AER/AGS Special Report 127

Alberta Energy Regulator

Diamond Potential in Alberta: Reinterpretation and Distribution of Kimberlite-Indicator Minerals Outside Known Kimberlite Fields

AGS
ALBERTA GEOLOGICAL SURVEY

AER/AGS Special Report 127

Diamond Potential in Alberta: Reinterpretation and Distribution of Kimberlite-Indicator Minerals Outside Known Kimberlite Fields

G.A. Harris[1] and G.P. Lopez[2]

[1] Formerly of University of Alberta (see page ii for current address)
[2] Formerly of Alberta Geological Survey
Alberta Energy Regulator (see page ii for current address)

November 2025

ISBN 978-1-4601-5731-2

Harris, G.A. and Lopez, G.P. (2025): Diamond potential in Alberta: reinterpretation and distribution of kimberlite-indicator minerals outside known kimberlite fields; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Special Report 127, 31 p.

Author addresses:

G.A. Harris
APEX Geoscience Ltd.
#100
11450 – 160 Street NW
Edmonton, AB T5M 3Y7
Canada

Tel: 780.467.3532
Email: gharris@apexgeoscience.com

G.P. Lopez
Ronacher McKenzie Geoscience Inc.
6 – 2140 Regent Street
Sudbury, ON P3E 5S8
Canada

Tel: 705.419.1508
Email: gloria.lopez@rmgeoscience.com

Published November 2025 by:

Alberta Energy Regulator
Alberta Geological Survey
Suite 205
4999 – 98 Avenue NW
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Email: AGS-Info@aer.ca
Website: ags.aer.ca

Contents

Figures

Acknowledgements

We would like to acknowledge the Diamond Exploration Research Training School (DERTS) at the University of Alberta as well as a Canada Excellence Research Chairs (CERC) grant awarded to Dr. D. Graham Pearson for providing funding to support Garrett Harris' internship at the Alberta Geological Survey (AGS). The collaboration with DERTS and the AGS allowed for the compilation of kimberlite-indicator-mineral microprobe analytical data (AER/AGS Digital Data 2020-0009) and creation of this report. The compilation resulted from the collaboration of the authors of this report, and Anetta Banas and Roy Eccles from APEX Geoscience Ltd. We also wish to thank Anetta Banas for her review of this manuscript and comments to improve it.

The Alberta Geological Survey would like to acknowledge Calla Knudson (Alberta Geological Survey) and Greg Driedger (Alberta Geological Survey) for editing the manuscript and figures, respectively.

Abstract

This report accompanies the Alberta Geological Survey's (AGS) *Alberta Kimberlite Indicator Mineral Microprobe Analyses* digital file (AER/AGS Digital Data 2020-0009), which is a compilation of microprobe analytical data for kimberlite-indicator-mineral grains from samples collected by government agencies and industry in Alberta and released to the public between 1993 and 2012. This compilation involved a revision and reclassification of the interpreted kimberlite-indicator-mineral mineralogy, and this report describes the methodology used to complete the mineral reclassifications. Additionally, this report presents the results of a preliminary assessment of the data to identify areas of interest for diamond exploration outside of the known kimberlite and ultramafic fields of Mountain Lake, Birch Mountains, and Buffalo Head Hills in northern Alberta, which have already been assessed by industry for their diamond content.

Kimberlite-indicator minerals (KIMs) include garnet, clinopyroxene, ilmenite, chromite, and olivine. The classification schemes that were applied to KIMs in this work allowed for the identification of minerals that may be associated with kimberlite and diamonds, and could potentially lead to identifying an undiscovered diamond-bearing kimberlite.

Seven areas outside of known kimberlite fields have been identified as having higher potential to contain diamond-bearing kimberlite. The assessment was based on the presence of (1) alluvial diamonds, (2) garnet or clinopyroxene grains with chemistry associated with diamonds, (3) a high number of interpreted KIMs with mineral chemistry related to kimberlite, and (4) a high number of species of interpreted KIMs with mineral chemistry related to kimberlite. These areas are

- Buffalo Head Hills north,
- Buffalo Head Hills west,
- Calling Lake,
- Hinton,
- Peace River,
- St. Paul, and
- Utikuma Lake.

Additional areas that contain fewer KIMs with favourable chemistry for the presence of diamonds are classified as having moderate potential. These include the Birch Mountains east, Chain Lakes, Chinchaga, Cold Lake, Hay–Zama lakes, Kakwa River, Lesser Slave Lake, Mary Lake, Peerless Lake, Ram River, Swan Hills, Sweet Grass Hills, West Edmonton, and Whitecourt areas.

Two areas that have KIMs with favourable chemistry for the presence of kimberlite, but without favourable chemistry for diamonds (i.e., an absence of either diamonds or garnet/clinopyroxene grains with chemistry related to diamonds), are considered to have a lower potential. These are the Clear Hills and Pembina areas.

In addition, the study of clinopyroxene geothermobarometry indicated that the lithosphere most favourable for diamonds is in the northeastern portion of the province, north of 54°N latitude and east of 116°W longitude. This quadrant of the province has the coolest geotherm relative to the rest of the province with an associated lithospheric thickness of ~200 km.

The work described herein preceded the Mineral Grant (provided by the Government of Alberta dated June 22, 2021) and the Mineral Mapping Program (initiated by the Government of Alberta, Alberta Energy Regulator, and Alberta Geological Survey in 2021). This special report does not include any new data collected during the Mineral Mapping Program.

1 Introduction

Since the initial discovery of kimberlitic pipes in northern Alberta in 1989–1990, government agencies and mineral exploration companies have collected thousands of samples to obtain kimberlite-indicator minerals (KIMs) from both discovered kimberlites and surface sediments throughout Alberta. Subsequently, KIMs, which include garnet, clinopyroxene, ilmenite, spinel/chromite, and olivine, were analyzed by electron microprobe to determine their chemistry. This mineral chemistry can be used to predict the location of undiscovered diamond-bearing kimberlites.

Compilation datasets of mineral chemistry obtained through microprobe analyses of KIMs provide the necessary chemical data to support diamond exploration by generating and prioritizing diamond exploration targets. Previous government KIM chemical data compilations for Alberta include Dufresne et al. (1996), Eccles et al. (2002), Dufresne and Eccles (2005), Eccles (2007b, 2011), and Banas et al. (2016). The compilation by Eccles et al. (2002) included microprobe analytical data for approximately 18 000 KIMs. This compilation and dataset were used by Dufresne and Eccles (2005) to identify KIM trends in Alberta. Subsequently, the 2002 KIM compilation was updated to create a special report on the first 20 years of diamond exploration in northern Alberta (Eccles, 2011). More recently, an internal database of over 27 000 KIM records was used to determine areas of diamond potential in the central and northern parts of the province (Banas et al., 2016).

The existence of additional publications containing KIM chemical data not included in the previous compilations, along with the need to consolidate several compilations into one dataset, resulted in the creation of an internal KIM database and the subsequent release of this data to the public as a digital file of tabular data (AER/AGS Digital Data 2020-0009; Lopez et al., 2020). This digital file includes multiple datasets containing sample information, mineral counts, and chemical data (data complied by Eccles [2007b]) for nearly 32 000 KIMs collected between 1993 and 2011. Thus, this digital file brings together most of the publicly available microprobe analytical data reported in government publications and mineral assessment reports for the entire province. The objective of the current compilation was threefold: (1) to provide available KIM microprobe analytical data for Alberta in one file; (2) to assess the quality of the compiled chemical data; and (3) to provide consistent mineral classifications across the entire dataset by applying congruous mineral classification schemes to the compiled microprobe analytical data.

This report describes the methodologies used to classify the mineralogical data in the Alberta KIM microprobe analyses digital file (Lopez et al., 2020), and provides a reassessment of results to complement the previous diamond potential assessment by Banas et al. (2016). This reassessment of results is focused on diamond potential outside of the known kimberlite and ultramafic fields (i.e., outside Mountain Lake, Buffalo Head Hills, and Birch Mountains). For a more detailed explanation of Alberta's discovered kimberlites, nature and timing of intrusion, xenocryst chemistry, and interpreted mantle characteristics, the reader should consult the comprehensive AGS bulletins 63 (Dufresne et al., 1996) and 65 (Eccles, 2011).

2 Background

2.1 Alberta Kimberlites and Other Ultramafic Occurrences

Globally, diamonds are mined from two types of volcanic rocks: kimberlites and lamproites, with kimberlites being the significantly more dominant host rock. Most occurrences of kimberlite and lamproite are barren or contain very low quantities of diamond. Approximately 7000 kimberlites and lamproites have been identified globally, however, only 1000 of these are reported to contain diamonds and only 67 are being, or have been, economically mined (de Wit et al., 2016). This makes the discovery of an economically viable diamond mine an approximately 1 in 100 chance. Several factors influence the economic viability of a kimberlite with grade, tonnage, and location of the diamondiferous body being the most dominant factors. As a result, diamondiferous kimberlites with moderate tonnage and grade that are remotely located are not developed, whereas similar deposits close to infrastructure may be developed into a mine.

Although most of the Alberta Plains are covered by the sedimentary rocks of the Phanerozoic Western Canada Sedimentary Basin, this Phanerozoic cover is underlain by an Archean to Proterozoic crystalline basement (Dufresne and Eccles, 2005). Traditionally, occurrences of diamondiferous kimberlites were thought to be restricted to Archean blocks known as cratons (Figure 1). However, there is evidence to suggest that nonconventional, off-craton localities found in parts of Alberta have the potential to host economic diamond deposits.

Parts of Alberta are underlain by a 150 km thick (and thicker) cold lithosphere, which is a favourable environment for diamond formation and preservation in the upper mantle (Schaeffer and Lebedev, 2014). The mantle under Alberta has been characterized by a shallow (<135 km), low temperature zone of fertile lherzolite and wehrlite, underlain by depleted lherzolite (135–160 km), and depleted/metasomatized lherzolite (160–190 km), which overlies a dominant metasomatized lherzolitic mantle component (>190 km; Aulbach et al., 2004; Eccles, 2011). Additionally, major Proterozoic to Phanerozoic structures, such as the Great Slave Lake shear zone, Snowbird tectonic zone, Peace River Arch, Grosmont High, and Southern Alberta Rift, could have controlled the ascent of kimberlitic or lamproitic magma from the mantle to the surface. Three kimberlite fields containing diamonds—Buffalo Head Hills, Birch Mountains, and Mountain Lake—were identified intruding the Buffalo Head accreted terrane, the Taltson magmatic arc, and Chinchaga accreted terrane, respectively (Figure 2). Thousands of KIMs have been collected throughout the province to evaluate the potential of a diamond-bearing kimberlite outside of the identified kimberlite fields (Figure 2). The presence of a thick cold lithosphere, structures that penetrate the basement, diamond-bearing kimberlites, and abundant favourable KIM chemistry across Alberta makes it a prime target for diamond exploration.

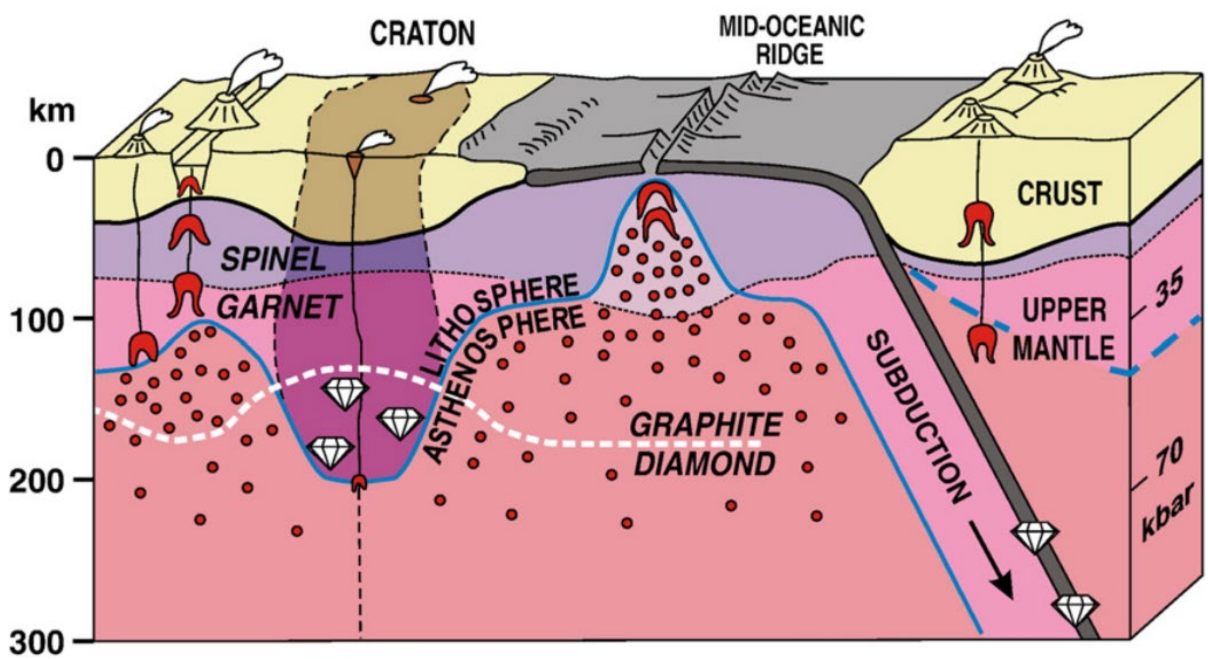

Figure 1. Cross-section through the crust and upper mantle of the Earth showing the favourable location for diamond formation and ascent to the surface (reprinted from Stachel and Harris, 2008, based on Brey and Stachel, 1997; with permission from Elsevier).

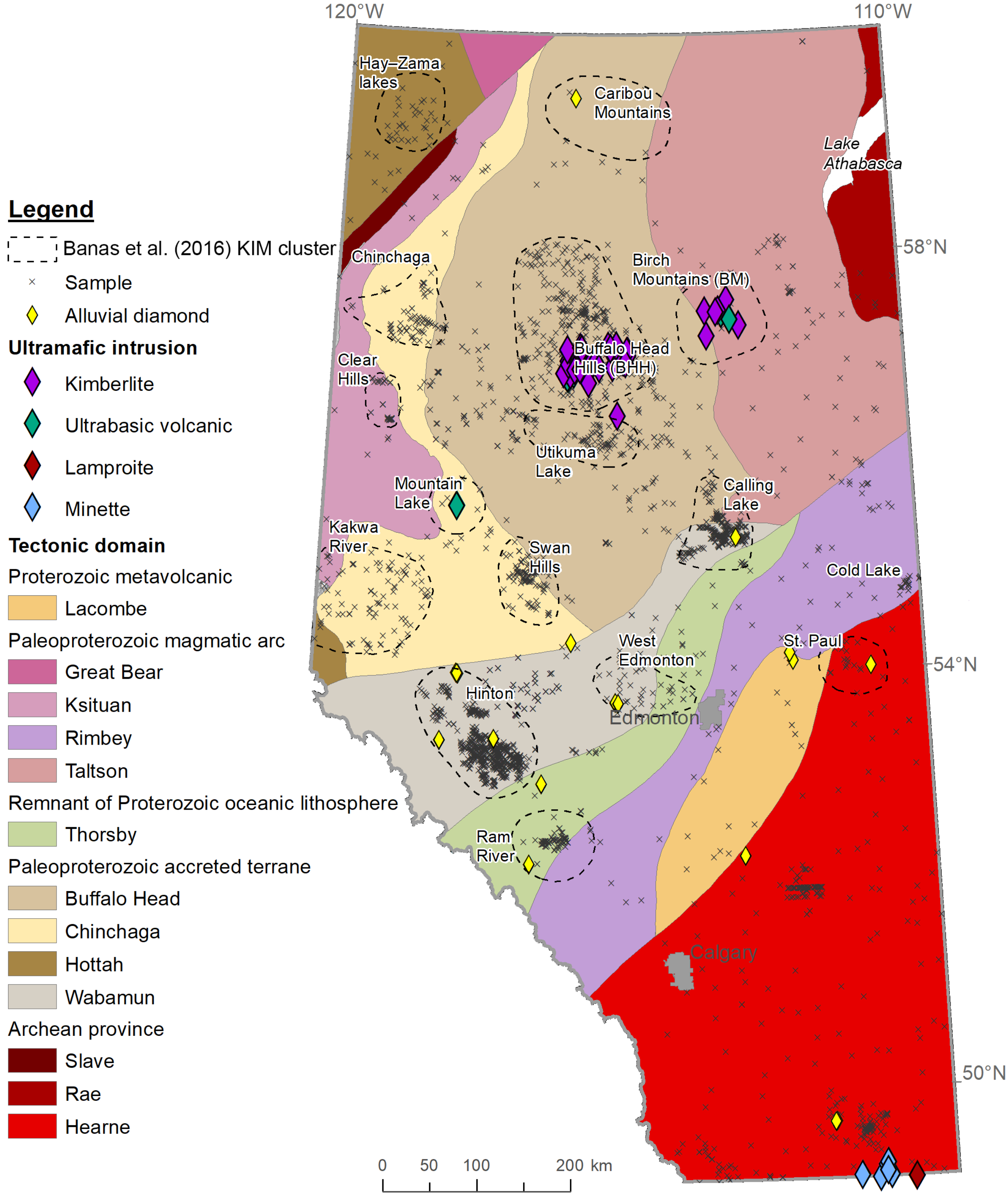

Figure 2. Alberta's tectonic domains (modified from Ross et al., 1994), locations of ultramafic intrusions, including kimberlite (modified from Eccles, 2011), locations of alluvial diamonds (Eccles, 2007a), diamond potential areas based on kimberlite-indicator-mineral (KIM) clusters defined in 2016 (Banas et al., 2016), and locations of KIM samples with microprobe analytical data compiled for this report (Lopez et al., 2020).

The first hint of diamondiferous source rocks in Alberta was a perfect octahedral diamond, estimated to weigh about one carat, found by E. Opdahl in 1958 in the Evansburg area of central Alberta (Dufresne et al., 1996). Since then, several other alluvial diamonds have been reported in the Caribou Mountains (1; Ashton Mining of Canada Inc., 1999, cited in Eccles, 2007a), Calling Lake (1; Buffalo Diamonds Ltd., 1999, cited in Eccles, 2007a), Hinton area (22; Gilmour, 1995, cited in Eccles, 2007a), Edmonton (2; Tom Bryant, pers. comm., 2004, 2005, cited in Eccles, 2007a), Whitecourt (2; Eccles, 2005, cited in Eccles, 2007a), and the Etzikom Coulee (2; Edmonton Journal, 1992, Morton et al., 1993, cited in Eccles, 2007a). The first discovery of kimberlite in Alberta was at Mountain Lake in 1989. Although this body contains diamonds, it has a very low diamond content and is considered uneconomic. In the early 1990s, a claim-staking rush occurred in Alberta corresponding to the discovery of diamondiferous kimberlites in the Lac de Gras field, Northwest Territories. Initial exploration in Alberta did not yield much success. The staking rush was reignited later with the discovery of the Buffalo Head Hills kimberlite field in 1997. Between 1997 and 2008, 41 kimberlites were discovered at Buffalo Head Hills, of which 28 are diamondiferous and 6 have economic potential. Currently, the highest grade reported for the Buffalo Head Hills is up to 55 carats per hundred tonnes from kimberlite K252 and the largest diamonds were collected from kimberlite K6 including a 1.77 carat colourless stone. Alongside the Buffalo Head Hills discovery, eight kimberlites were discovered at Birch Mountains in northeastern Alberta between 1998 and 2000. Two of the eight kimberlites in Birch Mountains have been reported to have low diamond contents and the remainder are barren.

In 2011, a comprehensive review of kimberlite fields discovered in northern Alberta was published (Eccles, 2011). The review included detailed information about the exploration history, setting, morphology, chemistry, timing, and diamond content of the three kimberlite fields: Buffalo Head Hills, Birch Mountains, and Mountain Lake. The Buffalo Head Hills and Birch Mountains kimberlites occur in complex volcanic fields as intrusive dikes or sills interbedded with pyroclastic and resedimented volcaniclastic rocks ranging in age from Late Cretaceous to Paleocene (ca. 88 to 60 Ma). These areas are distinguishable from each other by the primitive magmatic signature in Buffalo Head Hills and the evolved magmatic signature in the Birch Mountains. Subsequent work on the two Mountain Lake intrusions concluded that these were not archetypal kimberlites but should be classified as alkali olivine basalts or basanites. The magmatism of the Mountain Lake intrusions has been dated at ca. 76–75 Ma.

In southern Alberta, seven outcrops of Eocene potassic intrusions exist in the Milk River area, which are related to the Sweet Grass Hills alkaline province in Montana. This area is interesting because it is underlain by Archean basement, a setting most frequently related to economic kimberlites worldwide unless the basement is dry or heavily metasomatized. Six of the seven occurrences were classified as minettes and one occurrence as a diorite porphyry on the basis of whole rock major and trace element geochemistry (Kjarsgaard, 1994). Minettes are shallowly derived and are associated with low diamond potential, which was confirmed by the lack of diamonds recovered from any of the occurrences. However, difficulties were recognized in classifying and discriminating chromium (Cr)-bearing spinel (also known as chrome spinel or chromian spinel) grains from minettes versus Cr-spinel grains from kimberlite or lamproite. Based on new petrological, mineralogical, and geochemical evidence, Rukhlov and Pawlowicz (2012) suggested that the minette occurrence at the 49th parallel locality in the Milk River area can be classified as sanidine-phlogopite lamproite. The existence of a lamproite occurrence in the province is very important because the type of magma that formed these rocks may have carried quality diamonds. However, Kjarsgaard (1997) noted that metasomatic overprinting of the basement beneath this area may have affected diamond preservation.

2.2 Alberta Kimberlite-Indicator Minerals and Areas of Potential

Carbon is stable in the form of diamond in the mantle at depths greater than 150 km; at shallower depths carbon is stable in the form of graphite. However, the conversion of diamond to graphite at shallower depths requires a lot of energy, so diamond remains metastable at depths shallower than its formation depth. The main source of diamonds in the mantle is the deep subcratonic lithosphere (Stachel and Harris, 2009). The lithospheric mantle is mainly composed of peridotite (95–99%) with ~1% (Schulze, 1989) to 5% (Dawson and Stephens, 1975) eclogite and minor components of websterite. The minerals that make up these rocks in the mantle include garnet, olivine, clinopyroxene, spinel, and chromite. In the mantle, these minerals have a large variation in chemical composition, however, the chemical composition of these minerals, which are associated with diamonds, has been determined from studies of inclusions in diamonds. Inclusions in lithospheric diamonds indicate that 33% of diamonds containing inclusions are derived from an eclogitic source, with peridotitic and websteritic parageneses comprising 65% and 2%, respectively (Stachel and Harris, 2008). Based on these studies, certain compositions of mantle minerals have been identified to be associated with diamond-forming fluids. Since mantle minerals are found in far greater abundance than diamonds, these diamond-associated mantle minerals can be used in diamond exploration.

During the formation of kimberlites and lamproites, diamonds and mantle material are carried to the surface. Due to the higher abundance of mantle minerals, also known as KIMs, compared to that of diamonds, initial exploration efforts are focused on recovering these KIMs. To be considered a KIM, the mineral must be genetically linked to the kimberlite (e.g., crystallized from the kimberlite magma or originated from mantle material and transported by kimberlite magma), be abundant in the kimberlite and surface environment, possess chemical and physical properties that makes it resistant to weathering in the surface and sedimentary environment, and have physical properties (e.g., density, colour, magnetism) that allow ease of recovery and identification. The most common KIMs recovered are garnet, clinopyroxene, olivine, ilmenite, and spinel/chromite (not in order of abundance). Less common KIMs include orthopyroxene, phlogopite, zircon, and diamond. In Canada, major surface transport methods of KIMs are glaciers and streams. As a result, diamond-exploration sampling programs target till and stream sediments to recover KIMs (Figure 3). Once KIMs are recovered, they can be sorted qualitatively into mineral species by stereo microscope. However, to understand the source (i.e., crustal or mantle derivation) and their potential as a diamond indicator, a quantitative determination by electron probe microanalysis is required. Methods for properly interpreting these minerals are becoming increasingly more refined, which is essential for the future discovery of kimberlites and diamonds in Alberta and globally.

In 2016, an assessment of diamond potential (based on KIM chemistry data) for four land-use planning areas in central and northern Alberta resulted in the identification of several KIM clusters (Banas et al., 2016). These comprised seven clusters with high diamond potential, namely in the Birch Mountains, Central Buffalo Head Hills, North Buffalo Head Hills, West Buffalo Head Hills, Utikuma Lake, Calling Lake, and Swan Hills areas, and ten clusters with moderate diamond potential, namely in the Hay–Zama lakes, Caribou Mountains, Chinchaga, Mountain Lake, Clear Hills, Kakwa River, Hinton, Ram River, St. Paul, and West Edmonton areas.

3 Methodology for Kimberlite-Indicator-Mineral Classification

The 2020 data compilation (Lopez et al., 2020) included microprobe analyses for nearly 32 000 KIMs and 4000 non-KIMs from 89 government and industry sources dating from 1993 to 2012. Some of these sources consisted of previous data compilations (e.g., Eccles et al., 2002; Dufresne and Eccles, 2005; Eccles, 2007a, b), which greatly facilitated the current work. For completeness, microprobe analyses of intrusion xenocrysts were also included in this compilation.

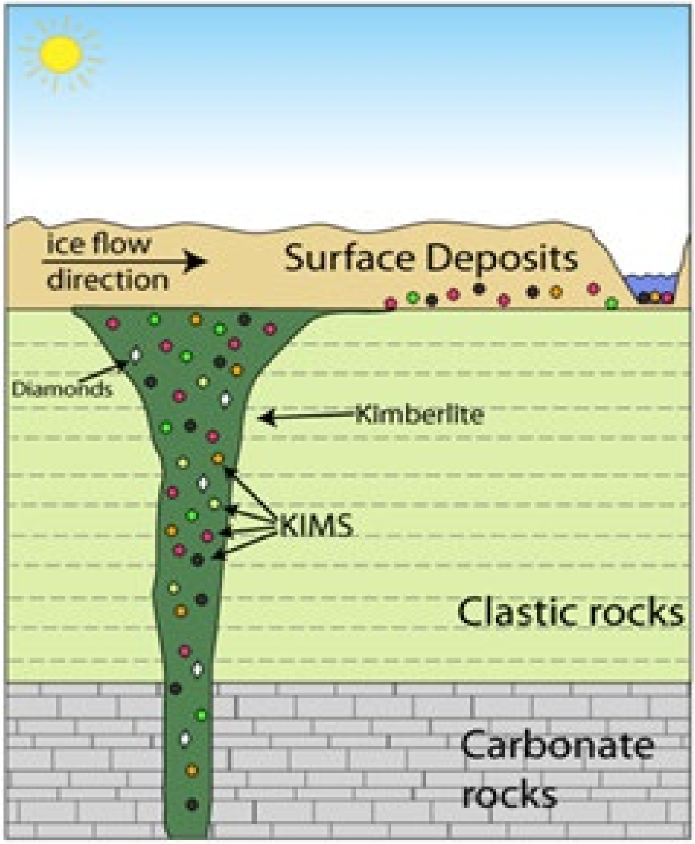

Figure 3. Schematic cross-section showing a kimberlite pipe eroded by a glacier. The kimberlite-indicator minerals (KIMs) are transported by the glacier and deposited on the surface and in streams, where they are further transported by water (from Banas et al., 2016).

All of the KIM microprobe analyses were individually identified and assessed to ensure correctness and completeness throughout the database. Element oxide totals occasionally did not match the data in the source publication, therefore, the total for element oxides was recalculated for each sample in the current database.

In addition, mineral counts were included as separate datasets in the digital data publication. These mineral counts were calculated from the microprobe analyses with the objective of facilitating the evaluation of mineralogy, quantity, and spatial distribution of KIMs within GIS software. Mineral count datasets include mineral group counts, clinopyroxene counts, garnet-class counts, ilmenite counts, spinel/chromite counts, and interpreted KIM counts. The weight of samples was not always available in the data sources; therefore, sample weights were not included in this compilation. Due to the lack of sample weight data, mineral counts could not be normalized by weight so the user must remain cognizant that the count data are not directly comparable.

For generic mineral interpretations from microprobe analytical data, only element oxide totals between 90 and 105 wt. % were considered acceptable. For further classification of minerals (i.e., detailed species classification), only totals between 98.5 and 101 wt. % were considered acceptable. Oxide minerals, such as spinel, chromite, and ilmenite, with a silica content above 1.00 wt. % SiO_2 were considered to have silicate contamination.

Mineral reclassifications were based on the most recent research literature (detailed below) for the interpretation of garnet, ilmenite, spinel and chromite, olivine, and clinopyroxene. Mineral discrimination was based on the schemes discussed below.

3.1 Garnet

Garnet is found in metamorphic and igneous rocks. The mineral most relied on in diamond exploration is high-Cr pyrope garnet (Cr_2O_3 ≥1 wt. %), specifically the subset classified as harzburgitic (G10) garnet, which has a strong affinity with diamond. Garnet microprobe analytical data were first classified by using Grew's Excel spreadsheet (Grew et al., 2013) to recast analyses into end-member components based on dominant valency. Pyrope and andradite end-members were differentiated from their Cr-bearing counterparts using the scheme proposed by Dredge et al. (1996). The Cr-pyrope and Cr-andradite correspond to a pyrope or andradite when Cr_2O_3 is greater than 2 wt. %.

After the above classification, garnet grains were further classified based on their CaO versus Cr_2O_3 content to determine the respective garnet (G)-class (i.e., G0, G1 macrocryst, G3, G4, G5, G9, G10, G11 high Ti, and G12), according to the scheme of Grütter et al. (2004). The G-class results for Alberta garnets are shown in Figure 4.

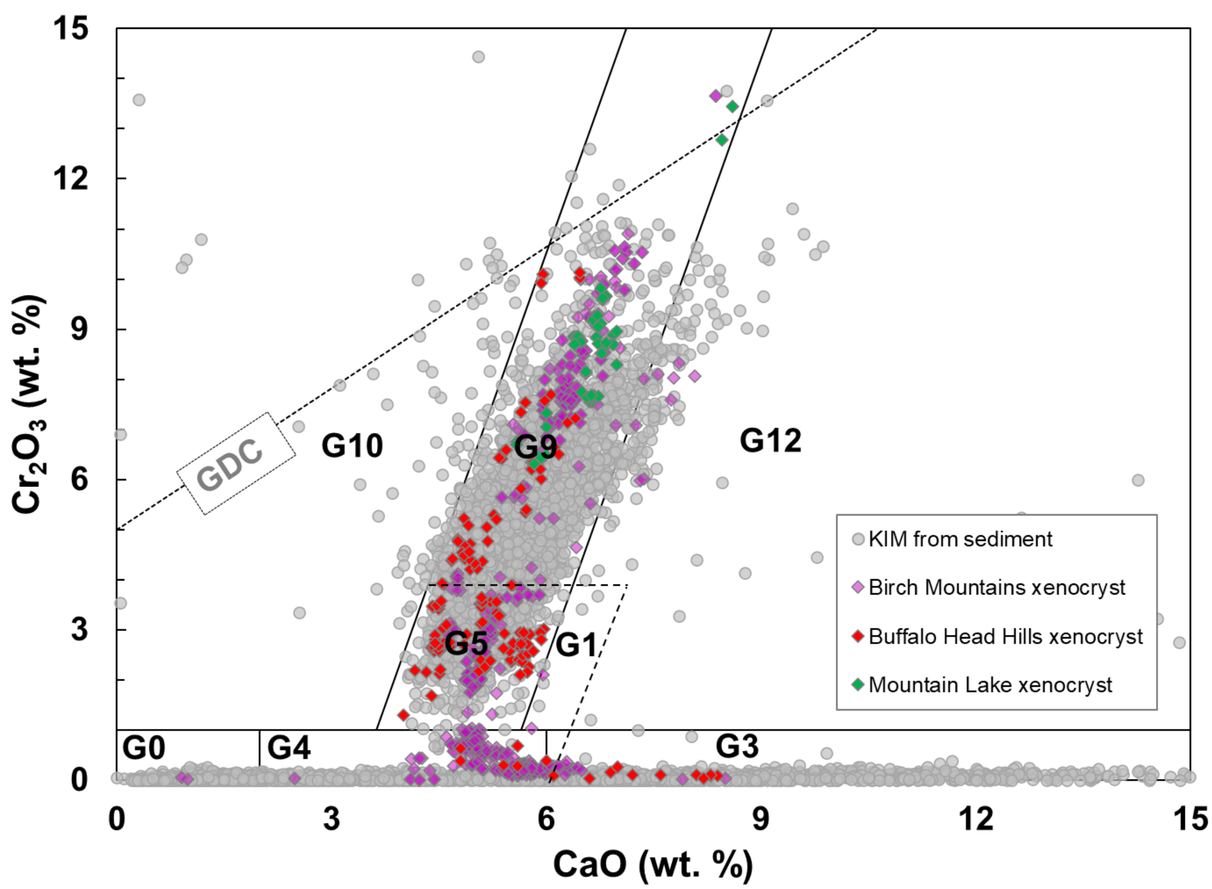

Figure 4. Garnet classification diagram (based on Grütter et al., 2004), for kimberlite-indicator-mineral (KIM) garnet grains from Alberta sediment samples. Garnet grain data from Lopez et al. (2020). Garnet xenocrysts from Birch Mountains, Buffalo Head Hills, and Mountain Lake kimberlite intrusions are shown for reference (Eccles, 2007b; Lopez et al., 2020). Abbreviation: GDC, graphite–diamond constraint.

When garnet is formed in an environment suitable for diamond growth, the suffix 'D' may be added to the end of garnet classes G3, G4, G5, and G10 according to the scheme of Grütter et al. (2004). A high number of garnet grains with the suffix D is of great interest to the diamond explorer because it could indicate an area of high potential for the presence of diamond-bearing kimberlite.

Peridotitic garnet comprises classes G9 (lherzolitic), G10 (harzburgitic), G11 (high-TiO_2 peridotitic), and G12 (wehrlitic). Eclogitic and eclogitic-pyroxenitic garnet comprises classes G3, G4, and G5. Diamond-associated garnet can be of peridotitic, eclogitic, and/or pyroxenitic origin. To discriminate low-Cr G3 and G4 garnets of crustal origin from those of mantle eclogitic-pyroxenitic origin, the logistic regression calculation of Hardman et al. (2018) was used.

In this report, the G9A garnet class of Grütter and Menzies (2003) was added to include lherzolitic G9 garnets associated with diamondiferous kimberlites (e.g., Buffalo Head Hills). Thus, G9A diamond-associated garnets have Cr_2O_3 ≥5.0 wt. % plus 0.94*CaO, or a calcium intercept of <4.3 wt. % and MnO ≤0.37 wt. %.

3.2 Ilmenite

Ilmenite is formed in a variety of rock types, including kimberlites and other unrelated rocks. Picroilmenite and Cr-picroilmenite are the favourable compositions of ilmenite when exploring for diamonds; therefore, the classification suggested by Creighton and Stachel (2008) was used to classify ilmenite. Accordingly, ilmenite was classified as Cr-picroilmenite if Cr_2O_3 >1.5 wt. % and MgO >8 wt. %, and picroilmenite if MgO >8 wt. %, with the remaining grains classified as ilmenite.

The discrimination plot of TiO_2 versus MgO (Wyatt et al., 2004) was used to separate kimberlitic from nonkimberlitic ilmenite (Figure 5). In addition, the composition of ilmenite can provide information on how well diamonds in kimberlite have been preserved. The presence of picroilmenite with low iron content indicates that this picroilmenite was transported in reducing conditions, which are conducive to diamond preservation (Haggerty, 1975; Gurney and Zweistra, 1995). High counts of low-iron picroilmenite indicate a high potential for diamond preservation, whereas iron-rich picroilmenites indicate a low potential for diamond preservation in the kimberlite magma.

3.3 Spinel and Chromite

Spinel can occur in numerous rock types. The group includes chromite, magnesiochromite, hercynite, spinel (sensu stricto), magnetite, and ulvospinel as end-members. To determine the end-member component, spinel microprobe analyses were classified using Ferracutti's software, which is based on mineral proportions (Ferracutti et al., 2015). Following the end-member classification, Creighton's Excel add-in (Creighton and Stachel, 2008) was used to calculate the magnesium number (Mg#) and classify spinel grains as related to diamond inclusion, kimberlite groundmass, ultramafic, or basaltic compositions. For diamond exploration, the most important compositions are related to diamond inclusion, kimberlitic, and ultramafic variants.

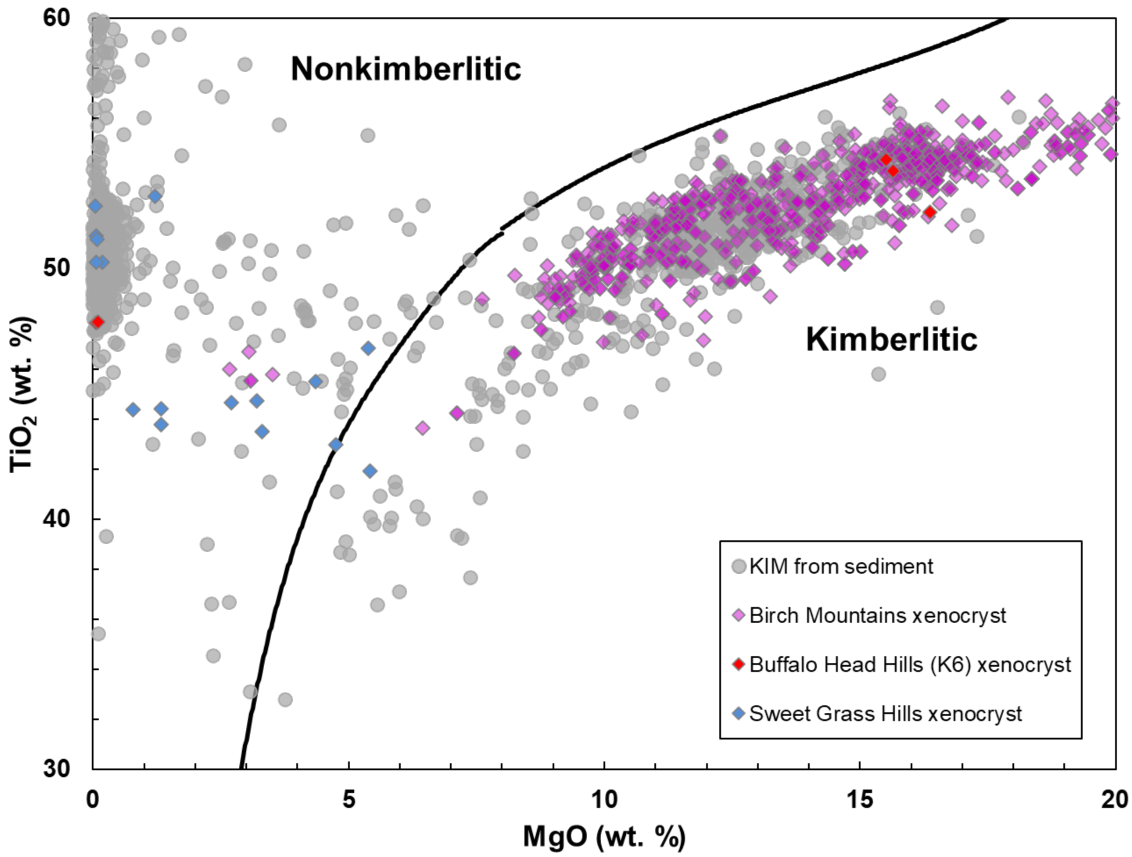

Figure 5. Discrimination scheme of Wyatt et al. (2004) to determine kimberlitic or nonkimberlitic ilmenite grains from Alberta sediment samples. Xenocrysts from Birch Mountains, Buffalo Head Hills (Eccles, 2007b), and Sweet Grass Hills (Rukhlov and Pawlowicz, 2012) kimberlite intrusions are shown as reference. Ilmenite data from Lopez et al. (2020). Abbreviation: K6, kimberlite intrusion in Buffalo Head Hills.

3.4 Olivine

Olivine is a very common mineral in kimberlite and mantle peridotite (Mitchell, 1989). Olivine is found in other rock types, but these rocks are rare in northern Alberta and olivine is not known to form in any sedimentary rock formation in the province (Banas et al., 2016). Because olivine is easily weathered, its occurrence in a sediment sample may suggest the presence of a kimberlite nearby. Commonly, olivine from disaggregated mantle peridotite has a Mg# greater than 91.5 (McClenaghan and Kjarsgaard, 2007).

3.5 Clinopyroxene

Clinopyroxene forms in a variety of rock types including kimberlites, and other igneous and metamorphic rocks. In particular, peridotitic clinopyroxene (also known as Cr-diopside) is a xenocryst in kimberlites and is frequently derived from lherzolite.

To classify pyroxene groups, the WinPyrox software developed by Yavuz (2013) was used to calculate structural formulas from microprobe analyses to determine pyroxene name, percentage of jadeite, end-member calcium Tschermak's pyroxene, and modifiers. Subsequently, a combination of Mg# and Cr_2O_3 was used to discriminate Cr-diopside grains from diopside grains, with Cr-diopside grains defined as having greater than 0.5 wt. % Cr_2O_3 and a Mg# greater than 88 (Ramsay and Tompkins, 1994; Nimis, 1998; Cookenboo and Grütter, 2010).

Kimberlite-related clinopyroxene can also provide information about the thermal and pressure conditions of the upper mantle. Consequently, clinopyroxene grains were selected for geothermobarometry using the compositional filters from Grütter (2009). A geotherm was constructed, using FITPLOT (Mather et al., 2011), from pressures and temperatures calculated from clinopyroxene grains that passed the compositional filters. The geotherm was based on pressure-temperature (P-T) calculations of Nimis and Taylor (2000).

4 Results

This section provides an assessment of the chemistry and distribution of interpreted KIMs in the province, highlighting those minerals that best indicate the proximity to a diamond-bearing kimberlite. Nearly 32 000 KIM microprobe analyses were used for this assessment, which were derived from 3229 sediment samples. This assessment excludes microprobe analyses of xenocrysts from kimberlite and other ultramafic/ultrabasic bodies. To learn about kimberlite xenocryst interpretations and how their chemistry compares to KIMs from sediments, consult the thorough reviews by Dufresne and Eccles (2005) and Eccles (2011).

Similar to the criteria used by Banas et al. (2016) to identify and qualify areas of potential, this report uses interpreted KIM mineralogy, counts, and spatial distribution to determine the most favourable areas for mineral exploration. This report also includes the results of clinopyroxene geothermobarometry, which can predict the region with the most favourable conditions for the formation of diamond-bearing kimberlites.

4.1 Garnet

Garnet is ubiquitous throughout Alberta (Figure 6). The majority of peridotitic garnet grains occur along a northwest trend, which includes the Buffalo Head Hills and Calling Lake areas. These areas are dominated by lherzolitic G9 garnet grains, followed by megacrystic G11 garnet grains, and harzburgitic G10 garnet grains (Figure 7). Eclogitic-pyroxenitic garnet grains occur throughout the province, however, mantle-related eclogitic-pyroxenitic garnet grains are significantly more abundant in the Hinton area (Figure 8).

Based on the classification of Grütter et al. (2004), a total of 104 garnet grains were classified as G3D, 42 garnet grains as G4D, 178 garnet grains as G9A, and 37 garnet grains as G10D, all of which correspond to garnets that formed in an environment suitable for diamond growth.

Areas of interest, which are outside of known kimberlite fields, containing diamond-associated garnet grains include the Birch Mountains east, Buffalo Head Hills north and west, Calling Lake, Chain Lakes, Chinchaga, Cold Lake, Hinton, Kakwa River, Lesser Slave Lake, Mary Lake, Peace River, Peerless Lake, St. Paul, Swan Hills, Sweet Grass Hills, Utikuma Lake, and West Edmonton (Figure 9).

4.2 Ilmenite

The discrimination scheme created by Wyatt et al. (2004), which separates kimberlitic from nonkimberlitic ilmenites, was applied to KIMs from sediment samples collected in Alberta. Figure 10a shows the discrimination plot, TiO_2 versus MgO, of the ilmenite grains from north of latitude 55°N, whereas Figure 10b shows the distribution of the ilmenite grains from south of latitude 55°N. On a map view, the kimberlitic picroilmenite grains occur dominantly along a southeast trend from the Buffalo Head Hills to Calling Lake (Figure 11a and b). Other areas of interest are Chinchaga, Cold Lake, Swan Hills, and St. Paul.

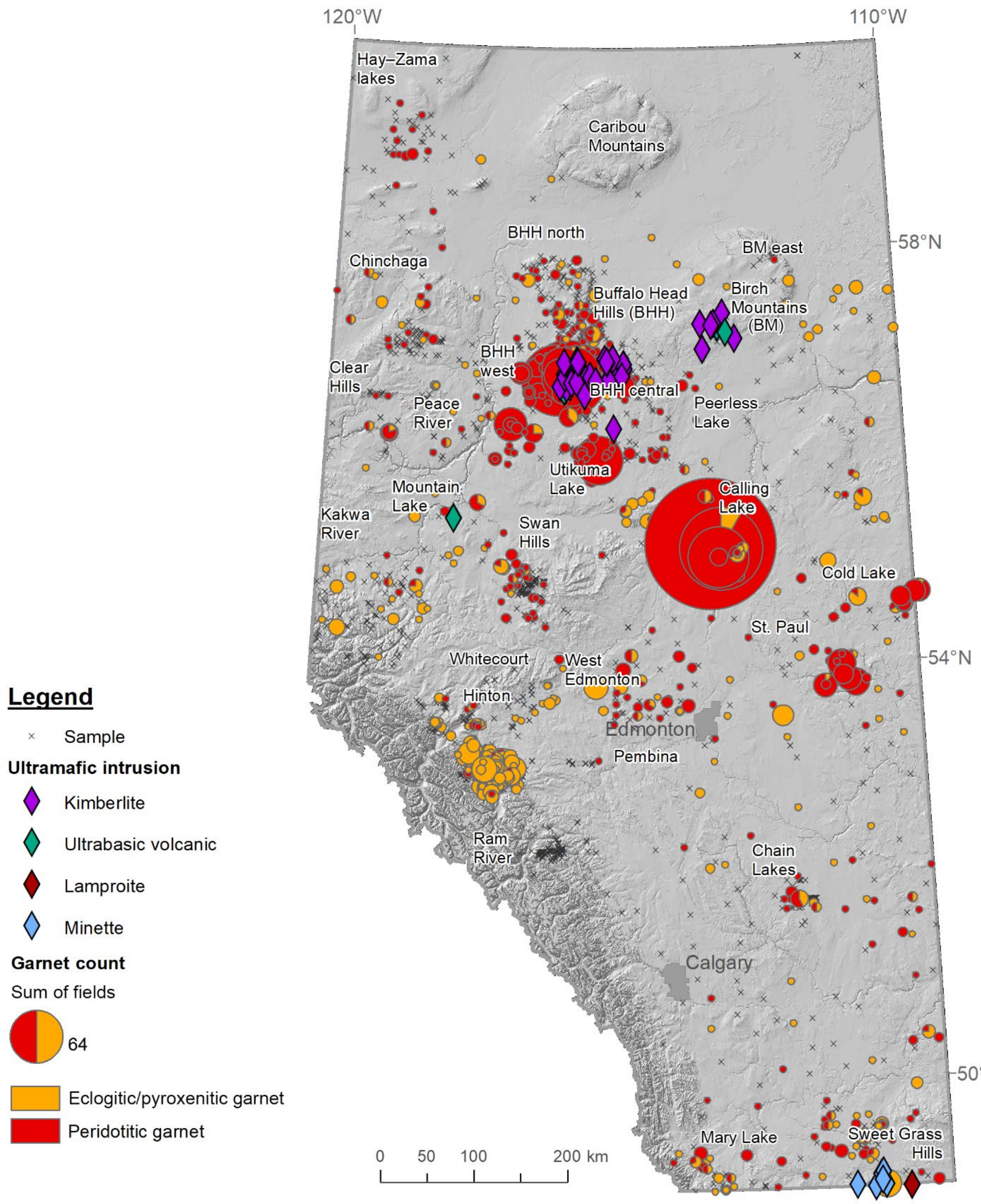

Figure 6. Distribution of eclogitic-pyroxenitic and peridotitic garnet grains from Alberta sediment samples (data from Lopez et al., 2020). Circle size proportional to number of garnet grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

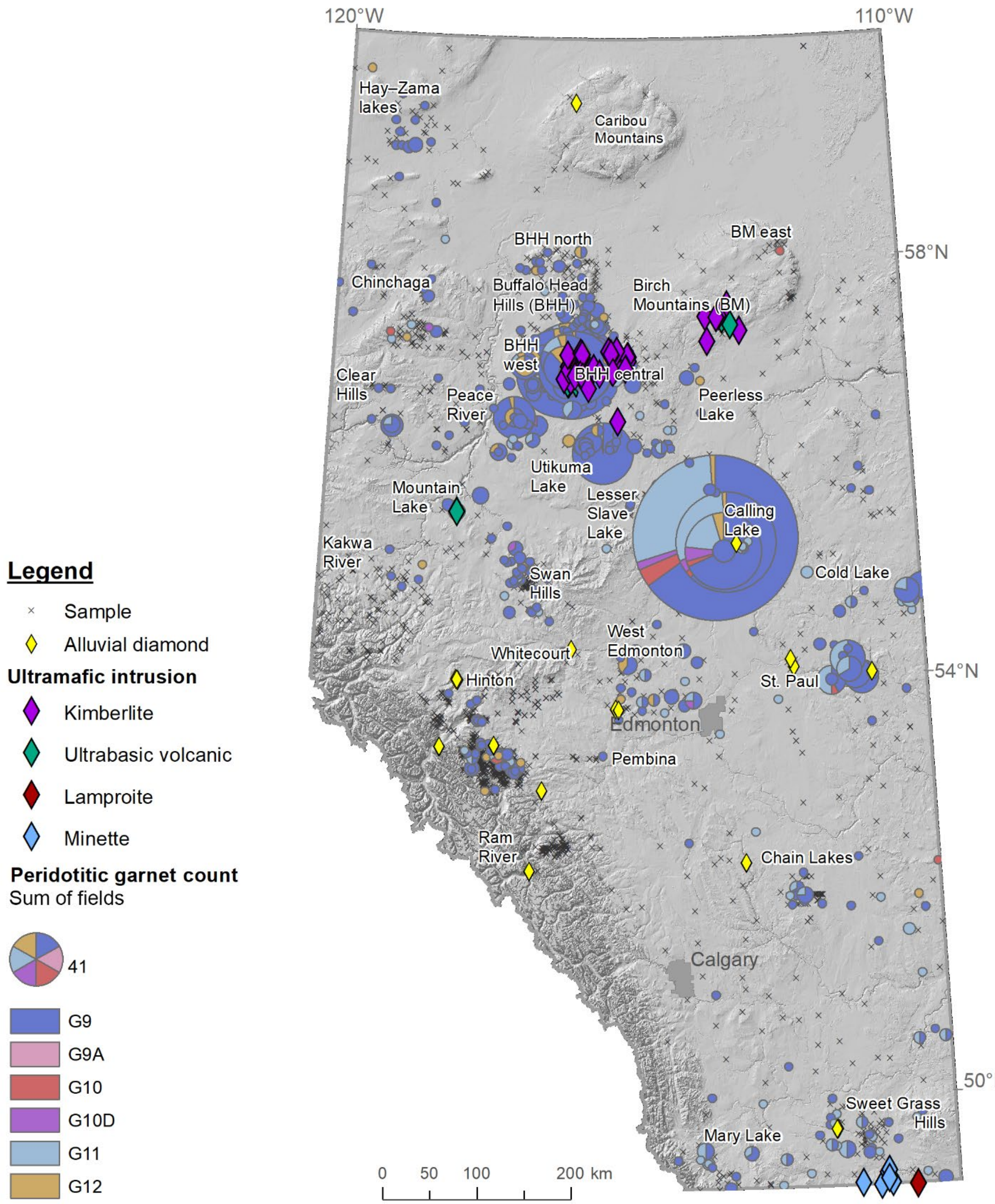

Figure 7. Distribution of peridotitic garnet grains from Alberta sediment samples based on their G-class (data from Lopez et al., 2020). Circle size proportional to number of garnet grains. Alluvial diamond data from Eccles (2007a). Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

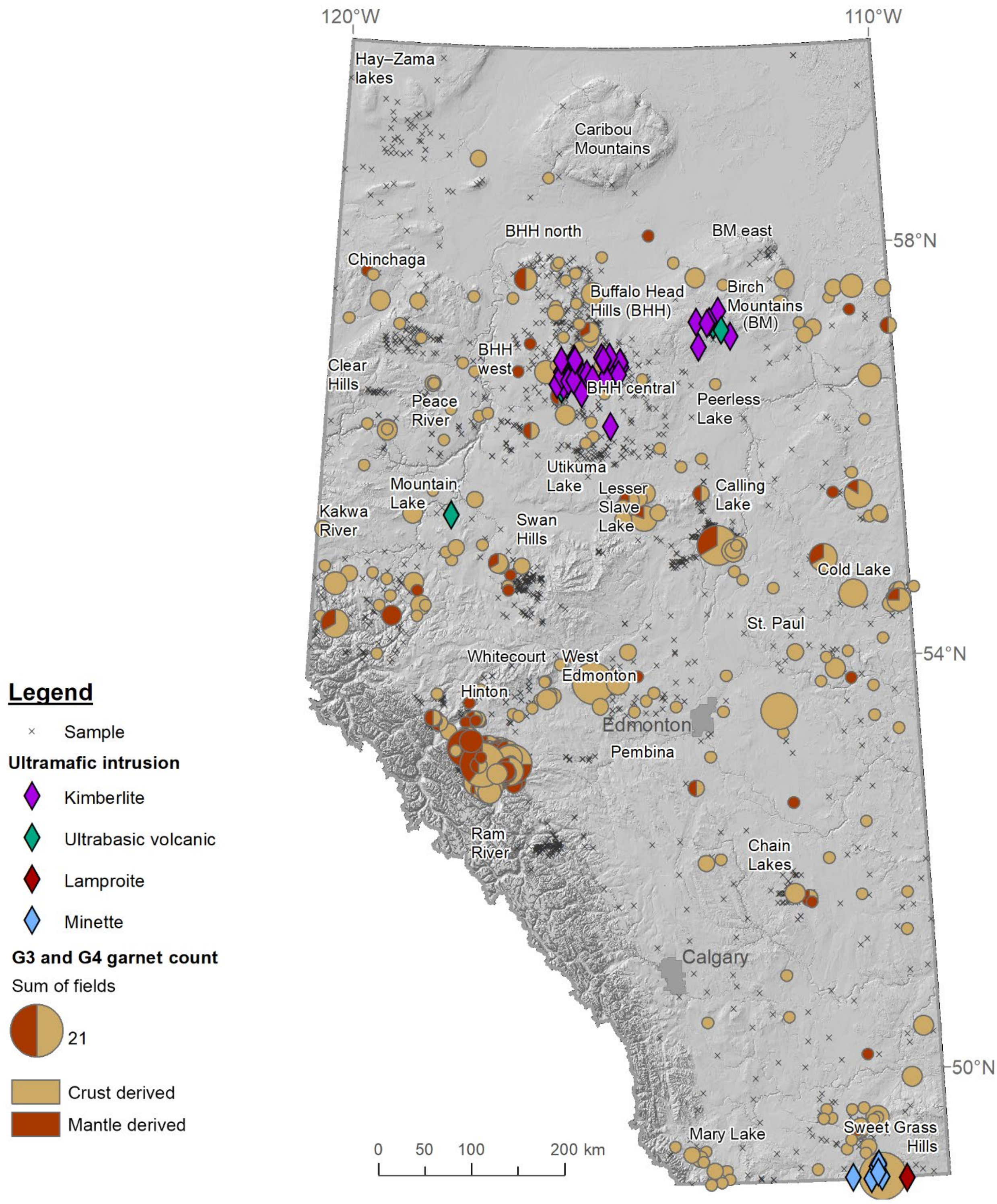

Figure 8. Distribution of eclogitic-pyroxenitic garnet grains (classes G3 and G4) from Alberta sediment samples based on crust/mantle source (data from Lopez et al., 2020). Circle size proportional to number of garnet grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

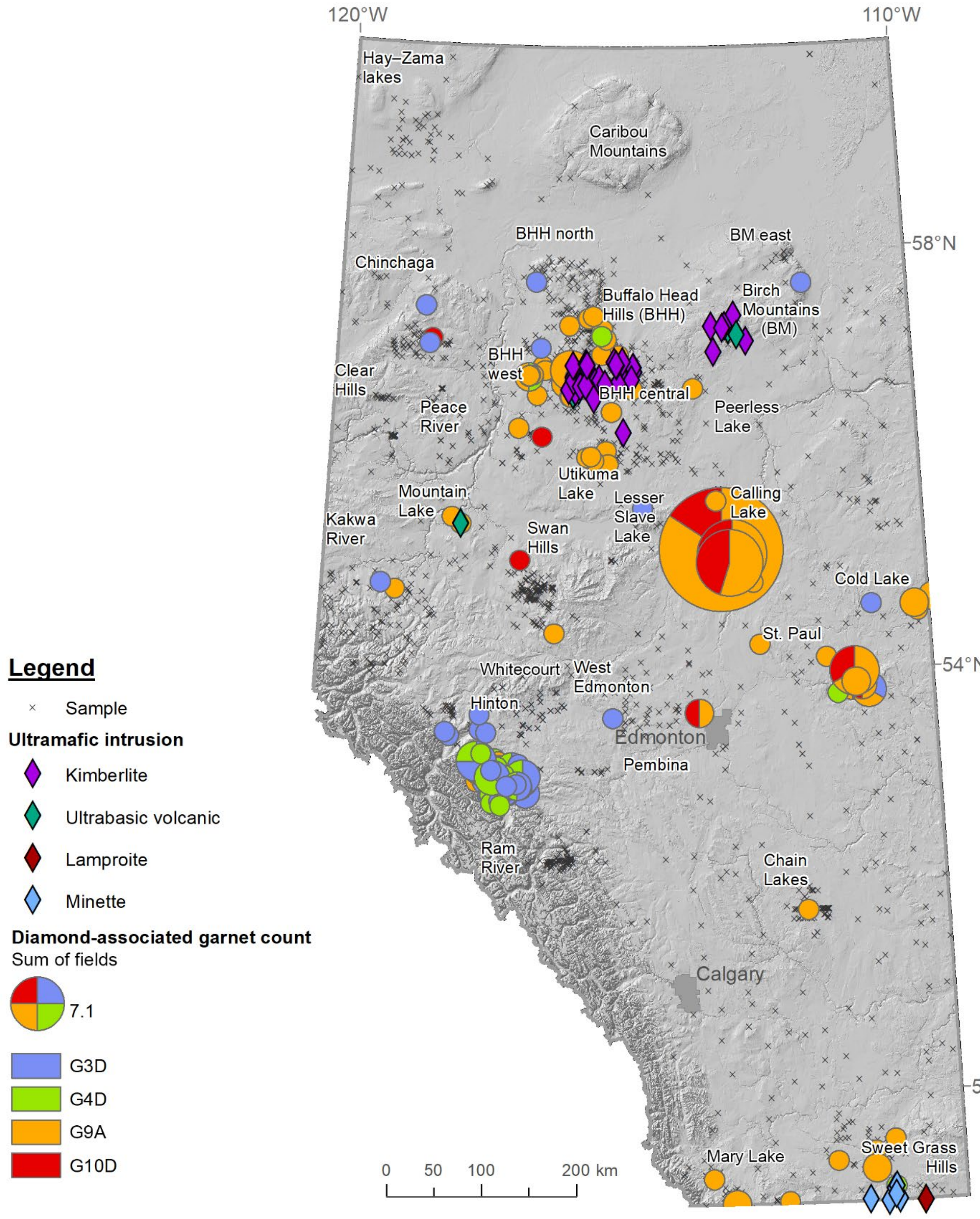

Figure 9. Distribution of diamond-associated garnet grains from Alberta sediment samples. Diamond-associated eclogitic-pyroxenitic garnet (classes G3D and G4D) and diamond-associated peridotitic garnet (classes G9A and G10D) data from Lopez et al. (2020). Circle size proportional to number of garnet grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

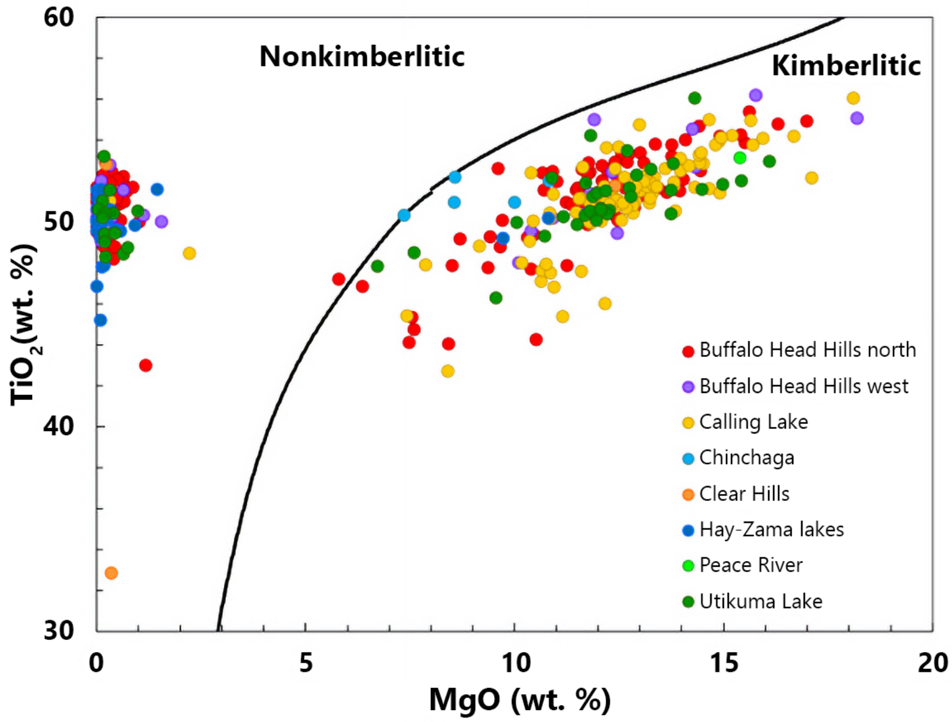

Figure 10a. Discrimination plot of Wyatt et al. (2004) to determine kimberlitic or nonkimberlitic ilmenite grains from sediment samples from northern Alberta (north of lat. 55°N). Data from Lopez et al. (2020).

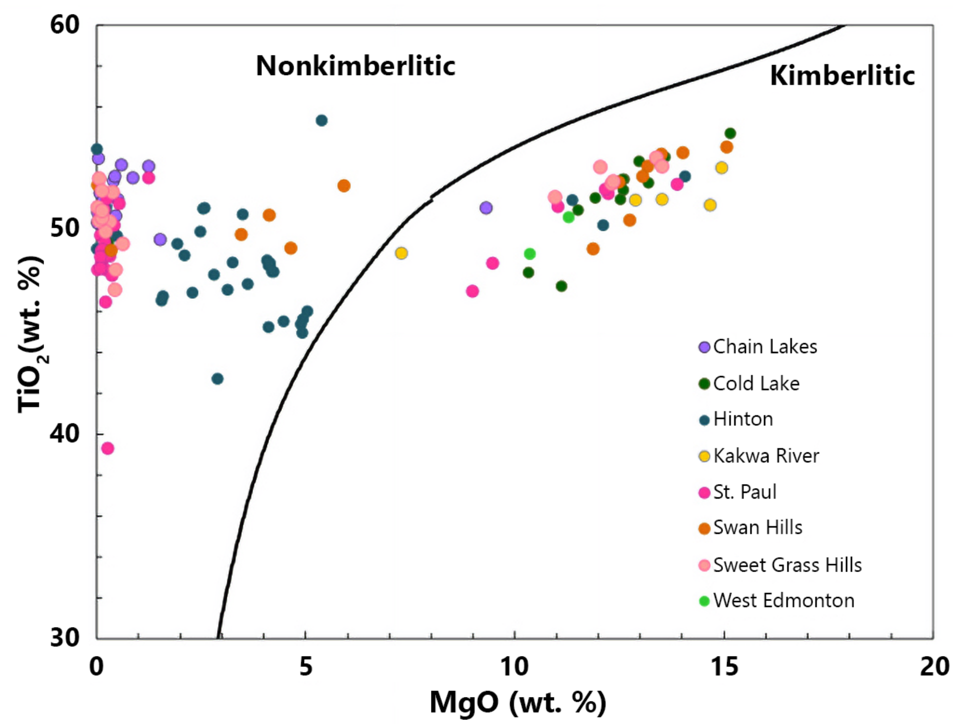

Figure 10b. Discrimination plot of Wyatt et al. (2004) to determine kimberlitic or nonkimberlitic ilmenite grains from sediment samples from southern Alberta (south of lat. 55°N). Data from Lopez et al. (2020).

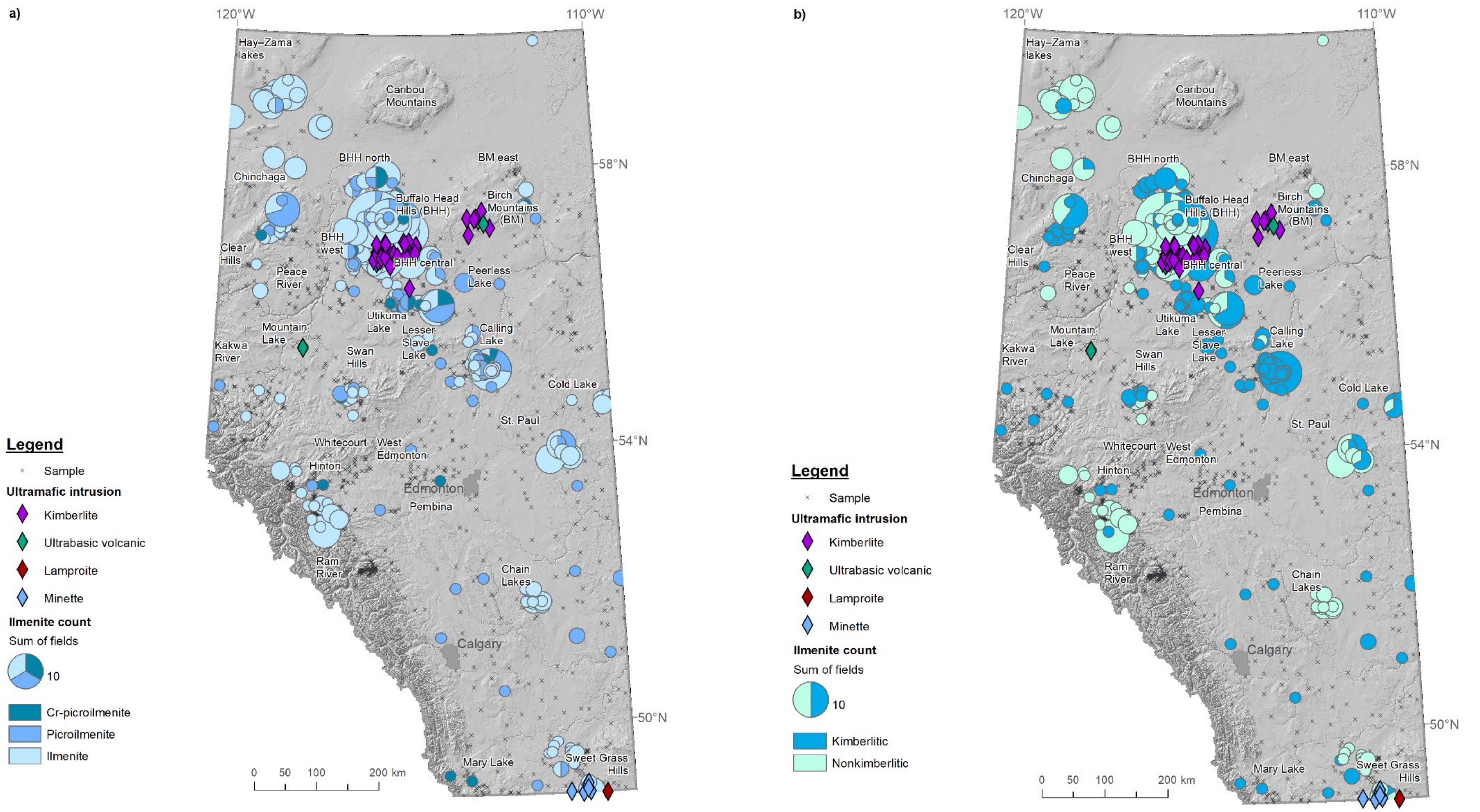

Figure 11. Distribution of ilmenite grains from Alberta sediment samples: (a) Cr-picroilmenite, picroilmenite, and ilmenite grains according to classification of Creighton and Stachel (2008); (b) kimberlitic ilmenite grains in relation to nonkimberlitic ilmenite grains according to discrimination scheme of Wyatt et al. (2004). Data from Lopez et al. (2020). Circle size proportional to number of ilmenite grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

4.3 Spinel and Chromite

Spinel and chromite are more abundant along the foothills of the Rocky Mountains relative to the plains region (Figure 12). Ultramafic spinel/chromite grains from sediment samples occur in high numbers in the Hinton, Kakwa River, Ram River, St. Paul, and Pembina areas. The Hinton area has a significant amount of diamond inclusion spinel/chromite grains suggesting the presence of a diamond-bearing kimberlite nearby.

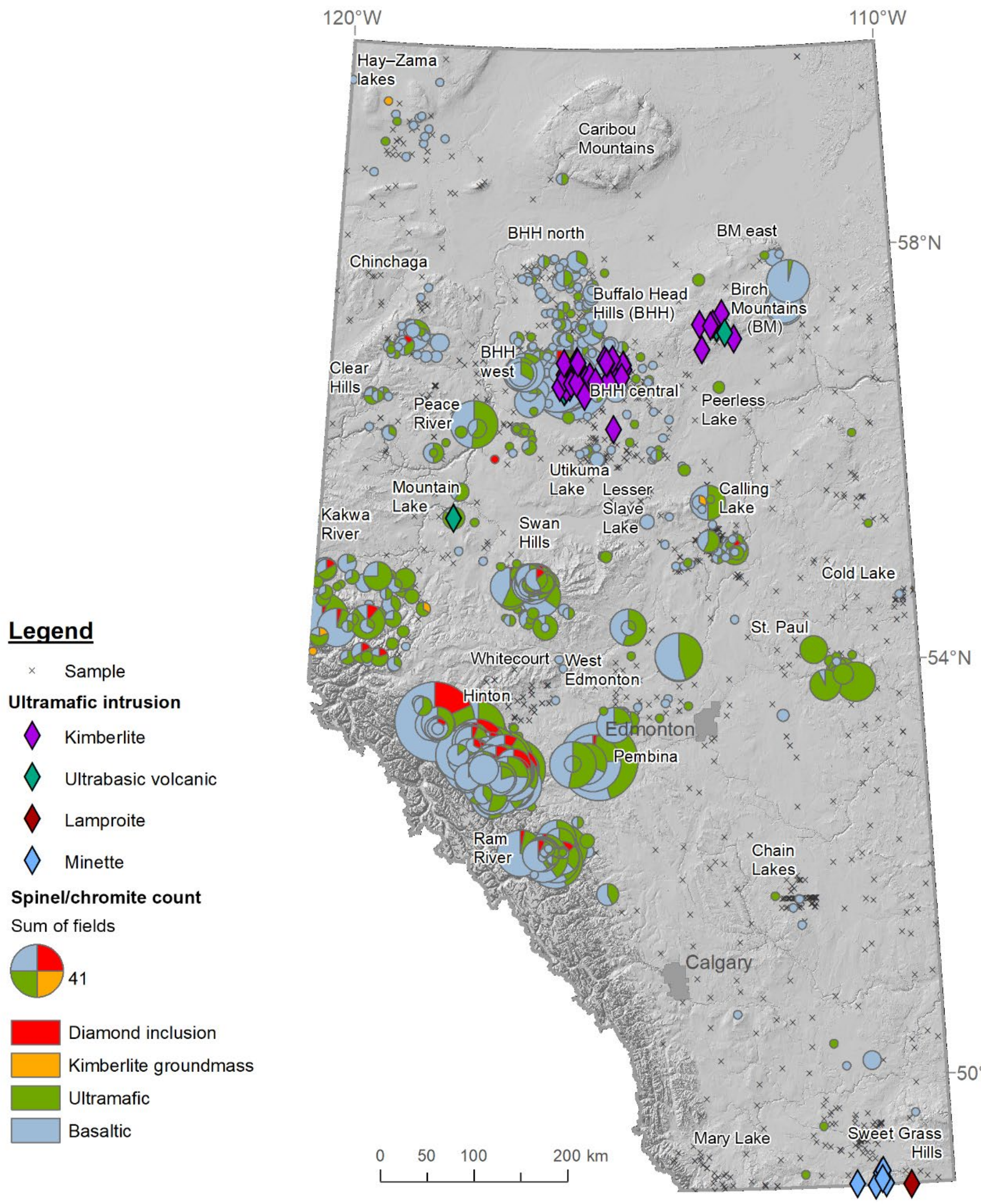

Figure 12. Distribution of spinel/chromite grains from Alberta sediment samples according to their classification as diamond inclusion, kimberlite groundmass, ultramafic, or basaltic variants (data from Lopez et al., 2020). Circle size proportional to number of spinel/chromite grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

4.4 Olivine

Olivine grains with high Mg# occur in the areas of the Buffalo Head Hills north and west, Clear Hills, Hay–Zama lakes, Hinton, Peace River, Pembina, Utikuma Lake, and north of the Chinchaga area (Figure 13). Samples containing higher numbers of Mg-rich olivine grains (Mg# >91.5) occur in the Buffalo Head Hills north and west, Hinton, Peace River, and Utikuma Lake areas. In the Buffalo Head Hills north area, 8 samples contain 9 Mg-rich olivine grains, whereas in the Buffalo Head Hills west area, 6 samples contain 16 grains. The source of this olivine is unknown and may indicate the presence of kimberlite in these two areas. In the Hinton area, 49 samples contain 163 Mg-rich olivine grains. This olivine may indicate the presence of a kimberlite or lamproite in the foothills. In the Peace River area, 4 samples contain 13 Mg-rich olivine grains, whereas in the Utikuma Lake area, 12 samples contain 28 grains. The source of this olivine may be either from these areas or up-ice from the Buffalo Head Hills kimberlite field.

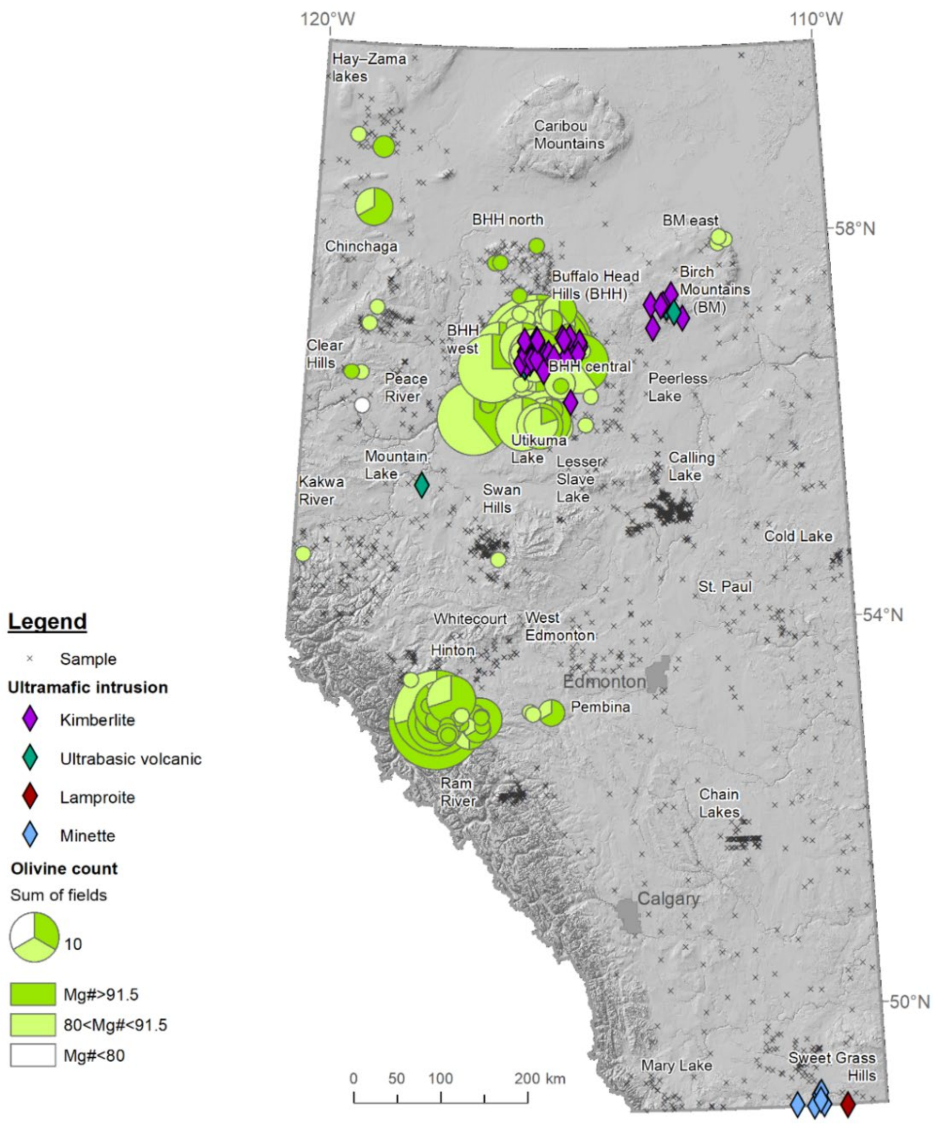

Figure 13. Distribution of olivine grains from Alberta sediment samples based on magnesium number (Mg#; data from Lopez et al., 2020). Circle size proportional to number of olivine grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

4.5 Clinopyroxene

Clinopyroxene is ubiquitous in Alberta despite being a soft and easily weathered mineral. The majority of clinopyroxene grains in the province consists of diopside, Cr-diopside, and augite (Figure 14). Nearly half of the samples containing clinopyroxene grains in Alberta include Cr-diopside (426 out of 904 samples). Chrome-diopside is more dominant in north-central Alberta, from St. Paul and Hinton up to the northern boundary of Buffalo Head Hills north.

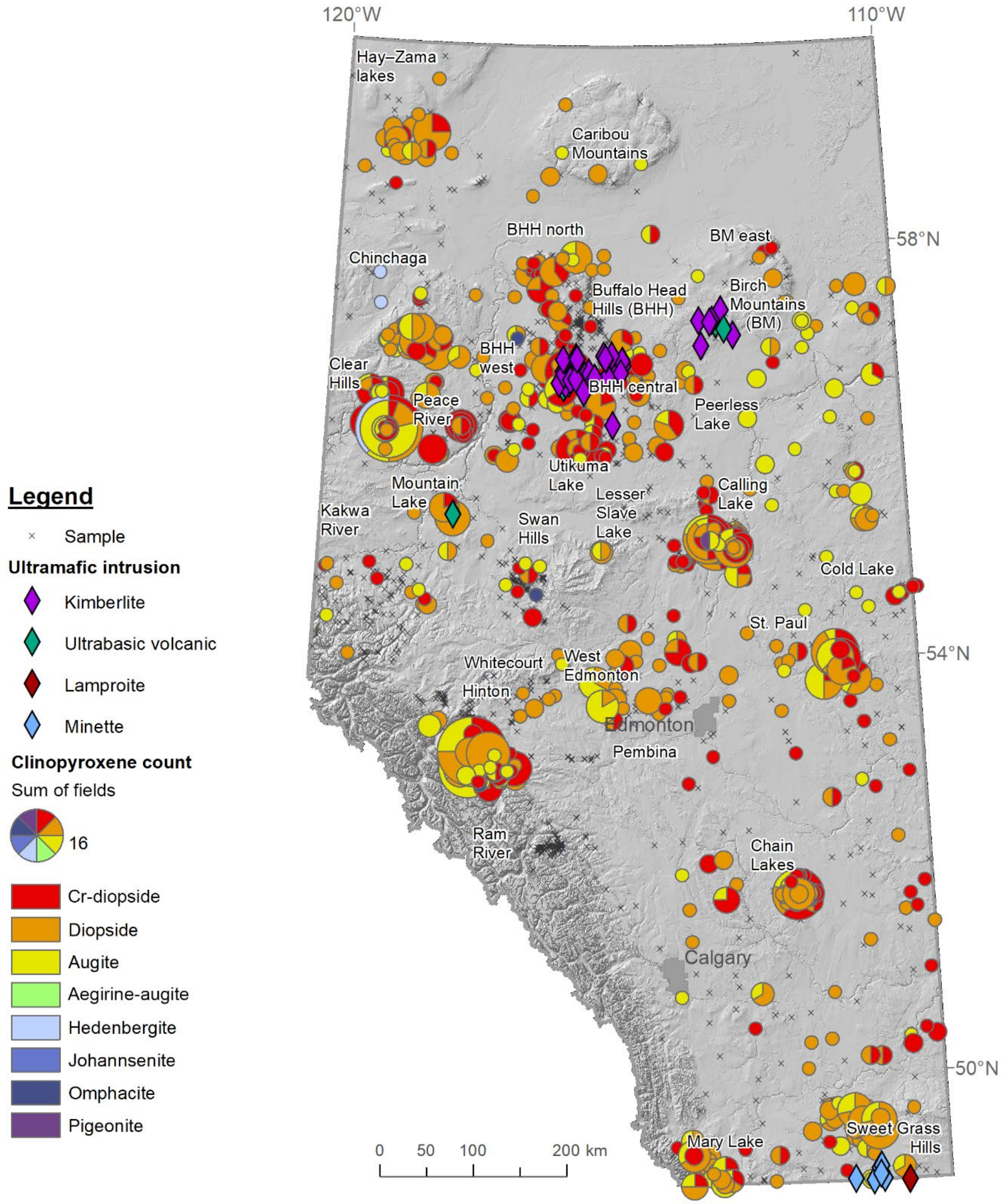

Figure 14. Distribution of clinopyroxene grains from Alberta sediment samples (data from Lopez et al., 2020). Circle size proportional to number of clinopyroxene grains. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

Using FITPLOT (Mather et al., 2011), a geotherm was constructed from pressure-temperature calculations from clinopyroxene grains that passed the compositional filters for geothermobarometry (Grütter et al., 2009). A variation in geotherms defined by the filtered clinopyroxene data was observed across the province. To accommodate these variations, the dataset was split into quadrants across the province. The first division was made along latitude 54°N. Within the southern dataset, a natural break occurs at longitude 115°W, separating the clinopyroxene of the eastern slope's sediments from clinopyroxene of the plains sediments. The northern clinopyroxene data was split east-west at longitude 116°W (Figure 15) because clinopyroxene from the Buffalo Head Hills (between longitudes 115° and 116°W) cluster within the diamond stability field with a geotherm consistent to that of the northeastern part of the province.

The four geotherms highlight the different pressure-temperature (P-T) conditions in the mantle for the four quadrants. The lithosphere most favourable for diamond potential is in the northeastern quadrant of the province, recording the coolest geotherm and thickest lithosphere of ~200 km (Figure 16). This lithospheric thickness is consistent with the thickness recorded in the Archean Rae craton in central Canada, which contains several kimberlite fields (e.g., Harris et al., 2018).

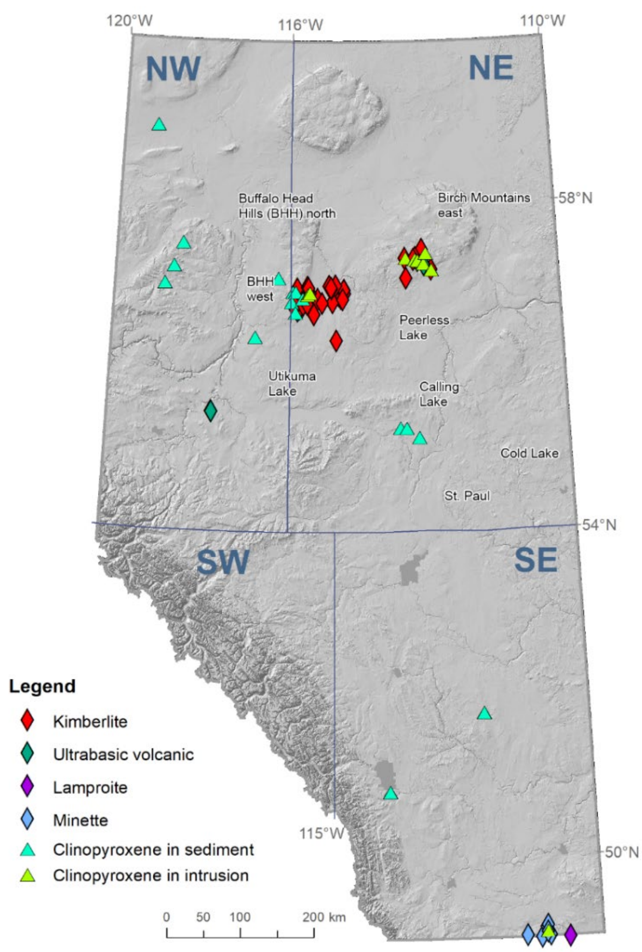

Figure 15. Spatial distribution of clinopyroxene grains, from Alberta sediment and intrusion samples (Lopez et al., 2020), that yielded pressure-temperature (P-T) conditions in the diamond stability field. Areas most favourable for diamond potential are indicated; all of which are in the northeastern quadrant. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

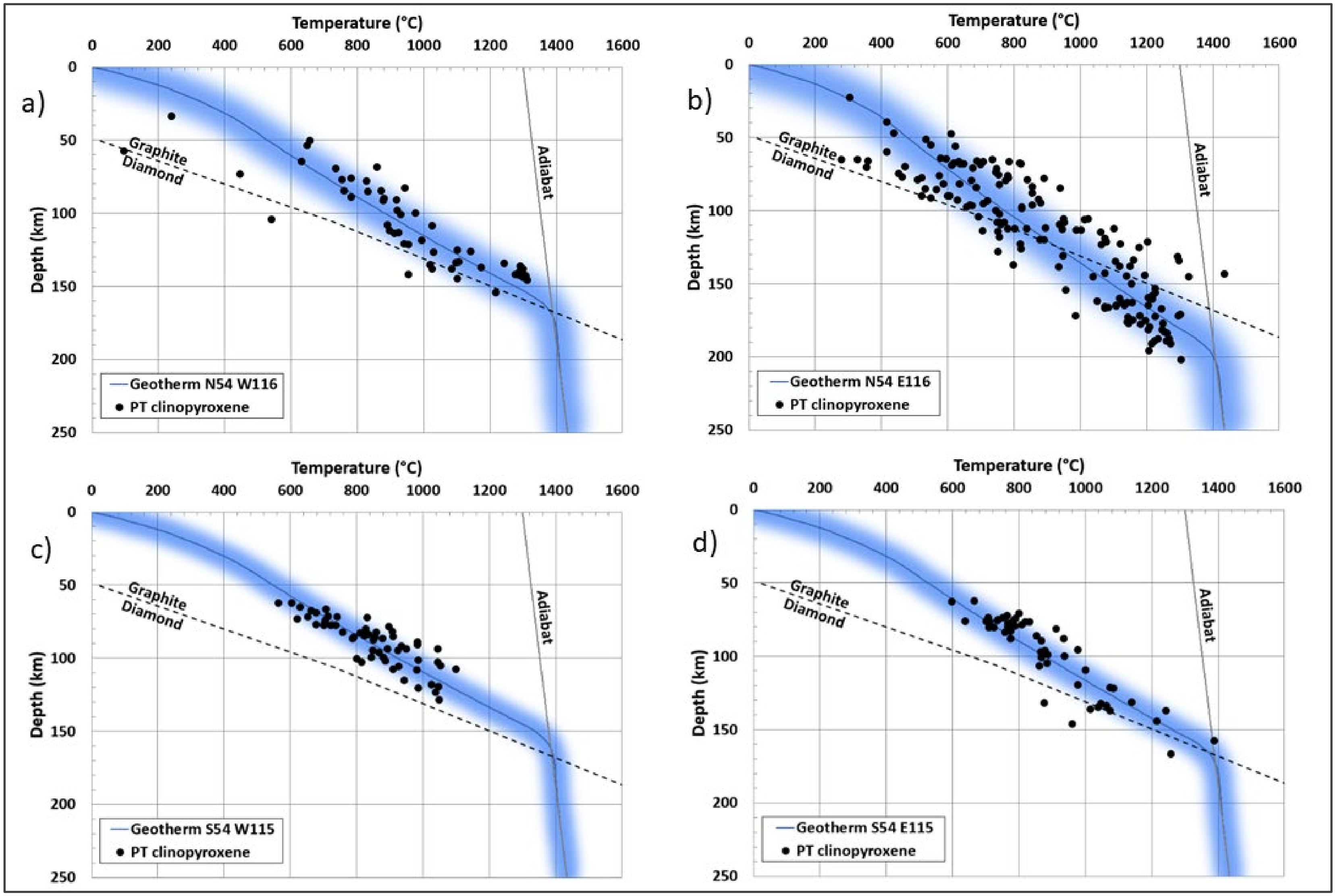

Figure 16. Geotherm diagrams of filtered clinopyroxene grains for the four quadrants of Alberta shown in Figure 15: (a) northwest (north of 54° lat., west of 116° long. [N54 W116]), (b) northeast (north of 54° lat., east of 116° long. [N54 E116]), (c) southwest (south of 54° lat., west of 115° long. [S54 W115]), (d) southeast (south of 54° lat., east of 116° long. [S54 E115]). The geotherm (blue band) was constructed using FITPLOT (Mather et al., 2011) and pressure-temperature (PT) calculations of Nimis and Taylor (2000).

4.6 Diamond Potential

By interpreting the chemistry of garnet, ilmenite, spinel/chromite, olivine, and clinopyroxene grains derived from sediment samples, numerous KIMs closely related to the presence of kimberlite were identified. The locations of these KIMs with favourable kimberlite-related chemistry, including some with diamond-related chemistry, form clusters. Clusters of KIMs outside known kimberlite fields (i.e., Buffalo Head Hills, Birch Mountains, and Mountain Lake) occur in the Birch Mountains east, Buffalo Head Hills north and west, Calling Lake, Chain Lakes, Chinchaga, Clear Hills, Cold Lake, Hay–Zama lakes, Hinton, Kakwa River, Lesser Slave Lake, Mary Lake, Peace River, Peerless Lake, Pembina, Ram River, St. Paul, Swan Hills, Sweet Grass Hills, Utikuma Lake, West Edmonton, and Whitecourt areas (Figure 17). Many of these clusters were already identified by Banas et al. (2016), except for Birch Mountains east, Chain Lakes, Cold Lake, Lesser Slave Lake, Mary Lake, Peace River, Peerless Lake, Pembina, Sweet Grass Hills, and Whitecourt.

The presence of alluvial diamonds and garnet or clinopyroxene grains with diamond affinity gives a cluster a relatively high priority for further investigation. Therefore, alluvial diamonds listed in Eccles (2007a) were added for the following assessment of clusters with diamond potential. From the clusters listed above (i.e., with favourable kimberlite-related indicator chemistry), the areas with diamond potential are Birch Mountains east, Buffalo Head Hills north and west, Calling Lake, Chain Lakes, Chinchaga, Cold Lake, Hay–Zama lakes, Hinton, Kakwa River, Lesser Slave Lake, Mary Lake, Peace River, Peerless Lake, Ram River, St. Paul, Swan Hills, Sweet Grass Hills, Utikuma Lake, West Edmonton, and Whitecourt (Figure 18). Although not a cluster, the area of Long Lake (Figures 17 and 18) contains one G9A garnet that meets the criteria of Grütter and Menzies (2003) for diamond affinity.

Clusters with the potential for the presence of a diamond-bearing kimberlite were ranked based on the following criteria:

- presence of alluvial diamonds
- presence of garnet/clinopyroxene grains with an affinity to diamond
- number of interpreted KIMs with mineral chemistry related to kimberlite
- number of species of interpreted KIMs with mineral chemistry related to kimberlite

For the ranking of clusters, an equal weight and nature of samples was assumed in order to use mineral count data to define areas of higher versus lower potential. Results presented below may change once a KIM microprobe analytical data compilation is completed with sample weights from tabling data, total number of picked grains, size fraction analyzed, and description of sediment units.

The following areas, which are outside known kimberlite fields, contain alluvial diamonds or garnet/clinopyroxene grains with diamond affinity and a high number of KIMs (>100 grains) encompassing multiple mineral species related to an undiscovered kimberlite and are considered to have higher potential:

- Buffalo Head Hills north: peridotitic garnet (68 grains, including 6 G9A garnets), crustal-derived eclogitic-pyroxenitic G3D/G4D garnet (2 grains), Cr-diopside (19 grains), kimberlitic ilmenite (74 grains, including 24 picroilmenite and 6 Cr-picroilmenite), diamond inclusion chromite (1 grain), kimberlite groundmass chromite (1 grain), and olivine with Mg# >91.5 (9 grains)
- Buffalo Head Hills west: peridotitic garnet (382 grains, including 12 G9A garnets), mantle-derived eclogitic-pyroxenitic garnet (3 grains, including 2 G3D/G4D garnets), Cr-diopside (7 grains), clinopyroxene from diamond stability field (1 grain), kimberlitic ilmenite (14 grains), and olivine with Mg# >91.5 (16 grains)
- Calling Lake: alluvial diamond (1 grain), peridotitic garnet (>1200 grains, including 89 G9A and 25 G10D garnets), Cr-diopside (173 grains), clinopyroxene from diamond stability field (3 grains), kimberlitic ilmenite (83 grains, including 5 Cr-picroilmenite and 21 picroilmenite), diamond inclusion chromite (2 grains), and kimberlite groundmass chromite (2 grains)

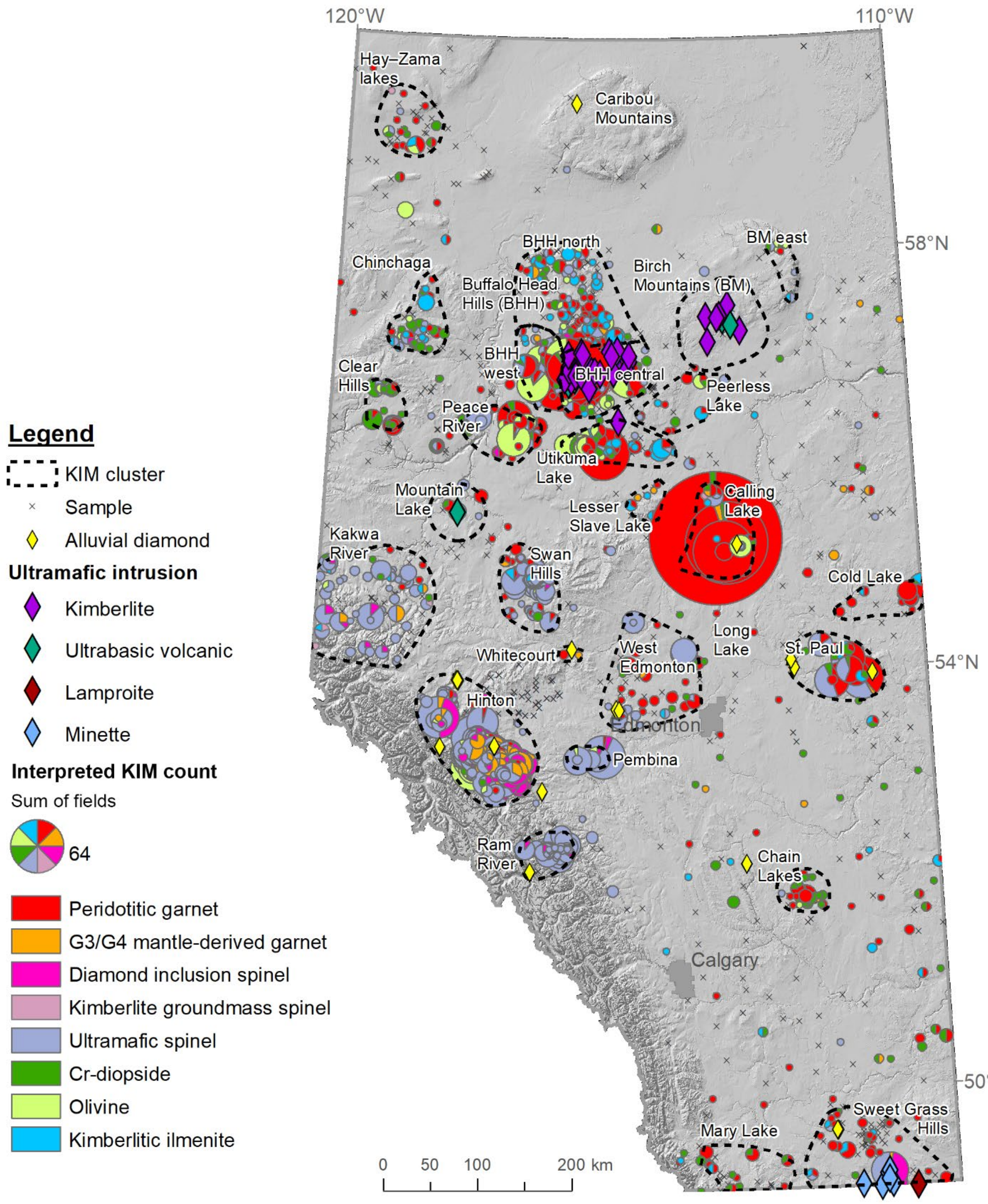

Figure 17. Distribution of interpreted kimberlite-indicator minerals (KIMs) from Alberta sediment samples. Circle size proportional to number of KIM grains. Alluvial diamond data from Eccles (2007a) and KIM data from Lopez et al. (2020). Areas of potential (outlined in dashed black line) for hosting a diamond-bearing kimberlite are based on KIM clusters identified in this work and Banas et al. (2016). Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

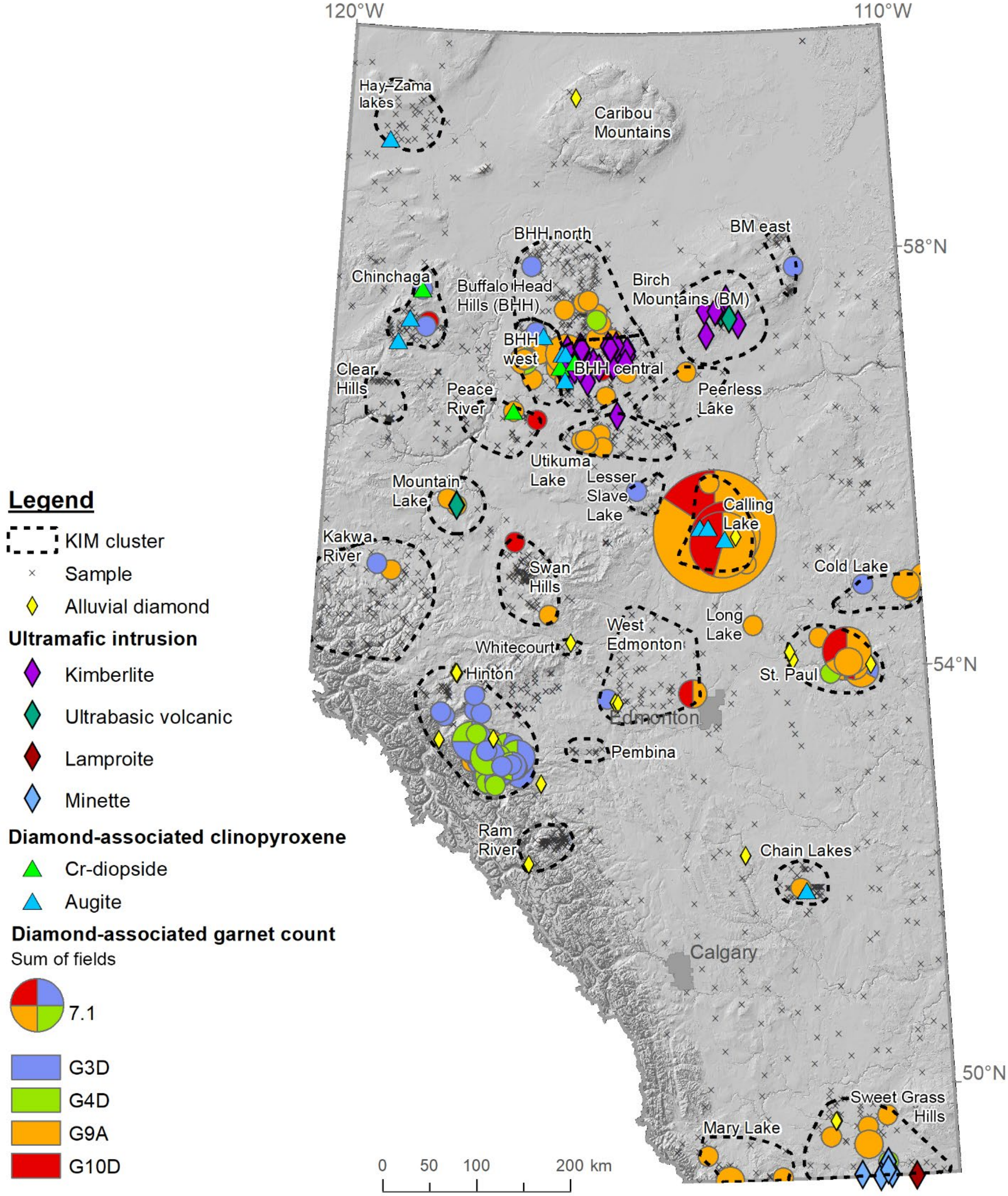

Figure 18. Distribution of alluvial diamonds, diamond-associated garnet grains (G3D, G4D, G9A, G10D), and diamond-associated clinopyroxene grains from kimberlite-indicator minerals (KIMs) in Alberta sediment samples. Circle size proportional to number of garnet grains. Alluvial diamond data from Eccles (2007a) and KIM data from Lopez et al. (2020). The KIM clusters are from Figure 17. Locations of ultramafic intrusions modified from Eccles (2011). Background image is a hill-shaded rendering of Alberta's ground surface topography created from digital elevation data (NASA JPL, 2013).

- Hinton: alluvial diamond (22 grains), peridotitic garnet (49 grains, including 3 G9A and 1 G10D garnets), mantle-derived eclogitic-pyroxenitic garnet (295 grains, including 93 G3D and 36 G4D garnets), Cr-diopside (87 grains), diamond inclusion spinel/chromite (9 grains), kimberlite groundmass chromite (3 grains), kimberlitic ilmenite (3 grains), and olivine with Mg# >91.5 (163 grains)
- Peace River: peridotitic garnet (92 grains, including 1 G9A and 1 G10D garnets), Cr-diopside (19 grains), clinopyroxene from diamond stability field (1 grain), diamond inclusion spinel/chromite (1 grain), kimberlitic ilmenite (1 picroilmenite grain), and olivine with Mg# >91.5 (13 grains)
- St. Paul: alluvial diamond (2 grains), peridotitic garnet (99 grains, including 13 G9A and 4 G10D garnets), mantle-derived eclogitic-pyroxenitic garnet (1 grain), Cr-diopside (20 grains), and kimberlitic ilmenite (6 grains, including 4 picroilmenite)
- Utikuma Lake: peridotitic garnet (103 grains, including 6 G9A and 1 G10D garnets), Cr-diopside (30 grains), kimberlitic ilmenite (6 Cr-picroilmenite grains and 8 picroilmenite grains), and olivine with Mg# >91.5 (28 grains)

The following areas, which are outside known kimberlite fields, contain diamonds or garnet/clinopyroxene grains with diamond affinity, but a lower number of KIMs (<100 grains) encompassing multiple or single mineral species related to an undiscovered kimberlite and are considered to have moderate potential:

- Birch Mountains east: peridotitic garnet (1 G3D garnet), Cr-diopside (3 grains), and kimberlitic ilmenite (4 grains, including 2 Cr-picroilmenite)
- Chain Lakes: peridotitic garnet (17 grains, including 3 G9A garnets), mantle-derived eclogitic-pyroxenitic garnet (3 grains), Cr-diopside (33 grains), and clinopyroxene from diamond stability field (1 grain)
- Chinchaga: peridotitic garnet (11 grains, including 1 G10D garnet), eclogitic G3D garnet (2 grains), Cr-diopside (21 grains, including 3 clinopyroxene in diamond stability field), kimberlitic ilmenite (19 grains, including 12 Cr-picroilmenite/picroilmenite), and diamond inclusion chromite (1 grain)
- Cold Lake: peridotitic garnet (73 grains, including 11 G9A garnets), mantle-derived eclogitic-pyroxenitic garnet (2 grains), Cr-diopside (9 grains), and kimberlitic ilmenite (11 grains, including 3 Cr-picroilmenite/picroilmenite)
- Hay–Zama lakes: peridotitic garnet (14 grains), Cr-diopside (6 grains), clinopyroxene from diamond stability field (1 grain), kimberlitic ilmenite (2 grains, including 1 picroilmenite), and olivine with Mg# >91.5 (2 grains)
- Kakwa River: peridotitic garnet (5 grains, including 1 G9A garnet), mantle-derived eclogitic-pyroxenitic garnet (6 grains, including 1 G3D), Cr-diopside (5 grains), diamond inclusion chromite (9 grains), kimberlite groundmass chromite (3 grains), and kimberlitic ilmenite (6 grains, including 2 picroilmenite)
- Lesser Slave Lake: peridotitic garnet (5 grains, including 1 G3D garnet), mantle-derived eclogitic-pyroxenitic garnet (3 grains), and kimberlitic ilmenite (4 grains, including 1 Cr-picroilmenite)
- Mary Lake: peridotitic garnet (23 grains, including 4 G9A garnets), Cr-diopside (9 grains), and kimberlitic ilmenite (1 Cr-picroilmenite grain)
- Peerless Lake: peridotitic garnet (9 grains, including 1 G9A garnet), Cr-diopside (3 grains), kimberlitic ilmenite (4 picroilmenite grains), and ultramafic spinel (3 grains)
- Ram River: alluvial diamond (inferred) and diamond inclusion chromite (13 grains)
- Swan Hills: peridotitic garnet (43 grains, including 1 G9A and 1 G10D garnets), mantle-derived eclogitic-pyroxenitic garnet (3 grains), diamond inclusion chromite (13 grains), Cr-diopside (5 grains), and kimberlitic ilmenite (12 grains, including 4 Cr-picroilmenite/picroilmenite)
- Sweet Grass Hills: alluvial diamond (2 grains), peridotitic garnet (35 grains, including 9 G9A garnets), mantle-derived eclogitic-pyroxenitic garnet (2 grains), Cr-diopside (7 grains), diamond inclusion spinel/chromite (25 grains), and kimberlitic ilmenite (7 grains, including 3 picroilmenite)

- West Edmonton: alluvial diamond (Opdahl diamond [near Evansburg] and an indeterminate number of diamonds at the Entwistle occurrence), peridotitic garnet (32 grains, including 1 G9A and 1 G10D garnets), mantle-derived eclogitic garnet (1 grain), Cr-diopside (6 grains), and kimberlitic ilmenite (2 grains, 1 Cr-picroilmenite and 1 picroilmenite)
- Whitecourt: alluvial diamond (2 grains), peridotitic garnet (2 grains), and mantle-derived eclogitic-pyroxenitic garnet (1 grain)

The following areas, which are outside of known kimberlite fields, do not contain either alluvial diamonds or garnet/clinopyroxene grains with diamond affinity and are considered to have lower potential for a diamond-bearing kimberlite:

- Clear Hills: Cr-diopside (57 grains), peridotitic garnet (24 grains), mantle-derived eclogitic-pyroxenitic garnet (3 grains), kimberlitic ilmenite (1 grain), and olivine with Mg# >91.5 (1 grain)
- Pembina: peridotitic garnet (1 grain), diamond inclusion chromite (3 grains), kimberlitic ilmenite (1 picroilmenite grain), and olivine with Mg# >91.5 (2 grains)

These results are influenced by the density of sampling as more heavily sampled areas may tend to yield more indicators. Also, KIM counts per sample are not necessarily comparable. The KIM microprobe data compiled by Lopez et al. (2020) do not include information about sample weights during collection or the separation of grain-size fractions during mineral processing. Therefore, it was not possible to normalize mineral counts by sample weight for this study. This can influence results, for example, a larger sample may contain more KIMs than a smaller one simply because of its size. Furthermore, samples were collected from various sediment types and horizons that are not equivalent or comparable. The KIM numbers across a till section at the same location tend to increase with depth; therefore till from the A or B horizon contains fewer KIMs than the C horizon, which is right above bedrock. On the other hand, sometimes not all grains picked from samples undergo microprobe analysis and only a representative number of KIMs per sample is sent to laboratories to reduce analytical costs, which adds uncertainty to the number of KIMs reported in laboratory certificates.

To further refine the prediction of diamond potential, the geophysical and second-order structural features of the basement should be interpreted and used to understand the controls on the spatial distribution of kimberlite fields. Secondly, stream and ice movement paths should be considered for the interpretation of the provenance of KIM clusters to predict the location of kimberlitic source rocks.

The geothermobarometry of clinopyroxene chemistry data indicates that the region with a lithosphere most favourable for diamonds is the northeastern portion of the province (north of lat. 54°N and east of long. 116°W). The estimated thickness of the lithosphere (~200 km) in this region is consistent with the thickness recorded elsewhere in the Rae craton. The areas underlain by this thick lithosphere favourable for diamonds, regardless of their level of potential given by KIMs counts, are the Birch Mountains east, Buffalo Head Hills north and west, Calling Lake, Cold Lake, Peerless Lake, St. Paul, and Utikuma Lake areas (Figure 15). The lithosphere is less favourable for hosting diamonds in the southwestern portion of the province (south of lat. 54°N and west of long. 115°W).

The current assessment of potential is based on KIM geochemistry data that is publicly available. Due to the lack of data over many areas, including the northeastern corner of Alberta, the current assessment does not exclude the possibility of the presence of diamond-bearing kimberlites elsewhere in Alberta.

5 Conclusions

The compilation and levelling of existing kimberlite-indicator-mineral (KIM) microprobe analytical data into a single dataset allows a comprehensive view of the distribution of results for key KIMs. Although the highest potential for an economic, diamond-bearing kimberlite is within the known kimberlite fields in the Buffalo Head Hills and Birch Mountains, other areas in the province display KIM chemistry favourable for the possible presence of undiscovered kimberlites, which warrant further investigation. The reassessment of KIM chemistry data from sediment samples collected throughout the province and released to the public between 1993 and 2012 has identified areas of relatively high potential for diamond exploration outside of known kimberlite fields.

Based on the presence in sediment samples of alluvial diamonds, and garnet and clinopyroxene grains with a chemistry associated with diamonds, a high number of interpreted KIMs with mineral chemistry related to kimberlite, and a high number of species of interpreted KIMs with mineral chemistry related to kimberlite, the following areas have relatively higher potential to contain a diamond-bearing kimberlite:

- Buffalo Head Hills north
- Buffalo Head Hills west
- Calling Lake
- Hinton
- Peace River
- St. Paul
- Utikuma Lake

Additional areas with diamonds or garnet and clinopyroxene grains with favourable chemistry for the presence of a diamond-bearing kimberlite, but with lower count numbers of KIMs, are considered to have moderate potential:

- Birch Mountains east
- Chain Lakes
- Chinchaga
- Cold Lake
- Hay–Zama lakes
- Kakwa River
- Lesser Slave Lake
- Mary Lake
- Peerless Lake
- Ram River
- Swan Hills
- Sweet Grass Hills
- West Edmonton
- Whitecourt

Other areas with favourable chemistry for the presence of a kimberlite, but without the favourable chemistry related to diamonds, are considered to have a lower potential. These are the Clear Hills and Pembina areas.

Clinopyroxene geothermobarometry analysis of available data shows that the area most favourable for diamonds to occur is located in the northeastern portion of the province because it displays the coolest geotherm and thickest lithosphere (~200 km) relative to the rest of the province.

The review of KIMs and assignment of areas of diamond/kimberlite potential is limited to those areas where KIM data are available. It should be recognized that there are vast tracts of Alberta that have limited KIM information. Ongoing support for comprehensive KIM field studies—in conjunction with other exploration techniques such as geophysical surveys and subsurface probing—are required. Noticeable areas with minimal KIM data include, but are not limited to,

- the Archean Hearne craton, a stable, ancient craton with a thick mantle root (keel), which is a requirement for diamonds to form and be preserved;
- notable major transcrustal lineaments such as the Snowbird tectonic zone and Great Slave Lake shear zone, which could serve as pathways for deep-seated magmas to reach the surface; and
- the area north of the Buffalo Head Hills, including the Caribou Mountains; these mountains have a modern-day surface expression similar to the Buffalo Head Hills and Birch Mountains, which could reflect complex basement structures and significant anomalies at depth.

6 References

Ashton Mining of Canada Inc. (1999): Ashton reports new anomalies and diamond found in Alberta; news release transmitted by Canadian Corporate News, September 27, 1999. URL <http://www.ashton.ca/news/1999/99-09.html> [November 2006; dead link].

Aulbach, S., Griffin, W.L., O'Reilly, S.Y. and McCandless, T.E. (2004): Genesis and evolution of the lithospheric mantle beneath the Buffalo Head Terrane, Alberta (Canada); Lithos, v. 77, no. 1–4, p. 413–451.

Banas, A., Eccles, D.R. and Dufresne, M.B. (2016): Diamond potential in Alberta: distribution of kimberlite and kimberlite indicator mineral clusters; Alberta Energy Regulator, AER/AGS Special Report 103, 50 p., URL <https://ags.aer.ca/publication/spe-103> [November 2022].

Brey, G.P. and Stachel, T. (1997): 700 km auf dem Weg zum Mittelpunkt der Erde; Forschung Frankfurt, v. 2, p. 4–15.

Buffalo Diamonds Ltd. (1999): Exploration progress update; news release transmitted by Canadian Corporate News, January 13, 1999.

Cookenboo, H.O. and Grütter, H.S. (2010): Mantle-derived indicator mineral compositions as applied to diamond exploration; Geochemistry; Exploration, Environment, Analysis, v. 10, p. 81–95.

Creighton, S. and Stachel, T. (2008): An empirical chromite classification for positive identification of kimberlite in diamond exploration; 9th International Kimberlite Conference, Frankfurt, Germany, August 10–15, 2008, Extended Abstract No. 9IKC-A-00402, 3 p.

Dawson, J.B. and Stephens, W.E. (1975): Statistical classification of garnets from kimberlite and associated xenoliths; The Journal of Geology, v. 83, no. 5, p. 589–607.

de Wit, M.C.J., Bhebhe, Z., Davidson, J., Haggerty, S.E., Hundt, P., Jacob, J., Lynn, M., Marshall, T., Skinner, C., Smithson, K., Stiefenhofer, J., Robert, M., Revitt, A., Spaggiari, R. and Ward, J. (2016): Overview of diamond resources in Africa; Episodes, v. 39, no. 2, p. 199–238.

Dredge, L.A., Kjarsgaard, I.M., Ward, B.C., Kerr, D.E. and Stirling, J.A.R. (1996): Distribution and geochemical composition of kimberlite indicator minerals, Point Lake map area, Northwest Territories (86H); Geological Survey of Canada, Open File 3341, 21 p.

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, 277 p., URL <https://ags.aer.ca/publication/spe-020> [November 2022].

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 Energy, Alberta Geological Survey, Bulletin 63, 158 p., URL <https://ags.aer.ca/publication/bul-063> [November 2022].

Eccles, D.R. (2005): There's diamond in them there alluvium; Alberta Energy and Utilities Board, Alberta Geological Survey, Rock Chips, Winter 2005, p. 1–3.

Eccles, D.R. (2007a): Alberta diamond occurrences dataset; Alberta Energy and Utilities Board, EUB/AGS Digital Data 2007-0009, URL <https://ags.aer.ca/publication/dig-2007-0009> [November 2022].

Eccles, D.R. (2007b): Alberta kimberlite xenocryst dataset; Alberta Energy and Utilities Board, EUB/AGS Digital Data 2007-0008, URL <https://ags.aer.ca/publication/dig-2007-0008> [November 2022].

Eccles, D.R. (2011): Northern Alberta kimberlite province: the first 20 years; Energy Resources Conservation Board, ERCB/AGS Bulletin 65, 116 p., URL <https://ags.aer.ca/publication/bul-065> [November 2022].

Eccles, D.R., Dufresne, M., Copeland, D., Csanyi, W. and Creighton, S. (2002): Alberta kimberlite-indicator mineral geochemical compilation; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-20, 8 p., URL <https://ags.aer.ca/publication/esr-2001-20> [November 2022].

Edmonton Journal (1992): Prospector low-key about diamond find; Edmonton Journal, October 17, 1992.

Ferracutti, G.R., Gargiulo, M.F., Ganuza, M.L., Bjerg, E.A. and Castro, S.M. (2015): Determination of the spinel group end-members based on electron microprobe analyses; Mineralogy and Petrology, v. 109, no. 2, p. 153–160.

Gilmour, W.R. (1995): Report on the Hinton property, Alberta; Alberta Energy and Minerals, Mineral Assessment Report 19950017, 104 p.

Grew, E.S., Locock, A.J., Mills, S.J., Galuskina, I.O., Galuskin, E.V. and Hålenius, U. (2013): Nomenclature of the garnet supergroup; American Mineralogist, v. 98, p. 785–811.

Grütter, H.S. (2009): Pyroxene xenocryst geotherms: techniques and application; Lithos, v. 112, Suppl. 2, p. 1167–1178.

Grütter, H.S. and Menzies, A. (2003): Mutually consistent classification schemes for mantle- derived garnet and chromite, for use by diamond explorers; 8th International Kimberlite Conference, Victoria, Canada, June 22–27, 2003, Extended Abstract, 5 p.

Grütter, H.S., Gurney, J.J., Menzies, A.H. and Winter, F. (2004): An updated classification scheme for mantle-derived garnet, for use by diamond explorers; Lithos, v. 77, p. 841–857.

Gurney, J.J. and Zweistra, P. (1995): The interpretation of the major element compositions of mantle minerals in diamond exploration; Journal of Geochemical Exploration, v. 53, p. 293–310.

Haggerty, S.E. (1975): The chemistry and genesis of opaque minerals in kimberlites; *in* Physics and chemistry of the Earth, 1st International Kimberlite Conference, Capetown, South Africa, September 24–28, 1973, v. 9, p. 295–308.

Hardman, M.F., Pearson, D.G., Stachel, T. and Sweeney, R.J. (2018): Statistical approaches to the discrimination of crust- mantle-derived low-Cr garnet – major-element-based methods and their application in diamond exploration; Journal of Geochemical Exploration, v. 186, p. 24–35.

Harris, G.A., Pearson, D.G., Liu, J., Harman, M.F., Snyder, D.B. and Kelsch D. (2018): Mantle composition, age, and geotherm beneath the Darby kimberlite field, west central Rae Craton; Mineralogy and Petrology, v. 112, p. 57–70.

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

Kjarsgaard, B.A. (1997): Diamonds in Alberta: studies of potential host rocks of deep-seated origin and applications of indicator mineral exploration techniques; *in* Exploring for minerals in Alberta: Geological Survey of Canada geoscience contributions, Canada-Alberta Agreement on Mineral Development (1992–1995), R.W. Macqueen (ed.), Geological Survey of Canada, Bulletin 500, p. 185–207.

Lopez, G.P., Harris, G.A., Banas, A. and Eccles, D.R. (2020): Alberta kimberlite indicator mineral (KIM) microprobe analyses (tabular data, tab delimited format); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Digital Data 2020-0009, URL <https://ags.aer.ca/publication/dig-2020-0009> [November 2022].

Mather, K.A., Pearson, D.G., McKenzie, D., Kjarsgaard, B. and Priestley, K. (2011): Constraining the depth and thermal history of cratonic lithosphere using peridotite xenolith and xenocryst thermobarometry and seismology; Lithos, v. 125, p. 729–742.

McClenaghan, M.B. and Kjarsgaard, B.A. (2007): Indicator mineral and surficial geochemical exploration methods for kimberlite in glaciated terrain; examples from Canada; *in* Mineral deposits of Canada: a synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods, W.D. Goodfellow (ed.), Geological Association of Canada, Mineral Deposits Division, Special Publication 5, p. 983–1006.

Mitchell, R.H. (1989): Aspects of the petrology of kimberlites and lamproites: some definitions and distinctions; *in* Volume 1: kimberlites and related rocks, their composition, occurrences, origin and emplacement, J. Ross (ed.), Proceedings of the 4th International Kimberlite Conference, Perth, Australia, 1986, Geological Society of Australia, Special Publication No. 14, p. 7–45.

Morton, R.D., Stewart, J.P., Bale, W.C. and Day, R.C. (1993): A review of diamond occurrences and potentials in Alberta, Canada; *in* Mid-continent diamonds, K.P.E. Dunne and B. Grant (ed.), Geological Association of Canada–Mineralogical Association of Canada Symposium Volume, Joint Annual Meeting, May 17–18, 1993, Edmonton, Alberta, p. 101–104.

NASA JPL (2013): NASA Shuttle Radar Topography Mission Global 1 arc second; NASA EOSDIS Land Processes Distributed Active Archive Center, zipped HGT format, doi:10.5067/MEaSUREs/SRTM/SRTMGL1.003.

Nimis, P. (1998): Evaluation of diamond potential from the composition of peridotitic chromian diopside; European Journal of Mineralogy, v. 10, p. 505–519.

Nimis, P. and Taylor, W.R. (2000): Single clinopyroxene thermobarometry for garnet 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.

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* Volume 2: diamonds: characterization, genesis and exploration, H.O.A. Meyer and O.H. Leonardos (ed.), Proceedings of the 5th International Kimberlite Conference, Araxá, Brazil, June 18–July 4, 1991, v. 5, p. 329–345.

Ross, G.M., Broome, J. and Miles, W. (1994): Potential fields and basement structure; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists, Calgary, Alberta, and Alberta Research Council, Edmonton, Alberta, URL <https://ags.aer.ca/atlas-the-western-canada-sedimentary-basin/chapter-4-potential-fields-and-basement-structure> [November 2022].

Rukhlov, A.S. and Pawlowicz, J.G. (2012): Eocene potassic magmatism of the Milk River area, southern Alberta (NTS 72E) and Sweet Grass Hills, northern Montana: overview and new data on mineralogy, geochemistry, petrology and economic potential; Energy Resources Conservation Board, ERCB/AGS Open File Report 2012-01, 88 p., URL <https://ags.aer.ca/publication/ofr-2012-01> [November 2022].

Schaeffer, A.J. and Lebedev S. (2014): Imaging the North American continent using waveform inversion of global and USArray data; Earth and Planetary Science Letters, v. 402, p. 26–41.

Schulze, D.J. (1989): Constraints on the abundance of eclogite in the upper mantle; Journal of Geophysical Research, v. 94, no. B4, p. 4205–4212.

Stachel, T. and Harris, J.W. (2008): The origin of cratonic diamonds—constraints from mineral inclusions; Ore Geology Reviews, v. 34, p. 5–32.

Stachel, T. and Harris, J.W. (2009): Formation of diamond in the Earth's mantle; Journal of Physics: Condensed Matter, v. 21, no. 36, art. 364206, 10 p.

Wyatt, B.A., Baumgartner, M., Anckar, E. and Grütter, H. (2004): Compositional classification of "kimberlitic" and "non-kimberlitic" ilmenite; Lithos, v. 77, p. 819–840.

Yavuz, F. (2013): WinPyrox: a Windows program for pyroxene calculation classification and thermobarometry; American Mineralogist, v. 98, p. 1338–1359.