ALKALIC ULTRAMAFIC MAGMAS IN NORTH-CENTRAL MONTANA, USA: GENETIC CONNECTIONS OF ALNOITE, KIMBERLITE, AND CARBONATITE

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The extent of genetic relationships among kimberlites, carbonatites, alnoites, and other rare alkalic igneous rocks continues to be an important field of research and speculation. Compositions of groundmass spinels have been cited as definitive indicators for separating true kimberlites from alnoitic and other non-kimberlitic rocks (Mitchell, 1986). Igneous rocks and related breccia-facies occurrences in a stable cratonic setting in the Missouri River Breaks area of north-central Montana provide geochemical evidence for a continuum of compositions between alnoitic rocks and kimberlitic rocks (here referred to as kimberlites) that are closely similar to true kimberlites in contents of major and trace elements, including the rare earths (REE), and contain groundmass spinels that are transitional between alnoitic and true kimberlitic spinels. In addition, the Missouri Breaks rocks provide evidence for late-stage carbonatitic derivatives that have similarities to isolated carbonate-rich mica peridotite intrusions in east-central Montana. All of the occurrences are known or inferred to have been emplaced during the middle Eocene, 46 to 51 Ma, following a longer span of mafic alkalic and felsic alkalic igneous activity from late Cretaceous to middle Eocene time in several nearby igneous centers, and preceding the 27 Ma old lamproite at Smoky Butte 120 km to the southeast (Marvin et al, 1980).

Diatremes and intrusions in the Missouri River Breaks area consist of alnoite (ALN) (= turjaite, melilite-bearing), monticellite peridotite (MoP) (melilite-free), carbonate-rich mica peridotite (CMiP), kimberlite (KI) (phlogopite-calcite-serpentine KI), and rare carbonatite (CAR), which tend to show a continuum of major- and trace-element compositions. Ranges of MgO content (ALN, 10-25; MoP and CMiP, 19-31: KI 23-32 wt percent) overlap, as do the fields of major-element oxides versus MgO, except for CaO and SiO_2 which show adjacent but offset ALN and MoP-CMiP fields. The Williams Ranch KI values plot close to or within most MoP oxide fields, but have higher K_2O (fig. 1) and P_2O_5. Compositional trends among intrusions and within single intrusions suggest that the major control is the addition/subtraction of Fo 80-90 olivine, with subsidiary control attributable to shallow-level fractionation of phlogopite, Fe-Ti oxide, nepheline, and apatite. Montana KI and MgO-rich MoP-CMiP values plot within the general KI compositional fields defined by African, Russian, and several United States KI (Dawson, 1978; Fesq et al, 1975; Danchin et al, 1975), except for higher K_2O in Montana KI. However, the higher K_2O is similar to K_2O in phlogopite-rich African KI such as New Elands (Dawson, 1978). In Montana CAR, only Al_2O_3, Na_2O, TiO_2, and P_2O_5 are similar to some ALN.

Trace elements versus MgO also show overlapping ranges for ALN and MoP-CMiP, and for MoP-CMiP and KI, although KI tends to have higher abundances of Cs, Hf, and U than MoP-CMiP. Cr and Co are positively correlated with MgO, while many magmaphile elements show poorly defined negative correlation with MgO. The ranges of trace-element abundances of the Montana samples are similar to ranges defined by the general compositions of African, Russian, and United States KI (Mitchell and Brunfelt, 1975; Fesq et al, 1975). REE patterns for ALN, MoP, and KI are all light REE-enriched, steep, and nearly linear (La 120-600X, Lu 2-10X chondrite), with KI in the higher part of the ranges (fig. 2). CAR and CMiP patterns are also linear, more strongly light REE-enriched, and slightly steeper (La 500-1000X, Lu 4-7X chondrite). The REE abundances of Montana ALN, MoP, CMiP, CAR, and KI are all in the general world-wide KI range (Mitchell and Brunfelt, 1975; Fesq et al, 1975), but are lower than some carbonate-rich, evolved KI such as de Bruyn, South Africa (Fesq et al, 1975) (fig. 2).

The overlapping ranges of major, trace, and rare-earth elements among Montana ALN, MoP, CMiP, KI and CAR suggest a close genetic relationship by processes of magma generation and fractionation, and further suggest that the MgO-rich members are transitional to or equivalent to true kimberlites. Montana KI and some CMiP, in keeping with the continuity of ranges of chemical compositions, have groundmass spinel compositions (Table 1) that are also intermediate between those typical of alnoitic rocks and those in kimberlites from elsewhere. The mineralogical variability within rocks classified as true kimberlites suggests that their groundmass mineralogical characteristics may overlap with other alkalic ultramafic rocks. The wide variations in late-stage conditions of emplacement, diatreme formation, and crystallization may be more important than initial differences in composition in determining the development of mineralogic characteristics of true kimberlite. The existence of a wide spectrum of related magmas of kimberlitic affinity, reinforced by the occurrences of diamond in lamproitic rocks, indicates that rock types other than kimberlite could have economic potential.

TABLE 1: Cation ratios of groundmass spinels

	Mg/(Mg + Fe)	Cr/(Cr + Al)	Ti/(Ti + Cr + Al)
Williams Ranch KI			
FeCr spinel	0.2 - 0.5	0.6 - 0.7	0.07 - 0.2
MgCr Usp magnetite	0.1 - 0.3	0.1 - 0.8	0.78 - 0.96
Macdougal Springs CMiP			
FeCr spinel	0.25 - 0.45	0.60 - 0.85	0.05 - 0.40
MgCr Usp magnetite	0.2 - 0.3	0.2 - 0.4	0.5 - 0.6

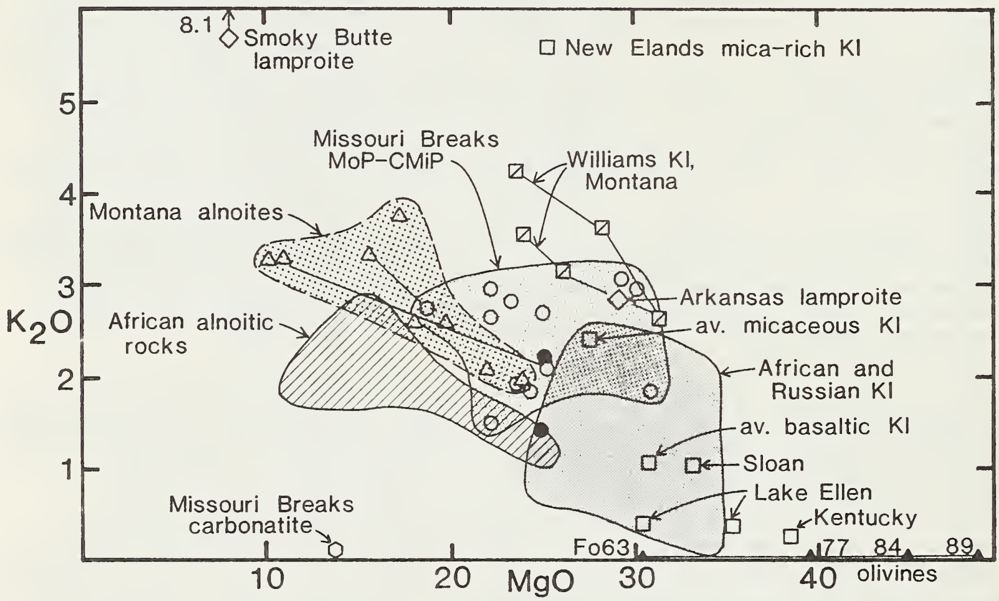

Fig. 1 K_2O - MgO variation for Montana rocks in comparison with African alnoitic rocks and African and Russian kimberlites (Dawson, 1978; Danchin et al, 1975; Fesq et al, 1975); kimberlites from the Sloan pipe, Colorado, Lake Ellen, Michigan, and Elliott County, Kentucky, USA; and lamproites from Smoky Butte, Montana, and Prairie Creek, Arkansas, USA. Olivine compositions from Fo 63 to 89 are shown on the MgO axis. Lines connect samples from the same intrusions. Triangles: Missouri Breaks alnoites; open circles: Missouri Breaks monticellite peridotites (MoP) and carbonate-rich mica peridotites (CMiP); closed circles: east-central Montana CMiP; squares: kimberlites (KI); diamonds: lamproites; hexagon: Missouri Breaks carbonatite dike.

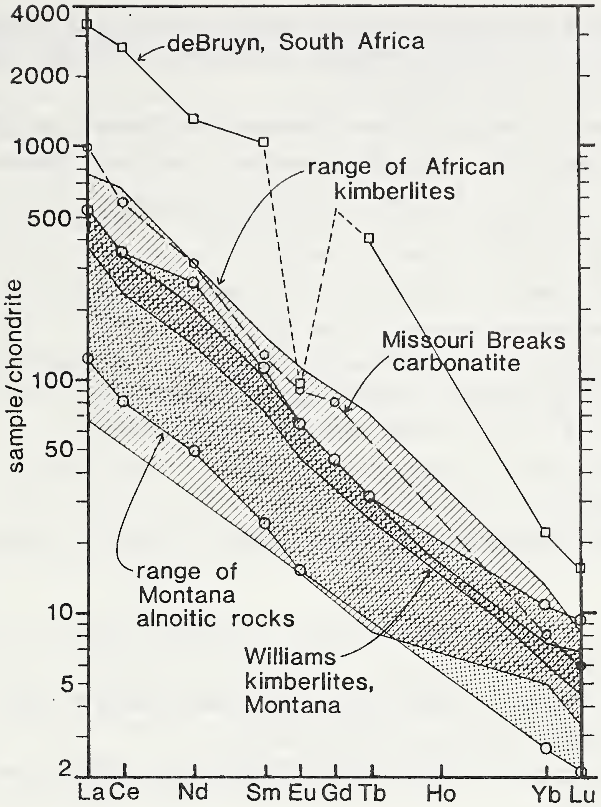

Fig. 2 Ranges of chondrite-normalized rare-earth element patterns for Montana alnoitic rocks (includes alnoites, monticellite peridotites, and carbonate-rich mica peridotites), Montana kimberlites, and a Missouri Breaks carbonatite, in comparison with the range of African kimberlites and the enriched de Bruyn kimberlite, South Africa (Fesq et al, 1975; Mitchell and Brunfelt, 1975).

DANCHIN R.V., FERGUSON J., MACIVER J.R., and NIXON P.H. 1975. The composition of late stage kimberlite liquids as revealed by nucleated autoliths. In Ahrens L.H., Dawson J.B., Duncan A.R., and Erlank A.J., eds, Physics and Chemistry of the Earth, Vol 9, pp. 235-245. Pergamon Press, Oxford.

DAWSON J.B. 1978. Kimberlites and Their Xenoliths. 252 pp. Springer-Verlag, Berlin.

FESQ H.W., KABLE E.J.D., and GURNEY J.J. 1975. Aspects of the geochemistry of kimberlites from the Premier Mine, and other selected South African occurrences with particular reference to the rare earth elements. In Ahrens L.H., Dawson J.B., Duncan A.R., and Erlank A.J., eds, Physics and Chemistry of the Earth, Vol 9, pp. 687-707.

MARVIN R.F., HEARN B.C.JR., MEHNERT H.H., NAESER C.W., ZARTMAN R.E., and LINDSEY D.A. 1980. Late Cretaceous-Paleocene-Eocene igneous activity in north-central Montana. Isochron/West 29, 5-25.

MITCHELL R.H. 1986. Kimberlites: Mineralogy, Geochemistry, and Petrology. 220 pp. Plenum Publishing, New York.

MITCHELL R.H., and BRUNFELT A.O. 1975. Rare earth element geochemistry of kimberlite. In Ahrens L.H., Dawson J.B., Duncan A.R., and Erlank A.J., eds, Physics and Chemistry of the Earth, Vol 9, pp. 671-686. Pergamon Press, Oxford.