ULTRAPOTASSIC MAGMAS: END-PRODUCTS OF SUBDUCTION AND MANTLE RECYLING OF SEDIMENTS?

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Isotopic studies indicate that some examples of potassic magmatism are derived from ancient, highly enriched (radiogenic $^{87}Sr/^{86}Sr$, unradiogenic $^{143}Nd/^{144}Nd$) sources, and in an attempt to investigate the origins of these enriched components, we have undertaken a comparative Sr, Nd and Pb isotopic and geochemical examination of potassic magmatism from a number of localities. Diamond-bearing lamproites from Western Australia, leucitites from Gaussberg, high-K alkaline dykes from MacRobertson Land, Enderby Land and Queen Mary Land regions of east Antarctica and madupites, wyomingites and orendites from Leucite Hills, Wyoming, have remarkably similar geochemical characteristics (Fig. 1). All have high Ni and Cr contents and high Mg numbers (each locality averaging Mg/(Mg+total Fe)>0.65 with the exception of Manning Massif, Mt Bayliss and Bunger Hills samples, which have Mg numbers of 0.58, 0.58 and 0.50 respectively) as well as high to extreme abundances of K_20, $Ti0_2$, F, Cl, SO_2, H_20, P_20_5, Ba, LREE, high K_20/Na_20, Fe^{3+}/Fe^{2+}, Th/U, La/Nb and Ba/La ratios, low K/Rb and K/Ba ratios and relatively low abundances of Al_2O_3, CaO and Na_20. On a Sr-Nd isotope diagram (Fig. 2), these magmas lie within the "enriched" quadrant, indicating that their sources have had long histories (>1 byrs) of high Rb/Sr and low Sm/Nd (ie; LREE enrichment). Pb isotopic compositions (Fig. 3) indicate multistage histories of U/Pb fractionation, requiring an earlier high U/Pb stage to generate the high $^{207}Pb/^{204}Pb$, followed by a low U/Pb stage during which the evolution of $^{206}Pb/^{204}Pb$ is retarded.

There are a number of possible mechanisms which could account for these unusual chemical and isotopic properties, the most obvious of which is crustal contamination. However, the extremely high concentrations of Sr, Pb and the REE make these magmas insensitive to bulk contamination processes, requiring the assimilation of substantial amounts of crustal material to account for their isotopic compositions. Because of their extreme degree of LREE-enrichment, bulk assimilation of felsic granulite within the lower continental crust will effectively dilute the incompatible element contents of the magmas and should therefore produce a positive correlation between Nd concentration and εNd. In the case of the Western Australian lamproites, a correlation in the opposite sense was noted by McCulloch et al (1983). Crustal assimilation via specialised mechanisms, such as selective volatile transfer or zone refining, is conceivable but is unable to account for the high Mg numbers and Ni and Cr contents or the presence of mantle xenoliths (and in one case, diamonds). Furthermore, the remarkable similarities of unusual geochemical and isotopic compositions of these magmas from diverse localities are unlikely to be the result of random crustal contamination processes but instead, suggest their derivation by a common mechanism.

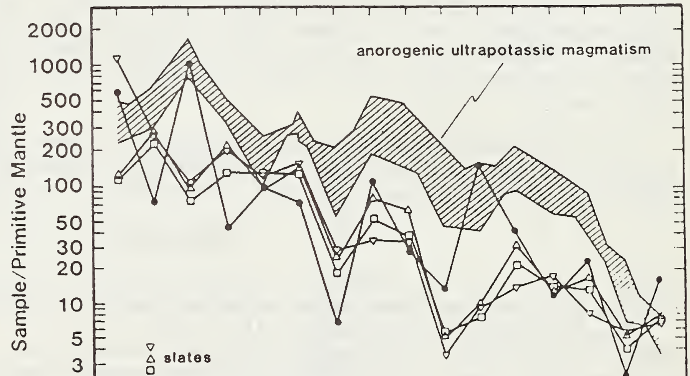


Figure 1. Trace element patterns, normalised to estimated primitive mantle abundances, of average potassic magmas (hatched) from Western Australia (McCulloch et al 1983, Nelson et al 1986, Jaques et al 1984, Nixon et al 1984), Priestley Peak and Gaussberg, Antarctica (Sheraton and England 1980, Sheraton 1983, Collerson and McCulloch 1983, Sheraton and Cundari 1980) and Leucite Hills (orendites and wyomingites, from Kuehner et al 1981, Vollmer et al 1984; Th and U data not available) compared with some examples of modern sediments (from Thompson et al 1984).

Petrogenetic models involving small degrees of partial melting of a lherzolitic or harzburgitic mantle source which has been variably "metasomatised" by an incompatible element rich component have been advocated by a number of workers (eg; Jaques et al 1984, Vollmer et al 1984). For example, enrichment events within the subcontinental lithosphere or upper mantle may result in crystallisation of phlogopite and LIL-rich titanates which are later reactivated to produce isotopically evolved ultrapotassic magmatism (cf. Jaques et al 1986). However, these models frequently fail to address the crucial question of the ultimate source of these metasomatic components. Furthermore, the unusual multistage histories of U/Pb fractionation indicated by the Pb isotopic compositions of these magmas, particularly the earlier high U/Pb stage, are not readily explained by models which favour the generation of these "metasomatic" components entirely within the upper mantle or subcontinental lithosphere.

Figure 2. Initial Sr-Nd isotope diagram showing fields for Western Australian lamproites (McCulloch et al 1983), Leucite Hills (Vollmer et al 1984 and analyses of two wyomingites from this study), Gaussberg (Collerson and McCulloch 1983) and the Priestley Peak melasyenite at its emplacement age of 482 myrs (initial Sr and age data from Black and James 1983). Initial εNd values for Manning Massif tristanite (emplacement age; 50 myrs, from Sheraton 1983), Mt Bayliss alkali melasyenite (414 myrs old) and Bunger Hills trachybasalt dyke (Cambrian or younger) are -9.3, -12.3 and <-16.3 respectively. Initial Sr not determined for these samples. Field of mid-ocean ridge basalts shown for comparison.

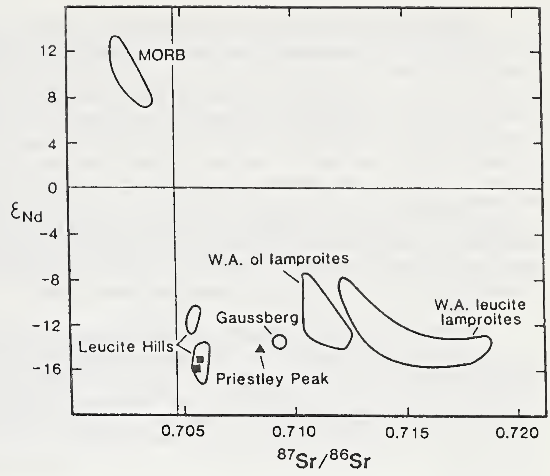
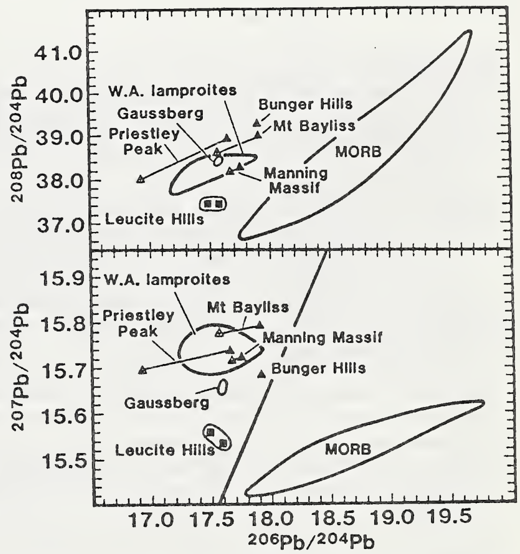


Figure 3. Pb-Pb isotope diagram showing compositions of Western Australian lamproites and Gaussberg leucities (from Nelson et al 1986), Leucite Hills and Antarctic dykes (▲ = measured, △ = age corrected). Field of mid-ocean ridge basalts for comparison. Corrections to $^{206}Pb/^{204}Pb$ for decay since emplacement are small for the 50 myr old Manning Massif tristanite and because of its low U/Pb, to the Mt Bayliss alkali melasyenite dyke but are considerably larger for the Priestley Peak melasyenite. Age corrections to the measured $^{207}Pb/^{204}Pb$ ratios are within analytical error for the Manning Massif and Mt Bayliss samples. The exact emplacement age of the Bunger Hills trachybasalt dyke is uncertain but is believed to be Cambrian or younger. Its high measured $^{207}Pb/^{204}Pb$ requires a long history (>1 byrs) of high U/Pb and is a feature that predates emplacement. The general features of the Nd and Pb isotopic compositions of the Antarctic dykes are independent of any uncertainty introduced by the age corrections and are similar to those of lamproites from Western Australia and leucitites from Gaussberg.



We propose that the geochemical and isotopic characteristics of these and possibly other examples of continental potassic magmatism are due predominantly to the involvement of a sedimentary component, and that these magmas represent mixtures of mantle and the fusion products of ancient sediments which have been subducted into the mantle (to depths within the field of diamond stability) and stored for long time periods within the subcontinental lithosphere. A number of other studies (see, for example, Nelson et al 1986 and references cited therein) have argued for the involvement of more recently subducted sediments in the generation of highly potassic magmatism from Italy and Spain, whilst the arclike Ba/La, Ba/Nb and La/Nb ratios of some examples of continental potassic magmatism has been previously pointed out by Thompson et al (1984) and Varne (1985). The high abundances of F, Cl, $P_2 0_5$, SO_2 and $H_2 0$, high K/Ba and low K/Rb ratios of these examples of continental potassic magmatism, their highly oxidised nature (evidenced by their high Fe^{3+}/Fe^{2+}) and their radiogenic Sr and unradiogenic Nd are readily explained by the involvement of a sedimentary component. By analogy with modern sediments, ancient oceanic sediments will probably have possessed high $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ due to the contribution of radiogenic Pb from the upper continental crust. Although the U/Pb ratio of modern pelagic oceanic sediments is variable, it is frequently low, and may have been generally lower during the Archean when the lower degree of oxidation of the Earth's atmosphere would favour the less soluble U^{4+} ion over U^{6+}. Ancient sediments therefore probably possessed low U/Pb ratios and the isotopic evolution of Pb would have been severely retarded following its erosion from the continents and deposition in the ocean basins. Hence, the unradiogenic $^{206}Pb/^{204}Pb$ of continental ultrapotassic magmas may be an indication of the time elapsed during sedimentation and storage within the mantle or subcontinental lithosphere, whereas the variation in $^{207}Pb/^{204}Pb$ may reflect the nature and age of the continental provenance.

The presence of diamonds in the Western Australian lamproites provides further support for the involvement of sediment recycling processes, as an extremely wide range of $\partial^{13}C$ values (including values as low as -34 per mil) have been documented by carbon isotopic studies of diamonds from kimberlites and lamproites (see Ozima et al 1985 and references therein), consistent with an origin of some diamonds from sedimentary sources of carbon. A wide range of $^3He/^4He$ ratios were also recently reported by Ozima et al (1985) for diamonds. These authors interpreted the high $^3He/^4He$ ratios of some South African examples as indicating that these diamonds had remained closed systems for almost the age of the Earth. However, an alternative interpretation is offered by the recently confirmed high $^3He/^4He$ ratios of modern ocean sediments (Ozima et al 1984) and manganese nodules (Sano et al 1985), believed to be carried by interplanetary dust particles. Furthermore, a common mineral assemblage of diamond inclusions, olivine + knorringite-rich garnet + enstatite, has been attributed to recrystallisation of the residue of olivine + chrome spinel + enstatite cumulates within oceanic crust following its hydrothermal alteration and partial melting during subduction into the mantle (Ringwood 1977). These data argue for the involvement of components derived from both subducted sediments and oceanic crust in the formation of diamonds.

Although these examples of continental potassic magmatism are not obviously associated with any known modern or past subduction zones, their unusual multistage Pb isotopic compositions require a significant time period (probably much greater than 1 byrs) to have elapsed between the fractionation events lowering the U/Pb ratio (ie; erosion and sedimentation at the Earth's surface) and subsequent potassic magmatism. As these suites all intrude old Archaean or Proterozoic cratons, their sources are probably stored for long periods within the subcontinental lithosphere. The existence of substantial reservoirs of low U/Pb, enriched mantle components within the subcontinental lithosphere may also account for the generally radiogenic Pb of the MORB and ocean island source reservoirs.

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