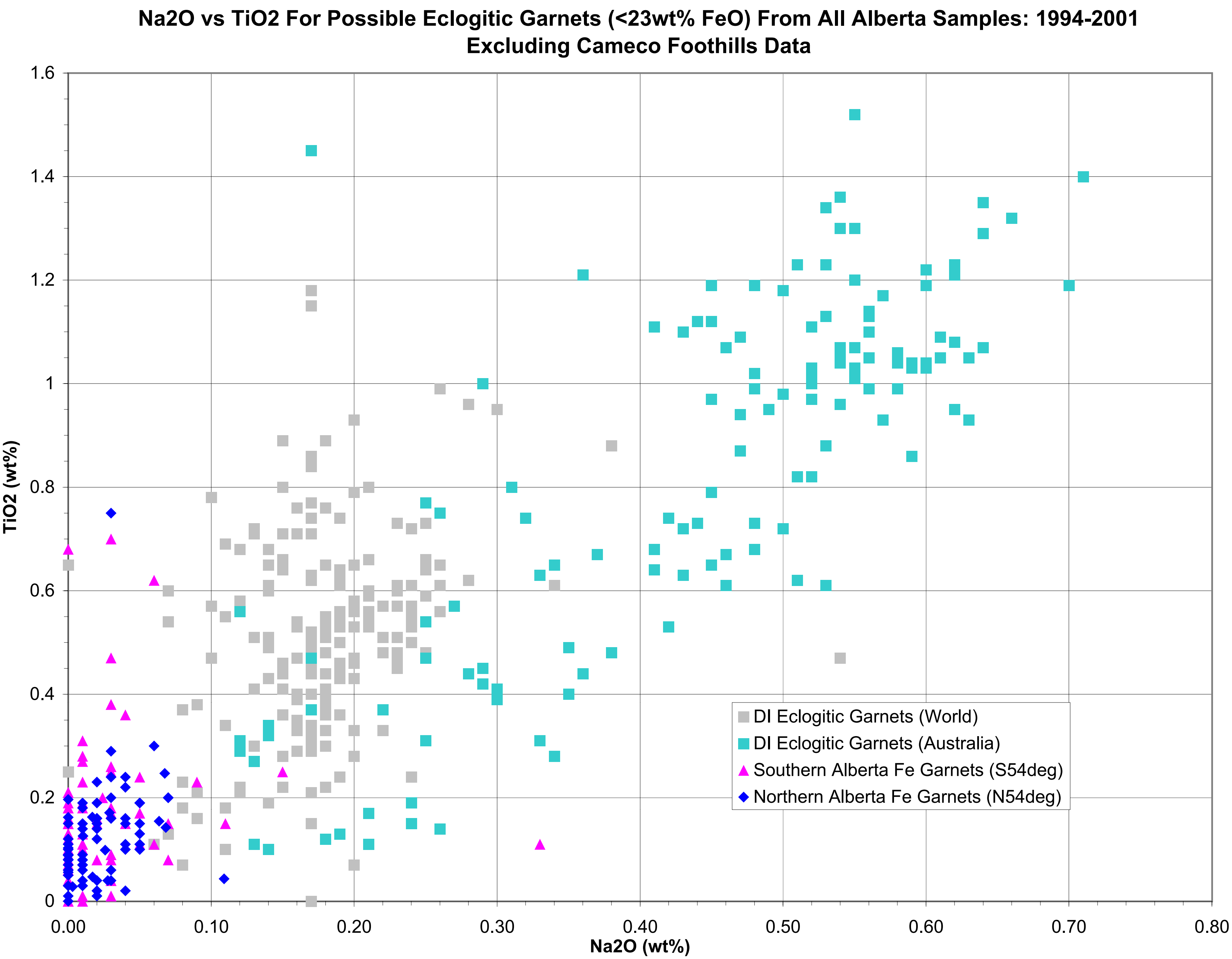
Appendix 4


CaO vs TiO2 For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001
Excluding Cameco Foothills Data
TiO2 (wt%)
CaO (wt%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (S54deg)
Northern Alberta Fe Garnets (N54deg)

Appendix 4

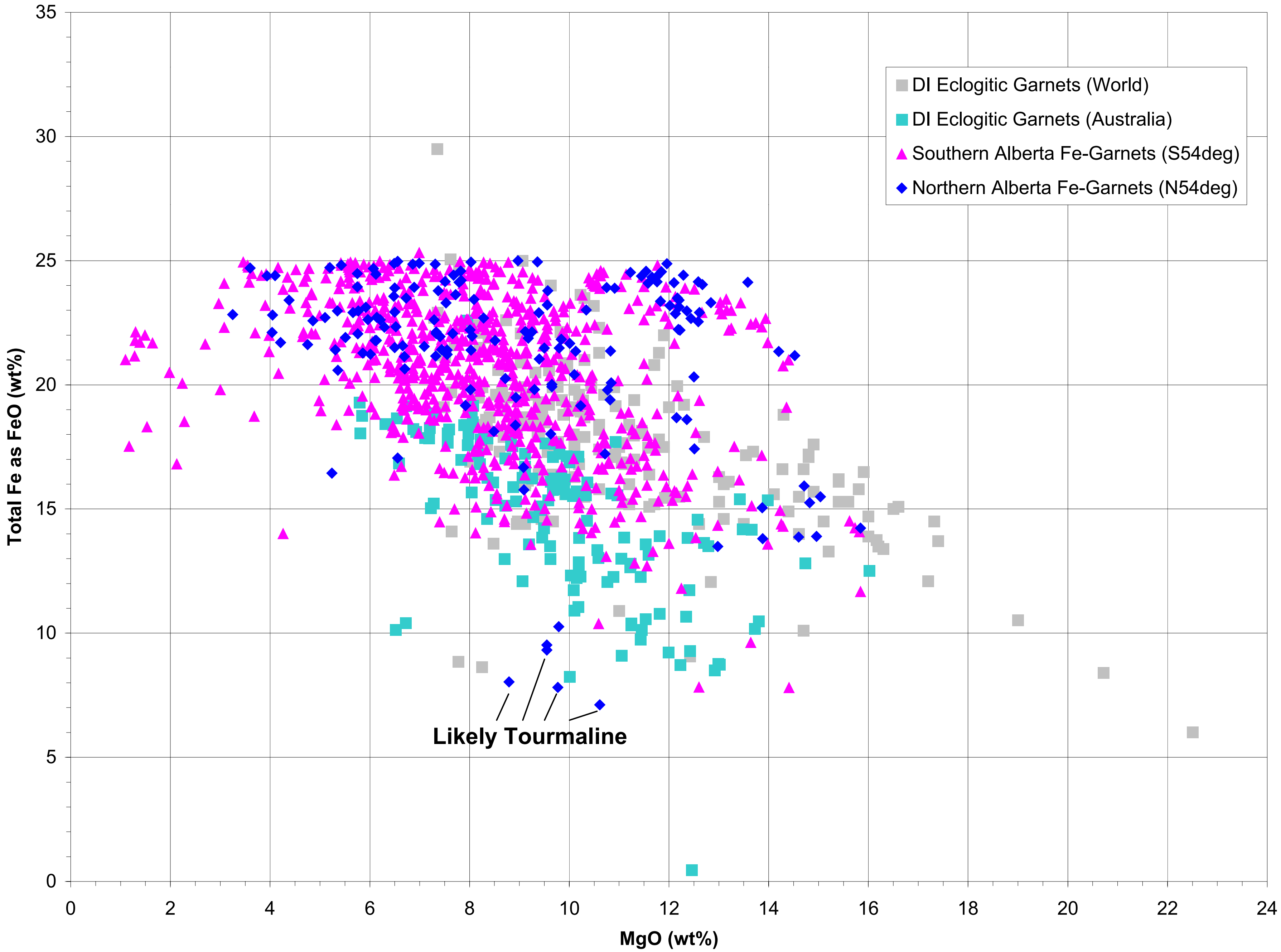

Na2O vs TiO2 For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (S54deg)
Northern Alberta Fe Garnets (N54deg)

Appendix 4

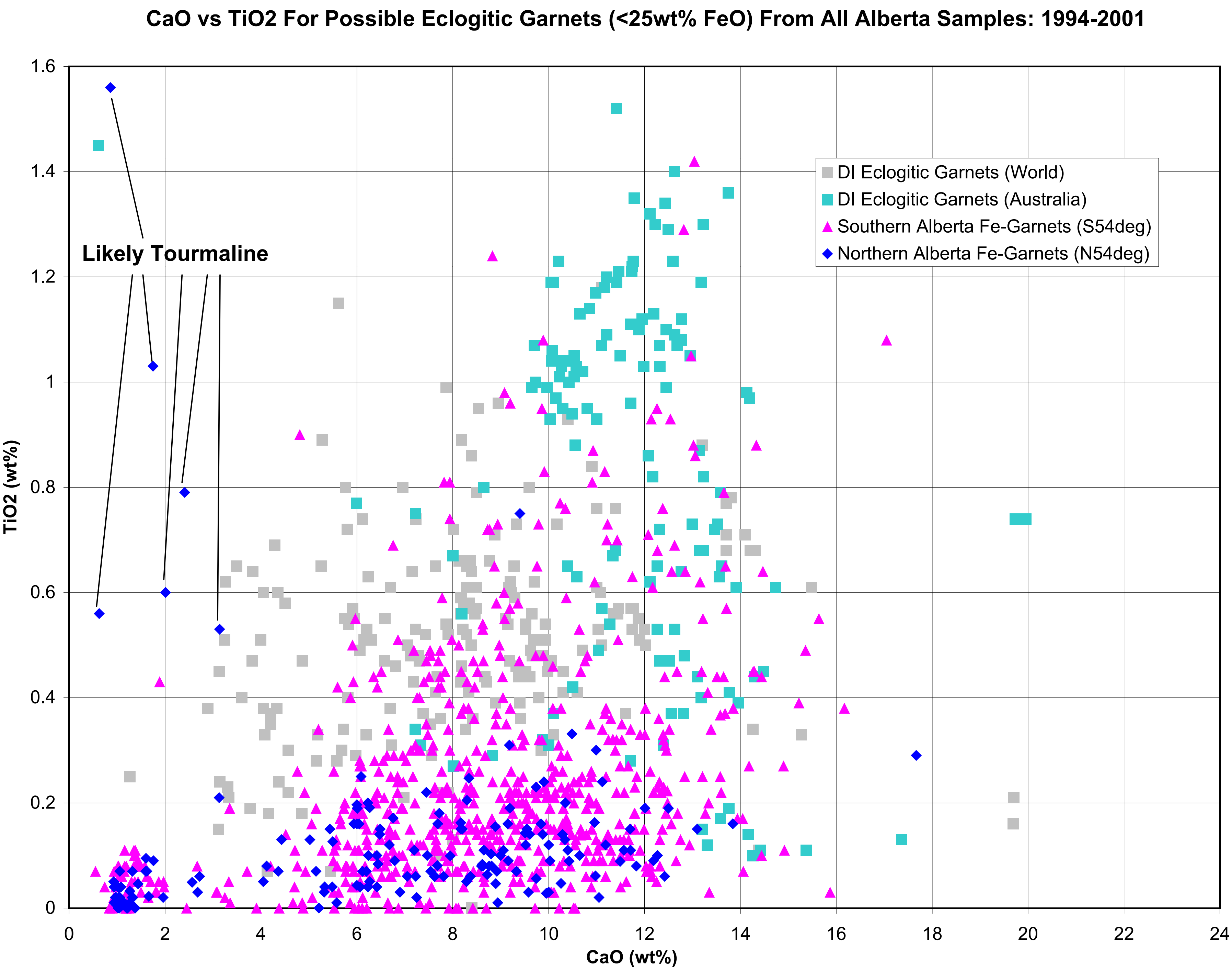

Na2O vs TiO2 For Possible Eclogitic Garnets (<23wt% FeO) From All Alberta Samples: 1994-2001
Excluding Cameco Foothills Data
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (S54deg)
Northern Alberta Fe Garnets (N54deg)

Appendix 4

MgO vs FeO For Possible Eclogitic Garnets (<25wt% FeO) From All Alberta Samples: 1994-2001

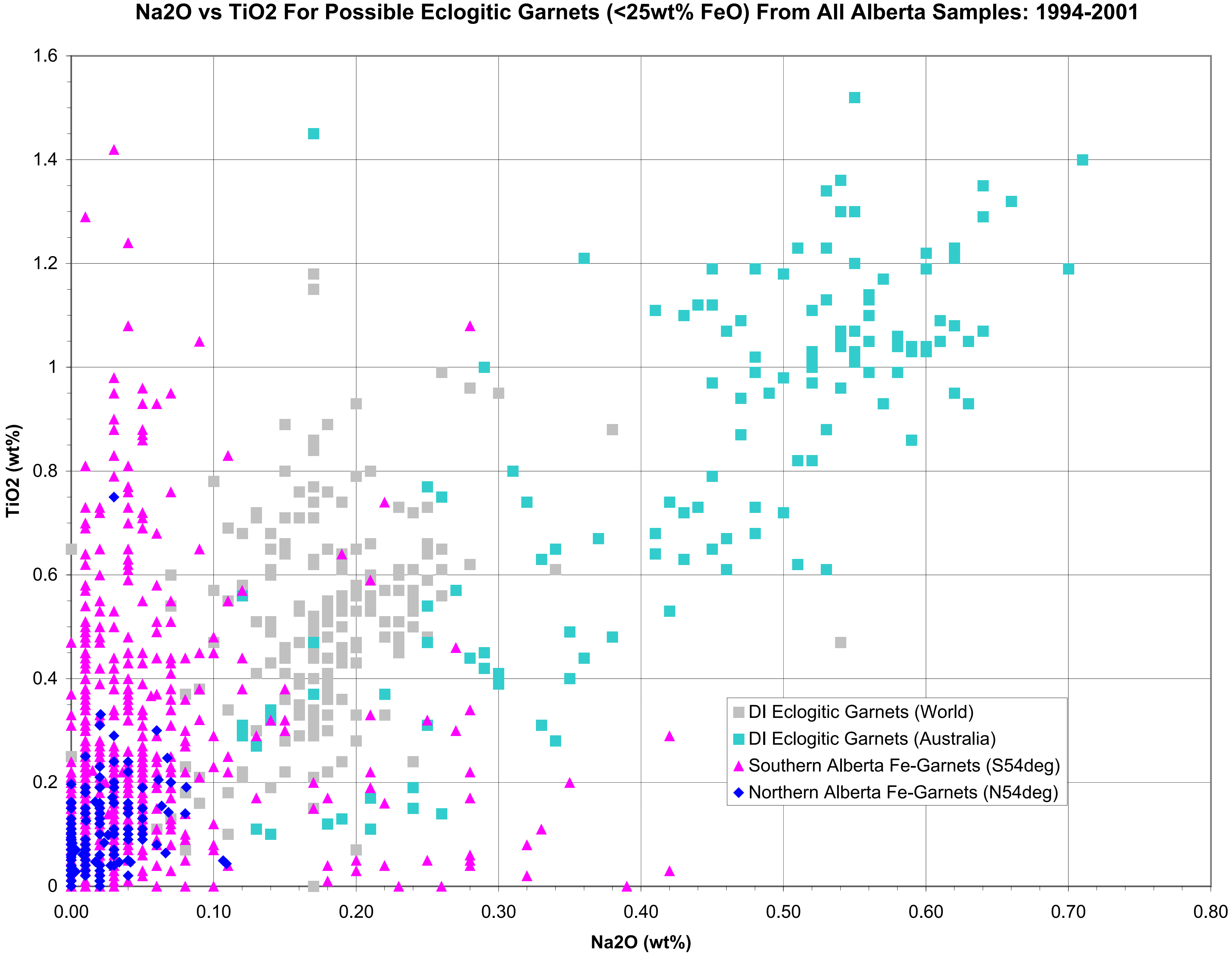


Appendix 4

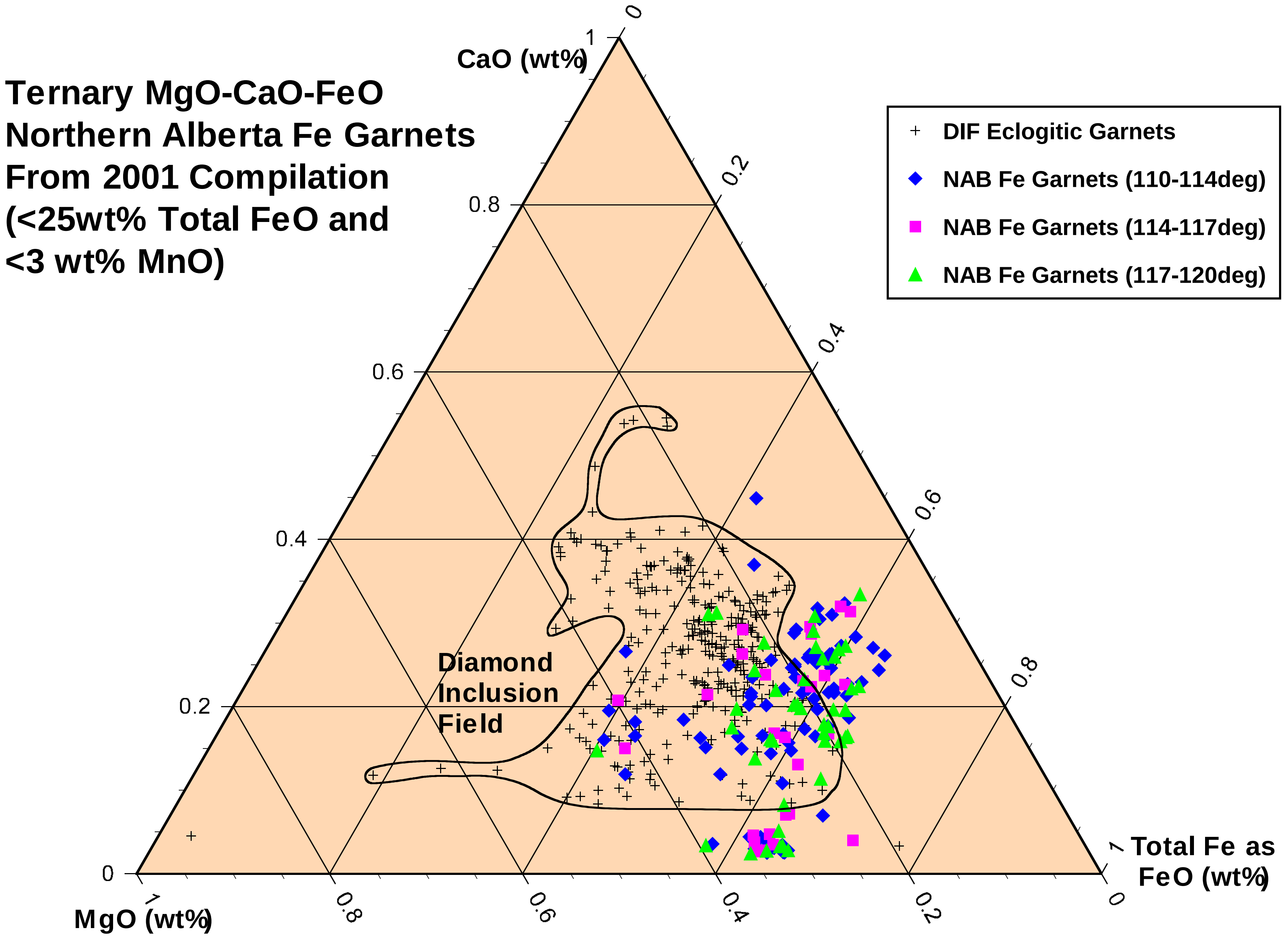


CaO vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From All Alberta Samples: 1994-2001
TiO2 (wt%)
CaO (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Likely Tourmaline
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe-Garnets (S54deg)
Northern Alberta Fe-Garnets (N54deg)

Appendix 4

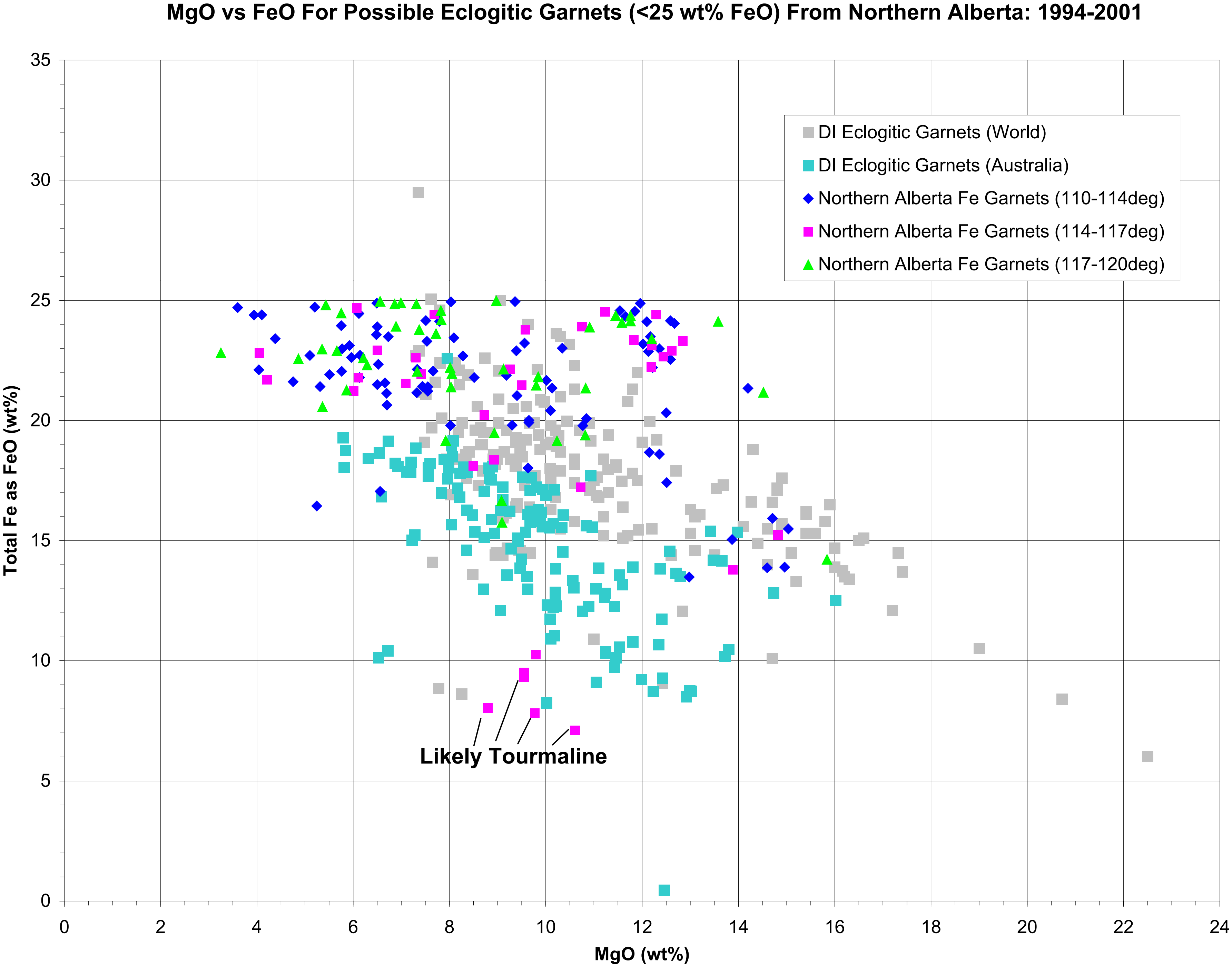

Na2O vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From All Alberta Samples: 1994-2001
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
TiO2 (wt%)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe-Garnets (S54deg)
Northern Alberta Fe-Garnets (N54deg)

Appendix 4

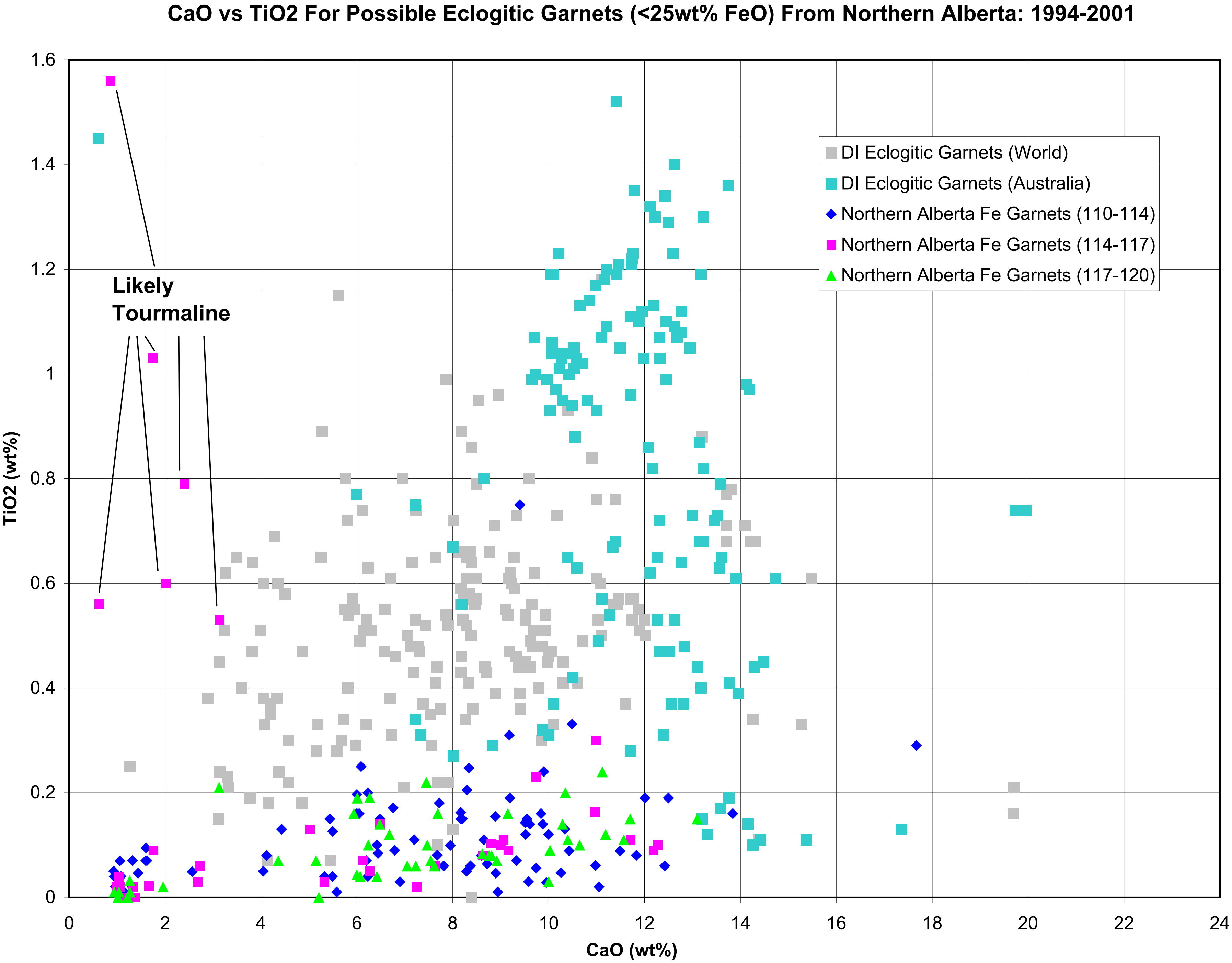


Ternary MgO-CaO-FeO
Northern Alberta Fe Garnets
From 2001 Compilation
(<25wt% Total FeO and
<3 wt% MnO)

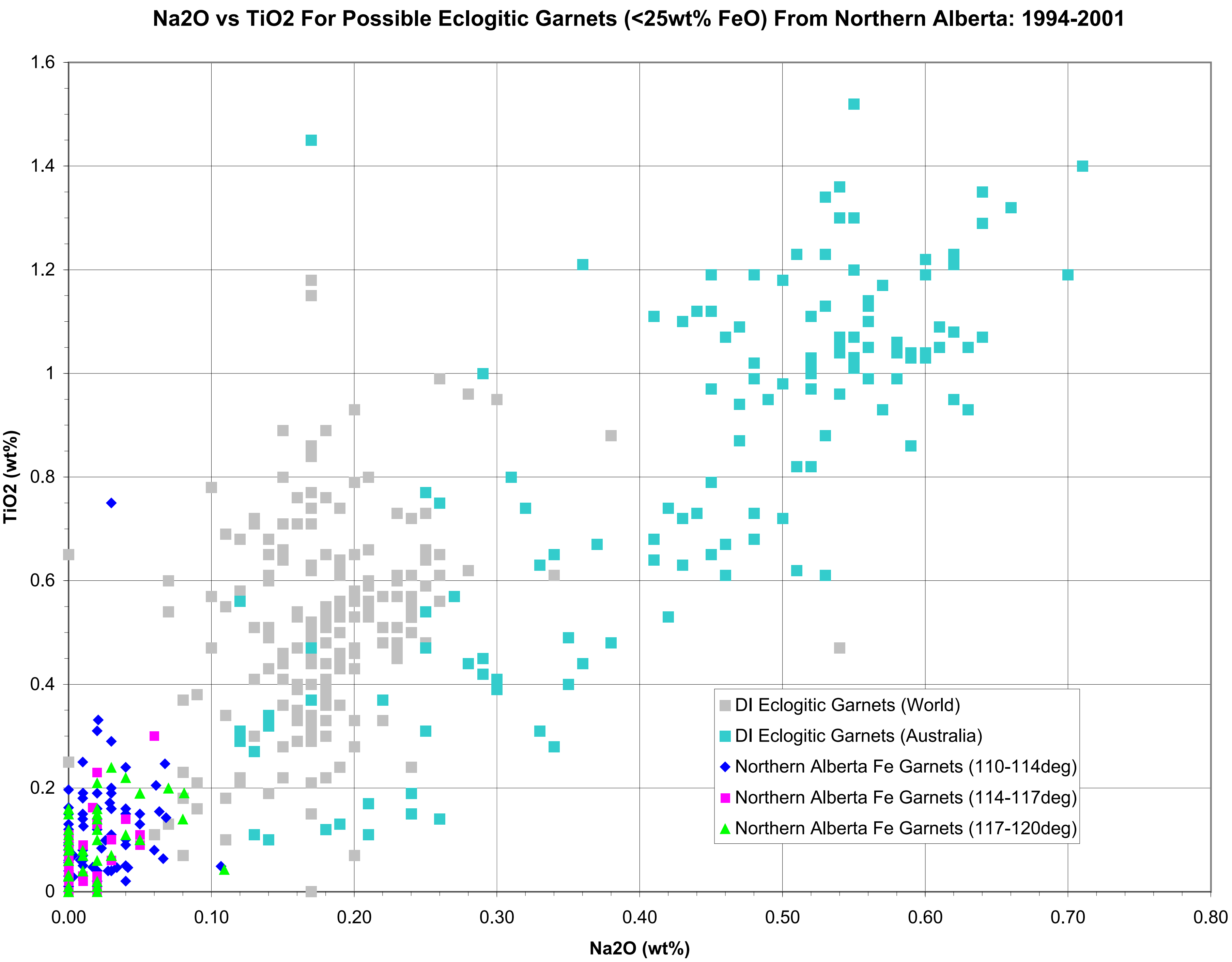
Appendix 4


MgO vs FeO For Possible Eclogitic Garnets (<25 wt% FeO) From Northern Alberta: 1994-2001
Total Fe as FeO (wt%)
0
5
10
15
20
25
30
35
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Northern Alberta Fe Garnets (110-114deg)
Northern Alberta Fe Garnets (114-117deg)
Northern Alberta Fe Garnets (117-120deg)
Likely Tourmaline

Appendix 4


CaO vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From Northern Alberta: 1994-2001
TiO2 (wt%)
CaO (wt%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
2
4
6
8
10
12
14
16
18
20
22
24
Likely Tourmaline
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Northern Alberta Fe Garnets (110-114)
Northern Alberta Fe Garnets (114-117)
Northern Alberta Fe Garnets (117-120)

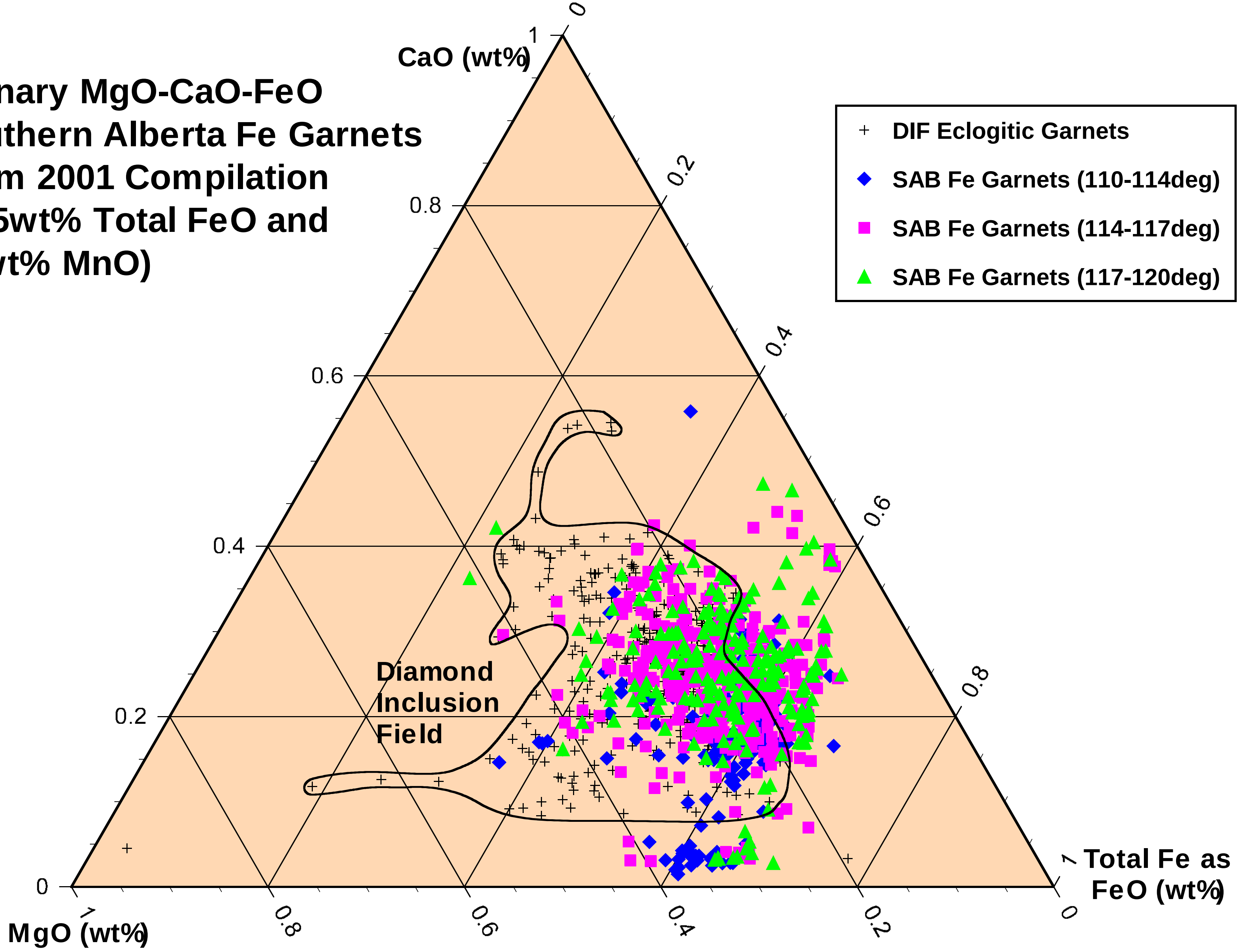
Appendix 4



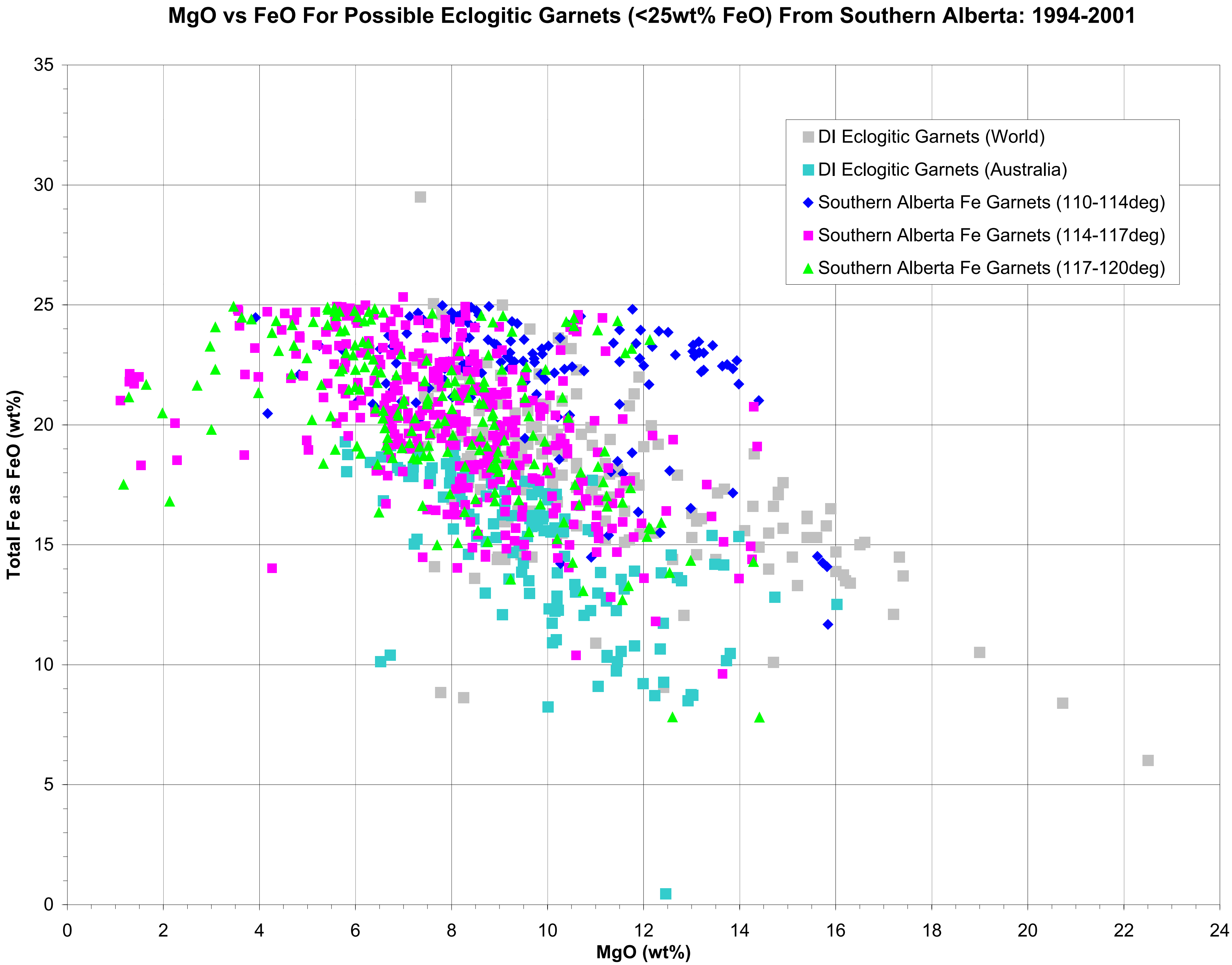
Na2O vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From Northern Alberta: 1994-2001
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Northern Alberta Fe Garnets (110-114deg)
Northern Alberta Fe Garnets (114-117deg)
Northern Alberta Fe Garnets (117-120deg)

Appendix 4

Ternary MgO-CaO-FeO Southern Alberta Fe Garnets From 2001 Compilation (<25wt% Total FeO and <3wt% MnO)

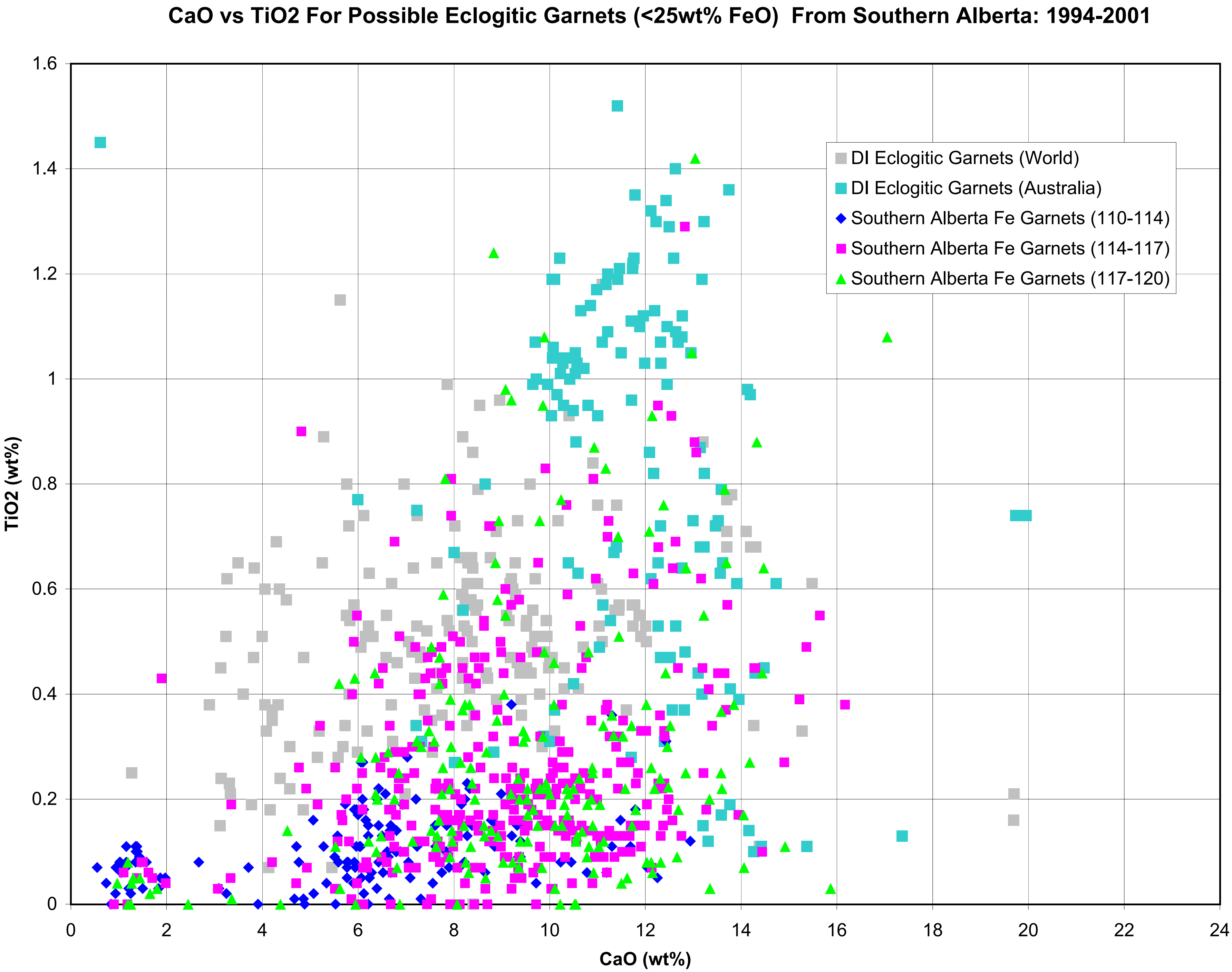


Appendix 4

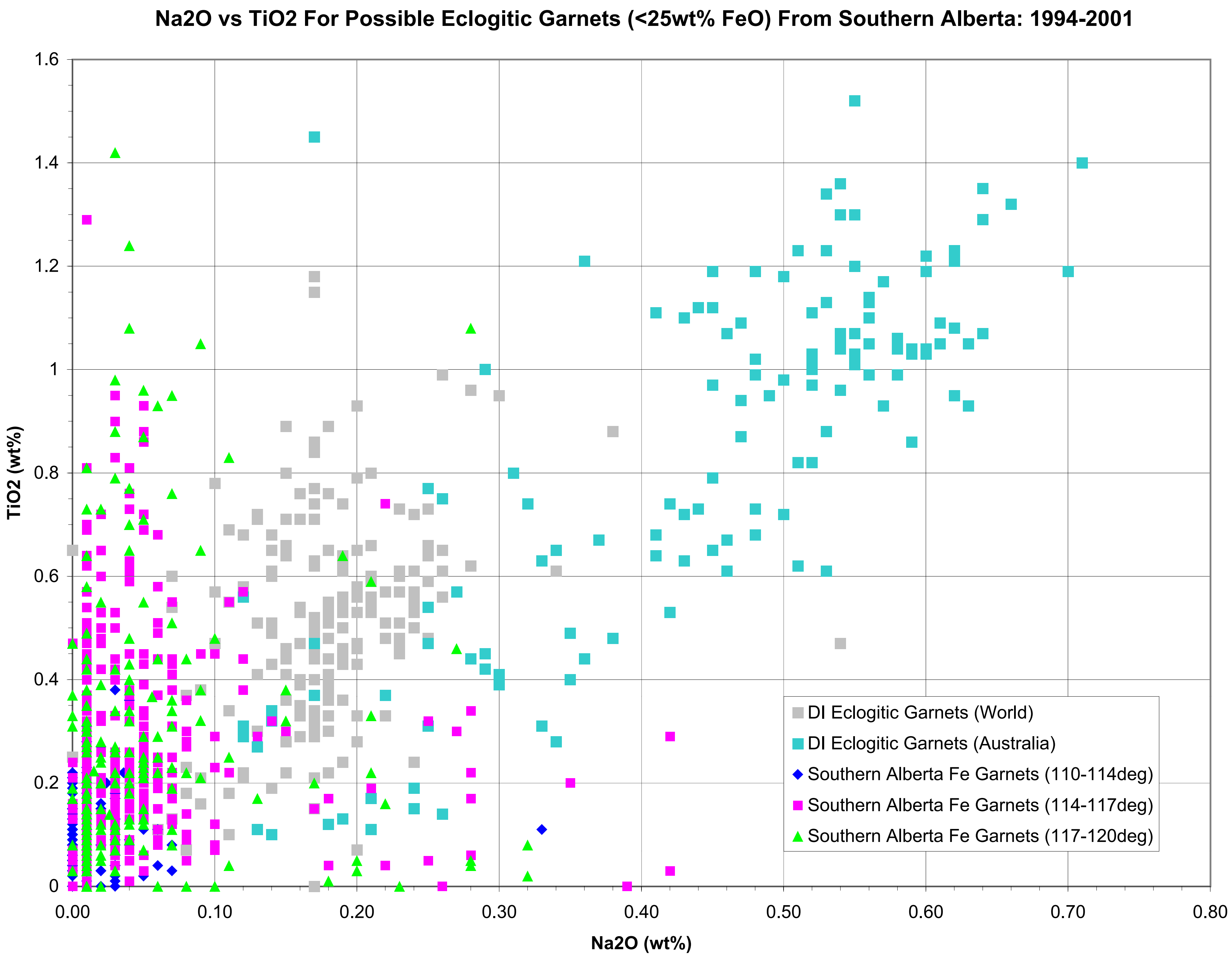


MgO vs FeO For Possible Eclogitic Garnets (<25wt% FeO) From Southern Alberta: 1994-2001
Total Fe as FeO (wt%)
MgO (wt%)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
16
18
20
22
24
■ DI Eclogitic Garnets (World)
■ DI Eclogitic Garnets (Australia)
◆ Southern Alberta Fe Garnets (110-114deg)
■ Southern Alberta Fe Garnets (114-117deg)
▲ Southern Alberta Fe Garnets (117-120deg)

Appendix 4


CaO vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From Southern Alberta: 1994-2001
TiO2 (wt%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
CaO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (110-114)
Southern Alberta Fe Garnets (114-117)
Southern Alberta Fe Garnets (117-120)

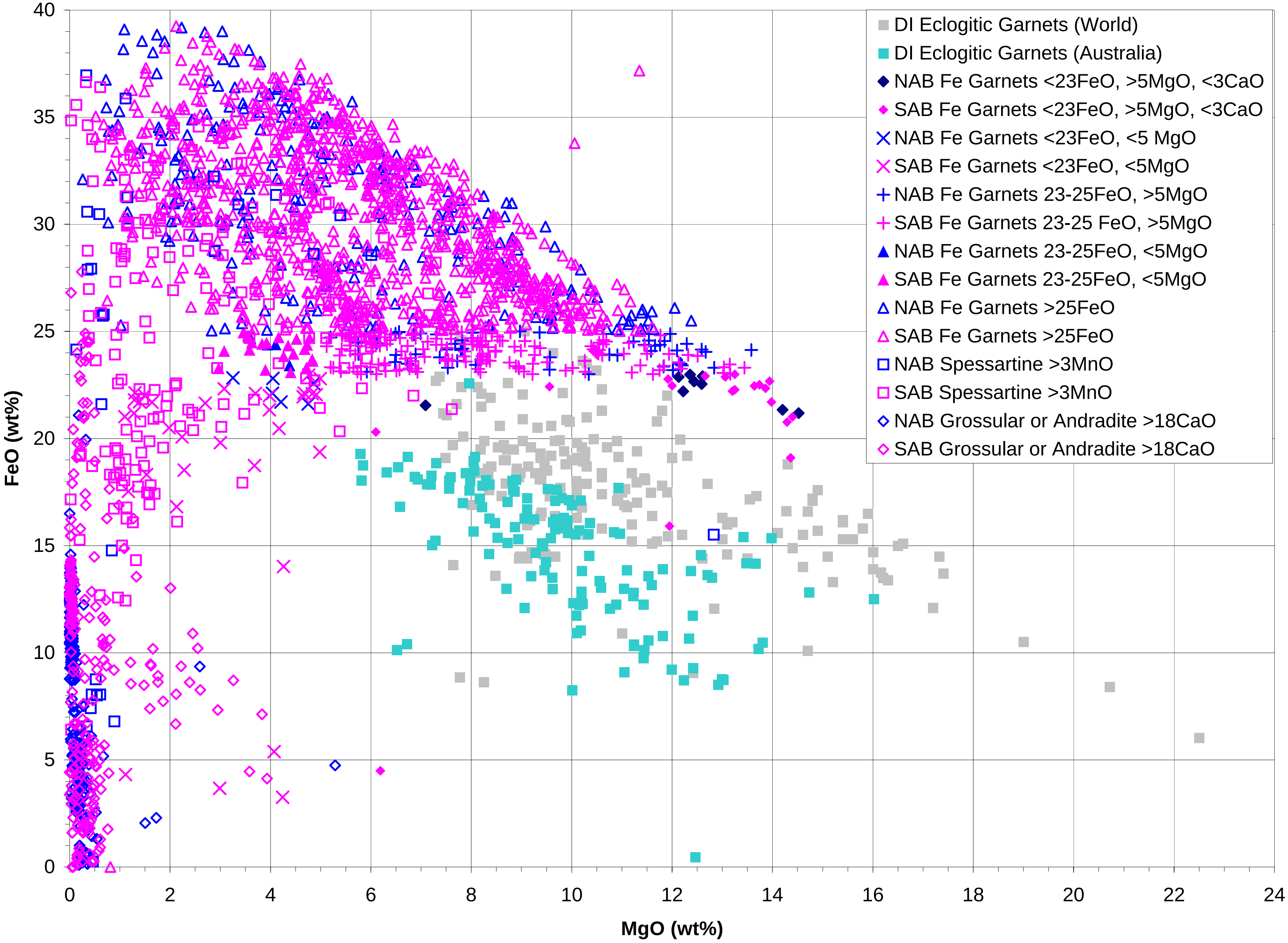
Appendix 4



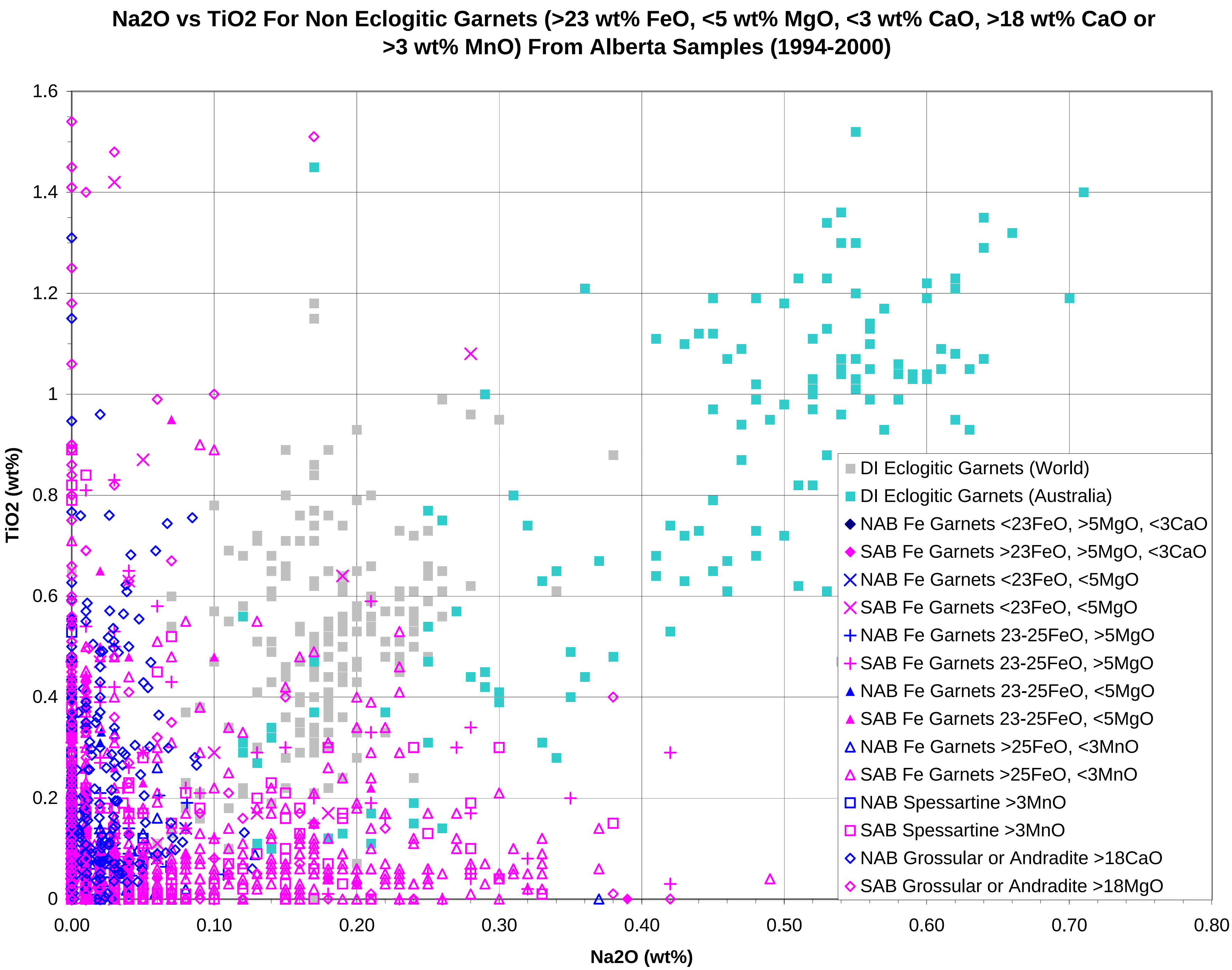
Na2O vs TiO2 For Possible Eclogitic Garnets (<25wt% FeO) From Southern Alberta: 1994-2001
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Southern Alberta Fe Garnets (110-114deg)
Southern Alberta Fe Garnets (114-117deg)
Southern Alberta Fe Garnets (117-120deg)

Appendix 4

MgO vs FeO For Non Eclogitic Garnets (>23 wt% FeO, <5 wt%MgO, <3 wt% CaO, >18 wt% CaO or >3 wt% MnO) From Alberta Samples (1994-2000)

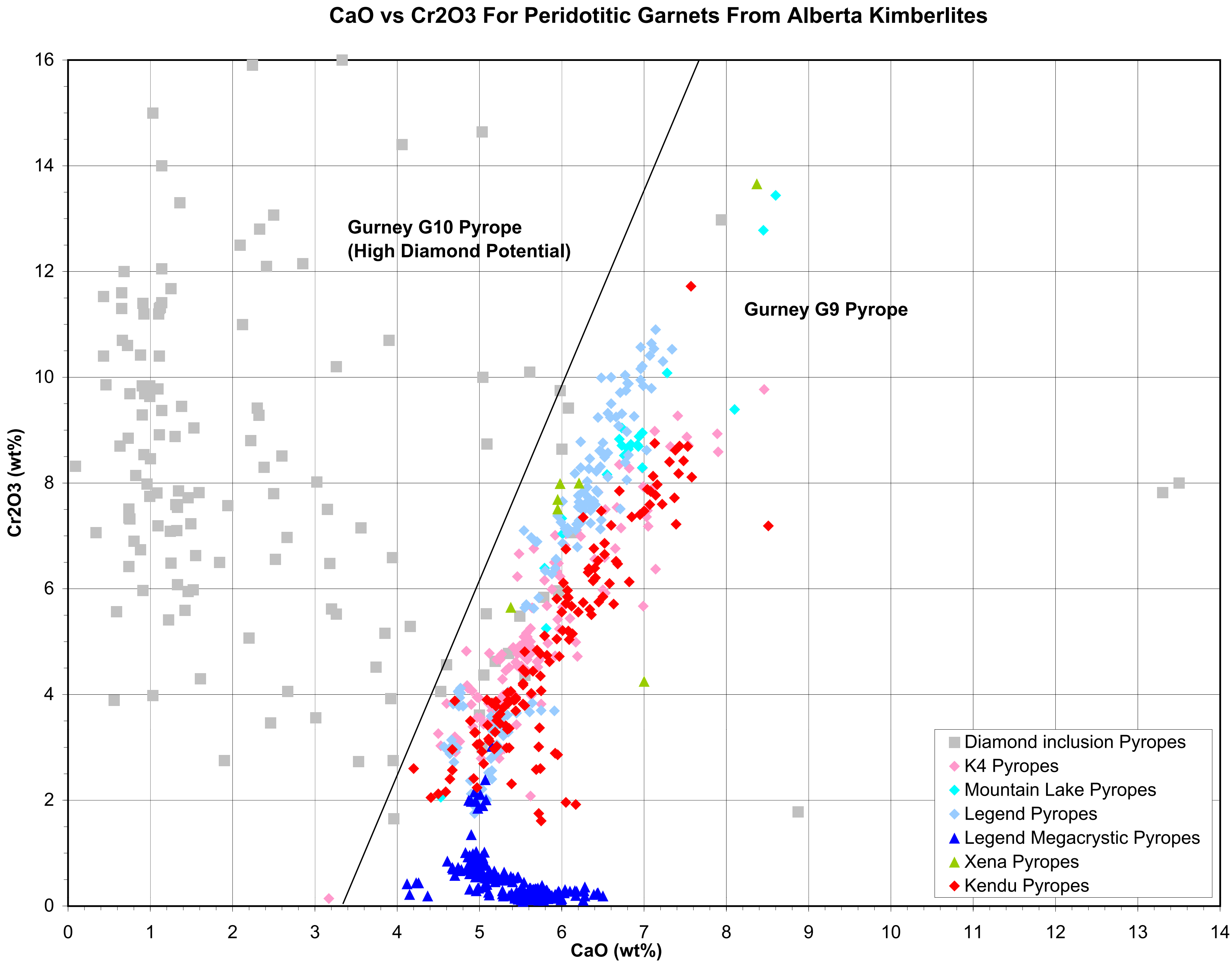


Appendix 4

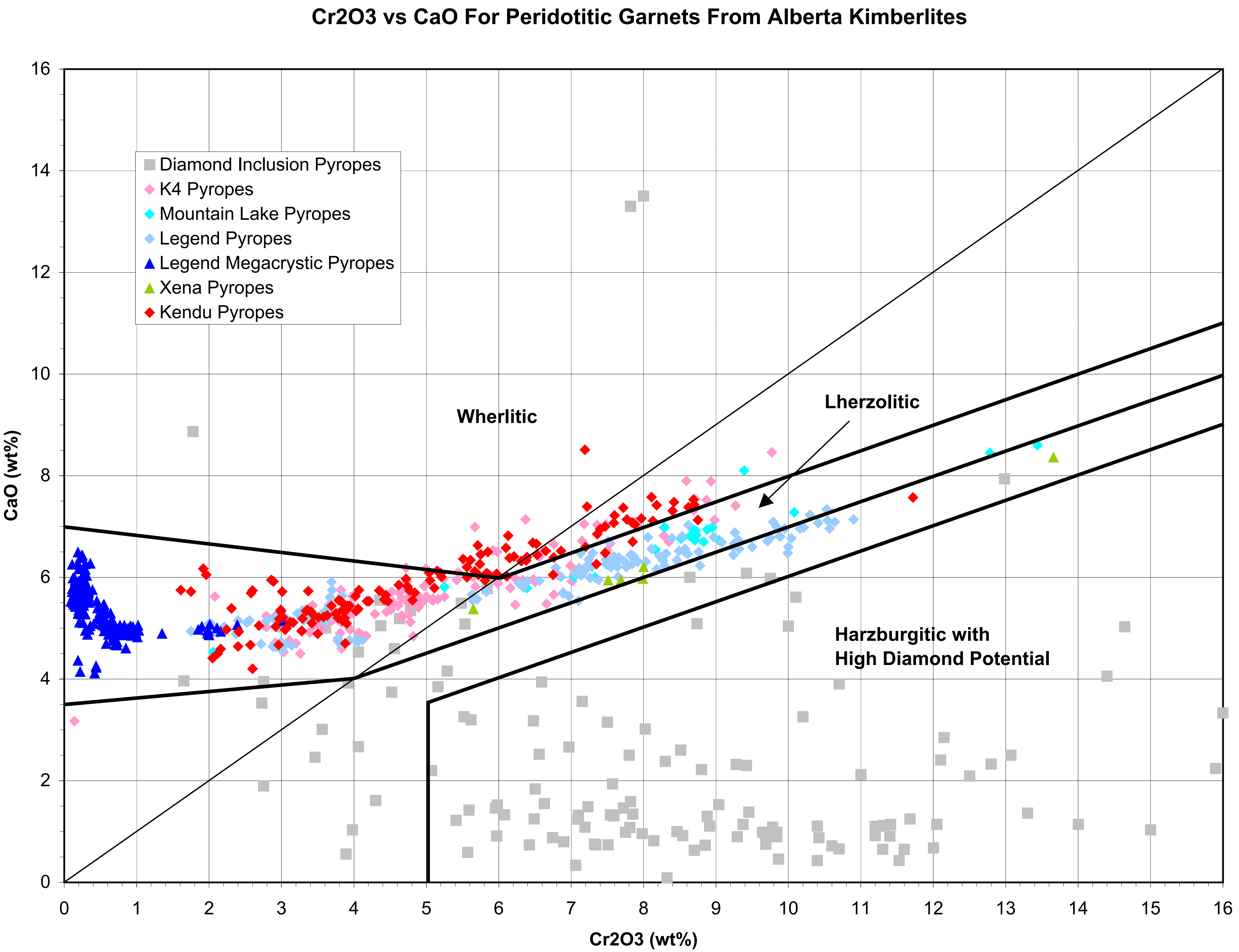


Na2O vs TiO2 For Non Eclogitic Garnets (>23 wt% FeO, <5 wt% MgO, <3 wt% CaO, >18 wt% CaO or >3 wt% MnO) From Alberta Samples (1994-2000)
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
NAB Fe Garnets <23FeO, >5MgO, <3CaO
SAB Fe Garnets >23FeO, >5MgO, <3CaO
NAB Fe Garnets <23FeO, <5MgO
SAB Fe Garnets <23FeO, <5MgO
NAB Fe Garnets 23-25FeO, >5MgO
SAB Fe Garnets 23-25FeO, >5MgO
NAB Fe Garnets 23-25FeO, <5MgO
SAB Fe Garnets 23-25FeO, <5MgO
NAB Fe Garnets >25FeO, <3MnO
SAB Fe Garnets >25FeO, <3MnO
NAB Spessartine >3MnO
SAB Spessartine >3MnO
NAB Grossular or Andradite >18CaO
SAB Grossular or Andradite >18MgO

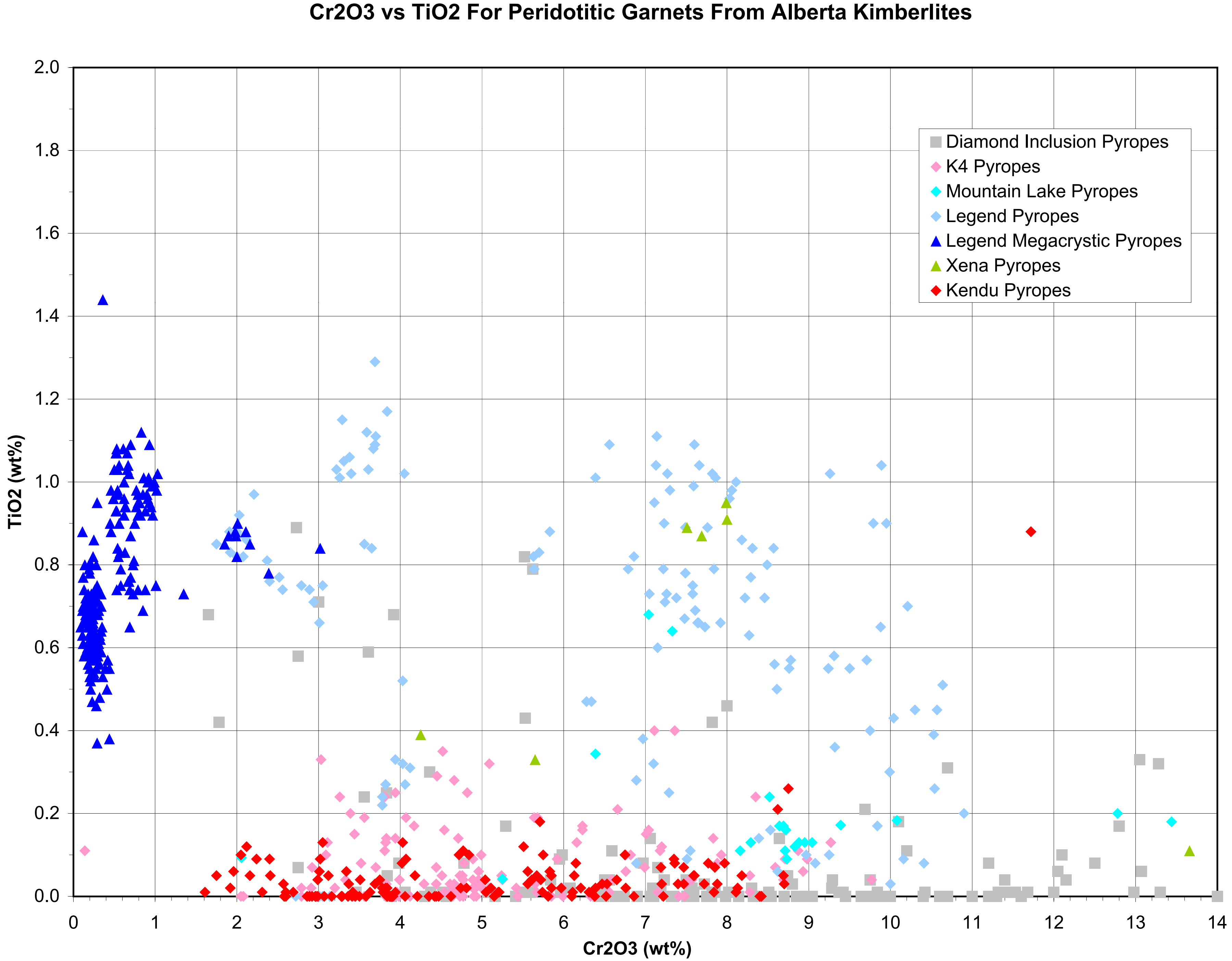
Appendix 4


CaO vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
Cr2O3 (wt%)
CaO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Diamond inclusion Pyropes
K4 Pyropes
Mountain Lake Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
Xena Pyropes
Kendu Pyropes

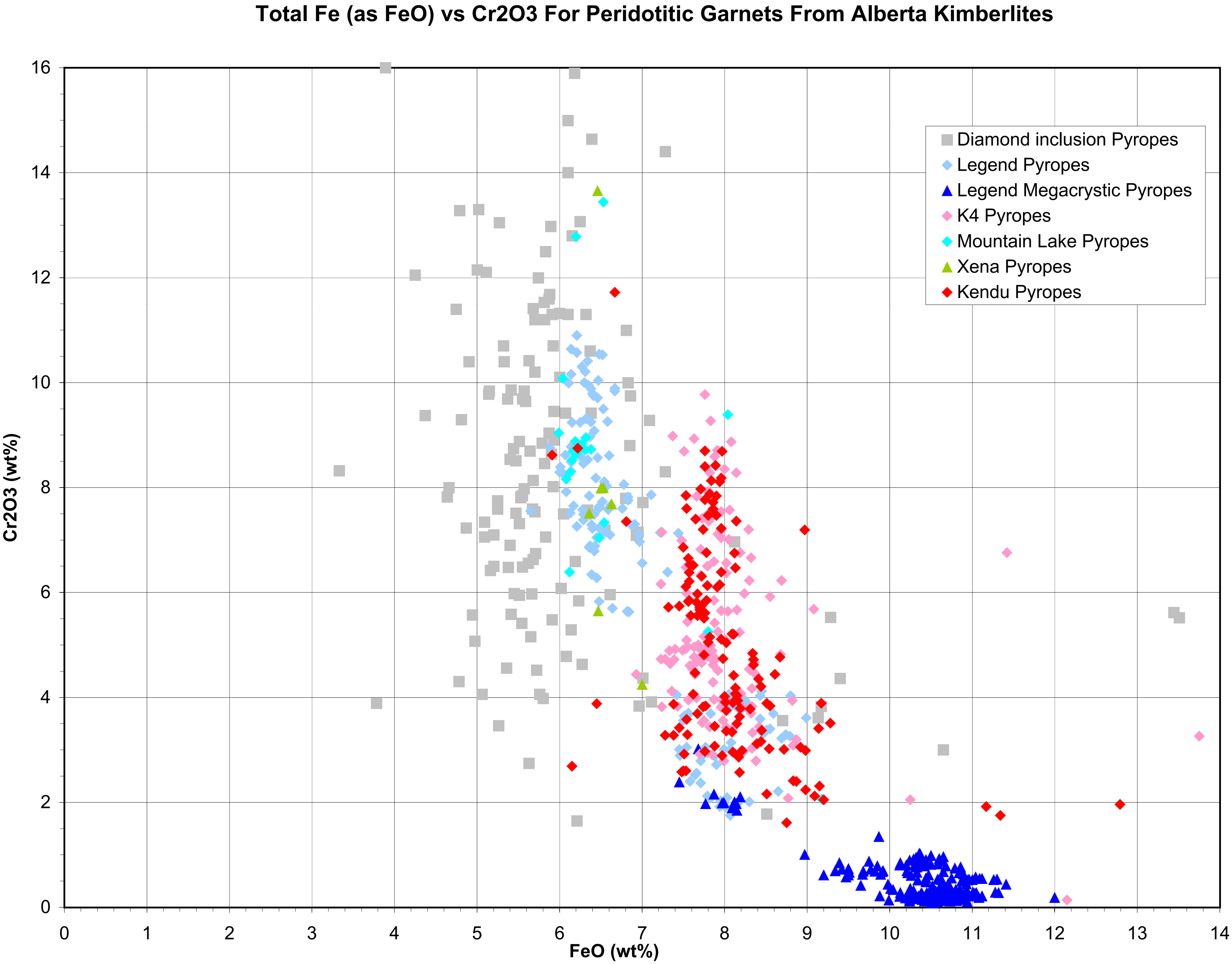
Appendix 4


Cr2O3 vs CaO For Peridotitic Garnets From Alberta Kimberlites
■ Diamond Inclusion Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
Wherlitic
Lherzolitic
Harzburgitic with
High Diamond Potential
CaO (wt%)
Cr2O3 (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

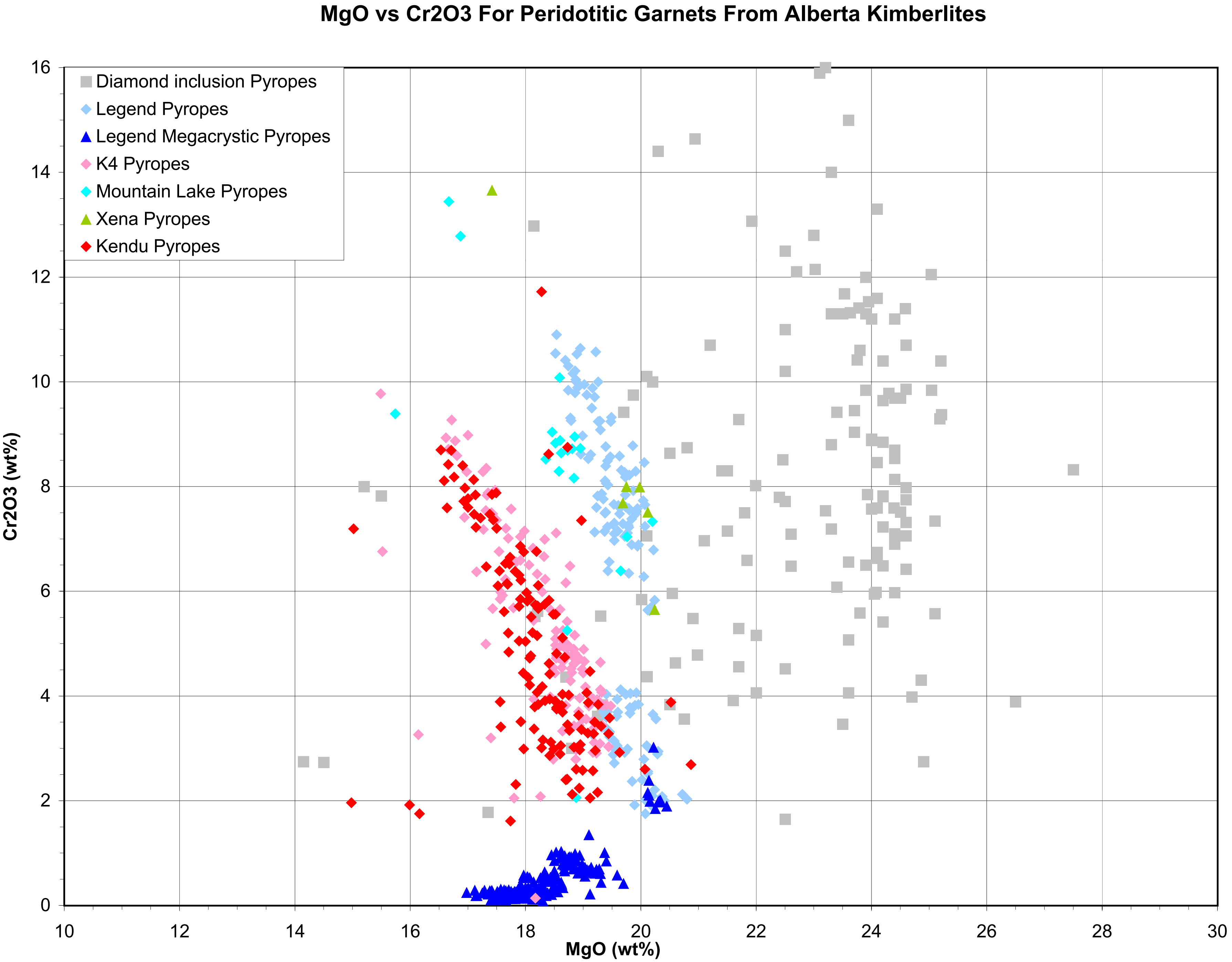
Appendix 4


Cr2O3 vs TiO2 For Peridotitic Garnets From Alberta Kimberlites
TiO2 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Cr2O3 (wt%)
Diamond Inclusion Pyropes
K4 Pyropes
Mountain Lake Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
Xena Pyropes
Kendu Pyropes

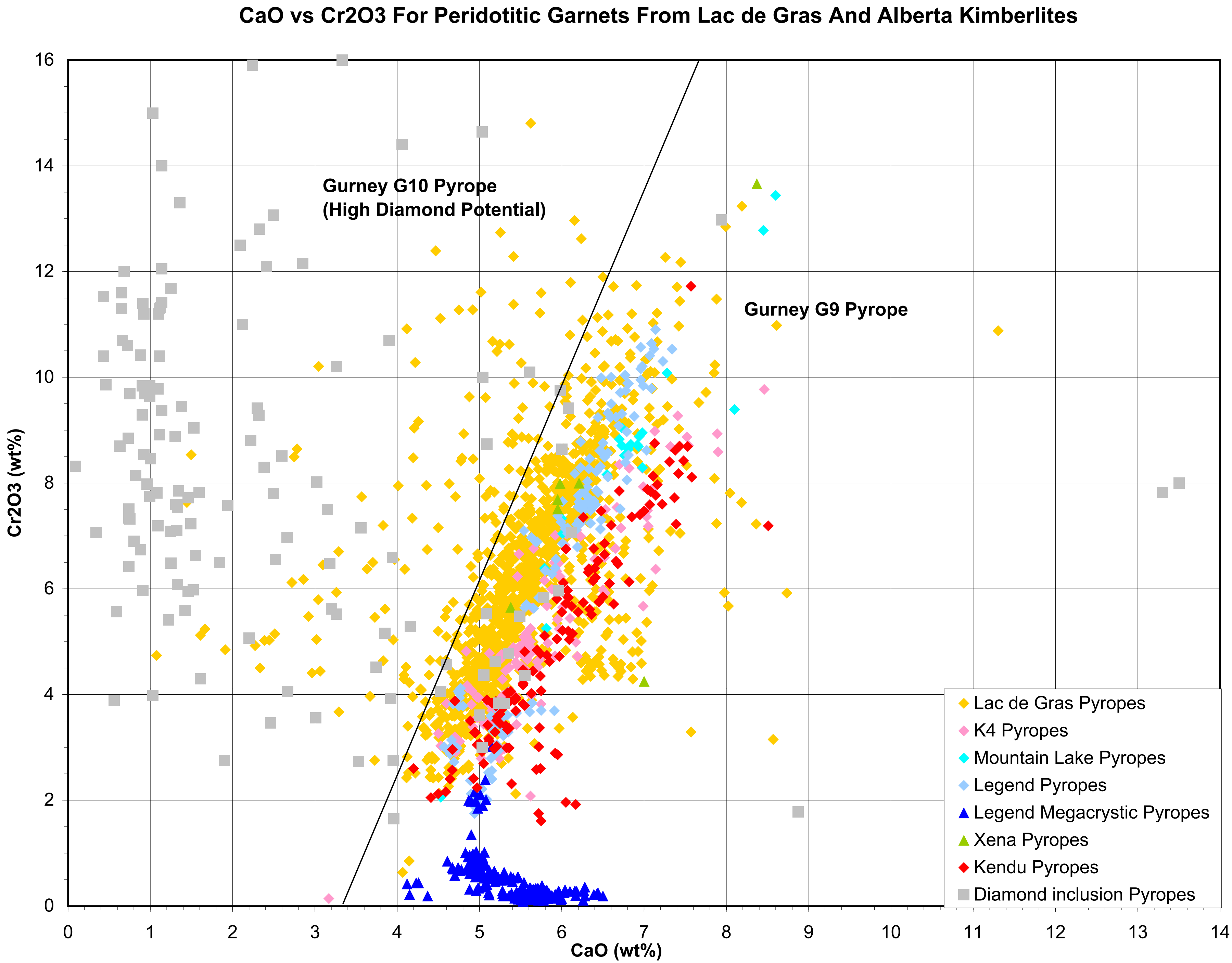
Appendix 4


Total Fe (as FeO) vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Cr2O3 (wt%)
FeO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
■ Diamond inclusion Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes

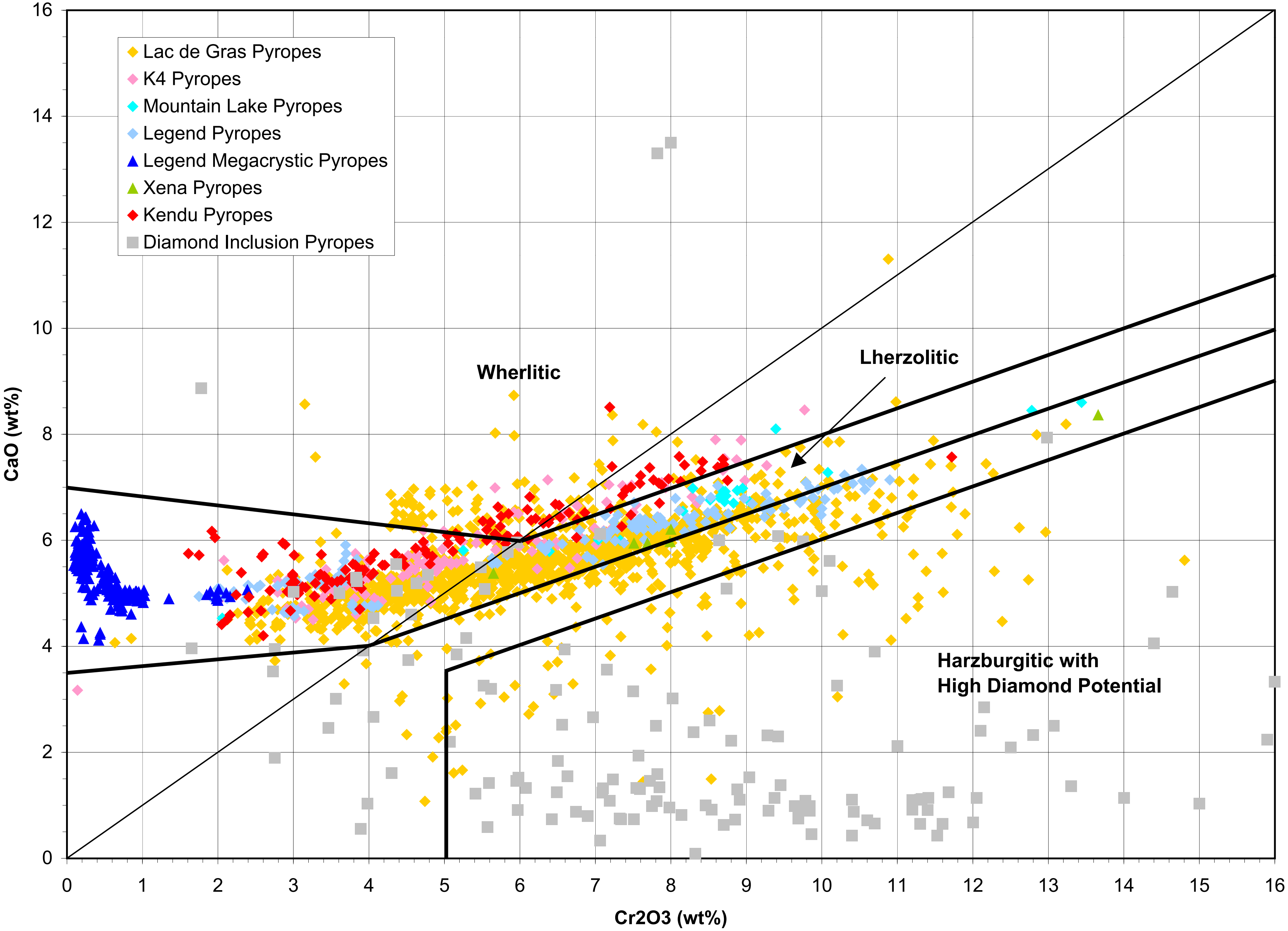
Appendix 4


MgO vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Diamond inclusion Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
K4 Pyropes
Mountain Lake Pyropes
Xena Pyropes
Kendu Pyropes
Cr2O3 (wt%)
0
2
4
6
8
10
12
14
16
MgO (wt%)
10
12
14
16
18
20
22
24
26
28
30

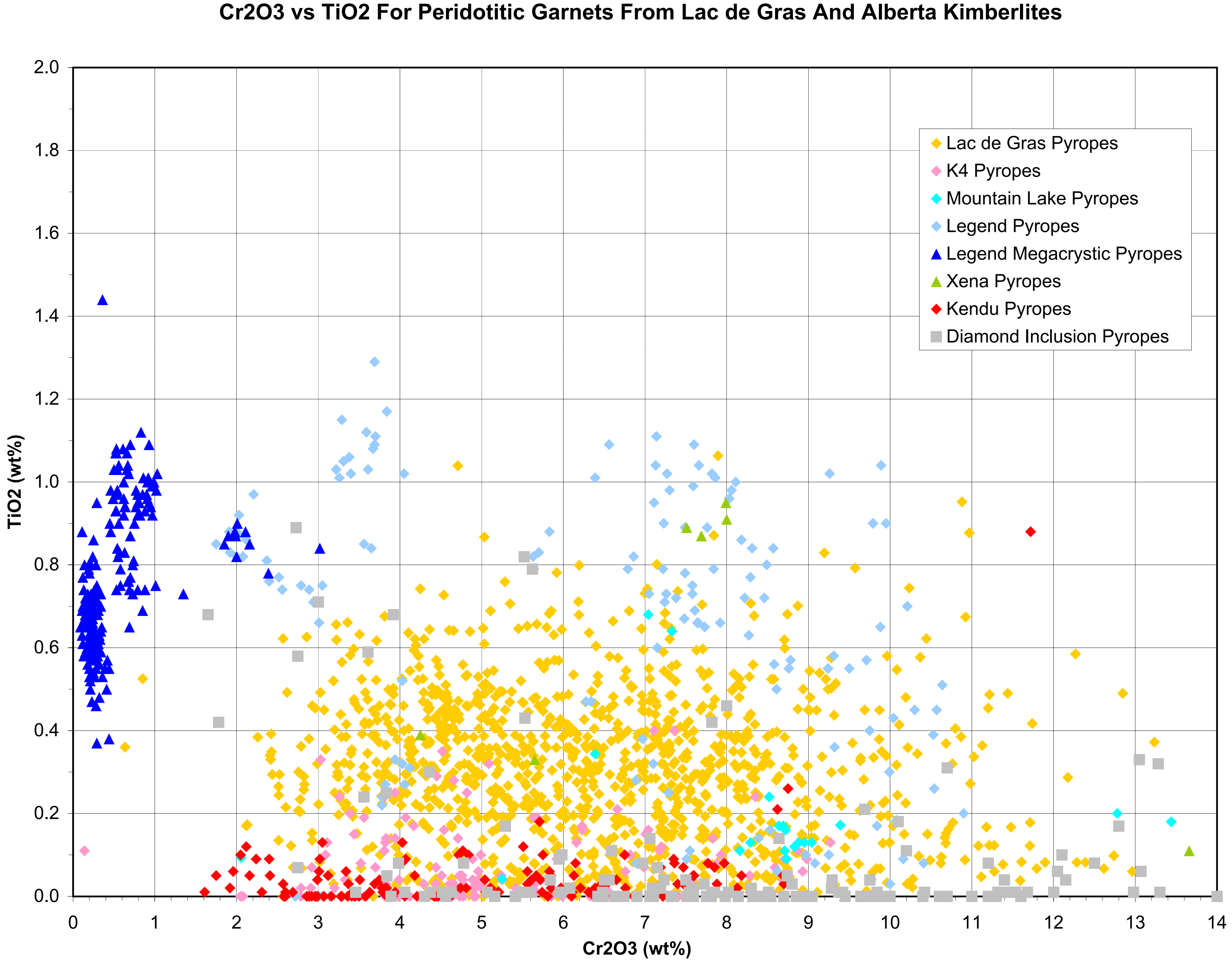
Appendix 4


CaO vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
CaO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
◆ Lac de Gras Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
■ Diamond inclusion Pyropes

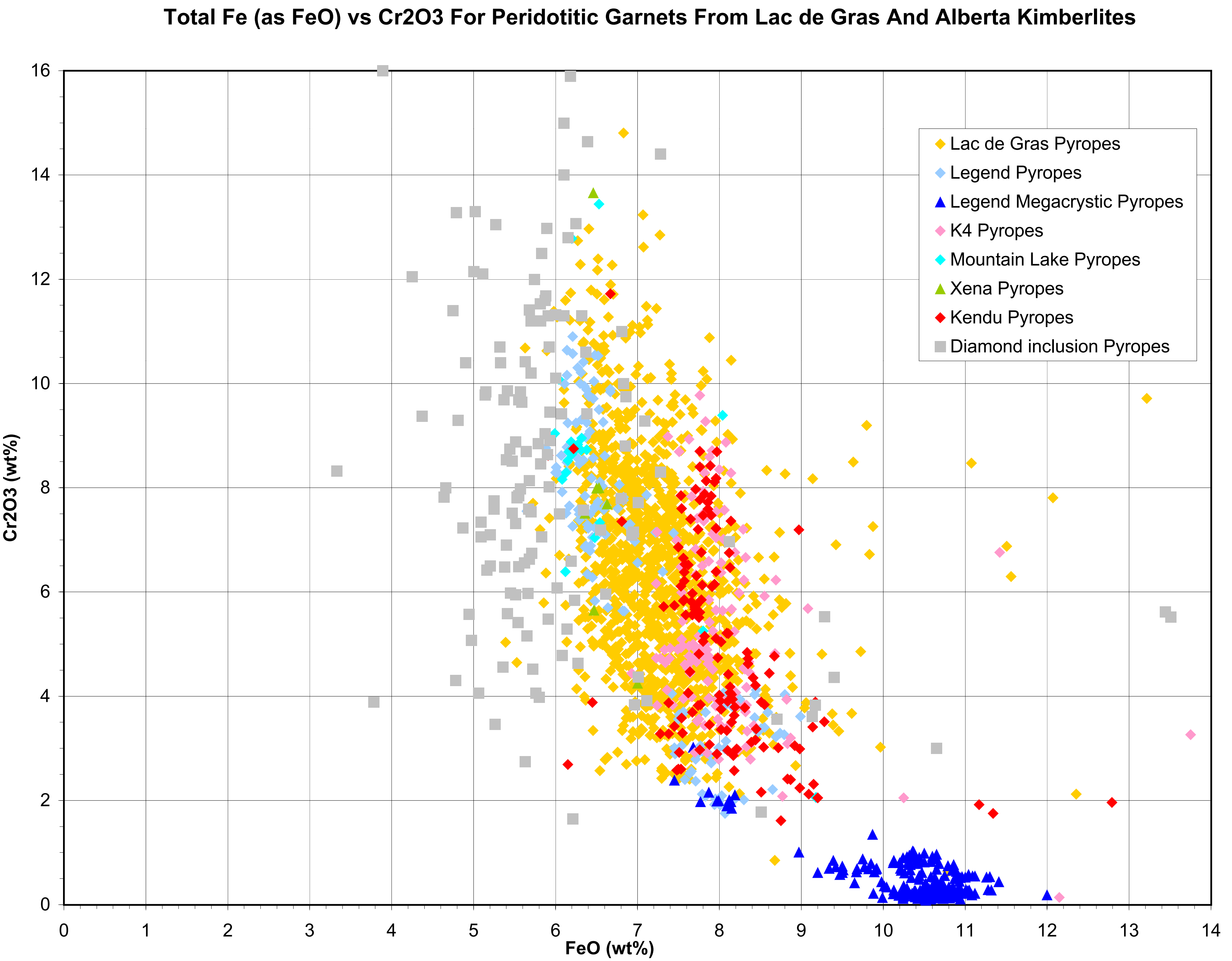
Cr2O3 vs CaO For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites



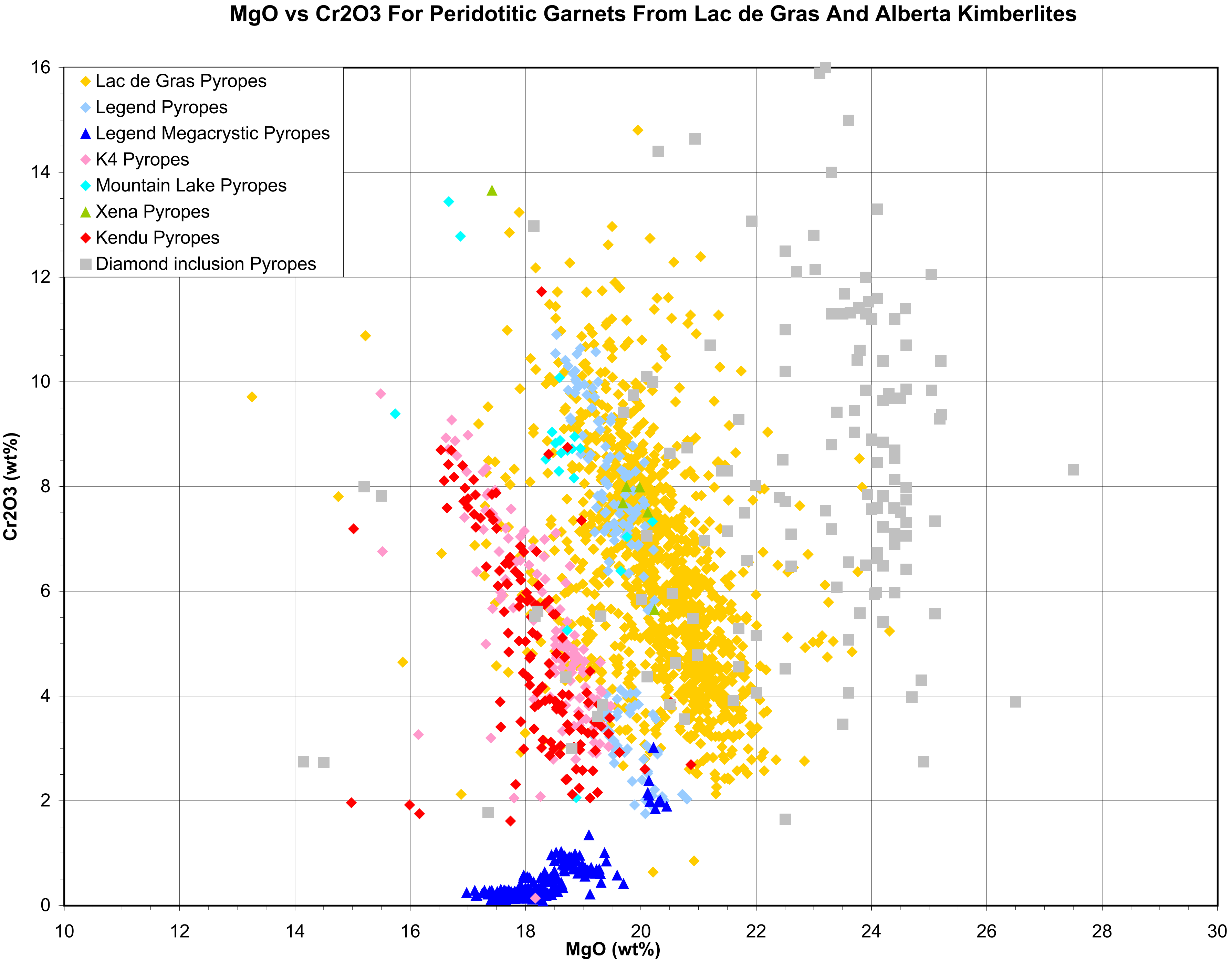
Appendix 4


Cr2O3 vs TiO2 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites
TiO2 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Cr2O3 (wt%)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Lac de Gras Pyropes
K4 Pyropes
Mountain Lake Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
Xena Pyropes
Kendu Pyropes
Diamond Inclusion Pyropes

Appendix 4

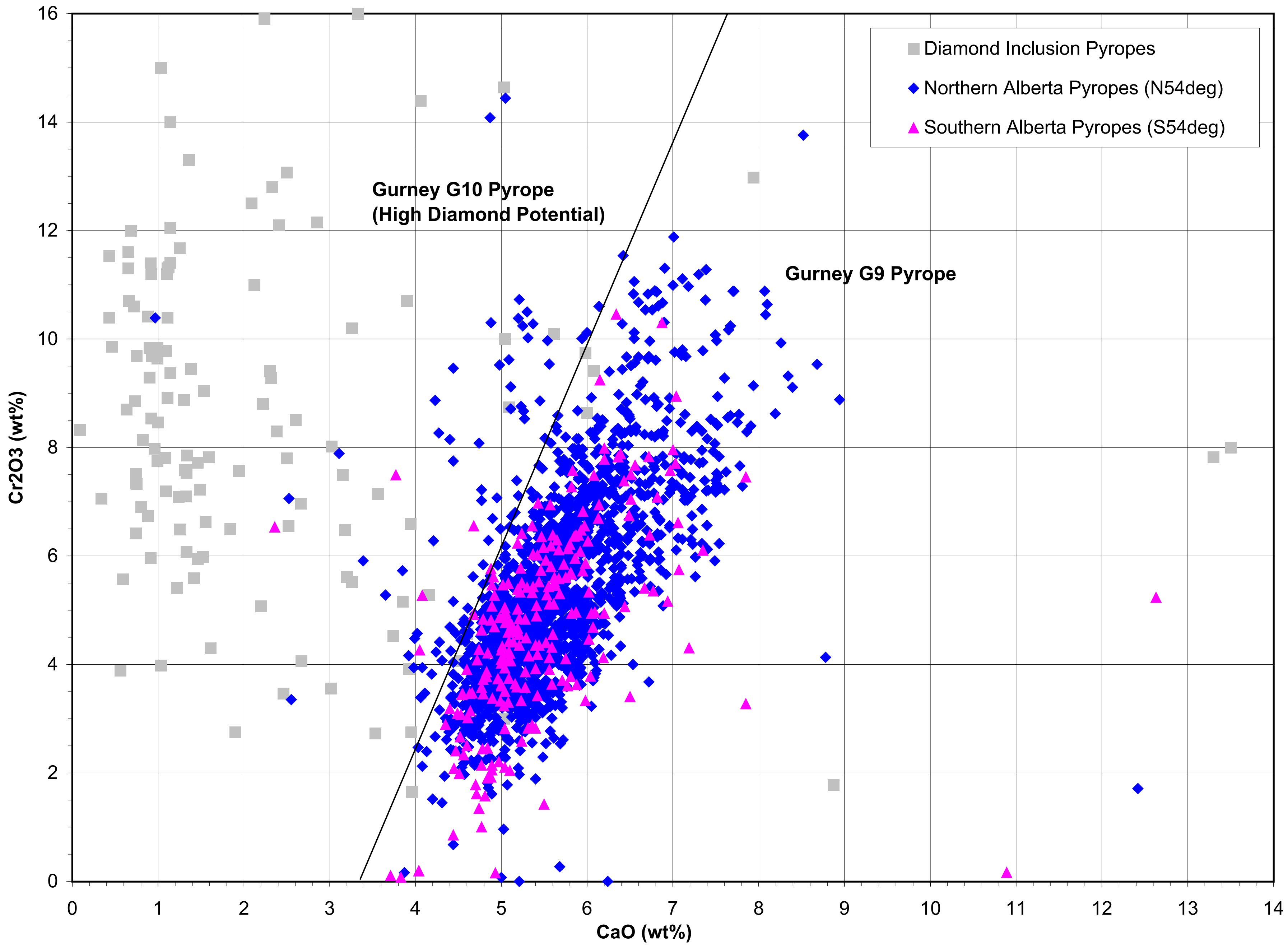

Total Fe (as FeO) vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
0
2
4
6
8
10
12
14
16
FeO (wt%)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
◆ Lac de Gras Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
■ Diamond inclusion Pyropes

Appendix 4


MgO vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites
◆ Lac de Gras Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
■ Diamond inclusion Pyropes
Cr2O3 (wt%)
16
14
12
10
8
6
4
2
0
MgO (wt%)
10
12
14
16
18
20
22
24
26
28
30

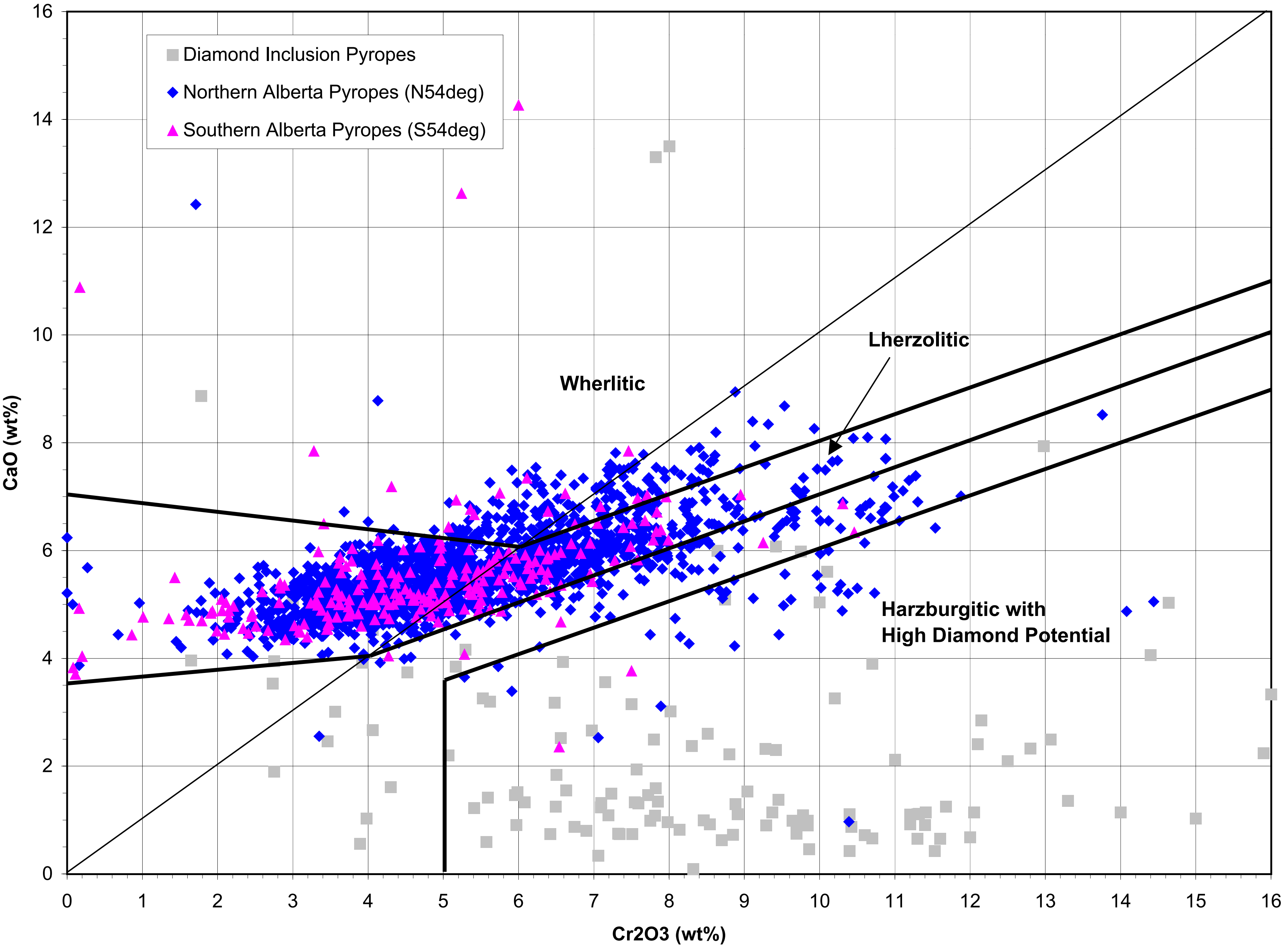
Appendix 4

CaO vs Cr2O3 For Peridotitic Garnets From All Alberta Samples: 1994 - 2001

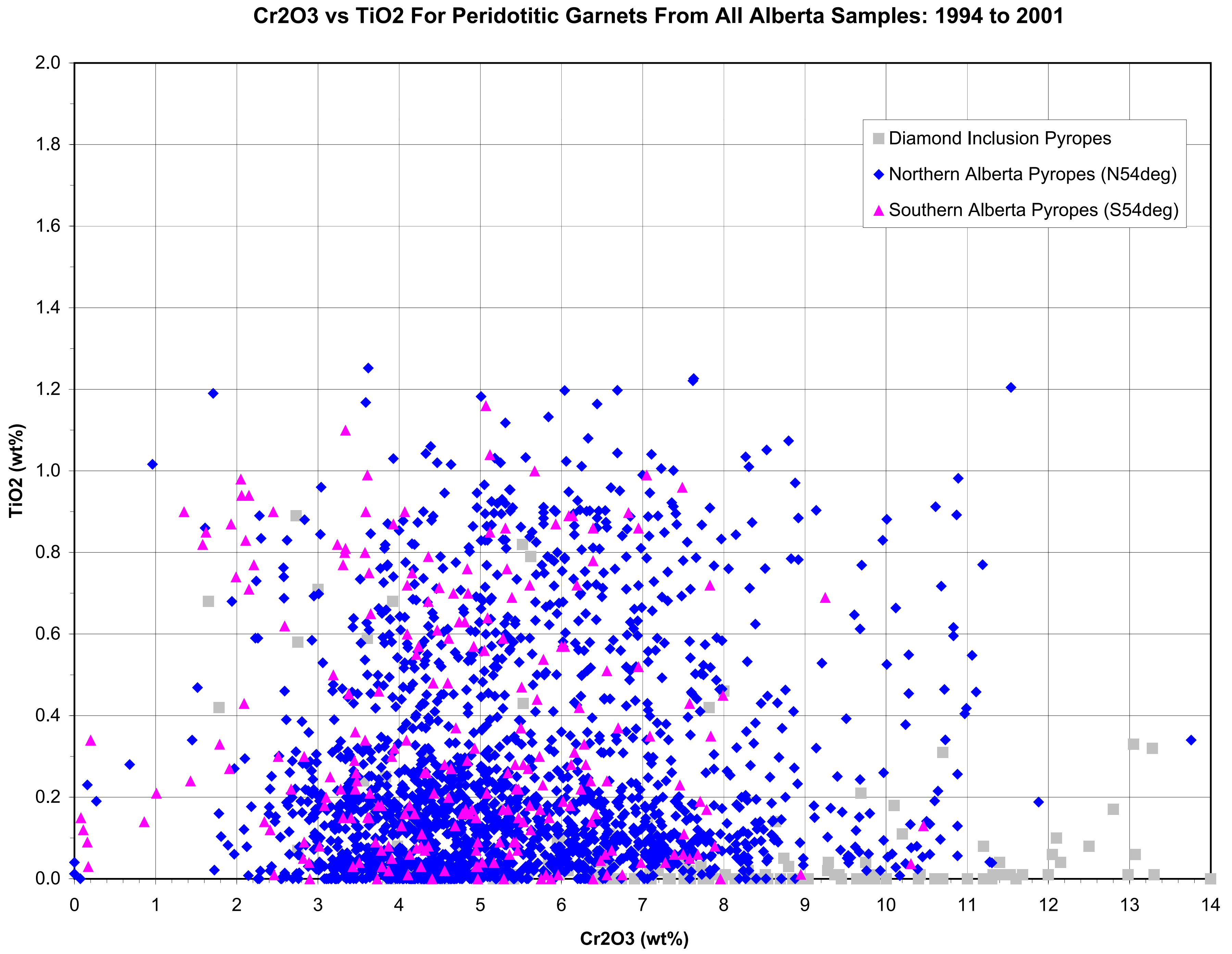


Appendix 4

Cr2O3 vs CaO For Peridotitic Garnets From All Alberta Samples: 1994 - 2001

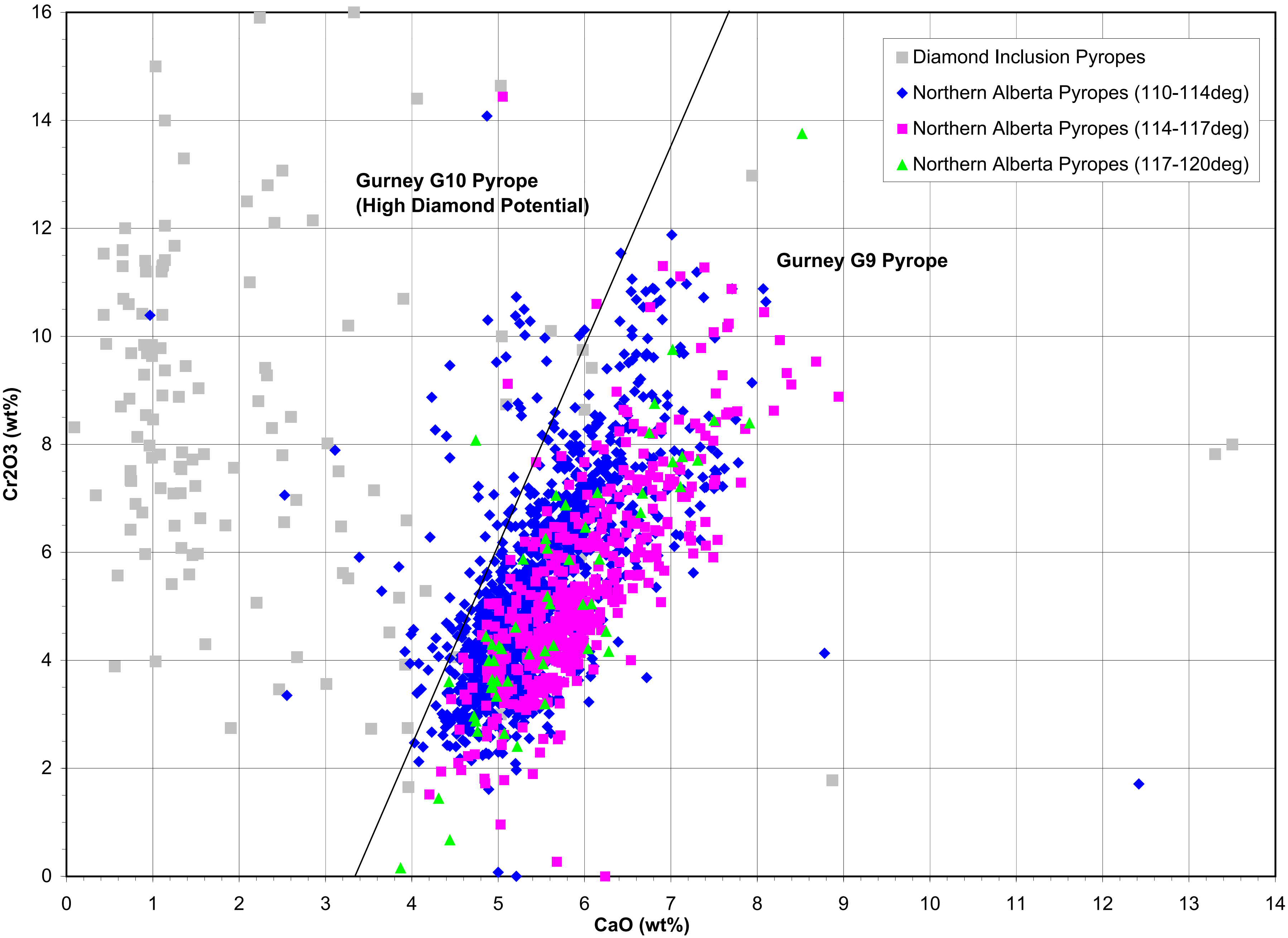


Appendix 4


Cr2O3 vs TiO2 For Peridotitic Garnets From All Alberta Samples: 1994 to 2001
TiO2 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Cr2O3 (wt%)
Diamond Inclusion Pyropes
Northern Alberta Pyropes (N54deg)
Southern Alberta Pyropes (S54deg)

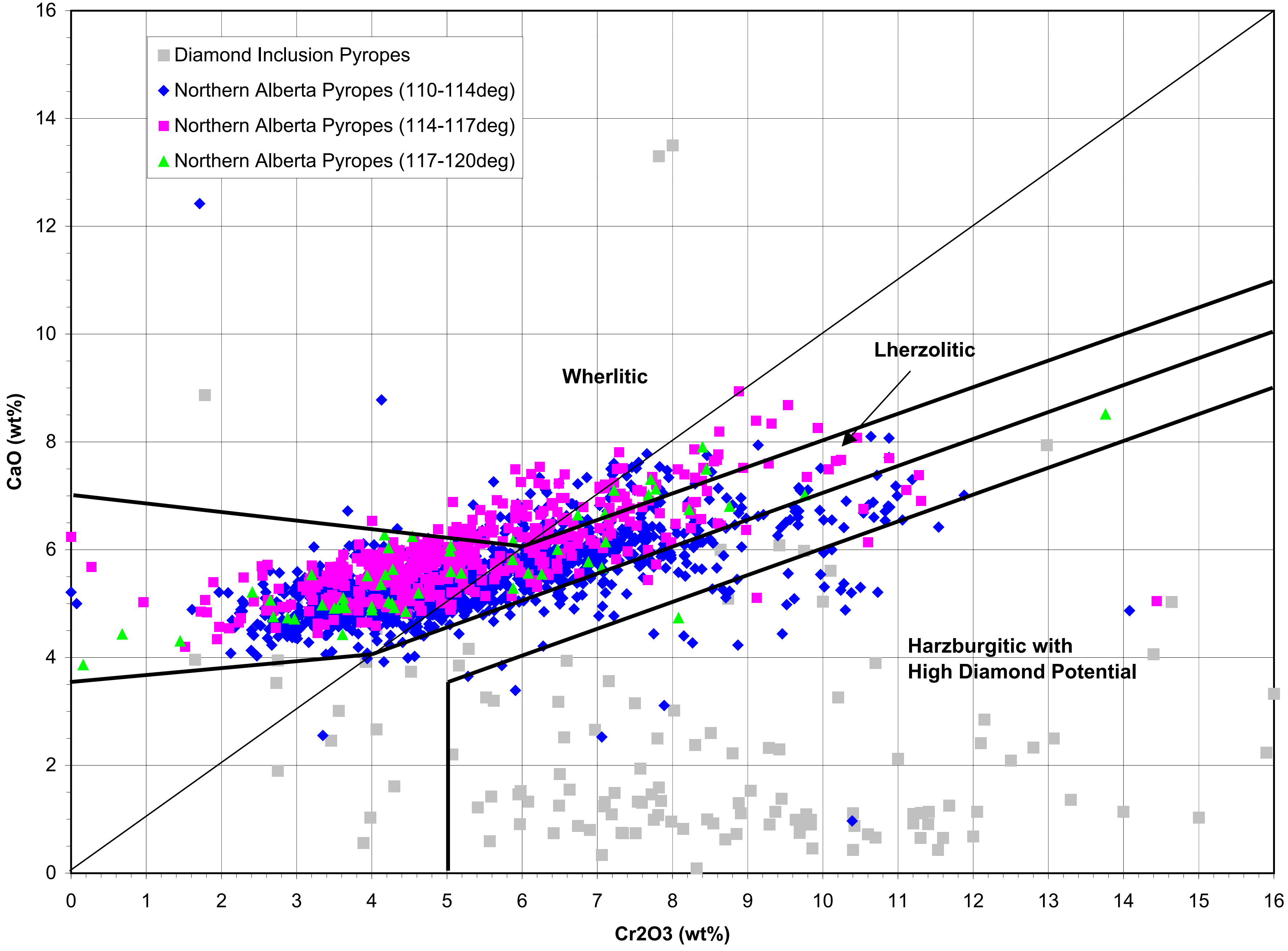
Appendix 4

CaO vs Cr2O3 For Peridotitic Garnets From Northern Alberta Samples: 1994 - 2001



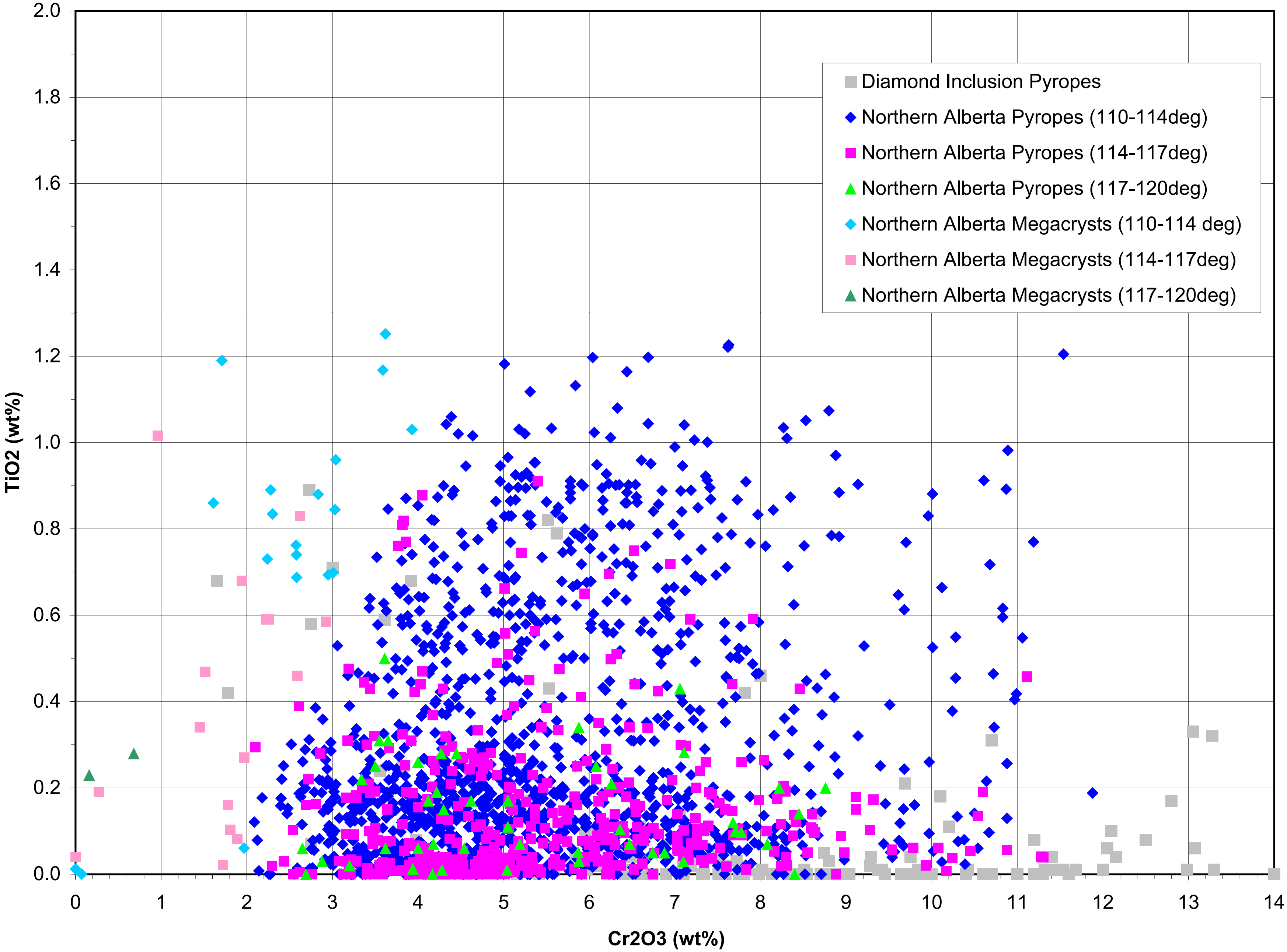
Appendix 4

Cr2O3 vs CaO For Peridotitic Garnets From Northern Alberta Samples: 1994 - 2001

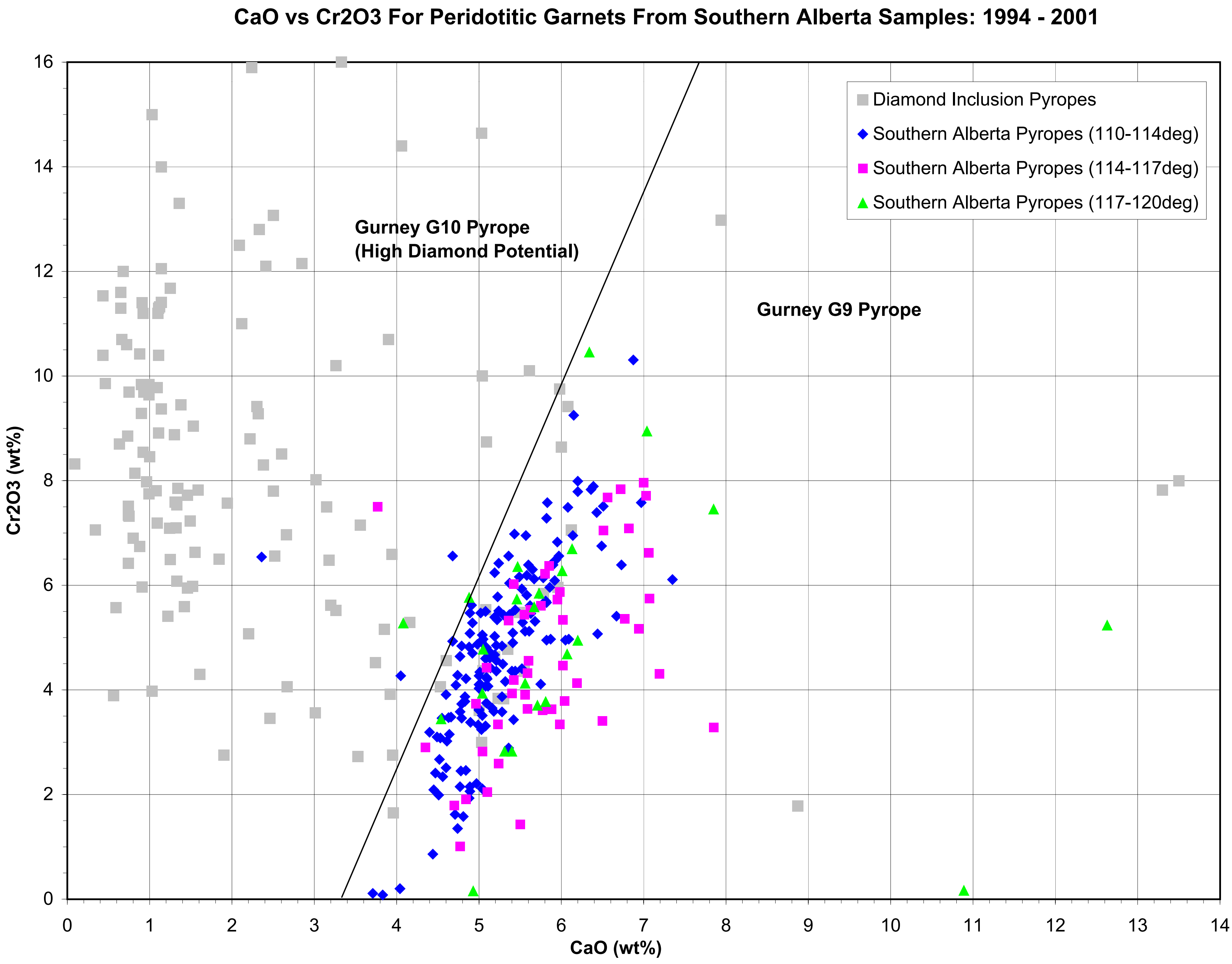


Appendix 4

Cr2O3 vs TiO2 For Peridotitic Garnets From Northern Alberta Samples: 1994 to 2001

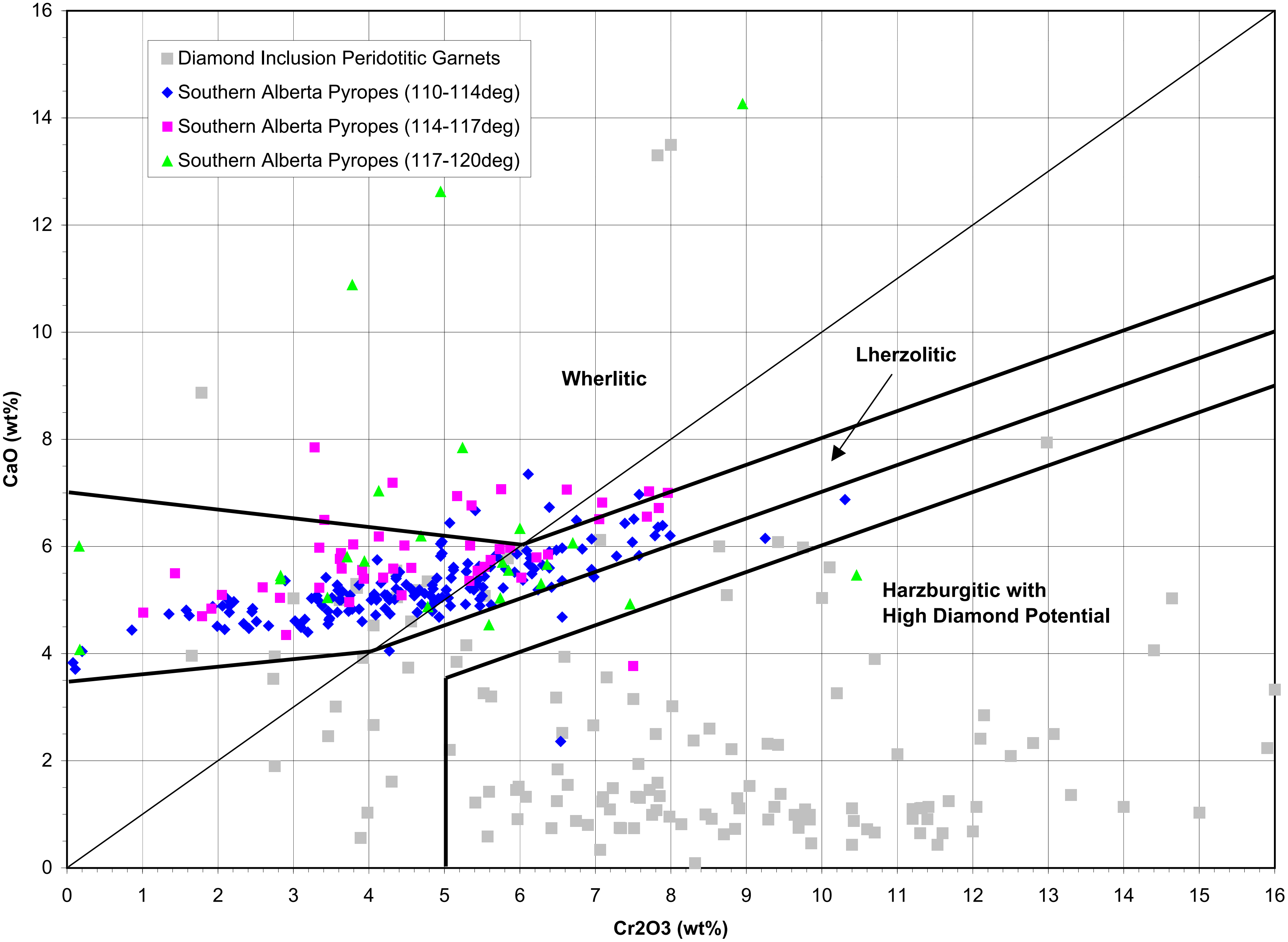


Appendix 4

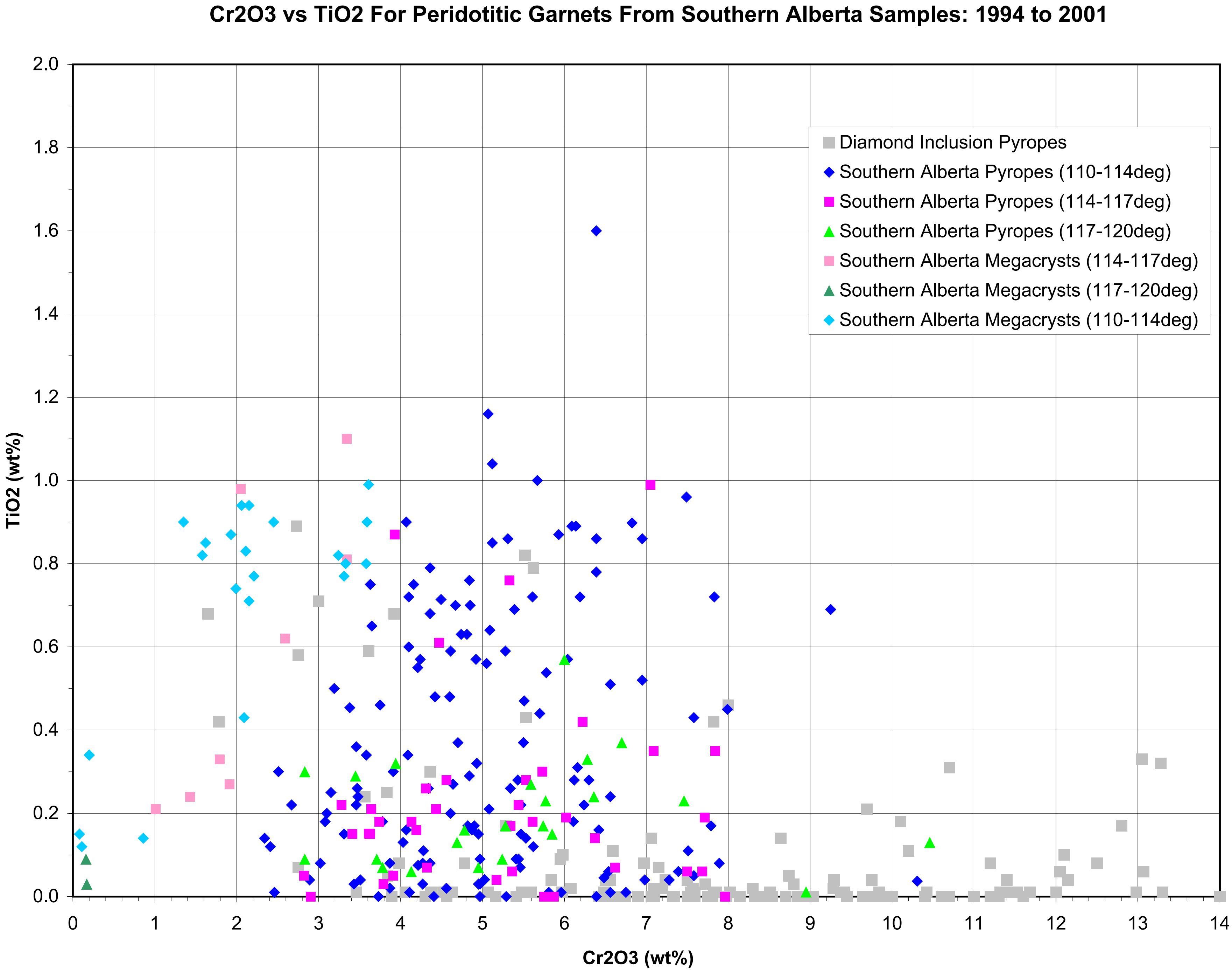

CaO vs Cr2O3 For Peridotitic Garnets From Southern Alberta Samples: 1994 - 2001
■ Diamond Inclusion Pyropes
◆ Southern Alberta Pyropes (110-114deg)
■ Southern Alberta Pyropes (114-117deg)
▲ Southern Alberta Pyropes (117-120deg)
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
Cr2O3 (wt%)
CaO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Appendix 4

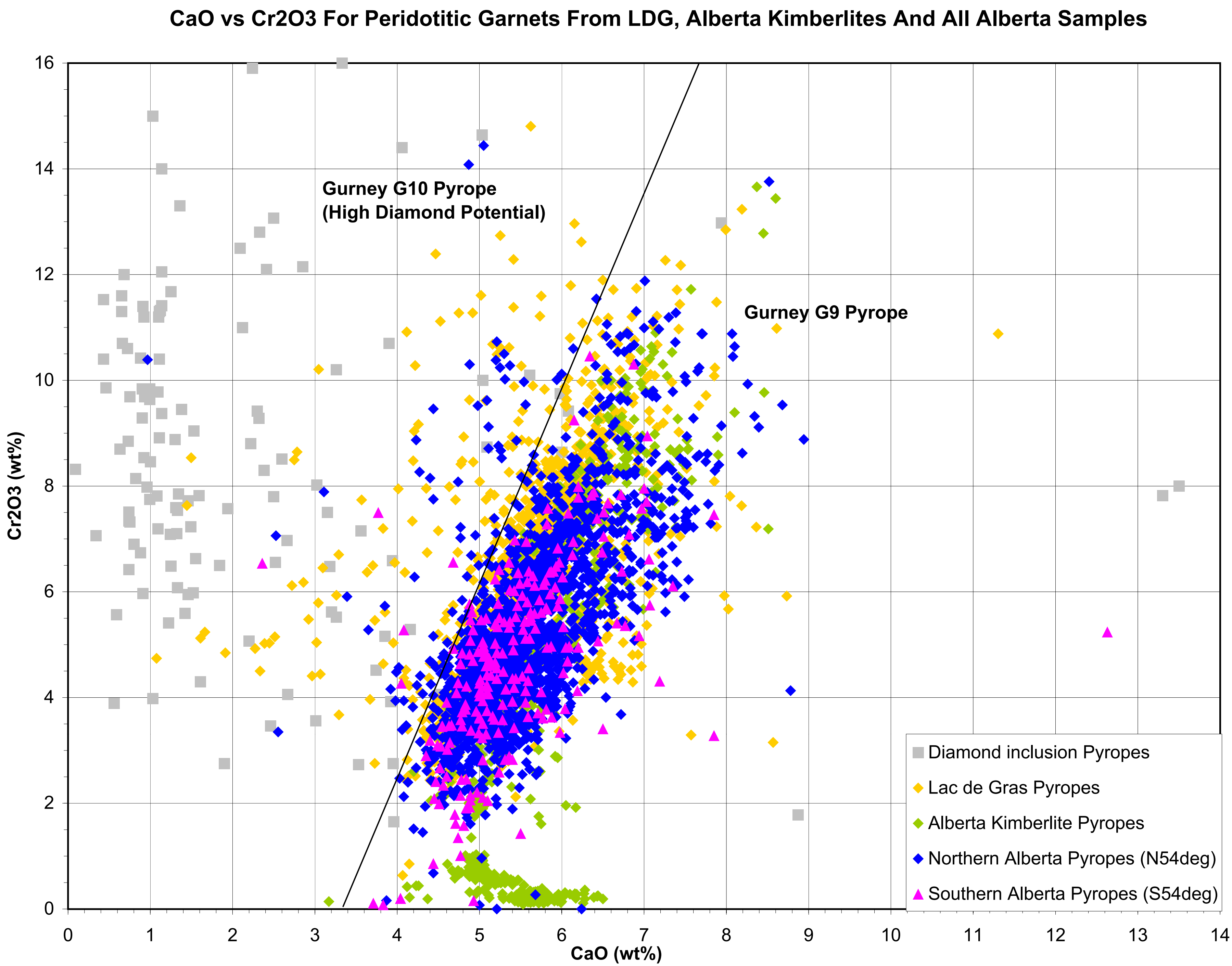
Cr2O3 vs CaO For Peridotitic Garnets From Southern Alberta Samples: 1994 - 2001



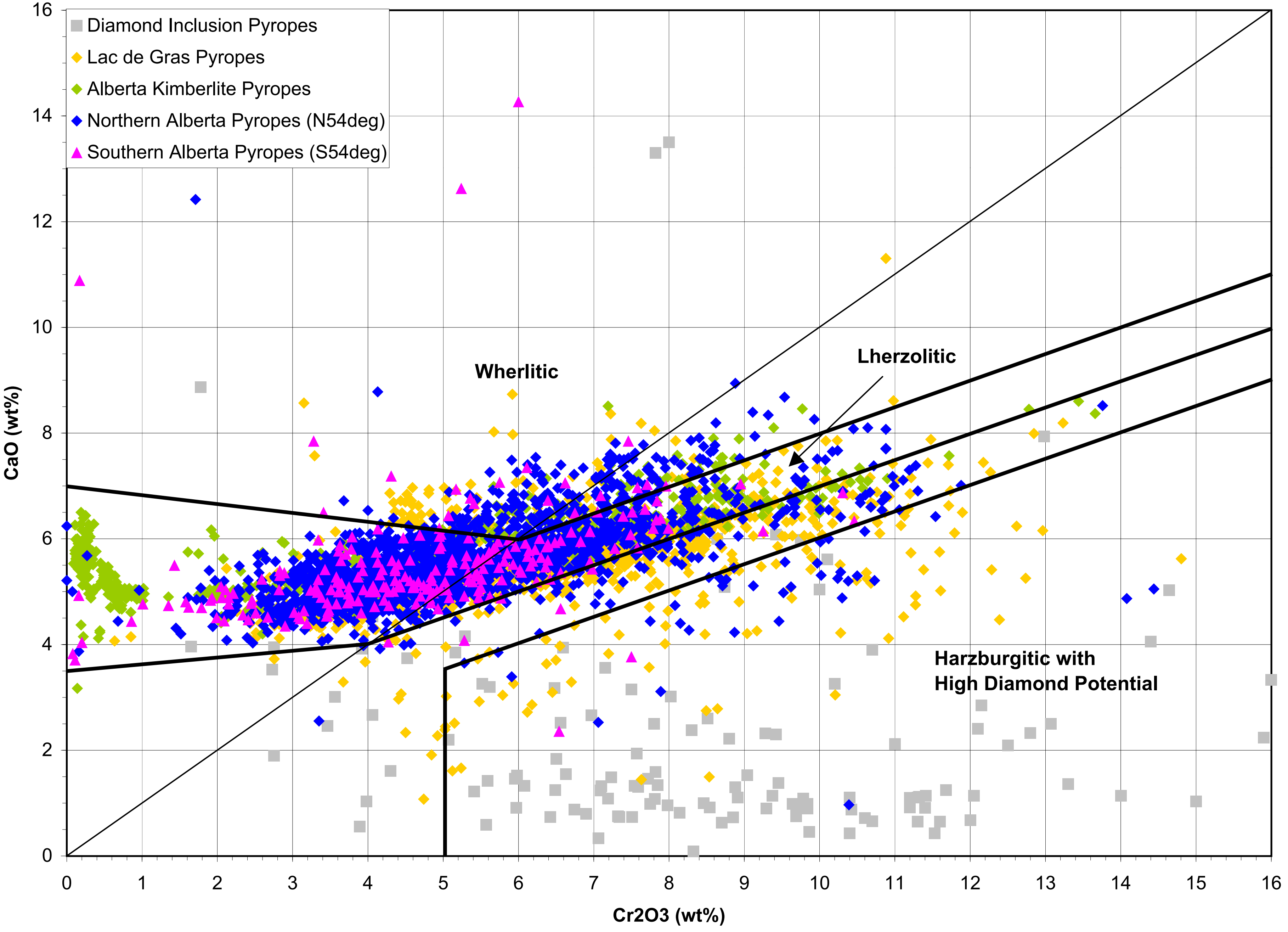
Appendix 4


Cr2O3 vs TiO2 For Peridotitic Garnets From Southern Alberta Samples: 1994 to 2001
TiO2 (wt%)
Cr2O3 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Diamond Inclusion Pyropes
Southern Alberta Pyropes (110-114deg)
Southern Alberta Pyropes (114-117deg)
Southern Alberta Pyropes (117-120deg)
Southern Alberta Megacrysts (114-117deg)
Southern Alberta Megacrysts (117-120deg)
Southern Alberta Megacrysts (110-114deg)

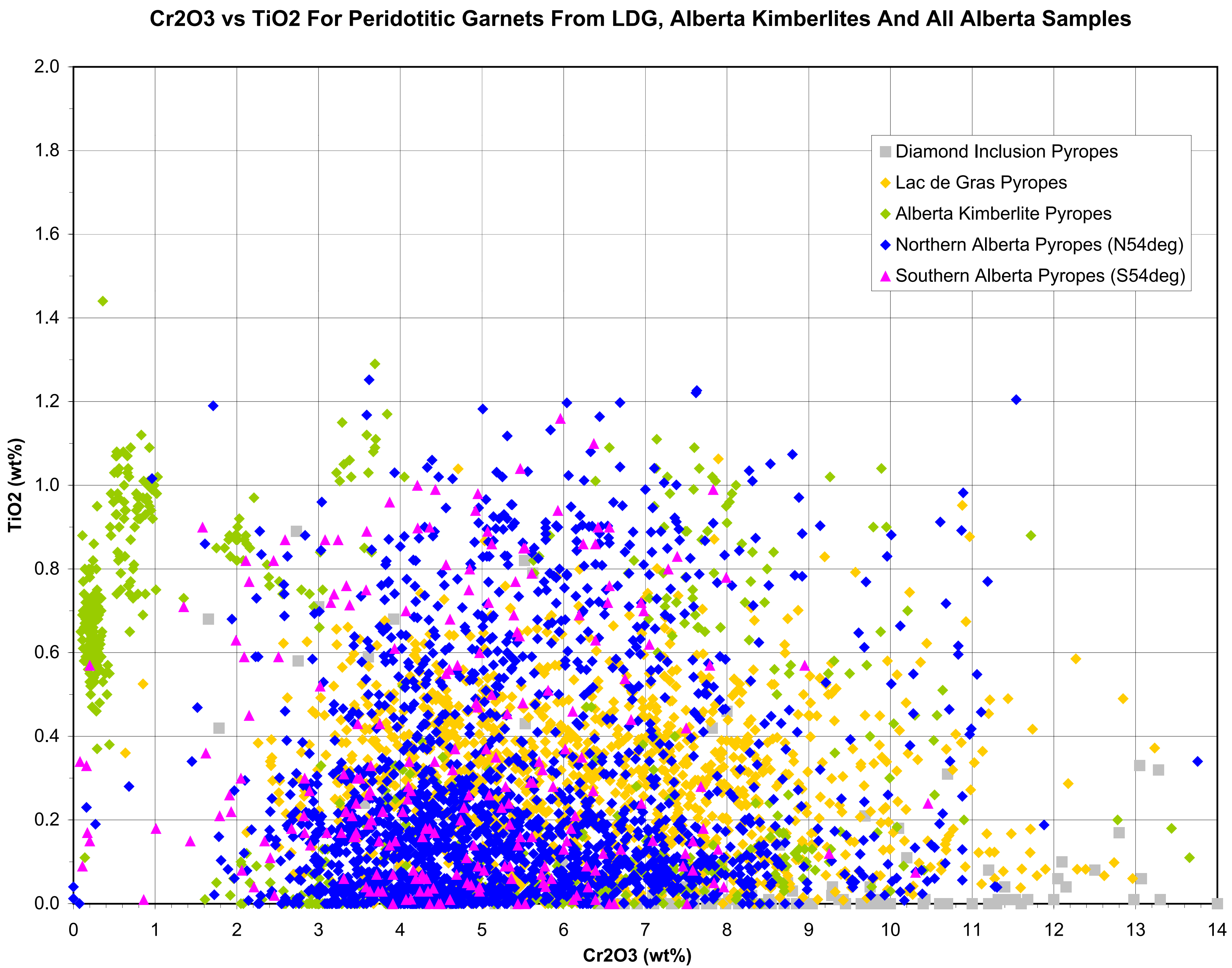
Appendix 4


CaO vs Cr2O3 For Peridotitic Garnets From LDG, Alberta Kimberlites And All Alberta Samples
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
Cr2O3 (wt%)
CaO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Diamond inclusion Pyropes
Lac de Gras Pyropes
Alberta Kimberlite Pyropes
Northern Alberta Pyropes (N54deg)
Southern Alberta Pyropes (S54deg)

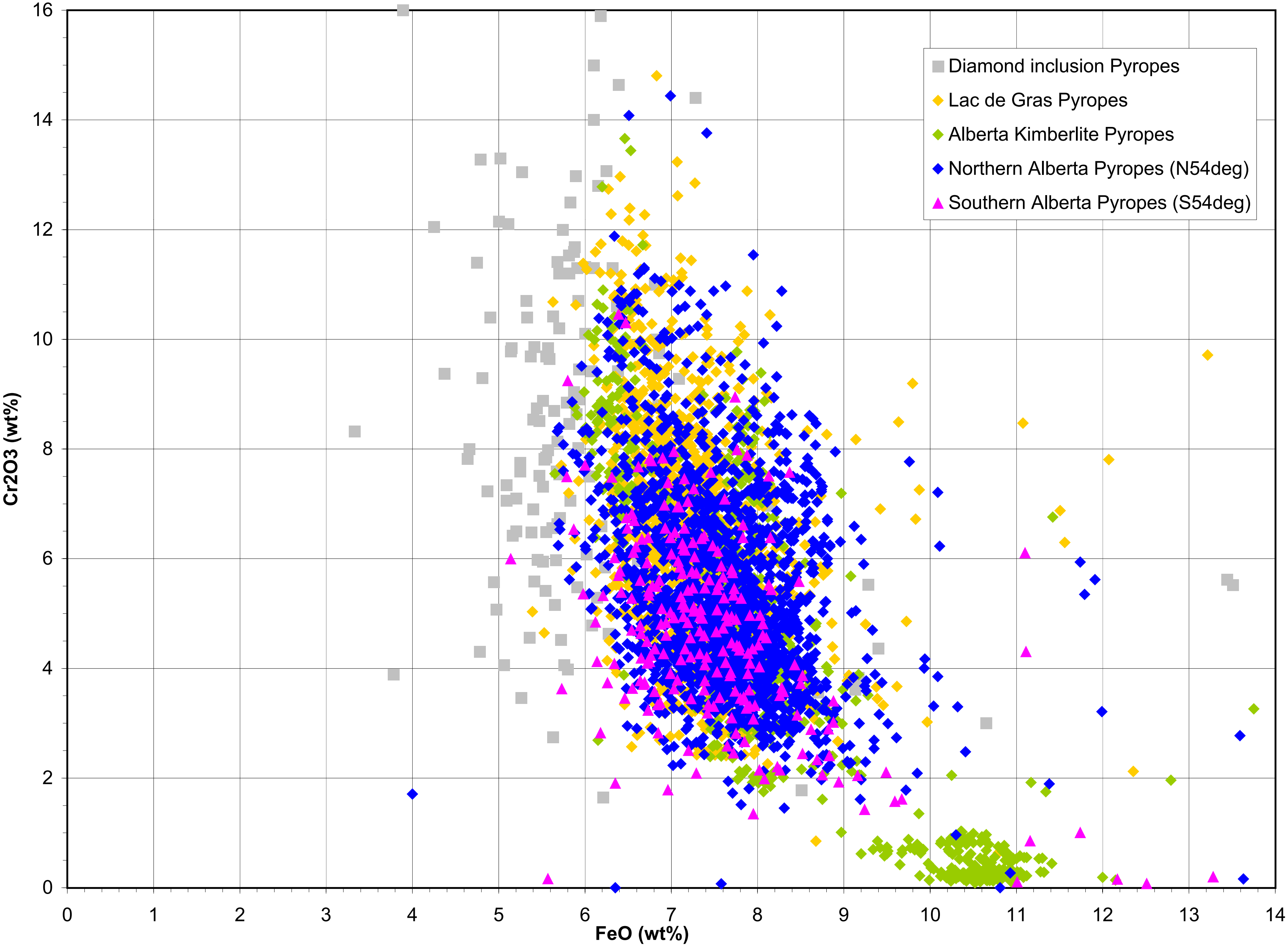
Cr2O3 vs CaO For Peridotitic Garnets From LDG, Alberta Kimberlites And All Alberta Samples



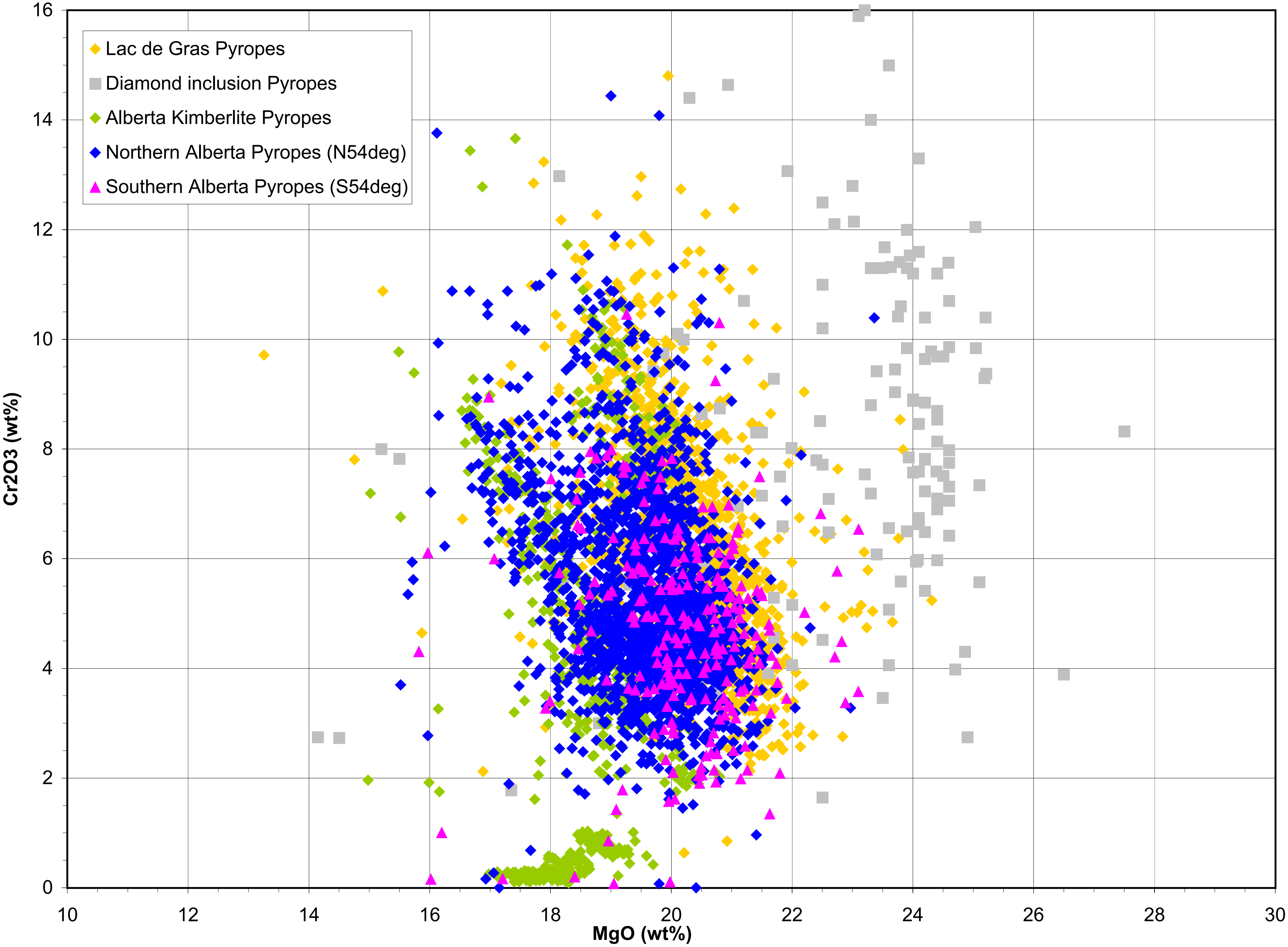
Appendix 4


Cr2O3 vs TiO2 For Peridotitic Garnets From LDG, Alberta Kimberlites And All Alberta Samples
TiO2 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Cr2O3 (wt%)
■ Diamond Inclusion Pyropes
◆ Lac de Gras Pyropes
◆ Alberta Kimberlite Pyropes
◆ Northern Alberta Pyropes (N54deg)
▲ Southern Alberta Pyropes (S54deg)

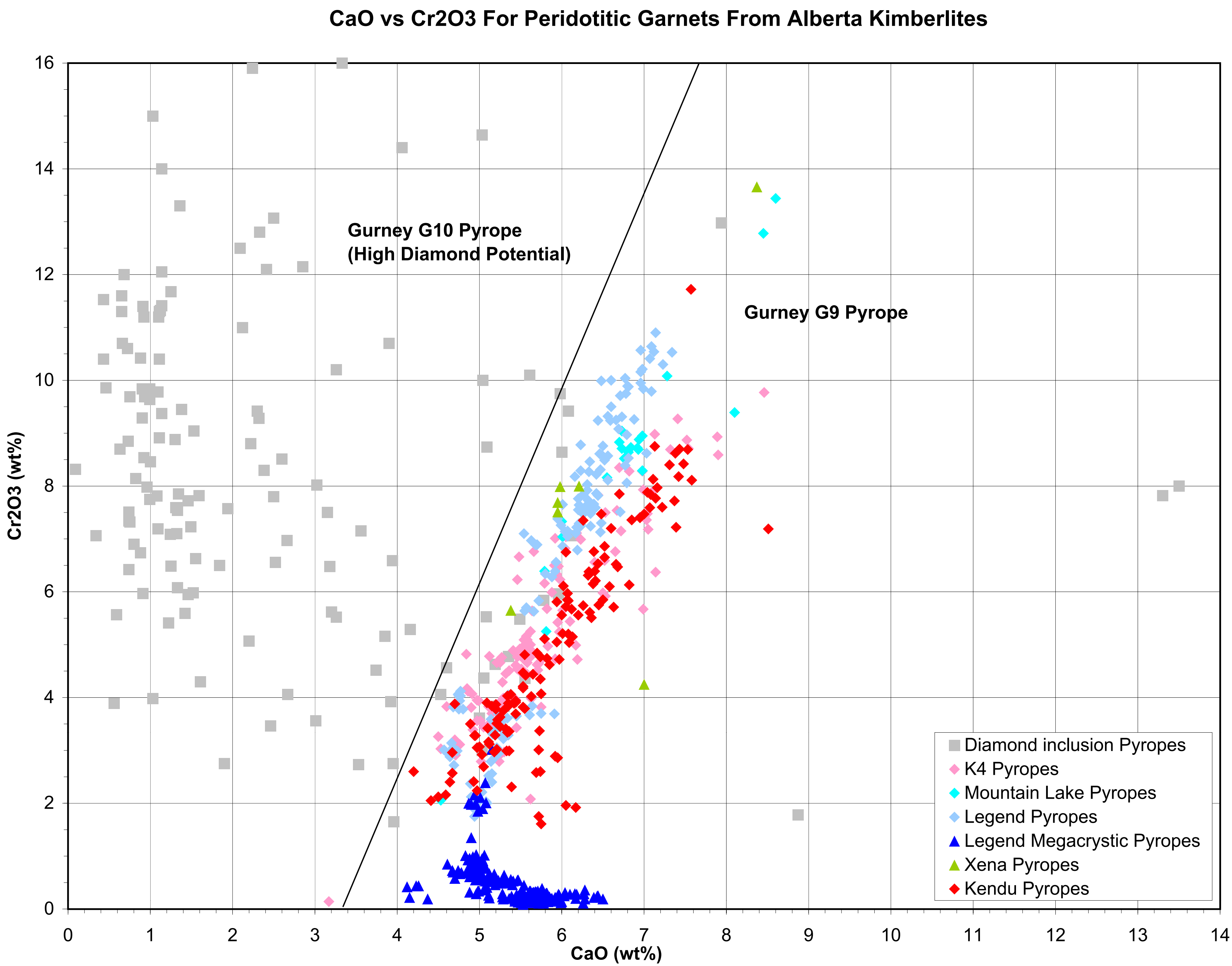
Total Fe vs Cr2O3 For Peridotitic Garnets From LDG, Alberta Kimberlites And All Alberta Samples



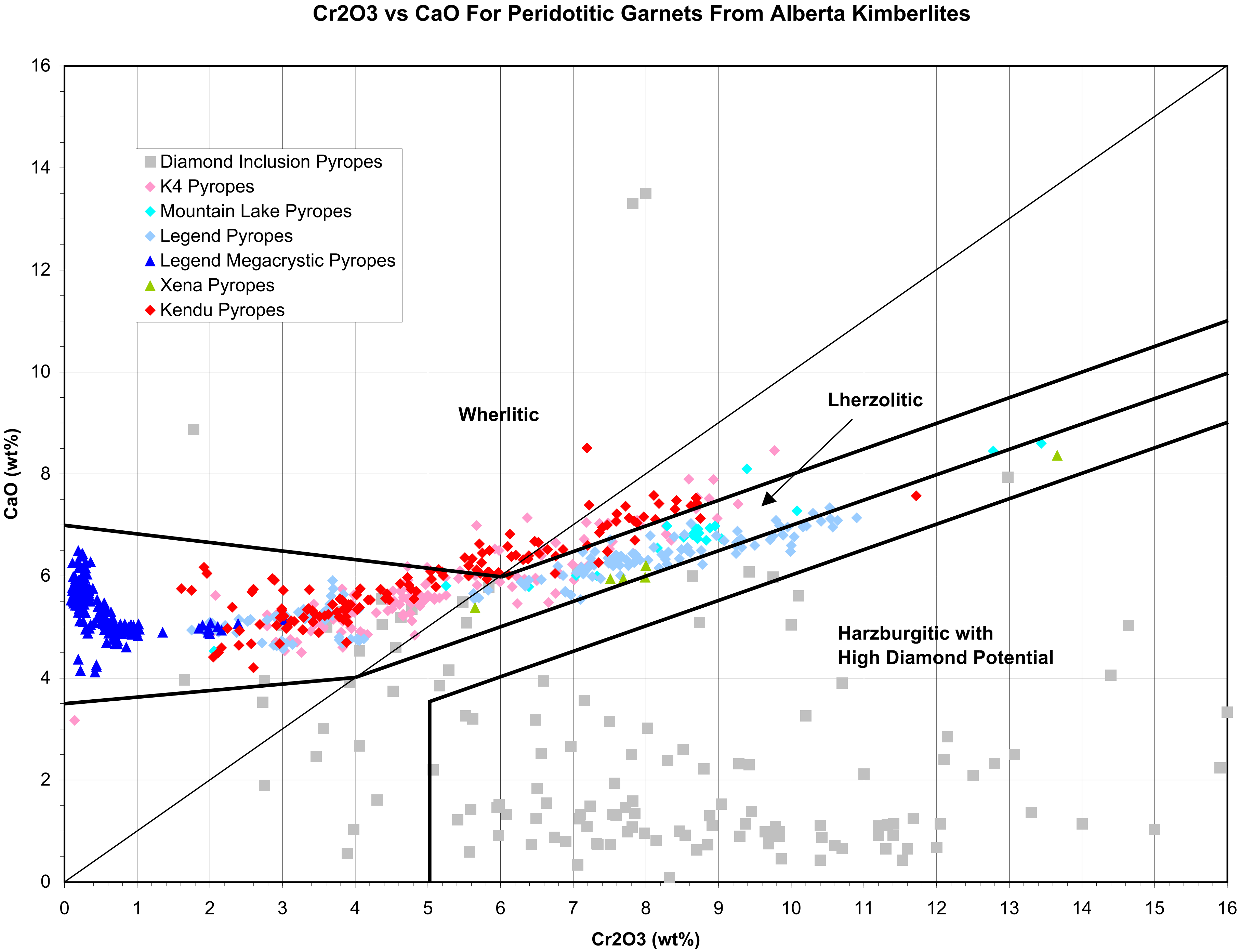
MgO vs Cr2O3 For Peridotitic Garnets From LDG, Alberta Kimberlites And All Alberta Samples



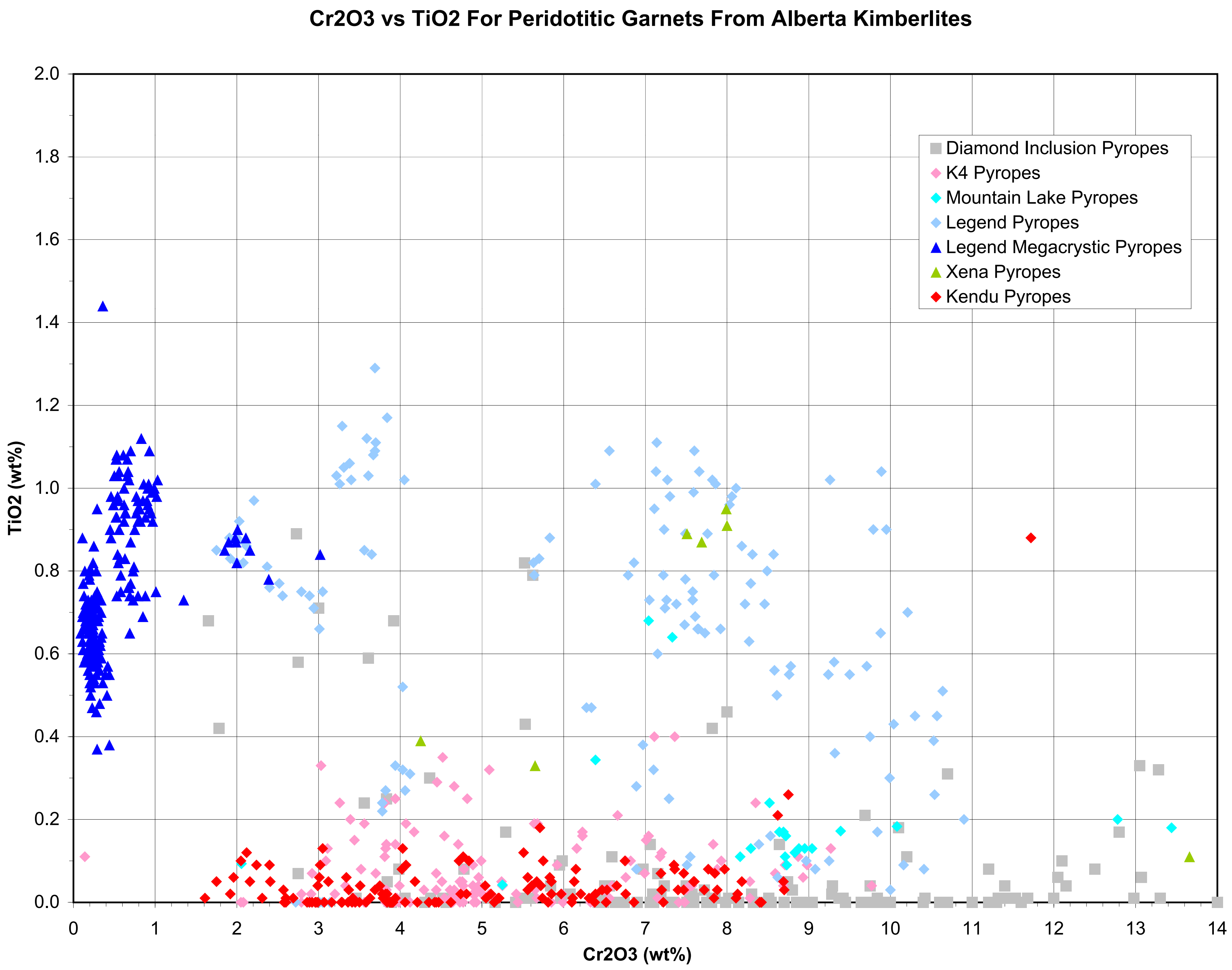
Appendix 4


CaO vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
Cr2O3 (wt%)
16
14
12
10
8
6
4
2
0
CaO (wt%)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Diamond inclusion Pyropes
K4 Pyropes
Mountain Lake Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
Xena Pyropes
Kendu Pyropes

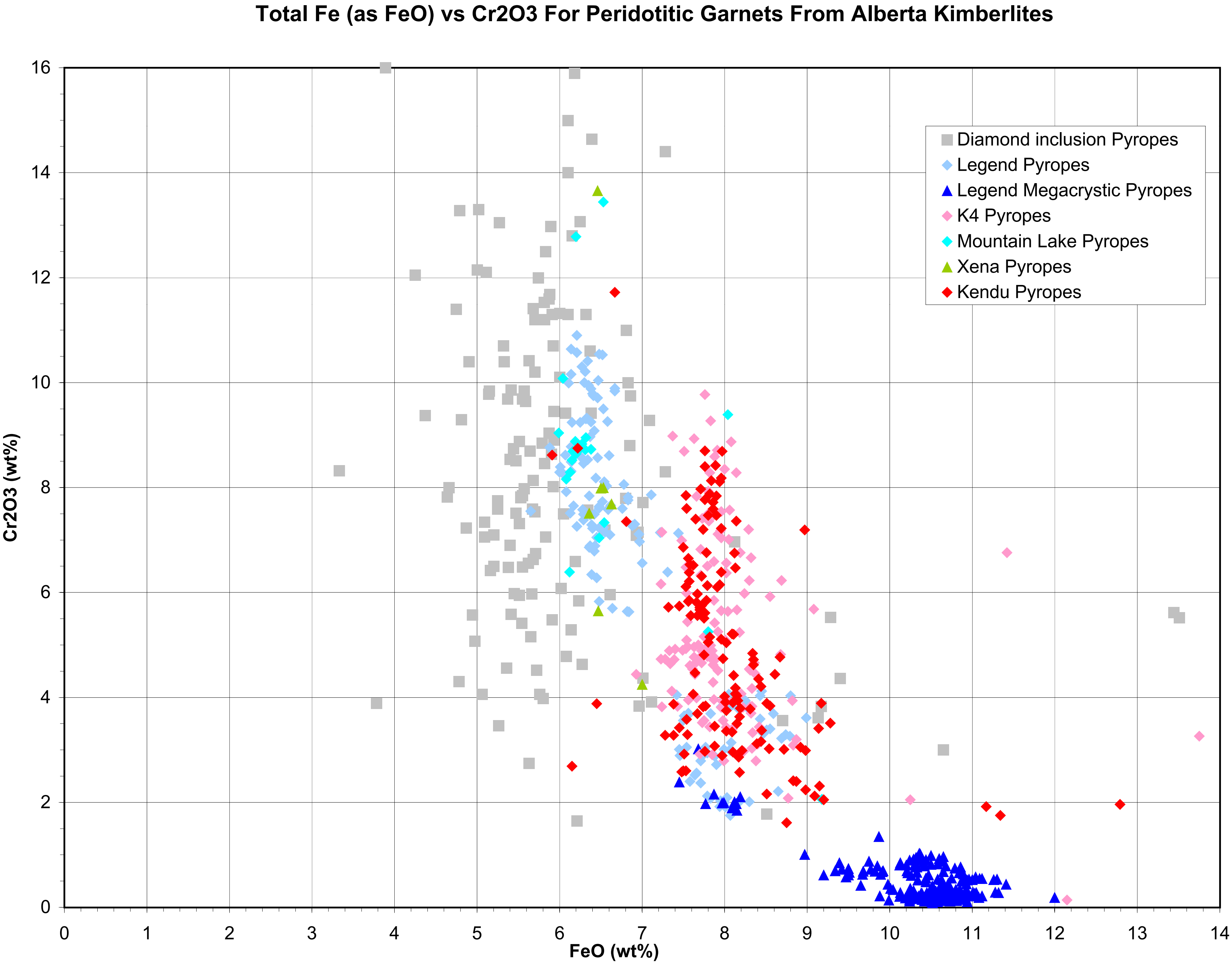
Appendix 4


Cr2O3 vs CaO For Peridotitic Garnets From Alberta Kimberlites
■ Diamond Inclusion Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
Wherlitic
Lherzolitic
Harzburgitic with
High Diamond Potential
CaO (wt%)
Cr2O3 (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Appendix 4

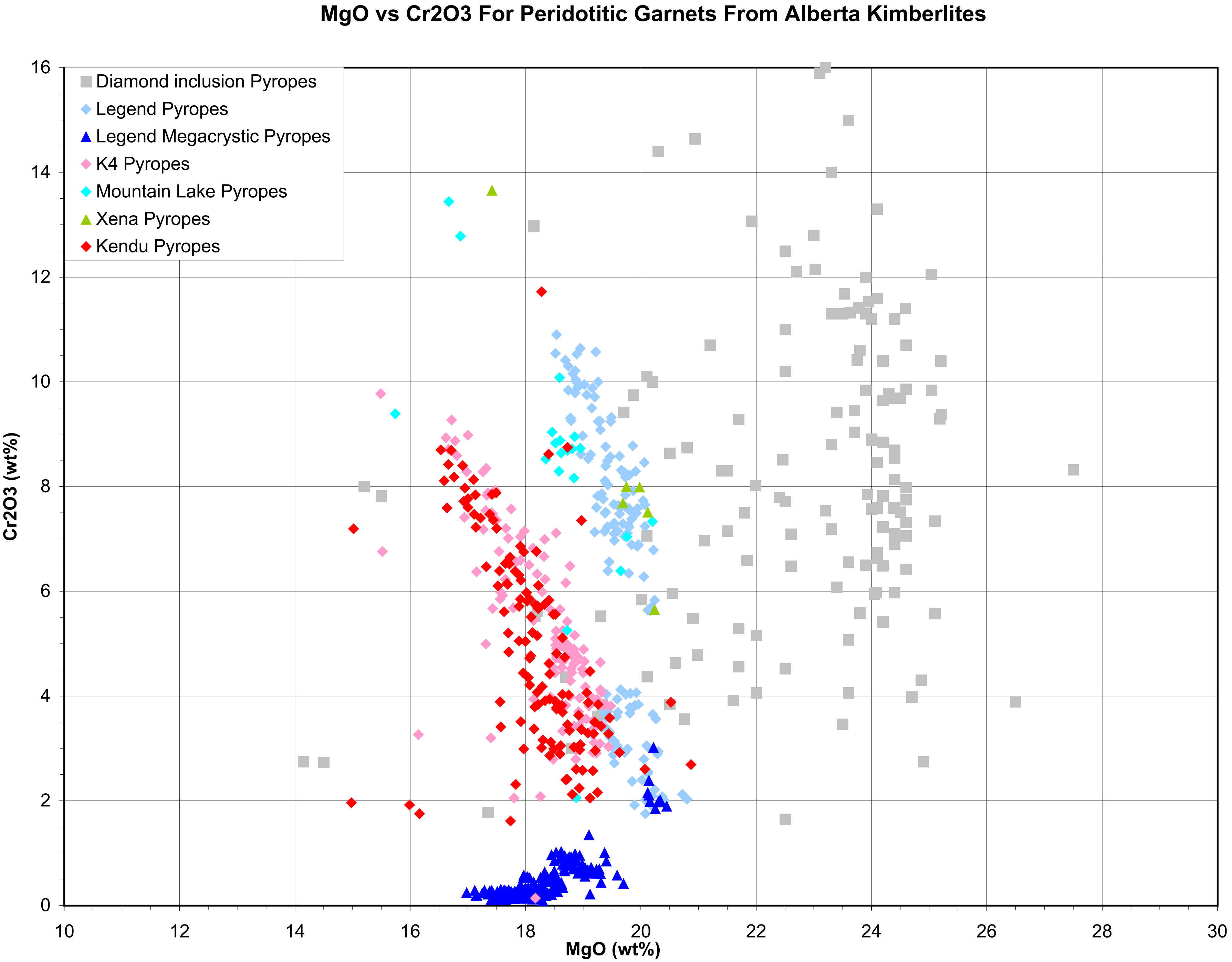

Cr2O3 vs TiO2 For Peridotitic Garnets From Alberta Kimberlites
TiO2 (wt%)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Cr2O3 (wt%)
■ Diamond Inclusion Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes

Appendix 4

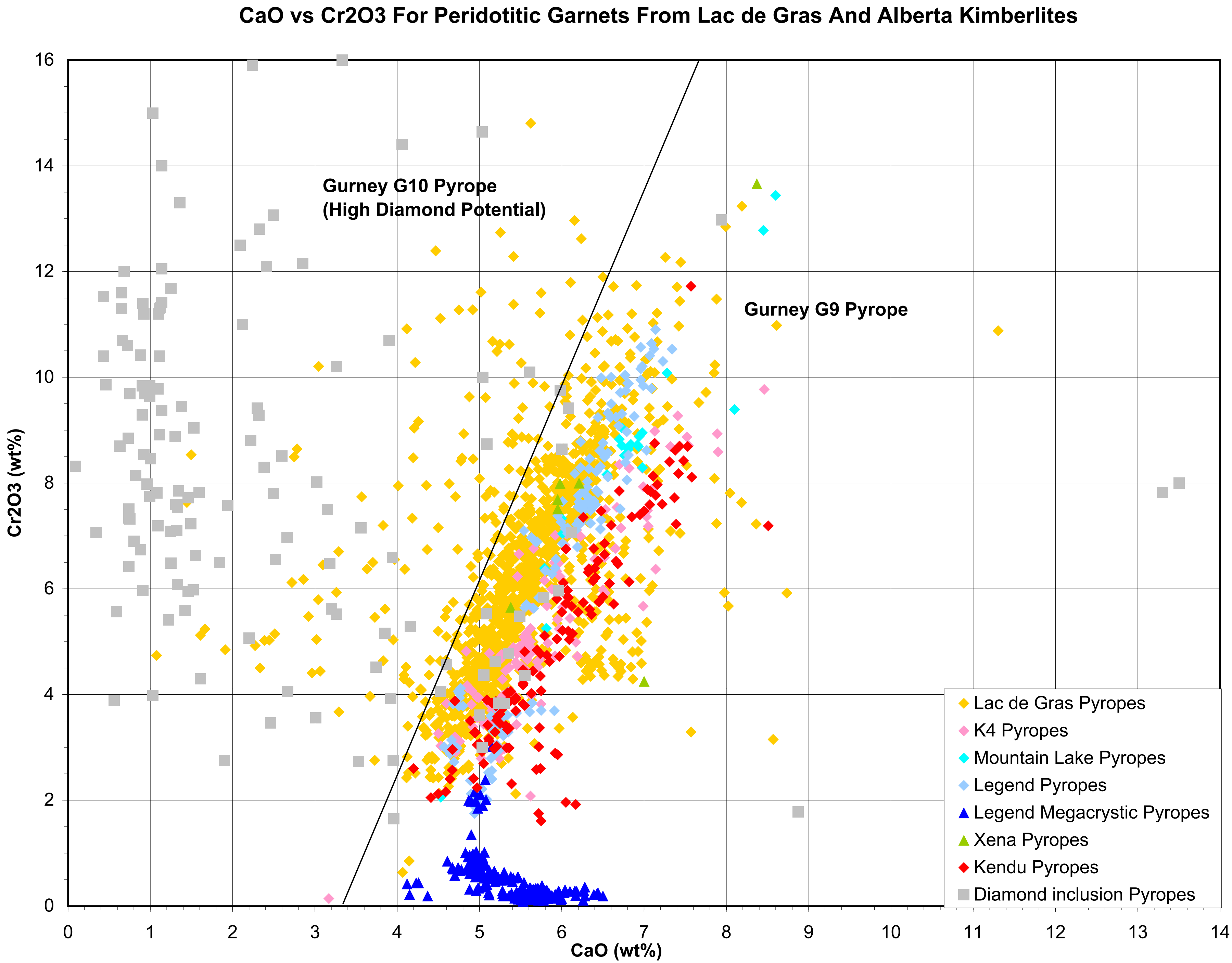


Total Fe (as FeO) vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Cr2O3 (wt%)
FeO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
■ Diamond inclusion Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes

Appendix 4

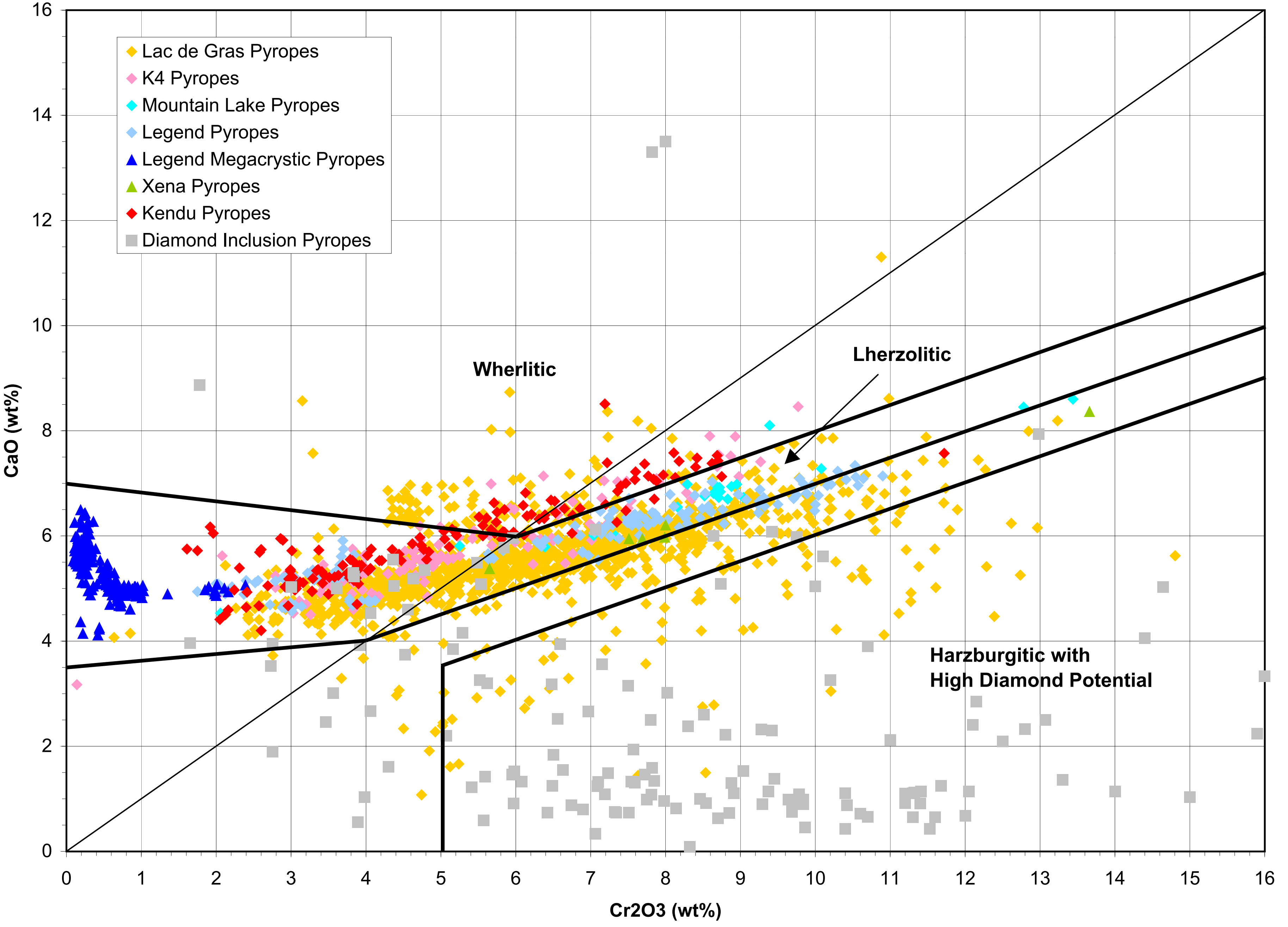

MgO vs Cr2O3 For Peridotitic Garnets From Alberta Kimberlites
Diamond inclusion Pyropes
Legend Pyropes
Legend Megacrystic Pyropes
K4 Pyropes
Mountain Lake Pyropes
Xena Pyropes
Kendu Pyropes
Cr2O3 (wt%)
16
14
12
10
8
6
4
2
0
10
12
14
16
18
20
22
24
26
28
30
MgO (wt%)

Appendix 4

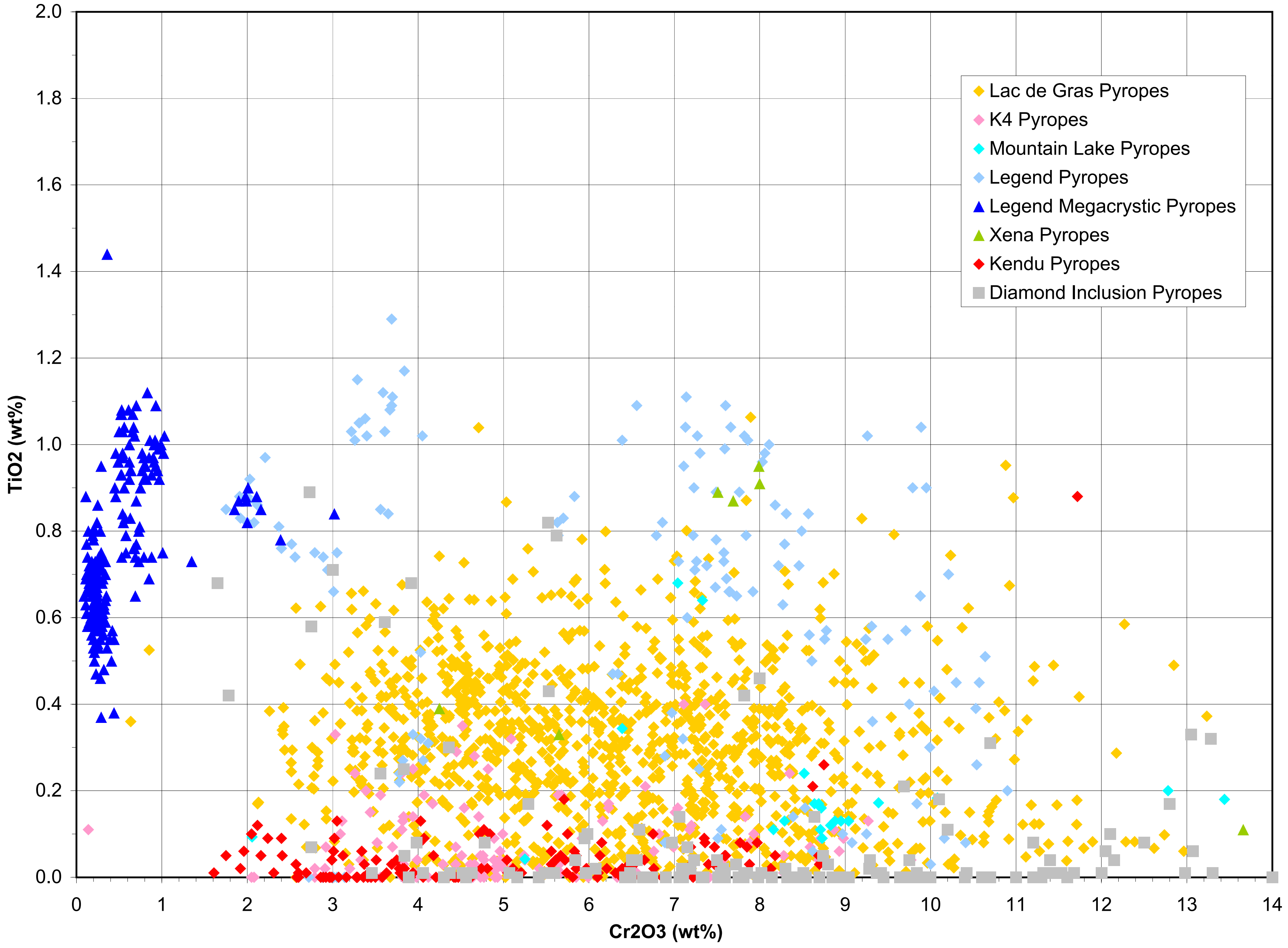

CaO vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
CaO (wt%)
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Gurney G10 Pyrope
(High Diamond Potential)
Gurney G9 Pyrope
◆ Lac de Gras Pyropes
◆ K4 Pyropes
◆ Mountain Lake Pyropes
◆ Legend Pyropes
▲ Legend Megacrystic Pyropes
▲ Xena Pyropes
◆ Kendu Pyropes
■ Diamond inclusion Pyropes

Appendix 4

Cr2O3 vs CaO For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites

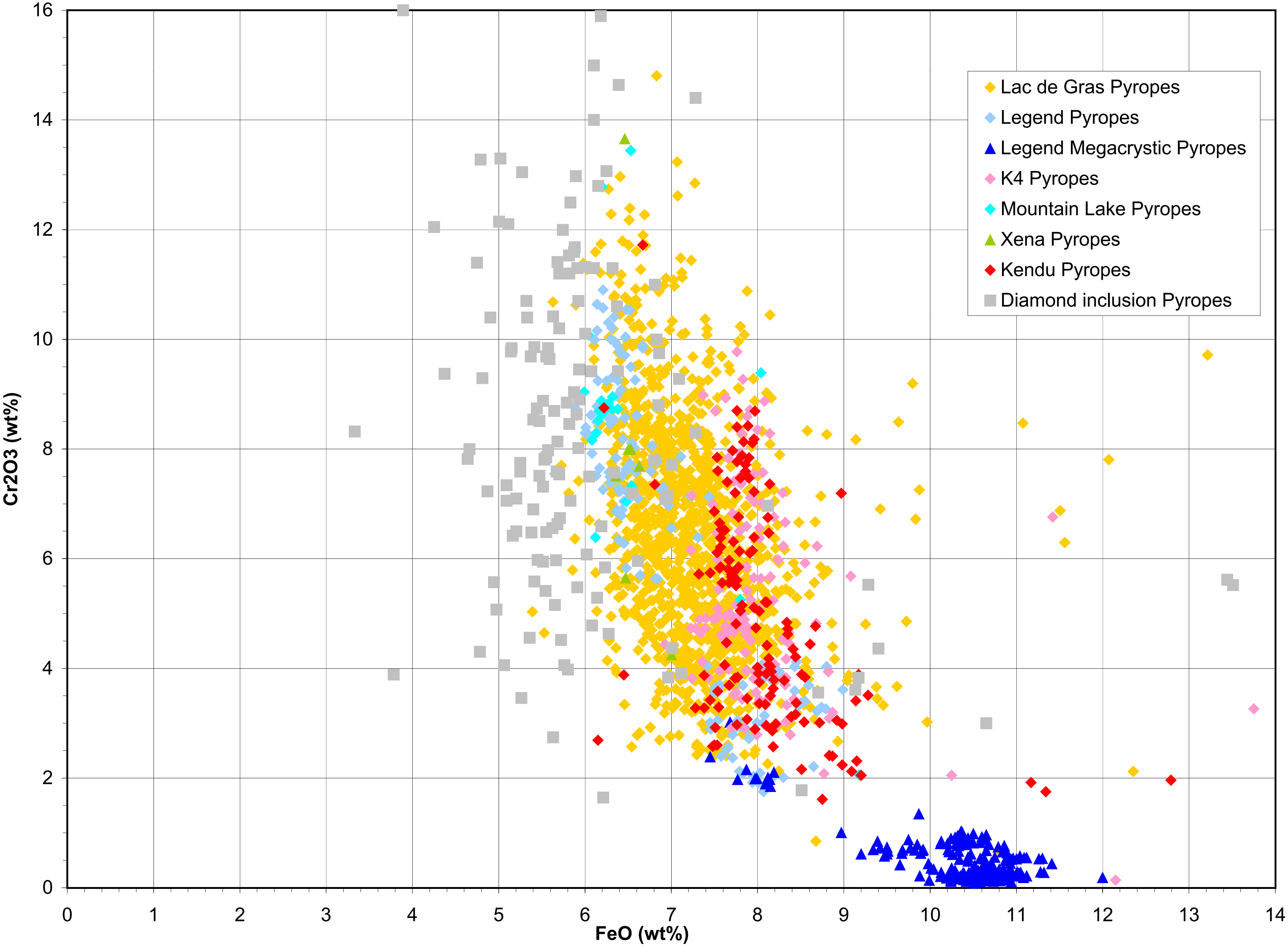


Cr2O3 vs TiO2 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites



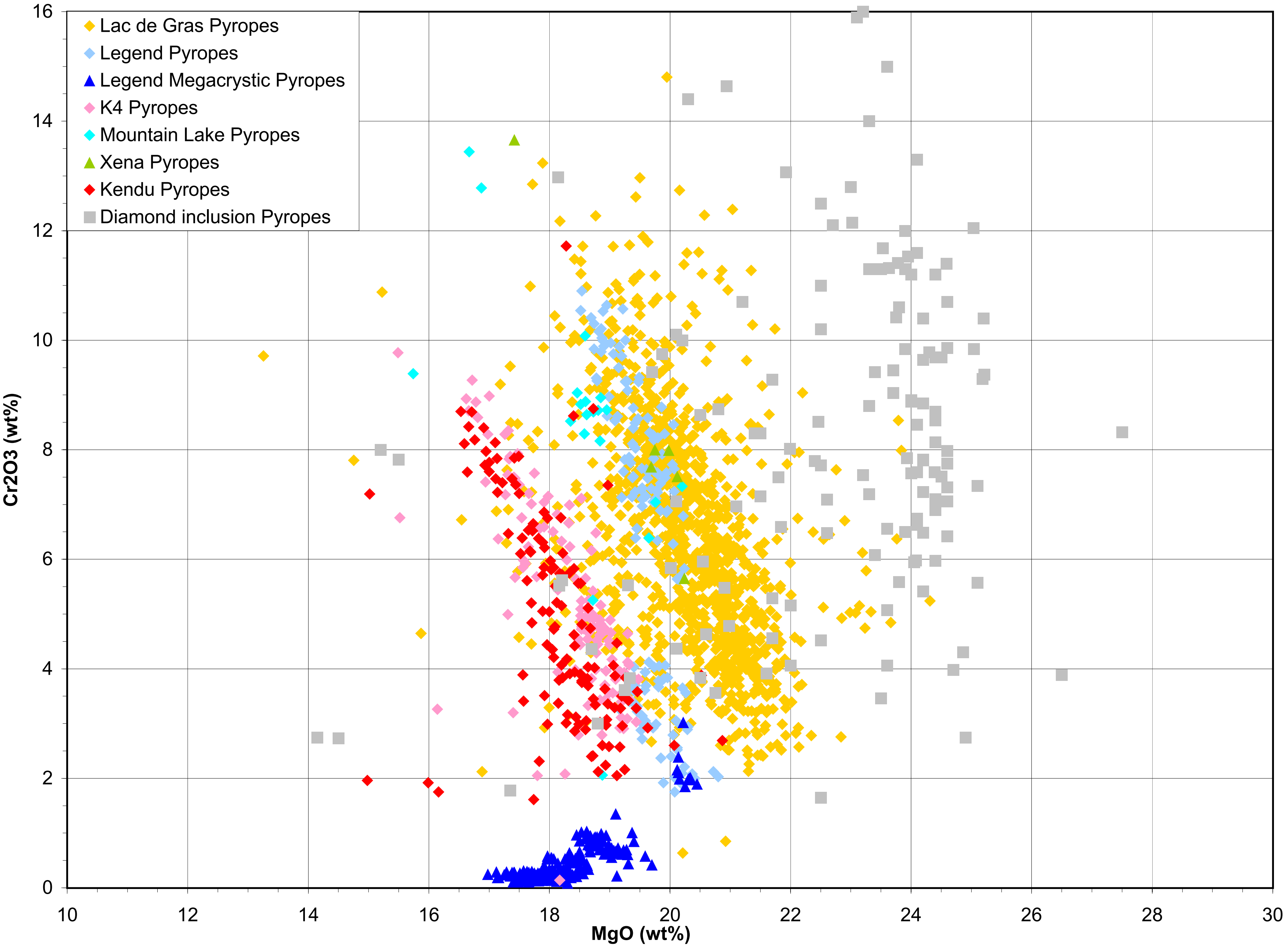
Appendix 4

Total Fe (as FeO) vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites



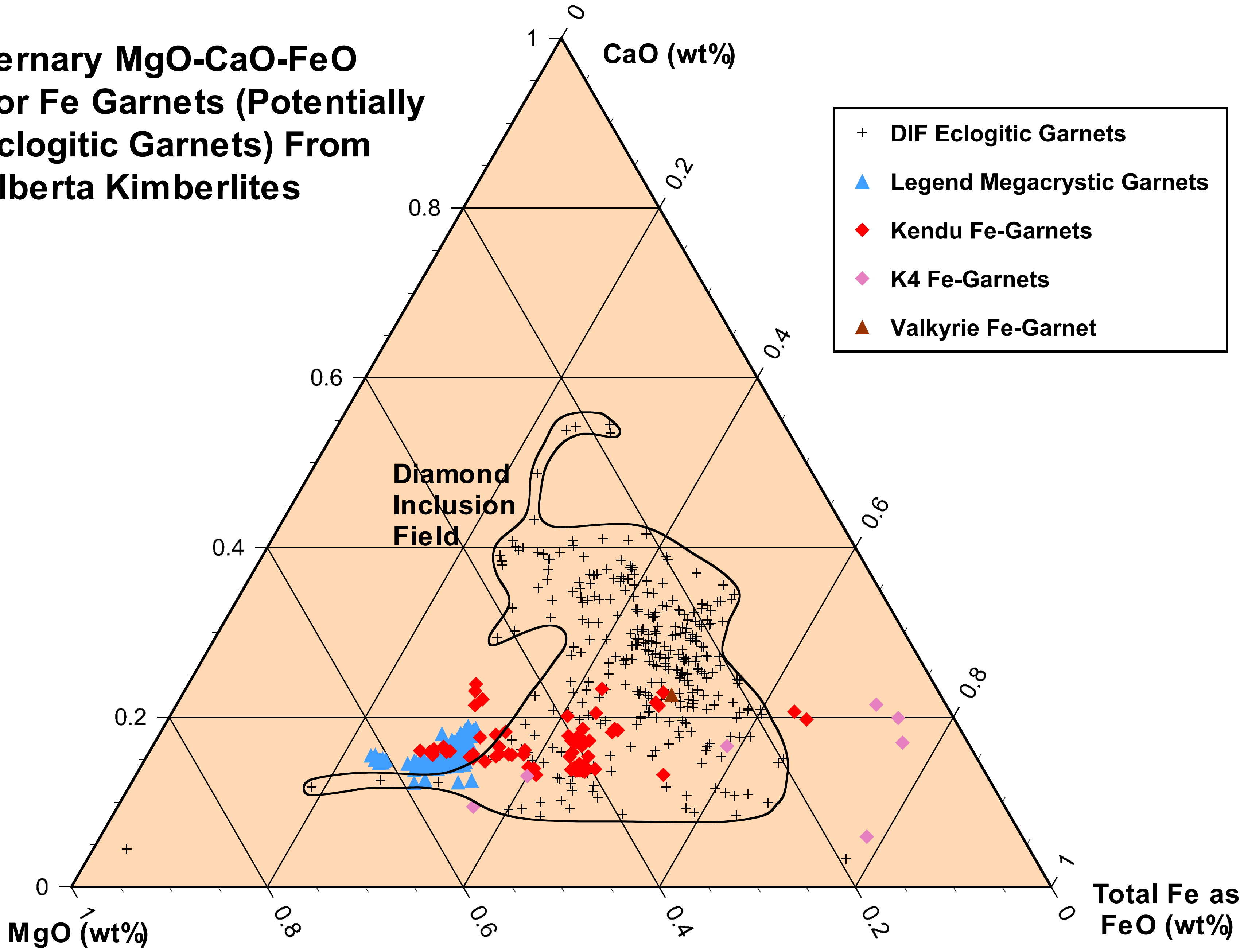
Appendix 5

MgO vs Cr2O3 For Peridotitic Garnets From Lac de Gras And Alberta Kimberlites

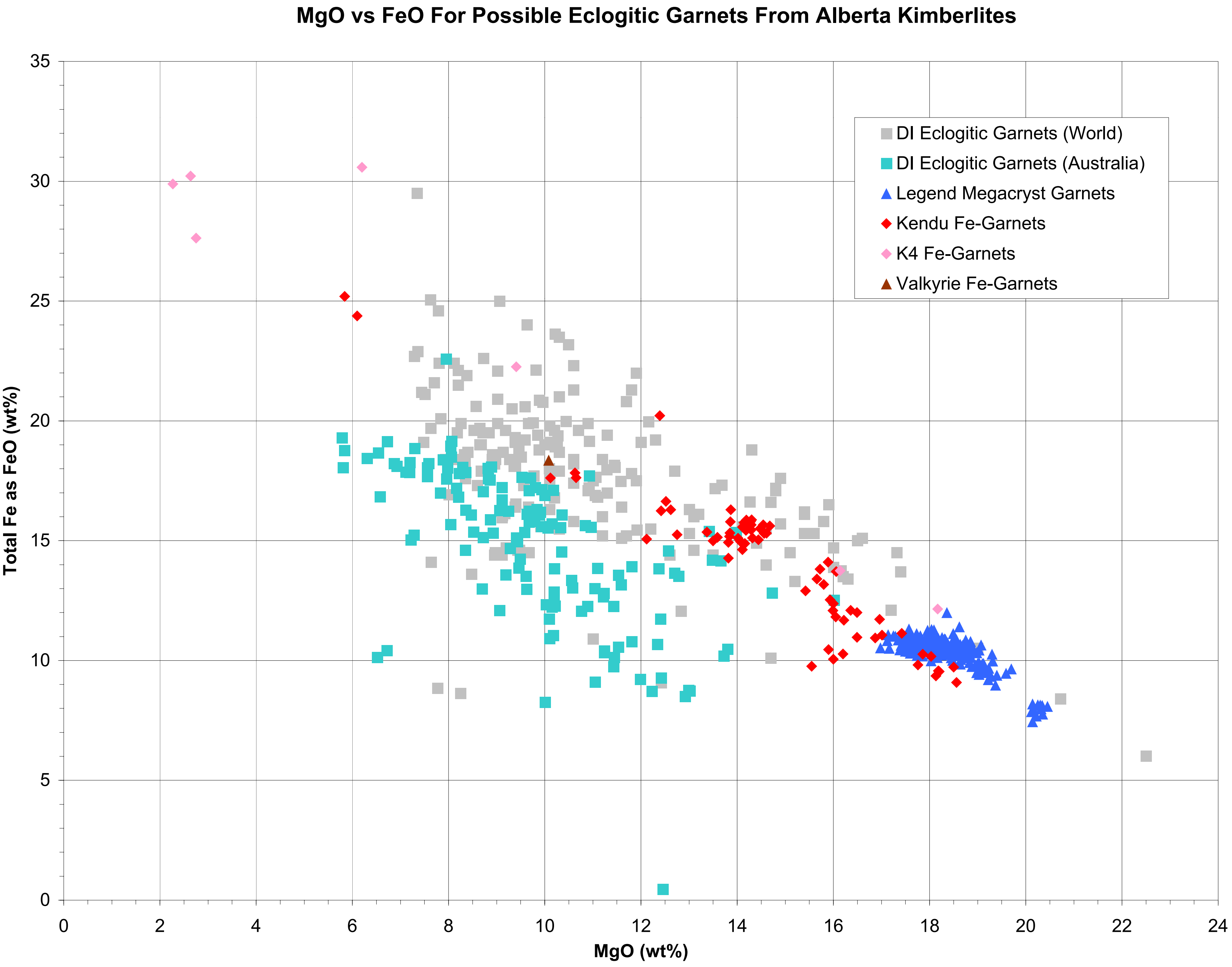


Appendix 5

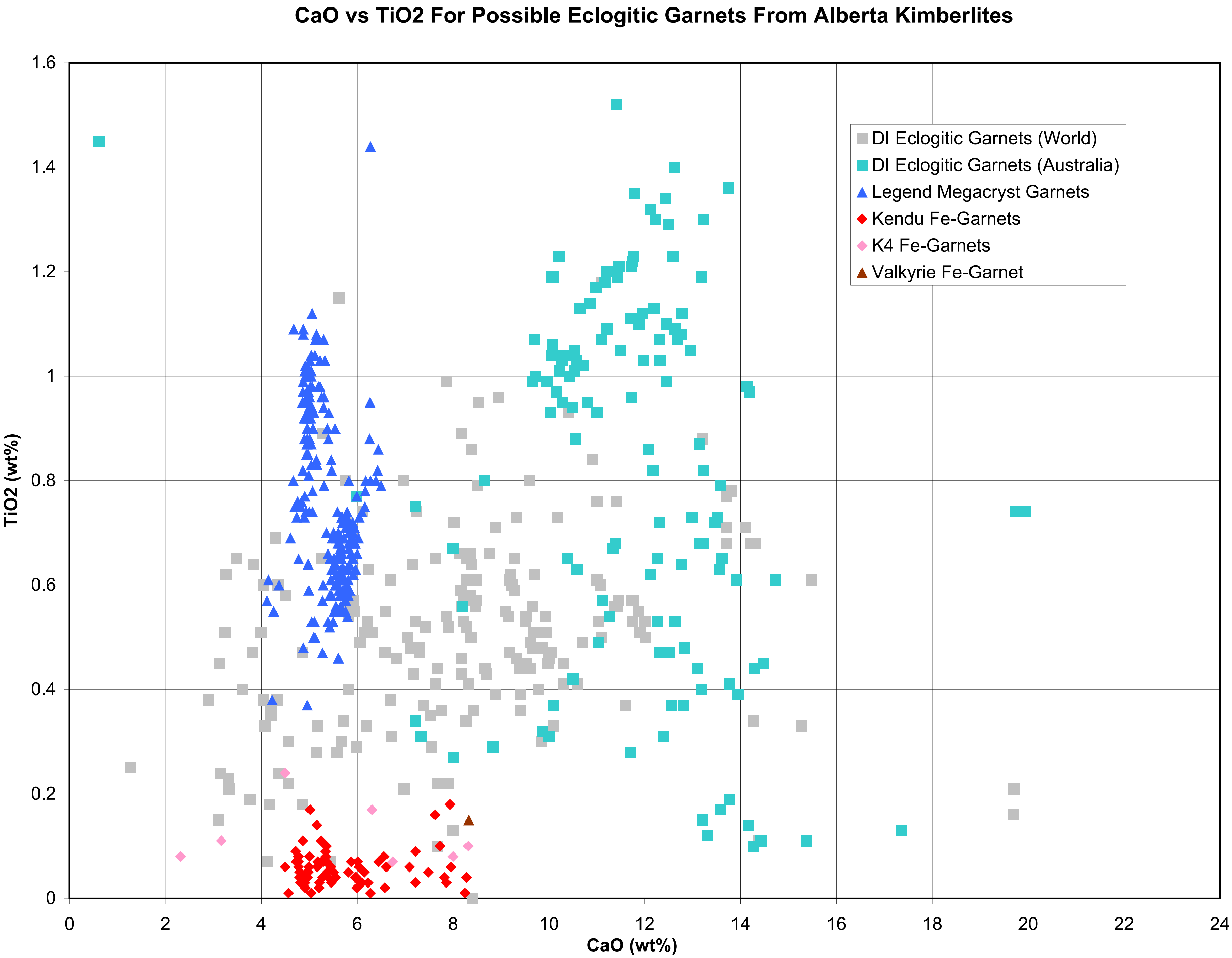
Ternary MgO-CaO-FeO For Fe Garnets (Potentially Eclogitic Garnets) From Alberta Kimberlites



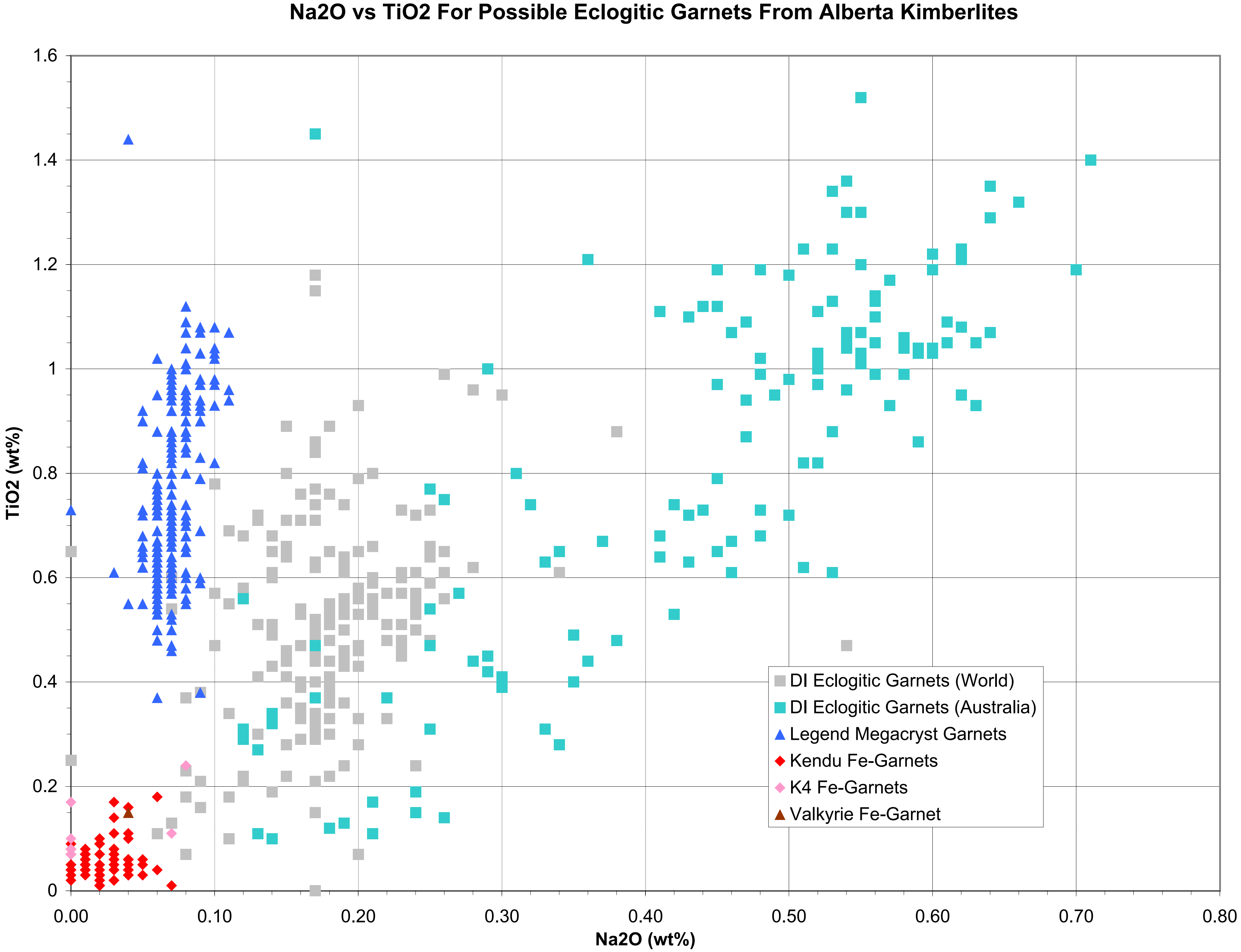
Appendix 5


MgO vs FeO For Possible Eclogitic Garnets From Alberta Kimberlites
Total Fe as FeO (wt%)
MgO (wt%)
0
5
10
15
20
25
30
35
0
2
4
6
8
10
12
14
16
18
20
22
24
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Legend Megacryst Garnets
Kendu Fe-Garnets
K4 Fe-Garnets
Valkyrie Fe-Garnets

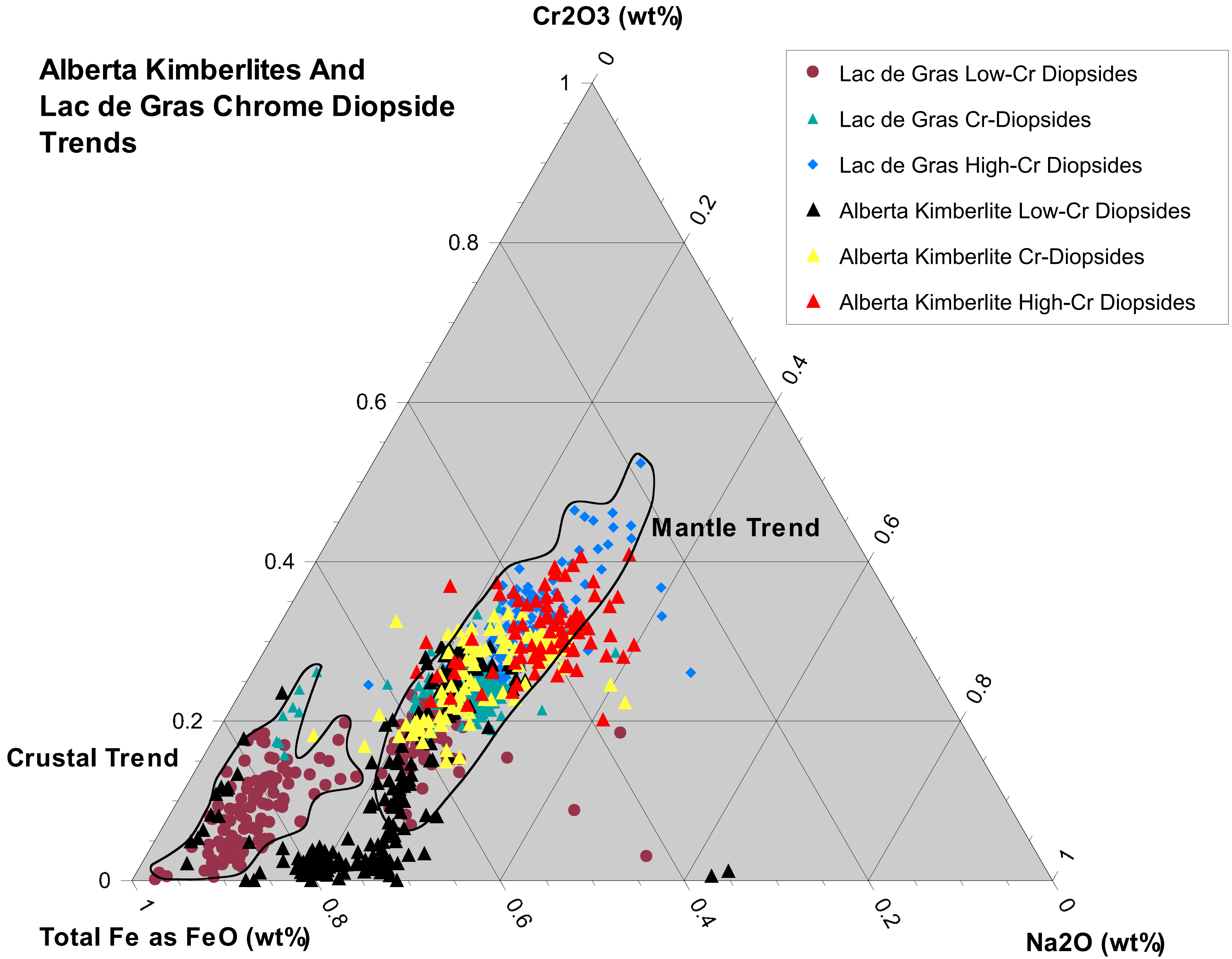
Appendix 5


CaO vs TiO2 For Possible Eclogitic Garnets From Alberta Kimberlites
TiO2 (wt%)
CaO (wt%)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
2
4
6
8
10
12
14
16
18
20
22
24
■ DI Eclogitic Garnets (World)
■ DI Eclogitic Garnets (Australia)
▲ Legend Megacryst Garnets
◆ Kendu Fe-Garnets
◆ K4 Fe-Garnets
▲ Valkyrie Fe-Garnet

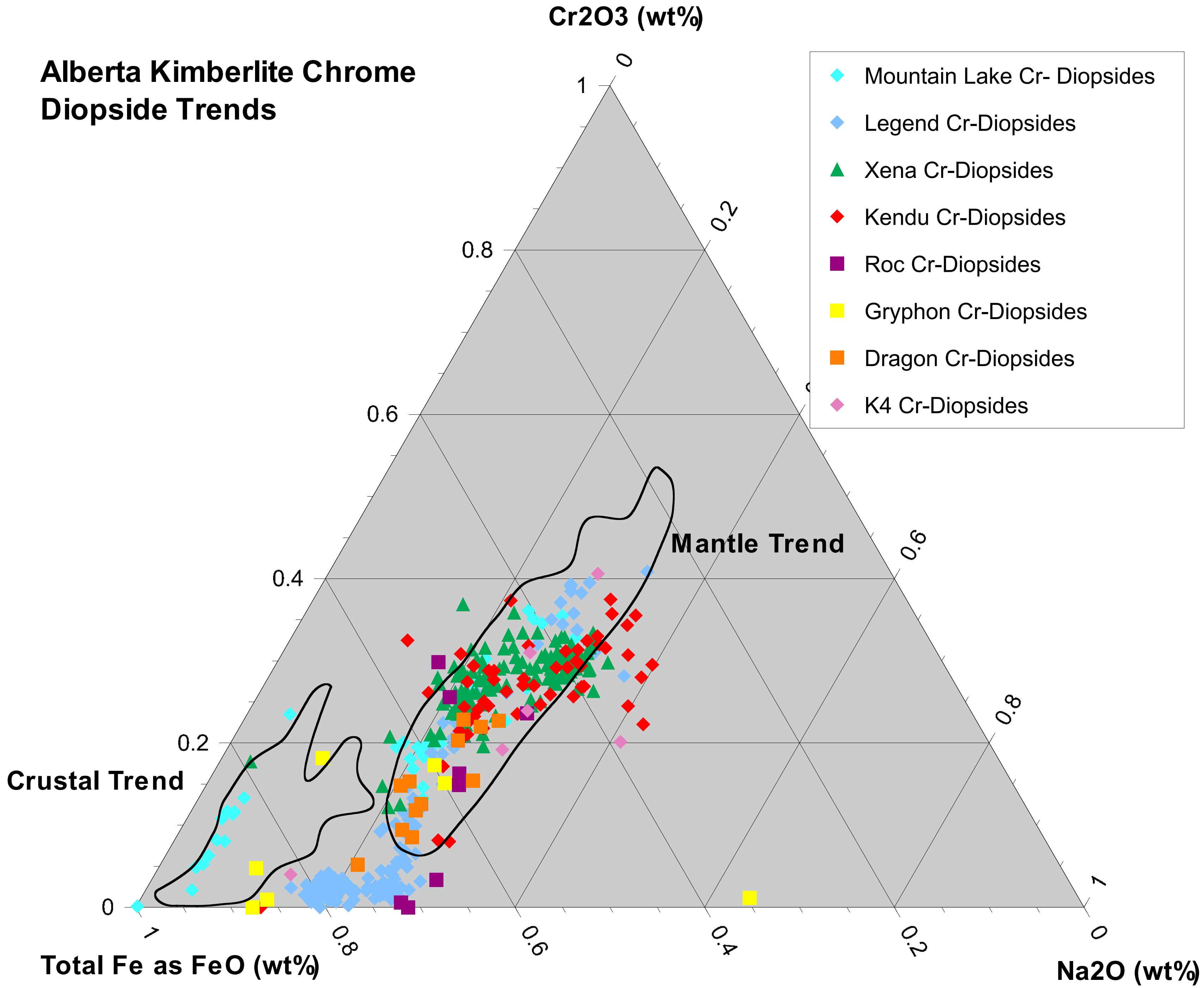
Appendix 5


Na2O vs TiO2 For Possible Eclogitic Garnets From Alberta Kimberlites
TiO2 (wt%)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Na2O (wt%)
DI Eclogitic Garnets (World)
DI Eclogitic Garnets (Australia)
Legend Megacryst Garnets
Kendu Fe-Garnets
K4 Fe-Garnets
Valkyrie Fe-Garnet

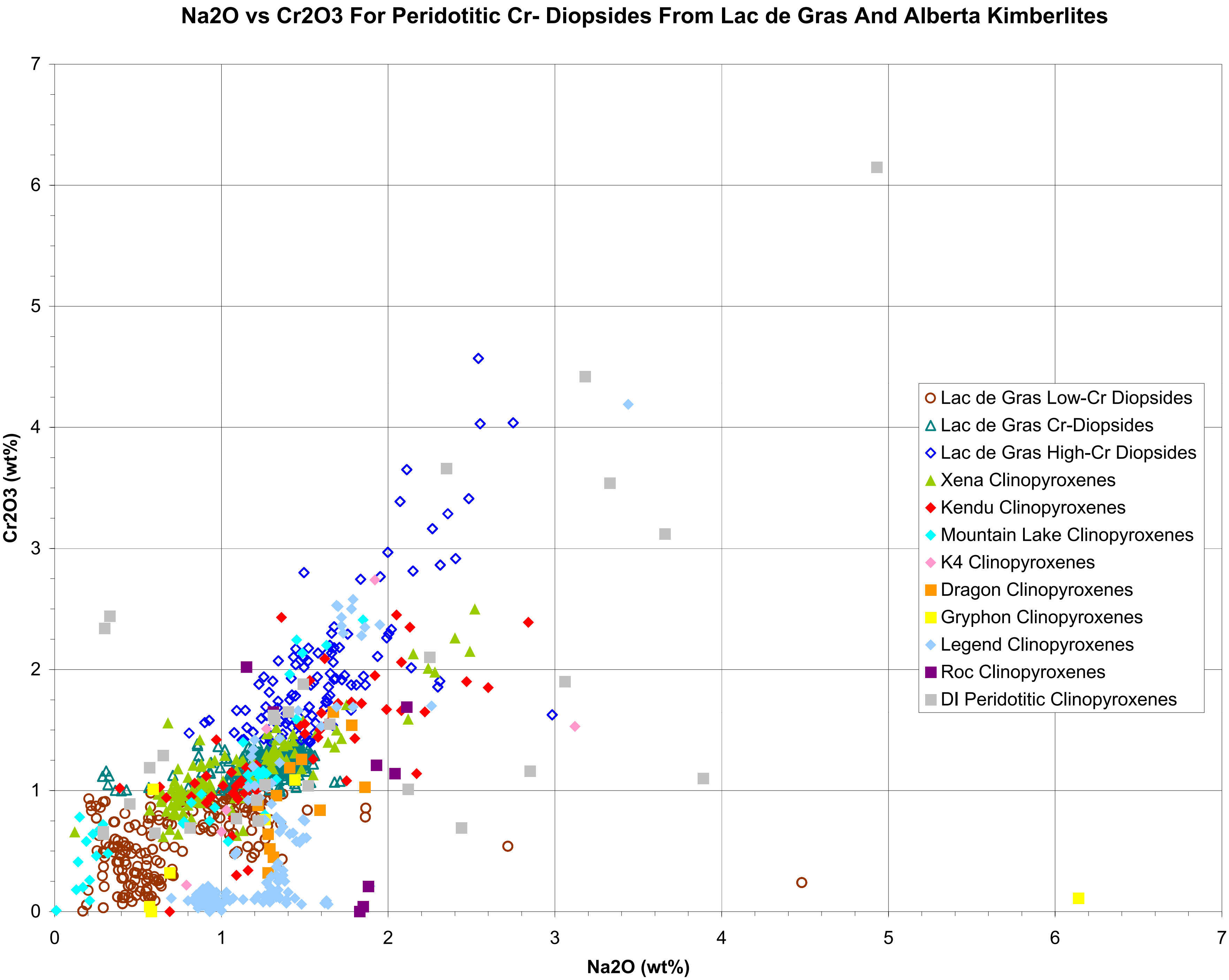
Appendix 5


Alberta Kimberlites And Lac de Gras Chrome Diopside Trends

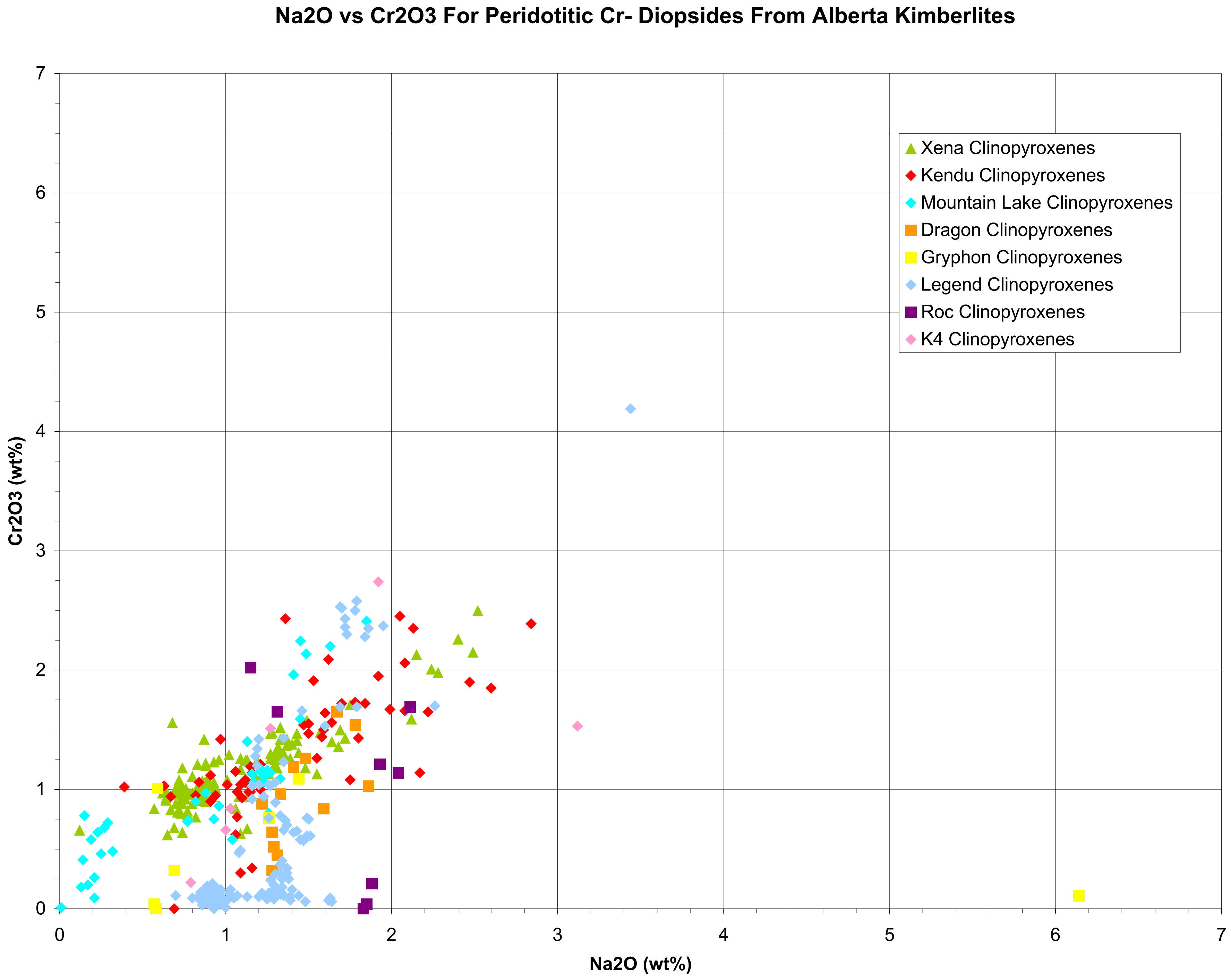
Appendix 5


Alberta Kimberlite Chrome Diopside Trends
Cr2O3 (wt%)
Total Fe as FeO (wt%)
Na2O (wt%)
Crustal Trend
Mantle Trend
0
0.2
0.4
0.6
0.8
1
Mountain Lake Cr- Diopsides
Legend Cr-Diopsides
Xena Cr-Diopsides
Kendu Cr-Diopsides
Roc Cr-Diopsides
Gryphon Cr-Diopsides
Dragon Cr-Diopsides
K4 Cr-Diopsides

Appendix 5

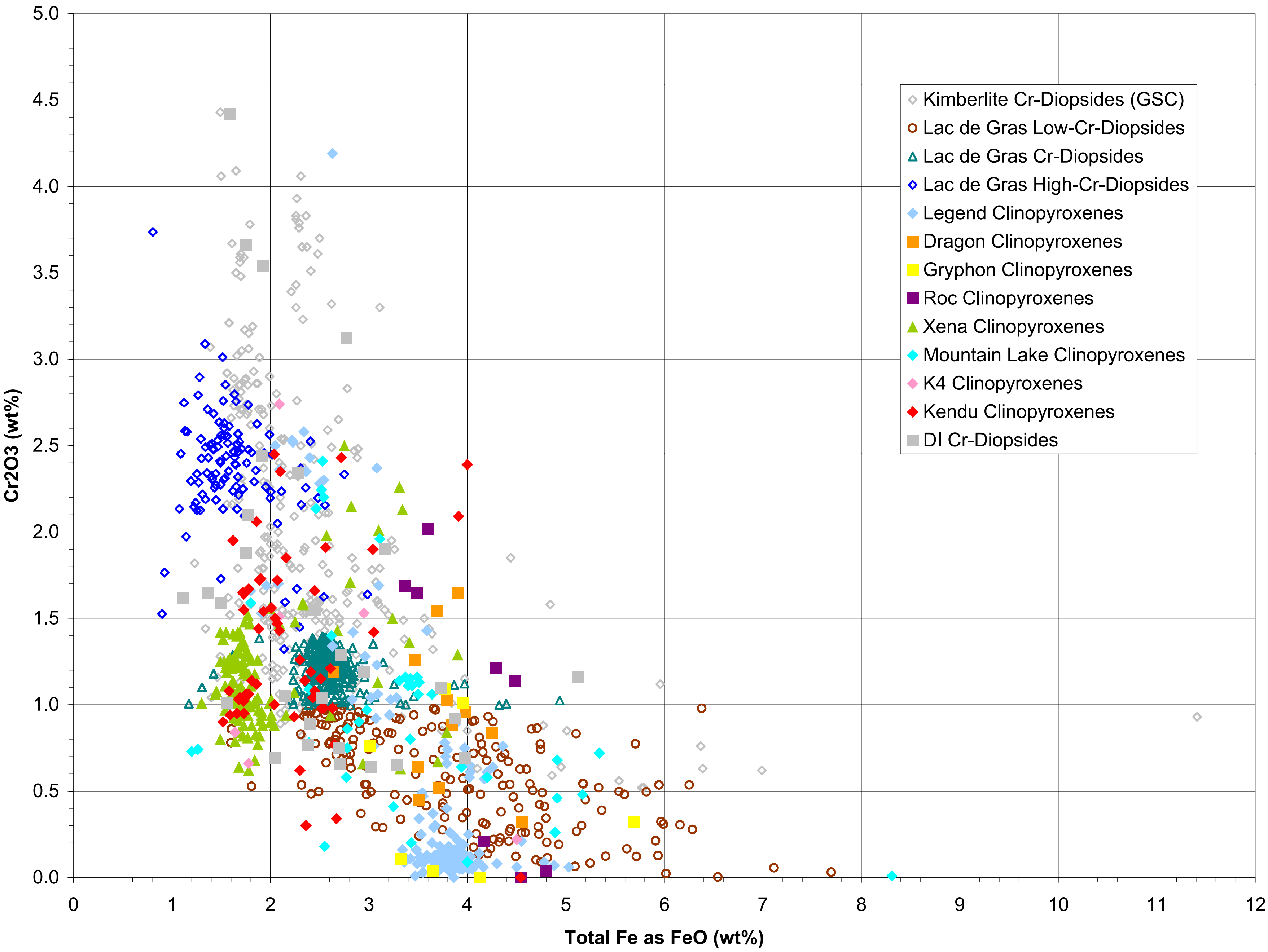

Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
Lac de Gras Low-Cr Diopsides
Lac de Gras Cr-Diopsides
Lac de Gras High-Cr Diopsides
Xena Clinopyroxenes
Kendu Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
DI Peridotitic Clinopyroxenes

Appendix 5


Na2O vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Cr2O3 (wt%)
Na2O (wt%)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
▲ Xena Clinopyroxenes
◆ Kendu Clinopyroxenes
◆ Mountain Lake Clinopyroxenes
■ Dragon Clinopyroxenes
■ Gryphon Clinopyroxenes
◆ Legend Clinopyroxenes
■ Roc Clinopyroxenes
◆ K4 Clinopyroxenes

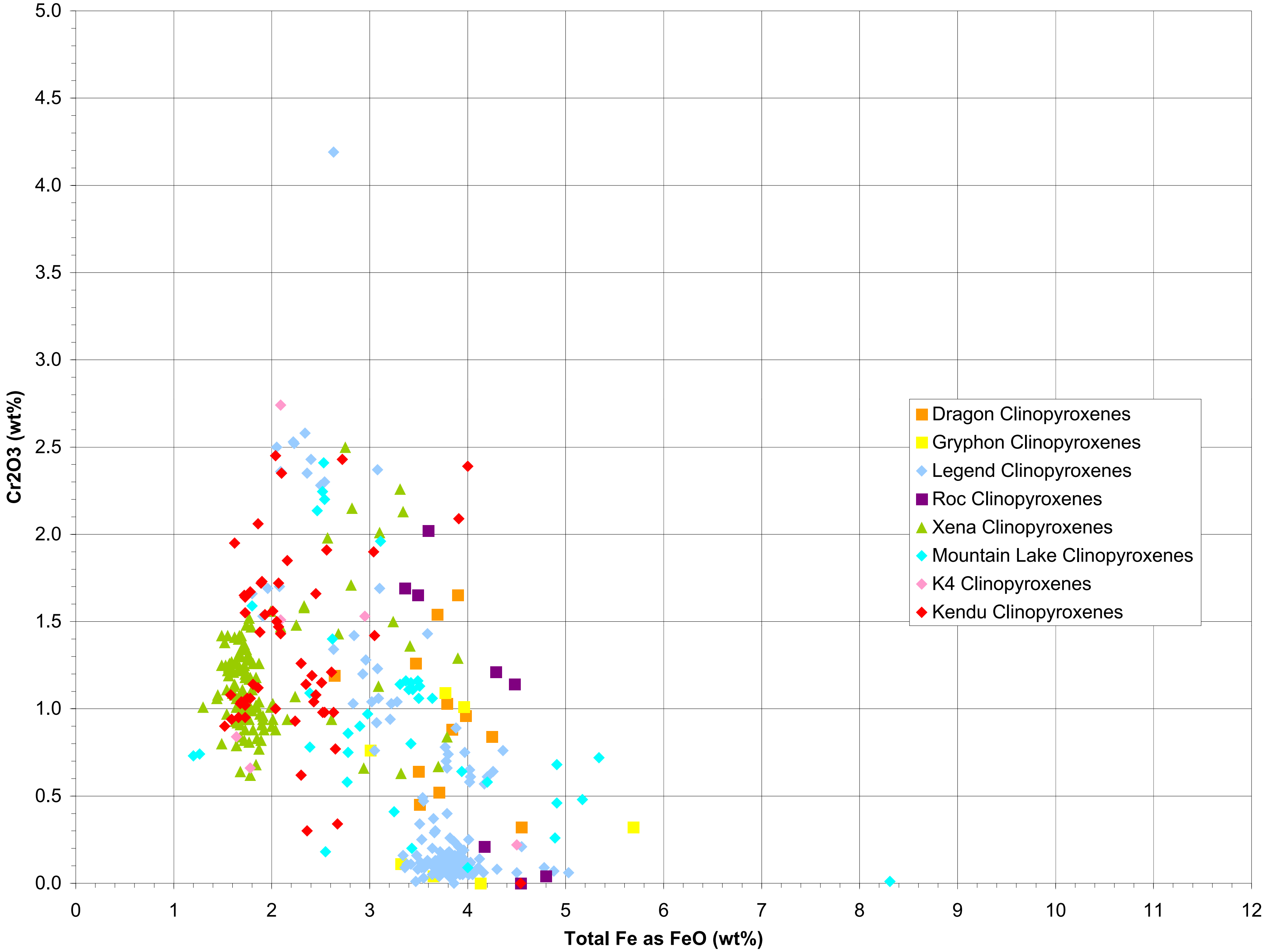
Appendix 5

FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites

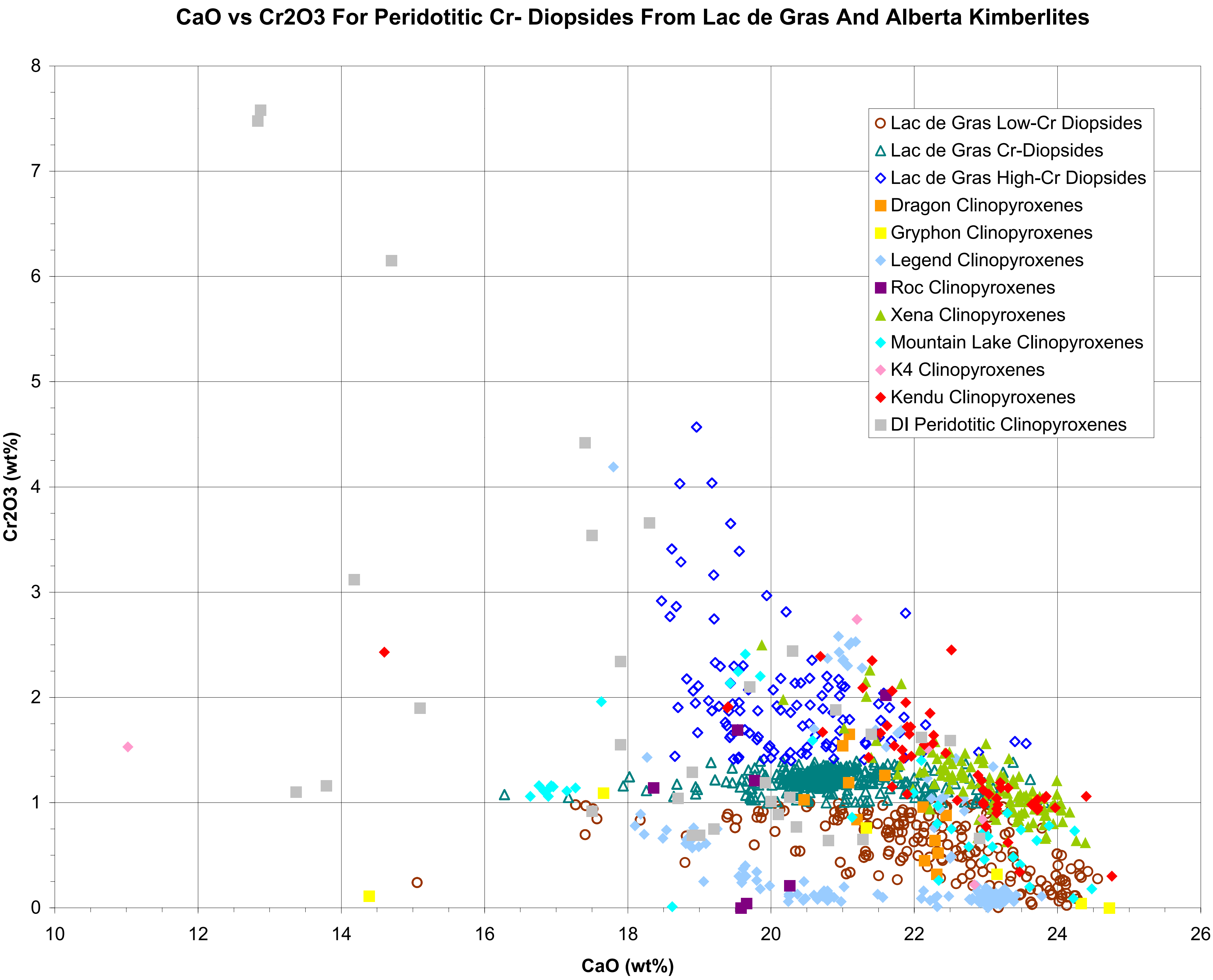


Appendix 5

FeO vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites

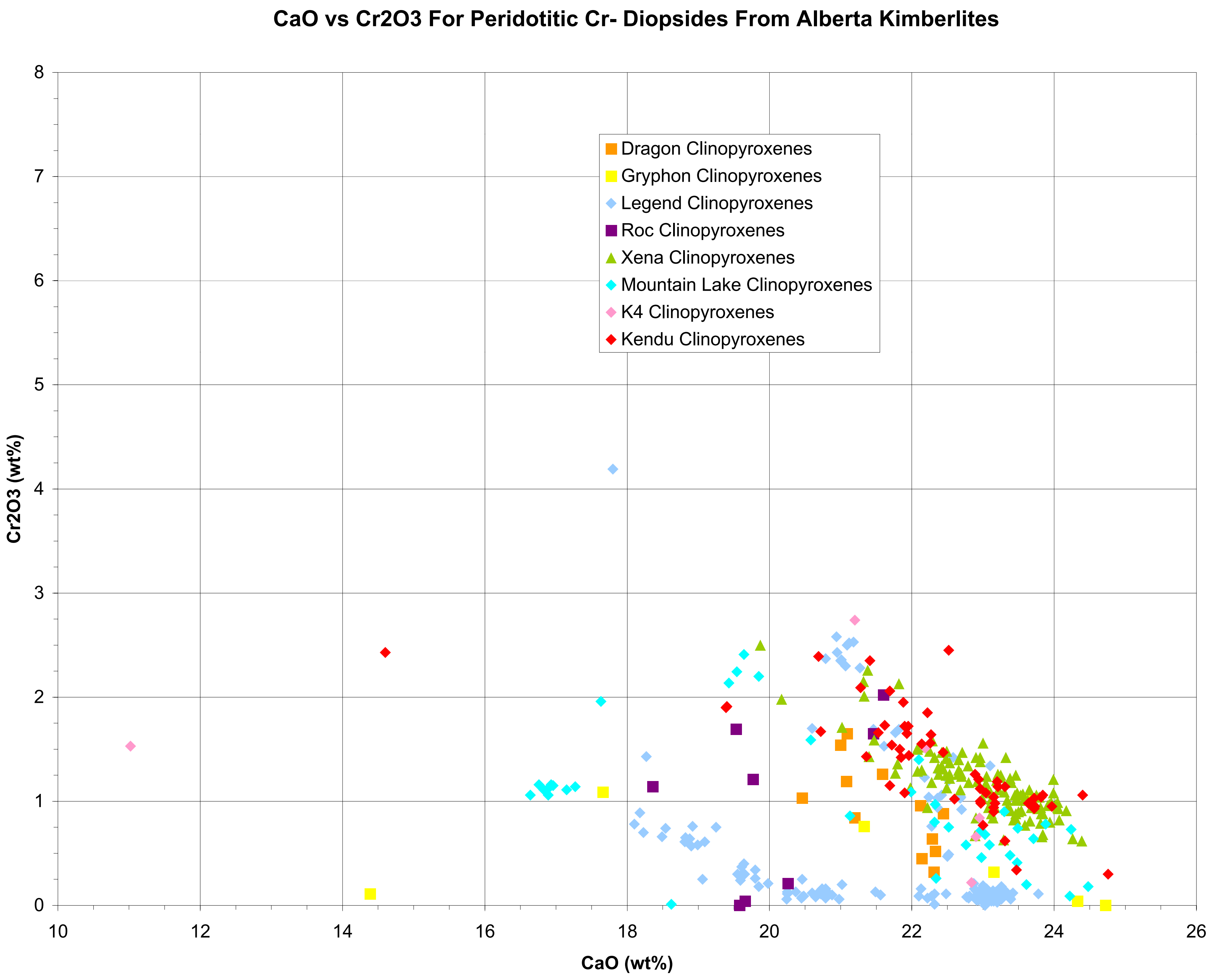


Appendix 5

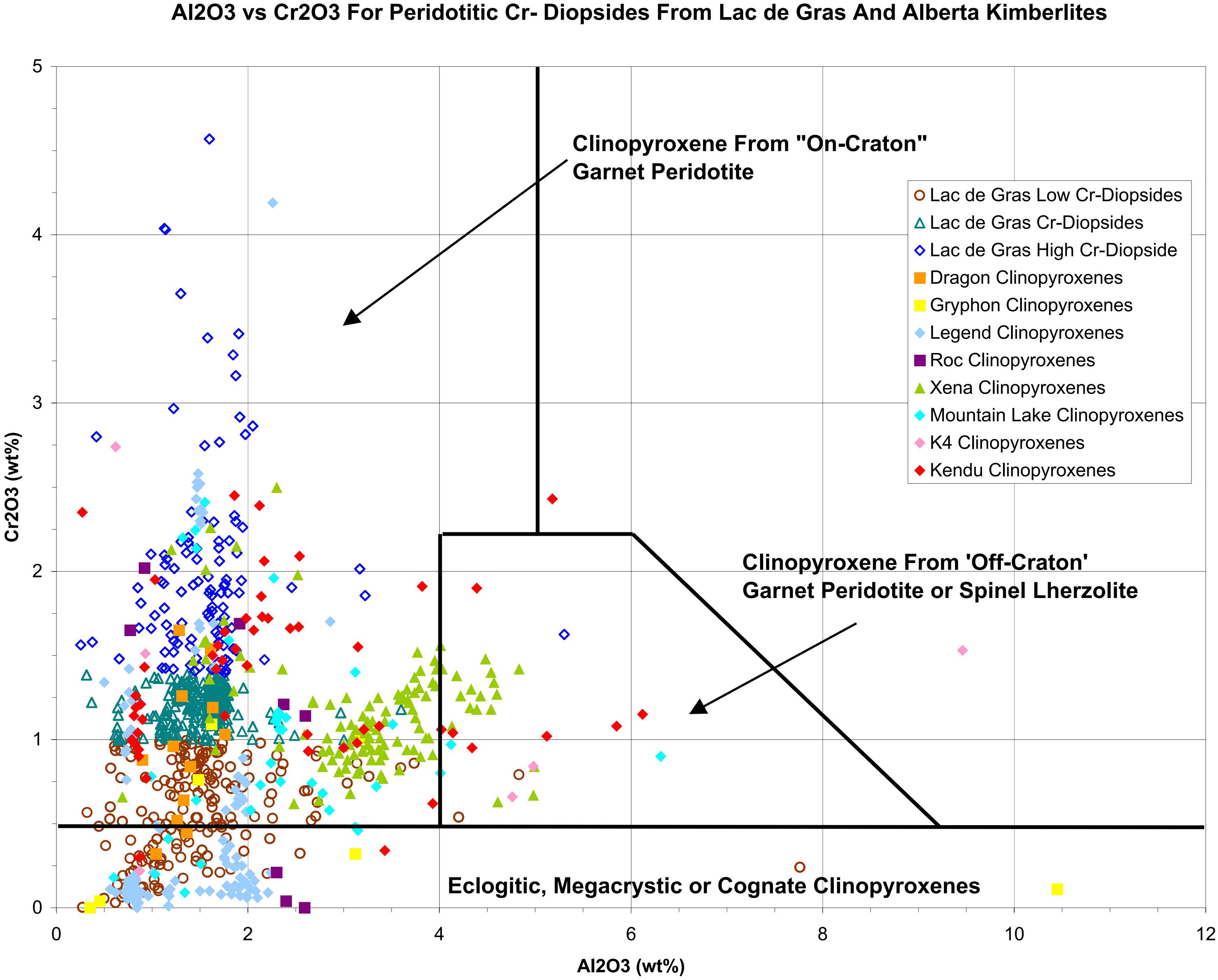


CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
8
7
6
5
4
3
2
1
0
CaO (wt%)
10
12
14
16
18
20
22
24
26
Lac de Gras Low-Cr Diopsides
Lac de Gras Cr-Diopsides
Lac de Gras High-Cr Diopsides
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes
DI Peridotitic Clinopyroxenes

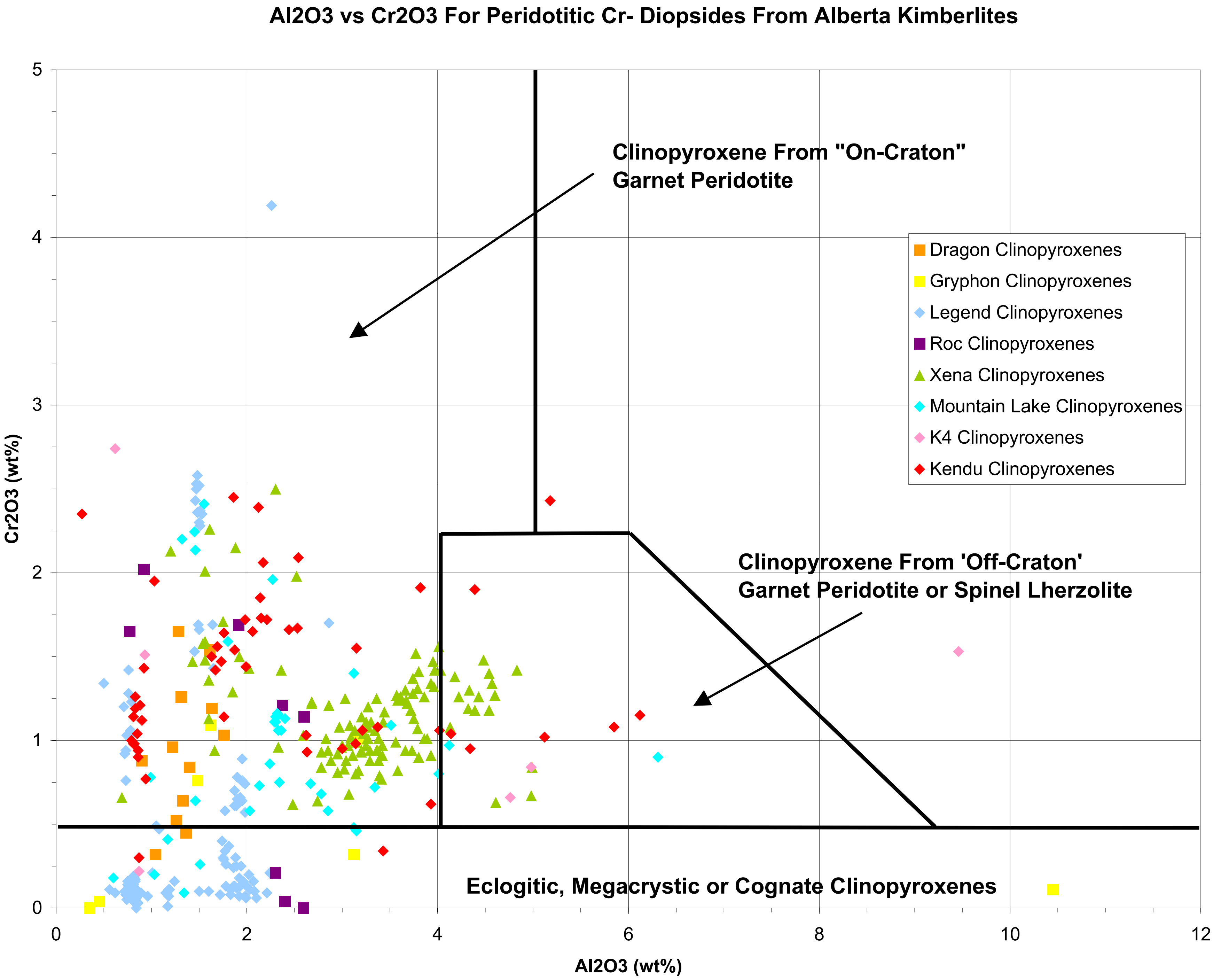
Appendix 5


CaO vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Cr2O3 (wt%)
CaO (wt%)
0
1
2
3
4
5
6
7
8
10
12
14
16
18
20
22
24
26
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes

Appendix 5

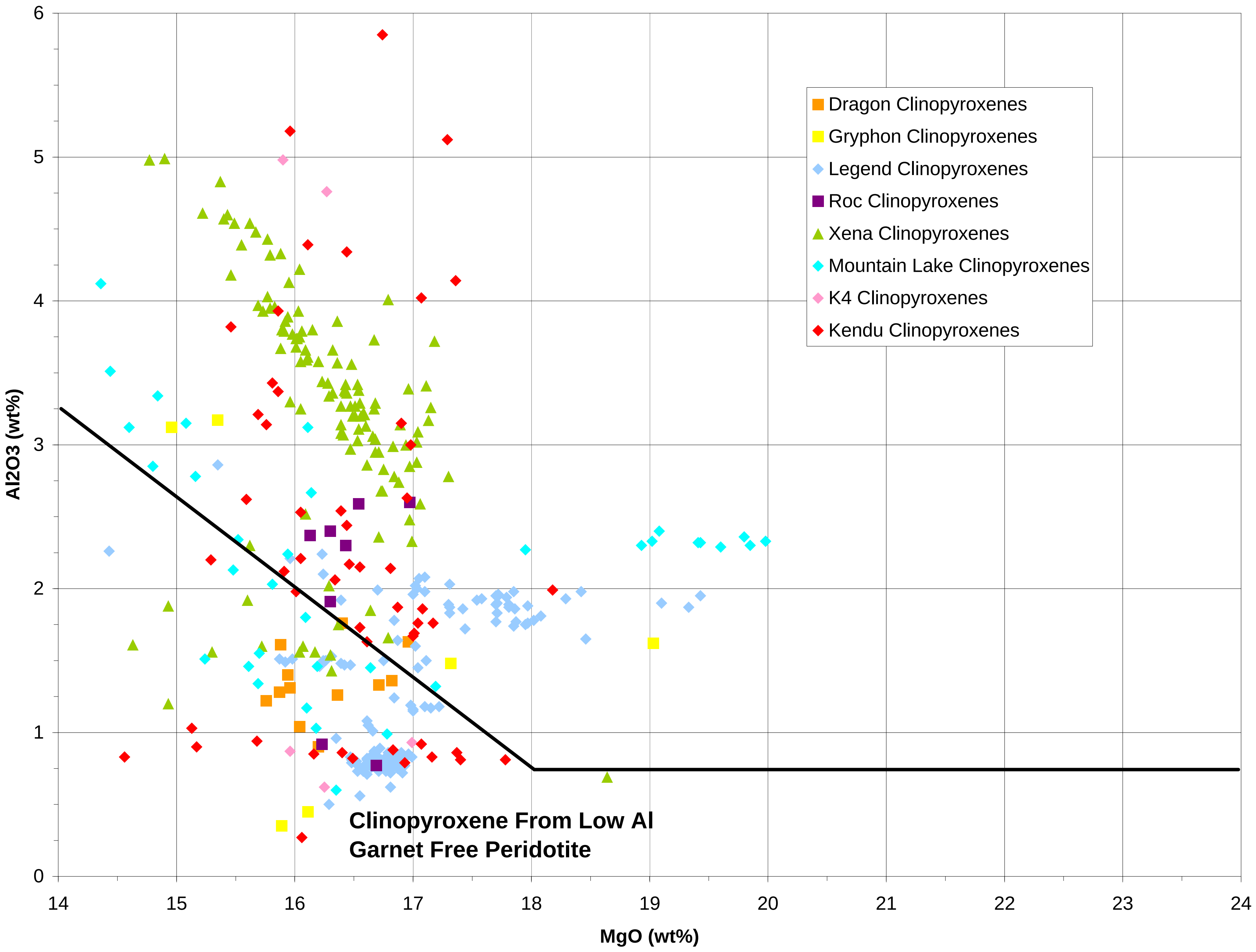

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From Lac de Gras And Alberta Kimberlites
Cr2O3 (wt%)
Al2O3 (wt%)
0
1
2
3
4
5
0
2
4
6
8
10
12
Clinopyroxene From "On-Craton" Garnet Peridotite
Clinopyroxene From 'Off-Craton' Garnet Peridotite or Spinel Lherzolite
Eclogitic, Megacrystic or Cognate Clinopyroxenes
○ Lac de Gras Low Cr-Diopsides
△ Lac de Gras Cr-Diopsides
◇ Lac de Gras High Cr-Diopside
■ Dragon Clinopyroxenes
■ Gryphon Clinopyroxenes
◆ Legend Clinopyroxenes
■ Roc Clinopyroxenes
▲ Xena Clinopyroxenes
◆ Mountain Lake Clinopyroxenes
◆ K4 Clinopyroxenes
◆ Kendu Clinopyroxenes

Appendix 5

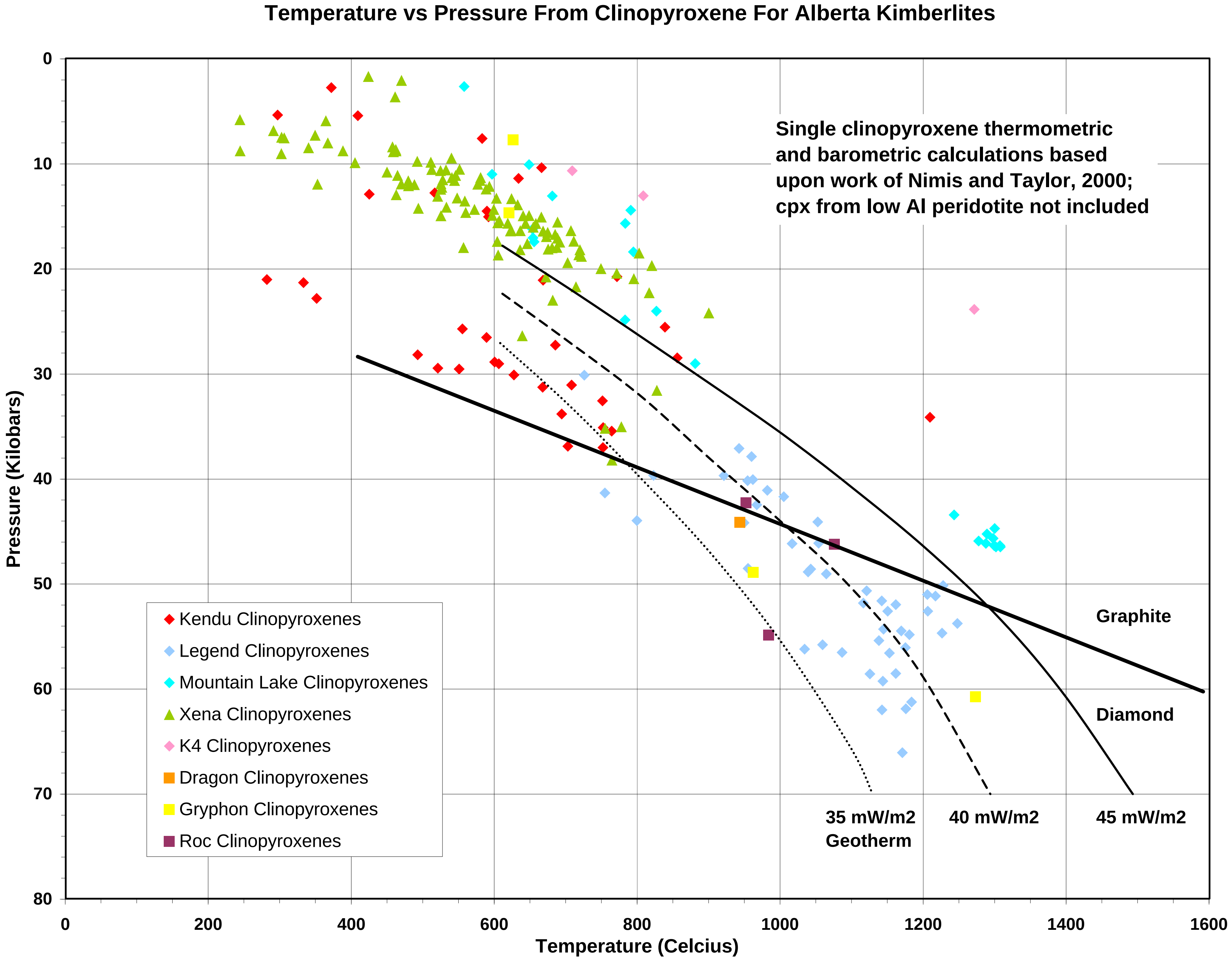

Al2O3 vs Cr2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites
Clinopyroxene From "On-Craton" Garnet Peridotite
Clinopyroxene From 'Off-Craton' Garnet Peridotite or Spinel Lherzolite
Eclogitic, Megacrystic or Cognate Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Legend Clinopyroxenes
Roc Clinopyroxenes
Xena Clinopyroxenes
Mountain Lake Clinopyroxenes
K4 Clinopyroxenes
Kendu Clinopyroxenes
Cr2O3 (wt%)
0
1
2
3
4
5
Al2O3 (wt%)
0
2
4
6
8
10
12

Appendix 6

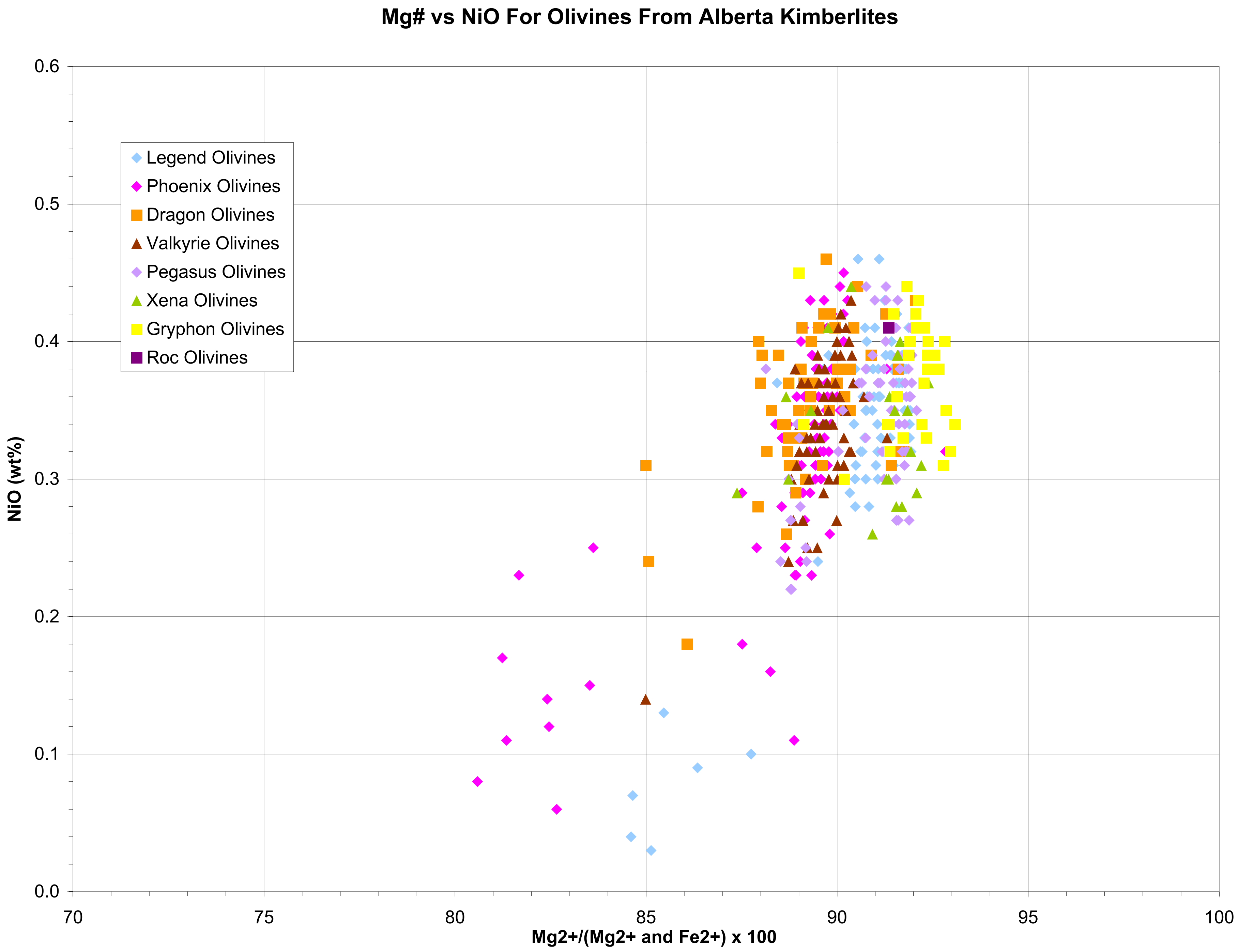
MgO vs Al2O3 For Peridotitic Cr- Diopsides From Alberta Kimberlites



Appendix 6

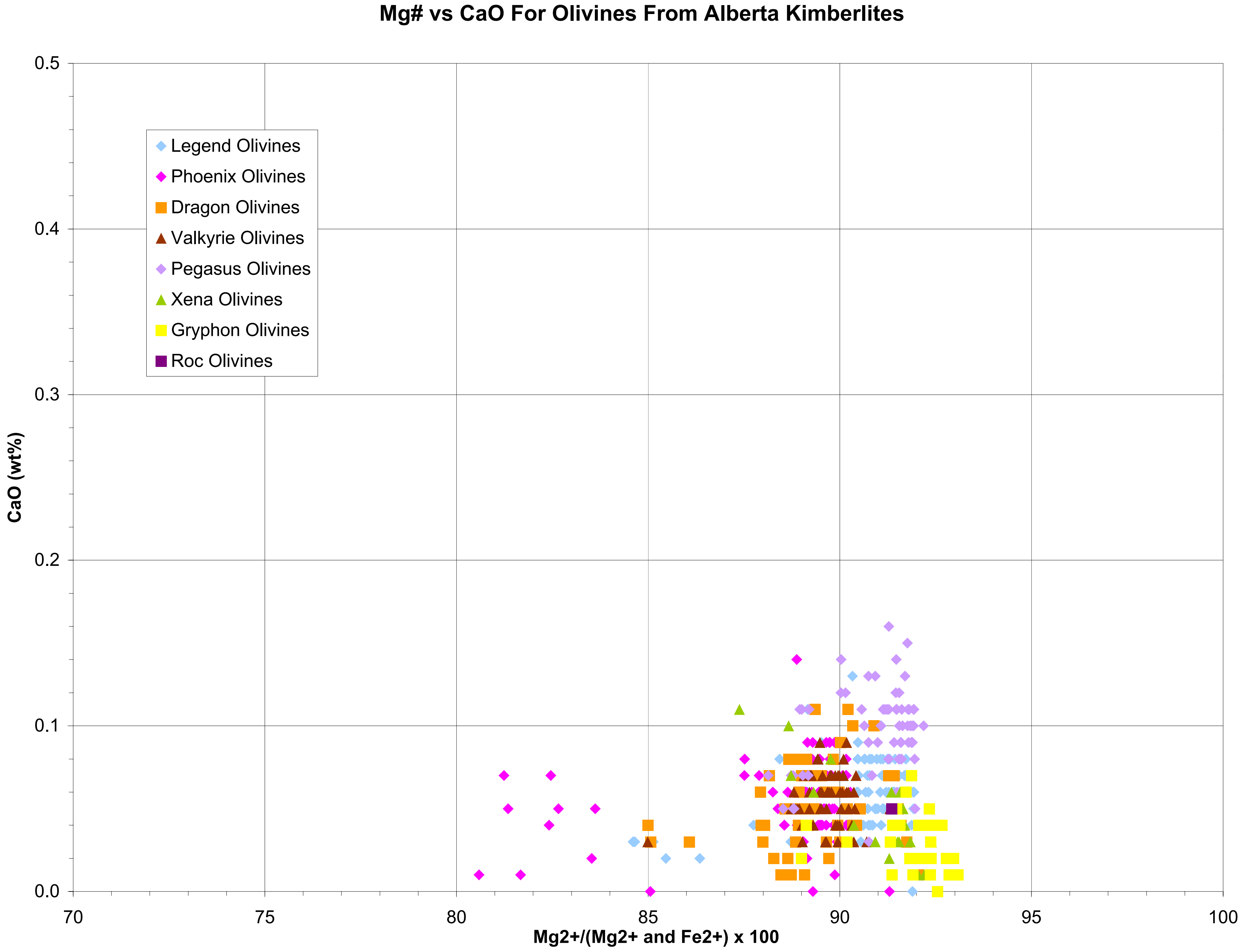

Temperature vs Pressure From Clinopyroxene For Alberta Kimberlites
Single clinopyroxene thermometric and barometric calculations based upon work of Nimis and Taylor, 2000; cpx from low Al peridotite not included
Pressure (Kilobars)
0
10
20
30
40
50
60
70
80
Temperature (Celcius)
0
200
400
600
800
1000
1200
1400
1600
Kendu Clinopyroxenes
Legend Clinopyroxenes
Mountain Lake Clinopyroxenes
Xena Clinopyroxenes
K4 Clinopyroxenes
Dragon Clinopyroxenes
Gryphon Clinopyroxenes
Roc Clinopyroxenes
Graphite
Diamond
35 mW/m2
Geotherm
40 mW/m2
45 mW/m2

Appendix 6

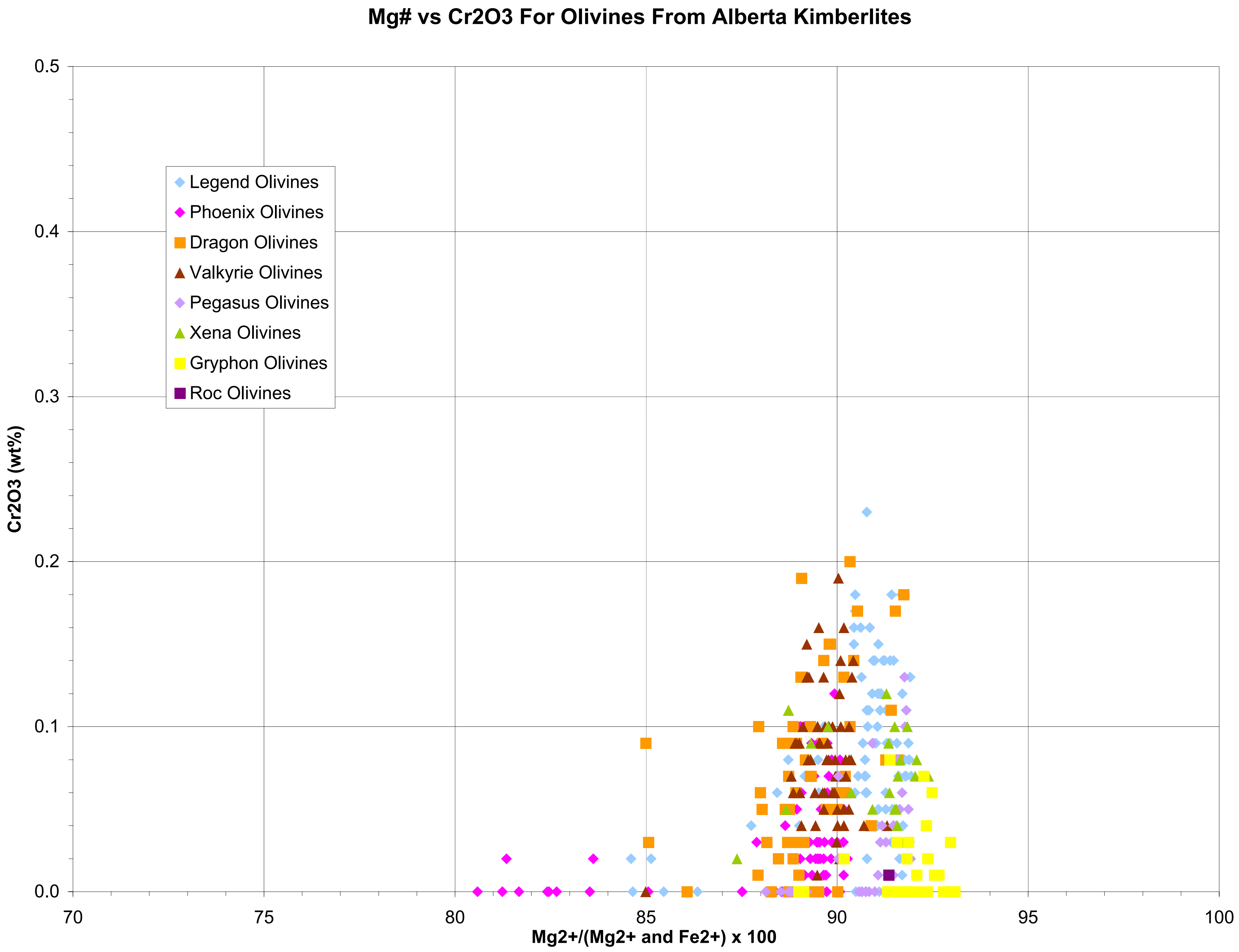


Mg# vs NiO For Olivines From Alberta Kimberlites
NiO (wt%)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100
Legend Olivines
Phoenix Olivines
Dragon Olivines
Valkyrie Olivines
Pegasus Olivines
Xena Olivines
Gryphon Olivines
Roc Olivines

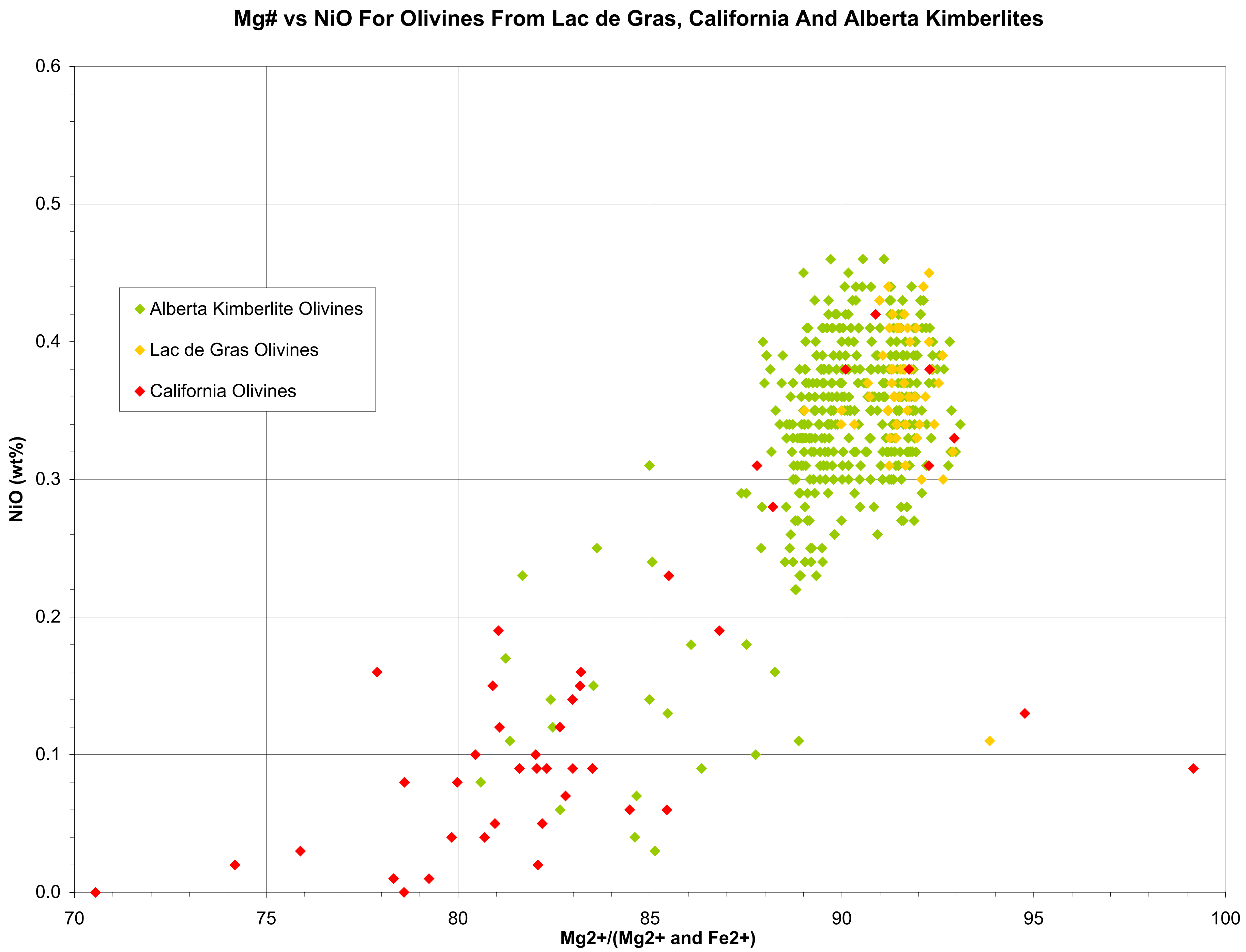
Appendix 6


Mg# vs CaO For Olivines From Alberta Kimberlites
CaO (wt%)
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100
Legend Olivines
Phoenix Olivines
Dragon Olivines
Valkyrie Olivines
Pegasus Olivines
Xena Olivines
Gryphon Olivines
Roc Olivines

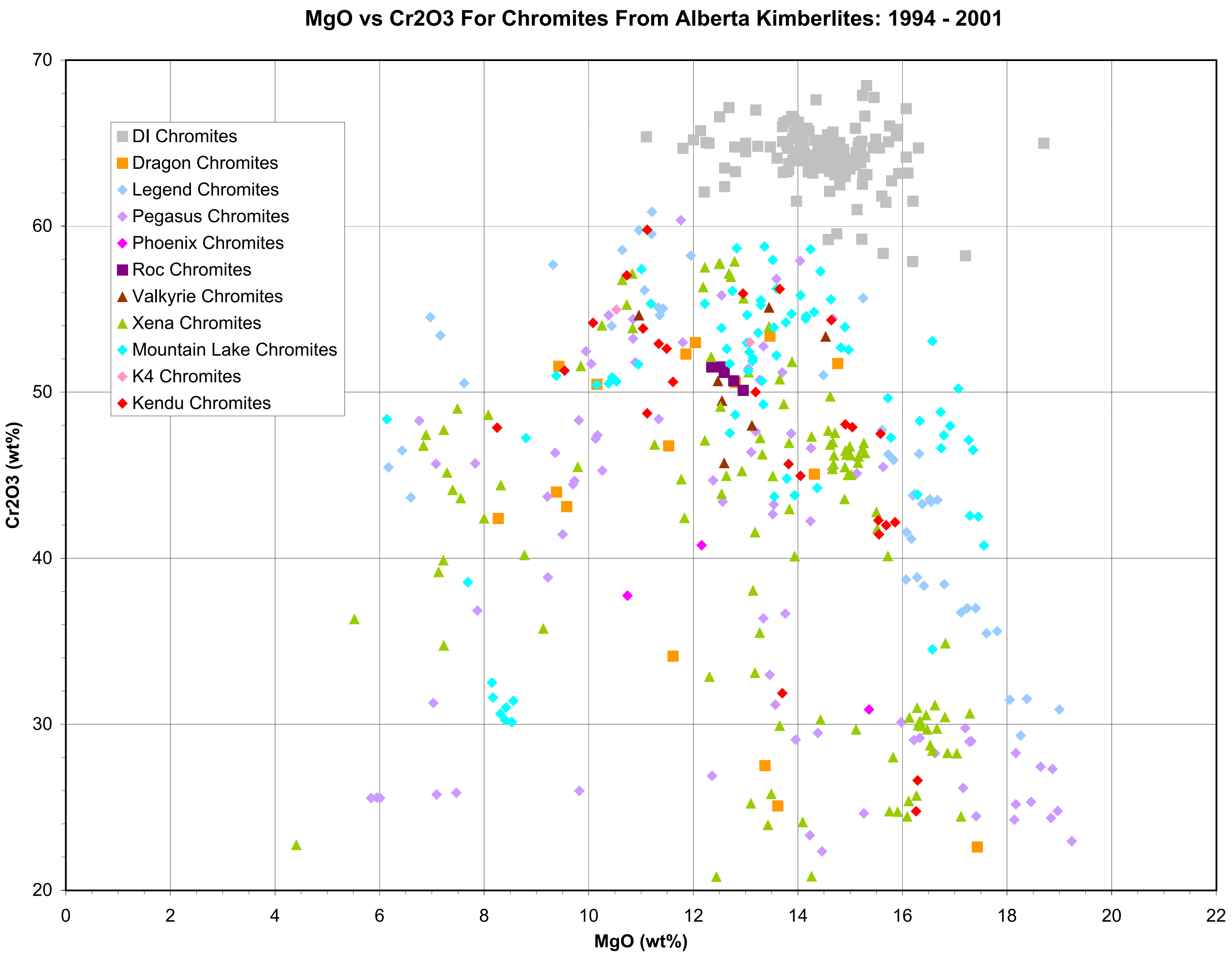
Appendix 6


Mg# vs Cr2O3 For Olivines From Alberta Kimberlites
Cr2O3 (wt%)
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100
◆ Legend Olivines
◆ Phoenix Olivines
■ Dragon Olivines
▲ Valkyrie Olivines
◆ Pegasus Olivines
▲ Xena Olivines
■ Gryphon Olivines
■ Roc Olivines

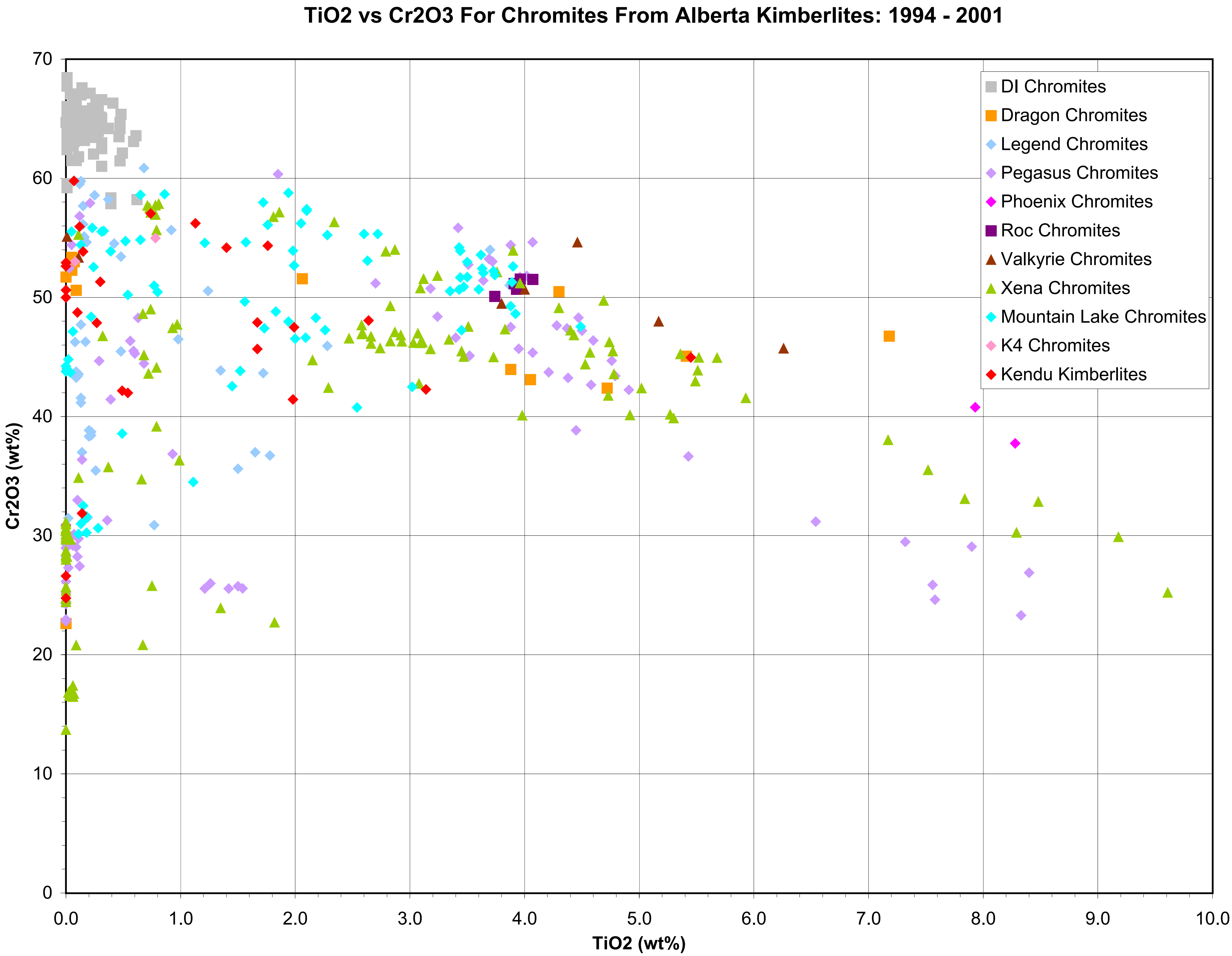
Appendix 6


Mg# vs NiO For Olivines From Lac de Gras, California And Alberta Kimberlites
◆ Alberta Kimberlite Olivines
◆ Lac de Gras Olivines
◆ California Olivines
NiO (wt%)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+)

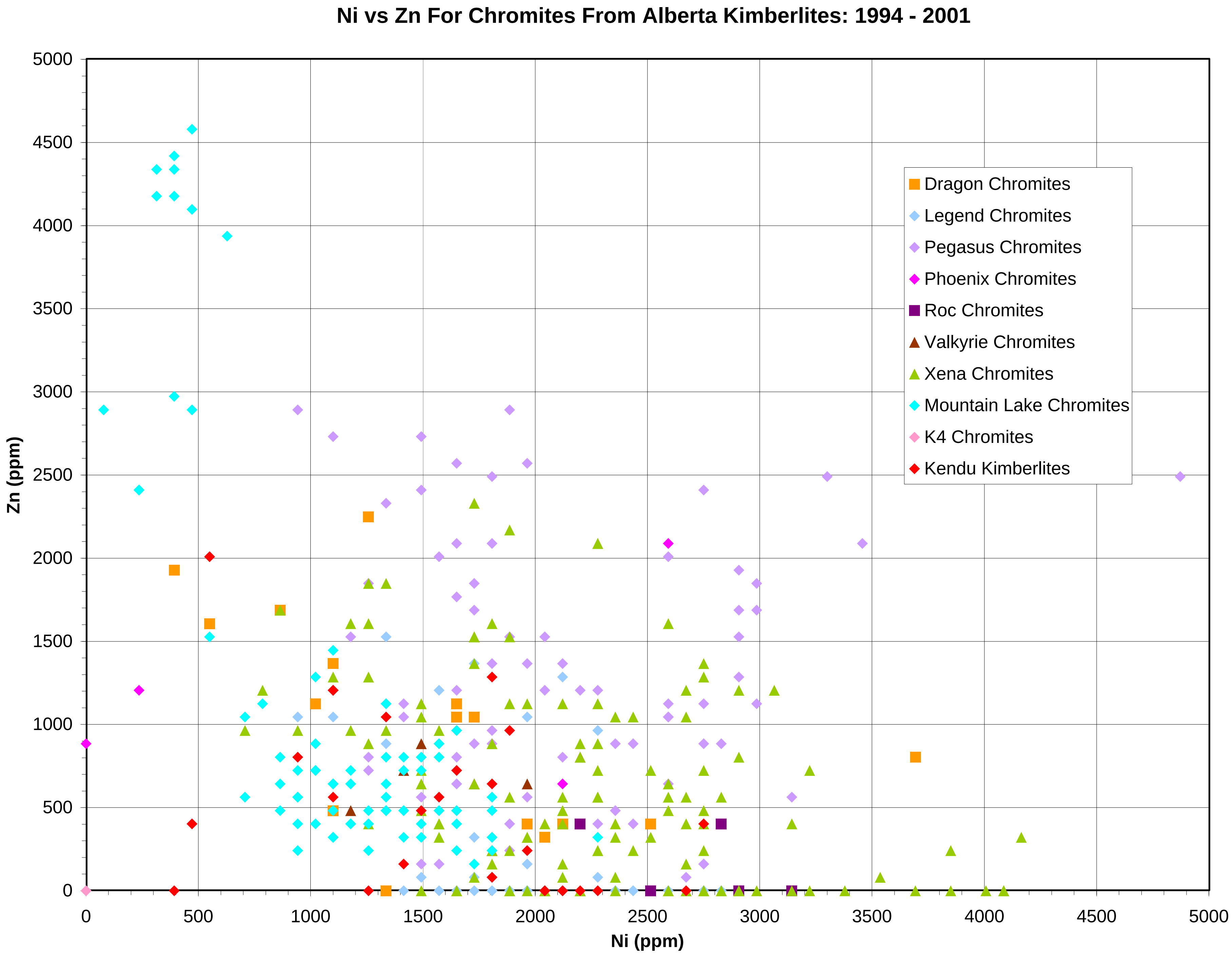
Appendix 6


MgO vs Cr2O3 For Chromites From Alberta Kimberlites: 1994 - 2001
DI Chromites
Dragon Chromites
Legend Chromites
Pegasus Chromites
Phoenix Chromites
Roc Chromites
Valkyrie Chromites
Xena Chromites
Mountain Lake Chromites
K4 Chromites
Kendu Chromites
Cr2O3 (wt%)
70
60
50
40
30
20
0
2
4
6
8
10
12
14
16
18
20
22
MgO (wt%)

Appendix 7


TiO2 vs Cr2O3 For Chromites From Alberta Kimberlites: 1994 - 2001
Cr2O3 (wt%)
0
10
20
30
40
50
60
70
TiO2 (wt%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
DI Chromites
Dragon Chromites
Legend Chromites
Pegasus Chromites
Phoenix Chromites
Roc Chromites
Valkyrie Chromites
Xena Chromites
Mountain Lake Chromites
K4 Chromites
Kendu Kimberlites

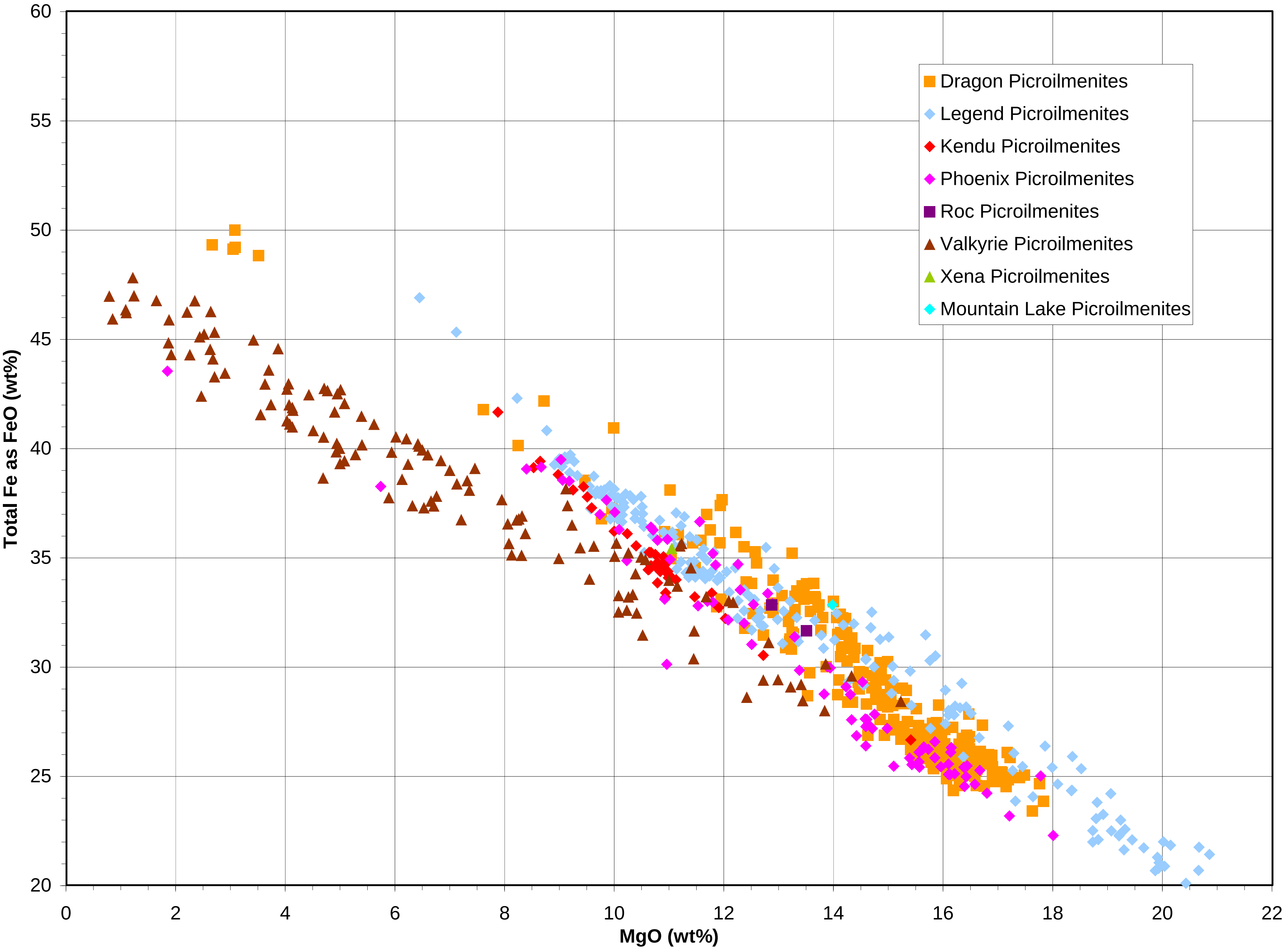
Appendix 7



Ni vs Zn For Chromites From Alberta Kimberlites: 1994 - 2001
Zn (ppm)
Ni (ppm)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Dragon Chromites
Legend Chromites
Pegasus Chromites
Phoenix Chromites
Roc Chromites
Valkyrie Chromites
Xena Chromites
Mountain Lake Chromites
K4 Chromites
Kendu Kimberlites

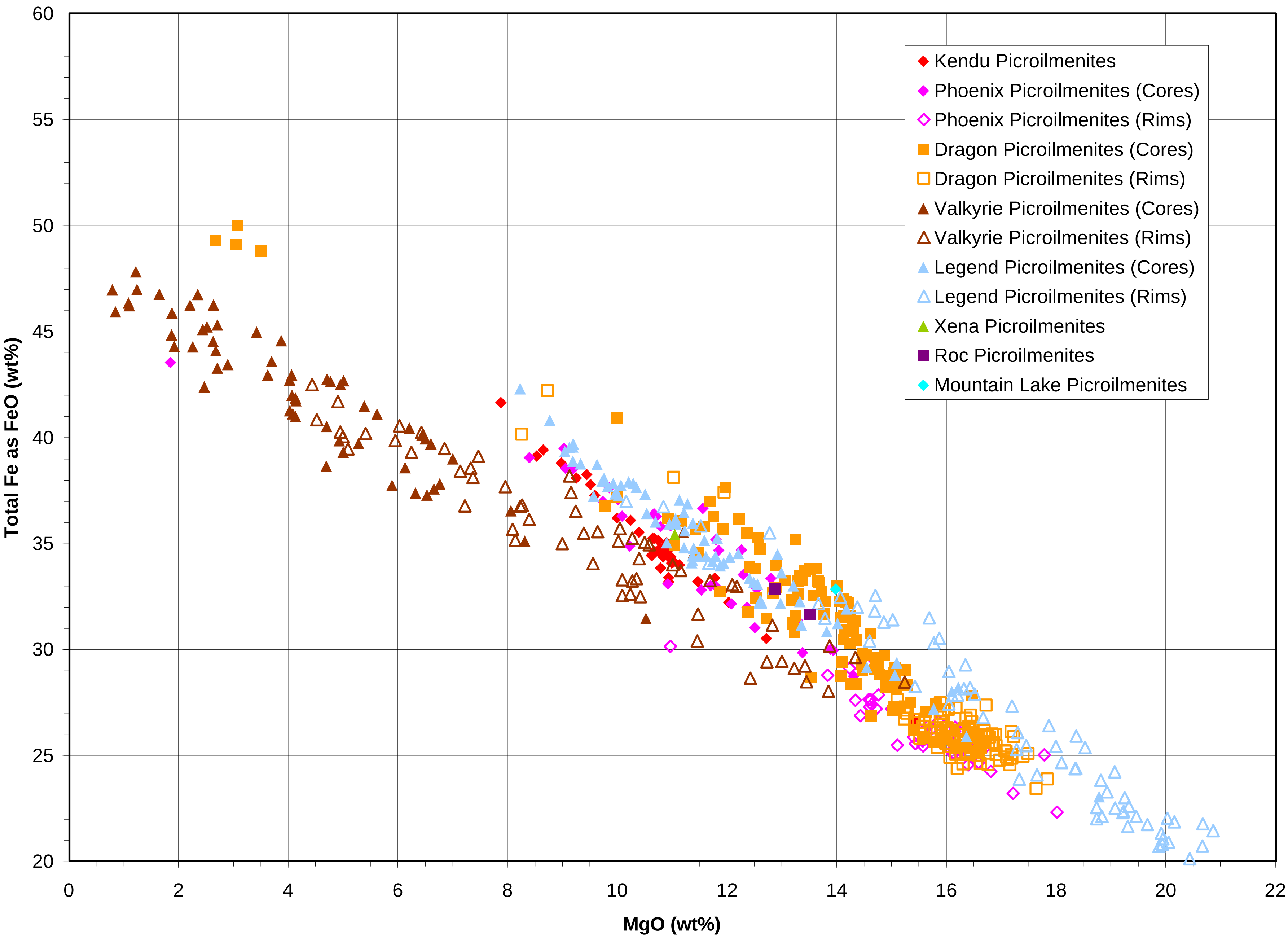
Appendix 7

MgO vs Total Fe as FeO For Picroilmenites From Alberta Kimberlites

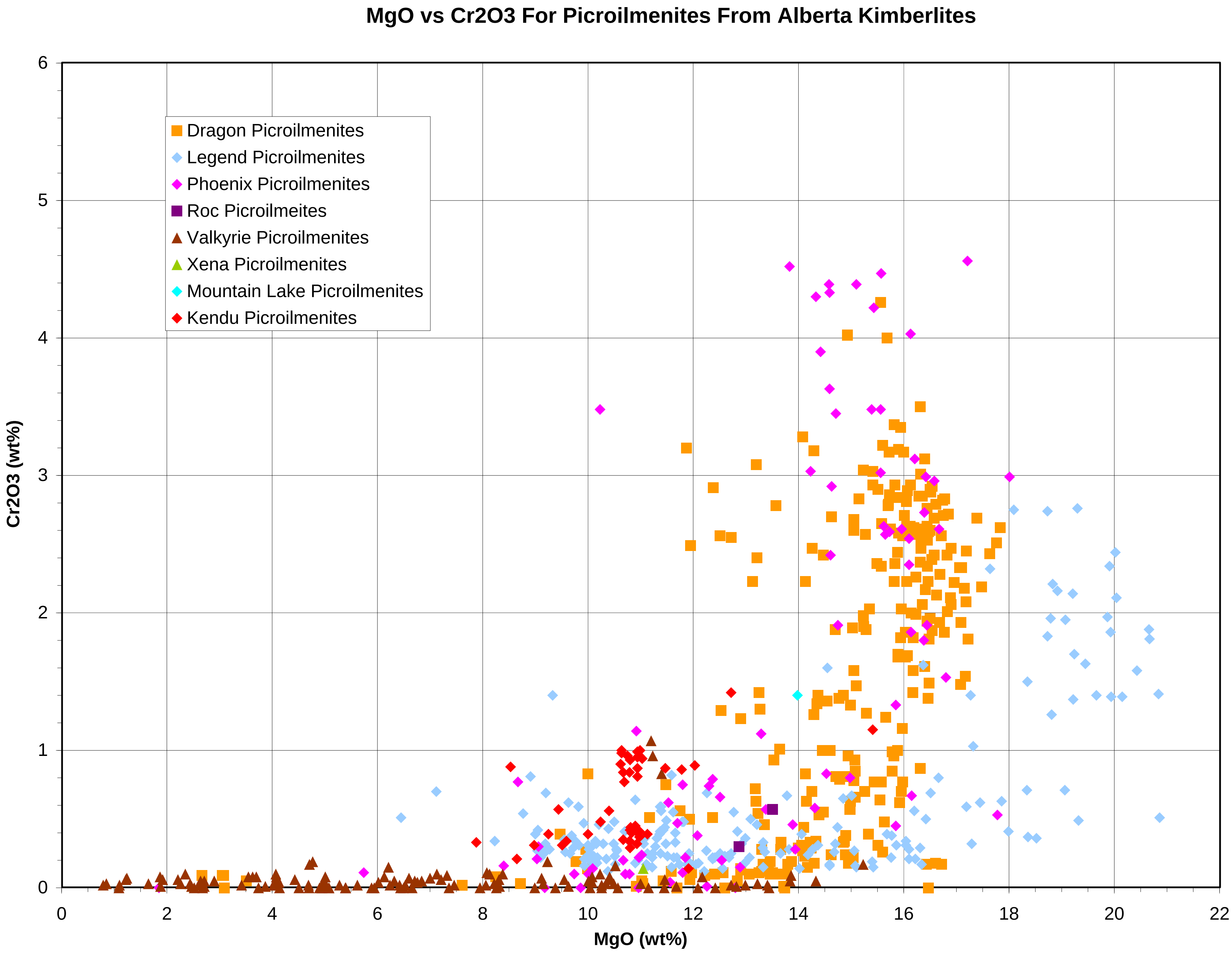


Appendix 7

MgO vs Total Fe as FeO For Picroilmenites From Alberta Kimberlites

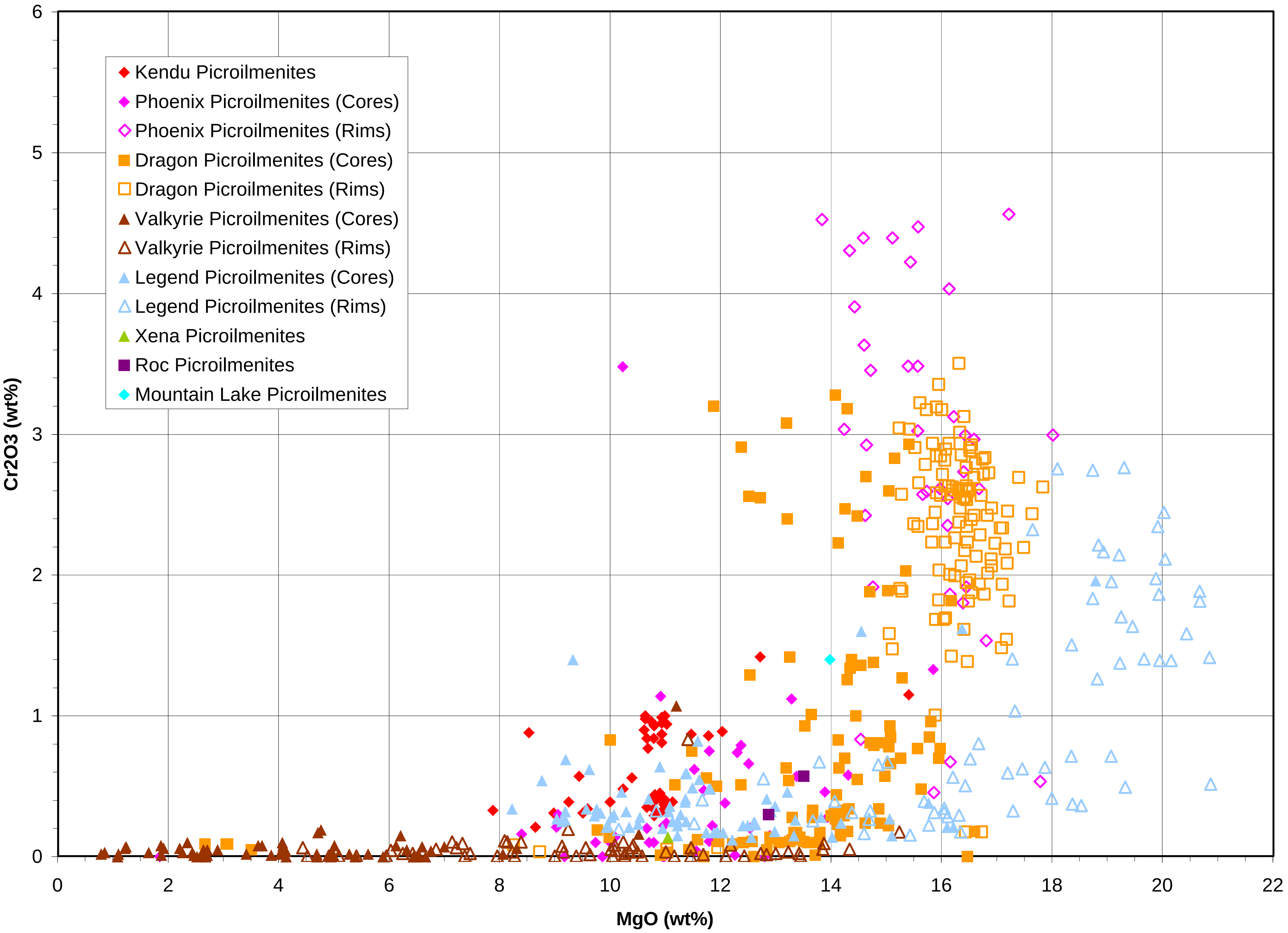


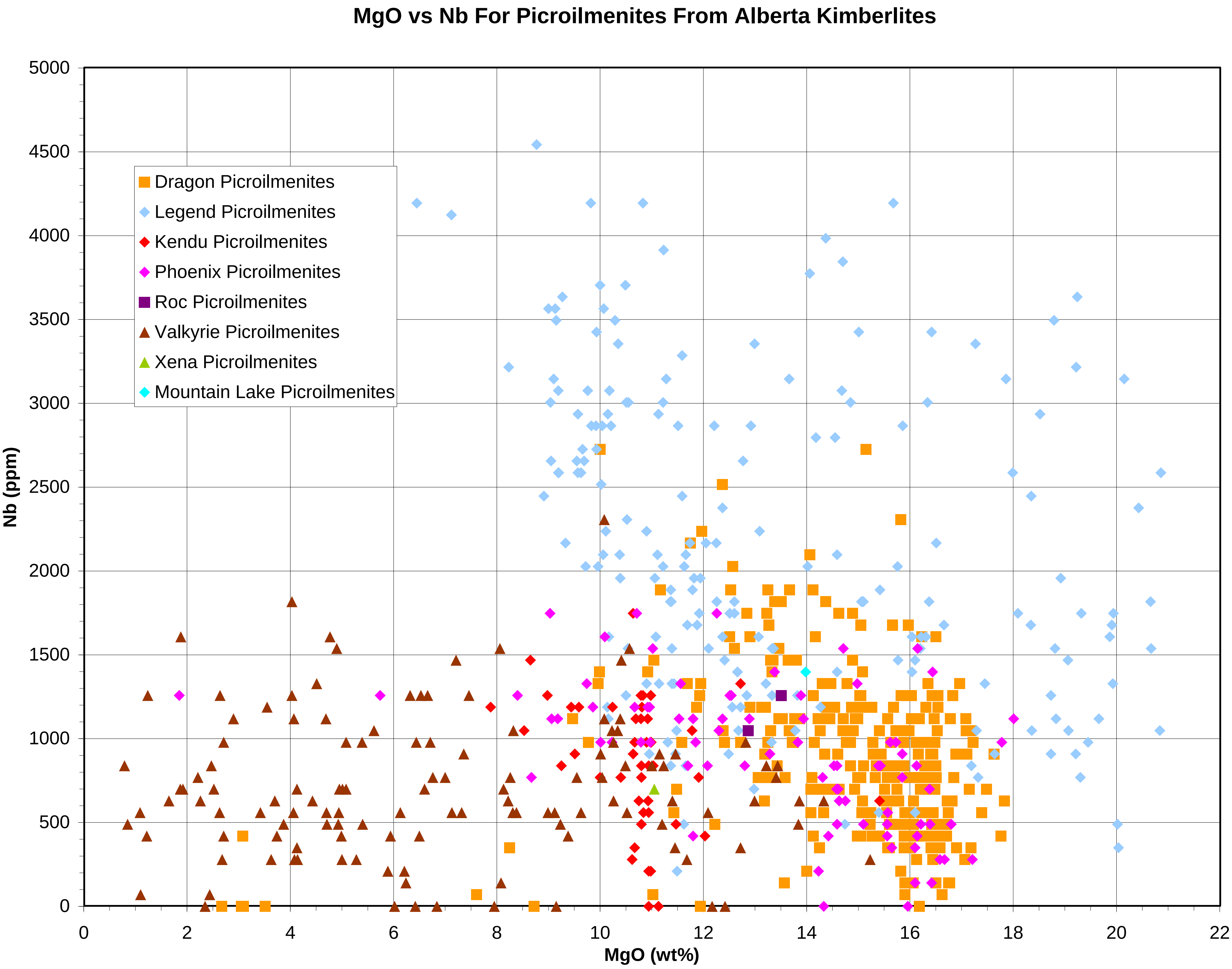
Appendix 7


MgO vs Cr2O3 For Picroilmenites From Alberta Kimberlites
■ Dragon Picroilmenites
◆ Legend Picroilmenites
◆ Phoenix Picroilmenites
■ Roc Picroilmeites
▲ Valkyrie Picroilmenites
▲ Xena Picroilmenites
◆ Mountain Lake Picroilmenites
◆ Kendu Picroilmenites
Cr2O3 (wt%)
0
1
2
3
4
5
6
MgO (wt%)
0
2
4
6
8
10
12
14
16
18
20
22

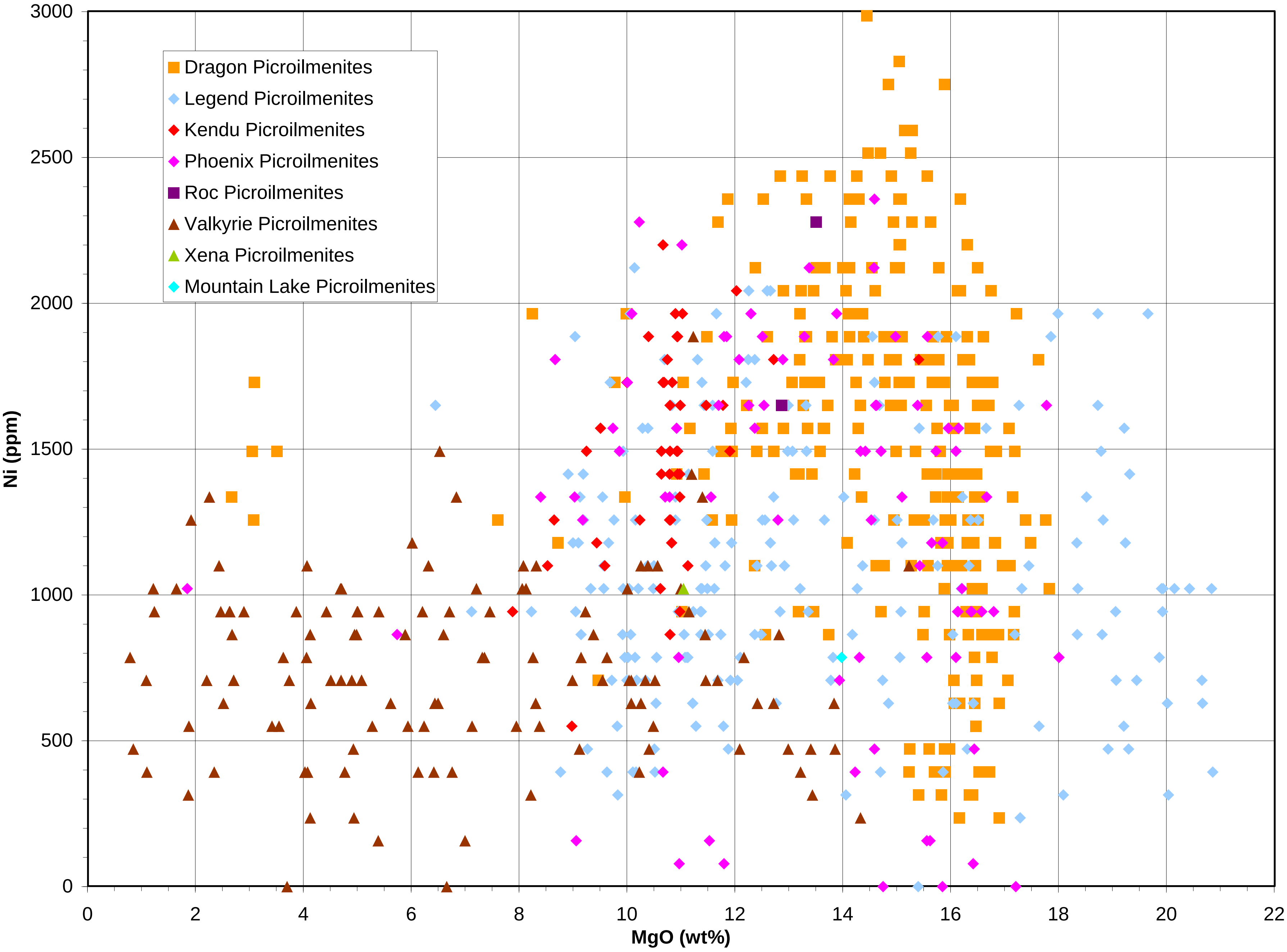
Appendix 7

MgO vs Cr2O3 For Picroilmenites From Alberta Kimberlites

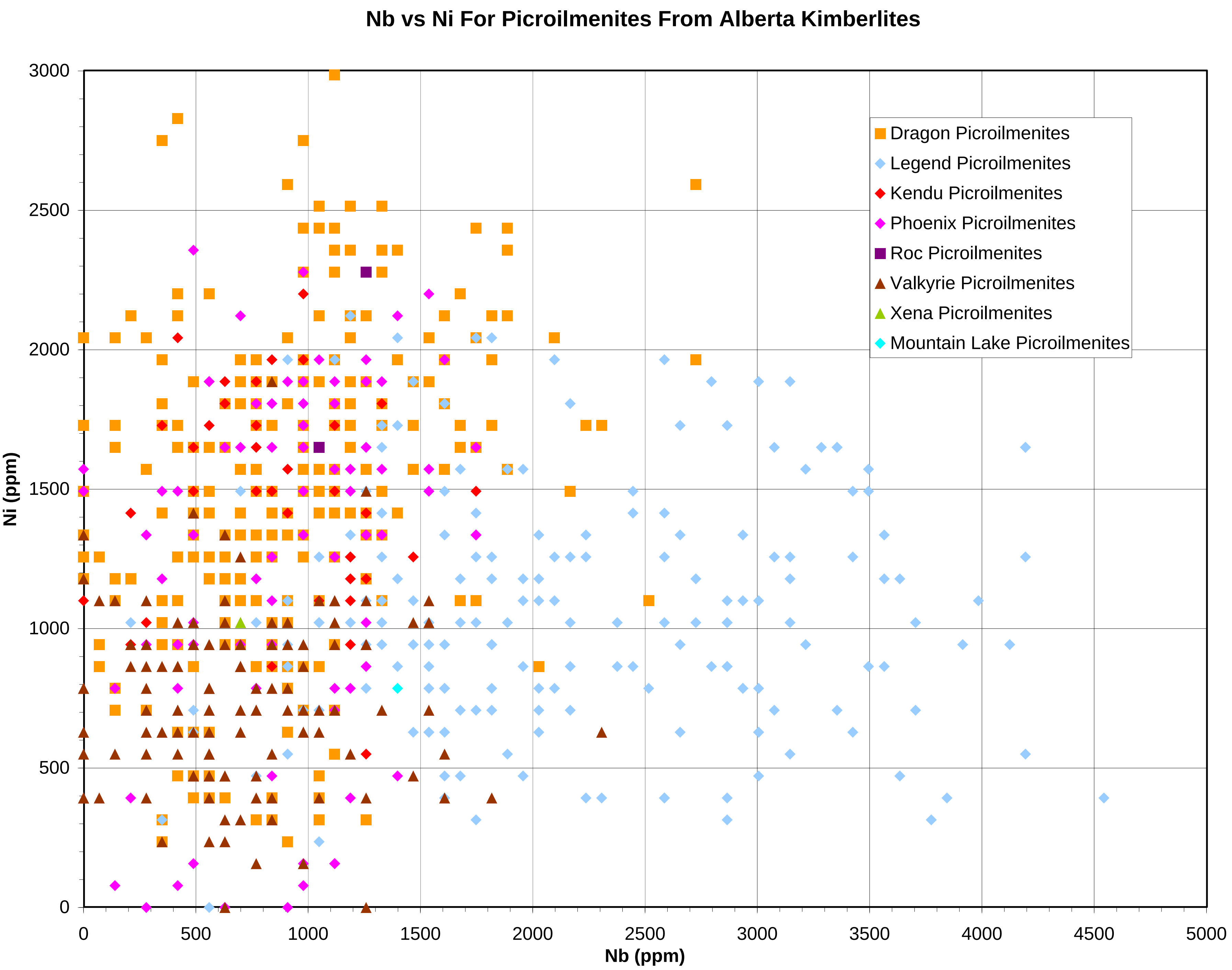



MgO vs Nb For Picroilmenites From Alberta Kimberlites
Dragon Picroilmenites
Legend Picroilmenites
Kendu Picroilmenites
Phoenix Picroilmenites
Roc Picroilmenites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites
Nb (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
16
18
20
22
MgO (wt%)

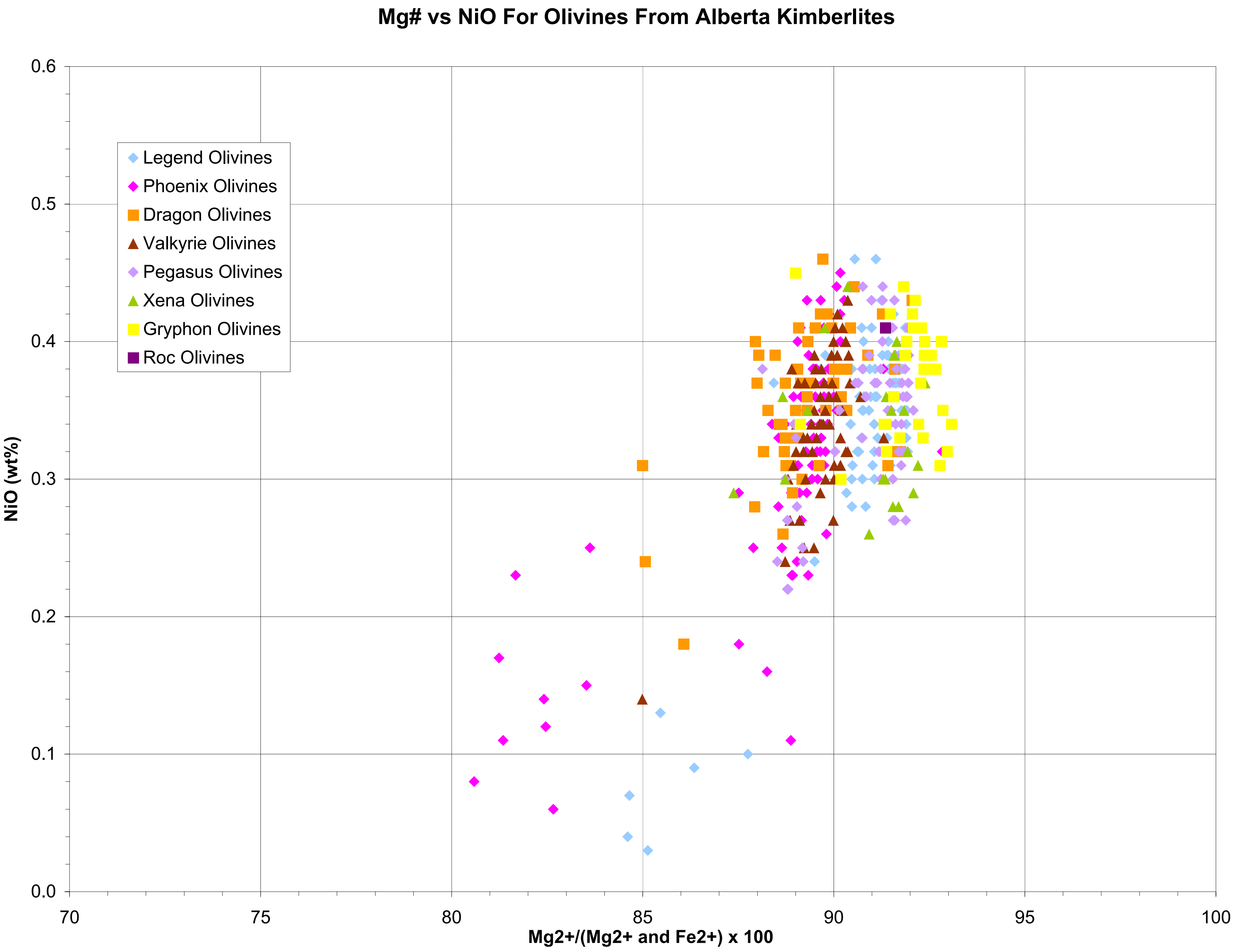
MgO vs Ni For Picroilmenites From Alberta Kimberlites



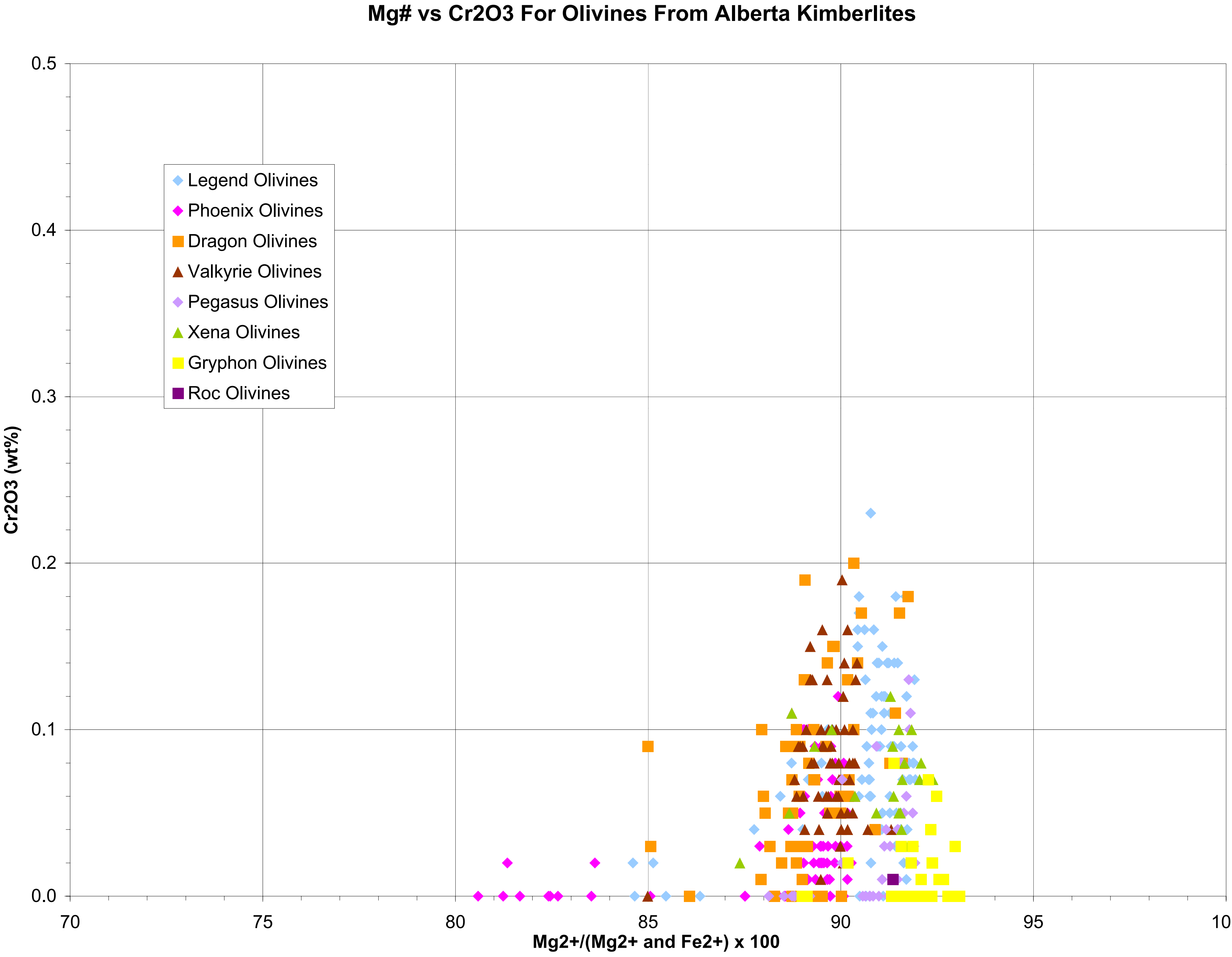
Appendix 7


Nb vs Ni For Picroilmenites From Alberta Kimberlites
Ni (ppm)
Nb (ppm)
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Dragon Picroilmenites
Legend Picroilmenites
Kendu Picroilmenites
Phoenix Picroilmenites
Roc Picroilmenites
Valkyrie Picroilmenites
Xena Picroilmenites
Mountain Lake Picroilmenites

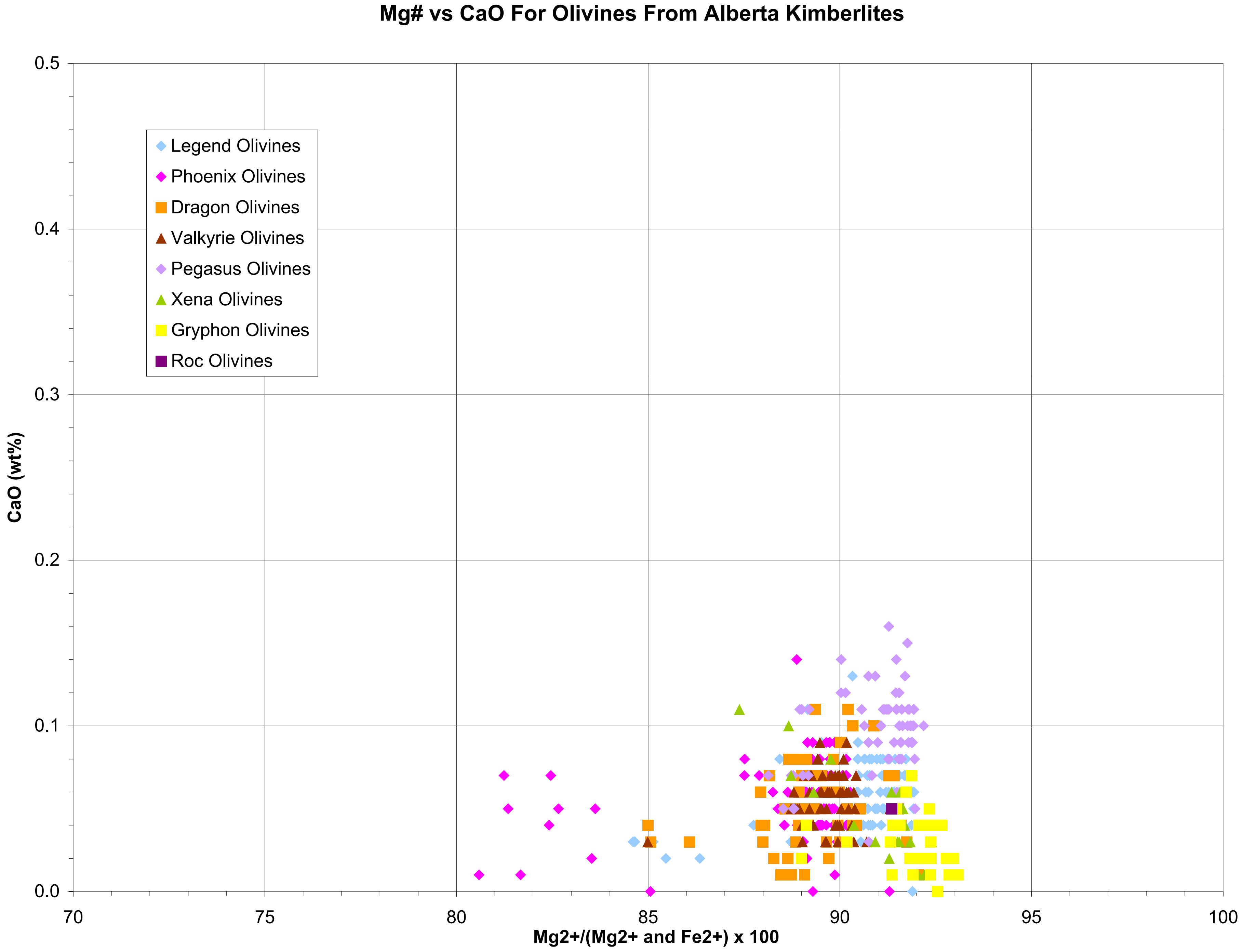
Appendix 7


Mg# vs NiO For Olivines From Alberta Kimberlites
◆ Legend Olivines
◆ Phoenix Olivines
■ Dragon Olivines
▲ Valkyrie Olivines
◆ Pegasus Olivines
▲ Xena Olivines
■ Gryphon Olivines
■ Roc Olivines
NiO (wt%)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100

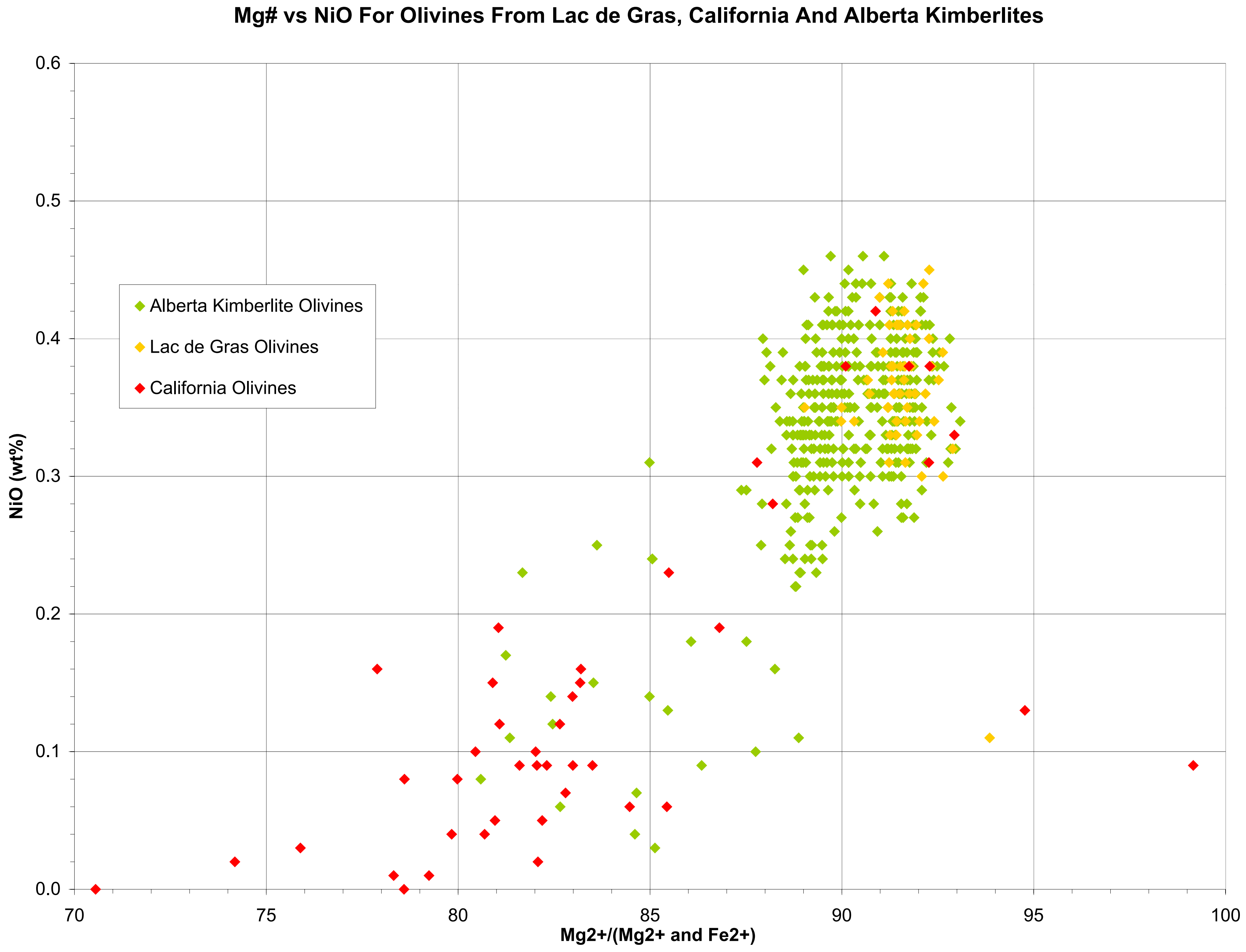
Appendix 7

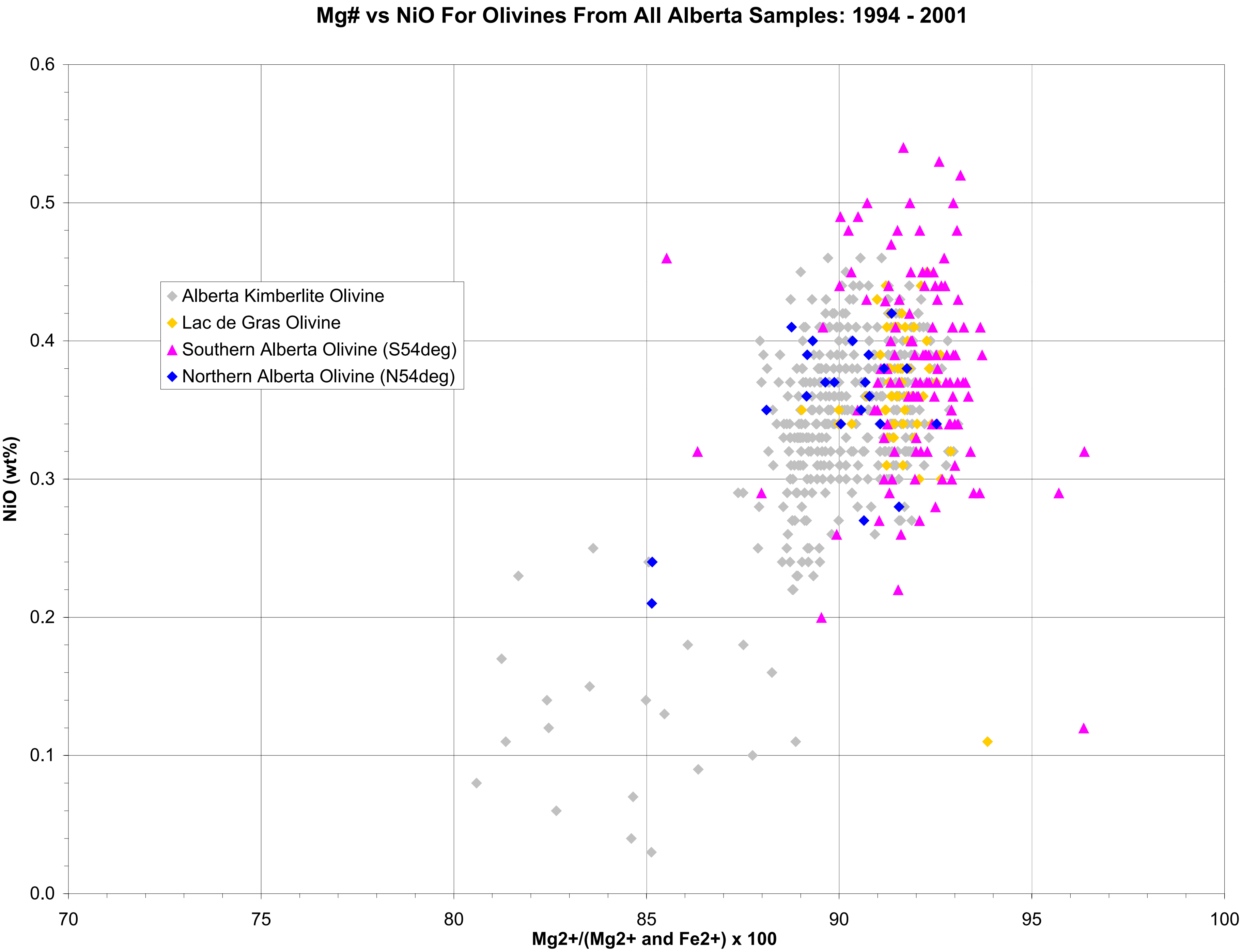

Mg# vs Cr2O3 For Olivines From Alberta Kimberlites
Cr2O3 (wt%)
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100
Legend Olivines
Phoenix Olivines
Dragon Olivines
Valkyrie Olivines
Pegasus Olivines
Xena Olivines
Gryphon Olivines
Roc Olivines

Appendix 7


Mg# vs CaO For Olivines From Alberta Kimberlites
Legend Olivines
Phoenix Olivines
Dragon Olivines
Valkyrie Olivines
Pegasus Olivines
Xena Olivines
Gryphon Olivines
Roc Olivines
CaO (wt%)
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100

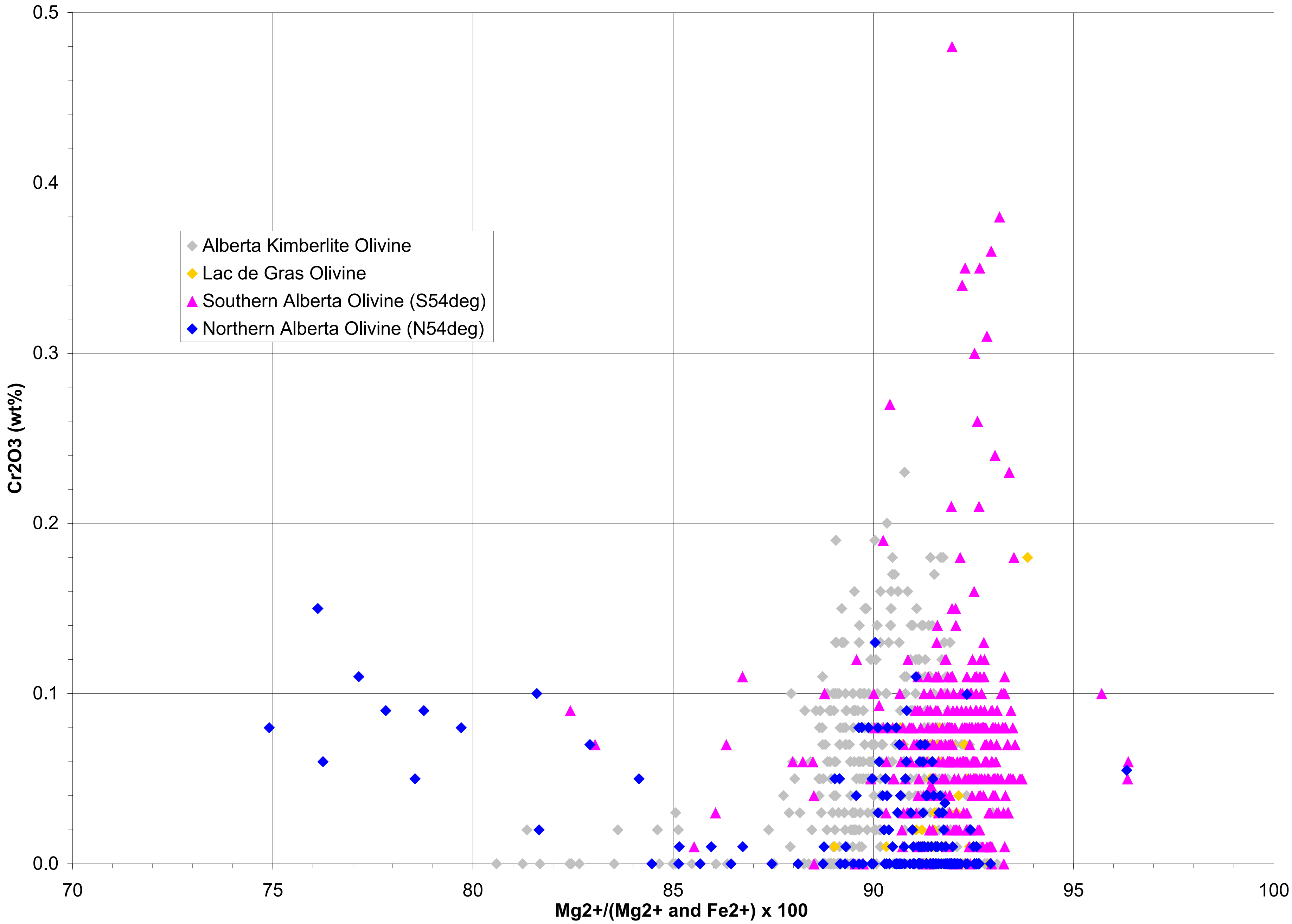
Appendix 7


Mg# vs NiO For Olivines From Lac de Gras, California And Alberta Kimberlites
NiO (wt%)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+)
Alberta Kimberlite Olivines
Lac de Gras Olivines
California Olivines


Mg# vs NiO For Olivines From All Alberta Samples: 1994 - 2001
NiO (wt%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
70
75
80
85
90
95
100
Mg2+/(Mg2+ and Fe2+) x 100
◆ Alberta Kimberlite Olivine
◆ Lac de Gras Olivine
▲ Southern Alberta Olivine (S54deg)
◆ Northern Alberta Olivine (N54deg)

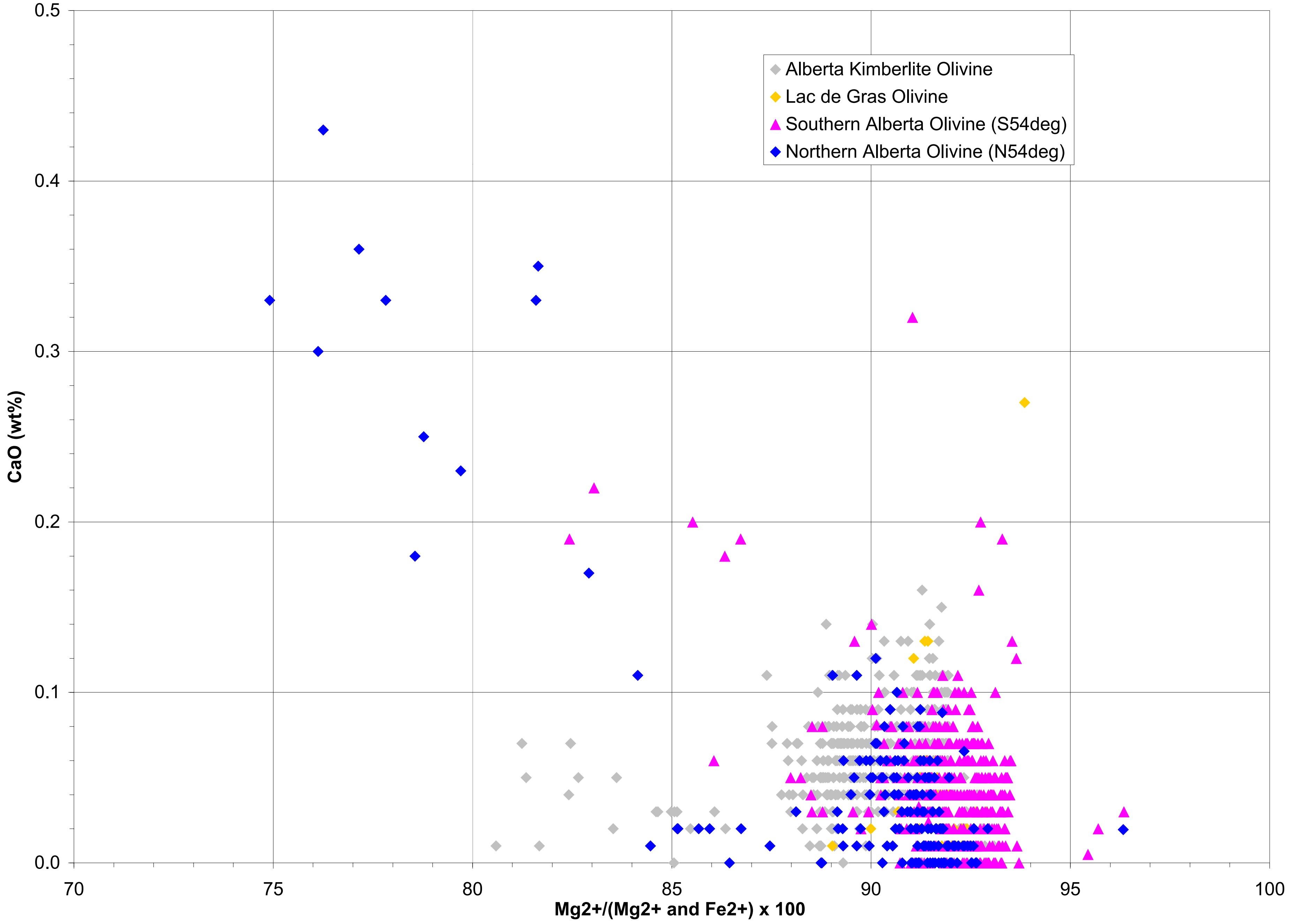
Appendix 7

Mg# vs Cr2O3 For Olivines From All Alberta Samples: 1994 - 2001

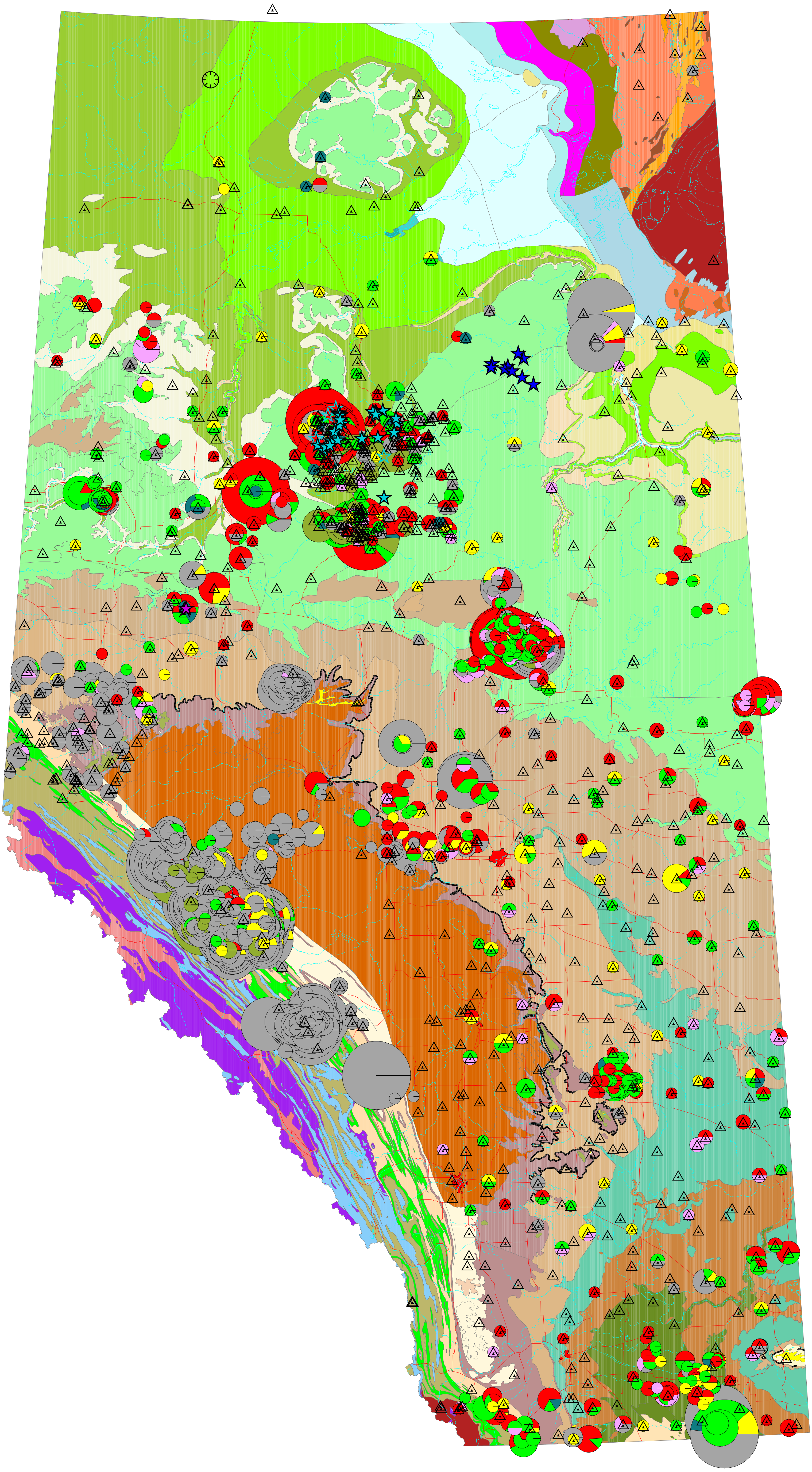


Appendix 7

Mg# vs CaO For Olivines From All Alberta Samples: 1994 - 2001



Appendix 8. Exploration and government indicator-minerals in Alberta (see next page for legend)



Appendix 8. Exploration and government indicator-minerals in Alberta (see previous page)

LEGEND

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱ Formation Boundary
╱ Major Highway
╱ Major River
╱ Bad Heart
╱ Whitemud
■ National Park
■ Major City

TERTIARY

■ Gravels
■ Porcupine Hills Fm
■ upper Porcupine Hills Fm
■ Willow Creek Fm

TERTIARY AND CRETACEOUS

■ Paskapoo Fm
■ Upper Paskapoo Fm
■ Lower Paskapoo Fm
■ Ravenscrag Fm

CRETACEOUS

■ Sweet Grass Intrusive - dark basic (minette) dykes
■ Sweet Grass Intrusive - pale green gray diorite porphyry plug
■ Scollard Fm
■ St. Mary River Fm
■ Blood Reserve Fm
■ Eastend Fm
■ Horseshoe Canyon Fm
■ Bearpaw Fm
■ Oldman Fm
■ Foremost Fm
■ Belly River Grp
■ Wapiti Grp
■ Pakowki Fm
■ Milk River Fm
■ Puskwaskau Fm
■ Lea Park Fm
■ Alberta Group
■ Kaskapau Fm
■ Smoky Grp
■ Dunvegan Fm
■ Shaftesbury Fm
■ LaBiche Fm
■ Peace River Fm
■ Pelican Fm
■ Joli Fou Fm
■ Loon River Fm
■ Grand Rapids Fm
■ Clearwater Fm
■ McMurray Fm
■ Keg River Fm
■ Chinchaga Fm
■ Coalspur Fm
■ Brazeau Fm
■ Paskapoo Fm
■ Brazeau Fm
■ Belly River St. Mary River Succession

DEVONIAN

■ Grosmont Fm
■ Mikkwa Fm
■ Ireton Fm
■ Waterways Fm
■ Hay River Fm
■ Slave Point Fm
■ Nyarling Fm
■ Fort Vermilion Fm
■ Muskey Fm
■ Fitzgerald Fm
■ Middle Devonian (undivided)

MESOZOIC

■ Lower Mesozoic-Lower Cretaceous

PALEOZOIC

■ Upper Paleozoic
■ Lower Paleozoic

PROTEROZOIC

■ Miette Grp
■ Purcell Supergroup

ARCHEAN

■ Undivided Archean
■ Granitoids
■ AxMylonitic Rocks
■ Charles lake Granitoids
■ High-grade metasedimentary Rocks
■ Granite Gneisses
■ Low Grade Metasedimentary & Metavolcanic Rocks

⊙ Astrobleme
△ Government sample locations

Olivine
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 38

Poss Eclogitic Garnets
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 13

Eclogitic Garnets >5% MgO & <23% Fe2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11

High NaAl Clinopyrozenes >2% Na2O & >2% Al2O3
▲ 1
⬢ 2

Eclogitic Clinopyroxenes
▲ 1
⬢ 2
⬢ 3

Chrome Diopside >0.5% Cr2O3 & <5% Fe2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 18

Cr-Picroilmenite >8% MgO & >1.5% Cr2O3
▲ 1
⬢ 2
⬢ 3

Picromentite >8% MgO
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 16

Pyropes >15.5% MgO
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 405

Mantle Chromites >8% MgO & >58% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 52

Kimberlitic Chromites >2% TiO2 & >40% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 9

Chromites >5% MgO & 20% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 94

Megacryst Pyrope
▲ 1
⬢ 2
⬢ 3

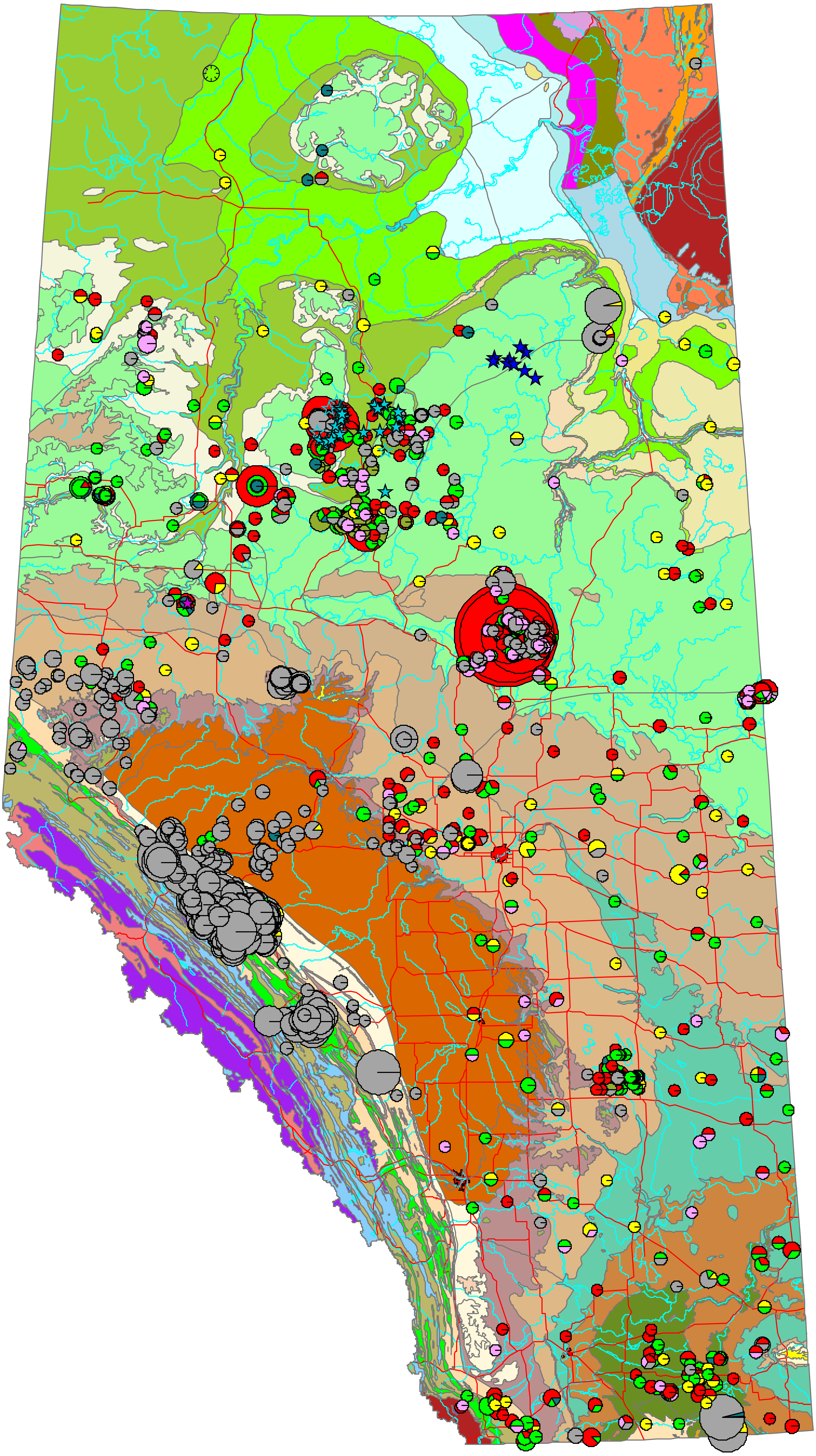
Low Ti Pyrope <0.4% TiO2
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 289

Hi Ti Pyrope >0.4% TiO2 & >2% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 114

High Cr2O3 Pyrope >8%
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 41

G10 Pyrope
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 33

Appendix 8. Indicator-minerals in Alberta (see next page for legend)



Appendix 8. Indicator-minerals in Alberta (see previous page)

LEGEND

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱ ╱ Bad Heart
╱╲ Whitemud
■ National Park
■ Major City

◌ Astrobleme
△ Government sample locations

Pie Chart Minerals
(size of chart proportional to total indicators)
■ Pyropes(>15.5mgo)
■ Eclogitic garnets (<23feo)
■ Cr-diopside(>0.5cr2o3<5feo)
■ Olivine
■ Eclogitic cpx
■ Ilmenites(>8mgo)
■ Chromites(>5mgo>20cr2o3)

TERTIARY

- ■ Gravels
- ■ Porcupine Hills Fm
- ■ upper Porcupine Hills Fm
- ■ Willow Creek Fm

TERTIARY AND CRETACEOUS

- ■ Paskapoo Fm
- ■ Upper Paskapoo Fm
- ■ Lower Paskapoo Fm
- ■ Ravenscrag Fm

CRETACEOUS

- ■ Sweet Grass Intrusive - dark basic (minette) dykes
- ■ Sweet Grass Intrusive - pale green gray diorite porphyry plug
- ■ Scollard Fm
- ■ St. Mary River Fm
- ■ Blood Reserve Fm
- ■ Eastend Fm
- ■ Horseshoe Canyon Fm
- ■ Bearpaw Fm
- ■ Oldman Fm
- ■ Foremost Fm
- ■ Belly River Grp
- ■ Wapiti Grp
- ■ Pakowki Fm
- ■ Milk River Fm
- ■ Puskwaskau Fm
- ■ Lea Park Fm
- ■ Alberta Group
- ■ Kaskapau Fm
- ■ Smoky Grp
- ■ Dunvegan Fm
- ■ Shaftesbury Fm
- ■ LaBiche Fm
- ■ Peace River Fm
- ■ Pelican Fm
- ■ Joli Fou Fm
- ■ Loon River Fm
- ■ Grand Rapids Fm
- ■ Clearwater Fm
- ■ McMurray Fm
- ■ Keg River Fm
- ■ Chinchaga Fm
- ■ Coalspur Fm
- ■ Brazeau Fm
- ■ Paskapoo Fm
- ■ Brazeau Fm
- ■ Belly River St. Mary River Succession

DEVONIAN

- ■ Grosmont Fm
- ■ Mikkwa Fm
- ■ Ireton Fm
- ■ Waterways Fm
- ■ Hay River Fm
- ■ Slave Point Fm
- ■ Nyarling Fm
- ■ Fort Vermilion Fm
- ■ Muskey Fm
- ■ Fitzgerald Fm
- ■ Middle Devonian (undivided)

MESOZOIC

- ■ Lower Mesozoic-Lower Cretaceous

PALEOZOIC

- ■ Upper Paleozoic
- ■ Lower Paleozoic

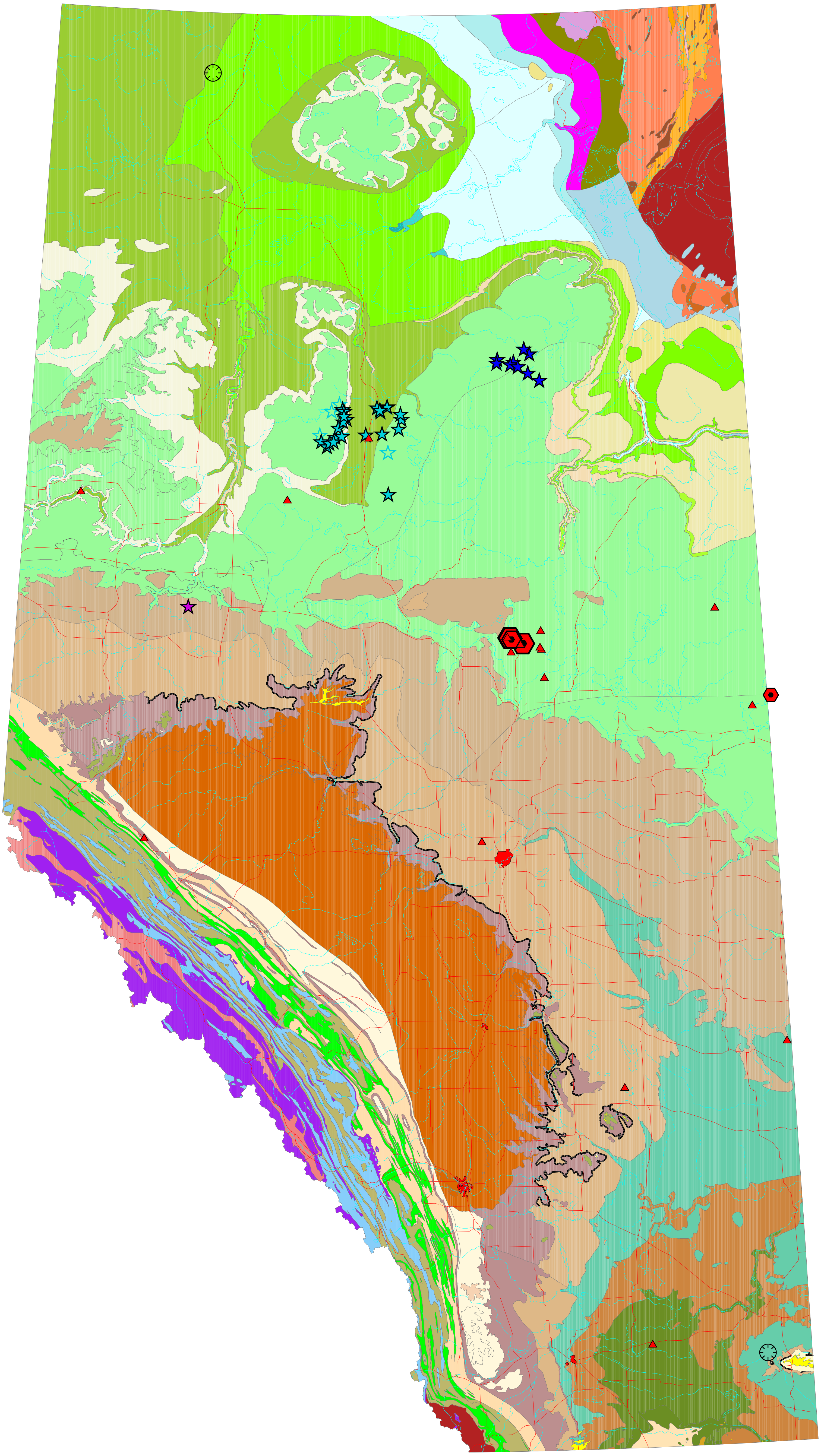
PROTEROZOIC

- ■ Miette Grp
- ■ Purcell Supergroup

ARCHEAN

- ■ Undivided Archean
- ■ Granitoids
- ■ AxMylonitic Rocks
- ■ Charles lake Granitoids
- ■ High-grade metasedimentary Rocks
- ■ Granite Gneisses
- ■ Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. G10 pyrope garnet (see next page for legend)



Appendix 8. G10 pyrope garnet (see previous page)

LEGEND

G10 Pyrope
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 33

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
Formation Boundary
Major Highway
Major River
Bad Heart
Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY
🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS
⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS
🟨 Sweet Grass Intrusive - dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River St. Mary River Succession

DEVONIAN
🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

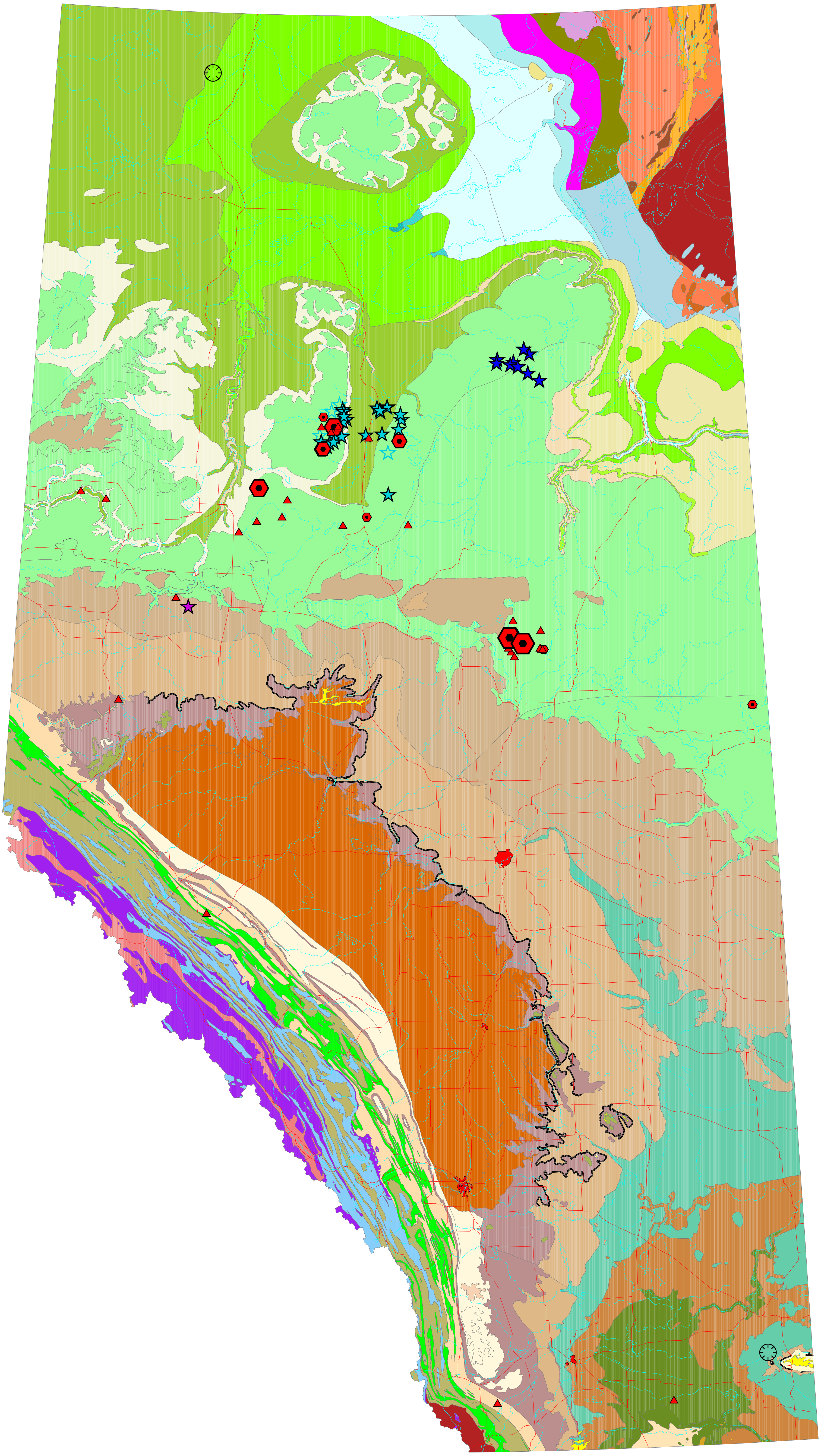
MESOZOIC
🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC
🟦 Upper Paleozoic
🟪 Lower Paleozoic

PROTEROZOIC
🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN
🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
⬜ Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. High-chrome pyrope garnet with >8 wt. % Cr2O3 (see next page for legend)



Appendix 8. High-chrome pyrope garnet with >8 wt. % Cr2O3 (see previous page)

LEGEND

High Cr2O3 Pyrope >8%
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 41

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱ ╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

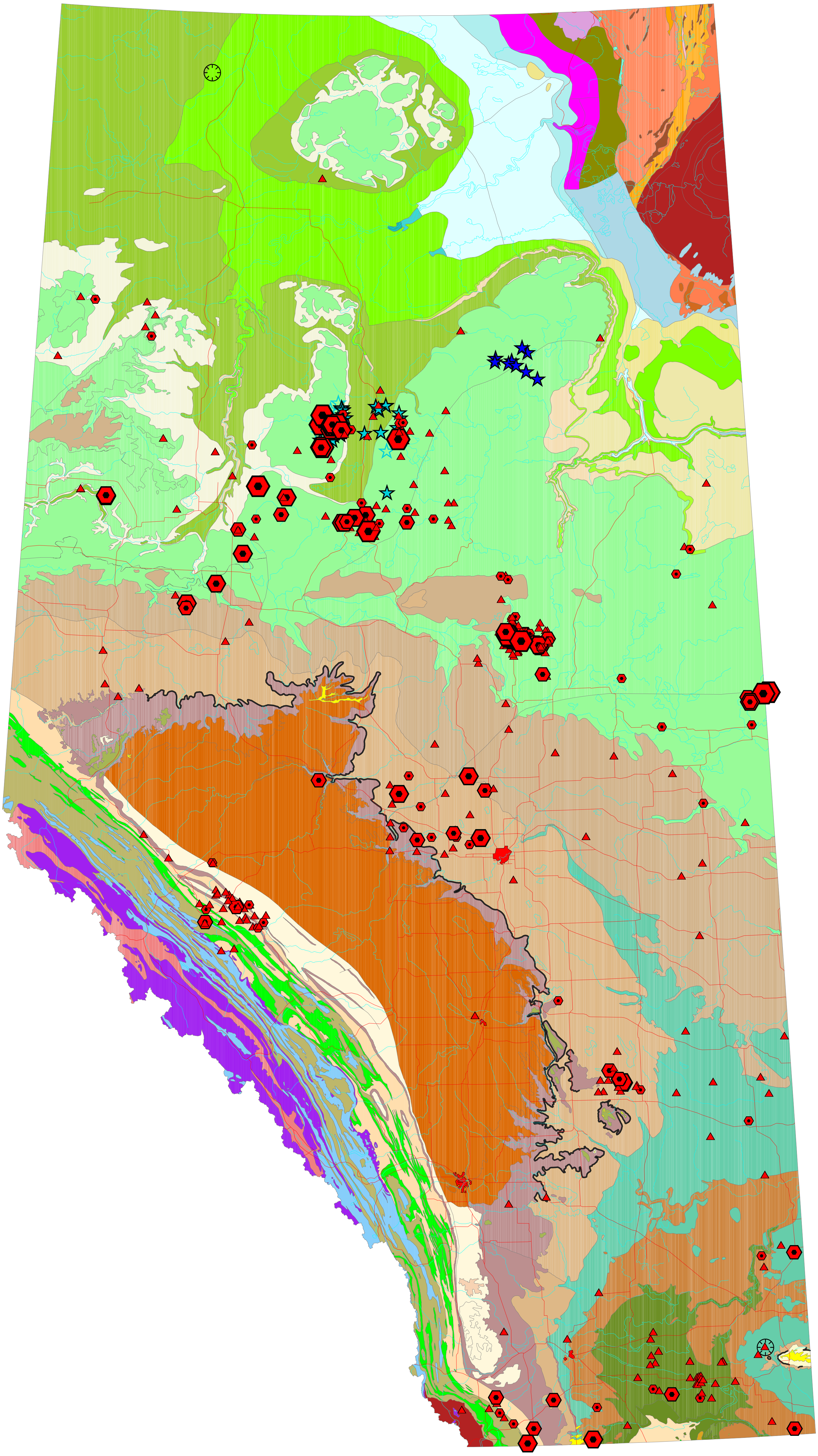
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟪 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. Pyrope garnet with >15.5 wt. % MgO (see next page for legend)



Appendix 8. Pyrope garnet with >15.5 wt. % MgO (see previous page)

LEGEND

High Cr2O3 Pyrope >8%
- ▲ 1
- ⬢ 2
- ⬢ 3 - 4
- ⬢ 5 - 10
- ⬢ 11 - 41

- ★ Birch Mountain Kimberlite
- ★ Buffalo Head Hills Kimberlite
- ☆ Possible Buffalo Head Hills Kimberlite

Mountain lake kimberlite.shp
- ★ Mountain Lake Kimberlite
- ╱╲ Formation Boundary
- ╱╲ Major Highway
- ╱╲ Major River
- ╱╱ Bad Heart
- ╱╲ Whitemud
- □ National Park
- ■ Major City
- ◌ Astrobleme

TERTIARY
- ■ Gravels
- ■ Porcupine Hills Fm
- ■ upper Porcupine Hills Fm
- ■ Willow Creek Fm

TERTIARY AND CRETACEOUS
- ■ Paskapoo Fm
- ■ Upper Paskapoo Fm
- ■ Lower Paskapoo Fm
- ■ Ravenscrag Fm

CRETACEOUS
- ■ Sweet Grass Intrusive - dark basic (minette) dykes
- ■ Sweet Grass Intrusive - pale green gray diorite porphyry plug
- ■ Scollard Fm
- ■ St. Mary River Fm
- ■ Blood Reserve Fm
- ■ Eastend Fm
- ■ Horseshoe Canyon Fm
- ■ Bearpaw Fm
- ■ Oldman Fm
- ■ Foremost Fm
- ■ Belly River Grp
- ■ Wapiti Grp
- ■ Pakowki Fm
- ■ Milk River Fm
- ■ Puskwaskau Fm
- ■ Lea Park Fm
- ■ Alberta Group
- ■ Kaskapau Fm
- ■ Smoky Grp
- ■ Dunvegan Fm
- ■ Shaftesbury Fm
- ■ LaBiche Fm
- ■ Peace River Fm
- ■ Pelican Fm
- ■ Joli Fou Fm
- ■ Loon River Fm
- ■ Grand Rapids Fm
- ■ Clearwater Fm
- ■ McMurray Fm
- ■ Keg River Fm
- ■ Chinchaga Fm
- ■ Coalspur Fm
- ■ Brazeau Fm
- ■ Paskapoo Fm
- ■ Brazeau Fm
- ■ Belly River St. Mary River Succession

DEVONIAN
- ■ Grosmont Fm
- ■ Mikkwa Fm
- ■ Ireton Fm
- ■ Waterways Fm
- ■ Hay River Fm
- ■ Slave Point Fm
- ■ Nyarling Fm
- ■ Fort Vermilion Fm
- ■ Muskey Fm
- ■ Fitzgerald Fm
- ■ Middle Devonian (undivided)

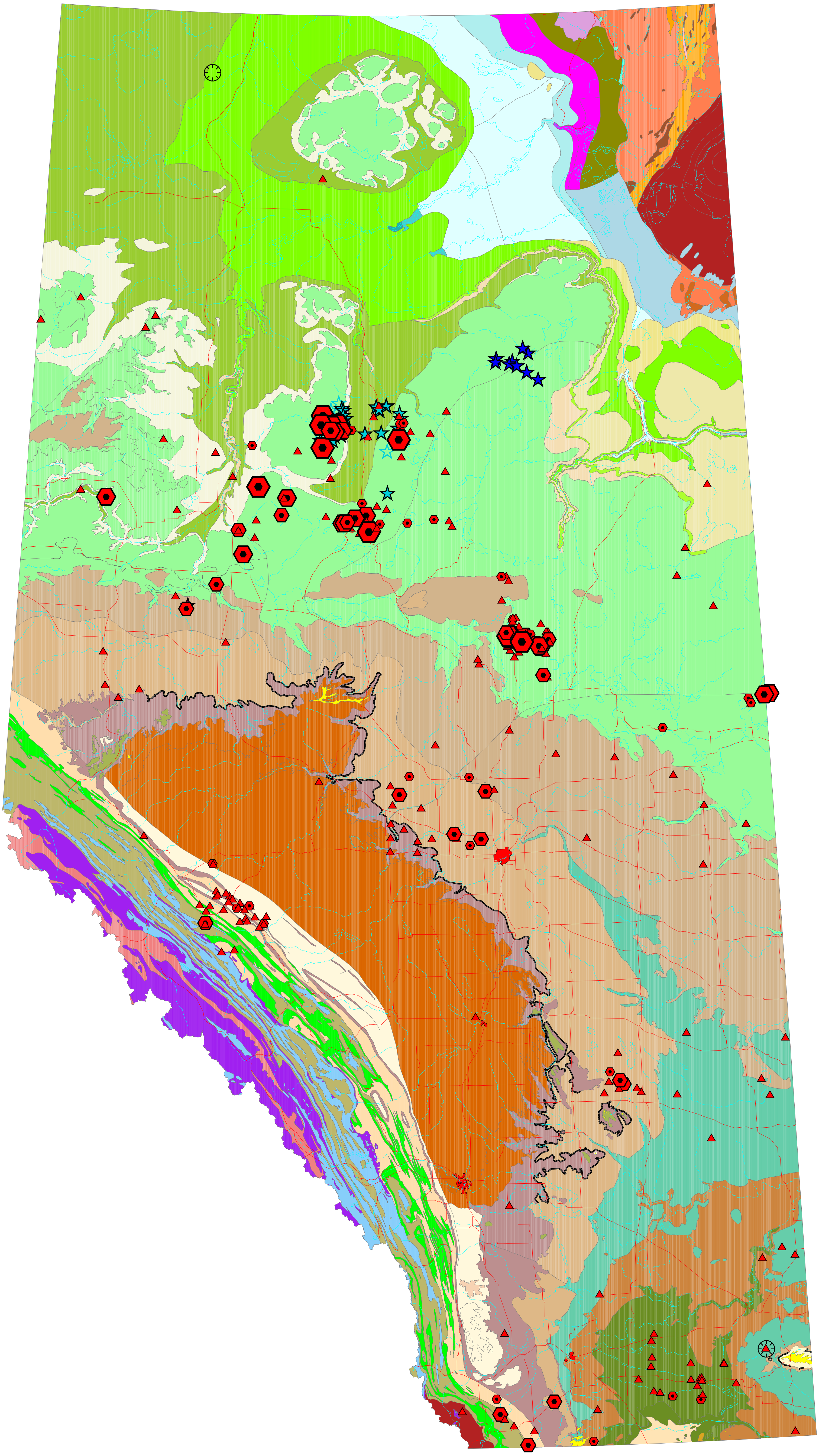
MESOZOIC
- ■ Lower Mesozoic-Lower Cretaceous

PALEOZOIC
- ■ Upper Paleozoic
- ■ Lower Paleozoic

PROTEROZOIC
- ■ Miette Grp
- ■ Purcell Supergroup

ARCHEAN
- ■ Undivided Archean
- ■ Granitoids
- ■ AxMylonitic Rocks
- ■ Charles lake Granitoids
- ■ High-grade metasedimentary Rocks
- ■ Granite Gneisses
- ■ Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Low-titanium pyrope garnet with <0.4 wt. % TiO2 (see next page for legend)



Appendix 8. Low-titanium pyrope garnet with <0.4 wt. % TiO2 (see previous page)

LEGEND

Low Ti Pyrope <0.4% TiO2
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 289

★ Birch Mountain Kimberlite

★ Buffalo Head Hills Kimberlite

☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
Formation Boundary
Major Highway
Major River
Bad Heart
Whitemud
National Park
Major City
Astrobleme

TERTIARY

Gravels
Porcupine Hills Fm
upper Porcupine Hills Fm
Willow Creek Fm

TERTIARY AND CRETACEOUS

Paskapoo Fm
Upper Paskapoo Fm
Lower Paskapoo Fm
Ravenscrag Fm

CRETACEOUS

Sweet Grass Intrusive -
dark basic (minette) dykes
Sweet Grass Intrusive - pale
green gray diorite porphyry plug

Scollard Fm
St. Mary River Fm
Blood Reserve Fm
Eastend Fm
Horseshoe Canyon Fm
Bearpaw Fm
Oldman Fm
Foremost Fm
Belly River Grp
Wapiti Grp
Pakowki Fm
Milk River Fm
Puskwaskau Fm
Lea Park Fm
Alberta Group
Kaskapau Fm
Smoky Grp
Dunvegan Fm
Shaftesbury Fm
LaBiche Fm
Peace River Fm
Pelican Fm
Joli Fou Fm
Loon River Fm
Grand Rapids Fm
Clearwater Fm
McMurray Fm
Keg River Fm
Chinchaga Fm
Coalspur Fm
Brazeau Fm
Paskapoo Fm
Brazeau Fm
Belly River
St. Mary River Succession

DEVONIAN

Grosmont Fm
Mikkwa Fm
Ireton Fm
Waterways Fm
Hay River Fm
Slave Point Fm
Nyarling Fm
Fort Vermilion Fm
Muskey Fm
Fitzgerald Fm
Middle Devonian (undivided)

MESOZOIC

Lower Mesozoic-Lower Cretaceous

PALEOZOIC

Upper Paleozoic
Lower Paleozoic

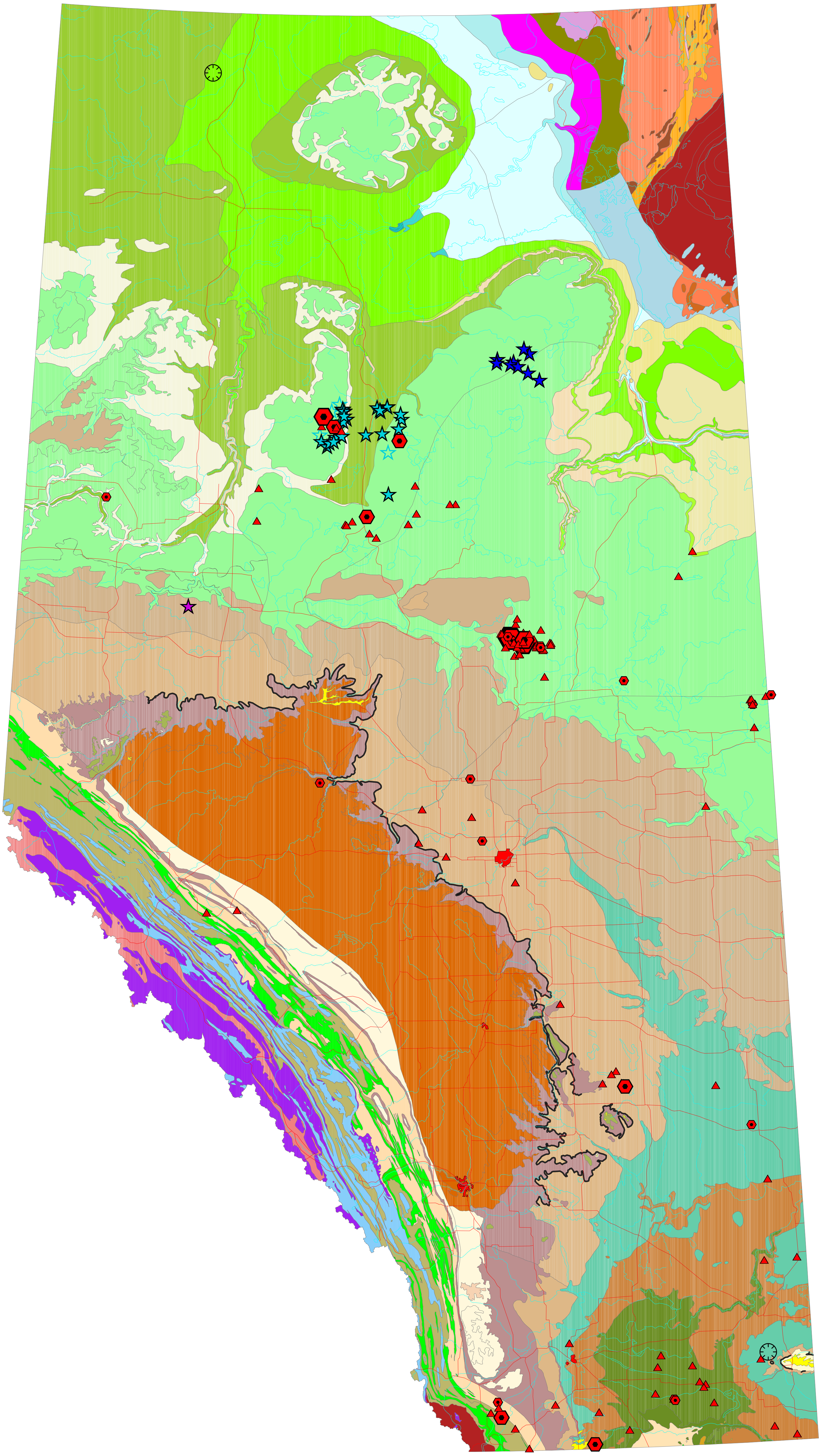
PROTEROZOIC

Miette Grp
Purcell Supergroup

ARCHEAN

Undivided Archean
Granitoids
AxMylonitic Rocks
Charles lake Granitoids
High-grade metasedimentary Rocks
Granite Gneisses
Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. High-chrome pyrope garnet with >2 wt. % Cr2O3 and >0.4 wt. % TiO2 (see next page for legend)



Appendix 8. High-chrome pyrope garnet with >2 wt. % Cr2O3 and >0.4 wt. % TiO2 (see previous page)

LEGEND

Hi Ti Pyrope >0.4% TiO2 & >2% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 114

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive - dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
🟧 Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
🟧 Peace River Fm
🟧 Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
🟧 Brazeau Fm
⬜ Paskapoo Fm
🟧 Brazeau Fm
🟫 Belly River St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

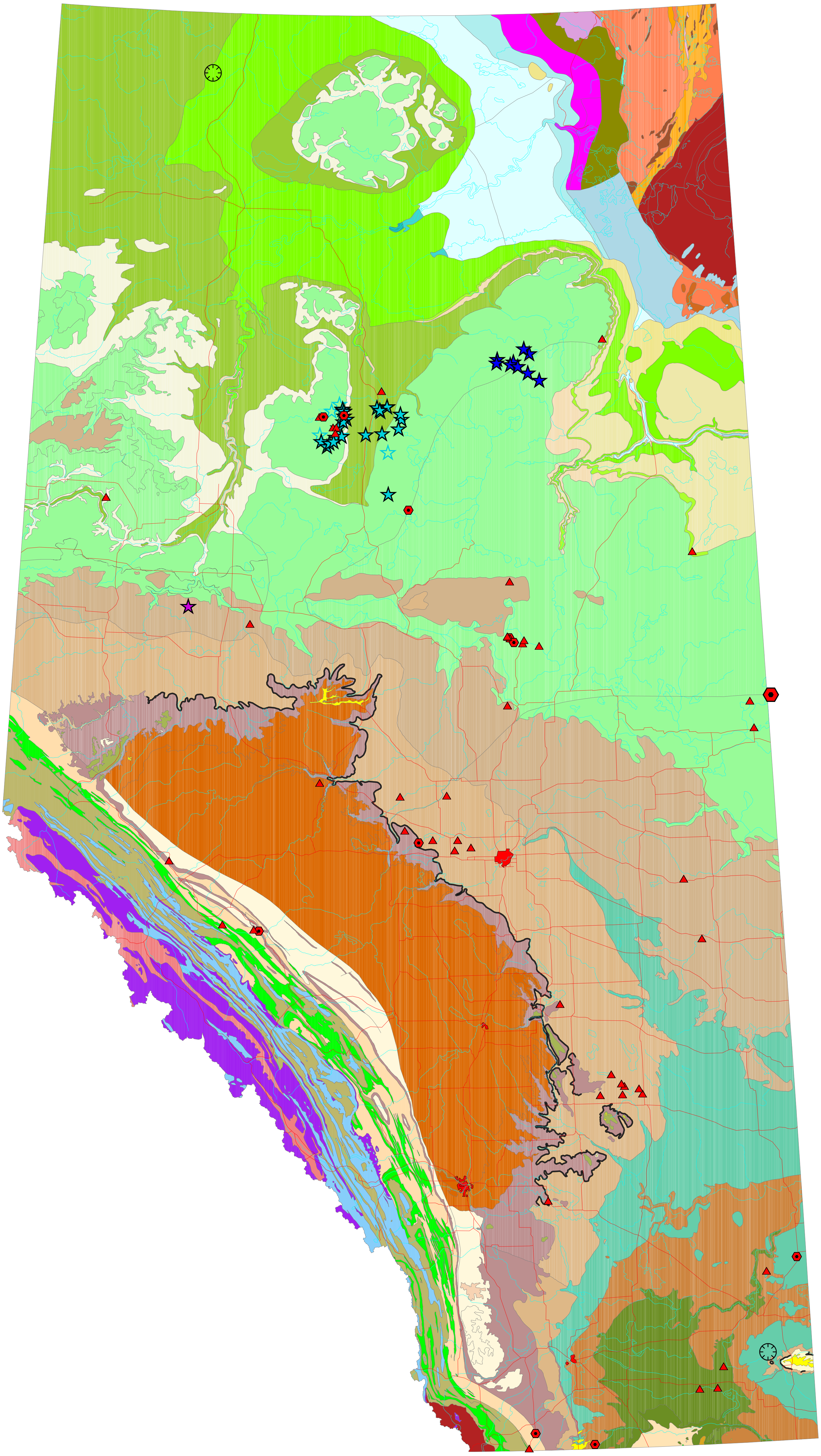
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Megacrystic pyrope garnet (see next page for legend)



Appendix 8. Megacrystic pyrope garnet (see next page for legend)

LEGEND

Megacryst Pyrope
▲ 1
⬢ 2
⬢ 3

★ Birch Mountain Kimberlite

★ Buffalo Head Hills Kimberlite

☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱ ╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
⬜ Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

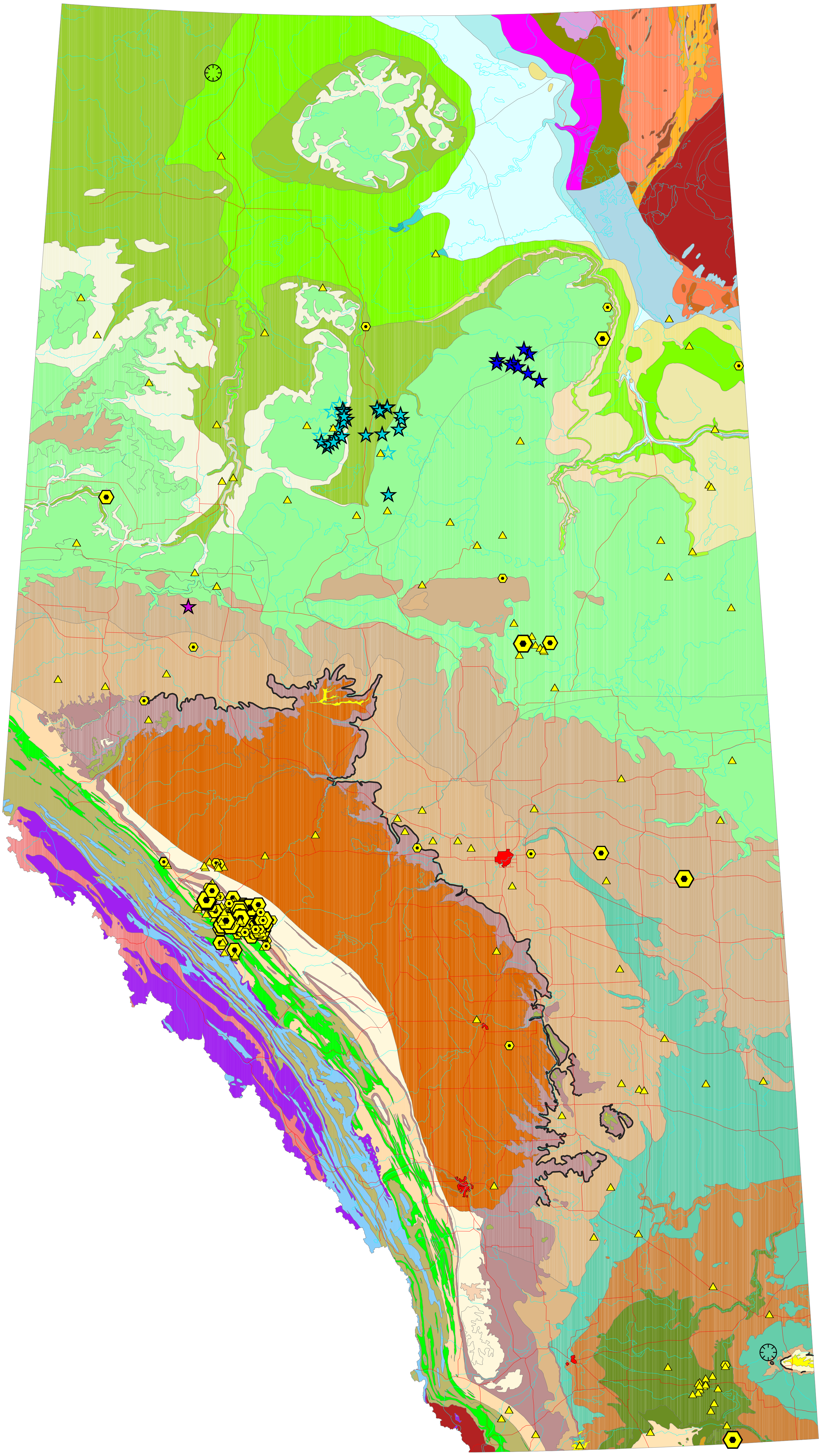
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. Eclogitic garnet with <23 wt. % FeO, >5 wt. % MgO and >3 wt. % CaO (see next page for legend)



Appendix 8. Eclogitic garnet with <23 wt. % FeO, >5 wt. % MgO and >3 wt. % CaO (see previous page)

LEGEND

Eclogitic Garnets >5% MgO & <23% Fe2O3 & >3%CaO
- △ 1
- ⬢ 2
- ⬢ 3 - 4
- ⬢ 5 - 10
- ⬢ 11

- ★ Birch Mountain Kimberlite
- ★ Buffalo Head Hills Kimberlite
- ☆ Possible Buffalo Head Hills Kimberlite

Mountain lake kimberlite.shp
- ★ Mountain Lake Kimberlite
- Formation Boundary
- Major Highway
- Major River
- Bad Heart
- Whitemud
- ⬜ National Park
- 🟥 Major City
- ◌ Astrobleme

TERTIARY
- 🟨 Gravels
- ⬜ Porcupine Hills Fm
- 🟧 upper Porcupine Hills Fm
- 🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS
- ⬜ Paskapoo Fm
- 🟧 Upper Paskapoo Fm
- 🟩 Lower Paskapoo Fm
- ⬜ Ravenscrag Fm

CRETACEOUS
- 🟨 Sweet Grass Intrusive - dark basic (minette) dykes
- ⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug

- 🟫 Scollard Fm
- 🟫 St. Mary River Fm
- 🟫 Blood Reserve Fm
- 🟫 Eastend Fm
- 🟫 Horseshoe Canyon Fm
- 🟩 Bearpaw Fm
- 🟧 Oldman Fm
- 🟧 Foremost Fm
- 🟫 Belly River Grp
- 🟫 Wapiti Grp
- 🟩 Pakowki Fm
- ⬜ Milk River Fm
- 🟩 Puskwaskau Fm
- 🟩 Lea Park Fm
- 🟩 Alberta Group
- 🟩 Kaskapau Fm
- 🟩 Smoky Grp
- ⬜ Dunvegan Fm
- 🟩 Shaftesbury Fm
- 🟩 LaBiche Fm
- ⬜ Peace River Fm
- ⬜ Pelican Fm
- 🟩 Joli Fou Fm
- 🟩 Loon River Fm
- 🟨 Grand Rapids Fm
- 🟩 Clearwater Fm
- 🟨 McMurray Fm
- 🟫 Keg River Fm
- 🟪 Chinchaga Fm
- 🟫 Coalspur Fm
- ⬜ Brazeau Fm
- ⬜ Paskapoo Fm
- ⬜ Brazeau Fm
- 🟫 Belly River St. Mary River Succession

DEVONIAN
- 🟦 Grosmont Fm
- 🟦 Mikkwa Fm
- ⬜ Ireton Fm
- ⬜ Waterways Fm
- ⬜ Hay River Fm
- 🟦 Slave Point Fm
- 🟪 Nyarling Fm
- 🟪 Fort Vermilion Fm
- 🟪 Muskey Fm
- 🟩 Fitzgerald Fm
- 🟦 Middle Devonian (undivided)

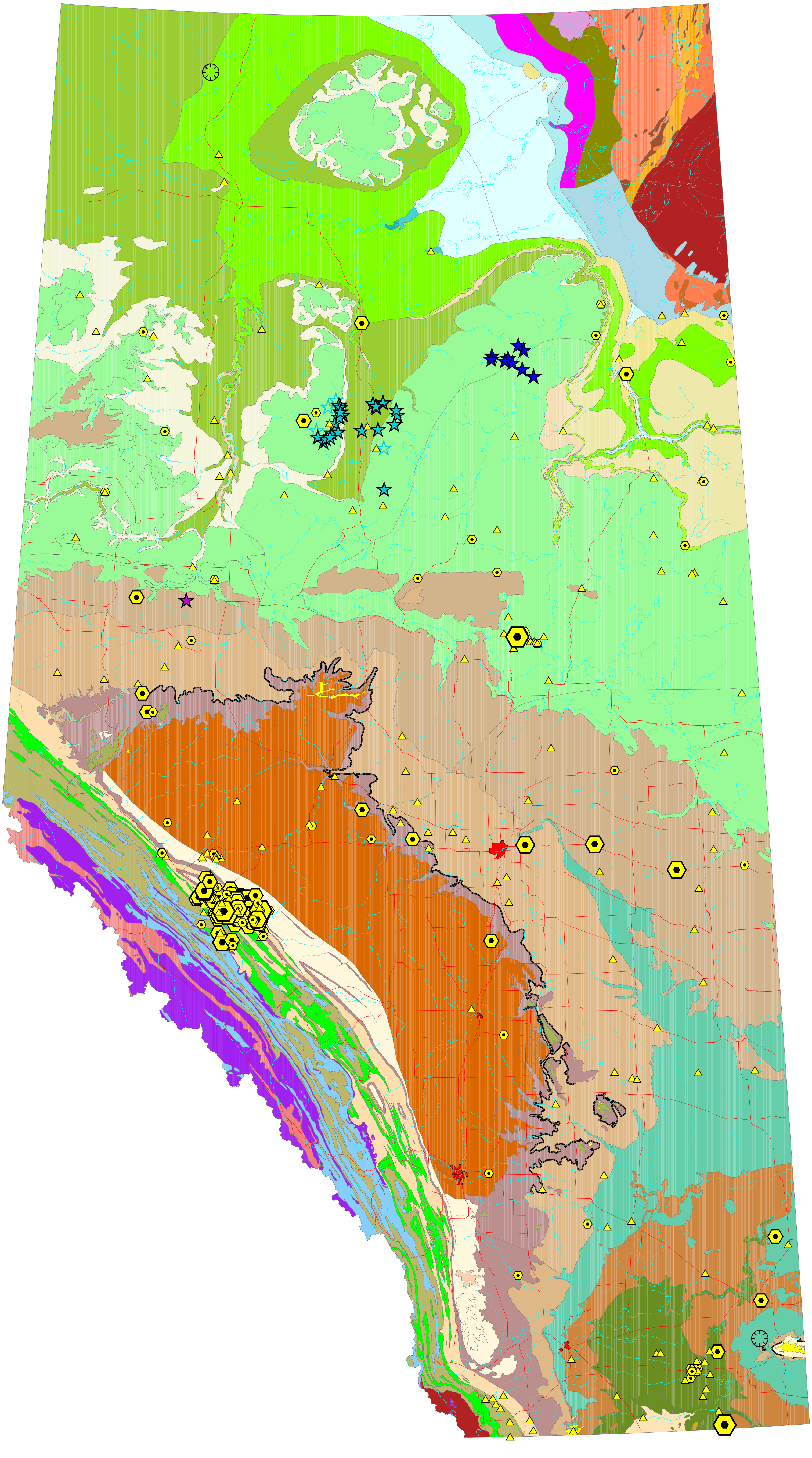
MESOZOIC
- 🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC
- 🟦 Upper Paleozoic
- 🟪 Lower Paleozoic

PROTEROZOIC
- 🟥 Miette Grp
- 🟥 Purcell Supergroup

ARCHEAN
- 🟥 Undivided Archean
- 🟧 Granitoids
- 🟧 AxMylonitic Rocks
- 🟥 Charles lake Granitoids
- 🟩 High-grade metasedimentary Rocks
- 🟧 Granite Gneisses
- 🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Eclogitic garnet with <25 wt. % FeO and >5 wt. % MgO (see next page for legend)



Appendix 8. Eclogitic garnet with <25 wt. % FeO and >5 wt. % MgO (see previous page)

LEGEND

Poss Eclogitic Garnets <25FeO & >5MgO
△ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 13

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
⋀ Formation Boundary
⋀ Major Highway
⋀ Major River
⋀ Bad Heart
⋀ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive - dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

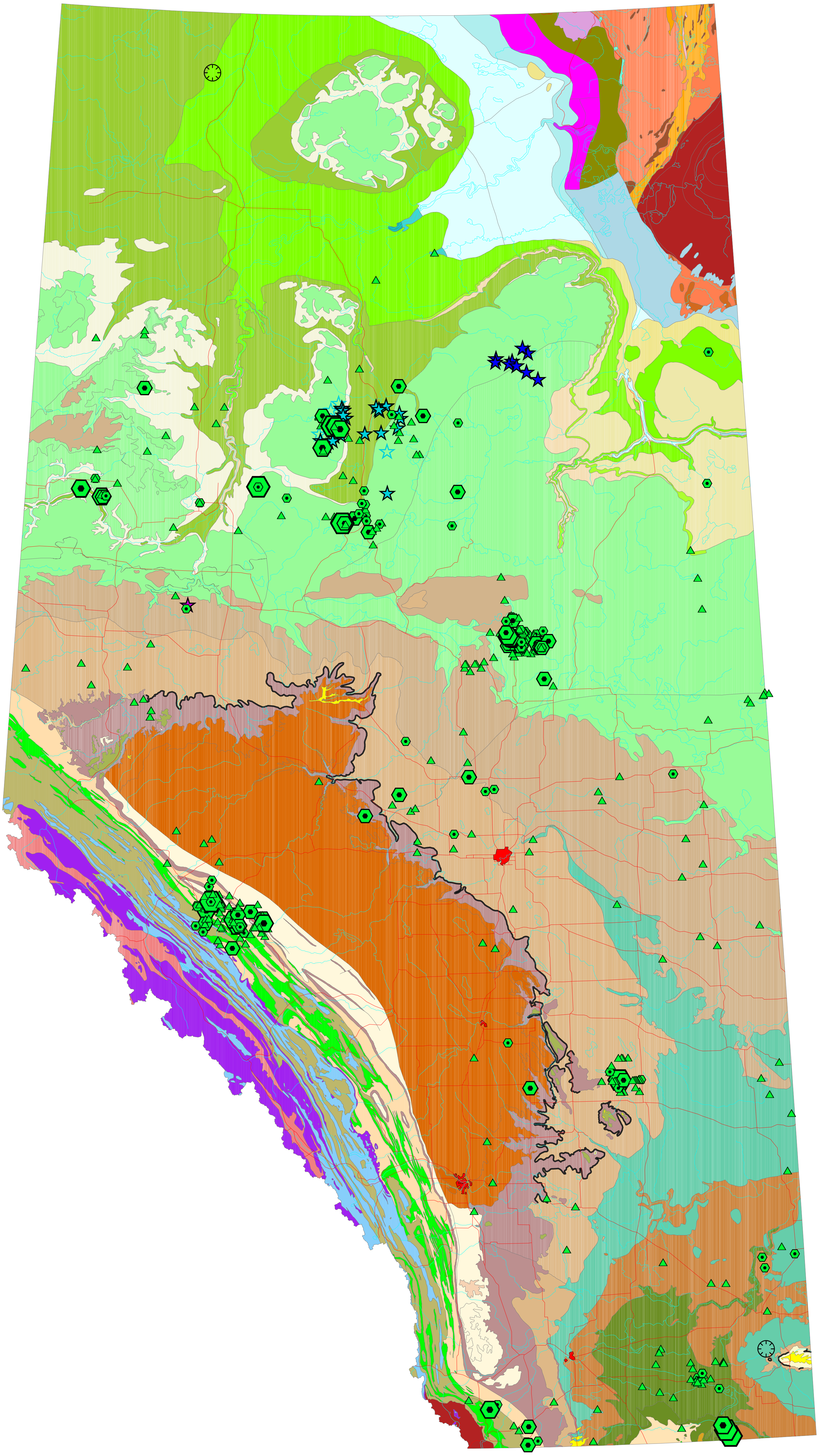
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Chrome diopside with >0.5 wt. % Cr2O3 and <5 wt. % Fe2O3 (see next page for legend)



Appendix 8. Chrome diopside with >0.5 wt. % Cr2O3 and <5 wt. % Fe2O3 (see previous page)

LEGEND

Chromite Diopside >0.5% Cr2O3 & <5% Fe2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 18

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
⋀ Formation Boundary
⋀ Major Highway
⋀ Major River
⋀ Bad Heart
⋀ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
🟧 Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
🟧 Peace River Fm
🟧 Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
🟧 Brazeau Fm
⬜ Paskapoo Fm
🟧 Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

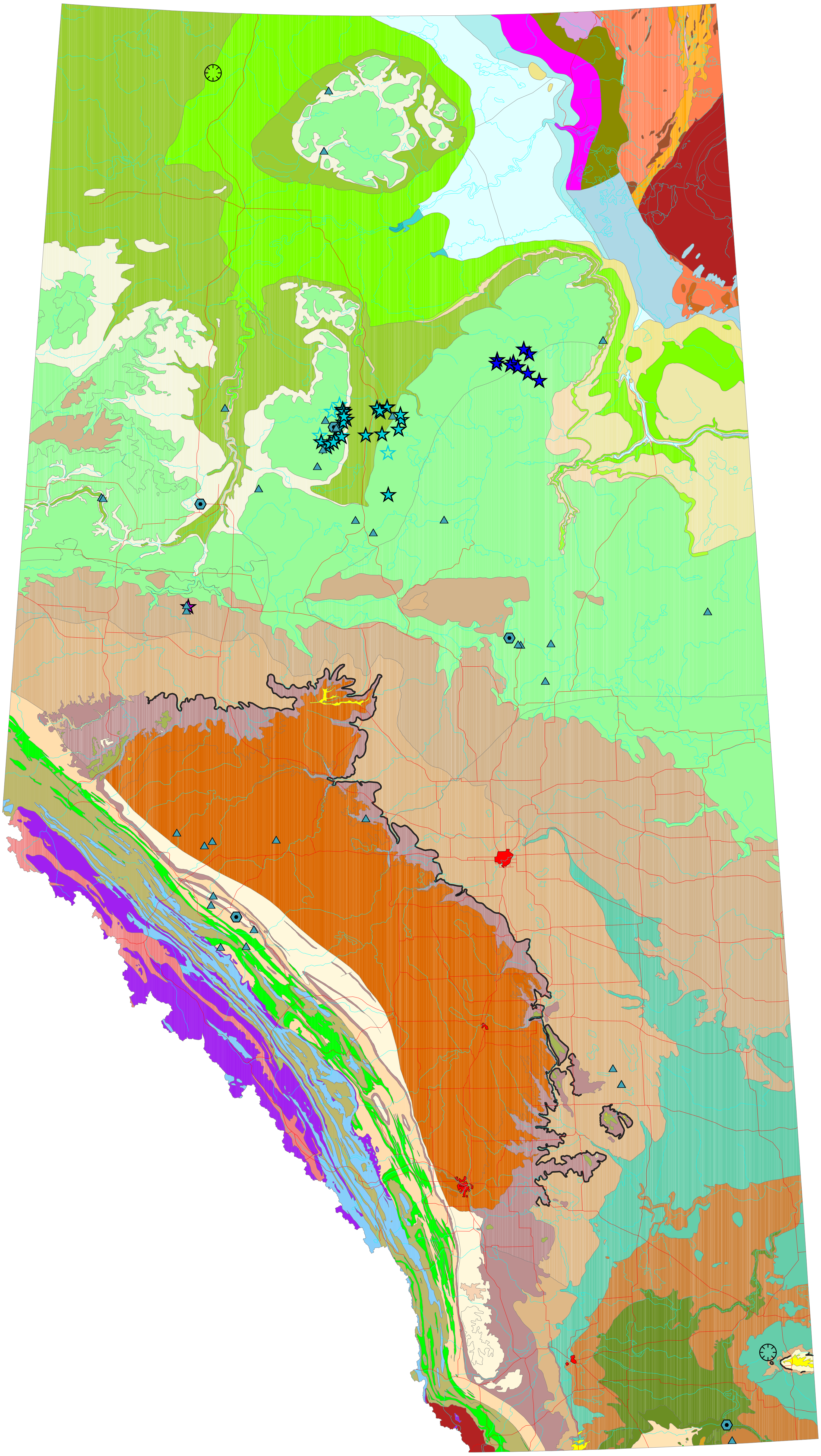
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. Clinopyroxene with >2 wt. % Na2O and >2 wt. % Al2O3 (see next page for legend)



Appendix 8. Clinopyroxene with >2 wt. % Na2O and >2 wt. % Al2O3 (see previous page)

LEGEND

High NaAl Clinopyroxenes >2% Na2O & >2% Al2O3

- ▲ 1
- ⬢ 2
- ★ Birch Mountain Kimberlite
- ★ Buffalo Head Hills Kimberlite
- ☆ Possible Buffalo Head Hills Kimberlite

Mountain lake kimberlite.shp

- ★ Mountain Lake Kimberlite
- ╱╲╱ Formation Boundary
- ╱╲╱ Major Highway
- ╱╲╱ Major River
- ╱ ╱ Bad Heart
- ╱╲╱ Whitemud
- ⬜ National Park
- 🟥 Major City
- ○ Astrobleme

TERTIARY

- 🟨 Gravels
- ⬜ Porcupine Hills Fm
- 🟧 upper Porcupine Hills Fm
- 🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

- ⬜ Paskapoo Fm
- 🟧 Upper Paskapoo Fm
- 🟩 Lower Paskapoo Fm
- ⬜ Ravenscrag Fm

CRETACEOUS

- 🟨 Sweet Grass Intrusive - dark basic (minette) dykes
- ⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug
- 🟫 Scollard Fm
- 🟫 St. Mary River Fm
- 🟫 Blood Reserve Fm
- 🟫 Eastend Fm
- 🟫 Horseshoe Canyon Fm
- 🟩 Bearpaw Fm
- 🟧 Oldman Fm
- 🟧 Foremost Fm
- 🟫 Belly River Grp
- 🟫 Wapiti Grp
- 🟩 Pakowki Fm
- 🟧 Milk River Fm
- 🟩 Puskwaskau Fm
- 🟩 Lea Park Fm
- 🟩 Alberta Group
- 🟩 Kaskapau Fm
- 🟩 Smoky Grp
- ⬜ Dunvegan Fm
- 🟩 Shaftesbury Fm
- 🟩 LaBiche Fm
- 🟧 Peace River Fm
- 🟧 Pelican Fm
- 🟩 Joli Fou Fm
- 🟩 Loon River Fm
- 🟨 Grand Rapids Fm
- 🟩 Clearwater Fm
- 🟨 McMurray Fm
- 🟩 Keg River Fm
- 🟪 Chinchaga Fm
- 🟫 Coalspur Fm
- 🟧 Brazeau Fm
- ⬜ Paskapoo Fm
- 🟧 Brazeau Fm
- 🟩 Belly River St. Mary River Succession

DEVONIAN

- 🟦 Grosmont Fm
- 🟦 Mikkwa Fm
- ⬜ Ireton Fm
- ⬜ Waterways Fm
- ⬜ Hay River Fm
- 🟦 Slave Point Fm
- 🟪 Nyarling Fm
- 🟪 Fort Vermilion Fm
- 🟪 Muskey Fm
- 🟩 Fitzgerald Fm
- 🟦 Middle Devonian (undivided)

MESOZOIC

- 🟩 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

- 🟦 Upper Paleozoic
- 🟪 Lower Paleozoic

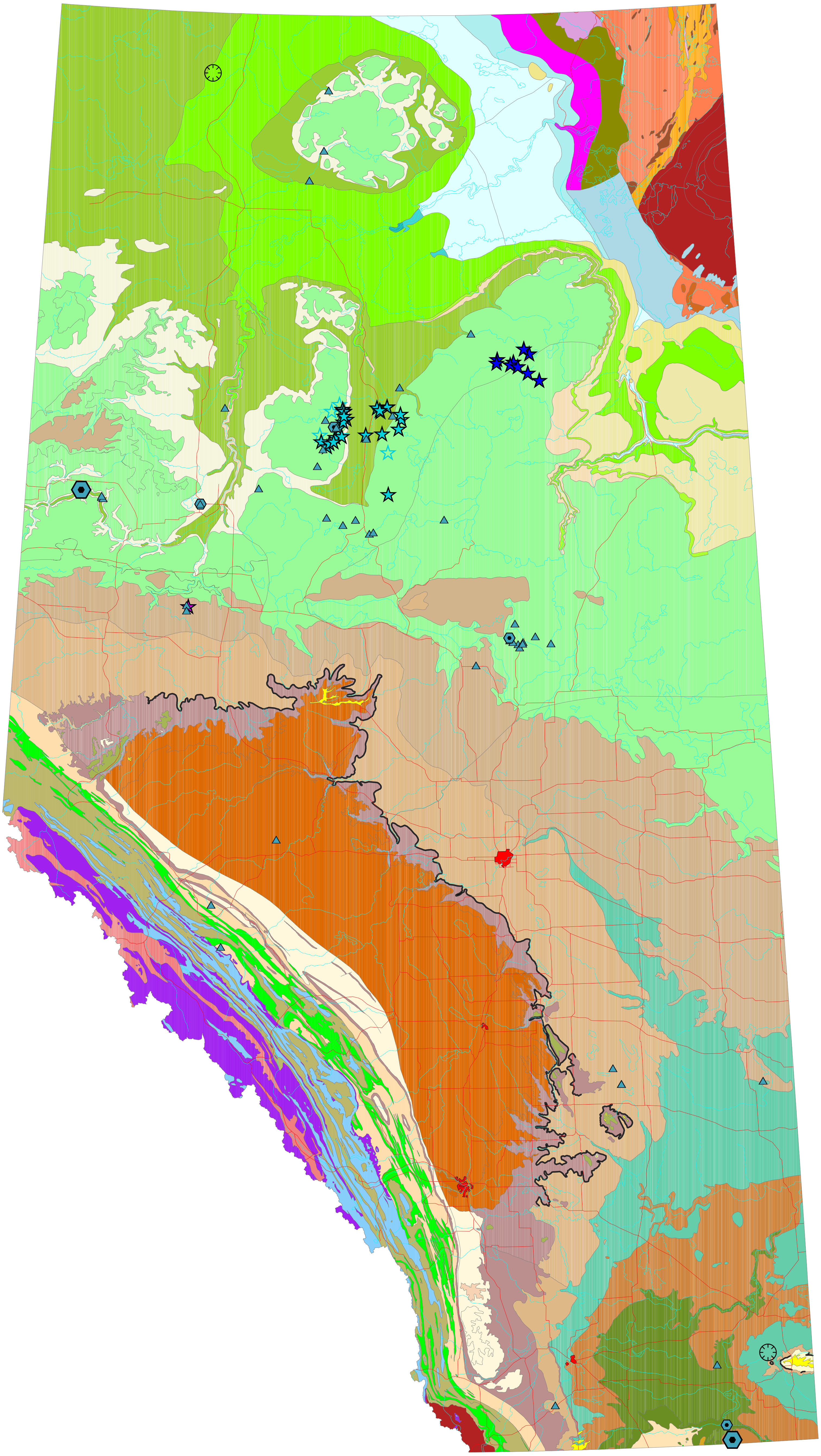
PROTEROZOIC

- 🟥 Miette Grp
- 🟥 Purcell Supergroup

ARCHEAN

- 🟥 Undivided Archean
- 🟧 Granitoids
- 🟧 AxMylonitic Rocks
- 🟥 Charles lake Granitoids
- 🟩 High-grade metasedimentary Rocks
- 🟧 Granite Gneisses
- 🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Eclogitic clinopyroxene (see next page for legend)



Appendix 8. Eclogitic clinopyroxene (see previous page)

LEGEND

Eclogitic Clinopyroxenes

- ▲ 1
- ⬢ 2
- ⬢ 3

- ★ Birch Mountain Kimberlite
- ★ Buffalo Head Hills Kimberlite
- ☆ Possible Buffalo Head Hills Kimberlite

Mountain lake kimberlite.shp

- ★ Mountain Lake Kimberlite
- ⋀ Formation Boundary
- ⋀ Major Highway
- ⋀ Major River
- ⋀ Bad Heart
- ⋀ Whitemud
- □ National Park
- ■ Major City
- ◌ Astrobleme

TERTIARY

- ■ Gravels
- ■ Porcupine Hills Fm
- ■ upper Porcupine Hills Fm
- ■ Willow Creek Fm

TERTIARY AND CRETACEOUS

- ■ Paskapoo Fm
- ■ Upper Paskapoo Fm
- ■ Lower Paskapoo Fm
- ■ Ravenscrag Fm

CRETACEOUS

- ■ Sweet Grass Intrusive - dark basic (minette) dykes
- ■ Sweet Grass Intrusive - pale green gray diorite porphyry plug
- ■ Scollard Fm
- ■ St. Mary River Fm
- ■ Blood Reserve Fm
- ■ Eastend Fm
- ■ Horseshoe Canyon Fm
- ■ Bearpaw Fm
- ■ Oldman Fm
- ■ Foremost Fm
- ■ Belly River Grp
- ■ Wapiti Grp
- ■ Pakowki Fm
- ■ Milk River Fm
- ■ Puskwaskau Fm
- ■ Lea Park Fm
- ■ Alberta Group
- ■ Kaskapau Fm
- ■ Smoky Grp
- ■ Dunvegan Fm
- ■ Shaftesbury Fm
- ■ LaBiche Fm
- ■ Peace River Fm
- ■ Pelican Fm
- ■ Joli Fou Fm
- ■ Loon River Fm
- ■ Grand Rapids Fm
- ■ Clearwater Fm
- ■ McMurray Fm
- ■ Keg River Fm
- ■ Chinchaga Fm
- ■ Coalspur Fm
Brazeau Fm
- ■ Paskapoo Fm
Brazeau Fm
- ■ Belly River
St. Mary River Succession

DEVONIAN

- ■ Grosmont Fm
- ■ Mikkwa Fm
- ■ Ireton Fm
- ■ Waterways Fm
- ■ Hay River Fm
- ■ Slave Point Fm
- ■ Nyarling Fm
- ■ Fort Vermilion Fm
- ■ Muskey Fm
- ■ Fitzgerald Fm
- ■ Middle Devonian (undivided)

MESOZOIC

- ■ Lower Mesozoic-Lower Cretaceous

PALEOZOIC

- ■ Upper Paleozoic
- ■ Lower Paleozoic

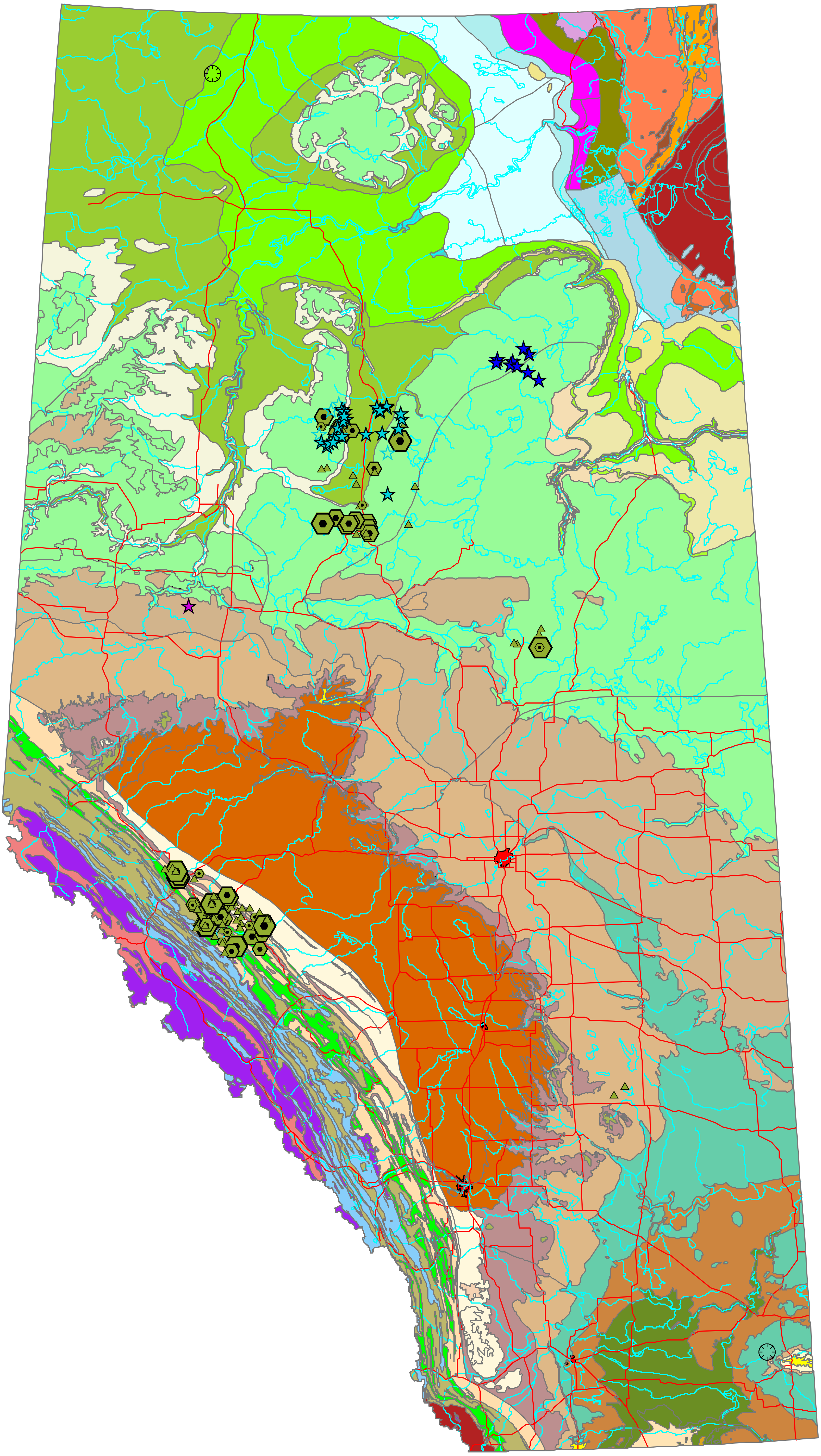
PROTEROZOIC

- ■ Miette Grp
- ■ Purcell Supergroup

ARCHEAN

- ■ Undivided Archean
- ■ Granitoids
- ■ AxMylonitic Rocks
- ■ Charles lake Granitoids
- ■ High-grade metasedimentary Rocks
- ■ Granite Gneisses
- ■ Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Olivine with a magnesian forsterite (Fo>70; see next page for legend)



Appendix 8. Olivine with a magnesian forsterite (Fo>70; see previous page)

LEGEND

Olivine
- ▲ 1
- ⬢ 2
- ⬢ 3 - 4
- ⬢ 5 - 10
- ⬢ 11 - 38

- ★ Birch Mountain Kimberlite
- ★ Buffalo Head Hills Kimberlite
- ☆ Possible Buffalo Head Hills Kimberlite

Mountain lake kimberlite.shp
- ★ Mountain Lake Kimberlite
- ⋀ Formation Boundary
- ⋀ Major Highway
- ⋀ Major River
- ⁄ Bad Heart
- ⋀ Whitemud
- ■ National Park
- ■ Major City
- ◌ Astrobleme

TERTIARY
- ■ Gravels
- ■ Porcupine Hills Fm
- ■ upper Porcupine Hills Fm
- ■ Willow Creek Fm

TERTIARY AND CRETACEOUS
- ■ Paskapoo Fm
- ■ Upper Paskapoo Fm
- ■ Lower Paskapoo Fm
- ■ Ravenscrag Fm

CRETACEOUS
- ■ Sweet Grass Intrusive - dark basic (minette) dykes
- ■ Sweet Grass Intrusive - pale green gray diorite porphyry plug
- ■ Scollard Fm
- ■ St. Mary River Fm
- ■ Blood Reserve Fm
- ■ Eastend Fm
- ■ Horseshoe Canyon Fm
- ■ Bearpaw Fm
- ■ Oldman Fm
- ■ Foremost Fm
- ■ Belly River Grp
- ■ Wapiti Grp
- ■ Pakowki Fm
- ■ Milk River Fm
- ■ Puskwaskau Fm
- ■ Lea Park Fm
- ■ Alberta Group
- ■ Kaskapau Fm
- ■ Smoky Grp
- ■ Dunvegan Fm
- ■ Shaftesbury Fm
- ■ LaBiche Fm
- ■ Peace River Fm
- ■ Pelican Fm
- ■ Joli Fou Fm
- ■ Loon River Fm
- ■ Grand Rapids Fm
- ■ Clearwater Fm
- ■ McMurray Fm
- ■ Keg River Fm
- ■ Chinchaga Fm
- ■ Coalspur Fm
- ■ Brazeau Fm
- ■ Paskapoo Fm
- ■ Brazeau Fm
- ■ Belly River St. Mary River Succession

DEVONIAN
- ■ Grosmont Fm
- ■ Mikkwa Fm
- ■ Ireton Fm
- ■ Waterways Fm
- ■ Hay River Fm
- ■ Slave Point Fm
- ■ Nyarling Fm
- ■ Fort Vermilion Fm
- ■ Muskey Fm
- ■ Fitzgerald Fm
- ■ Middle Devonian (undivided)

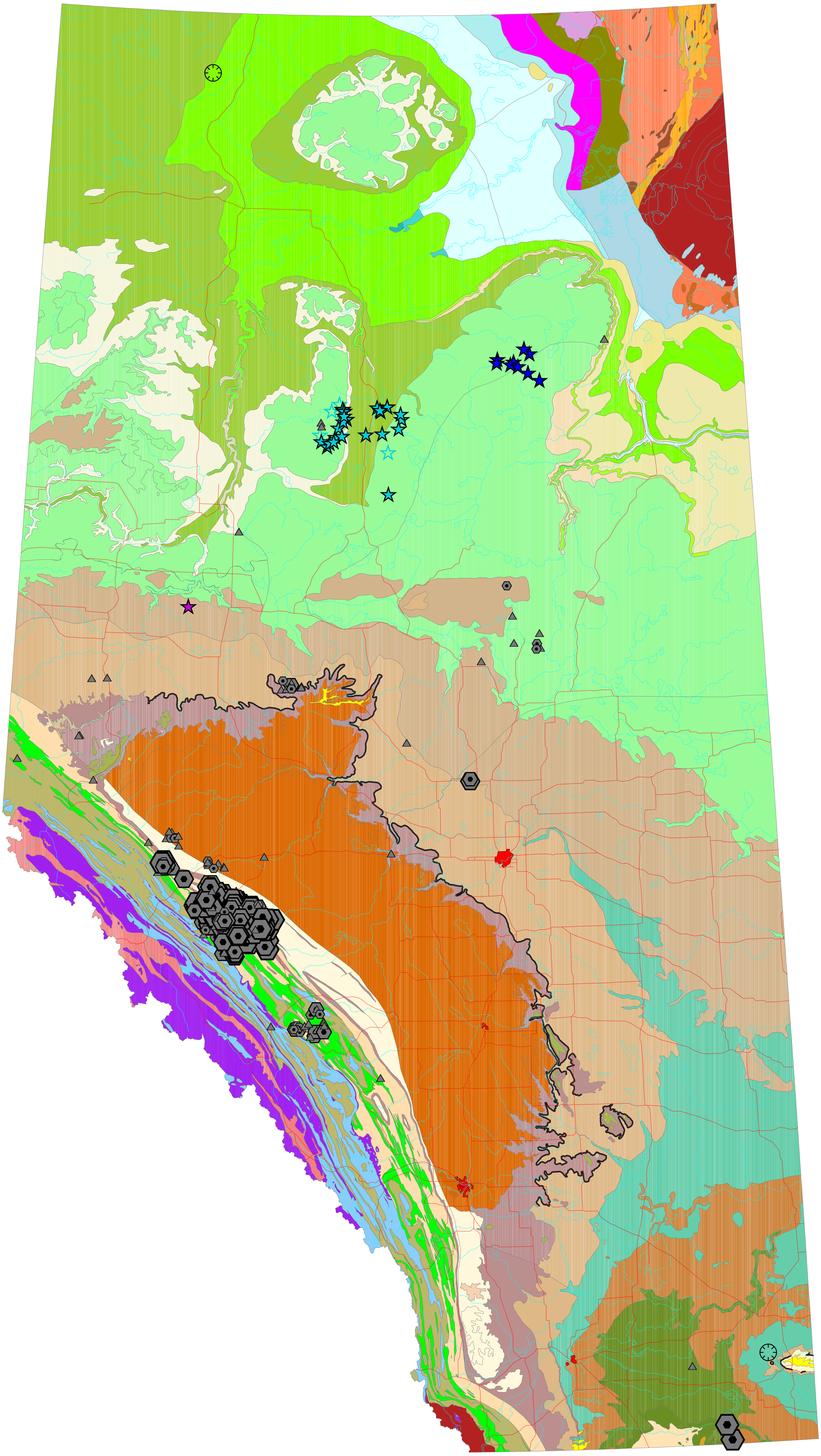
MESOZOIC
- ■ Lower Mesozoic-Lower Cretaceous

PALEOZOIC
- ■ Upper Paleozoic
- ■ Lower Paleozoic

PROTEROZOIC
- ■ Miette Grp
- ■ Purcell Supergroup

ARCHEAN
- ■ Undivided Archean
- ■ Granitoids
- ■ AxMylonitic Rocks
- ■ Charles lake Granitoids
- ■ High-grade metasedimentary Rocks
- ■ Granite Gneisses
- ■ Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. High-chrome chromite with >8 wt. % MgO and >58 wt. % Cr2O3 (see next page for legend)



Appendix 8. High-chrome chromite with >8 wt. % MgO and >58 wt. % Cr2O3 (see previous page)

LEGEND

Mantle Chromites >8% MgO & >58% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 52

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱ Formation Boundary
╱ Major Highway
╱ Major River
╱ Bad Heart
╱ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
🟨 Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive - dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
🟧 Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟩 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
🟧 Brazeau Fm
⬜ Paskapoo Fm
🟧 Brazeau Fm
🟫 Belly River St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

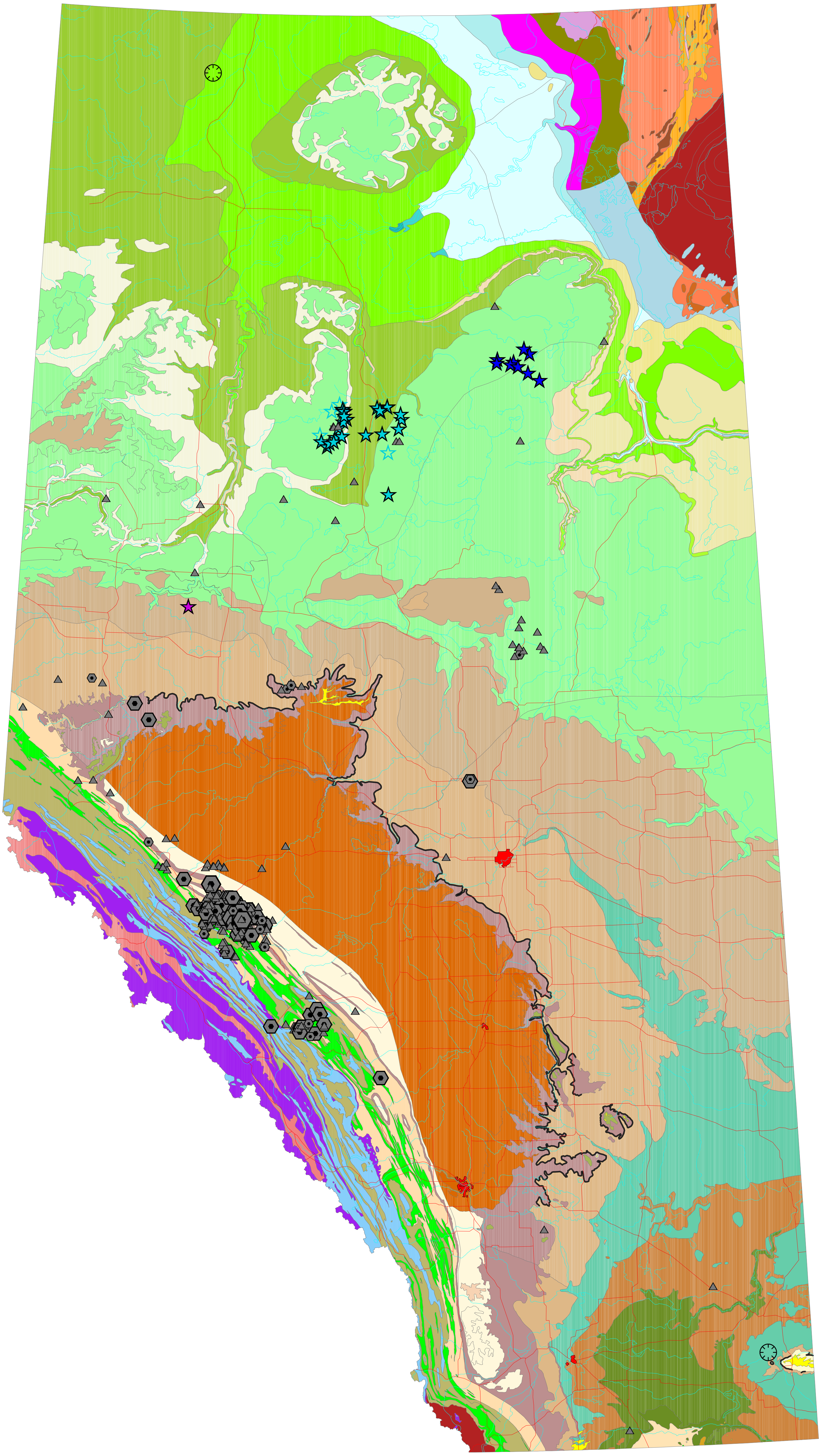
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Kimberlitic chromite with >40 wt. % Cr2O3 and >2 wt. % TiO2 (see next page for legend)



Appendix 8. Kimberlitic chromite with >40 wt. % Cr2O3 and >2 wt. % TiO2 (see previous page)

LEGEND

Kimberlitic Chromites >2% TiO2 & >40% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 9
★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive - dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale green gray diorite porphyry plug
🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

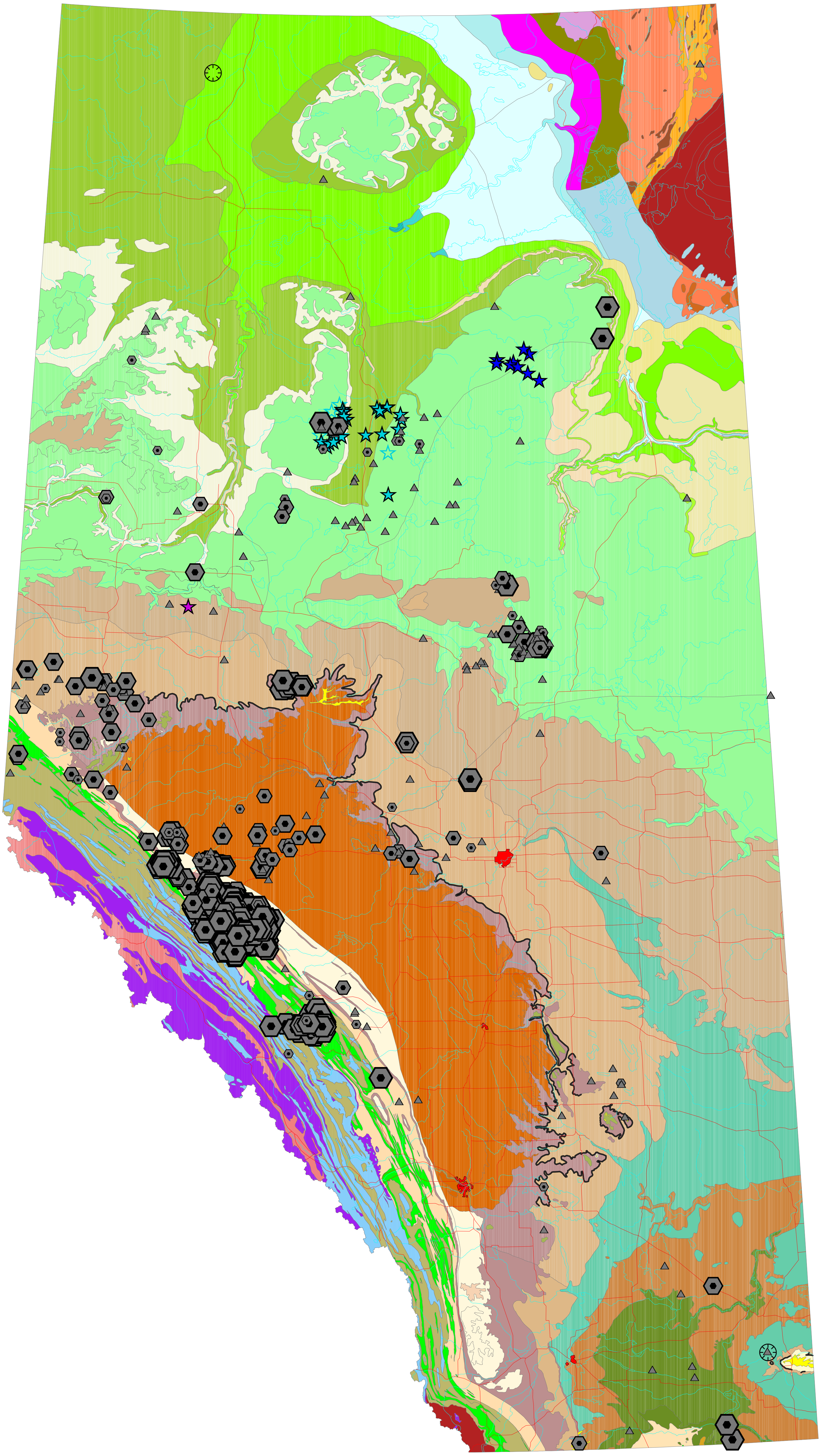
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. Mg-chromite with >20 wt. % Cr2O3 and >5 wt. % MgO (see next page for legend)



Appendix 8. Mg-chromite with >20 wt. % Cr2O3 and >5 wt. % MgO (see previous page)

LEGEND

Chromites >5% MgO & 20% Cr2O3
▲ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 94

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
○ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
🟧 Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
🟧 Peace River Fm
🟧 Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
🟧 Brazeau Fm
⬜ Paskapoo Fm
🟧 Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

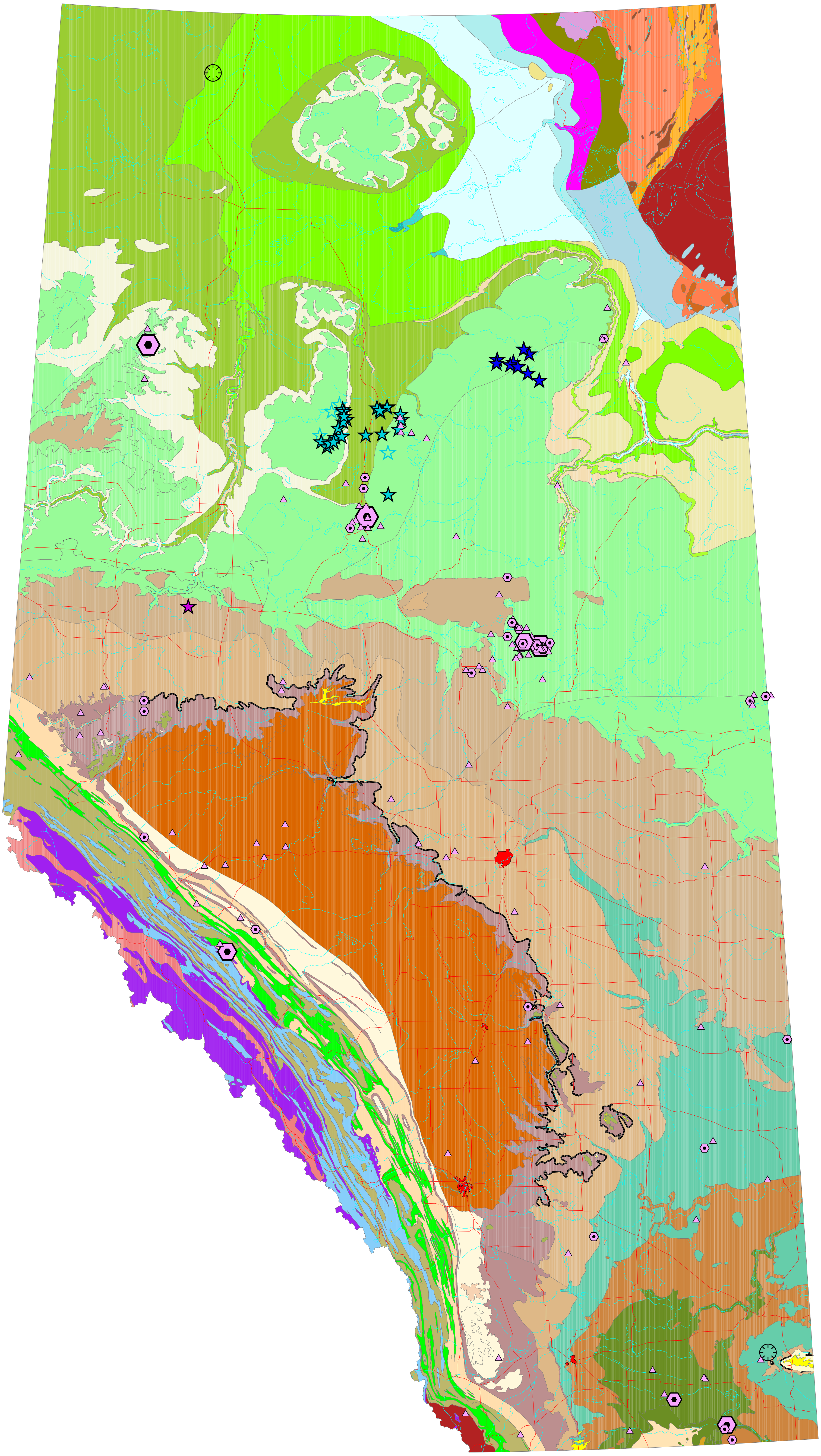
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. Picroilmenite with >4 wt. % MgO (see next page for legend)



Appendix 8. Picroilmenite with >4 wt. % MgO (see previous page)

LEGEND

Picromentite >4% MgO
△ 1
⬡ 2
⬡ 3
⬡ 5 - 10
⬡ 11- 16

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱ ╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
◌ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

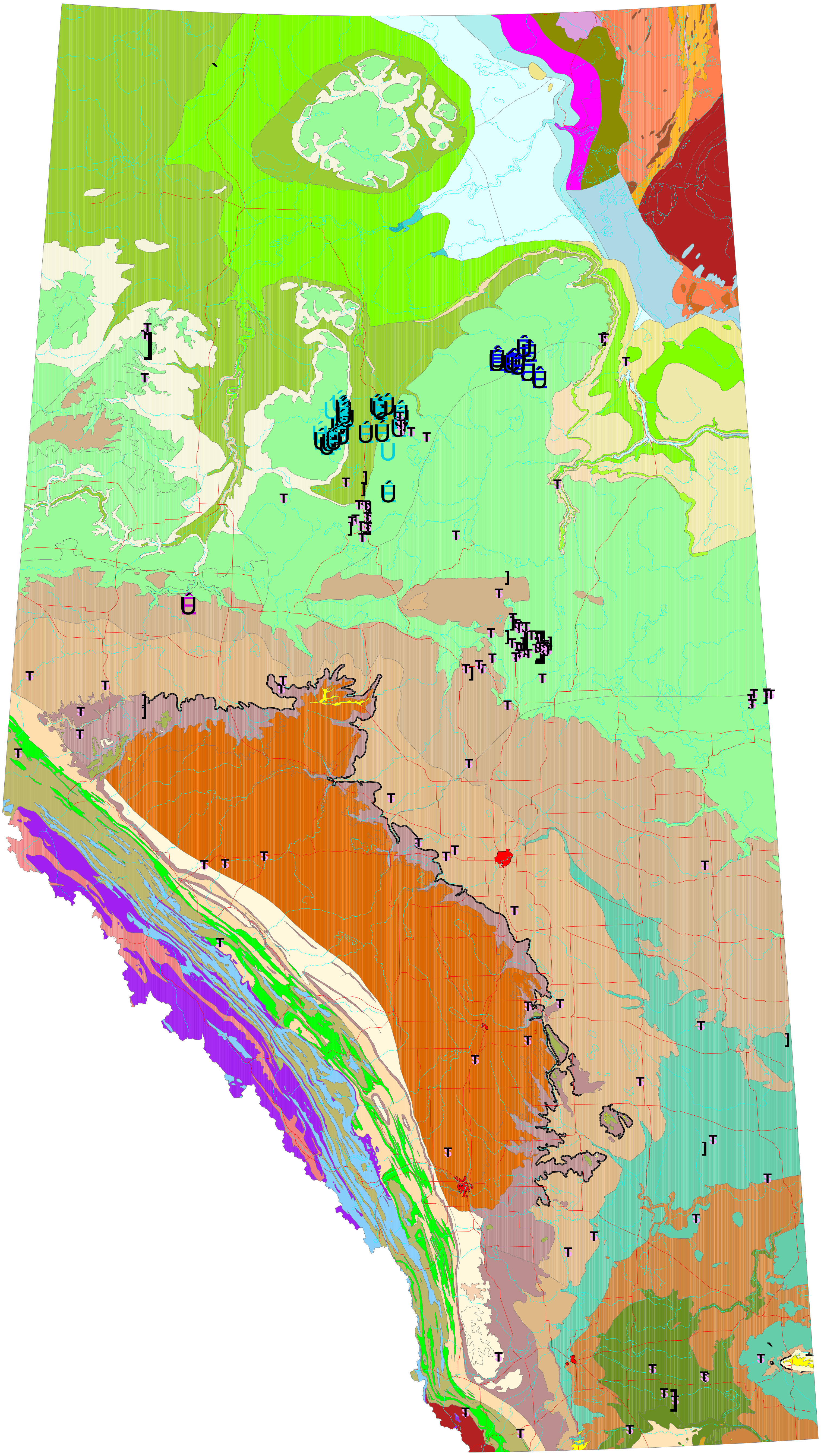
PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks

Appendix 8. Picroilmenite with >8 wt. % MgO (see next page for legend)



Appendix 8. Picroilmenite with >8 wt. % MgO (see previous page)

LEGEND

Picromentite >8% MgO
△ 1
⬢ 2
⬢ 3 - 4
⬢ 5 - 10
⬢ 11 - 16

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
Formation Boundary
Major Highway
Major River
Bad Heart
Whitemud
National Park
Major City
Astrobleme

TERTIARY

- Gravels
- Porcupine Hills Fm
- upper Porcupine Hills Fm
- Willow Creek Fm

TERTIARY AND CRETACEOUS

- Paskapoo Fm
- Upper Paskapoo Fm
- Lower Paskapoo Fm
- Ravenscrag Fm

CRETACEOUS

- Sweet Grass Intrusive - dark basic (minette) dykes
- Sweet Grass Intrusive - pale green gray diorite porphyry plug
- Scollard Fm
- St. Mary River Fm
- Blood Reserve Fm
- Eastend Fm
- Horseshoe Canyon Fm
- Bearpaw Fm
- Oldman Fm
- Foremost Fm
- Belly River Grp
- Wapiti Grp
- Pakowki Fm
- Milk River Fm
- Puskwaskau Fm
- Lea Park Fm
- Alberta Group
- Kaskapau Fm
- Smoky Grp
- Dunvegan Fm
- Shaftesbury Fm
- LaBiche Fm
- Peace River Fm
- Pelican Fm
- Joli Fou Fm
- Loon River Fm
- Grand Rapids Fm
- Clearwater Fm
- McMurray Fm
- Keg River Fm
- Chinchaga Fm
- Coalspur Fm
- Brazeau Fm
- Paskapoo Fm
- Brazeau Fm
- Belly River St. Mary River Succession

DEVONIAN

- Grosmont Fm
- Mikkwa Fm
- Ireton Fm
- Waterways Fm
- Hay River Fm
- Slave Point Fm
- Nyarling Fm
- Fort Vermilion Fm
- Muskey Fm
- Fitzgerald Fm
- Middle Devonian (undivided)

MESOZOIC

- Lower Mesozoic-Lower Cretaceous

PALEOZOIC

- Upper Paleozoic
- Lower Paleozoic

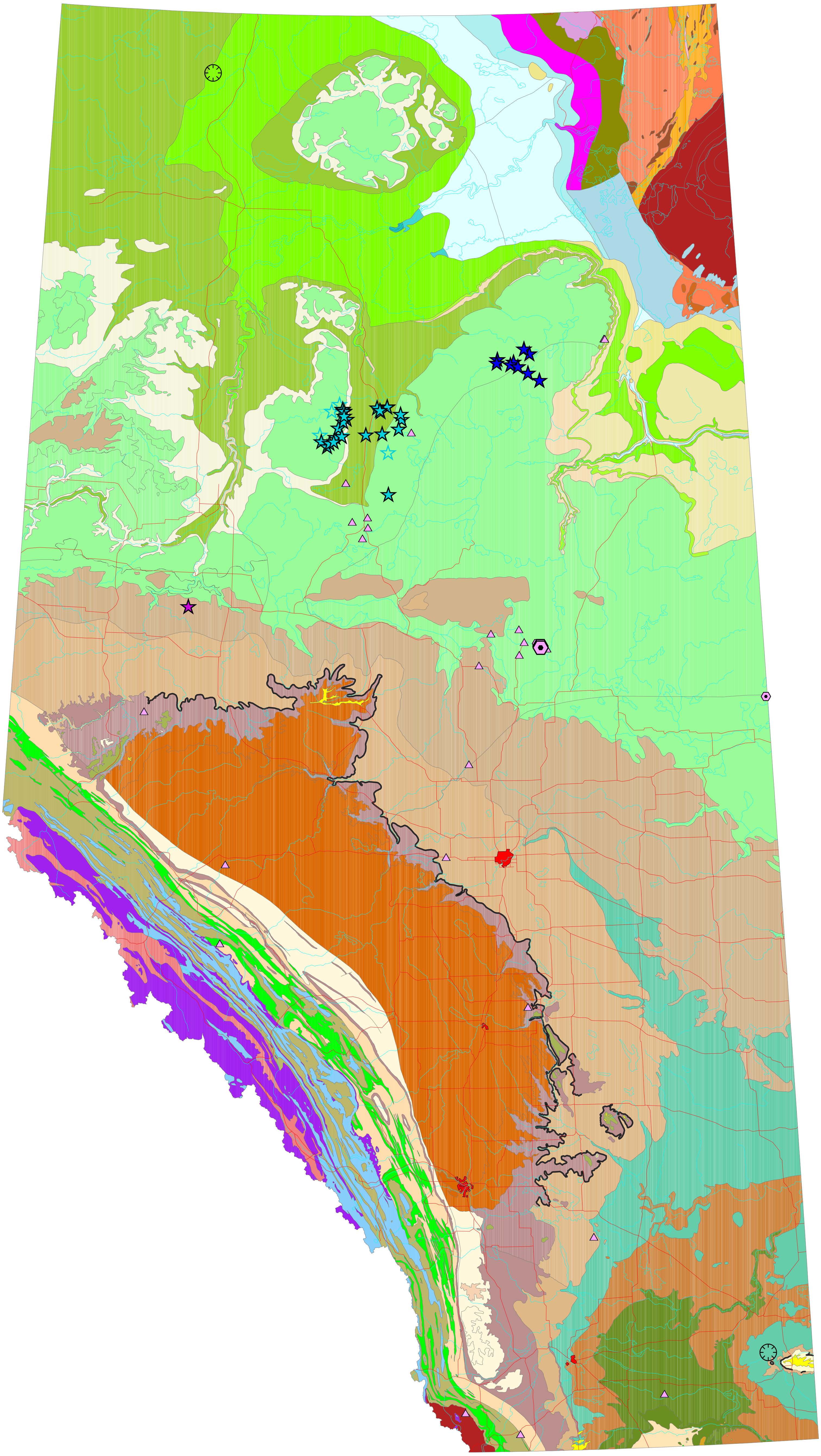
PROTEROZOIC

- Miette Grp
- Purcell Supergroup

ARCHEAN

- Undivided Archean
- Granitoids
- AxMylonitic Rocks
- Charles lake Granitoids
- High-grade metasedimentary Rocks
- Granite Gneisses
- Low Grade Metasedimentary & Metavolcanic Rocks

Appendix 8. High-chrome picroilmenites with >8 wt. % MgO and >1.5 wt. % Cr_2O_3 (see next page for legend)



Appendix 8. High-chrome picroilmenites with >8 wt. % MgO and >1.5 wt. % Cr2O3 (see previous page)

LEGEND

Cr-Picroilmenite >8% MgO & >1.5% Cr2O3
△ 1
⬡ 2
⬡ 3

★ Birch Mountain Kimberlite
★ Buffalo Head Hills Kimberlite
☆ Possible Buffalo Head Hills Kimberlite
Mountain lake kimberlite.shp
★ Mountain Lake Kimberlite
╱╲ Formation Boundary
╱╲ Major Highway
╱╲ Major River
╱ ╱ Bad Heart
╱╲ Whitemud
⬜ National Park
🟥 Major City
⊕ Astrobleme

TERTIARY

🟨 Gravels
⬜ Porcupine Hills Fm
🟧 upper Porcupine Hills Fm
🟫 Willow Creek Fm

TERTIARY AND CRETACEOUS

⬜ Paskapoo Fm
🟧 Upper Paskapoo Fm
🟩 Lower Paskapoo Fm
⬜ Ravenscrag Fm

CRETACEOUS

🟨 Sweet Grass Intrusive -
dark basic (minette) dykes
⬜ Sweet Grass Intrusive - pale
green gray diorite porphyry plug

🟫 Scollard Fm
🟫 St. Mary River Fm
🟫 Blood Reserve Fm
🟫 Eastend Fm
🟫 Horseshoe Canyon Fm
🟩 Bearpaw Fm
🟧 Oldman Fm
🟧 Foremost Fm
🟫 Belly River Grp
🟫 Wapiti Grp
🟩 Pakowki Fm
⬜ Milk River Fm
🟩 Puskwaskau Fm
🟩 Lea Park Fm
🟩 Alberta Group
🟩 Kaskapau Fm
🟩 Smoky Grp
⬜ Dunvegan Fm
🟩 Shaftesbury Fm
🟩 LaBiche Fm
⬜ Peace River Fm
⬜ Pelican Fm
🟩 Joli Fou Fm
🟩 Loon River Fm
🟨 Grand Rapids Fm
🟩 Clearwater Fm
🟨 McMurray Fm
🟫 Keg River Fm
🟪 Chinchaga Fm
🟫 Coalspur Fm
⬜ Brazeau Fm
⬜ Paskapoo Fm
⬜ Brazeau Fm
🟫 Belly River
St. Mary River Succession

DEVONIAN

🟦 Grosmont Fm
🟦 Mikkwa Fm
⬜ Ireton Fm
⬜ Waterways Fm
⬜ Hay River Fm
🟦 Slave Point Fm
🟪 Nyarling Fm
🟪 Fort Vermilion Fm
🟪 Muskey Fm
🟩 Fitzgerald Fm
🟦 Middle Devonian (undivided)

MESOZOIC

🟫 Lower Mesozoic-Lower Cretaceous

PALEOZOIC

🟦 Upper Paleozoic
🟪 Lower Paleozoic

PROTEROZOIC

🟥 Miette Grp
🟥 Purcell Supergroup

ARCHEAN

🟥 Undivided Archean
🟧 Granitoids
🟧 AxMylonitic Rocks
🟥 Charles lake Granitoids
🟩 High-grade metasedimentary Rocks
🟧 Granite Gneisses
🟫 Low Grade Metasedimentary &
Metavolcanic Rocks