Soil and Lake Sediment Geochemistry in Diamond Exploration: NWT, Canada

By

John Gravel – Acme Analytical Laboratories Ltd.
Ray Hrkac and Margaret Hanrahan – GGL Diamond Corp.
Paul Richardson – Richardson Consulting
Diamond Exploration using Geochemistry
Kimberlite Indicator Minerals

- Bulk sampling of alluvium, glacial drift and loams followed by heavy mineral concentration of Kimberlite indicator grains
  - Counting of grains, mapping of dispersion trails, grain chemistries and microscope examination of grain surfaces.


- Subsequently used extensively across the Slave Craton of northern Canada to discover kimberlites.
Diamond Exploration using Geochemistry
Kimberlite Indicator Minerals

GGL begins NWT Diamond Exploration (1992)

- Alternative exploration methods to establish an edge.
- Consultant Dr. Stan Hoffman proposes soil and lake sediment geochemistry for rapid definition of kimberlite’s unique geochemical signature.
- Integrated with conventional KIM surveys and part of the toolbox including geophysics, surficial mapping, structural analysis, etc.

Advantages (circa 1992) included:
- Low analytical cost (1/20th of indicator mineral analysis),
- Rapid turnaround for data (2 weeks versus 1 - 6 months for KIM analysis) and
- New ICP-MS packages coming on stream providing low detection limits for a wide range of elements.

Perth, IGES - Sept, 2005
Premise for Geochemical Surveys

- **Unique chemical signature:**
  - Kimberlite is a peralkaline ultrabasic (elevated K)
  - Also enriched in incompatible elements (ie. Nb) and REEs
  - Likely to contrast strongly with local host rocks.

- Comprises mantle derived rocks that are unstable at surface and weather rapidly. Thus they likely erode easily and form topographic depressions with debris plumes extending down-ice in an arctic post-glacial terrain. Hence are good targets for geochemical exploration via:
  - Regional lake sediment surveys, and
  - Regional soil lines oriented perpendicular to glacial trend.
Premise for Geochemical Surveys

Perth, IGES - Sept, 2005

[Graph showing geochemical elements and their concentrations in different rock types, such as Kimberlite and Granite.]
Premise for Geochemical Surveys

Plan View

1) +Cr, Ni, Nb, Mg, Co, Ti

2) +Cr, Ni, Nb, Mg, Co, Ti

3) +Cr, Ni, Nb, Mg, Co, Ti

Profile View

+Cr, Ni, Nb, Mg, Co, Ti
Premise for Geochemical Surveys

- Literature search in 1992 yielded limited case studies in glaciate terrains.
  - Conventional knowledge states that soil surveys are effective but generally limited to the immediate vicinity of the intrusion.
  - No reference was found for conducting lake sediment geochemistry.
  - Considerable body of work published since this time with large contribution by Beth McClenaghan and Bruce Kjarsgaard of the GSC.
Doyle Lake Case Study
Doyle Lake Case Study

Doyle Sill

Dip 5 to 17°

Known extent by drilling to date
Doyle Lake Case Study

- Soil survey integrated with KIM survey
  - 1 kg samples from “frost boils”
  - Reconnaissance sampling at 200m X 1000m density, detailed sampling at 50m X 100m density.

- Analysis by Acme Labs in Vancouver, Canada
  - Samples dried and sieved to -63 microns.
  - Group 1E - 4-Acid digestion / ICP-ES for 35 elements.
  - Group 1EX - 4-acid digestion / ICP-MS for “kimberlite package” (41 elements + REEs)

- QA/QC using lab duplicates and reference materials also a project reference material developed early on.

- Dr. Hoffman predicts discovery of kimberlite in area

Perth, IGES - Sept, 2005
Doyle Lake Case Study

Perth, IGES - Sept, 2005
## Doyle Lake Case Study

### Group 1EX “kimberlite suite”

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection</th>
<th>Detection</th>
<th>Detection</th>
<th>Detection</th>
<th>Detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>0.1 ppm</td>
<td>Co</td>
<td>0.2 ppm</td>
<td>Na</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Ag</td>
<td>0.1 ppm</td>
<td>Cr</td>
<td>0.1 ppm</td>
<td>Nb</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Al*</td>
<td>0.01 %</td>
<td>Cu</td>
<td>0.1 ppm</td>
<td>Ni</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>As</td>
<td>1 ppm</td>
<td>Fe*</td>
<td>0.01 %</td>
<td>P</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Ba*</td>
<td>1 ppm</td>
<td>K</td>
<td>0.01 %</td>
<td>Pb</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Be*</td>
<td>1 ppm</td>
<td>La</td>
<td>0.1 ppm</td>
<td>Rb</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Bi</td>
<td>0.1 ppm</td>
<td>Li</td>
<td>0.1 ppm</td>
<td>S</td>
<td>0.1 %</td>
</tr>
<tr>
<td>Ca</td>
<td>0.01 %</td>
<td>Mg*</td>
<td>0.001 %</td>
<td>Sb</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Cd</td>
<td>0.1 ppm</td>
<td>Mn</td>
<td>1 ppm</td>
<td>Sc</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Ce</td>
<td>1 ppm</td>
<td>Mo</td>
<td>0.1 ppm</td>
<td>Sn*</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sr</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Nd*</td>
<td></td>
<td></td>
<td></td>
<td>Ta*</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Sm*</td>
<td></td>
<td></td>
<td></td>
<td>Th</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Eu*</td>
<td></td>
<td></td>
<td></td>
<td>Ti*</td>
<td>0.001 %</td>
</tr>
<tr>
<td>Gd*</td>
<td></td>
<td></td>
<td></td>
<td>U</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Tb*</td>
<td></td>
<td></td>
<td></td>
<td>V</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Dy*</td>
<td></td>
<td></td>
<td></td>
<td>W*</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Ho*</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Er*</td>
<td></td>
<td></td>
<td></td>
<td>Zn</td>
<td>0.1 ppm</td>
</tr>
<tr>
<td>Tm*</td>
<td></td>
<td></td>
<td></td>
<td>Zr*</td>
<td>1 ppm</td>
</tr>
<tr>
<td>Yb*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lu*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discovery of Doyle Lake Kimberlite Sill

- Very broad KIM train and even broader soil anomalies
- Terminate adjacent to major meltwash channel suggesting “blind” source east of the channel
- Systematic drilling back along trend uncovers unusual “sill like” kimberlite directly underlying part of soil anomaly

Perth, IGES - Sept, 2005
Discovery of Doyle Lake Kimberlite Sill

Recent drilling further expands the trace of the sill whereby the vast majority of soil anomalies overlie or are found immediately down-ice of the kimberlite body.

Perth, IGES - Sept, 2005
Extrapolating from the Doyle Lake kimberlite, other soil anomalies gain importance.

Possible Kimberlites?

Indicator Trains

Perth, IGES - Sept, 2005
Awry Lake Case Study

1993
Geophysical interpretation of regional air mag data identifies a discontinuity in regional structures
Awry Lake Case Study

1994
Weakly anomalous kimberlite indicator mineral train leads to the south shore of Awry Lake.

Lake sediment sampling is conducted at two locations targeting magnetic lows.
Awry Lake Case Study

Orientation studies conducted in Kimberlite-bearing lakes lead to development of a Kimberlite-potential factor using commonly enriched elements.

Samples from Awry Lake scored very high.

Perth, IGES - Sept, 2005
Awry Lake Case Study

Geochemical soil survey is conducted on the southern shore of Awry Lake.

Highly anomalous soils define a plume down-ice of the lake.
Bathymetry survey reveals that Awry Lake is extremely deep with a unique bottom profile. Additional lake sediment samples are collected that are remarkably similar in composition.
Awry Lake Case Study

2003 & 2004
Additional KIM sampling discovers several highly anomalous samples on south shore.

Lake-shore prospecting finds brecciated granite boulders. Geologist Torre Charter discovers that they have a carbonate matrix.

Boulder is submitted for KIM analysis and a G9 garnet is recovered.

Perth, IGES - Sept, 2005
Geological mapping along the lake shore discovers an extensive region of granite brecciation indicating a very large system.
Awry Lake Case Study

A drilling program is planned in 2005.

Four holes selected:
- Central Gravity low
- Magnetic low adjacent to anomalous lake sediments
- Central bathymetry low
- Magnetic high.
Drilling on Awry Lake Anomalies

GGL Diamond Corp. Drill Log
Hole Number: FB0512

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lithology</th>
<th>CaO</th>
<th>CO2</th>
<th>Er (ppm)</th>
<th>Ce (ppm)</th>
<th>Nb (ppm)</th>
<th>MgO</th>
<th>Ni (ppm)</th>
<th>Rh (ppm)</th>
<th>Ba (ppm)</th>
<th>Sr (ppm)</th>
<th>Pb (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>GRANITE</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>0</td>
<td>350</td>
<td>0</td>
<td>15</td>
<td>2</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>GRANITE: with Calcite filled fractures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>GRANITE: Very fractured</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>GRANITE: with Calcite filled fractures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>GRANITE: Very fractured</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>BRECCIA: Brecciated Granite, Carbonate matrix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>BRECCIA: Low competency brecciated granite with carbonate matrix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>BRECCIA: Brecciated Granite, Carbonate matrix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>GRANITE: Fractured</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>GRANITE: Increasingly competent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Perth, IGES - Sept, 2005
Drilling on Awry Lake Anomalies

Granite Breccia

Carbonate filled fracture

PERTH, IGES - SEPT, 2005
Drilling on Awry Lake Anomalies

GGL Diamond Corp. Drill Log

Hole Number: DDH FB 05 11

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lithology</th>
<th>Kimberlite Indicators</th>
<th>CO2</th>
<th>Er (ppm)</th>
<th>Nb (ppm)</th>
<th>Ni (ppm)</th>
<th>Ba (ppm)</th>
<th>Fe2O3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GRANITE</td>
<td></td>
<td>8</td>
<td>7</td>
<td>42</td>
<td>3</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>BRECCIA</td>
<td></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1</td>
<td>17</td>
<td>2</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>7</td>
<td>51</td>
<td>13</td>
<td>0</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>3</td>
<td>18</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>0</td>
<td>18</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Perth, IGES - Sept, 2005
Recovered Pyrope and Eclogitic garnets with selvages of kimberlite still attached.
Refined Geochemical Exploration Model

**Simple**
- Kimberlite
- Brecciated and CO$_2$ altered host
- Metasomatised host

**Complex**
- Hydromorphic
- Catastrophic
- Mechanical
- Mechanical
- Talik
- Frozen

Chemical changes:
- +Cr, Ni, Nb, Mg, Co, Ti, Fe, V, Ce (LREE), (±K, P)
- +Ca, CO$_2$, K, Er (HREE), -(Ni, Nb, Mg, Co)
- +Ba, Sr, Rb, Pb, ±(Ni, Nb, Mg, Co, U)
Conclusions

Soil Geochemistry

- Is a great adjunct to defining kimberlites whose potential is indicated by other geological disciplines... limited dispersion is an asset not a detriment.

- Depth of overburden, glaciofluvial processes and permafrost may be less of an impediment then believed with anomalies forming directly over their source.

- Geochemical patterns bear a direct relation with erosion products hence a good correlation with kimberlite indicator minerals. Overlapping trains from kimberlite clusters and their associated metasomatised and brecciated halos will add complexity.

Perth, IGES - Sept, 2005
Conclusions

Lake Sediment Geochemistry

- Is a highly effective regional exploration tool capable of defining the kimberlite potential within lake basins.
- Dispersion in the sediments may be by mechanical and/or hydromorphic means resulting in decoupling or combining of elements suites associated with the kimberlite and its brecciated and metasomatised halos.
- Lake shore prospecting of boulders and beach deposits may readily detect kimberlite(s) within the lake basin.