KIMBERLITIC DIATREMES IN NORTHERN COLORADO AND SOUTHERN WYOMING

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Since 1960, 36 kimberlitic diatremes and dikes have been discovered in the northern Front Range of Colorado and southern Laramie Range of Wyoming. The diatremes occur in three groups: a single pipe near Boulder, Colorado (Kridelbaugh and others, 1972); a cluster of 19 pipes approximately 120 km north of Boulder near the Colorado-Wyoming state line (McCallum and Eggler, 1968, and this report); and a group of 16 pipes and dikes 190 km north of Boulder at Iron Mountain (Farthing), Wyoming (W. A. Braddock, pers. comm., 1973). The diatremes penetrate Precambrian granitic rocks which comprise much of the cores of the Ranges. Local geologic setting and ages of sedimentary rock inclusions in many of the pipes indicate Middle Paleozoic (Late Silurian to Early Devonian) intrusion.

The pipes range from 3 to 550 m in longest dimension. Most are roughly circular to elliptical in surface outline. Larger pipes exhibit a greater degree of ellipticity, which is generally a reflection of joint control. The largest known diatreme (Sloan diatreme) is situated at the intersection of two prominent faults. Joint-controlled, kimberlitic dikes up to about 2 m in width are abundant at several of the Iron Mountain localities. On a regional scale, the north-south trend of pipe locations roughly parallels the eastern mountain front, and kimberlite emplacement may have been controlled by a deep-seated fracture system that also dominated the structural evolution of the Laramie and Front Ranges.

The cluster of 19 diatremes near the Colorado-Wyoming state line has been studied in considerable detail, including petrographic, X-ray, and electron microprobe techniques. Kimberlite is predominantly an intrusive breccia of subrounded to angular clasts in a finely-crystalline matrix of serpentine, calcite, dolomite, phlogopite, chlorite, talc, hematite, and perovskite. Clasts include individual grains of magnesium ilmenite, olivine, enstatite (rare), garnet, diopside, phlogopite, chromite, picotite, perovskite, magnetite, and serpentine pseudomorphs after olivine and enstatite; nodules of cognate kimberlite, spinel and garnet lherzolite, eclogite (rare), and carbonatite (sövite); and xenoliths of country rocks, including Precambrian crystalline rocks and blocks of fossiliferous Lower Paleozoic carbonates.

Cognate kimberlite and carbonatite (sövite) nodules are present in several pipes but are abundant only at the Sloan diatreme. Well-rounded kimberlite nodules are compositionally similar to host kimberlite, and commonly contain angular cores of sedimentary or granitic xenoliths. Carbonatite nodules range up to 25 cm in diameter and include biotite, phlogopite (?), and barite-rich varieties. Oxygen and carbon isotope data indicate an igneous origin for the carbonatite and for most of the matrix calcite in kimberlite (McCallum and Eggler, 1971).

Eight eclogite nodules have been found. Most are bimineralic, containing pyropic garnet (40-60 mole % Py) and omphacitic clinopyroxene

(28-43 mole % jadeite). Two eclogites contain accessory kyanite. Finely-crystalline interstitial material present in some samples is locally rich in Na_2O or K_2O and may contain minor secondary (?) kaersutitic amphibole or phlogopite. However, these eclogites lack the hydrous phases that characterize most of the Colorado Plateau eclogite inclusions of probable crustal origin (Essene and Ware, 1970). They are more similar to nodules from the Stockdale kimberlite in western Kansas (Meyer and Brookins, 1971) which, like these nodules, is interpreted to have come from the mantle.

Lherzolite nodules are relatively abundant in the diatremes, but most are altered to serpentine, hematite, and carbonates, and locally to talc and quartz. Both spinel and garnet-bearing varieties are present, and a few contain appreciable phlogopite. Many spinel lherzolites contain fresh olivine (Fo_{91}) and enstatite (En_{91}). However, in garnet lherzolites all olivine and enstatite have been replaced by serpentine, quartz, and hematite. Garnets are very pyropic (65-75 mole %) and have high Cr_2O_3 contents (3-11 weight %). Diopsides are also chromian; spinel lherzolite clinopyroxenes are more calcic than those from garnet lherzolites (Fig. 1).

Monomineralic inclusions have been classed into two groups, nodules and megacrysts, depending on whether the mean diameter is greater than 2 cm. Megacrysts include subcalcic diopside, garnet, and ilmenite. Diopside megacrysts show little compositional variation (Fig. 1) and are distinguished from monomineralic nodules and lherzolite diopsides chiefly by their low Cr_2O_3 content (0.20 wt %). Garnet megacrysts also show little chemical variation, with one exception (Fig. 1). The main group is characterized by higher Fe, much lower Cr, and somewhat higher Ti content than lherzolite garnets. Garnet megacrysts range up to 13 cm in length. Ilmenite megacrysts and ilmenite monomineralic nodules contain 25-50 mole % $MgTiO_3$; Mg-rich ilmenite megacrysts are enriched in Cr_2O_3 (about 3.0 wt %).

Monomineralic diopside nodules are very similar in composition to diopsides from lherzolite, and many are probably derived from disaggregated lherzolite. However, some are much larger than lherzolite phases, notably one megacryst from the Sloan pipe. Monomineralic garnet nodules probably have a variety of sources. Many purple chromian garnets are similar to garnets from lherzolite, while others resemble garnet megacrysts. A group of orange to pink garnets with less than 10 mole % Ca has variable Fe content but uniformly low content of TiO_2 (less than 0.15 wt %) and 2.0 wt % or less Cr_2O_3.

All polymineralic nodules are considered to be accidental inclusions in kimberlite. Temperature and depth of equilibration of spinel lherzolite, estimated from the diopside-enstatite solvus (Davis and Boyd, 1966) and Al_2O_3 content of enstatite (MacGregor, in preparation), are about 850-950° C and 50-65 km. From a geotherm passing through those points and temperature estimates from the diopside solvus and Fe-Mg distribution between clinopyroxene and garnet (Hensen, 1973), it is considered that eclogites equilibrated in the deep crust or in pockets in mantle below the crust (about 50 km, 850° C), and that garnet lherzolites have equilibrated at 60-100 km (950-1250° C).

Certain chemical trends in the nodules and the large size of many megacrysts suggest that melting has occurred in the source region some time before inclusion of the nodules in kimberlite. Compositions of garnets and diopsides of lherzolites and associated monomineralic

nodules are consistent with the model of Boyd and Nixon (1973), whereby lherzolite nodules are subjected to varying degrees of partial melting before inclusion. Such depletion is reflected in Fe/Mg ratios and in Cr content, inasmuch as Cr is strongly partitioned into residual garnet or spinel. The large size of some chromian diopside nodules, noted above, suggests these nodules grew in the presence of melt. Olivine compositions, used with data on Fe-Mg partitioning between melt and crystals (assuming negligible Fe^{3+} content), indicate the melt was very magnesian ($Mg/Mg+Fe_{tot} = 0.75$).

On the other hand, diopside and garnet megacrysts could not have grown in such a melt, because they have low Cr contents and because they are more Fe-rich. The limited compositional variation of these megacrysts suggests they grew together in a batch of magma separated from host peridotite (Eggler and McCallum, 1973). The Mg/Mg+Fe ratios of diopside (0.87) and garnet (0.77) indicate they have equilibrated at 1250° C and that the melt (if a melt existed at 1250° C) had $Mg/Mg+Fe_{tot} = 0.67$. The melt may well have been alkalic, as diopside contains 1.4 wt % Na_2O; the Fe/Mg ratio is consistent with an olivine basanite or melilitite composition. A magma temperature of 1250° C is possible, inasmuch as it falls below the peridotite solidus, only if the mantle contained H_2O or H_2O+CO_2. Ilmenite megacrysts, unlike diopside and garnet, show wide compositional variation, suggesting they were phenocrysts in a fractionating magma. Data on partitioning of Mg-Fe between ilmenite and silicates indicates the Mg-rich ilmenites could have been in equilibrium with garnet and diopside megacrysts. However, whether they grew from the same melt is problematic.

Summary. A north-south trending belt of kimberlitic diatremes in Colorado and Wyoming penetrated Precambrian crystalline rocks in the Middle Paleozoic. The intrusive breccia is interpreted to have come from a depth of at least 100 km through an upper mantle section consisting of garnet and spinel lherzolite and pockets of eclogite. The lherzolites have been melted before inclusion in kimberlite; a separate melt has precipitated megacrysts of chrome-poor diopside, garnet, and ilmenite. The pipes also contain distinctive nodules of sövite.

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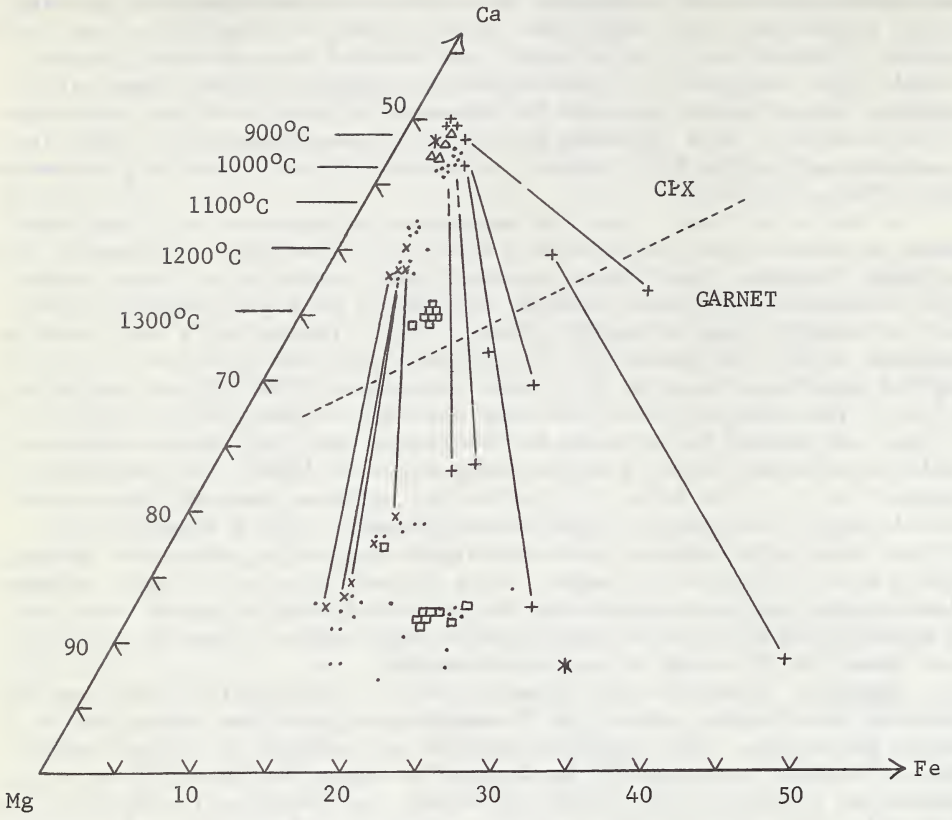

Fig. 1. Compositions of clinopyroxenes and garnets from Colorado-Wyoming kimberlitic diatremes, in mole per cent. Temperatures on diopside solvus are from Davis and Boyd (1966). Solid lines connect compositions of coexisting phases.

- • monomineralic nodules
- □ monomineralic megacrysts
- △ spinel lherzolite
- × garnet lherzolite
- ✳ other inclusions
- \+ eclogites