Module B. Colour from the Cosmos

Lesson 10 - Diamond Geology and Geography

Restatement of Lesson 10 Learning Objectives

* Define and differentiate between primary and secondary diamond deposits
* Describe the geological conditions necessary for diamond formation
* Describe the geological events that bring diamond from the mantle to the surface
* State the shape of kimberlite diamond deposits
* Describe why diamonds are rare
* Describe the global distribution of diamond deposits, geographically and geologically
* Briefly summarize the change in diamond production by country through history
* Describe the distribution of diamond deposits in Canada, geographically and geologically
* Be aware of the steps taken to discover diamonds in Canada after watching the 'Queen of Diamonds' video

The Origins and Geology of Diamonds and Kimberlite

Diamonds occur in primary and secondary deposits. Primary deposits are found in volcanic rocks both on the surface and in un-erupted magma that feed volcanoes. Volcanic rocks that host diamond are called kimberliteand lamproite. Secondary deposits include diamonds that have been moved from their primary source and concentrated in a new location. Rivers and nearshore currents are the usual transport mechanisms.

*Diamond Growth*

Diamonds are stable only at great depths below the surface, where pressures are very high. The required depth for diamond growth is at least 150 km. However, at these depths, underneath large amounts of rock, temperatures are typically on the order of 1500 °C; this temperature is too hot for diamond to grow! In order for diamond to stabilize, a "cool region" of between 900 and 1200 °C is required. Consequently, we cannot just pile a bunch of rocks up and expect diamond to form. Instead, we need to pile up a bunch of "cold" rocks so that a locally cool region can exist even at a great depth.

At the center of many continents are collections of rocks called Archean cratons. These are old (greater than 2.5 billion years), typically cool, and their great thicknesses push a keel down into the upper mantle. This is similar to how only the tip of a floating iceberg will show above the water's surface. At the base of this keel is an environment favourable for diamond growth, characterized by high pressures and "cool" temperatures, relative to the local environment. This set of Pressure-Temperature conditions that define the diamond stability field is often referred to as the Diamond Window. Away from these temperatures and pressures, the stable mineral for pure C is graphite.

Schematic vertical section through the Earth's crust and part of the upper mantle. Figure from Stachel, T. and J.W. Harris (2008, "The origin of cratonic diamonds - Constraints from mineral inclusions", *Ore Geology Reviews*, Volume 34, Issues 1-2, pp 5-32).

The cartoon diagram of the Earth's crust (above) shows an old craton with a deep keel, the outline of which is indicated by a blue line. The Stability Zone separating diamond from graphite is indicated by the dashed white line: below the line diamond is the stable C mineral, whereas above it, graphite is the stable C mineral. The red dots indicate areas where igneous magma is being generated and the red chevrons (V-shaped patterns) indicate where magma has accumulated. Note how even though igneous rocks formed at mid-ocean ridges and along subduction zones are sourced from the same general magmatic region, they are generated above the diamond-graphite line, resulting in the production of only graphite, the stable C mineral.

This Temperature-Pressure diagram highlights the relationship between the two carbon minerals; graphite and diamond. The area in red indicates the typical pressures and temperatures in cratonic lithosphere, whereas the area in green indicates the typical temperatures and pressure in the asthenosphere. Diamonds will only form in the lithosphere (not the asthenosphere), so the "fertile" region for diamonds is a small window (yellow area) within the lithospheric region below the diamond-graphite line. Figure from Stachel, T. and J.W. Harris (2008, "The origin of cratonic diamonds - Constraints from mineral inclusions",*Ore Geology Reviews*, Volume 34, Issues 1-2, pp 5-32).

*Kimberlite Volcanoes*

Sourcing diamonds from underneath 150 km of cold cratonic rock is not an easy task. Special conditions are required to bring these crystals from deep within the Earth to the surface. The main mechanism to bring diamonds upwards is kimberlite magmas. These magmas are generated at the base of the craton, ascend through the 150 km of crust very quickly, and then erupt in special volcanoes on the Earth's surface.

*En route*, the kimberlite magmas pick up diamonds that are in their pathway, then deposit them volcanically on the surface. This process has to be rapid in order to both prevent diamonds from transforming to graphite, as well as exhume them (i.e., to bring to the surface) uncorroded. The deep-seated magma for these odd volcanic rocks is sourced from the upper mantle and is Fe- and Mg-rich (also termed ultramafic) as well as rich in K (or ultrapotassic). Kimberlite magmas can also be generated away from diamond-bearing regions below the cratons, but these kimberlites will never carry diamonds. In fact, they are classified asbarren kimberlite.

The morphology of kimberlite volcanoes on the surface is tied to their igneous nature as well as the nature of the rocks they are passing through. As the magma ascends upwards through the crust it moves into regions with less and less confining pressure, which then continually allows faster and faster propagation of the magma.

As the magma approaches the Earth's surface it will most likely interact with groundwater. An eruption occurs when hot magma boils water that it comes in contact with, resulting in a rapid and violent expansion of gases. Although no kimberlite eruptions have been witnessed, the textures found in the rock record support an explosive depositional environment. Emplacement of kimberlite volcanoes often results in a vertical and carrot-shaped body known as a diatreme, typically up to 1 km across at the surface. The figure below shows an idealized schematic of all parts to a kimberlite volcano, however, in most geological settings not each and every part is present. This is either due to variations in the emplacement of the volcano or subsequent erosion on the Earth's surface since eruption.

Typical morphology of a classical kimberlite diatreme, or pipe, with other associated igneous rock bodies, based on examples from South Africa. Terminology on the left reflects nomenclature generated from South African kimberlite, and terminology on the right reflects nomenclature as revised from studies of kimberlites across the globe. Figure from Kjarsgaard, B. (2007, "Kimberlite Diamond Deposits", In *Mineral Deposits of Canada*, Goodfellow, W. D., ed., Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 245-272).

This figure shows the plan views (top) and vertical side views (bottom, also known as a "Cross Section") of the five diamondiferous kimberlite pipes that make up the Kimberley mine site kimberlite cluster. Note their close approximation to the 'carrot-shaped' schematic above. (From Field et al 2008)

This figure shows the plan views (top) and vertical side views (bottom, also known as a "Cross Section") of the Premier Mine, historically known as the Cullinan Mine. Note the close approximation to the 'carrot-shaped' schematic above as well as the horizontal gabbro intrusive body that cuts across the kimberlite - this later feature actually destroyed diamonds within a few meters from the contact between it and the kimberlite rocks. (From Field et al 2008)

This figure shows a 3D cross section of one of the the Ekati diamond bearing kimberlite pipes (Koala Pipe) with the extent of the open pit as of December 2012. Red lines indicate diamond drill holes used to determine the 3D distribution of rock types. The different shades of the kimberlite pipe rock outline indicate different classes of kimberlite. From [2013 NI43-101 Report on the Ekati Project](https://connect.ubc.ca/bbcswebdav/pid-2559704-dt-content-rid-10494246_1/courses/SIS.UBC.EOSC.118.99C.2014WC.44220/Course_Files/moduleB/lesson10/download/Ekati43101.pdf) (if you are interested in diamond exploration, the 2013 43101 is an excellent view of industry from exploration to production, however, it is a highly technical report!).

Besides bringing diamond to the surface, kimberlite also entrains non-gem minerals and other rocks formed in the same deep environment. Sampling such super-deep material allows geoscientists to look at material otherwise inaccessible and to study the inner workings of the Earth. The rocks and minerals that get pulled up are more abundant than diamond, but are not necessarily common minerals on the surface of the Earth.

Minerals that commonly occur in diamond-bearing kimberlites include green olivine, purple pyrope garnet, chromium-bearing diopside, chromium-bearing spinel, and the iron titanium oxide, ilmenite. Detailed descriptions of these minerals can be found in your text. These minerals are often called indicator mineralsbecause of their association with diamond. Their presence on the surface of the Earth *can indicate* to geoscientists that kimberlite rocks might be nearby.

This Kimberlite Pipe Flash Animation from Diamondex Resources Ltd. is an excellent animated cartoon about the emplacement of diamonds through kimberlite volcanism and their subsequent disruption and dispersion from glaciation.



*Lamproite*

Lamproite is another rock type (similar to kimberlite) that hosts diamond, but much less commonly. An important difference between these rock types is in their geochemistry. Lamproite commonly includes the mineral leucite while kimberlite does not. In addition, lamproites can exist in areas outside of Archean cratons, unlike most kimberlites. Only one mine, the [Argyle Diamond Mine](http://www.argylediamonds.com.au/) in [northern Australia](https://maps.google.ca/maps?hl=en&ll=-16.712987,128.405542&spn=0.076615,0.084543&t=h&lci=org.wikipedia.en&z=14), produces diamonds from lamproite rocks on a commercial scale. Notably, the Argyle Mine also produces over 90% of the world's pink diamonds as well as many champagne diamonds!

Computer-generated 3D model of an Australian diamond mine. The lamproite is the body shown in green, blue, and purple. Image from [Argyle Diamond Mine](http://www.argylediamonds.com.au/index.html).