DSPMU UNIVERSITY, RANCHI.
DEPARTMENT OF GEOLOGY

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KIMBERLITES

Kimberlites are highly alkaline (usually K-rich) ultramafic rocks that represent magmas derived from great mantle depths and are known for the principal source of diamonds. They mainly occur in Archaean and Proterozoic cratons.

The first Kimberlites were described by Vanuxen in 1837 from Ludlowiville near Ithaca, New York state; however, the term Kimberlite was introduced by Lewis (1887) to describe the diamond-bearing, porphyritic mica peridotites of the Kimberley area of South Africa.

PETROGRAPHY

The petrography of Kimberlites is both unusual, and complex, because:

1) They are hybrid rocks the contain minerals, rock fragments and congealed magmatic materials that formed in diverse physical and chemical environments.
2) They vary greatly in modal compositions: Olivine, serpentine group minerals, phlogopite, garnet (usually pyrope), pyroxenes, carbonate minerals, monticellite, ilmenite, chromite and Perovskite are the minerals usually found in Kimberlites.

As said previously the modal composition of Kimberlites vary greatly. Olivine is usually the most abundant mineral, but it may be partly, or completely, replaced by secondary minerals. Some Kimberlitic rocks contain three generation of olivine: Large rounded olivine megacrysts (> 3-4mm) with composition in the range Fo84-86; Medium-sized olivine with composition that are often more magnesium-rich than Fo90 and small groundmass olivines with composition that are intermediate between the other two type. The abundance of phlogopite and carbonate minerals are also highly variable; for this reason Kimberlites can be divided into 3 types:

Kimberlites (sensu stricto);

Micaceous Kimberlites;

Calcareous Kimberlites

Mitchell (1970) defined Kimberlites as:

"A porphyritic, alkali peridotite, containing rounded and corroded phenocrystals of olivine (serpentinized, carbonatized or fresch), phlogopite (fresh or chloritized), magnesian ilmenite, pyrope and Cr-pyrope set in a fine grained groundmass composed of second generation olivine and phlogopite together with calcite, serpentine, magnetite, apatite, Perovskite. Diamond and garnet peridotite xenoliths may or may not occur."

In general, kimberlites exhibit a distinctive inequigranular texture resulting from the presence of macrocrysts (and in some instances megacrysts) set in a fine grained matrix. The megacryst/macrocryst assemblage consists of rounded anhedral crystals of magnesian ilmenite, Cr-poor titanian pyrope, olivine, Cr-poor clinopyroxene, phlogopite, enstatite and Ti-poor chromite. Olivine is the dominant member of the macrocryst assemblage. The matrix minerals may include: second generation euhedral primary olivine and/or phlogopite, together with perovskite, spinel (titaniferous magnesian aluminous chromite, titanian chromite, members of the magnesian ulvospinel-ulvospinel-magnetite series), diopside (Al- and Ti- poor), monticellite, apatite, calcite, and primary late-stage serpentine (commonly Fe rich). Some kimberlites contain late-stage poikilitic eastonite phlogopites. Nickeliferous sulphides and rutile are common accessory minerals. The replacement of early-formed olivine, phlogopite, monticellite, and apatite by deuteric serpentine and calcite is common. Evolved members of the clan may be devoid of, or poor in, macrocrysts, and composed essentially of calcite, serpentine, and magnetite together with minor phlogopite, apatite and perovskite.

Based on studies of numerous kimberlite deposits, geologists have divided kimberlites into 3 distinct units based on their morphology and petrology. These units are:

1) Crater Facies Kimberlite
2) Diatreme Facies Kimberlite
3) Hypabyssal Facies Kimberlite

Crater Facies Kimberlite

The surface morphology of an unweathered kimberlite is characterised by a crater, up to 2 kilometers in diameter, whose floor may be several hundred meters below ground level. The crater is generally deepest in the middle. Around the crater is a tuff ring which is relatively small, generally less than 30 meters, when compared to the diameter of the crater (Figure-1). Two main categories of rocks are found in crater facies kimberlite: pyroclastic, those deposited by eruptive forces; and epiclastic, which are rocks reworked by water.

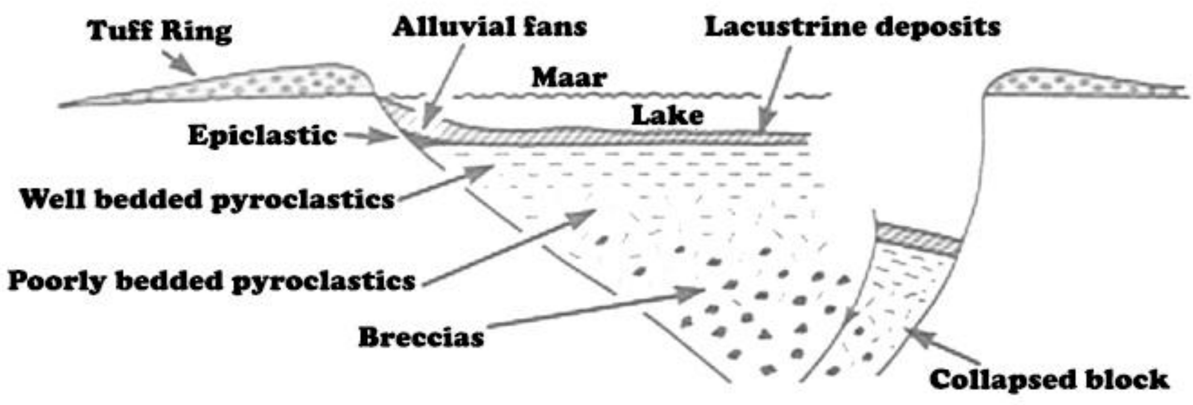

Figure 1- Crater Facies Kimberlite. (Modified after Mitchell, 1986)

Diatreme Facies Kimberlite

Kimberlite diatremes are 1-2 kilometer deep, generally carrot-shaped bodies which are circular to elliptical at surface and taper with depth. The dip contact with the host rocks is usually 80-85 degrees. The zone is characterized by fragmented volcanoclastic kimberlitic material and xenoliths plucked from various levels in the Earth's crust during the kimberlites journey to surface.

Some Textural features of Diatreme Facies Kimberlite:

Country rock fragments-angular; Cognate fragments (juvenile)-rounded to angular; Country rock xenoliths found 1000 meters below depositional unit; Local stratigraphy is crudely preserved by floating reefs in diatreme; Pelletal lapilli appear to have formed by the rapid crystallization of a volatile poor magma containing phenocrysts. They are characterised by a crystal nucleus surrounded by microphenocrysts which align themselves tangentially to the central crystal; Matrix composed almost entirely of fine-grained diopside, serpentine and phlogopite; Crystallisation in diatreme occurs at low temperatures based on the lack of thermal effects seen in intruded limestones; Contact metasomatic/metamorphic effects with the country rock are few; Upwarping and fractures associated with the intrusive body are absent.

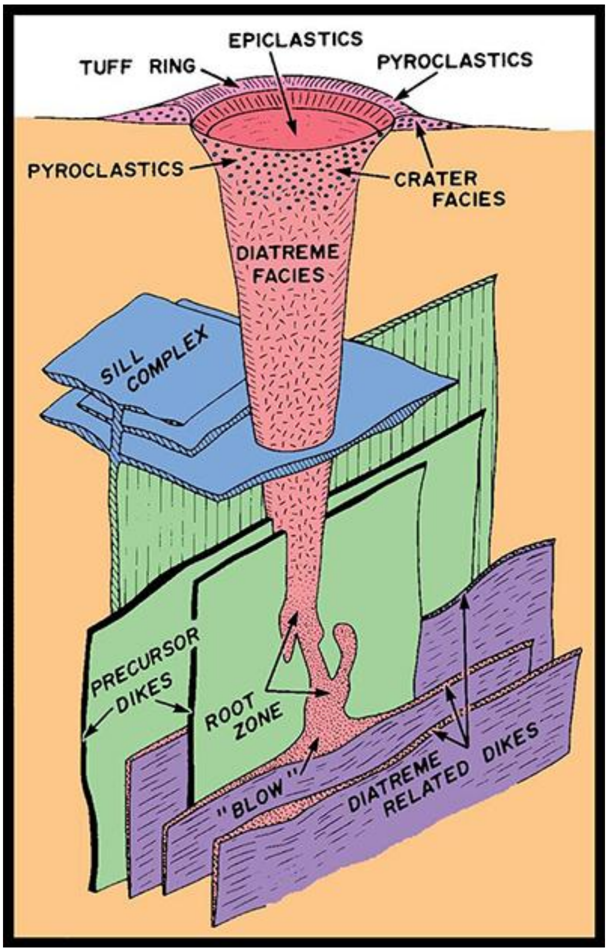

Figure 2: Kimberlite Pipe. Modified after Mitchell, 1986

Hypabyssal Facies Kimberlite

These rocks are formed by the crystallization of hot, volatile-rich kimberlite magma. Generally, they lack fragmentation features and appear igneous. Some Textural features: Calcite-serpentine segregations in matrix; Globular segregations of kimberlite in a carbonate-rich matrix; Rock fragments have been metamorphosed or exhibit concentric zoning; Inequigranular texture creates a pseudoporphyritic texture.

Figure 3- Hypabyssal facies kimberlite. The white matrix is calcite while the green material is serpentine.

GEOCHEMISTRY

According to Dawson (1980) and Mitchell (1986, 1989) who summarized previous geochemical studies of the kimberlites, concluded that kimberlites are undersaturated ultrabasic rocks with low SiO_2 (25-35 wt%), Al_2O_3 (<5 wt %) and high MgO (15-43 wt%) and K_2O (up to 3 wt%) contents. The prevailing potassic nature of kimberlites is demonstrated by low Na_2O/K_2O (0.5) values. Trace element compositions of kimberlites are characteristically enriched in light rare earth elements (LREE) compared to other ultramafic rocks, but strongly depleted in heavy rare earth elements (HREE).

PETROGENESIS

The rocks of the Kimberlite kindred are a paradox, as they generally have major element composition the are similar to primitive pricrites; yet they are also enriched in the incompatible elements, and enrichment of this type is characteristically found in more differentiated rocks. Many authors have proposed that kimberlitic magmas are generated in a source region that is relatively deep within the mantle, and the magmas are the product of a low degree of partial melting.

Kimberlite magmas are sourced from deeper in the Earth' s mantle than any other magma type, this is clear not only from the occurrence of diamond in many (a property shared with some lamproites), but also from analysis of the garnet lherzolite and harzburgite xenoliths that kimberlites typically contain. Such xenoliths are fragments of conduit wall-rock detached by kimberlite magma during its rapid ascent through the lithosphere, and they place useful constraints on where and under what conditions the kimberlite melt formed.

Experimental studies by Willie and Huang (1975), and others, have shown the kimberlitic magmas are most likely to be generated by the partial melting of suitable peridotitic materials when CO2 is present in the source region. The experimental studies indicate that, at pressure of between 5.0 – 6.0 GPa, the initial partial melt, of phlogopite-bearing garnet lherzolite source rock in the presence of CO_2 and H_2O, is likely to be kimberlitic in composition. They also suggest that at pressure greater than 5.0GPa, kimberlitic liquid might be relatively common within the mantle and that the rarity of kimberlites as rocks may be attribuited to the rarity of tectonic setting conductive to the ascent of appropriate magmas.

In order to explain why kimberlitic rocks contain high incompatible element abundance, and also why they normally contain megacrysts and xenolith that equilibrated at high pressures, Harris and Middlemost (1970) proposed that kimberlitic magmas are generated in two-stage processes. In the first stage a tenuous magma, enriched in volatile components (mainly CO_2 and H_2O), generated by volatiles degassing from deep mantle, rise from a deep approximately of 600 Km. at higher levels in the upper mantle (260Km), the relatively hot, volatile and incompatible element-rich tenuous magma induces partial melting to occur in the garnet Iherzolite mantle rock. The new magma, which is in equilibrium with the solid phase present at this deep in the upper mantle, is picritic in major element composition, but significantly enriched in the incompatible elements. Under ideal condition, such a kimberlitic magma rises rapidly (12m/s) towards the surface from a depth of at least 200Km. at 200 Km, the kimberlite material is essentially a magma, but as it rises to higher levels it become a mechanical mixture of liquid magma, phenocrysts, xenoliths, together with large volume of a separate low-viscosity fluid phase. As this mixture-magma is propelled upward through a variety of different physical and chemical environments, changes occur as the many phases of which it is composed attempt to adjust to the changing physical environments. The first batch of this magma-mixture that bursts explosively through to the surface is likely to produce a maar crater, or a low-relief coneless crater, that is surrounded by a crater-ring of kimberlitic pyroclastic materials.

With the arrival of more batches of kimberlitic magma, the materials in the surface vents and contiguous feeder-dyke are entrained and mixture; and the solids are abraided in a vigorous-active fluidized system. Eventually the fluidized system collapses, and the different materials coalesce, and the typical rocks of the kimberlite kindred form as the result of this process, assisted by crystallization and growth of a variety of low-temperature and low-pressure secondary minerals.

References-

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