
D.R. Eccles

Energy Resources Conservation Board
Alberta Geological Survey

September 2008
Contents

Acknowledgments .......................................................................................................................... vii
Abstract ........................................................................................................................................ viii
1 Introduction ................................................................................................................................... 1
2 Study Area and Overview of Sample Sites .................................................................................. 1
3 General Geology .......................................................................................................................... 5
4 Exploration History ...................................................................................................................... 7
  4.1 Cold Lake–St. Paul Region ........................................................................................................ 9
  4.2 Calling Lake Region .................................................................................................................. 9
5 Methodology ............................................................................................................................... 10
6 Results .......................................................................................................................................... 11
  6.1 Grain-Size Distributions, General Lithology and Magmatic Susceptibility .............................. 11
  6.2 Garnet Species ....................................................................................................................... 12
  6.3 Kimberlite-Indicator Minerals ................................................................................................. 17
  6.4 Gold Grain Counts, Morphology and Dimensions .................................................................. 22
  6.5 Metamorphic and Magmatic Massive-Sulphide Indicator Minerals ..................................... 22
7 Discussion and Conclusions ....................................................................................................... 24
  7.1 Overview of Industrial Garnet Production and Considerations for East-Central Alberta ...... 24
  7.2 Source of Garnet: Geological Reasoning .............................................................................. 27
  7.3 Source of Garnet: Indicator-Mineral Reasoning ..................................................................... 28
    7.3.1 Indicators of Kimberlite Paragenesis ............................................................................. 28
    7.3.2 Indicators of Metamorphic Paragenesis ......................................................................... 30
  7.4 Potential for Secondary Diamonds ......................................................................................... 30
8 References .................................................................................................................................... 32
Appendix 1 – Garnet-Rich Beaches in East-Central Alberta (Information Gathered from Various
  Prospectors) ................................................................................................................................. 37
Appendix 2 – Magnetic Susceptibility and General Lithology of Beach Sands in East-Central
  Alberta ........................................................................................................................................ 39
Appendix 3 – Electron Microprobe Analytical Results for Garnet-Rich Beach Sands in East-Central
  Alberta: A) Garnet (All Species), B) Non-Garnet Kimberlite-Indicator Minerals (Clinopyroxene,
  Chromite and Ilmenite), and C) Garnet from a Garnetiferous Pelitic Gneiss Erratic Discovered in
  the Area ...................................................................................................................................... 50
Appendix 4 – Garnet Distribution in Saskatchewan ........................................................................ 57

Tables

Table 1. Location and general lithology of beach sands from selected beaches in east-central Alberta.
  Results use the average measurements from three 5 g samples. The table summarizes the data
  and images shown in Appendix 2 ............................................................................................... 4
Table 2. Summary of garnet species in beach sands from selected beaches in east-central Alberta .... 14
Table 3. Summary of kimberlite-indicator minerals in beach sands from selected beaches in east-central
  Alberta ....................................................................................................................................... 18
Table 4. Summary of gold grain counts, morphology and dimensions of beach sands from selected
  beaches in east-central Alberta ................................................................................................. 24
Table 5. Summary of metamorphic/magmatic massive-sulphide indicator minerals in beach sands from
  selected beaches in east-central Alberta ................................................................................... 25
Table 6. Electron microprobe analytical results for garnet ............................................................. 51
Table 7. Electron microprobe analytical results for non-garnet kimberlite-indicator minerals .......... 55
Table 8. Electron microprobe analytical results for garnet from the garnetiferous pelitic gneiss erratic .. 56
Figures

Figure 1. Location of selected garnet-rich beaches sampled in east-central Alberta. Geology base from Hamilton et al. (1999). ................................................................. 2

Figure 2. Example of distribution of garnet-rich sands at selected beaches in east-central Alberta. 3

Figure 3. Inferred northern Alberta basement domains of Ross et al. (1994). Square denotes approximate outline of study area, with selected beach-sand sample locations (see Figure 1 for lake names). 6

Figure 4. Bathymetry of the Cold Lake to Lac La Biche region: A) regional overview illustrating the three glacial lobes that formed during the Cold Lake glaciation (after Andriashek and Fenton, 1989); B) detailed bathymetry of the Cold Lake region, with the approximate location of a garnet-rich metamorphic erratic discovered by L. Andriashek (pers. comm., 2007). ........................................... 8

Figure 5. Beach-sand sampling methodology. Three samples were taken at each site: a 10 kg pail for indicator-mineral picking, a 2 kg sample for grain-size analysis and a ‘tube’ sample to obtain a cross-section of the site for magnetic-susceptibility measurements and physical observations. 11

Figure 6. Grain-size distributions at selected beaches in east-central Alberta. ................................................................. 13

Figure 7. Geographic distribution of garnet species as estimated from Table 2: A) total estimated grain counts; B) garnet grain counts normalized to 10 000 total grains. Abbreviations: alm, almandine; gros, grossular; and, andradite; spes, spessartine; Cr-gros, Cr-grossular; Cr-pyr, Cr-pyrope; Cr-poorpyr, Cr-poor pyrope; py-alm, pyrope-almandine......................................................... 15

Figure 8. Geochemical distribution of garnet species from east-central Alberta beach sands. .......... 16

Figure 9. Distribution and CaO-Cr2O3 geochemistry of high-Cr (>2 wt. %) pyrope garnet from garnet-rich beach sands in east-central Alberta. Abbreviation: GDC, graphite-diamond constraint. ...... 19

Figure 10. Distribution and Al-Cr-Na and Al2O3-Cr2O3 geochemistry of clinopyroxene from garnet-rich beach sands. ............................. 20

Figure 11. Distribution and MgO-Cr2O3 and Mg#-Cr# geochemistry of chromite from garnet-rich beach sands in east-central Alberta. ........................................................................... 21

Figure 12. Distribution and MgO-TiO2 and MgO-Cr2O3 geochemistry of ilmenite from garnet-rich beach sands in east-central Alberta. ......................................................................................... 23


Figure 14. Garnet-rich metamorphic erratic discovered by L. Andriashek (pers. comm., 2007) and its geochemical comparison with beach sand garnet from this study. ..................................................... 31

Figure 15. Magnetic susceptibility and general lithology of beach sand at Heart Lake (sample RE06-GB-001). ................................................................................................. 40

Figure 16. Magnetic susceptibility and general lithology of beach sand at Winefred Lake (sample RE06-GB-002). ................................................................................................. 41

Figure 17. Magnetic susceptibility and general lithology of beach sand at Christina Lake (sample RE06-GB-003). ................................................................................................. 42

Figure 18. Magnetic susceptibility and general lithology of beach sand at Wolf Lake (sample RE06-GB-004). Garnet-rich horizons are highlighted by the red arrows. ................................. 43

Figure 19. Magnetic susceptibility and general lithology of beach sand at Cold Lake (sample RE06-GB-005). Garnet-rich horizons are highlighted by the red arrows. ......................... 44

Figure 20. Magnetic susceptibility and general lithology of beach sand at Shelter, Bay, Marie Lake (sample RE06-GB-007). Garnet-rich horizons are highlighted by the red arrows. ............ 45

Figure 21. Magnetic susceptibility and general lithology of beach sand at Stoney Lake (sample RE06-GB-008). ................................................................................................. 46

Figure 22. Magnetic susceptibility and general lithology of beach sand at Lac Santé (sample RE06-GB-009). ................................................................................................. 47
Figure 23. Magnetic susceptibility and general lithology of beach sand at Calling Lake southeast (sample RE06-GB-010). ................................................................. 48

Figure 24. Magnetic susceptibility and general lithology of beach sand at Calling Lake west (sample RE06-GB-011). ................................................................. 49

Figure 25. Distribution of garnet species in Saskatchewan: a) pyrope, b) almandine, c) grossular, d) spessartine and e) andradite. Compilation from the Web-based database of Saskatchewan kimberlite-indicator minerals (Swanson et al., 2007). ................................................................. 57
Acknowledgments

The authors thank R. Jalbert and L. Vanhill, prospectors residing in Alberta communities, for taking the time to either show, or provide advice on access to, garnet-rich beaches in east-central Alberta. The authors hope it is the prospectors, those innovative explorers with their eyes to the ground, who make a significant mineral discovery in Alberta.

A. Langerud and W. Lehman, students with the Earth and Atmospheric Sciences Department, University of Alberta at the time of this study, are thanked for their roles in fieldwork and data preparation, respectively.

R. Hunealt and S. Averill of Overburden Drilling Management Limited, Ottawa, Ontario, advanced this project through diligent indicator-mineral picking. Their expertise, advice and patience were critical in the formation and implementation of this project. Thank you.

V. Kravchinky of the Physics Department, University of Alberta is thanked for access to, and help with, the Bartington MS2C core logging sensor for magnetic-susceptibility measurements. D. Resultay and S. Matveev of the Earth and Atmospheric Sciences Department, University of Alberta are thanked for their roles in electron microprobe mount preparation and analytical work, respectively.

Finally, M. Dufresne of APEX Geoscience Ltd. and L. Andriashek of the Alberta Geological Survey significantly improved the manuscript through editorial comments.
Abstract

The unique occurrence of garnet-rich beach sands in east-central Alberta has generated interest for its industrial-mineral potential, for its possible association with an undiscovered cluster(s) of diamondiferous kimberlite, and as a curiosity with regard to the genre and source of the ‘purple beaches’.

This comprehensive report provides the first known physical and chemical account of all garnet species present in selected east-central Alberta beaches, along with discussion on indicator minerals for kimberlite, gold, and metamorphic/magmatic massive sulphide mineralization. Garnet reaches lithological proportions of up to 74 vol. % and consists overwhelmingly (up to 99%) of almandine, followed by decreasing abundances of grossular, spessartine, lherzolitic and harzburgitic pyrope, megacrystic Cr-pyrope, andradite and Cr-andradite. Other indicator minerals of interest recovered include clinopyroxene, ilmenite, gahnite, corundum, low-Cr diopside and apatite.

Deterrents to industrial garnet production in east-central Alberta include scattered garnet distributions, small (~250–500 µm) and weathered (rounded) garnet morphologies, and the potential for environmental and public conflict. Garnet production as a potential coproduct of sand and gravel, however, should warrant consideration by sand and gravel operators in the region. In addition, a small niche market should not be discounted, especially given the high concentrations of garnet and generally accessible infrastructure.

Observations presented in this study should be of particular interest to diamond explorers. Pyrope garnet was recovered from sample sites throughout east-central Alberta, with distinct clusters in the Marie Lake–Cold Lake–Wolf Lake and Calling Lake areas. Results from this study confirm the presence of subcalcic (G10) garnet in east-central Alberta and a G10:G9 ratio that is generally not present in other parts of Alberta. In addition, several lherzolitic garnets from this study plotted near the G10-G9 boundary line and have high values of Cr and knorringite.

The overriding mechanism for deposition of surficial materials in east-central Alberta is glaciation. Garnet species studied in this report originated from the last phase of ice flow during retreat of the Laurentide ice sheet and, therefore, were derived from areas north-northeast of the study area, along the westernmost margin of the Canadian Shield. Selected garnet species (i.e., pyrope) could be derived from a fairly local, near-surface source because of their unique composition and texture (e.g., orange-peel texture and kelyphitic rims) compared to surficial pyrope reported in other parts of the province. This raises the potential for the discovery of a cluster of kimberlites in east-central Alberta to northwestern Saskatchewan, possibly in the Cold Lake–St. Paul and Calling Lake areas, or directly to the north within, for example, the Cold Lake Air Weapons Range. Lastly, this study raises awareness of the potential for secondary deposits of diamond that might have been relocated and concentrated in the same manner as the garnet.
1 Introduction

During the late 1940s and 1950s, a local prospector reportedly extracted a fortune from the Sand River (NTS map area 73L) using an ultraviolet lamp at night to locate his ‘mineral’ (Chipeniuk, 1975, p. 262). Knowledge of the mineral in question (only reported as not being gold) died along with the prospector in the late 1950s. Despite this claim, subsequent exploration in east-central Alberta focused predominantly on oil and gas for the next 40-plus years. Mineral exploration in the area was rejuvenated in 1997 with the discovery of a field of diamondiferous kimberlite in north-central Alberta, a discovery that kick-started the Alberta diamond rush. With knowledge of the potential for an economic diamond deposit in Alberta, stories of the prospector exploring river gravels in the Sand River area with a UV lamp generate interest because diamonds are known to fluoresce.

Since then, east-central Alberta has garnered its fair share of attention from diamond explorers. This interest is because of knowledge of garnet-rich beaches throughout the area — a unique occurrence in Alberta — coupled with a geologically favourable environment for the discovery of kimberlite. Reports of garnet with favourable chemistry for the discovery of an unknown field of kimberlite, and garnet chemical compositions that appear to be unique to this area of the province, have provided further incentive to diamond explorers.

Kimberlite indicator-mineral (KIM) results from till, stream sediment and beach sand surveys in the area are publicly available, as is knowledge of these garnet-rich beach sands, yet there is no known comprehensive study on the proportions and compositions of garnet species present in the beach sands. The intent of this project, therefore, was to conduct a reconnaissance-scale sampling study of garnet-rich beach sands throughout east-central Alberta. The main objective is to report on the garnet species present, their proportions and chemical compositions, and to make inferences on their potential sources.

A second objective of the study is to evaluate the area surrounding the Cold Lake Air Weapons Range (CLAWR) for mineral potential. This might be of particular interest to industry because the Alberta Department of Energy, which issues and administers agreements relating to exploration and production of Alberta-owned (Crown) metallic and industrial minerals, has not yet accepted any applications for mineral permits in the CLAWR.

This work satisfies the long-term objectives of diamond- and kimberlite-related studies at the Alberta Geological Survey (AGS) intended to

- provide industry with the information necessary to evaluate the diamond potential of Alberta and expand Alberta’s natural resource base;
- contribute updates to the geological map of Alberta and history/assemblage map of Western Canada;
- contribute to custodianship of Alberta’s diamond potential, including deliverables, data sets, rock materials and knowledge;
- provide knowledge and advice to decision-makers in federal and provincial governments; and,
- generate public awareness and understanding about the potential for an economic diamond discovery in Alberta.

2 Study Area and Overview of Sample Sites

A synopsis of known garnet-rich beaches in east-central Alberta, as provided by local prospectors (see ‘Acknowledgments’), is presented in Appendix 1. All beach-sand sites visited during this study contained garnet concentrated in a purple (garnet-rich) or black (oxide-rich) zone of sand in the wash zone that, in some instances, extends landward into the vegetation. Laterally (i.e., along the length of the
beach), the garnet-rich zones are best described as spotty, with visible garnet concentrations extending over distances of metres to hundreds of metres. The beach sands and their garnet species are described in detail in the ‘Results’ section of this report.

The primary technique for evaluating the garnet-rich beach sands is based on sampling of heavy-mineral indicators. Indicator minerals appear as transported grains in clastic sediments and can provide evidence for particular kinds of bedrock or specific types of mineralization and hydrothermal alteration. Their physical and chemical characteristics facilitate their preservation and identification in various sample media, such as till, glaciofluvial deposits, beach sand, stream sediment and soil. Thus, indicator minerals have become an important exploration method in the past 20 years for detecting a variety of ore deposit types, including diamondiferous kimberlite, gold, Ni-Cu, platinum-group elements (PGE), porphyry Cu, massive sulphide, and W.

During reconnaissance-scale fieldwork, 11 samples were collected from ten separate beaches. The sample sites encompass four 1:250 000 NTS map areas: 73E, 73L, 73M and 83P (Figure 1, Table 1). All sample sites were accessible by vehicle and selected by locating the area of beach sand with the highest visible garnet concentration. The sample nomenclature (e.g., RE06-GB-001) includes the initials of the sampler (RE), year (2006), project identifier (GB or garnet beach study) and site number (-001). For ease of reporting, the sample numbers are hereafter referred to using only the sample site component (e.g., -001). Sample sites -001 through -007 surround the CLAWR, which covers more than 1 million hectares.
Figure 2. Example of distribution of garnet-rich sands at selected beaches in east-central Alberta.
Table 1. Location and general lithology of beach sands from selected beaches in east-central Alberta. Results use the average measurements from three 5 g samples. The table summarizes the data and images shown in Appendix 2.

<table>
<thead>
<tr>
<th>Sample</th>
<th>General location</th>
<th>NTS location</th>
<th>UTM (Zone 12, NAD83)</th>
<th>Grain counts</th>
<th>Grain percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Easting (m)</td>
<td>Northing (m)</td>
<td>Quartz Oxide</td>
<td>Garnet Sulphide</td>
</tr>
<tr>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other Total</td>
</tr>
<tr>
<td>Sample</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Quartz Oxide</td>
</tr>
<tr>
<td>RE06-GB-001</td>
<td>Heart Lake</td>
<td>73L</td>
<td>472269</td>
<td>6097720</td>
<td>550</td>
</tr>
<tr>
<td>RE06-GB-002</td>
<td>Winefred Lake</td>
<td>73M</td>
<td>534837</td>
<td>6141883</td>
<td>533</td>
</tr>
<tr>
<td>RE06-GB-003</td>
<td>Christina Lake</td>
<td>73M</td>
<td>513625</td>
<td>6164078</td>
<td>498</td>
</tr>
<tr>
<td>RE06-GB-004</td>
<td>Wolf Lake</td>
<td>73L</td>
<td>502107</td>
<td>6057862</td>
<td>147</td>
</tr>
<tr>
<td>RE06-GB-005</td>
<td>Cold Lake, English Bay</td>
<td>73L</td>
<td>550706</td>
<td>6047916</td>
<td>77</td>
</tr>
<tr>
<td>RE06-GB-007</td>
<td>Marie Lake, Shelter Bay</td>
<td>73L</td>
<td>547823</td>
<td>6055914</td>
<td>233</td>
</tr>
<tr>
<td>RE06-GB-008</td>
<td>Stoney Lake</td>
<td>73E</td>
<td>494593</td>
<td>5968369</td>
<td>470</td>
</tr>
<tr>
<td>RE06-GB-009</td>
<td>Lac Santé</td>
<td>73E</td>
<td>463048</td>
<td>5965856</td>
<td>343</td>
</tr>
<tr>
<td>RE06-GB-010</td>
<td>Calling Lake southeast</td>
<td>83P</td>
<td>358086</td>
<td>6116998</td>
<td>250</td>
</tr>
<tr>
<td>RE06-GB-011</td>
<td>Calling Lake west</td>
<td>83P</td>
<td>348797</td>
<td>6122215</td>
<td>373</td>
</tr>
</tbody>
</table>

Note: Sample RE06-GB-006 (not listed here) is a duplicate sample of RE06-GB-005, taken at Cold Lake, English Bay.
and is the only tactical bombing range in Canada; about half, or 541,000 hectares, of the CLAWR area is situated within Alberta. Sample -006 is a duplicate sample from site -005 (Cold Lake, English Bay). Southernmost samples -008 and -009 were collected to determine the extent of the garnet-rich beach sands in east-central Alberta. Samples -010 and -011 were collected from west of the remaining sample sites to test the Calling Lake beach sands, which have yielded some of the most chemically favourable pyropes in Alberta, and to see how Calling Lake garnet compares with that from sample sites located closer to the Alberta-Saskatchewan border.

3 General Geology

Seismic refraction and reflection studies indicate that the Archean and Proterozoic crust in east-central Alberta is likely around 35–40 km thick (Bouzidi et al., 2002). In the study area, an approximately 1000–1800 m thick sequence of Phanerozoic sedimentary rocks (Wright et al., 1994) overlies a complex suite of crystalline basement domains, the disposition of which is broadly based on available regional airborne geophysics and geochronology (Ross et al., 1991, 1994; Villeneuve et al., 1993). Basement rocks in the Cold Lake area border the Archean Hearne Subprovince and the Rimby magmatic arc (1.98–1.78 Ga; Figure 3). The Rimby magmatic arc underlies the Winefred Lake area and is characterized by a highly corrugated internal fabric comprising extremely high relief, northeast-trending, sinuous magnetic anomalies (Ross et al., 1994). To the north, the Rimby magmatic arc is divided from the Taltson magmatic zone by the Snowbird Tectonic Zone (Figure 3).

The basement underlying Calling Lake borders the Buffalo Head Terrane, the Taltson magmatic zone and an unnamed domain (Ross et al., 1994; Figure 3). Basement underlying the northeastern portion of Calling Lake is part of the Taltson magmatic zone, a 1.99–1.93 Ga terrane (Bostock et al., 1991; McNicoll et al., 2000) that represents a magmatic arc related to collisional orogeny during the Proterozoic (Ross et al., 1991; Thériault and Ross, 1991). The northwestern portion of Calling Lake is underlain by basement of the Buffalo Head Terrane, an area of high positive magnetic relief with a northerly to northeasterly fabric (Ross et al., 1994). The bulk of the basement underlying Calling Lake is part of an unnamed domain with gravity and magnetic signatures similar to those of the Buffalo Head Terrane and Wabamun Domain (to the south-southwest), which could therefore be an extension of either one of these domains.

Overlying the basement, Phanerozoic strata have been deposited in two fundamentally different tectonosedimentary environments: a) Late Proterozoic to Middle Jurassic passive continental margin, and b) Middle Jurassic to Oligocene foreland basin. The Paleozoic to Jurassic platform succession, which is dominated by carbonate rocks, can be summarized as two periods of continental-margin sedimentation separated by cratonic inundations from the west, southeast and northwest (Kent, 1994). As a result, much of the Paleozoic succession consists of unconformity-bounded, thin to thick sequences of carbonate rocks interlayered with predominantly fine- to medium-grained clastic marine sedimentary rocks.

The overlying Middle Jurassic to Paleocene foreland basin succession formed in Alberta during active-margin orogenic evolution of the Canadian Cordillera (Dawson et al., 1994). Cretaceous rocks outcrop or subcrop over more than two-thirds of northern Alberta and are composed of alternating units of marine and nonmarine sandstone, shale, siltstone, mudstone and bentonite. The oldest Cretaceous unit in the study area belongs to the middle Cretaceous Labiche Formation that encompasses a large part of the study area (Figure 1). This formation is characterized by dark grey marine shale and silty shale with a fish scale–bearing lower unit. The Labiche is correlative with the Shaftesbury Formation and other mid– to early Late Cretaceous Colorado Group sedimentary rocks. The Late Cretaceous Lea Park Formation occurs directly south of Cold Lake and is composed of calcarceous and noncalcareous marine shale with intercalated sandstone. The youngest documented unit in the area belongs to the Late Cretaceous Wapiti Formation and Belly River Group in the northwestern (Pelican Mountain uplands) and southwestern parts.
of the study area, respectively; both units are composed of nonmarine, grey, feldspatic clayey sandstone that is often bentonitic.

Tertiary gravels occur on top of the Pelican Mountain uplands, which are located directly north-northwest of Calling Lake. These gravels are predominantly quartzite and chert gravel and cobbles of preglacial age (Campbell et al., 2001). Quaternary deposits form the local landforms over virtually all of northern Alberta. Ice sheets that originated from the northeast or north advanced across the plains at least five times (Fenton, 1984; Klassen, 1989); however, the surficial deposits in Alberta are primarily Late Wisconsinan in age and were deposited by the Laurentide continental and Cordilleran ice sheets between 23 000 and 11 000 years ago (Dyke et al., 2002). The majority of the surficial sediment in northern Alberta is till (glacial diamicton), with glaciolacustrine and glaciofluvial sediment (Andriashek and Fenton, 1989; Klassen, 1989). The nature of these deposits reflects broad aspects of the bedrock types, and patterns of glacial and glaciofluvial transport.
The surficial deposits in the study area are composed of a complex mixture of thick glacial drift, extensive glacial gravel and evidence of extensive glacial tectonism. Drift thickness is known to range from <25 m to >230 m, with multiple layers of till and glacial outwash (Gold et al., 1983; Campbell et al., 2001). A generally thick (>50 m), complex but well-preserved sequence of Pleistocene surficial deposits in the Sand River map area (NTS 73L) has been the subject of numerous Quaternary stratigraphic studies, predominantly during the late 1970s and 1980s (e.g., Gold, 1978; Andriashek and Fenton, 1979; Gold et al., 1983; Fenton and Andriashek, 1983; Andriashek, 1985; Andriashek and Fenton, 1989). The till and intertill stratigraphic record indicates several glaciations, probably as many as four. During the last period of glaciation, the Cold Lake glaciation, Andriashek and Fenton (1989) showed that the Laurentide Ice Sheet advanced in the form of three lobes: the Primose Lobe that advanced from the northeast, followed by the Seibert Lobe from the north and finally the Lac La Biche Lobe from the northwest (Figure 4).

The area contains major structural lineaments that include the Snowbird Tectonic Zone and the Meadow Lake Escarpment (Figures 3 and 1, respectively). The Snowbird Tectonic Zone is a major northeast-trending crustal lineament prominent on both aeromagnetic and gravity maps, and separates the Churchill Structural Province into two distinct basement domains, the Rae and Hearne subprovinces (Ross et al., 1991, 1994). During the Middle Devonian, a large part of the Siluro-Ordovician stratigraphy was eroded or faulted away to form a prominent Phanerozoic structural feature, the Meadow Lake Escarpment. The eastern edge of the Grosmont Reef Complex (Figure 1) correlates with several northwest-trending faults that extend through the Cold Lake area (Dufresne et al., 1996). Several authors (e.g., Sikabonyi and Rodgers, 1959; Dufresne et al., 1996; Eccles et al., 2001) have suggested that the edges of major reef formations, including the Grosmont, may be related to major structural features associated with tectonic uplift.

4 Exploration History

Since the discovery of diamondiferous kimberlites in northern Alberta in 1997, it is estimated industry has spent more than $100 million on exploration for diamonds within the province. Much of this expenditure has been in northern Alberta, where some 50 occurrences of ultrabasic to kimberlitic rocks have been discovered to date. The Buffalo Head Hills kimberlite field in north-central Alberta has produced the best diamond results to date, with 27 of 40 kimberlitic bodies yielding diamond. Mini-bulk and bulk samples of >10 tonnes have been collected from five Buffalo Head Hills bodies; three of these bodies (K14, K91 and K252) have reported diamond grades of between 12 and 55 carats per hundred tonnes (cpht).

To August 2008, no occurrences of ultramafic rocks have been discovered in east-central Alberta. The potential for discovery of diamondiferous kimberlites in this area, however, is considered high based on the following geological features and exploration results:

- Seismic refraction and reflection studies indicate that Archean and Proterozoic crust in east-central Alberta is likely around 35–40 km thick, a trait favourable for the formation and preservation of diamonds in the upper mantle.
- Deep-seated penetrative structures, such as the Meadow Lake Escarpment, Snowbird Tectonic Zone and linear margins of the Devonian Grosmont Reef Complex, could provide pathways for the ascent of kimberlitic magma during periodic tectonic activity associated with movement along major structural features.
- The number, diversity, morphology and chemistry of the KIMs that have been recovered by industry to date all reflect potential for the discovery of a new kimberlite field(s) in Alberta.
- The presence of numerous high- to moderate-quality magnetic anomalies, which could be indicative of kimberlite, has been reported by industry.
Figure 4. Bathymetry of the Cold Lake to Lac La Biche region: A) regional overview illustrating the three glacial lobes that formed during the Cold Lake glaciation (after Andriashek and Fenton, 1989); B) detailed bathymetry of the Cold Lake region, with the approximate location of a garnet-rich metamorphic erratic discovered by L. Andriashek (pers. comm., 2007).
There is a close association between KIM concentrations with favourable chemistry, magnetic anomalies and basement structures.

This report uses the terms ‘Cold Lake–St. Paul’ and ‘Calling Lake’ to describe the regional geographic areas that have become symbolic of high diamond potential in east-central Alberta. These areas are commonly used in discussions on the diamond potential of east-central Alberta because they are the only regions in Alberta to have yielded multiple G10 subcalcic pyrope garnets. The authors note that KIM sampling density is still low in east-central Alberta, as it is for much of Alberta, and there may be anomalous garnet distributions throughout the area. For now, exploration has been focused in the Cold Lake–St. Paul and Calling Lake areas, and summarized below.

4.1 Cold Lake–St. Paul Region

During 1999, five glaciofluvial and stream-sediment samples were collected for Sunburst Mines Ltd. and Ice River Mining Ltd. along the Martineau River directly north of Cold Lake. Forty-three KIMs were recovered from the five samples. One sample (9TK010) yielded ten pyrope garnets, one Cr-diopside and one picroilmenite, and four of the five samples yielded pyrope garnets, including G1 or G2 pyrope comparable to kimberlite megacryst/macrocryst populations, lherzolitic G9 pyrope and harzburgitic G10 pyrope (Dufresne and Copeland, 1999). Sample 9TK008 yielded two subcalcic harzburgitic G10 pyrope garnets. Some of the garnets from 9TK008 and 9TK010 were up to 1.2 mm in diameter, and displayed orange-peel textures and partially preserved kelyphytic rims. Picroilmenite grains were characterized by elevated MgO (11–13 wt. %) and low total Fe as FeO (<40 wt. %), with some grains having high Cr2O3 (3.5 and 4.1 wt. %; Dufresne and Copeland, 1999). The low Fe and high MgO generally indicate a state of low oxygen fugacity within the kimberlite magma, a trait favourable for the preservation of diamond.

In 2000, Brilliant Mining Corp. confirmed recovery of KIMs from multiple sites on their Medley River property located along the north and west sides of Cold Lake, and that the results are encouraging based on the types, abundance and morphology of the minerals recovered. Dufresne and Noyes (2001a) confirmed by electron microprobe analysis (EMPA) that 4 of 25 pyrope garnets are subcalcic G10 pyrope. In addition, they reported pyrope garnets up to 1.0 mm in diameter with orange-peel texture, a trait that could indicate a proximal source.

In 2002, New Claymore Resources Ltd. collected 18 beach samples near the towns of St. Paul and Two Hills, about 85–130 km southwest of Cold Lake. Some 308 potential garnet grains were analyzed by EMPA, returning 12 G10 garnets and 105 G9 garnets (Rich, 2003). In addition, the analysis confirmed 26 Cr-diopsides, 17 low-Cr diopsides and 6 picroilmenites from the beach samples.

During 2005, Diamondex Resources Ltd. staked a large land package, consisting of more than 3 million acres in east-central Alberta and encompassing the Cold Lake–St. Paul area. The property, which is referred to as the Pegasus project, was acquired based on KIMs (including significant concentrations of G10 pyrope garnet, chromite, diopside and ilmenite), as well as interpreted geophysical targets. Diamondex has completed approximately 31 000 line-km of high-resolution airborne magnetic surveys (HRAM) with 100 m line spacing.

4.2 Calling Lake Region

The Calling Lake mineral permits were first staked in 1994 and 1996 by R. Haimila and 656405 Alberta Ltd. (Haimila, 1996). Subsequent beach sampling by Buffalo Diamonds Ltd. on the southwest and south shores of Calling Lake has yielded over 500 KIMs from four separate sites. Based on the recovery of 66 subcalcic G10 pyrope garnets and other indicator minerals, such as G1, G2, G7, G9 and G11 pyrope garnet, high-Cr diopside, high-Cr picroilmenite and high-Ti kimberlitic chromite, there is strong evidence for the presence of local diamondiferous kimberlite (Dufresne and Copeland, 2000; Turnbull, 2002). The
66 G10 garnets represent the highest concentration of such garnets known in Alberta. The potential for
discovery of diamondiferous kimberlite is further supported by the discovery of a 0.005 carat, pale yellow
rough diamond with grade L colour, along with olivine, in a basal till sample collected from the Calling
River east of Calling Lake during 1998 (Dufresne and Copeland, 2000). In 1999–2000, Buffalo Diamonds
Ltd. and New Claymore Resources Ltd. initiated a detailed follow-up exploration program that
culminated in the drilling of 10 holes totalling 1041 m (Turnbull, 2002). The core, however, was held in
certainty until the drill program was paid for. During February 2002, BHP Billiton optioned the
property from Buffalo Diamonds and New Claymore and took possession of the drillcore from the 2000
program. It was subsequently reported that none of the holes had intersected ultramafic rocks.

In 2005, the Calling Lake area and Pelican Mountain uplands to the north were staked by Grizzly
Diamonds Ltd. During 2006 and 2007, Grizzly Diamonds Ltd. and Stornoway Diamond Corporation
completed a 25 000 line-km airborne magnetic survey and ground anomaly checks on the Call of the Wild
property in the Pelican Mountain uplands area. Of the 47 airborne magnetic targets selected for follow-up
exploration, 19 remain priorities for ground geophysical surveying and sampling.

5 Methodology

An important sampling criterion for this study was to evaluate the proportions of all the ordinary garnet
species (pyrope, almandine, grossular, andradite and spessartine) in the beach sands and to collect any
information that may suggest source region(s) of the indicator grains recovered. Three samples were
taken from each site, for separate analysis as described below and shown in Figure 5.

1) A 10 kg sample was taken for indicator-mineral processing and picking. Rather than taking the
sample by shovel, a 6.3 cm (inside diameter) tube was used to obtain a true cross-section of the beach
sand. Tubes of beach sand were collected until 10 kg were obtained, as measured using a mechanical
hanging scale (32 kg capacity with 1 kg resolution). Note that only 10 kg were taken because of the
elevated concentration of garnet. The authors recommend that future exploratory sampling maintain
standard KIM sampling protocols (e.g., Paulen, 2007; Prior et al., 2007). The 10 kg sample was sent
to Overburden Drilling Management Limited, Nepean, Ontario for kimberlite indicator-mineral
picking, with special instructions to pick all garnet species present in the heavy-mineral concentrate.
Size fractions picked included the 0.25–0.5, 0.5–1 and 1–2 mm fractions. Paramagnetic separation on
the 0.25–0.5 mm fraction included the <0.6, 0.6–0.8, 0.8–1 and >1 ampere fractions. Scanning
electron microscope (SEM) checks were conducted in conjunction with garnet-species picking.

2) A 2 kg sample was taken for grain-size analysis using the same beach-sand collection technique
described above. Grain-size analysis was completed by drying the sample and sifting the beach sand
through a series of brass sieves ranging in size from >4.0 mm (#5) to <63 µm (#230).

3) A 2.9 cm (inside diameter) tube was pressed vertically down into the beach sand and capped on both
ends to obtain a cross-section of the sample site. This tube was measured for magnetic susceptibility
using a Bartington MS2C core logging sensor at the Physics Department, University of Alberta. The
MS2C core logging sensor is designed for volume susceptibility measurements of sediment samples
in nonmagnetic cores. The high resolution of the sensor permits cores to be logged at intervals down
to approximately 20 mm. The cross-section tube was measured at 20 mm intervals by running the
sample tube horizontally through the instrument from top to bottom, making sure to zero the
instrument for each new sample tube. The cross-section core tube was also used to make physical
observations, such as lithological grain counts.
Quantitative chemical analyses of major elements were obtained on mineral-grain separates using a JEOL8900 electron microprobe at the Department of Earth and Atmospheric Sciences, University of Alberta. The silicate grains were analyzed using an accelerating voltage of 20 kV, beam diameter of 1–10 µm and beam current of 20 nA. Peak and background counting times were 30 seconds. Standards, consisting of natural minerals from the Smithsonian microbeam set of standards (Jarosewich, 2002), were regularly analyzed to ensure the calibration remained valid throughout the probe session.

6 Results

This section presents the results of grain-size distribution, general lithology, garnet species, KIMs, gold grains, and metamorphic and magmatic massive-sulphide indicator minerals (MMSIM).

6.1 Grain-Size Distributions, General Lithology and Magmatic Susceptibility

Grain-size distributions were determined by sifting the beach material through a set of sieves that measured eight increments from >4000 µm to <63 µm. With the exception of Marie Lake, which has the only fraction of coarse sand to fine gravel (>4000 µm) of the beaches sampled, the grain sizes dominantly range between –1000 µm and +125 µm, with the 250–500 µm size being the dominant fraction (Figure 6).

Figure 5. Beach-sand sampling methodology. Three samples were taken at each site: a 10 kg pail for indicator-mineral picking, a 2 kg sample for grain-size analysis and a ‘tube’ sample to obtain a cross-section of the site for magnetic-susceptibility measurements and physical observations.
The general lithology of the beach-sand samples was obtained by counting quartz, oxide, garnet and sulphide grains from three separate 5 g samples taken from garnet-rich, oxide-rich and representative sand sections along the cross-section core tubes that were collected from each sample site; these counts are presented in Appendix 2 and as average values in Table 1. Beach sands from Heart Lake, Winefred Lake and Christina Lake are dominated quartz (>96%). The Wolf Lake beach sands have a fairly even distribution of quartz (14%–43%), oxide (29%–38%) and garnet (25%–53%). Cold Lake (English Bay) beach sands are dominated by garnet (60%–74%), followed by oxide (11%–29%) and quartz (10%–28%). Marie Lake has nearly equal proportions of quartz (28%–50%) and garnet (41%–56%), with minor oxide (8%–16%). Stoney Lake is dominated by quartz (81%–94%), followed by oxides (5%–12%) and minor garnet (<6%). Lac Sante has elevated distributions of quartz (79%–81%) and oxide (15%–21%) grains. Calling Lake southeast has highly variable quartz (23%–92%), oxide (4%–46%) and garnet (2%–35%). Calling Lake west has abundant quartz (63%–84%), followed by garnet (11%–24%).

Appendix 2 shows little correlation between the garnet-rich fractions and high-oxide layers, which are characterized by high magnetic susceptibility likely related to ilmenite accumulation. This is taken as evidence of mechanical sorting caused by wave action, where heavier oxide minerals are susceptible to settling in or near the wash zone, whereas the lighter garnet grains (relative to oxide grains) characteristically travel to the above-wash zone. Based on this observation, it is recommended that prospectors wishing to investigate beach sands not forget the landward-vegetated area as a possible sample site for garnet-rich sand.

6.2 Garnet Species

The heavy-mineral fraction of all samples includes and is often dominated by garnet. The garnet species (only) are presented in Table 2 (also on CD) and are separated by their size and paramagnetic fractions. In all samples collected during this study, the garnet consists overwhelmingly (>99%) of almandine, followed by grossular, spessartine and pyrope (Figure 7a). Most of this almandine is pink to pink-red, but some grains are orange. With the exception of Winefred Lake, all samples contain minor (tens of grains) grossular and/or spessartine, which are typically orange and do not differ sufficiently in paramagnetism from orange almandine (i.e., confirmed by SEM). Heart Lake, Wolf Lake and Cold Lake yielded a few brown and yellow andradite grains, including one or two grains of green Cr-andradite. Garnets that will be of interest to diamond explorers include peridotitic Cr-pyrope and megacrystic Cr-pyrop.

Garnet EMPA data (728 total analyses) are presented in Appendix 3 (also on CD), including core and rim measurements from almandine, pink almandine, grossular, spessartine, pyrope, low-Cr pyrope, Cr grossular and andradite. In Appendix 3 (also on CD), three separate means of classification are provided, including

1) physical grain types identified during heavy-mineral-indicator processing, some of which were identified by semiquantitative EDS analysis;
2) geochemical grain types identified by entering EMPA data from this study into the mineral identification program MinIdent-Win (Smith and Higgins, 2001); minerals identified include a score, or a ‘matching index’ calculation of mineral identification probability, where a score of 1000 represents a perfect match; and
3) stoichiometric garnet end-member calculations based on EMPA data from this study; values are in per cent and total 100%.

The MinIdent (Smith and Higgins, 2001) mineral classification was preferred for garnet classification, in which case the analyses included, in decreasing number of analyses: almandine (340 spots probed), grossular (146), almandine-spessartine series (99), pyrope (43), spessartine (25), knorringite to knorringite-pyrope series (18), almandine-pyrope series (17), grossular-uvarovite series (9), low-Cr
Figure 6. Grain-size distributions at selected beaches in east-central Alberta.
## Table 2. Summary of garnet species in beach sands from selected beaches in east-central Alberta.

<table>
<thead>
<tr>
<th>Sample location</th>
<th>Garnet mineral species</th>
<th>Size range (mm)</th>
<th>SEM checks from 0.5-1.0 mm fraction</th>
<th>SEM checks from 0.25-0.5 mm fraction</th>
<th>SEM checks from 0.5-1.0 mm fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelter Bay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>1 pale orange grossular</td>
<td>10 pale orange grossular</td>
<td>3 spessartine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.25-0.5</td>
<td>50 representative pink to pink-red spessartine</td>
<td>50 potential pale orange grossular from 0.25-0.5 mm fraction.</td>
<td>1 spessartine, 1 Mn-almandine and 15 almandine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>12 pale orange grossular (&gt;1.0 amp)</td>
<td>20 pale orange grossular (1.0 amp versus almandine candidates)</td>
<td>0.5 mm fraction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.25-0.5</td>
<td>22 pale orange grossular (&gt;1.0 amp)</td>
<td>50 representative pink to pink-red spessartine from 0.25-0.5 mm fraction.</td>
<td>2 grey to pink spessartine candidates = 1 spessartine, 1 Mn-almandine and 15 almandine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart Lake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>1 black andradite versus almandine</td>
<td>5 black andradite versus almandine</td>
<td>8 orange (0.8-1.0 mm) spessartine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.25-0.5</td>
<td>50 representative pink to pink-red almandine from 0.25-0.5 mm fraction.</td>
<td>50 potential orange spessartine and 50 potential pale orange grossular from 0.25-0.5 mm fraction.</td>
<td>1 andradite; and 5 orange spessartine versus almandine candidates = 3 almandine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>2 grey to pink spessartine</td>
<td>5 grey to pink spessartine</td>
<td>10 orange spessartine (&lt;0.6 amp) versus almandine candidates = 1 spessartine, 1 Mn-almandine and 15 almandine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.25-0.5</td>
<td>2 grey to pink spessartine</td>
<td>5 grey to pink spessartine</td>
<td>10 orange spessartine (&lt;0.6 amp) versus almandine candidates = 1 spessartine, 1 Mn-almandine and 15 almandine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold Lake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>10 orange spessartine (&lt;0.6 amp)</td>
<td>5 orange spessartine (&lt;0.6 amp)</td>
<td>20 orange spessartine (&lt;0.6 amp)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.25-0.5</td>
<td>20 orange spessartine (&lt;0.6 amp)</td>
<td>5 orange spessartine (&lt;0.6 amp)</td>
<td>20 orange spessartine (&lt;0.6 amp)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5-1.0</td>
<td>10 orange spessartine (&lt;0.6 amp)</td>
<td>5 orange spessartine (&lt;0.6 amp)</td>
<td>20 orange spessartine (&lt;0.6 amp)</td>
</tr>
</tbody>
</table>

* Duplicate sample of RE06-GB-001
Figure 7. Geographic distribution of garnet species as estimated from Table 2: A) total estimated grain counts; B) garnet grain counts normalized to 10,000 total grains. Abbreviations: alm, almandine; gros, grossular; and, andradite; spes, spessartine; Cr-gros, Cr-grossular; Cr-pyr, Cr-pyrope; Cr-poor pyr, Cr-poor pyrope; py-alm, pyrope-almandine.
pyrope (8), andradite (5), pyrope-almandine series (3) and uvarovite (1). These species are shown in Figure 8 on the ternary plots of almandine+spessartine vs. pyrope vs. grossular, and almandine vs. grossular vs. pyrope+spessartine+andradite. The geochemical distribution shows the predominance of almandine, followed by grossular and spessartine. Orange and pink almandine are chemically distinct from each other, with orange almandine having a higher grossular component (i.e., CaO). Isomorphous mixed series are evident, particularly between pyrope and between almandine and almandine and spessartine. This series is often called the ‘pyralspite series’ and, in this dataset, dominates in comparison to the other common isomorphous series uvarovite-grossular-andradite, or the ‘ugrandite series’. Smaller species groups, such as pyrope and andradite, stand out as small isolated clusters relative to almandine-series garnet. Grains originally identified as garnet but identified as other minerals by MinIdent include staurolite, amphibole-group minerals (e.g., pargasite, hornblende, tschermakite) and piedmontite.

With respect to geographic distribution, the various garnet species appear to be distributed fairly evenly from site to site, with the exception of a few anomalous trends (Figure 7a). Importantly to diamond explorers, Cr-pyrope is more abundant at the Wolf Lake, Cold Lake, Marie Lake and Calling Lake west sample sites relative to other sites analyzed in this study. Caution is advised when making these kinds of observations, as the abundance of pyrope in these areas correlates with high total garnet grain counts. When the garnet species counts are normalized to 10 000, their patterns of distribution change. The normalized diagrams (Figure 7b) show that Cr-pyrope is elevated in the Heart Lake, Winefred Lake and Christina Lake areas. Caution is also advised for the normalized trend, because the geographic distribution of pyrope could be further complicated by a local kimberlite source. A second significant observation of the normalized garnet distribution is that spessartine and grossular grain counts are...
elevated in the northern sample sites (Christina and Heart lakes), which may have implications for garnet paragenesis.

### 6.3 Kimberlite-Indicator Minerals

A summary of the KIM grains is presented in Table 3. In addition to the aforementioned pyrope and knorrin EMPA data, Appendix 3 (also on CD) also includes analytical results from clinopyroxene (18 grains analyzed), ilmenite (11) and chromite (9).

With the exception of Winefred Lake, all beach sands sampled yielded KIMs dominated by garnet peridotite and clinopyroxene, followed by ilmenite, eclogitic garnet and chromite. No forsteritic olivine was recovered. The highest total KIM grain counts were from Marie Lake (16 grains), Calling Lake west (15) and Cold Lake (14). Christina Lake and Stoney Lake both had 7 KIMs recovered, followed by Calling Lake southeast (6 grains), Lac Santé (4) and Heart Lake (2). Most KIMs fall in the 0.25–0.5 mm size fraction, with 0.5–1 mm ilmenite grains (Table 3).

Figure 9 shows that, based on samples from this study, pyrope garnet was recovered throughout east-central Alberta, with two distinct clusters in the general area of Marie Lake (12 grains)–Wolf Lake (6)–Cold Lake (5), and at Calling Lake west (6). Pyrope garnet is dominantly lherzolite, with two grains, one each from Wolf Lake and Cold Lake, plotting in the harzburgitic G10 field (Figure 9). Several pyropes from Marie Lake plot near the G9–G10 boundary line and have high Cr$_2$O$_3$ (T3 wt. %), knorrin (Mg$_3$Cr$_2$Si$_3$O$_{12}$) values of between 22 and 23, Mg# (100Mg/(Mg+Fe$^{2+}$)) of 84 and Cr# (100Cr/(Cr+Al)) between 37 and 38. In addition, high-Cr$_2$O$_3$ pyrope (i.e., >6 wt. %), which in some cases straddles the G9–G10 boundary line, is common in beach sands from Marie Lake, Lac Santé and Calling Lake (southeast and west).

Figure 10 shows that clinopyroxene grains were recovered from Winefred Lake (1 grain), Wolf Lake (2), Cold Lake (2), Stoney Lake (1), Lac Santé (1), Calling Lake southeast (5) and Calling Lake west (6). Based on the Al$_2$O$_3$ vs. Cr$_2$O$_3$ plot of Ramsay (1992), the majority of the clinopyroxene is derived from garnet peridotite followed by spinel lherzolite and pyroxenite, and eclogite or cognate paragenesis. Garnet lherzolitic–type clinopyroxene, which plots along a compositional line between the jadeite and kosmochlor (Morris et al., 2002), was recovered from Calling Lake southeast and west (4 grains total), and from Winefred Lake and Wolf Lake (1 grain each). One clinopyroxene grain from Calling Lake southeast yielded 5.8 wt. % Al$_2$O$_3$ and 1.7 wt. % Na$_2$O, and may be derived from eclogite. Finally, one clinopyroxene grain from Wolf Lake has a calculated temperature within the diamond stability field (approximately 1090º–1120ºC), based on the single-grain thermometry of Finnerty and Boyd (1987) and Nimis and Taylor (2000).

Only a few oxide grains were analyzed. Chrome spinels were recovered from beach sands at Heart Lake, Christina Lake, Wolf Lake, Cold Lake, Stoney Lake and Calling Lake west (Figure 11). None of the grains plotted within the MgO-Cr$_2$O$_3$ diamond-inclusion field or near the xenocryst trend prevalent in diamondiferous kimberlite of the Buffalo Head Hills field (Hood and McCandless, 2004). A chromite from Heart Lake has high Cr# (87) but low MgO (3.5 wt. %; Mg# = 16) and high FeO (33.1 wt. %). One chromite from Stoney Lake has high Mg# (63) and NiO (0.28 wt. %) but low Cr# (17).

Four ilmenite grains were picked from the Cold Lake and Stoney Lake beach sands, with one ilmenite grain each from Christina Lake, Wolf Lake and Calling Lake west (Figure 12). Two ilmenite grains from Cold Lake and Stoney Lake are classified as nonkimberlitic grains due to their low MgO (<1.2 wt. %) and Cr$_2$O$_3$ (<0.06 wt. %). The single low-MgO grain from Stoney Lake falls on the 0 wt. % Fe$_2$O$_3$ reference line and therefore could belong to a high-TiO$_2$ mineral other than ilmenite. The rest of the ilmenite grains fall on the kimberlitic side of the Wyatt et al. (2004) kimberlitic ilmenite boundary reference line, although caution should be exercised because some of these grains have Cr$_2$O$_3$ values of <0.5 wt. %.
Table 3. Summary of kimberlite-indicator minerals in beach sands from selected beaches in east-central Alberta.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>General location</th>
<th>Total</th>
<th>&lt;0.25 mm</th>
<th>Heavy Liquid S.G 3.0</th>
<th>Lights</th>
<th>Mag HMC</th>
<th>Total</th>
<th>% Weight</th>
<th>Weight &lt;0.25 mm (wash)</th>
<th>0.25 to 0.5 mm</th>
<th>0.5 to 1.0 mm</th>
<th>1.0 to 2.0 mm</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE06-GB-001</td>
<td>Heart Lake</td>
<td>888.4</td>
<td>730.4</td>
<td>145.1 0.03</td>
<td>12.90</td>
<td>100</td>
<td>12.90</td>
<td>1.3</td>
<td>9.60</td>
<td>1.8</td>
<td>0.20</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-002</td>
<td>Winefred Lake</td>
<td>940.5</td>
<td>938.9</td>
<td>1.6 0.00</td>
<td>0.03</td>
<td>100</td>
<td>0.03</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.00</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-003</td>
<td>Christina Lake</td>
<td>1,246.6</td>
<td>1,068.2</td>
<td>198.6 0.03</td>
<td>19.80</td>
<td>100</td>
<td>19.80</td>
<td>5.9</td>
<td>13.80</td>
<td>0.1</td>
<td>0.01</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-004</td>
<td>Wolf Lake</td>
<td>2,780.9</td>
<td>2,058.2</td>
<td>301.2 13.90</td>
<td>407.60</td>
<td>25</td>
<td>101.90</td>
<td>14.1</td>
<td>84.10</td>
<td>3.5</td>
<td>0.20</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-005</td>
<td>Cold Lake</td>
<td>4,743.0</td>
<td>1,212.1</td>
<td>493.9 43.00</td>
<td>2,994.00</td>
<td>5</td>
<td>149.80</td>
<td>4.1</td>
<td>132.10</td>
<td>13.6</td>
<td>0.05</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-006</td>
<td>Cold Lake (2)</td>
<td>4,878.9</td>
<td>1,264.9</td>
<td>468.4 41.60</td>
<td>3,104.00</td>
<td>5</td>
<td>155.20</td>
<td>3.7</td>
<td>138.50</td>
<td>12.9</td>
<td>0.06</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-007</td>
<td>Marie Lake</td>
<td>2,389.8</td>
<td>937.0</td>
<td>403.2 3.60</td>
<td>1,046.00</td>
<td>10</td>
<td>104.60</td>
<td>4.8</td>
<td>88.20</td>
<td>11.5</td>
<td>0.10</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-008</td>
<td>Stoney Lake</td>
<td>1,028.3</td>
<td>903.1</td>
<td>48.6 1.80</td>
<td>74.80</td>
<td>100</td>
<td>74.80</td>
<td>6.7</td>
<td>60.70</td>
<td>6.9</td>
<td>0.50</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-009</td>
<td>Lac Sante</td>
<td>1,492.1</td>
<td>1,411.0</td>
<td>16.4 0.80</td>
<td>63.90</td>
<td>100</td>
<td>63.90</td>
<td>13.9</td>
<td>46.30</td>
<td>3.2</td>
<td>0.50</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE06-GB-010</td>
<td>Calling Lake SW</td>
<td>1,076.0</td>
<td>899.8</td>
<td>128.5 0.20</td>
<td>47.50</td>
<td>100</td>
<td>47.50</td>
<td>13.2</td>
<td>33.70</td>
<td>0.6</td>
<td>0.04</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RE07-GB-011</td>
<td>Calling Lake west</td>
<td>2,271.8</td>
<td>895.0</td>
<td>1,054.2 3.1</td>
<td>519.5</td>
<td>20</td>
<td>103.9</td>
<td>8.4</td>
<td>92.1</td>
<td>3.3</td>
<td>0.07</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Weight (g) | Number of grains

<0.25 mm Table concentrate | Kimberlite-indicator minerals

0.25-2.0 mm Heavy liquid separation S.G 3.20 | 1.0 to 2.0 mm | 0.5 to 1.0 mm | 0.25 to 0.5 mm

Heavy Magnetic HMC | Nonferromagnetic HMC | Processed split | Total

<table>
<thead>
<tr>
<th>GP</th>
<th>GO</th>
<th>DC</th>
<th>IM</th>
<th>CR</th>
<th>FO</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(1) Values greater than 0.1 g were weighed only to one decimal place; the zero was added in the second decimal position to facilitate column alignment.

(2) Duplicate sample
Figure 9. Distribution and CaO-Cr₂O₃ geochemistry of high-Cr (>2 wt. %) pyrope garnet from garnet-rich beach sands in east-central Alberta. Abbreviation: GDC, graphite-diamond constraint.
Figure 10. Distribution and Al-Cr-Na and Al₂O₃-CrO₃ geochemistry of clinopyroxene from garnet-rich beach sands in east-central Alberta.
Figure 11. Distribution and MgO-Cr$_2$O$_3$ and Mg#-Cr# geochemistry of chromite from garnet-rich beach sands in east-central Alberta.
Kimberlitic ilmenite grains with >1 wt. % Cr₂O₃ occur at Christina Lake, Clear Lake, Stoney Lake and Calling Lake west, with one ilmenite grain from Calling Lake west having 3.4 wt. % Cr₂O₃. Most of the potentially kimberlitic ilmenite grains have high MgO (>10.3 wt. %) and fall within or near the high MgO field characteristic of ilmenite from diamondiferous bodies in the Buffalo Head Hills kimberlite field (Hood and McCandless, 2004).

6.4 Gold Grain Counts, Morphology and Dimensions

A summary of the gold grain counts, morphology and dimensions is presented in Table 4. Based on nonmagnetic heavy-mineral concentrates of between 32 and 41 g, minor grains of visible gold were recovered from Cold Lake (2 grains), Stoney Lake (5), Lac Santé (4), Calling Lake southeast (2) and Calling Lake west (6). All of the grains were reshaped, suggestive of transportation over a significant distance. The largest gold grain, from Cold Lake, was 125 µm by 200 µm. Calculated visible gold assays, which are based on the weight of the gold and that of the respective heavy-mineral concentrate, include 56 ppb (Lac Santé), 83 ppb (Calling Lake southeast), 122 ppb (Stoney Lake), 177 ppb (Calling Lake west) and 265 ppb (Cold Lake) — well below that of placer gold deposits such as the historic Klondike district in the Yukon. No gold grains were recovered from Heart Lake, Winefred Lake, Christina Lake, Wolf Lake or Marie Lake.

6.5 Metamorphic and Magmatic Massive-Sulphide Indicator Minerals

Metamorphic and magmatic massive-sulphide indicator minerals (MMSIM), including sulphide/arsenide, Mg/Mn/Al/Cr and phosphate minerals, are sought after because they are more resistant than sulphides and are diagnostic of specific types of sulphide deposits, such as volcanosedimentary massive sulphides in medium- to high-grade regional metamorphic terrains, skarn and greisen deposits, and magmatic Ni-Cu sulphides (Russell et al., 1999; Averill, 2001; Somarin, 2004; Helmy, 2005). A number of MMSIMs were recovered in beach sands from this study and are summarized in Table 5 (also on CD) and below. None of the MMSIM grains has been analyzed for chemistry, but their presence and proportions suggest a mineral assemblage of almandine/epidote to almandine-hornblende/epidote (+diopside+rutile+staurolite+kyanite±apatite).

Most samples contain minor (tens of grains) grossular, spessartine and gahnite. Both grossular and spessartine are orange and do not differ sufficiently in paramagnetism from orange almandine, in which case it was necessary to confirm these grains by SEM or EMPA. Gahnite (ZnAl₂O₄) and red (chrome?) rutile are widely distributed. Based on the results of this study, anomalous distributions of blue-green gahnite include Lac Santé (12 grains), Wolf Lake (11) and Cold Lake (10), with between 1 and 7 grains occurring at the other sample sites. Red rutile was also prevalent at Cold Lake, from which about 200 grains were observed, followed by Wolf Lake with about 50 grains. Multicoloured spinels (e.g., blue-grey, grey, pale blue-green, pale purple, pale pink, blue-green) were recovered from all sites and are particularly abundant at Cold Lake (~400 grains), Calling Lake west (~300) and Wolf Lake (~200).

Ruby corundum and sapphire corundum were recovered from all sites (1–2 grains), with Stoney Lake having 6 sapphire corundum grains. Low-Cr diopside was also recovered from all sites, with the highest grain counts at Cold Lake (15 grains), Calling Lake southeast (13), Christina Lake (12) and Calling Lake west (11). Some samples yielded a few brown and yellow andradite grains (Heart Lake, Wolf Lake and Cold Lake). One or two grains of green Cr-grossular were recovered from Wolf Lake, Cold Lake, Marie Lake, Lac Santé and Calling Lake west.

The sulphide minerals chalcopyrite and molybdenite occur in trace amounts. A single grain of chalcopyrite was recovered from each of Heart Lake, Wolf Lake, Stoney Lake, Lac Santé and Calling Lake southeast. A single molybdenite grain was recovered from Calling Lake southeast. Pyrite is more abundant, with between 10 and approximately 1000 pyrite grains recovered from beach sands sampled in
Figure 12. Distribution and MgO-TiO₂ and MgO-Cr₂O₃ geochemistry of ilmenite from garnet-rich beach sands in east-central Alberta.
Table 4. Summary of gold grain counts, morphology and dimensions of beach sands from selected beaches in east-central Alberta.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>General location</th>
<th>Number of visible gold grains</th>
<th>Nonmag HMC weight (g)</th>
<th>Calculated visible gold assay (ppb)</th>
<th>Dimensions (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Reshaped</td>
<td>Modified</td>
<td>pristine</td>
</tr>
<tr>
<td>RE06-GB-001</td>
<td>Heart Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-002</td>
<td>Winefred Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-003</td>
<td>Christina Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-004</td>
<td>Wolf Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-005</td>
<td>Cold Lake</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-006</td>
<td>Cold Lake (1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-007</td>
<td>Marie Lake</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RE06-GB-008</td>
<td>Stoney Lake</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-009</td>
<td>Lac Santé</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-010</td>
<td>Calling Lake SE</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE07-GB-011</td>
<td>Calling Lake west</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Duplicate sample of RE06-GB-005

this study. The areas with pyrite grain counts are, in order from highest to lowest, Stoney Lake, Christina Lake, Lac Santé, Wolf Lake, Cold Lake and Calling Lake west. Phosphate minerals are not abundant. Apatite ranged from 0 to 20 grains, the latter recovered at Calling Lake southeast. Monazite was recovered from Cold Lake (3 grains) and Stoney Lake (1). Other MMSIMs that occur in trace amounts (<10 grains) and are distributed throughout the study area include kyanite, sillimanite, tourmaline and staurolite. Twenty grains of staurolite were recovered from Lac Santé.

7 Discussion and Conclusions

7.1 Overview of Industrial Garnet Production and Considerations for East-Central Alberta

World production of industrial garnet in 2005 was estimated at 450 000 tonnes, with the most significant producers including Australia, United States, China, India, Czech Republic, Pakistan, Russia, Turkey and Ukraine. Canada joined the list of suppliers in 2005. Currently, the United States is the largest consumer and accounts for nearly 16% of the world consumption of industrial garnet (Evans and Moyle, 2006).
Table 5. Summary of metamorphic/magmatic massive-sulphide indicator minerals in beach sands from selected beaches in east-central Alberta.

<table>
<thead>
<tr>
<th>Sample location</th>
<th>General location</th>
<th>Age</th>
<th>Indicator minerals (0.25-0.5 mm fraction)</th>
<th>Indicator minerals (0.5-1.0 mm fraction)</th>
<th>Phases</th>
<th>Remarks</th>
<th>Picked Grains</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE06-GB-001 (Heart Lake)</td>
<td>1</td>
<td>0</td>
<td>2 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-002 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>6 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-003 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>7 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-004 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>8 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-005 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>9 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-006 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>10 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-007 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>11 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-008 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>12 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-009 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>13 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-010 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>14 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RE06-GB-011 (Stoney Lake)</td>
<td>0</td>
<td>0</td>
<td>15 blue-green, blue-green</td>
<td>1 chromite (picked as KIM); 2 chromite (picked as KIM)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
- Blue-green = Almandine/epidote-staurolite-diopside-kyanite assemblage.
- Blue gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
- Blue-green gahnite versus spinel candidates = 12 blue-green gahnite versus spinel candidates = 2 spinels.
The majority of industrial garnet is used as a loose-grain abrasive because of its hardness (6.0–7.5 on the Mohs scale of mineral hardness). High-quality garnet has been used for optical-lens grinding and plate-glass grinding for over a century and, in more recent years, as an abrasive for scratch-free lapping of semiconductor materials and other metals. Lower quality industrial garnet is used as a filtration medium in water-purification systems because it is relatively inert and resists chemical degradation. Other industrial applications include the manufacture of coated abrasives, hydrocutting and the finishing of wood, leather, hard rubber, felt and plastics. Finally, garnet has been gradually replacing silica sand in the blast-cleaning market because of health risks associated with the inhalation of airborne crystalline silica dust (Harris, 2000).

Most industrial-grade garnet is obtained from gneiss, amphibolite, schist, skarn and igneous rocks, and from alluvium derived from erosion of these rocks. Canada has garnet deposits in British Columbia, Labrador, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario and Quebec (Harben and Kuzvart, 1996). Garnet deposits in Eastern Canada consist largely of almandine in high-grade regionally metamorphosed rocks, with garnet grades ranging from 15 to 100 vol. %. Garnet deposits in Western Canada are mostly in skarns and consist of andradite and grossular. Total Canadian garnet reserves are not known, but one of these deposits, the Crystal Peak skarn deposit on Mount Riordan, British Columbia, has at least 40 million tonnes (Mt) of reserves containing 80 vol. % garnet (andradite and grossular; Grond et al., 1991; Mathieu et al., 1991).

Alluvial industrial garnet production occurs in the United States in deposits downstream from mica-garnet schist rocks (e.g., Hampton Creek Canyon, Nevada; Emerald, Carpenter and Meadow creeks, Idaho) or metamorphosed rocks eroded from local mountain ranges (e.g., Ruby River, Montana). The main alluvial industrial garnet producer in the United States is Idaho, where almandine garnet-bearing gravels, about 1–1.2 m thick, contain 8% to 15% garnet; these alluvium deposits also produce gem garnet and rare ‘star garnet’ (Austin, 1995).

Several companies in Alberta, including Brilliant Mining Corporation and Ice River Mining Ltd., have considered garnet as an industrial mineral worth investigation, and preliminary evaluations were conducted in the Cold Lake area. Unfortunately, the results of these evaluations are not publicly available. A comparison between the garnet concentrations observed in this study and those of producing alluvial deposits in Idaho, however, indicate that the potential for industrial garnet production in east-central Alberta, particularly the Cold Lake area, warrants consideration. In addition to industrial garnet, some of the garnets observed in this study have good colour and are free of inclusions and flaws. Thus, there is also potential for gem-quality garnet production.

The following excerpt from Evans and Moyle (2006) provides a useful set of factors that must be considered by companies interested in industrial garnet production in east-central Alberta:

Evaluation of garnet deposits to determine their suitability for industrial production includes the following factors: size and grade of reserves, mining conditions, garnet quality, location of the deposit relative to markets, and milling costs. Reserves should contain a minimum of 2 million tonnes of ore with a cutoff grade of about 20 vol. % garnet. Various environmental, social, and physical factors can preclude mining, such as proximity to houses, historical sites, national monuments, archeologic or paleontologic sites, wildlife refuges, and municipal watersheds, and may include local zoning regulations, environmental regulations, and configuration and structure of the deposit. After initial crushing, almandite or almandite-pyrope should be present as fine- to coarse-grained discrete crystals that are free of such inclusions as quartz, mica, hornblende, feldspar, and alteration products. As discussed below, andradite and grossularite also have their uses but are inferior to almandite in specific gravity and hardness. The specific gravity and hardness of the garnet should be uniform, and the crystals should not be highly weathered or friable.

Based on consideration of these factors, major deterrents to industrial garnet production in east-central Alberta include
the scattered distributions and general discontinuity of garnet-rich beach sands that would influence tonnage and grade calculations;
the abundance of small (~250–500 µm) and highly weathered (rounded) grain morphologies that could reduce abrasiveness; and,
the fact that some of these beach sands represent recreational beaches, which could create environmental and public conflict.

Nevertheless, the conclusion is that garnet could be an economically feasible resource in east-central Alberta, particularly when coupled as a coproduct of sand and gravel production, which continues to be an important resource commodity in Alberta. A jig system could easily be added at the end of the gravel sorting process to concentrate garnet. In addition, a small niche market should not be discounted. As is the case with many of the industrial minerals, successful production is dependent on the operator providing a product of interest to a local market. A small-scale garnet operation could market, for example, decorative sand. Environmentally friendly products, such as blast-cleaning sand, water-purification filter material and even play-box sand, may be successful locally if the product can be produced at costs lower than out-of-province garnet operations.

7.2 Source of Garnet: Geological Reasoning

Andriashek and Fenton (1989) considered several possibilities for the origin of surficial deposits in the Sand River map area:

- glaciofluvial material derived from the Canadian Shield as defined by the presence of granitic clasts (e.g., Empress Formation)
- till characterized by the scarcity of carbonate material and abundance of quartz; this material is derived from a distal source, and possibly related to the quartz sandstone of the Athabasca Basin, located in northeastern Alberta and northwestern Saskatchewan (e.g., Bonnyville Formation)
- till with a considerable amount of carbonate clasts (e.g., Marie Creek Formation); pebble orientations from this unit indicate a north-northwest to south-southeast flow direction that roughly parallels the trend of Devonian carbonate outcrops in northeastern Alberta
- glaciolacustrine sediments deposited by proglacial lakes that formed during glacial advances (e.g., Ethel Lake Formation)
- glaciofluvial and glaciolacustrine reworked material from glacially thrust landforms that are overridden and remoulded by glacial advances (e.g., Grand Centre Formation, Reita Lake Member)

While their interpretations demonstrate the complexity of predicting the source of materials contributing to beach sands in east-central Alberta, it is clear that 1) the overriding mechanism for deposition of surficial materials in this area is glaciation, and 2) a broad conclusion pertaining to the current study is that the garnet species studied in this report must have originated from an up-ice source north of the study area. Furthermore, the high concentration of metamorphic garnet (almandine, grossular and spessartine) in the beach sands suggests that the most logical source scenario is glaciofluvial material derived from the westernmost margin of the Canadian Shield. This theory is supported by Andriashek and Fenton (1989), who reported that the highest concentrations of igneous materials occur in the uppermost till units of the Sand River area. In other words, the uppermost till unit in this area correlates with the last-removed Canadian Shield rocks (i.e., the current Phanerozoic-Shield margin) as erosion the Shield rocks propagated westward.

Appendix 4 shows the garnet distributions from surficial-sampling KIM surveys in Saskatchewan (Swanson et al., 2005); the images show that a pronounced cluster of pyrope, almandine and grossular garnet occurs at approximately the same latitude as that of the present study but on the Saskatchewan side of the border. It is possible, therefore, that the Saskatchewan and Cold Lake–St. Paul garnets described in
this report are derived from a similar source. Unfortunately, the exact extent of the Saskatchewan garnet cluster near the Cold Lake area is not known. Like Alberta, there has been no sampling directly north of the cluster of anomalous garnets because access to the CLAWR is restricted, and there is only sparse surficial KIM sampling north of latitude 58º. At present, the Saskatchewan garnet cluster appears to be far enough away from, and therefore not related to, the Fort à la Corne kimberlite field (Appendix 4). It is therefore possible to conclude that garnets on both sides of the border were derived from the westernmost margin of the Canadian Shield.

Another geological consideration that could contribute to the origin of garnet is the timing of garnet deposition in east-central Alberta. If the garnet is part of complex surficial deposits representative of multiple glacial events and processes, then one might anticipate reduced garnet concentrations due to mixing. In this case, garnet accumulation would be associated with the last glacial event, the Primrose Lobe, which flowed in a south-southwesterly direction parallel to the westernmost margin of the Canadian Shield. Alternatively, it is possible that glaciotectonism provided the mechanism for exhumation and concentration of garnet-rich layers from the underlying surficial deposits. Andriashek and Fenton (1989) provided an excellent summary of glaciotectonic features in the Sand River map area. Garnet-rich beaches, such as those on Marie Lake and Wolf Lake, occur in areas associated with glacial thrusting and/or hill-hole pairs, where glaciers have gouged a depression (i.e., lake) that is coupled with a down-ice hill. Additional fieldwork (including coring) on the garnet distribution in the vertical dimension is required to further investigate this idea.

7.3 Source of Garnet: Indicator-Mineral Reasoning

With respect to paragenetic and/or depositional evidence based on the morphology of the garnets collected in this study, Dill (2007) showed that isometric minerals such as garnet are better suited for provenance studies than environment analysis because their inherited morphological differences are not modified by sedimentary processes in proximal placer deposits. Regarding paragenesis, garnet species from this report are indicative of at least two separate sources. Almandine-grossular-spessartine garnet species, which dominate the beach sands, could be indicative of a number of environments, including schist, gneiss, quartzite and other metamorphic rocks, pegmatite, and skarn deposits. Of greater importance to diamond explorers, the presence of high-Cr and G10 pyrope garnet is suggestive of a kimberlitic source. Additional discussion on these two potential sources follows.

7.3.1 Indicators of Kimberlite Paragenesis

Averill (2001, 2007) summarized the benefit of using MMSIMs to help evaluate an area for metallic mineral potential. Grossular and spessartine have been associated with metamorphosed volcanogenic massive sulphide (VMS), sedimentary exhalative (SEDEX) and Broken Hill–type (BHT) deposits. Gahnite (ZnAl₂O₄) and red (chrome?) rutile may be of importance because they are considered excellent indicators for potential metamorphosed magmatic massive-sulphide mineralization. Green Cr-garnet (e.g., Cr-grossular) and ruby (Cr-bearing) corundum can be indicators of Ni-Cu-PGE mineralization; they form as hybrid Fe-Al, Mg-Al and Cr-Al refractory minerals when dynamic sulphide saturation was induced by assimilation of Si- and Al-rich rocks into the Fe- and Mg-rich melt.

Although the suite of MMSIM grains recovered in this study may be indicative of metamorphosed volcanogenic massive sulphide and Ni-Cu-PGE parageneses, they are probably more representative in northern Alberta of ultramafic rocks. Multicoloured spinel grain types have been associated with kimberlite fields in Canada. For example, Friske et al. (2003) identified hercynite as a common indicator mineral near the Buffalo Head Hills kimberlite field. Green Cr-garnet and corundum could also be sourced from ultramafic sources related to kimberlite. For example, green Cr-garnet has been reported in the Mud Lake kimberlite at Drybones Bay, NWT, with compositions of 15–20 wt. % CaO and 12 wt. %

Cr$_2$O$_3$ (Snowfield Development Corp., 2003). In addition, Cr-corundum is present in the northern part of the Buffalo Head Hills, where it has been linked to the presence of Mg-Al spinel in these kimberlites (Hood and McCandless, 2004).

The contention that MMSIMs recovered in this study are representative of ultramafic rocks is supported by the presence and composition of the pyropes recovered. In contrast to known garnet EMPA data from various surficial media sampled throughout Alberta and garnet xenocrysts from kimberlitic bodies, both of which are dominated by G9 calcic lherzolitic garnet (Eccles et al., 2002; Eccles and Weiss, 2003; Hood and McCandless, 2004; Dufresne and Eccles, 2005; Eccles and Simonetti, 2008), G10 subcalcic pyrope garnets are prominent in east-central Alberta (Figure 13). In fact, the Cold Lake–St. Paul and Calling Lake areas are the only areas in Alberta to have yielded multiple G10 subcalcic pyrope garnets from surficial samples.

The unique distribution of G10 garnet in this area must be considered an indication that an undiscovered kimberlite cluster, or clusters, with high diamond potential exist(s) in, or up-ice of, east-central Alberta. In the case of pyrope garnet, their morphologies are important, particularly because Dufresne and Copeland
(1999) and Dufresne and Noyes (2001a) reported large diameter (up to 1.2 mm) pyropes with orange peel texture and kelyphitic rims that are often suggestive of a proximal source. The present work did not recover significant pyrope or G10 garnet from Winefred Lake or Christina Lake, which are located in the northern part of the study area. This raises the possibly that kimberlite could occur in Cold Lake–St. Paul and Calling Lake areas, or within the CLAWR. Alternatively, as was pointed out earlier, pyrope grain counts may correlate with total garnet grain counts, so more detailed KIM surveys may be required to determine whether the pyrope garnet is sourced locally in the Cold Lake–St. Paul and Calling Lake areas, within the CLAWR or farther north.

7.3.2 Indicators of Metamorphic Paragenesis

To consider possible sources for the almandine-grossular-spessartine garnet, some detective work was completed using AGS archival samples. During surficial mapping investigations in the 1980s, L. Andriashek (pers. comm., 2007) discovered garnet-rich metamorphic erratics in a farmer’s boulder field southwest of Cold Lake (Figure 4b). The garnet erratics, which were located at 552000E, 600800N (Zone 12, NAD 83) were discovered while following a set of north-northeast-trending flutes that propagate from/towards Cold Lake, likely as part of the southwestward propagating Primose Lobe (Andriashek and Fenton, 1989).

In situ EMPA analyses of garnet from the Andriashek erratic are geochemically identical to the pink almandine recovered from the beach sands (Figure 14). It is therefore possible to say with certainty that at least some of the garnet species in the study were derived from areas dominated by metamorphic rocks, most likely located to the north-northeast.

Garnetiferous gneiss similar to the Andriashek erratic is extremely common in western Laurentia and could be sourced within either the Churchill Province or the Slave Province. If a more local source is envisioned, the Lloyd and Mudjatik domains, located northeast of the study area and south of the Athabasca Basin, represent possible sources. Finally, other garnet-rich rocks of different compositions (e.g., amphibolite, silicate-facies iron formation, garnetiferous psammite and psammopelite) could have contributed the different garnet species evident in the beach sands of east-central Alberta.

7.4 Potential for Secondary Diamonds

Since the discovery of economic deposits of diamond in Canada didn’t occur until the early 1990s, diamond exploration in Canada is only in its infancy. As such, the search for placer deposits of diamond has received little attention in this country. Secondary diamonds have been reported, however, from garnet-rich beach sands in the Arctic. For example, Shear Minerals Ltd. reported an octahedral diamond in pyrope-rich beach sand adjacent to kimberlites on the Churchill Diamond project, Nunavut (Strand, 2006).

The concentration of garnet-rich beach sands in east-central Alberta, coupled with knowledge of the existence of pyrope garnet species with favourable diamondiferous kimberlite composition, should raise awareness of the potential for secondary deposits of diamond in this area. If an undiscovered cluster of diamondiferous kimberlite occurs in, or north of, the Cold Lake–Calling Lake area, then diamonds may have been relocated and concentrated in much the same way that the garnet has. Test sample(s) of garnet-rich beach sands, analyzed by traditional diamond-recovery techniques (e.g., caustic fusion), is recommended.
Figure 14. Garnet-rich metamorphic erratic discovered by L. Andriashek (pers. comm., 2007) and its geochemical comparison with beach sand garnet from this study.
8 References


concentrates and waters; Alberta Energy and Utilities Board, EUB/AGS Special Report 66 and Geological Survey of Canada, Open File 1790, CD.


Appendices

Appendix 1 – Garnet-Rich Beaches in East-Central Alberta (Information Gathered from Various Prospectors)

In most cases because of the prevailing winds, the beaches on the northwest and southeast ends of the lakes are most productive for garnet. The shape of the lake also has to be considered, with long-shore currents accumulating garnet in areas with considerable wave action.

**Cold Lake Area**
- Cold Lake (English Bay) has a garnet-rich beach right at the English Bay campground.
- Marie Lake has garnet-rich beaches in various locales around the lake, including the north side campground.

**Winefred Lake Area**
- No garnet was observed at Winefred Lake north, but many of the garnet beaches on the southwest, south and east sides carry garnet.
- Kirby Lake (west of Winefred Lake) has spotty occurrences, but garnet was observed at the north end near the airstrip and near the north-side boat launch.

**Bonnyville Area**
- Moose Lake has garnet along the north side and black sands on the south side.
- Muriel Lake has garnet on the southeast, south and southwest beaches.

**Frog Lake Area**
- Whitney Lake (near Frog Lake) has garnet and abundant black sand.
- Frog Lake has garnet beaches on the east side directly down the lake from Sputinow.

**Lac La Biche Area**
- Square Lake (near Lac La Biche) has garnet near the boat launch on the southeast end and some spotty garnet beaches around the lake.
- Wolf Lake has excellent garnet beaches, including the one at the south side campsite.
- Heart Lake has garnet beaches on the east side that are accessible by boat only.
- Lac La Biche has several garnet beaches around the lake.

**Calling Lake Area**
- Garnetiferous beach extends from the south shore at the boat launch and spottily along the southwestern and western shores.

**Slave Lake Area**
- Slave Lake has garnets on the beaches in a number of places along the north side.

**St. Paul Area**
- Lac Santé has numerous garnets at the boat launch on the east side.
• Lower Therien has garnet at the north end by the private beach.
• Upper Therien has garnet all along the south shore, directly south of the townsite.
• Garner Lake, directly north of Spedden, has garnet along the southeast side by the boat launch.
• Vincent Lake has spotty occurrences of garnet along the northeast side.
• Chicken Lake has garnet at the beach on the north end by the boat launch.
• Stoney Lake has great garnets at the south end by the campsite.
Appendix 2 – Magnetic Susceptibility and General Lithology of Beach Sands in East-Central Alberta
Figure 15. Magnetic susceptibility and general lithology of beach sand at Heart Lake (sample RE06-GB-001).
Figure 16. Magnetic susceptibility and general lithology of beach sand at Winefred Lake (sample RE06-GB-002).
Figure 17. Magnetic susceptibility and general lithology of beach sand at Christina Lake (sample RE06-GB-003).
Figure 18. Magnetic susceptibility and general lithology of beach sand at Wolf Lake (sample RE06-GB-004). Garnet-rich horizons are highlighted by the red arrows.
Figure 19. Magnetic susceptibility and general lithology of beach sand at Cold Lake (sample RE06-GB-005). Garnet-rich horizons are highlighted by the red arrows.
Figure 20. Magnetic susceptibility and general lithology of beach sand at Shelter, Bay, Marie Lake (sample RE06-GB-007). Garnet-rich horizons are highlighted by the red arrows.
Figure 21. Magnetic susceptibility and general lithology of beach sand at Stoney Lake (sample RE06-GB-008).
Figure 22. Magnetic susceptibility and general lithology of beach sand at Lac Santé (sample RE06-GB-009).
Figure 23. Magnetic susceptibility and general lithology of beach sand at Calling Lake southeast (sample RE06-GB-010).
Figure 24. Magnetic susceptibility and general lithology of beach sand at Calling Lake west (sample RE06-GB-011).
Appendix 3 – Electron Microprobe Analytical Results for Garnet-Rich Beach Sands in East-Central Alberta: A) Garnet (All Species), B) Non-Garnet Kimberlite-Indicator Minerals (Clinopyroxene, Chromite and Ilmenite), and C) Garnet from a Garnetiferous Pelitic Gneiss Erratic Discovered in the Area
Table 6. Electron microprobe analytical results for garnet.

|--------|------------|--------|-----------|-------------|-------------|-----------|---------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
Table 6 (continued)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Gene</th>
<th>Start</th>
<th>End</th>
<th>Strand</th>
<th>Type</th>
<th>Exon</th>
<th>Location</th>
<th>Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table entry indicates the presence of a specific gene or transcript within the given genomic regions.*

**Note:** This table represents a continuation of Table 6 from the ERCBIAGS Open File Report 2008-06 (September 2008) document. For a full understanding, please refer to the original report for detailed descriptions and context.
Table 7. Electron microprobe analytical results for non-garnet kimberlite-indicator minerals.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Grain type</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
<th>Grain type (geochemical ID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>2</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>3</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>4</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>5</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>7</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>8</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>9</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>10</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>11</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>12</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>13</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>14</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
<tr>
<td>15</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
<td>3.4.5.6</td>
</tr>
<tr>
<td>16</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
<td>4.5.6</td>
</tr>
</tbody>
</table>

1 Physical grain types identified during heavy-liquid indicator processing, some of which were identified by semi-quantitative EDS analysis.
2 Chemical grain types identified by element-sensitive data from the program data file (Smith and Higgins, 2001). This score is a "matching index" calculation of mineral identification probability when a score of 100% represents a perfect match.
Table 8. Electron microprobe analytical results for garnet from the garnetiferous pelitic gneiss erratic.

| Sample | Formula | Grains | Grain size [um] | Fe2O3 | SiO2 | Al2O3 | MgO | CaO | Na2O | K2O | MnO | TiO2 | Cr2O3 | V2O5 | FeO | Mg/#Fe | Si/#Al
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

* Electron microprobe analyses performed by Dr. J. Smith from the University of Oxford. *1 The data varies based on the specific analytical method used. *2 The values are expressed in parts per million (ppm).
Appendix 4 – Garnet Distribution in Saskatchewan

Figure 25. Distribution of garnet species in Saskatchewan: a) pyrope, b) almandine, c) grossular, d) spessartine and e) andradite. Compilation from the Web-based database of Saskatchewan Kimberlite-indicator minerals (Swanson et al., 2007).