Ore deposits related to mafic igneous rocks – Diamonds

- GLY 361 – Lecture 4
More on kimberlites
Historically, kimberlites have been subdivided into two distinct varieties based primarily on petrographic observations (Wagner, 1914):

- **Basaltic**
- **Micaceous**

Later revised by Smith (1983) based on the isotopic affinities using the Nd, Sr and Pb systems:

- **Group I**: correspond to Wagner’s basaltic kimberlites.
- **Group II**: correspond to Wagner’s micaceous kimberlites.
Classification of kimberlites

- More recently revised by Mitchell (1995):
  - Group I and II display such distinct differences, that they may not be as closely related as once thought.
  - Group II actually shows closer affinities to lamproites than they do to Group I kimberlites.
  - Hence, Group II renamed as orangeites to prevent confusion.

- Lamproites:
  - ultrapotassic mantle-derived volcanic and subvolcanic rocks
  - geographically widespread
  - unlike kimberlites (exclusively in Archaean cratons), lamproites are found in terrains of varying age, ranging from Archaean to Palaeozoic and Mesozoic. They also vary widely in age, from Proterozoic to Pleistocene.
## Classification of kimberlites

<table>
<thead>
<tr>
<th>Group – I</th>
<th>Group – II (orangeites)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Olivine-rich, monticellite-serpentine-calcite kimberlites</strong></td>
<td><strong>Micaceous kimberlites</strong></td>
</tr>
<tr>
<td>Derived from mantle sources that are slightly depleted with respect to light rare-earth elements</td>
<td>Derived from sources that are slightly enriched. This enrichment and depletion are seen as evidence of past mantle metasomatic processes</td>
</tr>
</tbody>
</table>
Classification of kimberlites

modified after Mitchell (1986)
## Classification of kimberlites

<table>
<thead>
<tr>
<th>Group I</th>
<th>Age (Ma)</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuruman</td>
<td>1600</td>
<td></td>
</tr>
<tr>
<td>Premier</td>
<td>1180</td>
<td></td>
</tr>
<tr>
<td>Venetia</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Jwaneng</td>
<td>240</td>
<td>Dokolwayo</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>Dullstroom</td>
</tr>
<tr>
<td></td>
<td>165</td>
<td>Prieska</td>
</tr>
<tr>
<td>East Griqualand</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>140-145</td>
<td>Swartruggens, Lace</td>
</tr>
<tr>
<td></td>
<td>118-120</td>
<td>New Elands, Sover</td>
</tr>
<tr>
<td>Frank Smith</td>
<td>112-114</td>
<td>Newlands</td>
</tr>
<tr>
<td>Uintjiesberg</td>
<td>100-102</td>
<td></td>
</tr>
<tr>
<td>Orapa</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Monastery</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Kimberley, Kaalvallei</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Gibeon, Sutherland</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>
The tectonic setting of kimberlites

- Kimberlites are the products of continental intraplate magmatism and are therefore confined to regions underlain by old cratons.

- Economic kimberlites occur only on Archons (i.e. cratonic regions underlain by Archaean basement), whereas economic lamproites occur on some Protons (i.e. Proterozoic mobile belts adjacent to Archons).

- Old cratons commonly consist of an old core (craton) that is older than 2.4 billion years to which younger (1 billion-year) tectono-metamorphic terrains have been accreted.

- The cratons are generally covered with Phanerozoic platform sediments and associated continental volcanics.
The tectonic setting of kimberlites
Diamond formation

- Diamonds were formed at least 990 Ma ago (some are estimated to be < 4.25 Ga)
- Pressures: 45-60 kbar (125-200 km depths).
  - Some diamonds form at depths of 300-400 km, or even deeper, but these diamonds are particularly rare.
- Temperatures: 900°C to 1,300°C.
Fig. 3 – Diagram showing the relationship between the diamond pressure/temperature stability field and the structural roots of an Archaean Craton. A diamond ‘window’ is formed by the downward deflection of isotherms in the cool mantle root of a craton and the corresponding upward deflection of the diamond stability field. Kimberlites formed away from the craton (K) do not sample the diamond stability field, whilst those formed below the craton (K_1 and K_2) do (after Helmstaedt 1993).
Diamond formation
Mantle derived melt generation

- melt “window” where water saturated solidus is intersected by local geotherm.
- volatiles (CO$_2$, H$_2$O) (primordial/subduction?)
- heat source (mantle plumes?)
- conduit, e.g. fracture zone
Mantle derived melt generation

- Thermal plume rises below lithosphere.
- Lateral movement & melt concentration result in thinning of the lithosphere & melting.
- Contact with the cool peridotitic lithosphere may result in crystallization.
- H$_2$O-rich vapour formation near solidus may promote conduit formation.
Mantle derived melt generation

• Continued heat from the rising plume will promote thinning of the lithosphere, inducing further melting (decompression).

• Intersection of the solidus ledge at shallower depths will result in CO$_2$-rich metasomatism, contributing to further conduit formation.

• A variety of alkaline, non-kimberlitic rocks may be formed, e.g. nephelinites, melilitites.
Kimberlite emplacement - phreatomagmatism

- Interaction of magma with water.
- Applies to all magma types.
- Most of the thermal energy is converted into kinetic energy (80%), only a small part into the production of steam:
  - Shock waves brecciate country rock.
Kimberlite emplacement - phreatomagmatism

- Most effective at shallow depth and with low-viscosity magmas.
- Initial explosions close to surface.
- Diatreme growths towards depth.
- Eruption style depends on water/magma flux rate.
Ukinrek East, collapsing ash cloud and base surge, 1977. Photo: J. Kienle
VENETIA
• South Africa's largest producer – 40% of production.
• In Proterozoic Limpopo Belt.
• 12 bodies of Group I kimberlites.
• Grade = 110.7 cpht.
INTERNATIONAL EXAMPLE

LETSENG, Lesotho
World’s lowest grade kimberlite mine with the highest value diamonds

• operating specifications have to meet those of Canadian operations:

➤ Letseng temperatures in winter reach down to -20°C and the area can get up to 35 cm of snow.
World’s lowest grade kimberlite mine with the highest value diamonds

- highest percentage of large diamonds (diamonds > 10 cts) of any known kimberlite mine
- highest dollar per carat ratio of any mine
  - world average = US$ 70/carat,
  - Letseng during 2004: over US$ 1,000/carat. At the same time the grade at Letseng is only just over two cpht compared with about 200 carats per hundred tonnes (cpht) of other operations
The Lesotho Promise
- 603 cts
The Main Pipe
The Satellite Pipe
Resources

• 350 tonnes an hour production rate.

• **Satellite pipe: 24 Mt @ 2.26 cpht.**
  • **Main pipe: 54.43 Mt @ 2.00 cpht.**

• Letseng’s two pipes represent an economically open-pit mineable 100 million tones of kimberlite containing 2.3 million carats, which should take 25 years to mine.