EMPLACEMENT AND CRYSTALLISATION OF A KIMBERLITE DYKE FROM THE DE BEERS MINE, KIMBERLEY, SOUTH AFRICA.

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Introduction: A narrow (24 cm) vertical kimberlite dyke was sampled at the 585 m level in the De Beers Mine, Kimberley, where it intrudes the country rock adjacent to the main pipe. Prominent features of the dyke are the well-developed banding parallel to the dyke walls and the presence in some bands of abundant horizontally elongate light-coloured 'amygdales' set in a dark kimberlitic matrix.

Petrography: Petrographic study of a series of thin sections across the dyke allows the recognition of discrete bands which are described below in sequence from the margin to the centre of the dyke (bands I to VI). Band I (0.5 cm thick) is a narrow fine-grained band immediately adjacent to the dyke wall. Microphenocrysts of phlogopite, ilmenite and serpentine occur in a matrix of sub-parallel calcite laths, granular opaques and interstitial serpophite. There are no amygdales and the calcite and phlogopite grains show a preferred orientation parallel to the dyke wall. Band II (1 cm thick) contains elongate irregular white amygdales up to 6 mm long oriented normal to the dyke wall. They are filled by calcite and serpophite and make up about one third of the area of band II. We interpret some of the complex amygdales as having formed by coalescence of two or more individuals moving toward the interior of the dyke. The remainder of the band resembles band I but lacks the well-developed preferred orientation. Band III (2 cm thick) is uniformly fine-grained without amygdales. Like band I the microphenocrysts are oriented parallel to the dyke wall but band III differs from band I in having a much higher abundance of opaque oxides. The amygdales in band II do not transgress the boundary with band III. Band IV (1.5 cm thick) is characterised by the presence of elongate amygdales, 3 to 15 mm long, oriented normal to the dyke wall. These amygdales commonly have a broad rounded end facing the centre of the dyke with a narrower tail or tails pointing toward the dyke margin. Megacrysts of phlogopite, serpentine, calcite pseudomorphs after olivine, and rarer rutile are set in a matrix of serpophite, calcite and opaque oxides. Phlogopite is less abundant than in band III. Between the amygdales and oriented normal to the banding are narrow elongate branching calcite crystals up to 10 mm long. Band V (3 cm thick) lacks calcite laths and the amygdales present are fewer in number but are larger with more complex shapes. Carbonate-bearing amygdales contain either coarse plates of calcite and dolomite or elongate parallel-growth skeletons of calcite. Some of the large complex amygdales have a 'root zone' in band IV and become wider and more complex in band V. Towards the interior of the dyke the serpophite and carbonate of the amygdales either terminate abruptly or, in some cases, merge into the kimberlite matrix. Band V contains more abundant megacrysts (phlogopite, ilmenite and calcite and serpentine pseudomorphs after olivine) than band IV. The matrix consists of serpophite, carbonate and opaque minerals. Band VI (13 cm thick), occupying the middle of the dyke, does not carry amygdales but is otherwise similar to and grades into band V. Band VI has a still higher content of megacrysts which are mostly olivine or serpentine. Sharp boundaries divide zones with no fresh olivine from zones of partly serpentinised olivine. Megacrysts of pyrope and amphibole are rare and one inclusion of a serpentinised phlogopite-rutile-ilmenite peridotite was noted. The remainder of the dyke consists of a repetition of band V plus a thin marginal band that has not yet been properly sampled. The two sides of the dyke are asymmetric and the sequence of bands on one side is not wholly represented on the other. Amygdales in bands II, IV and V are filled with carbonate, serpophite, or a mixture of both phases. All have at least a thin lining of carbonate. Some amygdales are zoned with calcite cores and dolomite rims or with serpophite cores and calcite rims. Euhedral serpentine grains in some amygdales may be pseudomorphs after phlogopite.

Modal Variations: The modal variation across the dyke is complex, involving both abrupt and gradational changes across conformable contacts. Phlogopite, serpentine and ilmenite are present throughout the dyke as megacrysts or microphenocrysts. Fresh olivine is prominent only in the innermost band (band VI). The matrix comprises calcite, serpophite, ilmenite, perovskite, apatite, magnetite and chromite. Phlogopite is most abundant at the dyke margins and opaque oxides are most abundant in band III. Amygdales occupy about one third of some bands but the total carbonate and serpophite content of these bands is similar to that in adjacent amygdale-free bands. Total carbonate content is greatest in band V, where calcite pseudomorphs after olivine are most common, and decreases toward the centre of the dyke. Olivine is most abundant in band VI where the highest concentration of megacrysts occurs.

Mineral Chemistry: Olivine compositions range from $Fo_{91.6}$ to $Fo_{88.4}$ and normally zoned olivines are commonly mantled by a narrow reverse zoned rim. Phlogopite is magnesian ($Mg/_{Mg+Fe}0.9$), low in Ti and commonly shows evidence of reaction with the matrix. Serpentine is also highly magnesian but with a range of Ti, Al, Na and K contents. Calcite grains show a range of Fe and Mg contents with the higher values occurring in the carbonates in the amygdales. Dolomite was found only in the amygdales. Ilmenite is also Mg-rich but a range of Cr contents is present. Rutile occurs as rare-earth rich and rare-earth poor varieties. The complex oxide phases indicate a paragenetic sequence with the early crystallisation of Mg-Al-rich chromite and rutile followed by picroilmenite and Mg-Al-poor chromite, followed by titano-magnetite. Perovskite granules with up to 3 wt percent Nb_2O_5 occur throughout the matrix. Chalcopyrite, millerite and an Fe-Ni sulphide were also noted.

Emplacement and crystallisation of the dyke: The multiple shapes of calcite grains in the matrix and particularly the presence of elongate branching calcite crystals indicate crystallisation from a melt at different degrees of undercooling. The presence of amygdales also testifies to the presence of a melt whether they are filled gas cavities or immiscible liquid segregations. The contrasting textural and mineralogical character of the various bands within the dyke indicate that the dyke was emplaced as a sequence of discrete pulses of magma of similar composition. At least three pulses of magma would be required, corresponding to a) bands I and II, b) band III and c) bands IV to VI. Compositions of the first and second magma pulses (calculated from mineral compositions and abundances) are richer in CO_2 and K than the aphyric Benfontein kimberlite (Dawson and Hawthorne, 1973) and poorer in Mg and Fe. The second pulse (band III) is enriched in Cr, Ti and Fe over the first, and depleted in calcite components. It is difficult to calculate an average composition for the third pulse of magma. All three pulses carry similar megacryst phases. We conclude that the intrusions were nearly contemporaneous and derive from a common parent magma. The first magma pulse contained 20-30 percent microphenocrysts (serpentine and phlogopite) in a melt of 40-50 percent calcium carbonate, with the remainder equivalent to hydrous Mg-Fe silicate and Fe-Ti-Al-Cr oxides. Rapid cooling produced the chilled margin represented by band I. Slower cooling allowed the formation of amygdales in band II which has a similar total calcite content. The second magma pulse contained approximately the same proportion of megacrysts but in a melt that was considerably richer in Fe and Ti. Rapid cooling and continuous flow produced the oriented fine-grained texture of band III. The formation of band III was abruptly terminated by the third magma pulse consisting of 40 percent olivine, serpentine, phlogopite and opaque megacrysts in a carbonate-rich melt. The oriented branching calcites in band IV are evidence of stagnant conditions along the margins of the third intrusion and of supercooling prior to calcite crystallisation. Super-saturation was relieved by rapid dendritic crystallisation of calcite, by the formation of carbonate-rich amygdales, and by extensive metasomatic alteration of olivine to calcite. The concentration of megacrysts towards the centre of the dyke is ascribed to a combination of flow differentiation and increase in megacryst abundance with time. We assume that the three magma pulses are derived from a homogeneous mantle-derived kimberlite magma. Fractionation of crystals and melt in a shallow magma chamber and consequent tapping of the chamber provided the sequence of broadly similar magmas represented in this multiple intrusion. The sequence may represent sampling of successively deeper portions of a magma chamber or conduit that had differentiated by preferential settling of megacryst phases.

Formation of the amygdales: The amygdales may have formed as segregations of melt, as globules of an immiscible liquid, or as infilled gas cavities. The similarity in total carbonate content between amygdaloidal zones and adjacent zones free from amygdales (e.g. bands I and II) suggests that the material filling the amygdales crystallised contemporaneously with and probably derived from the kimberlite matrix. This indication is further reinforced by the similarity in phase compositions between the amygdales and the matrix. Carbonate and serpophite phases were crystallising contemporaneously in both amygdales and matrix and in some cases merge into one another (band V). These relationships are not consistent with formation as immiscible liquid droplets. We suggest the following model for the formation of the amygdales (cf. Smith, 1967; Mackenzie and White, 1970). Zones in the dyke that are characterised by amygdales have crystallised under stagnant conditions as evidenced by the development of delicate elongate carbonate laths at right angles to the direction of flow in the dyke. The presence of a vapour phase in association with a carbonate-rich melt allowed the nucleation of vesicles at relatively few equally spaced centres along the dyke margins. The vesicles then grew and expanded inward to the hotter more plastic interior. Cooling of the melt continued to a stage where carbonate and serpophite were crystallising directly from a residual fluid. This fluid in part migrated into the vesicles forming the carbonate-serpophite amygdales. Where the cavity walls effectively separated the fluid from the remainder of the dyke it could internally differentiate to produce the zoned amygdales. This physical separation was not always maintained towards the interior of the dyke and the carbonate and serpophite of the amygdales in some cases grade indistinguishably into the matrix of the kimberlite. The amygdales are thus interpreted as gas cavities infilled by the residual fluid resulting from crystallisation of the kimberlite.

References:

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