THE EMPLACEMENT OF SOME DIATREME-FACIES KIMBERLITES

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Intrusive kimberlite breccias from several South African pipes or pipe-like enlargements on dykes contain abundant fragments of country rock (mainly derived from Karroo strata) including huge, often brecciated, xenolithic masses ("floating reefs") which are located at positions well below their original stratigraphic levels. The fragments have been metasomatically altered but show no pyrometamorphic effects indicative of relatively high temperatures during or subsequent to their incorporation in the kimberlite. Tuffaceous kimberlites with xenolith contents similar to these intrusive breccias have been ascribed to explosive boring (Wagner, 1914) or gas-solid fluidised intrusion (Dawson, 1962). The origin of these intrusive breccias cannot, however, be attributed to either of these processes since the rocks lack the essentially fragmental textures characteristic of the tuffaceous varieties.

A striking petrographic feature of the intrusive breccias is the presence of numerous, frequently highly micaceous, globular or pellet-like segregations (0,1mm to 8 cms in diameter) which are set, together with scattered megacrysts and country rock xenoliths in a matrix of calcite and serpentine. In some examples sheaf-like aggregates of slender apatite crystals, considered to result from quenching (Wyllie, Cox & Biggar, 1962), are associated with the matrix calcite.

This texture is particularly well displayed by kimberlite from the Finsch pipe in which the segregations exhibit the following features: Many are spherical or ellipsoidal but others have irregularly curved shapes and lobate protrusions. The more irregular shapes are often the result of coalescence of two or more individuals. Sometimes clear separation of segregations is absent, the material forming web-like patches with lobate margins against the enclosing and interstitial calcite-serpentine matrix. Commonly individual segregations contain more or less centrally located kernels. Most kernels consist of single grains of olivine (often pseudomorphously replaced, mainly by serpentine). The two generations of olivine common to many kimberlites (Dawson, 1971) are represented among the kernel population. Megacrysts of phlogopite and garnet and rare peridotitic and dunitic fragments also occur as kernels as do metasomatically altered country rock fragments. Some segregations are, however, devoid of kernels. The fine-grained or crypto-crystalline material around the kernels or forming the bulk of kernel-free segregations consists mainly of reddish-brown slightly pleochroic phlogopite and a little colourless serpentine. Set in this groundmass are microphenocrysts (up to 0,4mm) of pale brown phlogopite and serpentinised olivine together with minute grains of perovskite, magnetite, and chromite. Elongate micro-phenocrysts are commonly oriented tangentially to the outer surfaces of the segregations.

The relative proportions of calcite and serpentine in the matrix surrounding the segregations vary considerably. In some instances calcite is restricted to scattered irregular grains, shreds and aggregates within serpentine but elsewhere the matrix consists almost entirely of calcite. The amount of calcite present depends on the degree to which it has been replaced by serpentine. Evidence of this replacement includes: Isolated rafts of calcite in serpentine which are optically continuous and show identical cleavage orientations, highly irregular replacement-type boundaries of many calcite grains against serpentine; pronounced embayments of serpentine in calcite, often with rhombohedrally stepped margins reflecting original calcite cleavages; pseudomorphous replacement of individual calcite aggregates by serpentine; and areas of serpentine containing numerous minute residual shreds of calcite where replacement has been incomplete. In view of this evidence it is concluded that the interstitial material between the segregations originally consisted largely of calcite. This conclusion is supported by the abundance of calcite in much of the kimberlite, by the poikilitic enclosure of small segregations in calcite and by the presence, even where the matrix is mainly serpentine, of residual aggregates of calcite which locally completely fill interstitial areas between segregations.

Kimberlites texturally similar to the Finsch material are present at the Monteleo, Andriesfontein, Muldersvlei, Dutoitspan, Wesselton, Koffyfontein and Klipfontein occurrences although the textural relationships are not always as clearly revealed. All these kimberlites do, however, contain segregations (similar to those of the Finsch kimberlite) which are set in serpentine-calcite matrices.

Several features of the matrix calcite in these kimberlites are interpreted as evidence that it is a late-crystallising primary mineral. These include the abundance of calcite (where massive replacement by serpentine has not occurred); the lack of gradational relationships between calcite and other minerals (except later serpentine); its occurrence as anhedral fine to medium sized grains (0,1 to 0,7mm), its poikilitic enclosure of other minerals and small phlogopitic segregations.

The clear separation of the carbonate and silicate phases, resulting in the emulsion-like textures described, is attributed to the development, during emplacement of the kimberlites, of late-stage, low temperature, immiscible K-rich silicate and carbonatitic liquids. Globular segregations of the silicate phase within the carbonate phase are ascribed to the greater viscosity of the former, the likelihood that it started to crystallise prior to the carbonatitic liquid, and the original abundance of the carbonatitic liquid which probably acted as a transporting medium during intrusion. Under these conditions it might be expected that solid material already present would provide nucleating centres around which the silicate fraction would tend to crystallise thereby accounting for the presence of kernels and the spherical shapes of many segregations. The carbonatitic liquid would be extremely fluid (Wyllie, 1966) and would crystallise in an interstitial relationship to the silicate segregations.

The following model for the development of the immiscibility relationships and emplacement of the kimberlites is proposed:

After the crystallisation of early phenocrysts the residual ascending kimberlite magma (carrying xenocrysts, phenocrysts and some xenoliths) differentiates, at relatively high crustal levels, into K-rich silicate and carbonatitic liquids, accompanied by a coexisting gaseous phase. Continued intrusion is accompanied by the separation of the gaseous phase and its accumulation at the head of the magma column where it forms a gas cap or aureole. Upon further uprise a stage is reached where the internal gas pressure exceeds the lithostatic load and the diatreme is formed by explosive breaching of the cap rocks. The rapid pressure drop resulting from break-through is accompanied by the upsurge of partly degassed magma fractions which incorporate explosively disrupted cap rock fragments and material which slumps from the walls of the diatreme. The presence of large "floating reefs" and smaller xenoliths at positions well below their original stratigraphic levels presents few difficulties if they are considered to have sunk through a low density, essentially carbonatitic liquid. The low temperatures envisaged, which are consistent with experimental results (eg. Wyllie, 1966; Franz and Wyllie 1967; Seifert and Schreyer, 1968), explain the absence of thermal metamorphic effects on xenoliths and wallrocks.

Franz and Wyllie (1967) suggested on experimental grounds that the fluid involved during the fluidised intrusion of some kimberlites may be a carbonatitic liquid rather than a dense gas phase; a concept which appears very similar to the final stages of emplacement proposed here. Postulation of an essentially carbonatitic transporting fluid (Watson, 1967; Franz and Wyllie, 1967 and this paper) overcomes many of the objections to high level magmatic activity within kimberlite diatremes.

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