Kimberlite Indicator Mineral Anomalies in a Regional, Local, and Bedrock context: Examples from Canada

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Introduction

- In support of diamond exploration over the last 20 years diamond surficial sediment sampling campaigns have been conducted by industry and government agencies over broad regions within Canada.

- Diamond exploration sampling campaigns change in scope and style based upon raw kimberlite indicator mineral grain counts and subsequent mineral chemistry.

- Government sponsored studies complement industry derived datasets and in certain areas provide a regional context in the absence of industry derived data.

- Internal industry generated datasets may be used for comparative purposes against data generated by government, competitors and new discoveries.
Maximizing Information from Till samples

- Sample collection costs vary greatly depending on property location.
- Strong desire to maximize information gained from each sample locality and any indicator grains that may be recovered.
- Starting with dependable and accurate metadata – ie. Location, datum, topography, media, colour, weight, weather etc…
Maximizing Information from Till samples

- Is there kimberlite in the sample?
- Routine ICP-MS on fine fraction – not a universal technique employed by companies
- Retention and examination of coarser fractions
Maximizing Information from Indicators

- Size, shape, morphology, colour, mineral ID, surface features etc..
- Sample collection, processing, observation, picking can cost >$1200/sample
- Probe analyses costs are in the range of $6 to $13/analysis
- Much critical information may be gleaned from the mineral chemistry of the full indicator suite
Recent advances regarding the origin of the indicator mineral suite based upon single grain major oxide mineral chemistry and crystal structure allows for relatively inexpensive, timely and informed decisions regarding the nature and diamond potential of the subcontinental lithospheric mantle underlying regional exploration targets.
Maximizing Information from Indicators

- Routine garnet analyses may be filtered with standardized classification schemes (i.e., Grütter et al., 2004), or utilized for preliminary estimations of **Pressure** (Grütter et al., 2006) or **Temperature** (Creighton, 2008).

An Example of a Standardized Classification scheme
Maximizing Information from Indicators

- New major oxide filters to determine paragenesis of spinels (Creighton and Stachel, 2008)

- Ilmenite paragenesis and chemical variation; based on major oxides. Large public compilations used as trial datasets (Wyatt et al., 2004)
Cautionary Tales

- Data checks between probe batches from the same locality, data checks within individual probe batches – can catch instrument drift, poor calibration, incorrect grain labeling etc..
Public Datasets – Powerful Comparative Tools

(Armstrong, 2003)
Public Datasets – Powerful Comparative Tools

Alberta Kimberlite and Diamond Indicator Mineral Summary Map

Pyrope Garnet
Number of Garnets >15.5% MgO

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 - 49

Eclogitic Garnet
Number of Garnets 0% Fe<sub>2</sub>O<sub>3</sub>, 15% MgO

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 - 49

Chrome Diopside
Number of Diopside >0.1% Cr<sub>2</sub>O<sub>3</sub>, 15% Fe<sub>2</sub>O<sub>3</sub>

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 - 49

Picrolimenite
Number of Picrolimines >20% MgO

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 - 49

Chromite
Number of Chromites >20% Cr<sub>2</sub>O<sub>3</sub>, >0.25% Fe<sub>2</sub>O<sub>3</sub>

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10 - 49

Kimberlite or kimberlite cluster

(Beaumier, compiled BHP regional sample Quebec)
Case Studies

Mature Exploration Play
Timiskaming Region
- Comparison of garnet signature from a recent discovery to regional tills and kimberlites

Area Selection Play
Aviat, Melville Peninsula
- Reconnaissance sampling leading to discovery and creation of internal comparative dataset

Regional Datasets as Exploration Tools
Coronation Gulf, Northern Slave Province
- Large public datasets as an exploration tool

Innovative Techniques in Emerging Plays
Foxtrot Property
- Use of innovative analytical techniques as a complement to traditional geochemical tools
- Timiskaming area has been explored since the late 1960’s with an estimated 26 kimberlite discoveries.

- Variable geotherms – with cooler geotherm in the Lake Timiskaming region

- The approximately 5ha 95-2 kimberlite, has returned some of the better grades with the eastern portion of the body returning grades of 12.5 to 16.3 cpht
Baby Kimberlite (BA-19) lies on the eastern edge of the field

Property scale till sampling was completed in proximity to the BA-19 target

BA-19 is associated with a ground magnetic and aero-magnetic geophysical anomaly extending for over 400 meters along strike, with another possible 200 meters strike extent across an off-setting magnetic lineament

Encouraging picking counts and chemistry in conjunction with geophysical surveys resulted in a drill test of the BA-19 target

Tuffisitic Kimberlite Breccia was interested between 93 and 124 meters on a 45 degree inclined hole. Representative portions of drill core were submitted for indicator mineral extraction.

The intersection of BA-19 was barren of diamond
Garnet Analyses: BA-19 Kimberlite and Tills

![Graph showing Cr2O3 wt.% vs. CaO wt.% for BABY KB and BABY Till samples.]

- **G10**
- **G9**

- BABY KB
- BABY Till
Mature Exploration Play – Baby Kimberlite

- Geological Survey of Canada has been quite active in the area with numerous quaternary and geochemical surveys (till and kimberlite)

- Good regional base of indicator studies that may be used for baseline and comparative studies

- > 14 publications

- Reliable comparative tool

GSC OF 4086
Garnet Analyses: BA-19 Kimberlite vs. Regional Compilation
Mature Exploration Play – Baby Kimberlite

- Till-derived pyropes are substantively different than those obtained from the intersected kimberlite
- The till anomaly may be derived from another phase of the BA-19 kimberlite or from an as yet to be discovered kimberlite.
- The suite of garnet chemistry from the BA-19 target (till and kimberlite) conforms well to the regional garnet signature and falls within the upper lherzolitic trend for the region
Applications – Case Studies #2

Aviat
Melville Pen.

- Cordillera
- Phanerozoic Cover
- Proterozoic Cover
- Proterozoic (<1.5 Ga)
- Proterozoic (>1.5 Ga)
- Archean (>2.5 Ga)
- Kimberlite cluster, field

Courtesy of B. Kjarsgaard GSC
Area Selection Play: Aviat

- Nov. 2001 - The Aviat Project Joint Venture is formed between Stornoway Ventures, Northern Empire Minerals and Hunter Exploration Group in order to explore the Melville Peninsula. An area of Canada, prospective for diamonds, but had seen limited evaluation.

- August 2002 - AV-1 kimberlite is discovered during a summer follow-up sampling program on the Melville Peninsula property.

- No previous diamond exploration, no information regarding diamond potential
Area Selection Play: Aviat

- Reconnaissance scale sampling of eskers, beaches, and tills returned a sample with a complement of kimberlite indicators with encouraging mineral chemistry

- August 2002 - Follow-up work in vicinity of the sample resulted in the discovery of the diamondiferous AV1 kimberlite

- What constitutes ‘encouraging mineral chemistry’
Area Selection Play: Aviat

Beach sample returned 17 garnets. Follow-up work in vicinity of the sample resulted in the discovery of the diamondiferous AV1 kimberlite, approx 650 metres up-ice from sample location.
Area Selection Play: Aviat

Initial Pyrope Mineral Chemistry: Beach Sample, Discovery Outcrop, and Float
Aviat: Start of 2004 Field Season

2002 + 2003 Picking
Total Grains
- 1 - 5
- 6 - 15
- 16 - 20
- 21 - 30
- 31 - 500
- Barren

AV1
- gnt(n=46), sp(n=10), pilm(n=11), ol(n=5)

AV2
- gnt(n=56), sp(n=7), pilm(n=9), ol(n=5)
Aviat: End of 2004 Field Season
Aviat: Start of 2005 Field Season

gnt(n=46), sp(n=10), pilm(n=11), ol(n=5)
gnt(n=6), sp(n=1), pilm(n=8)
Aviat: End of 2005 Field Season
Aviat: End of 2008 Field Season
Area Selection Play: Aviat

- Area selection successful in the discovery of significantly diamondiferous kimberlites
- High quality exploration and kimberlite mineral chemistry dataset available for internal comparative use
Applications – Case Studies #3

Coronation Gulf
Northern Slave Craton

Cordillera
Phanerozoic Cover
Proterozoic Cover
Proterozoic (<1.5 Ga)
Proterozoic (>1.5 Ga)
Archean (>2.5 Ga)
Kimberlite cluster, field

Courtesy of B. Kjarsgaard GSC
Regional Datasets as Exploration Tools
Regional Datasets as Exploration Tools

- Exploration for kimberlites in the Coronation Gulf region of the Northern Slave Craton has taken place since the mid-1990’s
- The region is host to approximately 24 kimberlites, several of which have been shown to be diamondiferous (10 to 25 cpht) and a suite of barren to poorly diamondiferous bodies
- Dispersion trains within the region are linear in nature and overall mineral abundances suggest dramatically different source rocks
- Ilmenite dominant trains are sourced from a variety of barren to weakly diamondiferous bodies (Kikerk 1, Kikerk 2, Perseus), trains with lherzolitic and weak hazburgitic signatures are sourced from the Artemisia, Potentilla, Stellaria, and Knife kimberlites
- The availability of public domain datasets allows for comparison of both the silicate and oxide mineral signatures from kimberlite sources
North Slave (Coronation) Anuri; Tenacity

Armstrong, 2003

Indicators Picked
- 0
- 1 - 2
- 3 - 5
- 6 - 25
- > 25
Regional Datasets as Exploration Tools
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Regional Datasets as Exploration Tools
The Foxtrot Project and Renard Kimberlites

Legend
- Stornoway/Soquem JV Properties
- HydroQuebec Facility
- Renard Kimberlites
- Kimberlitic Dyke
- Regional Kimberlites
- Exploration/Mining Projects
- Winter Road
- Road
- HydroQuebec Powerlines

Kimberlite Bodies Assessed for Mining

Hibou
Lynx
The Foxtrot Project and Renard Kimberlites

- Foxtrot property is host to at least 10 kimberlite pipes (Renard pipes) and two extensive flat-lying kimberlite dyke intrusions (Lynx and Hibou)

- Two distinct emplacement ages have been returned for the Foxtrot kimberlites.

- Neoproterozoic for the Renard pipes and a Cambrian age for the Lynx dyke

- One sample from a regional program of 48 samples, conducted in 2000, returned anomalous grains counts and a suite of indicator minerals

- Mineral chemistry was strongly suggestive of a source region with high diamond potential
Innovative Techniques – OH in Olivine

- FTIR spectroscopy of unpolished OL grains, of variable thickness yields H2O conc. and normalized intensity of the specific OH IR adsorption bands

- Matveev and Stachel state that for 80% of kimberlitic olivines these two parameters are significantly higher than those of non-kimberlitic olivines

- Require unaltered/serpentinized olivines – ideal for Canadian setting

- Study based on kimberlitic olivines from: Lac de Gras, FALC, Victor

- Some overlap with peridotitic OL

- Quick, inexpensive, non-destructive

Fig. 10 from Matveev and Stachel, 2007
Innovative Techniques – OH in Olivine
Innovative Techniques – OH in Olivine

- Blind samples of olivine recovered during kimberlite indicator studies were submitted for FTIR at UofA
- No mineral chemistry was performed on grains subsequent to FTIR work
Innovative Techniques – OH in Olivine

- Suite of randomly selected olivines from Ruler Train were submitted for FTIR
- Full suite displays grains lying to right and below of Field 2
- These grains were deemed to be altered and once removed the data plots in the ‘non-kimberlitic’ field
- Additional work on Ruler Train olivine concurrent with FTIR study identifies polymict ‘grains’ with non-kimberlitic (crustal) grains intergrown with OL
Summary

- New techniques are available to provide rapid classification and evaluation of inexpensive microprobe analyses
- Government sponsored compilations provide excellent comparative datasets and baseline data
- Industry generated datasets that become part of the public domain provide valuable information when compiled in a regional context
- Internal Industry generated datasets are useful for comparative work between and within areas of interest
- Innovative research may provide relatively inexpensive alternative techniques for determining grain paragenesis
- The more data, the merrier!