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Diamond Potential in Alberta: Distribution of Kimberlite and Kimberlite Indicator Mineral Clusters

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Diamond Potential in Alberta: Distribution of Kimberlite and Kimberlite Indicator Mineral Clusters

A. Banas, D.R. Eccles and M.B. Dufresne

Apex Geoscience Ltd.

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Author addresses:
Apex Geoscience Ltd.
#100, 9797 – 45 Avenue
Edmonton, AB T6E 5V8
Canada
780.439.5380

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Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Fax: 780.422.1459
E-mail: AGS-Info@aer.ca
Website: ags.aer.ca

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Acknowledgements

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Abstract

This report provides a description and an assessment of the distribution of kimberlite and kimberlite indicator mineral (KIM) clusters in Alberta. It is a combined release of four internal reports produced by Apex Geoscience Ltd. at the request of the Alberta Geological Survey as part of a project funded by Alberta Energy to enhance Alberta's mineral geoscience knowledge and to disseminate existing geological information. The specific purpose of this report was to provide geoscience information on Alberta's diamond potential to help guide land-use planning.

This report includes background information about kimberlites and KIMs, maps showing the distribution of kimberlites and KIMs, and assessments of diamond potential for the Lower Peace (LPRP), Upper Peace (UPRP), Upper Athabasca (UARP), and North Saskatchewan (NSRP) regional planning areas based on the presence of moderate to high counts of KIMs with favourable mineral chemistry, the presence of kimberlites, the presence of diamonds in surface samples, and the location relative to known kimberlites.

Two known kimberlite fields exist within the LPRP area (Buffalo Head Hills and Birch Mountains) and one kimberlite field has been discovered within the UPRP area (Mountain Lake). No kimberlites have been discovered within the UARP and NSRP areas to date.

The assessments of the four regional planning areas resulted in the identification of a total of seven areas with high diamond potential (Central Buffalo Head Hills, Birch Mountains, North Buffalo Head Hills, West Buffalo Head Hills, Utikuma Lake, Calling Lake, and Swan Hills) and ten areas with moderate diamond potential (Hay-Zama Lakes, Chinchaga, Caribou Mountains, Mountain Lake, Clear Hills, Kakwa River, Hinton, Ram River, St. Paul, and West Edmonton).

Distribution of Kimberlite and Kimberlite Indicator Mineral Clusters in the Lower Peace Regional Plan Area

Prepared For:
Alberta Geological Survey
4th Floor, Twin Atria Building
4999-98 Ave
Edmonton, AB
T6B 2X3

Prepared by:
APEX Geoscience Ltd.
#100, 9797-45 Ave
Edmonton, AB
T6E 5V8

Anetta Banas, M.Sc., P.Geol.
Roy Eccles, M.Sc., P.Geol.
Michael Dufresne, M.Sc., P.Geol.

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Edmonton, AB

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1 Summary

APEX Geoscience Ltd. (APEX) was contracted by the Alberta Geological Survey (AGS) to provide an assessment of the distribution of kimberlites and kimberlite indicator mineral clusters in the Lower Peace Regional Plan area.

This report is focused on assessing the diamond potential within the Lower Peace Regional Plan (LPRP) area based on the mineral chemistry of kimberlite indicator minerals (KIMs). There are two known kimberlite fields within the LPRP area: Buffalo Head Hills and Birch Mountains. This assessment has identified:

- Six areas within the LPRP area that have a high diamond potential:
  - Central Buffalo Head Hills
  - Birch Mountains
  - North Buffalo Head Hills
  - West Buffalo Head Hills
  - Utikuma Lake
  - Calling Lake

- Three areas within the LPRP area that have a moderate diamond potential:
  - Hay-Zama Lakes
  - Chinchaga
  - Caribou Mountains

These areas were selected based on the presence of moderate to high counts of KIMs with favourable mineral chemistry, the presence of kimberlites, the presence of diamonds in surface samples and the location relative to known kimberlites.

2 Introduction to the Northern Alberta Kimberlite Province

Diamonds are largely mined from a special type of volcano called kimberlite. However, not all kimberlites contain diamonds. In Alberta, 51 kimberlites have been discovered in three separate areas: Buffalo Head Hills, Birch Mountains and Mountain Lake. To date, the Buffalo Head Hills kimberlites have the highest diamond contents, with 28 of 41 kimberlites containing diamonds. Diamond grades of up to 55 carats per hundred tonnes have been reported. The discovery of diamond bearing kimberlites within the province has led to increased interest in diamond exploration across the province.

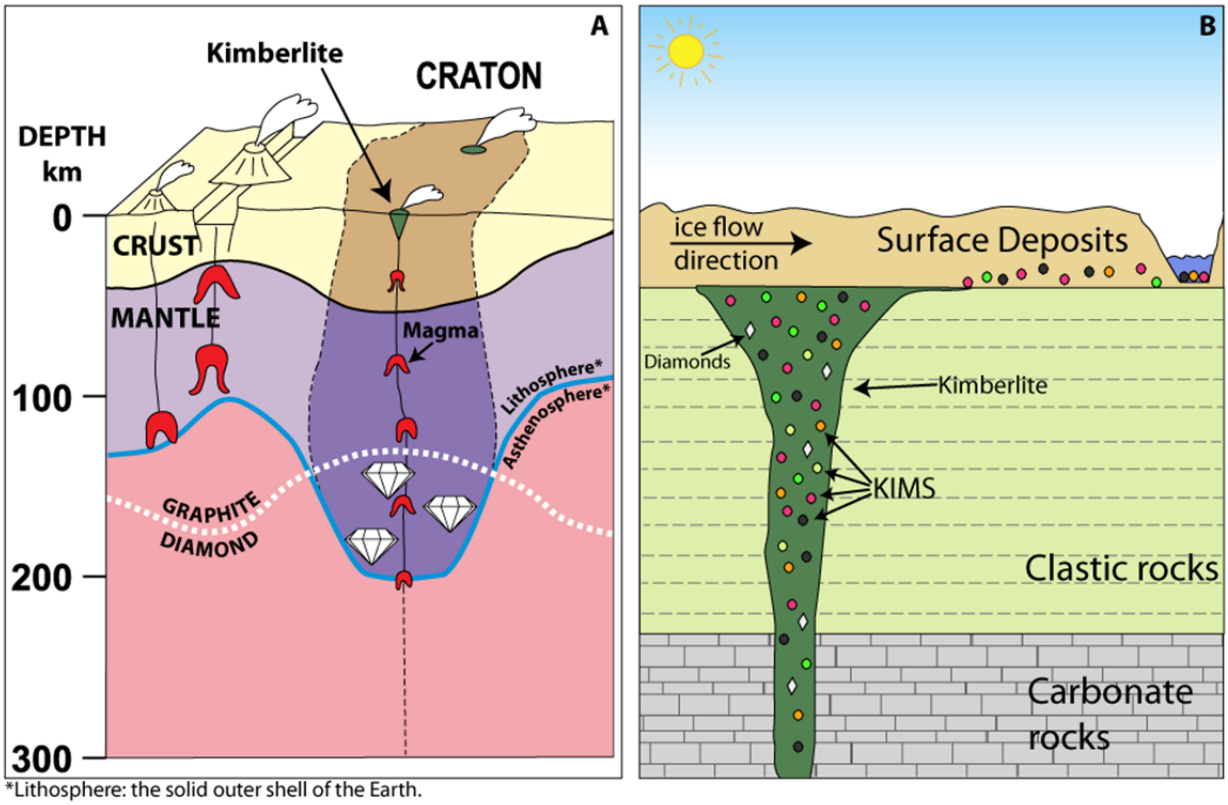
The first kimberlite in Alberta was discovered at Mountain Lake, near Grande Prairie, in 1989 by Monopros Limited, a subsidiary of De Beers. The Mountain Lake kimberlite has a very low diamond content and the kimberlite is considered uneconomic. In the Birch Mountains area of northeastern Alberta, eight kimberlites have been discovered: seven by Kennecott Canada Exploration Inc., Montello Resources Ltd. and Redwood Resources Ltd. in 1998; and one by New Blue Ribbon Resources Ltd. in 2000. Low diamond contents have been reported from two of the Birch Mountains kimberlites. In the Buffalo Head Hills kimberlite field, 38 kimberlites were

discovered between 1997 and 2003 by a joint venture led by Ashton Mining of Canada Inc. An additional three kimberlites were discovered in 2008 by Grizzly Discoveries Inc.

Diamonds are usually found in areas that are underlain by ancient rocks called cratons (Figure 1A). In northern Alberta the deep basement rocks consist of 1.8 – 2.4 billion year old cratonic rocks that have been shown to contain diamond. The basement rocks are covered by younger carbonate and sedimentary deposits which are in turn covered at the surface by glacial deposits (Figure 1B; Mossop and Shetsen, 1994; Carlson et al., 1999). The kimberlite carries the diamonds and mantle minerals from the deep, ancient mantle rocks through the overlying rocks to the surface. Kimberlites are typically steep-sided, carrot shaped pipes (Figure 1B; Hawthorne, 1975; Carlson et al., 1999).

Geophysical surveys are used to provide additional information for exploration programs and have been very successful in defining kimberlite targets in Alberta. Geophysical surveys are not part of this compilation and assessment, but are mentioned where the information is relevant to the assessment of diamond potential.

Figure 1 A) Cross-section through the Earths' crust and upper mantle (modified after Stachel and Harris, 2008). B) Schematic cross-section of a typical kimberlite, showing glacial erosion and subsequent distribution of kimberlite indicator minerals.



*Lithosphere: the solid outer shell of the Earth.
Asthenosphere: the ductile part of the Earth below the lithosphere.

3 Background Information: Using Kimberlite Indicator Minerals

Diamond forms deep within the earth – in the mantle – at depths of greater than 150 kilometres where high temperature and pressure converts carbon into diamond (Figure 1A). The diamonds, form together with other mantle minerals that include pyrope garnet, eclogitic garnet, clinopyroxene, olivine, chromite and ilmenite. Mantle minerals always occur in higher quantities than diamond. These minerals have special chemical properties that are tell-tale signs they formed in the same environment as diamond.

For this reason, diamond explorers typically look for mantle minerals rather than diamond. These mantle minerals are often referred to as Kimberlite Indicator Minerals (or KIMs). As the kimberlite wears down due to erosion, KIMs are spread out and can be found in a variety of settings such as river and stream sediments, and in sand and gravel that has been moved by glaciers (Figure 1B). Once the KIMs are collected by explorers, they are sorted visually into mineral groups. These minerals are then analyzed for their chemical properties. If the KIMs have a similar chemistry to the mantle, where diamonds form, then the explorer might be close to a diamond discovery.

3.1 Garnet as a KIM

Garnet can be divided into peridotitic garnet and eclogitic garnet, both of which are sources of diamond in the mantle. Based on their unique chemistry, individual garnet grains are classified into different groups (Grutter and Menzies, 2003; Grutter et al., 2004 and references therein).

- Peridotitic garnet, or pyrope garnet, are pink, purple, and red in colour. They are classified into Group 9 (G9), G9D, G10, G10D, G11 and G12 garnet.
- Eclogitic garnet are orange to red in colour. They are classified into Group 3 (G3), G3D, G4, G4D, G5 and G5D garnet.

The addition of the letter “D” to the end of the classification indicates that the garnet were formed in an environment suitable for diamond growth. A high number of garnet grains with the suffix “D” are of great interest to the diamond explorer because it could indicate an area of high potential for the presence of diamond-bearing kimberlite.

3.2 Clinopyroxene as a KIM

Clinopyroxene are also divided into peridotitic and eclogitic compositions (Ramsay and Tompkins, 1994; Nimis and Taylor, 2000).

- Peridotitic clinopyroxene, or chromian diopside, are bright emerald green. Their composition is used to determine the depth and temperature at which they formed. High numbers of chromian diopside with favourable compositions could indicate an area of high potential for diamond bearing kimberlite.
- Eclogitic clinopyroxene, or omphacitic pyroxene, are mossy green. Their composition can indicate if they formed in a diamond stable environment.

3.3 Olivine as a KIM

Olivine are a very common mineral in kimberlite and mantle peridotite rocks (Mitchell, 1989). Olivine are also found in other rock types but these are rare in northern Alberta. Olivine are not known to form in any sedimentary rock formation in Alberta, and are easily degraded in the sedimentary environment. Hence the presence of a large number of olivine grains in an area can be indicative of a nearby kimberlite.

3.4 Chromite as a KIM

Chromite can come from a variety of rocks. For diamond exploration three types of chromite are of interest (Creighton and Stachel, 2008 and references therein):

- Diamond inclusion chromite – have a composition similar to that measured for chromite removed from diamonds. A high number of diamond inclusion chromite can indicate the presence of diamond bearing rocks nearby.
- Kimberlitic chromite – have a composition that indicates they formed in the kimberlite itself. A high number of kimberlitic chromite grains indicate the presence of kimberlites nearby.
- Ultramafic chromite - have a composition that may indicate they are derived from peridotitic rocks. These can be used together with other minerals to assess the diamond potential of an area.

3.5 Ilmenite as a KIM

Ilmenite are formed in kimberlite and in other, unrelated, rock types. Two types of ilmenite are of high interest to diamond explorers: picroilmenite and Cr-rich picroilmenite. In exploration programs the composition of ilmenite is used in 2 ways. The composition of ilmenite can be used to determine if the ilmenite was formed in kimberlite (Mitchell, 1989). A high number of these compositions can indicate the presence of kimberlites nearby. The composition of ilmenite can also be used to provide information on how well diamonds in a kimberlite have been preserved (Haggerty, 1975; Gurney and Zweistra, 1995). Favourable ilmenite compositions can indicate that a kimberlite has a high diamond content.

4 Lower Peace Regional Plan (LRPR) Area Assessment

4.1 Data sources

For the LPRP area 1,328 samples have been compiled. From these samples 9,413 mineral chemistry analyses are available. For this assessment the AGS KIM Sample Microprobe database (KIM Sample Microprobed, 2015) was updated with data from eight government reports (Eccles, 2008; Paulen et al., 2005; Plouffe et al., 2006; Plouffe et al., 2007, Prior, 2007; Prior, 2010; Prior et al., 2005) and five industry-filed Mineral Assessment Reports (Dufresne, 2005; Dufresne, 2007a; Dufresne and Banas, 2010; Hartley, 2006; Ward and Willis, 2004). The AGS KIM Sample Microprobe database is largely based on the compilations reported in Dufresne and Eccles (2005) and Eccles et al. (2002) and references therein. This evaluation includes an assessment of those KIMs with associated chemical data. Many industry reports

include visually identified KIM pick counts with no associated mineral chemistry. These reports have not been systematically compiled. Known occurrences of high KIM pick counts are mentioned where the information is relevant to the assessment of diamond potential.

4.2 Kimberlite Fields

Two separate and distinct clusters of kimberlite are found within the LPRP area: Buffalo Head Hills and Birch Mountains.

4.2.1 Buffalo Head Hills

The Buffalo Head Hills (BHH) kimberlite field consists of 41 kimberlite pipes. It is located about 150 km north of Lesser Slave Lake. Within this field 28 kimberlites are known to contain diamond. Mini-bulk sampling was completed on five kimberlites. Kimberlites K11 and K91 returned grades of around 11 carats per hundred tonnes, while kimberlite K252 returned a highly encouraging grade of 55 carats per hundred tonnes (Eccles, 2011).

The composition of the mantle below the BHH is reflected by mineral inclusions in diamonds and mantle minerals recovered from the kimberlites. Understanding the chemistry of the minerals recovered directly from diamonds and kimberlites allows diamond explorers to identify similar compositions in the KIMs recovered from surface samples. This information is then used to identify areas of high diamond potential.

Mineral inclusions in BHH diamonds are mainly from mixed eclogitic (46%) and peridotitic (42%) mantle source rocks. In contrast the mantle minerals recovered from the BHH kimberlites are dominated by largely by peridotitic compositions with lesser amounts of eclogitic compositions. Very little information has been published about the chemistry of the eclogitic KIMs. A lot more information is available on the peridotitic minerals. There is a distinct difference between the compositions of minerals from the diamond bearing pipes versus the non-diamond bearing pipes (Hood and McCandless, 2004).

- Mantle mineral characteristics from diamond bearing kimberlites:
  - A significant proportion of garnet are G9D – from diamond stable mantle
  - Chromian diopside indicate formation at diamond stable conditions
  - Chromite are largely of ultramafic and kimberlitic composition
  - Olivine compositions indicate they are from peridotitic rocks
  - Rare ilmenite – recovered from only 2 kimberlites

- Mantle mineral characteristics from non-diamond bearing kimberlite:
  - Garnets are mainly G9 - not from the diamond stable area
  - Chromian diopside indicate formation outside of diamond stable conditions
  - Chromite do not have kimberlitic or ultramafic compositions
  - Small amounts of ilmenite

These differences are used to identify diamond related compositions within the KIMs recovered from surface samples. High numbers of KIMs with favourable compositions are used to define areas with high diamond potential.

4.2.2 Birch Mountains

The Birch Mountains kimberlite field consists of eight kimberlite pipes, seven of which fall within the area of the LPRP. This field is located approximately 225 km northeast of Lesser Slave Lake. Only two of the Birch Mountain kimberlites, Legend and Phoenix, contain diamonds but their diamond content is very low. Drilling of geophysical targets led to the discovery of all the known Birch Mountains kimberlites.

The mantle minerals recovered from the Birch Mountain kimberlites are characterized mainly by peridotitic compositions. The garnet are mainly characterized by G9 and G11 compositions that largely fall outside of the diamond stable conditions in the mantle. In contrast to the BHH kimberlites the Birch Mountains kimberlites have a high ilmenite content (Eccles, 2011 and references therein).

4.3 Diamond Potential Assessment

The diamond potential areas along with KIM distribution, kimberlite and diamond occurrences are presented in Figure 2. The area also includes a couple of isolated diamond discoveries that have been found in surface deposits such as river and stream sediments, and/or in sand and gravel that has been moved by glaciers. Please refer to Figure 2 throughout this section.

4.3.1 High Diamond Potential

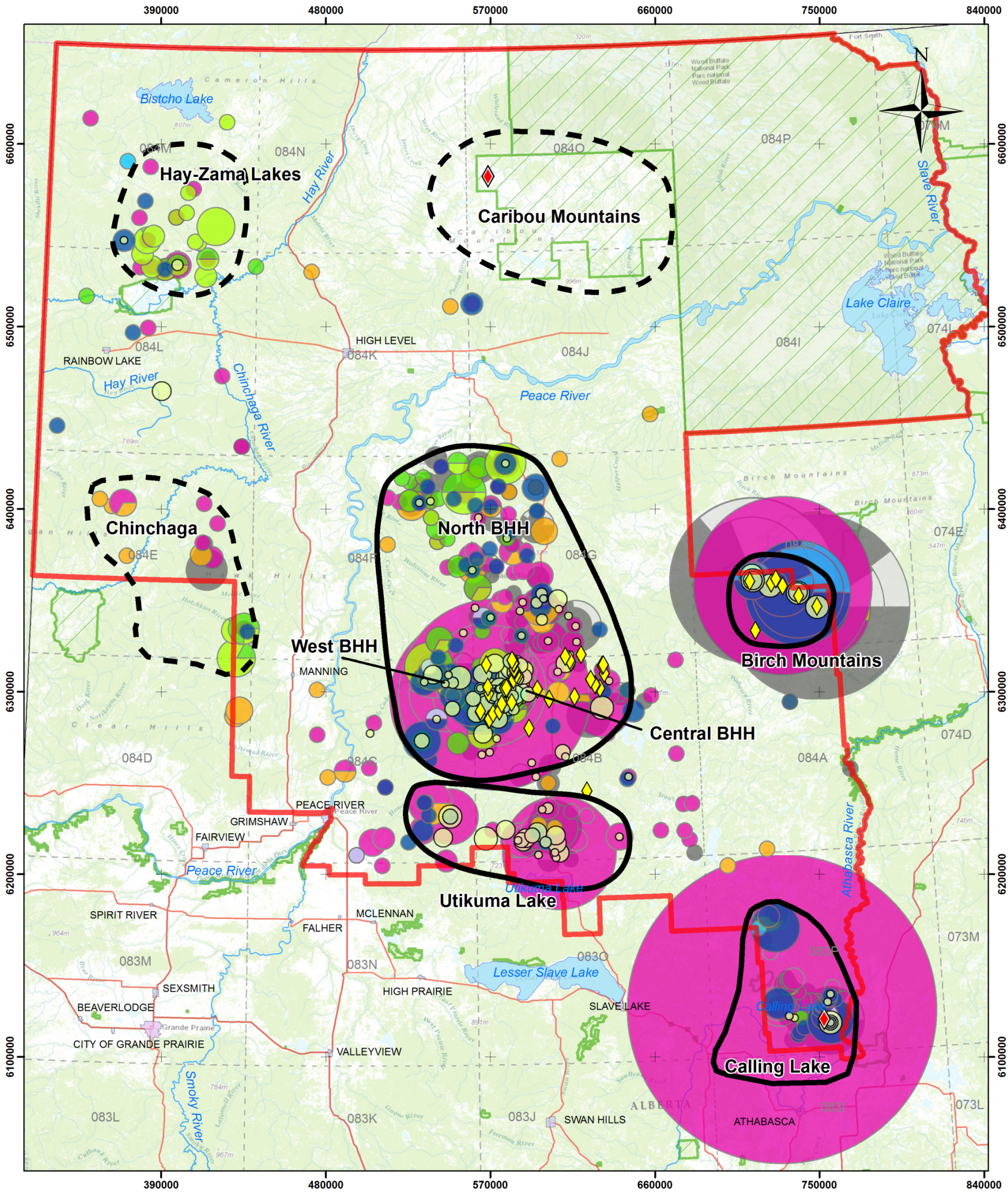
4.3.1.1 Central Buffalo Head Hills

The present financial market downturn has temporarily limited exploration in the BHH area. The presence of KIMs in surface samples that have compositions similar to those found in the diamond bearing kimberlites indicates that there are undiscovered kimberlites in this area. Additionally, numerous kimberlite-like targets have been identified from geophysical surveys (Dufresne et al., 2009). Further exploration is required to understand the source of these anomalies. The presence of KIMs with favourable chemistry in surface samples and kimberlite-like geophysical targets indicate that the Central Buffalo Head Hills area has high potential for the discovery of new, diamond bearing kimberlites. The encouraging diamond grades recovered from several of the BHH kimberlites indicate that kimberlites with potentially economic diamond grades could exist in this area.

4.3.1.2 North and West Buffalo Head Hills

KIMs recovered north and west of the main Buffalo Head Hills kimberlite cluster are of high interest. Glaciers in the area moved material in a general southerly direction. Consequently, KIMs found north and west of the BHH kimberlites are unlikely to come from known kimberlite pipes. The presence of high numbers of KIMs in these areas likely indicates that there are

Figure 2 Kimberlite Indicator Mineral (KIM) distribution, kimberlite fields and diamond occurrences in the Lower Peace Regional Plan area.



undiscovered kimberlites nearby. The presence of G3D, G4D and G9D garnet, chromian diopside, and diamond inclusion chromite indicate a high potential for the kimberlites to be diamond bearing. Additionally, exploration in these areas has identified numerous kimberlite-like geophysical targets that require further exploration (Dufresne , 2007b; Dufresne and Carey, 2007).

4.3.1.3 Birch Mountains

Very limited KIM sampling has been conducted down-ice of the Birch Mountains kimberlites therefore little is known about the overall diamond potential of the kimberlite field. The recovery of diamonds and favourable mantle mineral chemistry from the Legend kimberlite may be an indication of the possibility for the presence of undiscovered kimberlites with a higher diamond potential. Numerous kimberlite-like geophysical targets have been identified in the area. Additional exploration is required to test these targets (Dufresne et al., 2007).

4.3.1.4 Utikuma Lake

The KIM cluster in the Utikuma Lake area is spatially separate from the main BHH kimberlite field located to the north. KIMs recovered in this area include numerous peridotitic garnet, ultramafic chromite, olivine and picroilmenite. Several samples contain high counts of G9D garnet. One G10D garnet was also identified. The large distance from the BHH kimberlites and the favourable compositions of the KIMs in the Utikuma Lake area indicate that there is likely a local, as yet undiscovered kimberlite source in this area. The presence of high numbers of G9D garnet in this area indicate that there is a high potential for the kimberlite to be diamond-bearing.

4.3.1.5 Calling Lake

The Calling Lake area received a significant amount of exploration attention during the 2000's. The area contains: a diamond that was recovered from a glacial till sample; two samples with the highest known KIM counts in the entire province; and exceptional mantle chemistry. The highest count sample contains 419 KIMs of which 410 are garnet. From the garnet KIMs, 58 are classified as G9D and 6 are classified as G10D. The second highest count sample contains 56 G9D and 8 G10D garnet grains. Eclogitic clinopyroxene with compositions similar those measured from diamond stable mantle are found in several samples. Diamond inclusion chromite, olivine, picroilmenite and Cr-rich picroilmenite compositions have also been identified. Limited drilling to date has not discovered any kimberlites. The Calling Lake KIM cluster is located over 150 km southwest of the Buffalo Head Hills kimberlite field and it is unlikely that the KIMs come from the known BHH kimberlites. The abundance of KIMs with favourable chemistry and the presence of a diamond in a glacial till sample indicate that the source(s) for these KIMs is likely from a nearby kimberlite that has a high potential to be diamond-bearing.

4.3.2 Moderate Diamond Potential

4.3.2.1 Hay-Zama Lakes

Initial government sampling in the Hay-Zama Lakes area identified high numbers of KIMs in three separate samples. This area is spatially separate from known kimberlite fields in Alberta and the Northwest Territories. The presence of high counts of KIMs in the area may indicate the presence of an unknown kimberlite nearby. The sparseness of the samples does not allow a detailed assessment of the area. However the presence of peridotitic garnet, chromian diopside, omphacitic pyroxene, ultramafic and kimberlitic chromite and picroilmenite indicate that the area has moderate diamond potential.

4.3.2.2 Chinchaga

The Chinchaga area is spatially separate from the known kimberlite fields in Northern Alberta. This moderate potential area extends to the northwest into the Lower Peace Regional Plan area. This area is characterized the presence of a high number of samples that contain anomalous counts of KIMs. The samples contain numerous grains of garnet, including garnet of favourable G3D, G9D and G10D compositions. Additionally the samples contain chromian diopside, omphacitic pyroxene and picroilmenite. The high KIM counts, large number of samples with high KIM counts and favourable KIM chemistry in this area may be an indication of a nearby kimberlite source. Sampling in this area is limited so a detailed assessment of the area cannot be made at this time.

4.3.2.3 Caribou Mountains

A diamond was found in the Caribou Mountains in a surface sample collected by Ashton Mining of Canada Inc. in 1999. The diamond bearing sample also contained one peridotitic garnet and three chromite grains. Numerous samples in this area contain high counts of KIMs including peridotitic garnet, eclogitic garnet, olivine and chromian diopside (Skelton and Bursey, 2000). These grains were identified visually and chemical analyses were not completed. Due to the lack of mineral chemistry data a detailed assessment of the potential of this area cannot be made at this time. However the presence of a diamond in a surface sample is quite rare and may indicate the presence of a nearby kimberlite.

5 Conclusions

The Lower Peace Regional Plan area is internationally recognized for its diamond potential. To date, two kimberlite fields have been discovered and documented in the LPRP area: Buffalo Head Hills and Birch Mountains. These fields were only recently discovered (post-1998) showing the infancy of kimberlite exploration in Alberta. Kimberlites in the Buffalo Head Hills field contain significant diamond contents, with grades up to 55 carats per hundred tonnes. The Buffalo Head Hills represents the third largest field of diamond-bearing kimberlites in Canada.

In the Calling Lake area the discovery of a diamond in surficial material, and the number and favourable chemistry of the KIMs suggests that the area could have similar potential to, or

better than, the Buffalo Head Hills kimberlite field. The area has received significant exploration attention but the source for the KIMs has not been found.

When market conditions improve, the Buffalo Head Hills kimberlite field and diamond potential areas within the LPRP area will be of great interest to exploration companies and to the Government of Alberta.

The assessment of the kimberlite indicator mineral data has resulted in the identification of six areas with a high diamond potential and three areas with a moderate diamond potential:

High Diamond Potential areas:

- Central Buffalo Head Hills
- North Buffalo Head Hills
- West Buffalo Head Hills
- Utikuma Lake
- Calling Lake
- Birch Mountains

Moderate Diamond Potential areas:

- Hay-Zama Lakes
- Chinchaga
- Caribou Mountains

6 References

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999) The Buffalo Hills kimberlites: a newly-discovered diamondiferous kimberlite province in northcentral Alberta, Canada; *in* Proceedings of the Seventh International Kimberlite Conference, J.J. Gurney, J.L. Gurney, M.D. Pascoe, and S.H. Richardson (ed.), v. 1, p. 109–116.

Creighton, S., Stachel, T. (2008) An empirical chromite classification for positive identification of kimberlite in diamond exploration; 9th International Kimberlite Conference, Extended Abstracts, 9IKC-A-00402, 3 p.

Dufresne, M.B. (2005) Assessment report Swan Hills Property, North-Central Alberta Mineral Permits 9302040003 to 9302040023. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20040011, 224p.

Dufresne, M.B. (2007a) Assessment report for Diamond and Gold Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070009, 158p.

Dufresne, M.B. (2007b) Assessment report for the Smoky the Bear Property, Buffalo Head Hills. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR200700002, 91p.

Dufresne, M.B., Eccles, D.R. (2005) A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data. Alberta Energy and Utilities Board, EUB/AGS Special Report 20, 277p.

Dufresne, M.B., Carey, H. (2007) Assessment report for the Grand Cub Aidan Property, Buffalo Head Hills, Northern Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070015, 217p.

Dufresne, M.B., Banas, A. (2010) Assessment report for Diamond, Gold, Platinum, Bentonite and Lithium Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20100011, 409p.

Dufresne, M.B., Carey, H., Raffle, K. (2007) Assessment report for Legend Property, Birch Mountains, Northern Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070016, 342p.

Dufresne, M.B., Banas, A., Arsenault, D. (2009) Assessment report for Grizzly Diamond Ltd.'s Buffalo Head Hills Smoky the Bear Permits: 9305010838, 9306110739-42. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20090002, 290p.

Eccles, D.R. (2008) Geological Evaluation of Garnet-Rich Beaches in East-Central Alberta with Emphasis on Industrial Mineral and Diamondiferous Kimberlite Potential. Energy Resources and Conservation Board, ERCB/AGS Open File Report 2008-06, 57p.

Eccles, D.R. (2011) Northern Alberta kimberlite province: the first 20 years. Energy Resources Conservation Board, ERCB/AGS Bulletin 65, 116 p.

Eccles, D.R., Dufresne, M., Copeland, D., Csanyi, W., Creighton, S. (2002) Alberta Kimberlite-Indicator Mineral Geochemical Compilation. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-20, 8p.

Grutter, H.S., Menzies, A. (2003) Mutually Consistent Classification Schemes for Mantle-Derived Garnet and Chromite, For Use By Diamond Explorers. 8th International Kimberlite Conference Extended Abstract, 5p.

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

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

Hartley, G.S. (2006) Technical Report on the Grimshaw Property. Assessment report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20060006, 76p.

Haggerty, S.E. (1975) The chemistry and genesis of opaque minerals in kimberlites. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.295–308.

Hawthorne, J.B. (1975) Model of a kimberlite pipe. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.1-16.

Hood, C.T.S., McCandless, T.E. (2004) Systematic Variations in Xenocryst Mineral Composition at the Province Scale, Buffalo Hills Kimberlites, Alberta, Canada. ; Lithos, v. 77, p.733-747

KIM Sample Microprobed (2015) https://services2.arcgis.com/jQV6VMr2Loovu7GU Alberta Energy Regulator / Alberta Geological Survey

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

Mossop, G., Shetsen, I. (compilers) (1994) Geological Atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and ARC, Calgary, AB. 510 pp.

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

Paulen, R.C., Waight, B. and Kjarsgaard, I.M. (2005) Kimberlite indicator mineral content and chemistry from till samples, southwest Buffalo Head Hills (NTS 84C/East); Alberta Energy and Utilities Board, 1p.

Plouffe, A., Paulen, R.C., Smith, I.R. (2006) Indicator mineral content and geochemistry of glacial sediments from northwest Alberta (NTS 84L, M): new opportunities for mineral exploration. Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 77, Geological Survey of Canada, Open File 5121, 1 CD-ROM.

Plouffe, A., Paulen, R.C., Smith, I.R., Kjarsgaard, I.M. (2007) Chemistry of kimberlite indicator minerals and sphalerite derived from glacial sediments of northwest Alberta, Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 87, Geological Survey of Canada, Open File 5545, 1 CD-ROM.

Prior, G.J. (2007) Chemistry and mineralogy of kimberlite-indicator mineral grains from a till survey of the Sawn Lake area (NTS 84B/13), southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2007-01, 51p.

Prior, G.J. (2010) Till Geochemistry in the Sawn Lake Area, Southern Buffalo Head Hills, Alberta (NTS 84B/13). Energy Resources and Conservation Board, ERCB/AGS Open File Report 2010-14, 45p.

Prior, G.J. Paulen, R.C. Pawlowicz, J.G. Fenton, M.M. (2005) Kimberlite-Indicator Mineral Till Survey of the Sawn Lake Area (NTS 84B/13), Southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2005-02, 103p.

Ramsay, R.R., Tompkins, L.A. (1994) The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of the Boa Esperanca and Cana Verde pipes, Corrego D'Anta, Minas Gerais, Brazil. In: H.O.A. Meyer and O.H. Leonardos (editors) Diamonds; characterization, genesis and exploration. Proceedings of the International Kimberlite Conference, 1991, Vol. 5, Vol. 2, pp. 329-345.

Selton, D., Bursey, T. (2000) Assessment report Caribou Mountains (AL06) Property. Assessment report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20000009, 146p.

Stachel, T., Harris, J.W. (2008) The origin of cratonic diamonds—constraints from mineral inclusions. Ore Geology Reviews 34, 5-32

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Distribution of Kimberlite Indicator Mineral Clusters in the North Saskatchewan Regional Plan Area

Prepared For:
Alberta Geological Survey
4th Floor, Twin Atria Building
4999-98 Ave
Edmonton, AB
T6B 2X3

Prepared by:
APEX Geoscience Ltd.
#100, 9797-45 Ave
Edmonton, AB
T6E 5V8

Anetta Banas, M.Sc., P.Geol.
Roy Eccles, M.Sc., P.Geol.
Michael Dufresne, M.Sc., P.Geol.

January 22, 2016
Edmonton, AB

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1 Summary

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This report is focused on assessing the diamond potential within the North Saskatchewan Regional Planning (NSRP) area based on the mineral chemistry of kimberlite indicator minerals (KIMs). This assessment has identified:

- Three areas within the NSRP area have a moderate diamond potential:
  - West Edmonton
  - Ram River
  - St. Paul

These areas were selected based on the presence of moderate counts of KIMs with favourable mineral chemistry, the presence of diamond in surface samples and the location relative to known Alberta kimberlites.

2 Introduction to the Northern Alberta Kimberlite Province

Diamonds are largely mined from a special type of volcano called kimberlite. However, not all kimberlites contain diamonds. In Alberta, 51 kimberlites have been discovered in three separate areas: Buffalo Head Hills, Birch Mountains and Mountain Lake. The Buffalo Head Hills kimberlites have the highest diamond contents, with 28 of 41 kimberlites containing diamonds. Diamond grades of up to 55 carats per hundred tonnes have been reported. The discovery of diamond bearing kimberlites within the province has led to increased interest in diamond exploration across the province.

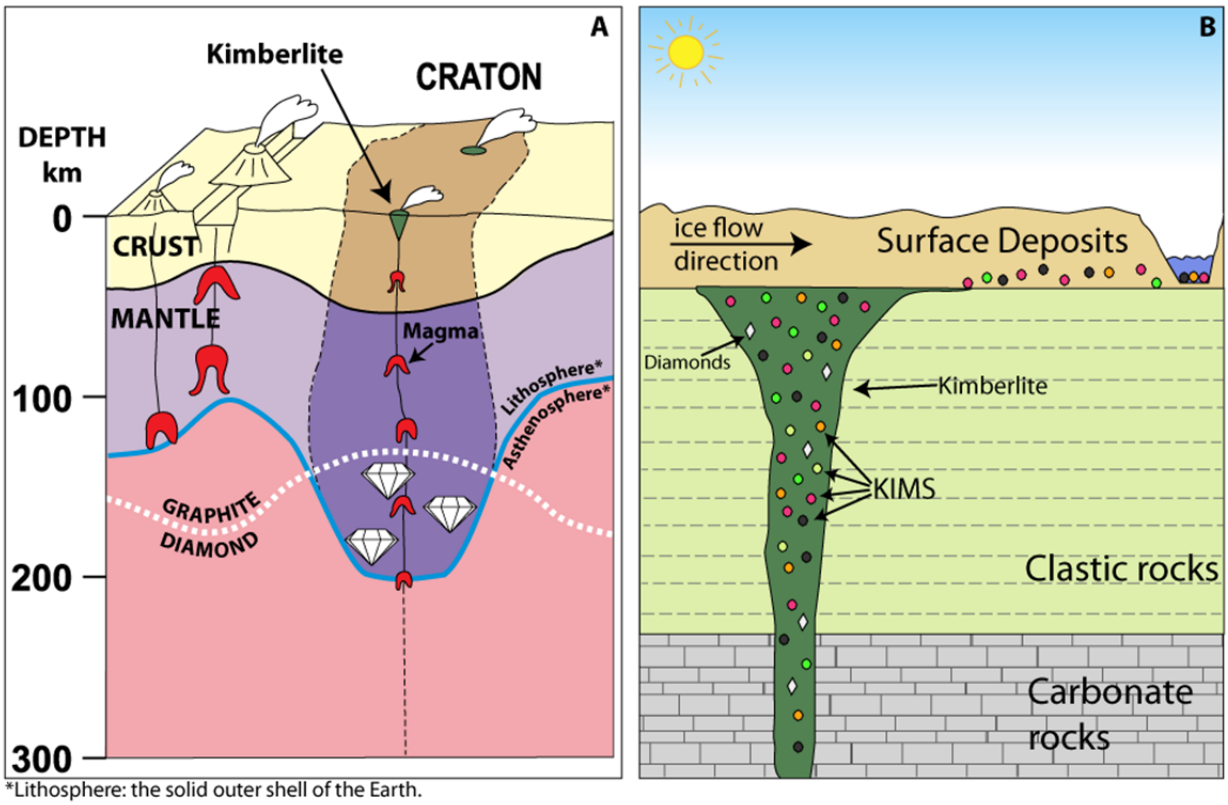
The first kimberlite in Alberta was discovered at Mountain Lake, near Grande Prairie, in 1989 by Monopros Limited, a subsidiary of De Beers. The Mountain Lake kimberlite has a low diamond content and the kimberlite is considered uneconomic. In the Birch Mountains area of northeastern Alberta, eight kimberlites have been discovered: seven by Kennecott Canada Exploration Inc., Montello Resources Ltd. and Redwood Resources Ltd. in 1998; and one by New Blue Ribbon Resources Ltd. in 2000. Low diamond contents have been reported from two of the Birch Mountains kimberlites. In the Buffalo Head Hills kimberlite field, 38 kimberlites were discovered between 1997 and 2003 by a joint venture led by Ashton Mining of Canada Inc. An additional three kimberlites were discovered in 2008 by Grizzly Discoveries Inc.

Diamonds are usually found in areas that are underlain by ancient rocks called cratons (Figure 1A). In northern Alberta the deep basement rocks consist of 1.8 – 2.4 billion year old cratonic rocks that have been shown to contain diamond. The basement rocks are covered by younger carbonate and sedimentary deposits which are in turn covered at the surface by glacial deposits (Figure 1B; Mossop and Shetsen, 1994; Carlson et al., 1999). The kimberlite carries the diamonds and mantle minerals from the deep, ancient mantle rocks through the overlying rocks

to the surface. Kimberlites are typically steep-sided, carrot shaped pipes (Figure 1B; Hawthorne, 1975; Carlson et al., 1999).

Geophysical surveys are used to provide additional information for exploration programs and have been very successful in defining kimberlite targets in Alberta. Geophysical surveys are not part of this compilation and assessment, but are mentioned where the information is relevant to the assessment of diamond potential.

Figure 1 A) Cross-section through the Earths' crust and upper mantle (modified after Stachel and Harris, 2008). B) Schematic cross-section of a typical kimberlite, showing glacial erosion and subsequent distribution of kimberlite indicator minerals.



*Lithosphere: the solid outer shell of the Earth.
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3 Background Information: Using Kimberlite Indicator Minerals

Diamond forms deep within the earth – in the mantle – at depths of greater than 150 kilometres where high temperature and pressure converts carbon into diamond (Figure 1A). The diamonds, form together with other mantle minerals that include pyrope garnet, eclogitic garnet, clinopyroxene, olivine, chromite and ilmenite. Mantle minerals always occur in higher quantities than diamond. These minerals have special chemical properties that are tell-tale signs they formed in the same environment as diamond.

For this reason, diamond explorers typically look for mantle minerals rather than diamond. These mantle minerals are often referred to as Kimberlite Indicator Minerals (or KIMs). As the kimberlite wears down due to erosion, KIMs are spread out and can be found in a variety of

settings such as river and stream sediments, and in sand and gravel that has been moved by glaciers (Figure 1B). Once the KIMs are collected by explorers, they are sorted visually into mineral groups. These minerals are then analyzed for their chemical properties. If the KIMs have a similar chemistry to the mantle, where diamonds form, then the explorer might be close to a diamond discovery.

3.1 Garnet as a KIM

Garnet can be divided into peridotitic garnet and eclogitic garnet, both of which are sources of diamond in the mantle. Based on their unique chemistry, individual garnet grains are classified into different groups (Grutter and Menzies, 2003; Grutter et al., 2004 and references therein).

- Peridotitic garnet, or pyrope garnet, are pink, purple, and red in colour. They are classified into Group 9 (G9), G9D, G10, G10D, G11 and G12 garnet.
- Eclogitic garnet are orange to red in colour. They are classified into Group 3 (G3), G3D, G4, G4D, G5 and G5D garnet.

The addition of the letter “D” to the end of the classification indicates that the garnet were formed in an environment suitable for diamond growth. A high number of garnet grains with the suffix “D” are of great interest to the diamond explorer because they could indicate an area of high potential for the presence of diamond-bearing kimberlite.

3.2 Clinopyroxene as a KIM

Clinopyroxene are also divided into peridotitic and eclogitic compositions (Ramsay and Tompkins, 1994; Nimis and Taylor, 2000).

- Peridotitic clinopyroxene, or chromian diopside, are bright emerald green. Their composition is used to determine the depth and temperature at which they formed. High numbers of chromian diopside with favourable compositions could indicate an area of high potential for diamond bearing kimberlite.
- Eclogitic clinopyroxene, or omphacitic pyroxene, are mossy green. Their composition can indicate if they formed in a diamond stable environment.

3.3 Olivine as a KIM

Olivine are a very common mineral in kimberlite and mantle peridotite rocks (Mitchell, 1989). Olivine are also found in other rock types but these are rare in northern Alberta. Olivine are not known to form in any sedimentary rock formation in Alberta, and are easily degraded in the sedimentary environment. Hence the presence of a large number of olivine grains in an area can be indicative of a nearby kimberlite.

3.4 Chromite as a KIM

Chromite can come from a variety of rocks. For diamond exploration three types of chromite are of interest (Creighton and Stachel, 2008 and references therein):

- Diamond inclusion chromite – have a composition similar to that measured for chromite removed from diamonds. A high number of diamond inclusion chromite can indicate the presence of diamond bearing rocks nearby.
- Kimberlitic chromite – have a composition that indicates they are formed in the kimberlite itself. A high number of kimberlitic chromite can indicate the presence of kimberlites nearby.
- Ultramafic chromite - have a composition that may indicate they are derived from peridotitic rocks. These can be used together with other minerals to assess the diamond potential of an area.

3.5 Ilmenite as a KIM

Ilmenite are formed in kimberlite and in other, unrelated, rock types. Two types of ilmenite are of high interest to diamond explorers: picroilmenite and Cr-rich picroilmenite. In exploration programs the composition of ilmenite is used in two ways. The composition of ilmenite can be used to determine if the ilmenite was formed in kimberlite (Mitchell, 1989). A high number of these compositions can indicate the presence of kimberlite nearby. The composition of ilmenite can also be used to provide information on how well diamonds in a kimberlite have been preserved (Haggerty, 1975; Gurney and Zweistra, 1995). Favourable ilmenite compositions could indicate that a kimberlite has a high diamond content.

4 North Saskatchewan Peace Regional Plan (NSPR) Area Assessment

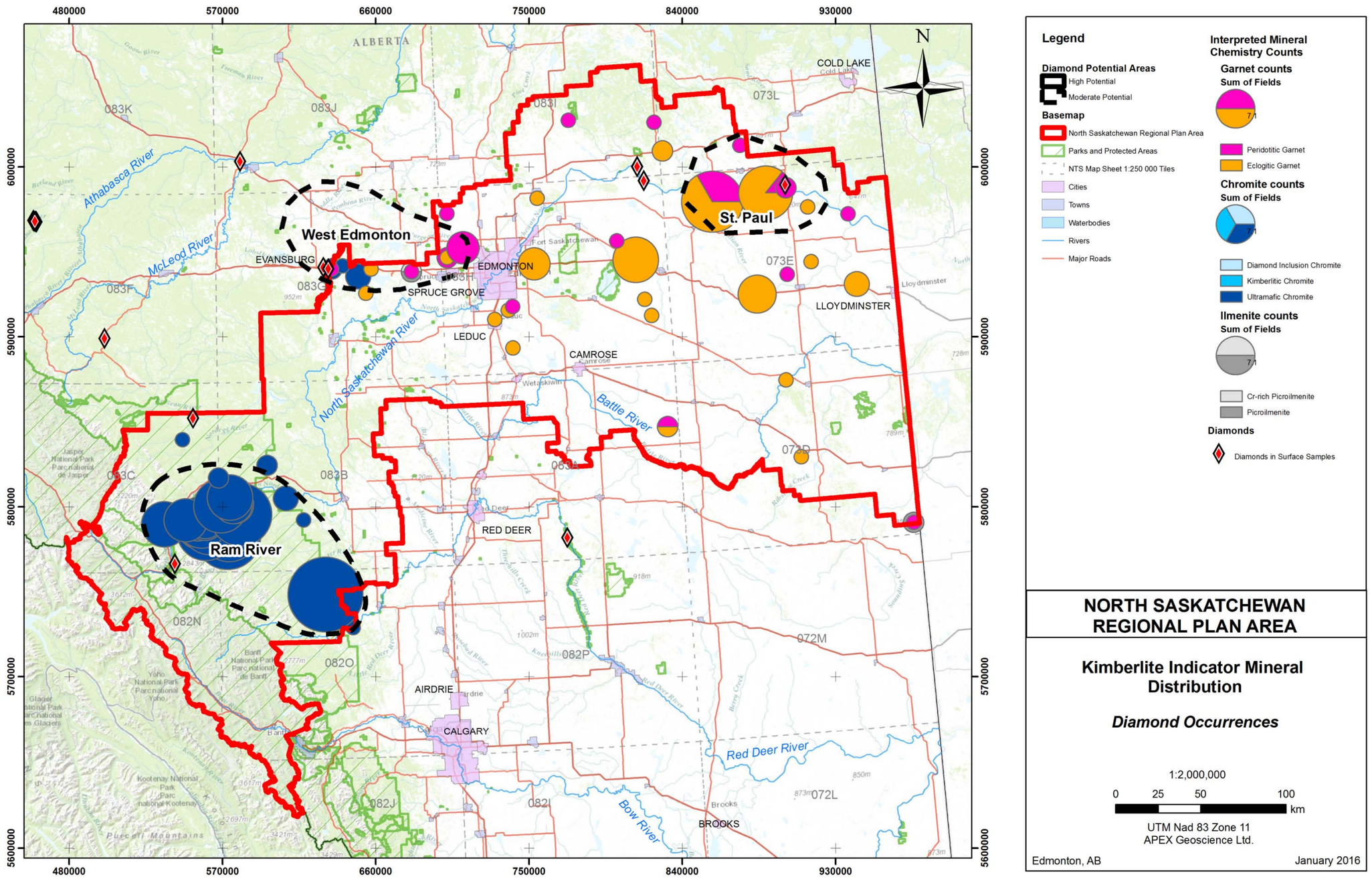
4.1 Data sources

For the NSRP area 283 samples have been compiled. From these samples 1,284 mineral chemistry analyses are available. For this assessment the AGS KIM Sample Microprobe database (KIM Sample Microprobed, 2015) was updated with data from eight government reports (Eccles, 2008; Paulen et al., 2005; Plouffe et al., 2006; Plouffe et al., 2007, Prior, 2007; Prior, 2010; Prior et al., 2005) and five industry-filed Mineral Assessment Reports (Dufresne, 2005; Dufresne, 2007; Dufresne and Banas, 2010; Hartley, 2006; Ward and Willis, 2004). The AGS KIM Sample Microprobe database is largely based on the compilations reported in Dufresne and Eccles (2005) and Eccles et al. (2002) and references therein. This evaluation includes an assessment of those KIMs with associated chemical data.

4.2 Diamond Potential Assessment

There are three areas of moderate diamond potential in the NSRP area. The diamond potential areas along with KIM distribution and diamond occurrences are presented in Figure 2. The area also includes several isolated diamond discoveries that have been found in surface deposits such as river and stream sediments, and/or in sand and gravel that has been moved by glaciers. Please refer to Figure 2 throughout this section.

Figure 2 Kimberlite Indicator Mineral (KIM) distribution and diamond occurrences in the North Saskatchewan Regional Plan area.



4.2.1 Moderate Diamond Potential

4.2.1.1 West Edmonton

The West Edmonton target area extends into the Upper Athabasca Regional Plan (UARP) area. The area is historically recognized for its diamond potential. In 1958 the Opdahl diamond was discovered in surficial soil from a farmer's field near Evansburg, west of Edmonton. It represents the first known diamond discovered in Alberta. Limited exploration was conducted in this area in the 1990's. From this exploration anomalous KIM counts were recovered from 11 samples. The KIMs in this area are comprised mainly of garnet, with three G3D and three G9D garnet recovered from six separate sample locations. Picroilmenite have also been recovered. Diamonds were additionally recovered at a second sample location in the area. The presence of high numbers KIMs, favourable KIM chemistry, and the presence of diamonds in surface material indicates that this area is of moderate potential for hosting diamond bearing kimberlite.

4.2.1.2 Ram River

Initial sampling in the Ram River area identified a concentration of samples with high KIM counts. The KIMs are almost exclusively of ultramafic chromite composition although several diamond inclusion and kimberlitic chromite have also been recovered. No other KIMs are reported from this area. Chromite on their own do not definitively indicate derivation from diamond bearing source rocks. However the presence of such anomalously high chromite KIM counts is an exceptional occurrence and it is important to point out that their source has not been found. Additional sampling is required to fully assess the potential of this area but the presence of diamond inclusion chromite and kimberlitic chromite allows for the possibility of kimberlite or kimberlite-like intrusions in this area.

4.2.1.3 St. Paul

Sampling of beach sands at several lakes in the St. Paul area has resulted in the recovery of numerous KIMs. The KIMs are dominated by garnet and consequently the beach sands are sporadically purple in colour. The majority of the garnet grains are derived from crustal rocks and are not related to diamond or kimberlite. However, anomalous counts of mantle derived garnet, including a single G9D garnet for which mineral chemistry is available, have been documented. Picroilmenite KIMs and a diamond were also recovered. Additional sampling by industry has been completed that indicates a higher presence of G9D and G10 garnets, chromian diopside, chromite and picroilmenite in the beach sands. Unfortunately, the mineral chemistry data is not available for these samples (Rich, 2003). The recovery of a diamond in surficial material, the abundant number of KIMs recovered and favourable composition of garnet may indicate the presence of a mantle derived intrusive such as kimberlite in the St. Paul area. This moderate potential area may extend east-northeast to the Cold Lake area where high counts of KIMs with favourable chemistry have also been recovered; however, the Cold Lake area was beyond the scope of the current NSRP assessment.

5 Conclusions

The North Saskatchewan Regional Plan area contains three spatially separate areas that have moderate potential to host diamond deposits. The discovery of the Buffalo Head Hills kimberlite field in Northern Alberta highlights the potential for the discovery of diamond-bearing deposits in Alberta. The Buffalo Head Hills represents the third largest field of diamond-bearing kimberlites in Canada with grades up to 55 carats per hundred tonnes. The North Saskatchewan Regional Plan area has been largely underexplored for diamonds although areas with diamond potential exist in the region. When market conditions improve the diamond exploration potential of this area will be of interest to exploration companies and to the Government of Alberta.

The assessment of the kimberlite indicator mineral data has resulted in the identification three areas with a moderate diamond potential in the North Saskatchewan Regional Plan area:

Moderate Diamond Potential areas:

- West Edmonton
- Ram River
- St. Paul

6 References

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999) The Buffalo Hills kimberlites: a newly-discovered diamondiferous kimberlite province in northcentral Alberta, Canada; *in* Proceedings of the Seventh International Kimberlite Conference, J.J. Gurney, J.L. Gurney, M.D. Pascoe, and S.H. Richardson (ed.), v. 1, p. 109–116.

Creighton, S., Stachel, T. (2008) An empirical chromite classification for positive identification of kimberlite in diamond exploration; 9th International Kimberlite Conference, Extended Abstracts, 9IKC-A-00402, 3 p.

Dufresne, M.B. (2005) Assessment report Swan Hills Property, North-Central Alberta Mineral Permits 9302040003 to 9302040023. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20040011, 224p.

Dufresne, M.B. (2007) Assessment report for Diamond and Gold Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070009, 158p.

Dufresne, M.B., Eccles, D.R. (2005) A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data. Alberta Energy and Utilities Board, EUB/AGS Special Report 20, 277p.

Dufresne, M.B., Banas, A. (2010) Assessment report for Diamond, Gold, Platinum, Bentonite and Lithium Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20100011, 409p.

Eccles, D.R. (2008) Geological Evaluation of Garnet-Rich Beaches in East-Central Alberta with Emphasis on Industrial Mineral and Diamondiferous Kimberlite Potential. Energy Resources and Conservation Board, ERCB/AGS Open File Report 2008-06, 57p.

Eccles, D.R., Dufresne, M., Copeland, D., Csanyi, W., Creighton, S. (2002) Alberta Kimberlite-Indicator Mineral Geochemical Compilation. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-20, 8p.

Grutter, H.S., Menzies, A. (2003) Mutually Consistent Classification Schemes for Mantle-Derived Garnet and Chromite, For Use By Diamond Explorers. 8th International Kimberlite Conference Extended Abstract, 5p.

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

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

Hartley, G.S. (2006) Technical Report on the Grimshaw Property. Assessment report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20060006, 76p.

Haggerty, S.E. (1975) The chemistry and genesis of opaque minerals in kimberlites. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.295–308.

Hawthorne, J.B. (1975) Model of a kimberlite pipe. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.1-16.

KIM Sample Microprobed (2015) https://services2.arcgis.com/jQV6VMr2Loovu7GU Alberta Energy Regulator / Alberta Geological Survey

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

Mossop, G., Shetsen, I. (compilers) (1994) Geological Atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and ARC, Calgary, AB. 510 pp.

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

Paulen, R.C., Waight, B. and Kjarsgaard, I.M. (2005) Kimberlite indicator mineral content and chemistry from till samples, southwest Buffalo Head Hills (NTS 84C/East); Alberta Energy and Utilities Board, 1p.

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Rich, A. (2003) Assessment Report on the St. Paul Permits. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20030008, 51p.

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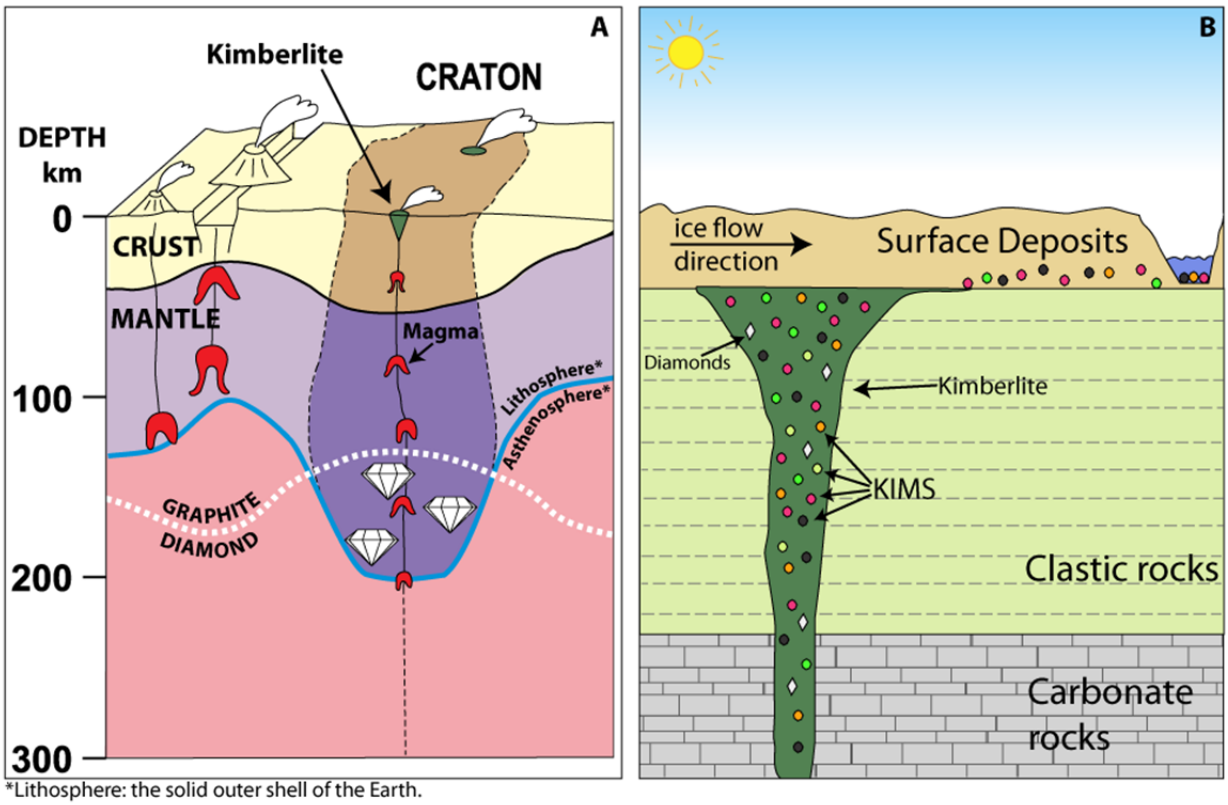

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Chromite can come from a variety of rocks. For diamond exploration three types of chromite are of interest (Creighton and Stachel, 2008 and references therein):

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- Kimberlitic chromite – have a composition that indicates they are formed in the kimberlite itself. A high number of kimberlitic chromite can indicate the presence of kimberlite nearby.
- Ultramafic chromite - have a composition that may indicate they are derived from peridotitic rocks. These can be used together with other minerals to assess the diamond potential of an area.

3.5 Ilmenite as a KIM

Ilmenite are formed in kimberlite and in other, unrelated, rock types. Two types of ilmenite are of high interest to diamond explorers: picroilmenite and Cr-rich picroilmenite. In exploration programs the composition of ilmenite is used in two ways. The composition of ilmenite can be used to determine if the ilmenite was formed from kimberlite (Mitchell, 1989). A high number of these compositions can indicate the presence of kimberlite nearby. The composition of ilmenite can also be used to provide information on how well diamonds in a kimberlite have been preserved (Haggerty, 1975; Gurney and Zweistra, 1995). Favourable ilmenite compositions could indicate that a kimberlite has a high diamond content.

4 Upper Athabasca Regional Plan (UAPR) Area Assessment

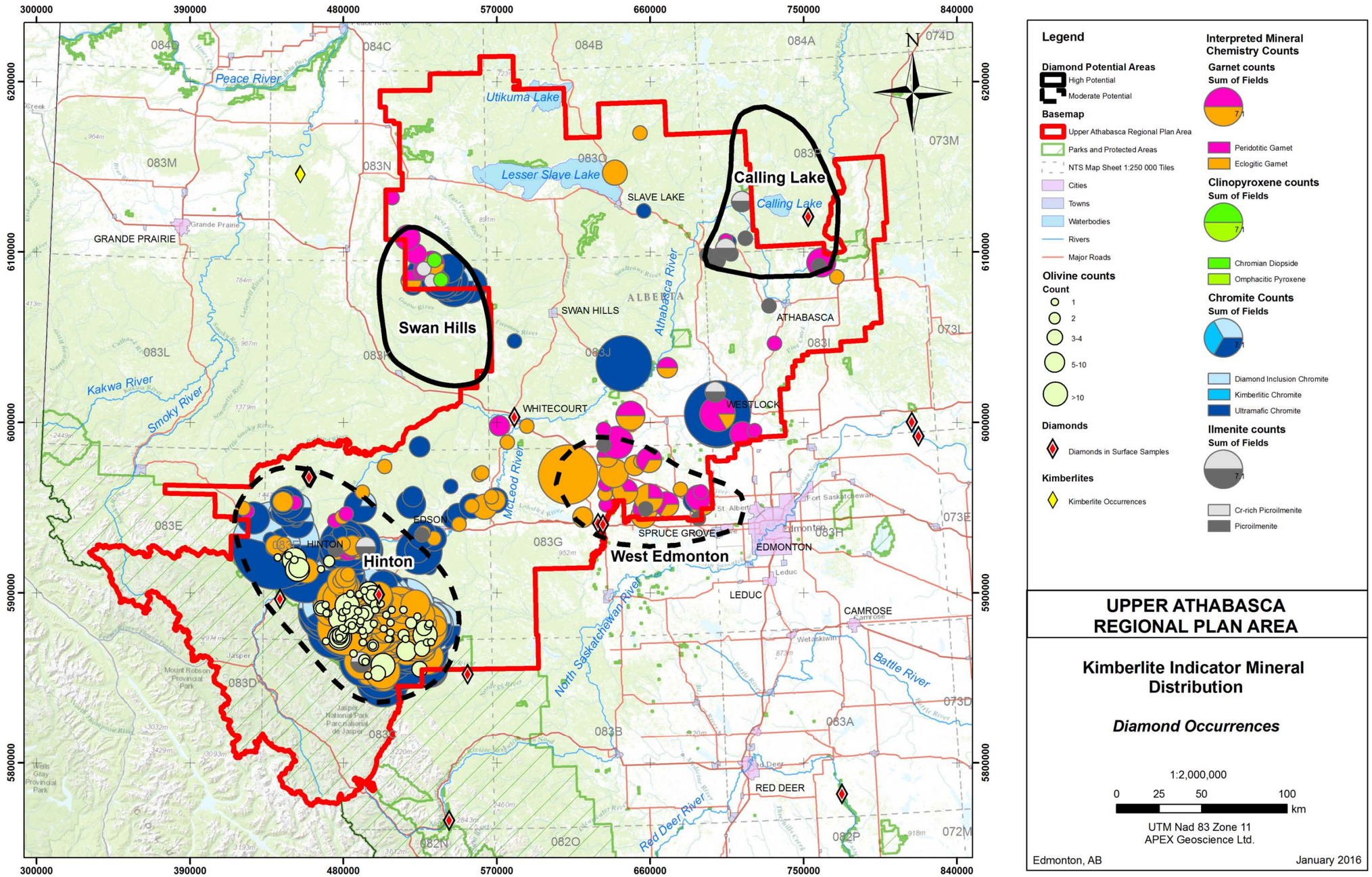
4.1 Data sources

For the UARP area 948 samples have been compiled. From these samples 4,071 mineral chemistry analyses are available. For this assessment the AGS KIM Sample Microprobe database (KIM Sample Microprobed, 2015) was updated with data from eight government reports (Eccles, 2008; Paulen et al., 2005; Plouffe et al., 2006; Plouffe et al., 2007, Prior, 2007; Prior, 2010; Prior et al., 2005) and five industry-filed Mineral Assessment Reports (Dufresne, 2005; Dufresne, 2007; Dufresne and Banas, 2010; Hartley, 2006; Ward and Willis, 2004). The AGS KIM Sample Microprobe database is largely based on the compilations reported in Dufresne and Eccles (2005) and Eccles et al. (2002) and references therein. This evaluation includes an assessment of those KIMs with associated chemical data.

4.2 Diamond Potential Assessment

There are two areas of high diamond potential and two areas of moderate diamond potential in the UARP area. The diamond potential areas along with KIM distribution are presented in Figure 2. The area also includes several isolated diamond discoveries that have been found in surface samples such as river and stream sediments, and/or in sand and gravel that has been moved by glaciers. Please refer to Figure 2 throughout this section.

Figure 2 Kimberlite Indicator Mineral (KIM) distribution and diamond occurrences in the Upper Athabasca Regional Plan area.



Legend

Diamond Potential Areas
- High Potential
- Moderate Potential

Basemap
- Upper Athabasca Regional Plan Area
- Parks and Protected Areas
- NTS Map Sheet 1:250 000 Tiles
- Cities
- Towns
- Waterbodies
- Rivers
- Major Roads

Olivine counts
Count
- 1
- 2
- 3-4
- 5-10
- >10

Diamonds
- Diamonds in Surface Samples

Kimberlites
- Kimberlite Occurrences

Interpreted Mineral Chemistry Counts

Garnet counts
Sum of Fields
- Peridotitic Garnet
- Eclogitic Garnet

Clinopyroxene counts
Sum of Fields
- Chromian Diopside
- Omphacitic Pyroxene

Chromite Counts
Sum of Fields
- Diamond Inclusion Chromite
- Kimberlitic Chromite
- Ultramafic Chromite

Ilmenite counts
Sum of Fields
- Cr-rich Picroilmenite
- Picroilmenite

UPPER ATHABASCA REGIONAL PLAN AREA

Kimberlite Indicator Mineral Distribution

Diamond Occurrences

1:2,000,000

0 25 50 100 km

UTM Nad 83 Zone 11
APEX Geoscience Ltd.

Edmonton, AB January 2016

4.2.1 High Diamond Potential

4.2.1.1 Calling Lake

The Calling Lake area received a significant amount of exploration attention during the 2000's. The area contains: a diamond that was recovered from a glacial till sample; two samples with the highest known KIM counts in the entire province; and exceptional mantle chemistry. The highest count sample contains 419 KIMs of which 410 are garnet. From the garnet KIMs, 58 are classified as G9D and 6 are classified as G10D. The second highest count sample contains 56 G9D and 8 G10D garnet grains. Eclogitic clinopyroxene with compositions similar those measured from diamond stable mantle are found in several samples. Diamond inclusion chromite, olivine, picroilmenite and Cr-rich picroilmenite compositions have also been identified. Limited drilling to date has not discovered any kimberlites. The Calling Lake KIM cluster is located over 150 km southwest of the Buffalo Head Hills kimberlite field and it is unlikely that the KIMs come from the known BHH kimberlites. The abundance of KIMs with favourable chemistry and the presence of a diamond in a glacial till sample indicate that the source for these KIMs is likely from a nearby kimberlite that has a high potential to be diamond-bearing.

4.2.1.2 Swan Hills

The Swan Hills area has an anomalous concentration of samples with high KIM counts. This high diamond potential area extends to the north-east into the Upper Athabasca Regional Plan area. The KIMs in this area are largely dominated by ultramafic chromite. However, diamond inclusion chromite have been recovered from 6 separate samples. High garnet counts have been recovered from numerous samples including highly favourable G9D and G10D compositions. Picroilmenite and Cr-rich picroilmenite are also present in several samples. The Swan Hills are geologically separated from the Buffalo Head Hills kimberlite field to the north and it is unlikely that the KIMs with favourable chemistry have travelled down ice from the known kimberlites. The presence of high KIM counts and favourable chemistry indicate that there is a high potential for the discovery of diamond bearing kimberlite in this region. Furthermore, high interest geophysical anomalies that may be indicative of kimberlite intrusions have been identified in this area (Dufresne, 2007). Collectively these anomalies require further investigation.

4.2.2 Moderate Diamond Potential

4.2.2.1 West Edmonton

The West Edmonton target area extends into the Upper Athabasca Regional Plan (UARP) area. The area is historically recognized for its diamond potential. In 1958 the Opdahl diamond was discovered in surficial soil from a farmer's field near Evansburg, west of Edmonton. It represents the first known diamond discovered in Alberta. Limited exploration was conducted in this area in the 1990's. From this exploration anomalous KIM counts were recovered from 11 samples. The KIMs in this area are comprised mainly of garnet, with three G3D and three G9D garnet recovered from six separate sample locations. Picroilmenite have also been recovered. Diamonds were additionally recovered at a second sample location in the area. The presence of high numbers KIMs, favourable KIM chemistry, and the presence of diamonds in surface

material indicates that this area is of moderate potential for hosting diamond bearing kimberlite.

4.2.2.2 Hinton

Around the Hinton area there is a high concentration of samples with above average to high KIMs counts. The KIMs are largely dominated by chromite with ultramafic compositions, however a significant proportion of the chromite have diamond inclusion compositions and a few have kimberlitic compositions. Numerous garnet have been recovered in the area, including many that have diamond associated compositions: 97 are classified as G3D garnet, 7 are G9D and 1 as a G10D. A large number of samples also contain olivine. The composition of the olivine indicates that they are from a cratonic source rock. Additionally, diamonds have been recovered at three separate locations in this area. The presence of the combination of diamond inclusion chromite, diamond related garnet, “cratonic” olivine and diamond indicates the material comes from a mantle source that is potentially diamond bearing. A complication that cannot be assessed at this time is whether the source of the anomalous KIMs is located nearby or if these minerals have been moved to this location by glaciers. Due to the extremely high number of KIMs recovered in this area, especially olivine, there is potential for a local diamond/kimberlite source.

5 Conclusions

The Upper Athabasca Regional Plan area has been underexplored for diamonds. Despite limited government and industry KIM sampling, the Upper Athabasca Regional Plan area contains four spatially separate areas that have the potential to host diamond deposits. The assessment of the kimberlite indicator mineral data has resulted in the identification two areas with a high diamond potential and two areas with a moderate diamond potential in the Upper Athabasca Regional Plan area:

High Diamond Potential areas:

- Swan Hills
- Calling Lake

Moderate Diamond Potential area:

- West Edmonton
- Hinton

In the Calling Lake area the discovery of a diamond in surficial material, and the number and favourable chemistry of the KIMs suggests that the area could have similar potential to, or better than, the Buffalo Head Hills kimberlite field. The area has received significant exploration attention but the source for the KIMs has not been found. The discovery of the Buffalo Head Hills kimberlite field in Northern Alberta highlights the potential for the discovery of diamond bearing deposits in Alberta. The Buffalo Head Hills represents the third largest field of diamond-bearing kimberlites in Canada with grades up to 55 carats per hundred tonnes.

In addition to positive KIM targets, numerous kimberlite-like targets have been identified by geophysical surveys in the UARP area. Collectively these targets require further exploration. When market conditions improve the diamond exploration potential of the UARP area will be of interest to exploration companies and to the Government of Alberta.

6 References

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999) The Buffalo Hills kimberlites: a newly-discovered diamondiferous kimberlite province in northcentral Alberta, Canada; *in* Proceedings of the Seventh International Kimberlite Conference, J.J. Gurney, J.L. Gurney, M.D. Pascoe, and S.H. Richardson (ed.), v. 1, p. 109–116.

Creighton, S., Stachel, T. (2008) An empirical chromite classification for positive identification of kimberlite in diamond exploration; 9th International Kimberlite Conference, Extended Abstracts, 9IKC-A-00402, 3 p.

Dufresne, M.B. (2005) Assessment report Swan Hills Property, North-Central Alberta Mineral Permits 9302040003 to 9302040023. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20040011, 224p.

Dufresne, M.B. (2007) Assessment report for Diamond and Gold Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070009, 158p.

Dufresne, M.B., Eccles, D.R. (2005) A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data. Alberta Energy and Utilities Board, EUB/AGS Special Report 20, 277p.

Dufresne, M.B., Banas, A. (2010) Assessment report for Diamond, Gold, Platinum, Bentonite and Lithium Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20100011, 409p.

Eccles, D.R. (2008) Geological Evaluation of Garnet-Rich Beaches in East-Central Alberta with Emphasis on Industrial Mineral and Diamondiferous Kimberlite Potential. Energy Resources and Conservation Board, ERCB/AGS Open File Report 2008-06, 57p.

Eccles, D.R., Dufresne, M., Copeland, D., Csanyi, W., Creighton, S. (2002) Alberta Kimberlite-Indicator Mineral Geochemical Compilation. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-20, 8p.

Grutter, H.S., Menzies, A. (2003) Mutually Consistent Classification Schemes for Mantle-Derived Garnet and Chromite, For Use By Diamond Explorers. 8th International Kimberlite Conference Extended Abstract, 5p.

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

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

Hartley, G.S. (2006) Technical Report on the Grimshaw Property. Assessment report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20060006, 76p.

Haggerty, S.E. (1975) The chemistry and genesis of opaque minerals in kimberlites. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.295–308

Hawthorne, J.B. (1975) Model of a kimberlite pipe. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.1-16

KIM Sample Microprobed (2015) https://services2.arcgis.com/jQV6VMr2Loovu7GU Alberta Energy Regulator / Alberta Geological Survey

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

Mossop, G., Shetsen, I. (compilers) (1994) Geological Atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and ARC, Calgary, AB. 510 pp.

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

Paulen, R.C., Waight, B. and Kjarsgaard, I.M. (2005) Kimberlite indicator mineral content and chemistry from till samples, southwest Buffalo Head Hills (NTS 84C/East); Alberta Energy and Utilities Board, 1p.

Plouffe, A., Paulen, R.C., Smith, I.R. (2006) Indicator mineral content and geochemistry of glacial sediments from northwest Alberta (NTS 84L, M): new opportunities for mineral exploration. Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 77, Geological Survey of Canada, Open File 5121, 1 CD-ROM.

Plouffe, A., Paulen, R.C., Smith, I.R., Kjarsgaard, I.M. (2007) Chemistry of kimberlite indicator minerals and sphalerite derived from glacial sediments of northwest Alberta, Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 87, Geological Survey of Canada, Open File 5545, 1 CD-ROM.

Prior, G.J. (2007) Chemistry and mineralogy of kimberlite-indicator mineral grains from a till survey of the Sawn Lake area (NTS 84B/13), southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2007-01, 51p.

Prior, G.J. (2010) Till Geochemistry in the Sawn Lake Area, Southern Buffalo Head Hills, Alberta (NTS 84B/13). Energy Resources and Conservation Board, ERCB/AGS Open File Report 2010-14, 45p.

Prior, G.J. Paulen, R.C. Pawlowicz, J.G. Fenton, M.M. (2005) Kimberlite-Indicator Mineral Till Survey of the Sawn Lake Area (NTS 84B/13), Southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2005-02, 103p.

Ramsay, R.R., Tompkins, L.A. (1994) The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of the Boa Esperanca and Cana Verde pipes, Corrego D'Anta, Minas Gerais, Brazil. In: H.O.A. Meyer and O.H. Leonardos (editors) Diamonds; characterization, genesis and exploration. Proceedings of the International Kimberlite Conference, 1991, Vol. 5, Vol. 2, pp. 329-345.

Stachel, T., Harris, J.W. (2008) The origin of cratonic diamonds—constraints from mineral inclusions. Ore Geology Reviews 34, 5-32

Ward, J., Willis, D. (2004) Assessment Report for the: Buffalo Hills Property 2004. Assessment Report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20040018, 85p.

Distribution of Kimberlite and Kimberlite Indicator Mineral Clusters in the Upper Peace Regional Plan Area

Prepared For:
Alberta Geological Survey
4th Floor, Twin Atria Building
4999-98 Ave
Edmonton, AB
T6B 2X3

Prepared by:
APEX Geoscience Ltd.
#100, 9797-45 Ave
Edmonton, AB
T6E 5V8

Anetta Banas, M.Sc., P.Geol.
Roy Eccles, M.Sc., P.Geol.
Michael Dufresne, M.Sc., P.Geol.

January 22, 2016
Edmonton, AB

Contents

Figures

1 Summary

APEX Geoscience Ltd. (APEX) was contracted by the Alberta Geological Survey (AGS) to provide an assessment of the distribution of kimberlites and kimberlite indicator mineral clusters in the Upper Peace Regional Plan area.

This report is focused on assessing the diamond potential within the Upper Peace Regional Plan (UPRP) area based on the mineral chemistry of kimberlite indicator minerals (KIMs). One kimberlite, Mountain Lake, has been discovered within the UPRP area. This assessment has identified:

- One area within the UPRP area that has a high diamond potential:
  - Swan Hills

- Four areas within the UPRP area that have a moderate diamond potential:
  - Mountain Lake
  - Chinchaga
  - Clear Hills
  - Kakwa River

These areas were selected based on the presence of moderate to high counts of KIMs with favourable mineral chemistry, the presence of kimberlites and the location relative to known kimberlites.

2 Introduction to the Northern Alberta Kimberlite Province

Diamonds are largely mined from a special type of volcano called kimberlite. However, not all kimberlites contain diamonds. In Alberta, 51 kimberlites have been discovered in three separate areas: Buffalo Head Hills, Birch Mountains and Mountain Lake. The Buffalo Head Hills kimberlites have the highest diamond contents, with 28 of 41 kimberlites containing diamonds. Diamond grades of up to 55 carats per hundred tonnes have been reported. The discovery of diamond bearing kimberlites within the province has led to increased interest in diamond exploration across the province.

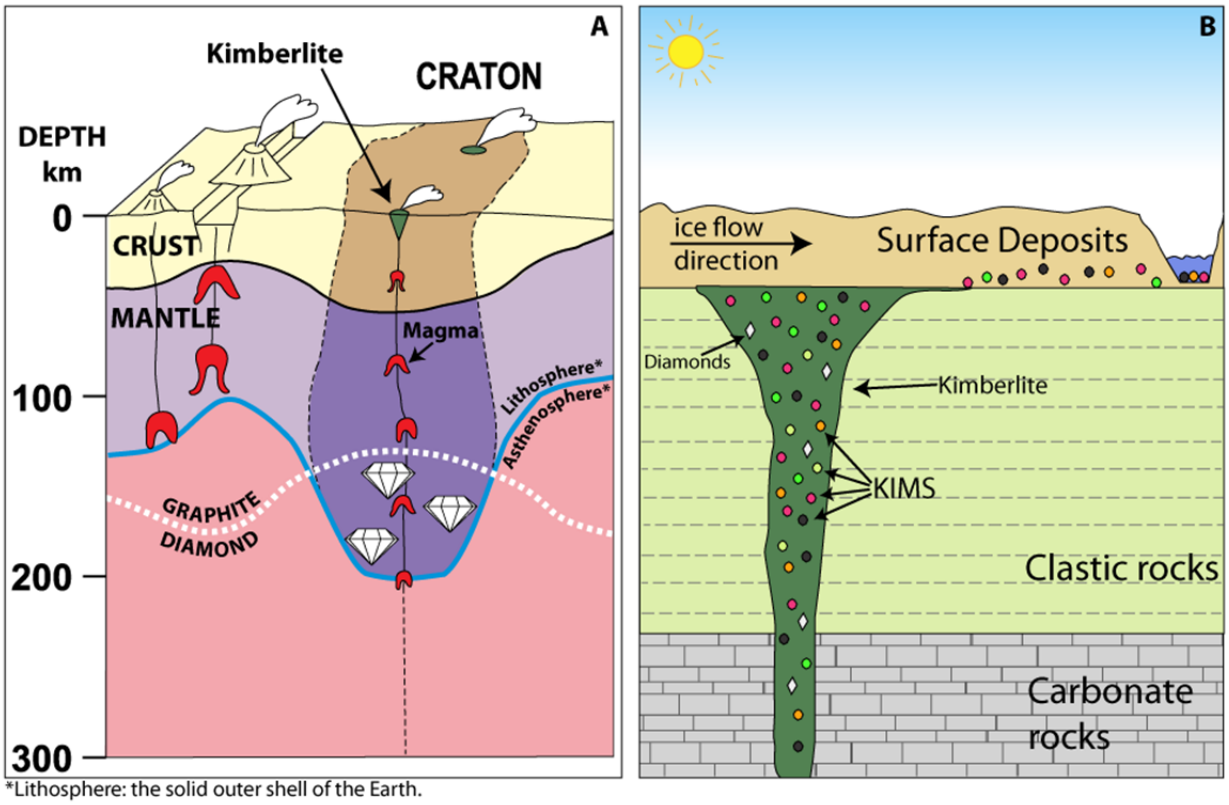
The first kimberlite in Alberta was discovered at Mountain Lake, near Grande Prairie, in 1989 by Monopros Limited, a subsidiary of De Beers. The Mountain Lake kimberlite has a low diamond content and the kimberlite is considered uneconomic. In the Birch Mountains area of northeastern Alberta, eight kimberlites have been discovered: seven by Kennecott Canada Exploration Inc., Montello Resources Ltd. and Redwood Resources Ltd. in 1998; and one by New Blue Ribbon Resources Ltd. in 2000. Low diamond contents have been reported from two of the Birch Mountains kimberlites. In the Buffalo Head Hills kimberlite field, 38 kimberlites were discovered between 1997 and 2003 by a joint venture led by Ashton Mining of Canada Inc. An additional three kimberlites were discovered in 2008 by Grizzly Discoveries Inc.

Diamonds are usually found in areas that are underlain by ancient rocks called cratons (Figure 1A). In northern Alberta the deep basement rocks consist of 1.8 – 2.4 billion year old cratonic

rocks that have been shown to contain diamond. The basement rocks are covered by younger carbonate and sedimentary deposits which are in turn covered at the surface by glacial deposits (Figure 1B; Mossop and Shetsen, 1994; Carlson et al., 1999). The kimberlite carries the diamonds and mantle minerals from the deep, ancient mantle rocks through the overlying rocks to the surface. Kimberlites are typically steep-sided, carrot shaped pipes (Figure 1B; Hawthorne, 1975; Carlson et al., 1999).

Geophysical surveys are used to provide additional information for exploration programs and have been very successful in defining kimberlite targets in Alberta. Geophysical surveys are not part of this compilation and assessment, but are mentioned where the information is relevant to the assessment of diamond potential.

Figure 1 A) Cross-section through the Earths' crust and upper mantle (modified after Stachel and Harris, 2008). B) Schematic cross-section of a typical kimberlite, showing glacial erosion and subsequent distribution of kimberlite indicator minerals.



*Lithosphere: the solid outer shell of the Earth.
Asthenosphere: the ductile part of the Earth below the lithosphere.

3 Background Information: Using Kimberlite Indicator Minerals

Diamond forms deep within the earth – in the mantle – at depths of greater than 150 kilometres where high temperature and pressure converts carbon into diamond (Figure 1A). The diamonds, form together with other mantle minerals that include pyrope garnet, eclogitic garnet, clinopyroxene, olivine, chromite and ilmenite. Mantle minerals always occur in higher quantities than diamond. These minerals have special chemical properties that are tell-tale signs they formed in the same environment as diamond.

For this reason, diamond explorers typically look for mantle minerals rather than diamond. These mantle minerals are often referred to as Kimberlite Indicator Minerals (or KIMs). As the kimberlite wears down due to erosion, KIMs are spread out and can be found in a variety of settings such as river and stream sediments, and in sand and gravel that has been moved by glaciers (Figure 1B). Once the KIMs are collected by explorers, they are sorted visually into mineral groups. These minerals are then analyzed for their chemical properties. If the KIMs have a similar chemistry to the mantle, where diamonds form, then the explorer might be close to a diamond discovery.

3.1 Garnet as a KIM

Garnet can be divided into peridotitic garnet and eclogitic garnet, both of which are sources of diamond in the mantle. Based on their unique chemistry, individual garnet grains are classified into different groups (Grutter and Menzies, 2003; Grutter et al., 2004 and references therein).

- Peridotitic garnet, or pyrope garnet, are pink, purple, and red in colour. They are classified into Group 9 (G9), G9D, G10, G10D, G11 and G12 garnet.
- Eclogitic garnet are orange to red in colour. They are classified into Group 3 (G3), G3D, G4, G4D, G5 and G5D garnet.

The addition of the letter “D” to the end of the classification indicates that the garnet were formed in an environment suitable for diamond growth. A high number of garnet grains with the suffix “D” are of great interest to the diamond explorer because they could indicate an area of high potential for the presence of diamond-bearing kimberlite.

3.2 Clinopyroxene as a KIM

Clinopyroxene are also divided into peridotitic and eclogitic compositions (Ramsay and Tompkins, 1994; Nimis and Taylor, 2000).

- Peridotitic clinopyroxene, or chromian diopside, are bright emerald green. Their composition is used to determine the depth and temperature at which they formed. High numbers of chromian diopside with favourable compositions could indicate an area of high potential for diamond bearing kimberlite.
- Eclogitic clinopyroxene, or omphacitic pyroxene, are mossy green. Their composition can indicate if they formed in a diamond stable environment.

3.3 Olivine as a KIM

Olivine are a very common mineral in kimberlite and mantle peridotite rocks (Mitchell, 1989). Olivine are also found in other rock types but these are rare in northern Alberta. Olivine are not known to form in any sedimentary rock formation in Alberta, and are easily degraded in the sedimentary environment. Hence the presence of a large number of olivine grains in an area can be indicative of a nearby kimberlite.

3.4 Chromite as a KIM

Chromite can come from a variety of rocks. For diamond exploration three types of chromite are of interest (Creighton and Stachel, 2008 and references therein):

- Diamond inclusion chromite – have a composition similar to that measured for chromite removed from diamonds. A high number of diamond inclusion chromite can indicate the presence of diamond bearing rocks nearby.
- Kimberlitic chromite – have a composition that indicates they are formed in the kimberlite itself. A high number of kimberlitic chromite can indicate the presence of kimberlites nearby.
- Ultramafic chromite - have a composition that may indicate they are derived from peridotitic rocks. These can be used together with other minerals to assess the diamond potential of an area.

3.5 Ilmenite as a KIM

Ilmenite are formed in kimberlite and in other, unrelated, rock types. Two types of ilmenite are of high interest to diamond explorers: picroilmenite and Cr-rich picroilmenite. In exploration programs the composition of ilmenite is used in two ways. The composition of ilmenite can be used to determine if the ilmenite was formed in kimberlite (Mitchell, 1989). A high number of these compositions can indicate the presence of kimberlite nearby. The composition of ilmenite can also be used to provide information on how well diamonds in a kimberlite have been preserved (Haggerty, 1975; Gurney and Zweistra, 1995). Favourable ilmenite compositions could indicate that a kimberlite has a high diamond content.

4 Upper Peace Regional Plan (UPRP) Area Assessment

4.1 Data sources

For the UPRP area 250 samples have been compiled. From these samples 1,126 mineral chemistry analyses are available. For this assessment the AGS KIM Sample Microprobe database (KIM Sample Microprobed, 2015) was updated with data from eight government reports (Eccles, 2008; Paulen et al., 2005; Plouffe et al., 2006; Plouffe et al., 2007, Prior, 2007; Prior, 2010; Prior et al., 2005) and five industry-filed Mineral Assessment Reports (Dufresne, 2005; Dufresne, 2007; Dufresne and Banas, 2010; Hartley, 2006; Ward and Willis, 2004). The AGS KIM Sample Microprobe database is largely based on the compilations reported in Dufresne and Eccles (2005) and Eccles et al. (2002) and references therein. This evaluation includes an assessment of those KIMs with associated chemical data. Numerous industry reports include visually identified KIM pick counts with no associated mineral chemistry. These reports have not been systematically compiled. Known occurrences of high KIM pick counts are mentioned where the information is relevant to the assessment of diamond potential.

4.2 Kimberlite Field

4.2.1 Mountain Lake

The Mountain Lake kimberlite is located within the UPRP about 75 km northeast of Grande Prairie. It is the only kimberlite in Alberta that has been found based on anomalous results from KIM sampling. The mantle garnet recovered from the Mountain Lake kimberlite are mainly classified as G9, some G11 and G12 garnet are also present. The composition of the garnet indicate that they formed outside of the diamond stable part of the mantle. The chromian diopside compositions indicate formation at depths too shallow to allow for diamond formation. The chromite are largely ultramafic with no diamond inclusion chromite or kimberlitic chromite recovered. The lack of minerals with diamond associated compositions correlates with the low diamond content reported for this kimberlite.

4.3 Diamond Potential Assessment

The diamond potential areas along with KIM distribution and Mountain Lake kimberlite occurrence are presented in Figure 2. Please refer to this figure throughout this section.

4.3.1 High Diamond Potential

4.3.1.1 Swan Hills

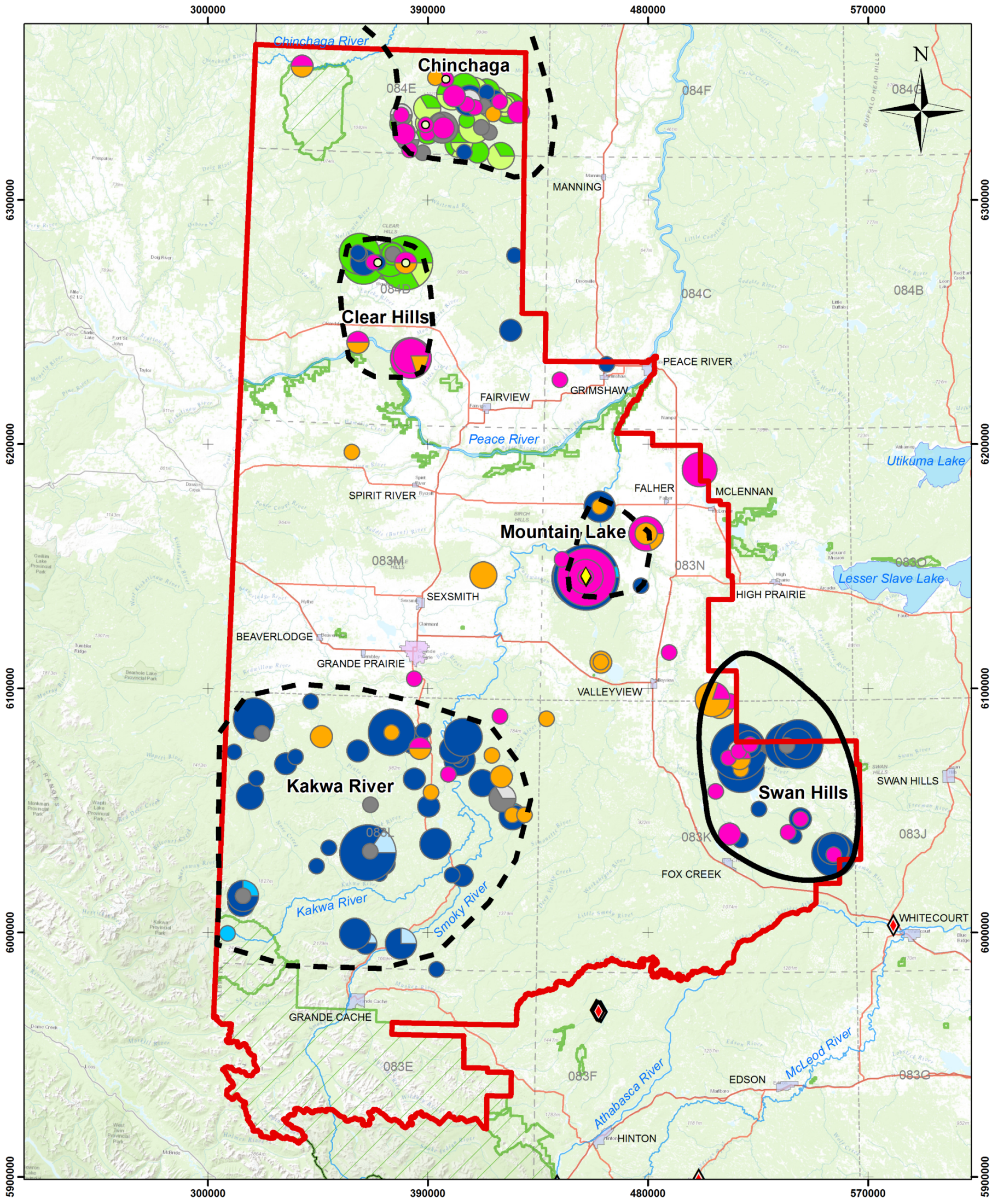
The Swan Hills area has an anomalous concentration of samples with high KIM counts. This high diamond potential area extends to the north-east into the Upper Athabasca Regional Plan area. The KIMs in this area are largely dominated by ultramafic chromite. However, diamond inclusion chromite have been recovered from 6 separate samples. High garnet counts have been recovered from numerous samples including highly favourable G9D and G10D compositions. Picroilmenite and Cr-rich picroilmenite are also present in several samples. The Swan Hills are geologically separated from the Buffalo Head Hills kimberlite field to the north and it is unlikely that the KIMs with favourable chemistry have travelled down ice from the known kimberlites. The presence of high KIM counts and favourable chemistry indicate that there is a high potential for the discovery of diamond bearing kimberlite in this region. Furthermore, high interest geophysical anomalies that may be indicative of kimberlite intrusions have been identified in this area (Dufresne, 2007). Collectively these anomalies require further investigation.

4.3.2 Moderate Diamond Potential

4.3.2.1 Mountain Lake

Limited sampling has been completed around the Mountain Lake kimberlite, therefore little is known about the overall diamond potential of this area. The presence of mantle derived minerals in this area indicates the possibility of an additional kimberlite source nearby. Geophysical surveys have defined several potential kimberlite targets that have yet to be explored (Faragher and Ryziuk, 1999).

Figure 2 Kimberlite Indicator Mineral (KIM) distribution and kimberlite occurrences in the Upper Peace Regional Plan area.



4.3.2.2 Chinchaga

The Chinchaga area is spatially separate from the known kimberlite fields in Northern Alberta. This moderate potential area extends to the northwest into the Lower Peace Regional Plan area. This area is characterized the presence of a high number of samples that contain anomalous counts of KIMs. The samples contain numerous grains of garnet, including garnet of favourable G3D, G9D and G10D chemistry. Additionally the samples contain chromian diopside, omphacitic pyroxene and picroilmenite. The high KIM counts, large number of samples with high KIM counts and favourable KIM chemistry in this area may be an indication of a nearby kimberlite source. Sampling in this area is limited so a detailed assessment of the area cannot be made at this time.

4.3.2.3 Clear Hills - Peace River

Anomalous concentrations of KIMs have been reported from numerous samples in the Clear Hills - Peace River area. The KIMs are largely dominated by high counts of chromian diopside. Ultramafic chromite, peridotitic garnet, eclogitic garnet, ilmenite and olivine have also been recovered. The chemistry of the recovered KIMs indicates the presence of mantle derived material in the area. Diamond stable garnet compositions including G3D, G9D and G10D, have been recovered from four samples. Additionally, several samples in the area have high counts of visually identified KIMs including eclogitic garnet, olivine, chromian diopside and chromite (Noyes and Dufresne, 2001). Unfortunately, mineral chemistry analyses were not completed for these samples. The presence of favourable mineral chemistry and elevated counts of visually identified KIMs in this area indicates the possibility of a nearby kimberlite source. Geophysical surveys have identified several kimberlite-like targets that have yet to be drill tested (Stapleton, 1999; Noyes and Dufresne, 2001).

4.3.2.4 Kakwa River

Initial government sampling in the Kakwa River area identified high numbers of KIMs in numerous samples. The KIMs are dominated by ultramafic chromite. Diamond inclusion chromite and kimberlitic chromite have been recovered in 13 samples, with picroilmenite and Cr-rich picroilmenite recovered from 21 samples. Numerous samples contain garnet, however only one garnet of a diamond related composition, a G3D garnet, has been identified. The presence of high counts of indicators in this area may indicate the presence of an unknown kimberlite nearby. The low density of samples in this area does not allow a detailed assessment of the area at this time.

5 Conclusions

The Upper Peace Regional Plan area has been underexplored for diamonds. Despite a limited amount of government and industry exploration sampling, the Upper Peace Regional Plan area contains five spatially separate areas that have the potential to host diamond deposits. Alberta's first kimberlite discovery, the Mountain Lake kimberlite, is located in this region. Subsequent kimberlite discoveries in the Buffalo Head Hills in nearby north-central Alberta highlight the potential for future discoveries of diamond bearing deposits in Alberta. To complement the sparse KIM data, numerous kimberlite-like targets have been identified by

geophysical surveys that require further exploration. When market conditions improve the diamond exploration potential of this area will be of interest to exploration companies and to the Government of Alberta.

The assessment of the kimberlite indicator mineral data has resulted in the identification one area with a high diamond potential and four areas with a moderate diamond potential in the Upper Peace Regional Plan Area:

High Diamond Potential area:

- Swan Hills

Moderate Diamond Potential areas:

- Mountain Lake
- Chinchaga
- Clear Hills
- Kakwa River

6 References

Carlson, S.M., Hillier, W.D., Hood, C.T., Pryde, R.P. and Skelton, D.N. (1999) The Buffalo Hills kimberlites: a newly-discovered diamondiferous kimberlite province in northcentral Alberta, Canada; *in* Proceedings of the Seventh International Kimberlite Conference, J.J. Gurney, J.L. Gurney, M.D. Pascoe, and S.H. Richardson (ed.), v. 1, p. 109–116.

Creighton, S., Stachel, T. (2008) An empirical chromite classification for positive identification of kimberlite in diamond exploration; 9th International Kimberlite Conference, Extended Abstracts, 9IKC-A-00402, 3 p.

Dufresne, M.B. (2005) Assessment report Swan Hills Property, North-Central Alberta Mineral Permits 9302040003 to 9302040023. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20040011, 224p.

Dufresne, M.B. (2007) Assessment report for Diamond and Gold Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20070009, 158p.

Dufresne, M.B., Eccles, D.R. (2005) A Guide to Kimberlite-Indicator Mineral Trends in Alberta Including Observations from Recently Compiled Indicator Mineral Data. Alberta Energy and Utilities Board, EUB/AGS Special Report 20, 277p.

Dufresne, M.B., Banas, A. (2010) Assessment report for Diamond, Gold, Platinum, Bentonite and Lithium Exploration on the Swan Hills Property, North-Central Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20100011, 409p.

Eccles, D.R. (2008) Geological Evaluation of Garnet-Rich Beaches in East-Central Alberta with Emphasis on Industrial Mineral and Diamondiferous Kimberlite Potential. Energy Resources and Conservation Board, ERCB/AGS Open File Report 2008-06, 57p.

Eccles, D.R., Dufresne, M., Copeland, D., Csanyi, W., Creighton, S. (2002) Alberta Kimberlite-Indicator Mineral Geochemical Compilation. Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-20, 8p.

Faragher, T., Ryziuk, B. (1999) Assessment Report Falher Project. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR19990023, 136p.

Grutter, H.S., Menzies, A. (2003) Mutually Consistent Classification Schemes for Mantle-Derived Garnet and Chromite, For Use By Diamond Explorers. 8th International Kimberlite Conference Extended Abstract, 5p.

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

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

Hartley, G.S. (2006) Technical Report on the Grimshaw Property. Assessment report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20060006, 76p.

Haggerty, S.E. (1975) The chemistry and genesis of opaque minerals in kimberlites. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.295–308

Hawthorne, J.B. (1975) Model of a kimberlite pipe. *In:* First International Kimberlite Conference, Physics and Chemistry of the Earth, v. 9, p.1-16

KIM Sample Microprobed (2015) https://services2.arcgis.com/jQV6VMr2Loovu7GU Alberta Energy Regulator / Alberta Geological Survey

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

Mossop, G., Shetsen, I. (compilers) (1994) Geological Atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists and ARC, Calgary, AB. 510 pp.

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

Noyes, A.K., Dufresne, M.B. (2001) Interim Assessment Report for the Spirit River Properties, Peace River, Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR20010002, 68p.

Paulen, R.C., Waight, B. and Kjarsgaard, I.M. (2005) Kimberlite indicator mineral content and chemistry from till samples, southwest Buffalo Head Hills (NTS 84C/East); Alberta Energy and Utilities Board, 1p.

Plouffe, A., Paulen, R.C., Smith, I.R. (2006) Indicator mineral content and geochemistry of glacial sediments from northwest Alberta (NTS 84L, M): new opportunities for mineral

exploration. Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 77, Geological Survey of Canada, Open File 5121, 1 CD-ROM.

Plouffe, A., Paulen, R.C., Smith, I.R., Kjarsgaard, I.M. (2007) Chemistry of kimberlite indicator minerals and sphalerite derived from glacial sediments of northwest Alberta, Alberta Energy and Utilities Board, Alberta Geological Survey, Special Report 87, Geological Survey of Canada, Open File 5545, 1 CD-ROM.

Prior, G.J. (2007) Chemistry and mineralogy of kimberlite-indicator mineral grains from a till survey of the Sawn Lake area (NTS 84B/13), southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2007-01, 51p.

Prior, G.J. (2010) Till Geochemistry in the Sawn Lake Area, Southern Buffalo Head Hills, Alberta (NTS 84B/13). Energy Resources and Conservation Board, ERCB/AGS Open File Report 2010-14, 45p.

Prior, G.J. Paulen, R.C. Pawlowicz, J.G. Fenton, M.M. (2005) Kimberlite-Indicator Mineral Till Survey of the Sawn Lake Area (NTS 84B/13), Southern Buffalo Head Hills, Alberta. Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2005-02, 103p.

Ramsay, R.R., Tompkins, L.A. (1994) The geology, heavy mineral concentrate mineralogy, and diamond prospectivity of the Boa Esperanca and Cana Verde pipes, Corrego D'Anta, Minas Gerais, Brazil. In: H.O.A. Meyer and O.H. Leonardos (editors) Diamonds; characterization, genesis and exploration. Proceedings of the International Kimberlite Conference, 1991, Vol. 5, Vol. 2, pp. 329-345.

Stachel, T., Harris, J.W. (2008) The origin of cratonic diamonds—constraints from mineral inclusions. Ore Geology Reviews 34, 5-32

Stapleton, M.J. (1999) Exploration of: West Peace River Diamond Indicator Mineral Trend, Diamond Indicator Geochemistry Anomalies – Montagneuse and Many Islands, and an Analysis of Bend in the Peace Geophysics, west of Hines Creek, Peace River District, Alberta. Assessment report submitted to the Coal and Mineral Development Branch, Government of Alberta, MAR19990025, 347p.

Ward, J., Willis, D. (2004) Assessment Report for the: Buffalo Hills Property 2004. Assessment Report submitted to Coal and Mineral Development Branch, Government of Alberta, MAR20040018, 85p.