CHARACTERIZATION OF METASOMATIC PROCESSES IN PERIDOTITE NODULES CONTAINED IN KIMBERLITE

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A comprehensive account has recently been given of a large suite of metasomatised peridotite nodules from the Kimberley pipes, particularly from Bultfontein (Erlank et al., 1986). We present first a summary of the distinguishing characteristics of the metasomatic changes observed in this suite, and then use them as a basis for examining metasomatic changes and styles in materials from other southern African kimberlites. The Kimberley suite is divided into garnet peridotites (GP) which contain no texturally equilibrated or primary (mantle derived) phlogopite, garnet phlogopite peridotites (GPP), which constitute the most abundant peridotites, phlogopite peridotites (PP) and phlogopite K-richterite peridotites (PKP). The latter two groups contain no garnet, while diopside may or may not be present in all four groups. The Cr-titanate minerals, lindsleyite and mathiasite (LIMA) are found only in PKP rocks, together with a new Ba- and Ce- rich Cr-titanate, Nb-Cr rutile and armalcolite (Haggerty et al., 1983, 1986).

Textural, mineralogical, chemical and isotopic data are consistent with an overall metasomatic process that is manifested by the GP-GPP-PP-PKP sequence recognized. The sequence does not imply that all PKP rocks will have formed from GP precursors, but does imply that the PKP suite represents the most highly metasomatised peridotites. The metasomatism can be viewed as one in which H_2O-rich fluids charged with K and other silicate-incompatible elements have migrated upwards in old lithospheric mantle, over a depth interval of some 30 - 50 km within the garnet stability field (Fig. 1) during the past 150 - 90 Ma (Fig. 2). The metasomatism is quantitatively dominated by the introduction of primary phlogopite, with many of the GPP rocks containing ~ 1 % or less phlogopite. At deeper levels garnet appears to be more abundant, and garnet replacement by phlogopite ± diopside is common, as manifested also by veins consisting mainly of these two minerals. However phlogopite has replaced all anhydrous silicates throughout the depth range involved. Enstatite, diopside, phlogopite and Cr-spinel together with constituent whole rocks show a well defined decrease in Al_2O_3 content within the GPP-PP-PKP sequence. Although some PKP rocks have formed from garnet-bearing rocks at shallower levels, most PKP rocks formed directly from Al-deficient harzburgitic rocks, with K-richterite replacing all pre-existing silicates, including phlogopite. Veined samples consist dominantly of K-richterite with lesser phlogopite and minor opaque minerals. The acme of metasomatism is represented by the growth of LIMA, and the new Ba and Ce-rich Cr-titanate, from precursor Cr-spinel, in PKP rocks. The latter suite shows highest levels of enrichment in S,Na,K,Rb,Ba,Sr,LREE,Fe,Ti,Zr and Nb (Fig. 3). These enrichments are reflected by associated mineralogical development, for example high Sr contents are found in diopside, K-richterite and particularly LIMA. Chemical and textural distinctions can be made between primary and secondary phlogopite (Fig. 4) and diopside. Nd-isotopic measurements indicate the existence of an ancient (> 1 Ga) enrichment in these sub-cratonic lithospheric mantle samples, and evidence for it is given by low Nd-isotopic ratios in diopside, phlogopite and non-metasmatic garnet from GPP rocks (Richardson et al., 1985).

The obvious similarities between PKP and MARID rocks, and to a lesser extent kimberlite, suggest that they must be related in some way in mantle space and time. Detailed assessment of mineralogical, major and trace element, and isotopic variations indicate that no simple relationships exist between these groups. Isotopic and trace element evidence is consistent with an asthenospheric (hot spot or subduction related?) origin for the fluids that led to the GPP and PP metasomatism (and possibly for the MARID parent magmas). If these fluids can be shown to be unrelated to the host kimberlite formation but are older, then their distribution over a considerable depth interval in the lithospheric mantle below Kimberley assumes a wider significance (Fig. 1). Kimberlites and MARID magmas may owe part of their geochemical signatures to interaction with stockwork-veined metasomatised mantle with linked channelways rich in incompatible elements (Erlank et al., 1986; Waters this volume). It is speculated that the PKP metasomatism may be derived in part from "last gasp" incompatible element-rich aqueous fluids escaping from crystallizing MARID magmas. One MARID nodule (from Newlands, kindly supplied by L. Daniels) has a thin rind of PKP material, interpreted as wall rock metasomite as depicted in Fig. 1.

The styles of metasomatism recognized in the Kimberley peridotites are also present elsewhere. Replacement of garnet by primary phlogopite, and the close spatial association of phlogopite and diopside with accompanying Cr-spinel (GPP and PP rocks), is common in peridotites from many other localities, including Jagersfontein (coarse peridotites only), Monastery, Lesotho localities such as Kao and Pipe 200, and the Precambrian Premier Kimberlite. We have also confirmed the presence of K-richterite in one Monastery and several Kampfersdam and Jagersfontein samples. There is also abundant edenitic and pargasitic amphibole with classic replacement textures in GPP rocks from Jagersfontein; we propose that these be called GPAP rocks, with Amphibole being non-richteritic. Both PKP and GPAP rocks at Jagersfontein contain examples that are veined; further details are given by Field et al., (this volume).

The southern African kimberlites referred to above are apparently Group I kimberlites with predicted $\mathcal{E}_{Sr}$ and $\mathcal{E}_{Nd}$ close to bulk earth values. In contrast enriched Group II kimberlites with higher $\mathcal{E}_{Sr}$ and lower $\mathcal{E}_{Nd}$ values (Smith, 1983) appear to be deficient in metasomatised nodules (M. Skinner, pers. comm.) which is counterintuitive. Thus we have not recognized any primary phlogopite or amphibole in a large suite of peridotites from the Finsch pipe. However, several MARID samples are present in the Newlands Group II kimberlite, including the one described above with a PKP rind.

For present purposes the different styles of metasomatism can be simply assessed in two ways. First we consider critical element abundances in primary phlogopites, the metasomatic mineral common to all suites. As shown by several workers TiO_2 and Cr_2O_3 are useful in this respect and Fig. 4 indicates the distinction that can be made for Kimberley peridotite phlogopites of various kinds. Ranges (in wt. percent) in composition for primary phlogopites from various peridotite types at other localities are as follows: Jagersfontein (0.1-0.9 TiO_2, 0.3-1.1 Cr_2O_3), Monastery (0.1-0.8 TiO_2, 0.1-1.0 Cr_2O_3, R.O. Moore, pers. comm.), Pipe 200 (0.2-0.5 TiO_2, 0.9-1.1 Cr_2O_3), Newlands (0.2-1.7 TiO_2, 0.3-1.0 Cr_2O_3), Premier (0.6-1.9 TiO_2, 0.3-0.8 Cr_2O_3), Matsoku (1.5-1.6 TiO_2, 0.5-0.8 Cr_2O_3, B. Harte and J.J. Gurney, pers. comm.). In general there is overlap with primary peridotite phlogopites from Kimberley (Fig. 4) with nearly all samples having < 1.2 % Cr_2O_3. In detail the Precambrian Premier and the Matsoku micas tend to have higher TiO_2 contents, however taken as a whole all these primary phlogopites are remarkably similar in bulk composition.

Consideration can next be given to silicate-incompatible trace elements by comparison of the mantle normalized diagrams shown in Figs. 3, 5 and 6. In a general sense the enrichment trends are similar, increasing in the sequence GP→ GPP→ PP and, where present, the PKP and GPAP suites. Furthermore the slopes of the trends are similar with least enrichment for Ti and maximum enrichment for Rb, Nb or K, and with enrichment factors of ~ 100X nominal mantle commonly being reached. In detail, although the enrichment trends for Kimberley and Premier are reasonably similar, they are somewhat different from those shown for Jagersfontein. In the latter the trends from Sr→ K→ Nb are generally smooth, while in the other two localities the most enriched samples show decreased abundances of Nb and Sr relative to K. Although the trends refer to average abundances, the differences arise from higher Nb contents (up to 53ppm) and lower Zr/Nb ratios (some <1), and higher Sr abundances (up to 420ppm in PKP and 480ppm in GPAP nodules) in the Jagersfontein samples. Coupled with the apparent greater proportion of GPAP relative to PKP nodules, and with amphibole compositions generally having $Na_2O>K_2O$ (Field et al., this volume) the above comments point to a greater diversity of mantle fluid compositions beneath Jagersfontein as compared with those beneath Kimberley, even though there are obvious similarities in metasomatic style for the respective metasomatic suites (e.g. PKP rocks, LIMA, rutile etc.).

Further work is required on nodules from other pipes (off-craton and on-craton, older and younger, Group I and Group II kimberlites) but the available evidence suggests a general similarity of metasomatic styles in terms of mantle space and time in sub-cratonic lithosphere beneath southern Africa.

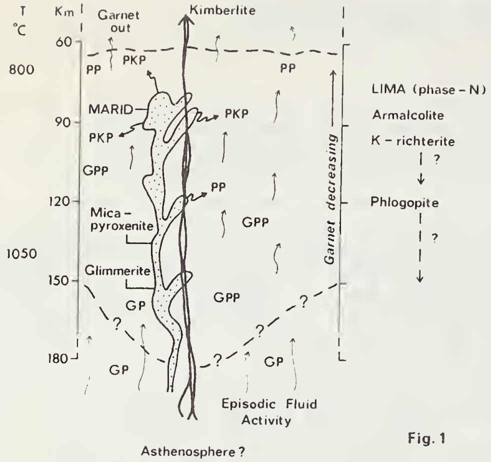


Fig.1. Scenario of recent MARID and metasomatic activity in old subcratonic lithosphere beneath Kimberley. Details from Erlank et al. (1986).

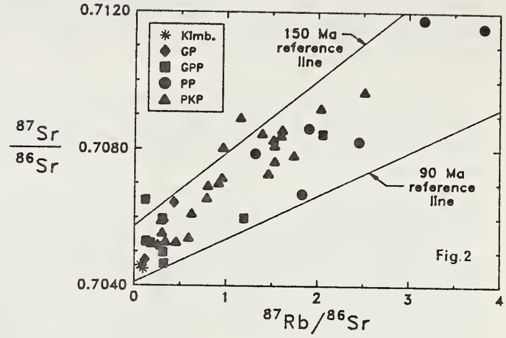


Fig.2. Rb-Sr isochron diagram. Reference lines indicate recent metasomatic activity and do not necessarily imply any age significance.

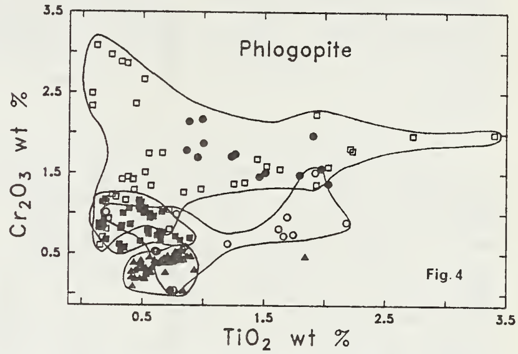
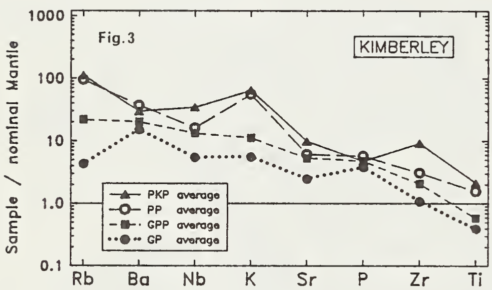
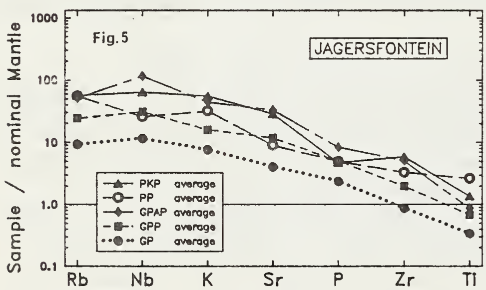
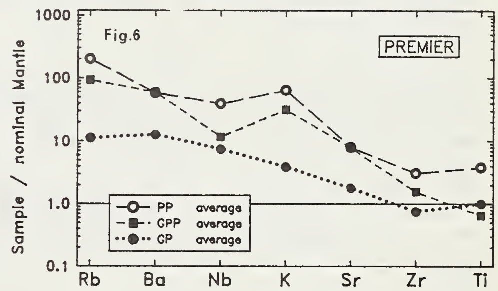


Fig.4. Kimberley nodules: Closed triangles -PKP; open circles - PP; filled squares - primary GPP; open squares - secondary GPP; filled circles - secondary GP.







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