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THE ULTRAPOTASSIC ROCKS OF THE WEST KIMBERLEY REGION, WESTERN AUSTRALIA, AND A NEW CLASS OF DIAMONDIFEROUS KIMBERLITE

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Diamonds have recently been found in kimberlitic rocks intimately associated with the leucite lamproites (Wade and Prider, 1940; Prider, 1960) of the Fitzroy area of Western Australia (Garlick, 1979; Atkinson et al., 1982). In this paper we present a summary of the geology, mineralogy and geochemistry of the ultrapotassic rocks of the province including the diamondiferous kimberlitic rocks, here termed 'kimberlitoids' to emphasize their unusual mineralogy and geochemistry.

Geological Setting

The ultrapotassic rocks of the West Kimberley region lie immediately south of the southwestern margin of the stable Proterozoic Kimberley block, and intrude the igneous, metamorphic and sedimentary rocks of Precambrian to Mesozoic age of the Lennard Shelf and adjacent Fitzroy Trough at the northern margin of the Canning Basin as shown in the figure below. Over 100 bodies, both of leucite lamproite and kimberlitoid composition, are now known. There are three main clusters which appear to be controlled by northwesterly-trending faults at the basin margin, and major northerly-trending faults: the Lennard Shelf (Ellendale area), the Shelf Margin (Calwynyardah area), and the Fitzroy Trough (Noonkanbah area). The majority of the bodies are intruded along the axes of major northwesterly-trending anticlines, and a number are elongated in an easterly direction.

The kimberlitoids (particularly the diamondiferous bodies) are confined mainly to the Lennard Shelf and shelf margin. In the Ellendale and Calwynyardah areas they occur as clusters of pipes, rare dykes and sills; the pipes tend to form topographic lows, in some cases surrounded by upstanding rim rocks. The largest pipe has a surface area of 128 ha. Individual pipes may be simple, or complex and zoned; many have an outer zone of tuff or tuff breccia and a central magmatic core. Several bodies have associated crater sediments indicating little erosion since their emplacement.

The leucite lamproites are most abundant in the Noonkanbah area where they form topographic highs. They occur as small volcanic plugs, vents, dykes, sills and, possibly, flows. The largest body forms a zoned pluton 3 km in diameter. Many of the plugs show concentric compositional zoning and have an outer zone of breccia. Concentric and radial jointing is also common.

Age

The leucite lamproites are considered to be of early Miocene age, 17-22 m.y. (Wellman, 1973), mainly on the basis of K-Ar dating of phlogopite. Two bodies of kimberlitoid, one of which is diamond-bearing, have yielded similar ages, 20-21 m.y. by both K-Ar and Rb-Sr methods. The close spatial association of these with the other kimberlitoids and their intimate association with the leucite lamproites (e.g. clasts of leucite lamproite in kimberlitoid) suggests that the other diamondiferous Ellendale pipes are also of Miocene age.

Petrography

Both the kimberlitoids and lamproites are strongly porphyritic. The kimberlitoids contain two generations of olivine; anhedral olivine xenocrysts up to 8 mm diameter coexist with euhedral olivine microphenocrysts in a fine-grained matrix of intergrown phlogopite and diopside with minor chrome spinel, perovskite, potassian titanian richterite, barite and apatite. Small xenoliths of deformed, granular dunite are common; most of the xenocrystic olivine is probably derived from disaggregated dunite. Lherzolite xenoliths appear to be rare. The tuffaceous kimberlitoids contain abundant olivine and magmatic fragments in a poorly sorted matrix of detritus derived from magmatic kimberlitoid. Tuff breccias are also present and contain abundant quartzitic country rock fragments.

The leucite lamproites contain phenocrysts of phlogopite, olivine, and/or leucite in a lamprophyric-textured groundmass of leucite, titan-phlogopite, diopside, potassian titanian richterite, apatite, barite, and priderite. Coarse-grained lamproite from Walgidee Hill also contains Sr-rich perovskite, wadeite, shcherbakovite and jeppeite. Pyroclastic rocks, agglomerate, tuff, and lapilli tuff, together with autolithic breccia and tuff breccia are common.

Most intrusions are deeply weathered and many are deuterically altered; olivine is commonly replaced by serpentine, nontronite, celadonite or chalcedony, and leucite is almost invariably replaced by K-feldspar. Carbonate veining is widespread in a number of bodies; other common secondary minerals include zeolite and montmorillonite.

Mineral Chemistry

Xenocrystal olivine compositions in the kimberlitoids lie in the range Mg_{91-93}($Mg=100Mg/(Mg+Fe)$) and groundmass/microphenocrystal olivine is Mg_{90-91}. Xenocrystal olivine in the leucite lamproites lies in the range Mg_{90-91}, whereas the phenocrysts range to more Fe-rich compositions, Mg_{83-90}. Phlogopite shows a wide range in composition from pale coloured Mg- and Al-rich phenocryst cores (Mg_{91-92}, 22-23% MgO, 10-12% Al_2O_3, 5-6% TiO_2) in the more mafic lamproites to strongly coloured Ti-Fe rich types (Mg_{70-80}, $\leq$30% FeO, 8-10% TiO_2, 1-3% Al_2O_3) present as rims on phenocrysts and in the groundmass. Groundmass phlogopite in individual kimberlitoids also shows extreme compositional ranges (2-12% Al_2O_3, 1-7% TiO_2). Diopside, rich in Ti (1-2% TiO_2) and poor in Al ($\leq$0.85% Al_2O_3, mostly <0.5%) is present in the groundmass of the kimberlitoids, and occurs as microphenocrysts and in the groundmass of the leucite lamproites. Potassian titanian richterite (2-6% TiO_2, 4-7% K_2O) is common in the groundmass of both kimberlitoids and lamproites, and is particularly abundant in the more evolved lamproites. Chrome spinel occurs in kimberlitoids and the more mafic lamproites. The spinels range from ferroan aluminous magnesiochromites (8-12% Al_2O_3, <1% TiO_2, Cr/(Cr+Al)=0.55-0.85) through rare titaniferous magnesian aluminous chromite (1-4% TiO_2, 10-11% Al_2O_3, Cr/(Cr+Al)=0.8-0.9) to titaniferous magnesian chromite (3-6% TiO_2, <10% Al_2O_3, Cr/(Cr+Al)$\geq$0.9). Ulvospinel-magnetite apparently does not occur, presumably because of the crystallisation of priderite which is present in almost all the lamproites examined. Minerals normally considered to be characteristic of kimberlite, including pyrope garnet, chrome diopside (1-2% Cr_2O_3) and ilmenite, have been found in bulk samples of kimberlitoid but are rare. The pyrope is rich in Cr (~7-8% Cr_2O_3, 6% CaO) whereas the ilmenite is mostly of Mg-poor composition ($\leq$8% MgO); Mg-poor ilmenite also occurs in some of the more mafic lamproites. Enstatite Mg_{92-93} (~1.5% Al_2O_3) is very rare.

Geochemistry

The leucite lamproites are characterised by extremely high K_2O (up to 12% with $K_2O \simeq Al_2O_3$), TiO_2 (3-8%) and BaO contents, and very low Na_2O contents (Wade and Prider, 1940; Prider, 1960). They show a wide range in MgO and SiO_2 contents (3-15% MgO, 45-60% SiO_2), and most follow an orenditic differentiation path of increasing silica saturation, coupled with increasing TiO_2 and K_2O contents.

In contrast, the kimberlitoids have much higher MgO contents (15-28% MgO), have MgO/K_2O ratios significantly greater than unity (typically 4-6, cf ≤ 1 for the leucite lamproites), and have lower SiO_2, TiO_2, Al_2O_3 and K_2O contents than the lamproites. Ni and Cr contents in the kimberlitoids are higher than those in the lamproites, typically 600-1000 ppm Ni, 1000-1500 ppm Cr.

Both the lamproites and the kimberlitoids are extremely enriched in 'incompatible' elements, typically containing >750 ppm Zr, >75 ppm Nb, $\geq$5000 ppm Ba, $\geq$200 ppm Rb, $\geq$20 ppm Th, $\geq$200 ppm La and $\leq$300 ppm Ce. Both the kimberlitoids and the lamproites have extremely fractionated REE patterns, typical of kimberlitic rocks in general. LREE abundances in the lamproites range from 600-2000 x chondrites whereas the kimberlitoids range from 500-1000 x chondrites. Contents of Nb are higher, and Zr/Nb ratios lower (<10, cf >10), in the kimberlitoids than the lamproites.

It is concluded that the leucite lamproites are alkalic (potassic) basic rocks whereas the kimberlitoids are alkalic ultrabasic rocks resembling kimberlite.

Relationship between leucite lamproites, kimberlitoids and kimberlites

Diamond has been found in both the kimberlitoids and the leucite lamproites, implying a similar, deep-seated origin for the suite as a whole. The similarities in mineralogy and geochemistry of the two rock types and their close spatial association also favours a genetic relationship. Observed differences are thought to be due to fractionation (cf. Prider, 1960).

In general, the West Kimberley kimberlitoids have a similar chemistry to 'typical' kimberlites but their SiO_2, K_2O and TiO_2 contents are higher and their CaO contents lower. However, there are several important mineralogical and petrographic features which combined indicate that the kimberlitoids are not 'typical' kimberlite. These include the rarity of garnet and picro-ilmenite, the presence of groundmass amphibole, the apparent absence of primary carbonate, and the close association with leucite-bearing rocks. These features are consistent with equilibration at lower pressures and, possibly, higher temperatures than 'typical' kimberlite.

Since economic diamond-bearing kimberlites have so far been restricted to cratons which have not been deformed since the Precambrian the discovery of diamond in kimberlitic rocks of unusual composition and in leucite-bearing basic rocks in a shelf environment, outside the craton, has important implications for diamond exploration. If, as we suspect, the rich Argyle pipe in the East Kimberley district proves to be of similar composition to the kimberlitoids of the West Kimberley then clearly a new class of potentially economic diamond-bearing rocks exists.

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H6 KIMBERLITE – LAMPROITE CONSANGUINITY

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The discovery of kimberlites associated with lamproites, both containing diamonds, in the West Kimberley, Western Australia (Atkinson, 1982 and pub. comm) has prompted investigation of the implied genetic relationship. However, lamproites embrace a range of rock types which we demonstrate, using the Spanish occurrences, can have different origins.

The term lamproite was used by Niggli (1923 and subsequent publications) within his classification scheme based on Niggli norms, for volcanic rocks rich in K and Mg. Subsequently, Tröger (1935) stated that lamproite was the effusive equivalent of lamprophyres rich in K and Mg. However, no rocks were described under this heading in Johannsen's (1938) comprehensive petrographic classification. Following Tröger (1935), Wade and Prider (1940) adopted the term for the Australian occurrences (which are mostly minor intrusions) and made the following subdivisions - fitzroyite, cedricite, mamilite, wolgidite and wyomingite. All but latter were new (see also Prider, 1960) and were described as differentiated members containing combinations of phlogopite, leucite, clinopyroxene, magnophorite (K-richterite) with commonly altered olivine.

The Spanish occurrences (Borley, 1967) - termed lamproites by Fuster et al. (1967) - consist of fortunite, verite and jumillite and contain sanidine (or K bearing glass) unlike the Australian rocks, together with clinopyroxene, phlogopite and apatite with or without orthopyroxene, olivine, amphibole, leucite, plagioclase, calcite and quartz. Xenoliths include sporadic mantle-type spinel lherzolites.

Even allowing for the range of petrographic types within each lamproite group it can be seen from the Table below that the Spanish lamproites have a relatively low K_2O/Na_2O ratio and TiO_2 content but with higher Al_2O_3. Of the minor elements, Nb (33ppm) and Zr (571ppm) are significantly lower than in the Australian rocks (150 and 942 ppm respectively).

	Spain	W. Australia		S. Africa
wt%	Lamp.(15)	Lamp.(9)	Kimb.(3)	Kimb.(80)*
SiO_2	54	52	37	36
TiO_2	1.4	5	3.5	1
Al_2O_3	10	7	4	3
Fe_2O_3	6	7	8	8
MgO	10	8	16	17
CaO	5	4	6	11
Na_2O	1.5	0.6	0.4	0.4
K_2O	6	8	3	1.5

*Gurney and Ebrahim (1973)

Numbers of samples analysed given in parentheses.

A major problem in Western Australia is the petrographic differentiation of rocks of kimberlite affinity which may be altered and contain serpentinised olivine (reflected by increased MgO content) and which may also contain deep seated xenoliths and