High Pressure Mineral Reactions in a Pyroxenite Granulite Nodule from the Stockdale Kimberlite, Riley County, Kansas

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STATE
GEOLOGICAL
SURVEY
OF
KANSAS

BULLETIN 199, PART 3

THE UNIVERSITY OF KANSAS
LAWRENCE, KANSAS - 1970

BULLETIN 199, PART 3

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Printed by authority of the State of Kansas
Distributed from Lawrence

UNIVERSITY OF KANSAS PUBLICATIONS
DECEMBER 1970

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ILLUSTRATIONS

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ABSTRACT

Sapphirine, kyanite, and a grossular-rich garnet have formed by reactions involving spinel, pyrope-almandine, clino- and orthopyroxene, and plagioclase in a pyroxenite granulite nodule from the Stockdale kimberlite, Kansas. The reactions responsible for formation of these minerals are thought to have occurred at pressures in excess of 13.5 kilobars (corresponding to a depth of formation of approximately 40 km) thus placing the source material for the nodule in the upper mantle. Sapphirine and kyanite are reported for the first time from the Riley County, Kansas, kimberlites.

INTRODUCTION

Brookins (1969a) has reported the presence of a green spinel (variety pleonaste) in an ultrabasic nodule from the Stockdale kimberlite, Riley County, Kansas. This particular nodule (sample 1128d) has been further studied by Woods (1970) and Woods and Brookins (unpublished information; manuscript in preparation) and classified as a plagioclase-rich, spinel- and garnet (pyrope-almandine)-poor, pyroxenite granulite. The mineralogic composition is clinopyroxene, 52 percent; orthopyroxene, 21 percent; plagioclase (An_{60}), 20 percent; spinel plus (pyrope-almandine) garnet, 6 percent; accessories and alteration products, 1 percent. Both pyroxenes are present as primary euhedra in an interlocking mosaic of plagioclase and garnet plus spinel. Each pyroxene contains exsolution laths of the other. The rock has been recrystallized and several minerals indicative of very high pressures of formation have been noted as reaction products which presumably formed at or close to the time of recrystallization. Three such minerals identified by X-ray analysis are sapphirine, kyanite, and a grossular-rich garnet. These minerals considered individually need not necessarily imply a high pressure of formation, but the probable reactions responsible for their formation as indicated by petrographic examination does indicate high pressure.

Acknowledgments

We wish to thank the State Geological Survey of Kansas and the Research Corporation, New York, for partial financial support.

SPECIFIC MINERAL REACTIONS

Kyanite occurs as fibrous sheaves growing into plagioclase from orthopyroxene. It is commonly (but not always) associated with a grossular-rich garnet which, while somewhat enriched in pyrope-almandine, is definitely unlike the primary almandine-pyrope found in the nodule. The latter is similar in composition to almandine-pyropes associated with some South African kyanite-bearing eclogites described by Rickwood, Mathias, and Siebert (1968). Some of the kyanite may be primary, but much of it has apparently formed by a reaction of the type

$$\underset{\text{(anorthite)}}{3\ CaAl_2Si_2O_8} = \underset{\text{(grossularite)}}{Ca_3Al_2Si_3O_{12}} + \underset{\text{(kyanite)}}{2\ Al_2SiO_5} + \underset{\text{(quartz)}}{SiO_2} \qquad \text{(I)}$$

which takes place at a pressure of 28.5 kilobars at 1000°C according to Hays (1966). Cohen, Ito, and Kennedy (1967; see also discussion in Ito and Kennedy, 1968) propose another quartz-producing reaction

$$\underset{\text{(anorthite)}}{CaAl_2Si_2O_8} + \underset{\text{(orthopyroxene)}}{2\ (Mg,Fe)SiO_3} = \underset{\text{(garnet)}}{Ca(Mg,Fe)_2Al_2Si_3O_{12}} + \underset{\text{(quartz)}}{SiO_2} \qquad \text{(II)}$$

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which involves extensive solid solution and takes place at pressures above 17 kilobars (near 1000°C). Free quartz produced by either reaction (I) or (II) is consumed by a reaction of the type

Al-pyroxene + quartz = (III)
orthopyroxene + kyanite + grossularite

which, while not yet studied in great detail quantitatively, will proceed to the right according to free energy considerations using data from Robie and Waldbaum (1968) for 1000°C and extrapolated to high (i.e., above 15 kilobars) pressures. Petrographic examination indicates that this reaction (III) probably does occur. Similarly, another reaction observed in thin section is thought to be

Al-clinopyroxene + 2 hypersthene = (IV)
grossular-rich almandine-pyrope +
clinopyroxene

which also proceeds to the right at high pressures. A precise range of T, P conditions for reactions (I-IV) cannot be given, but a minimum pressure above 12 kilobars is indicated (see discussion in Woods, 1970).

The presence of sapphirine in the nodule allows a further estimation of the T, P conditions under which the rock was recrystallized. Hollander (1968) has demonstrated that under T, P conditions corresponding to crustal sites, pleonaste will usually alter to a chlorite mineral rather than sapphirine. In sample 1128d, however, sapphirine occurs in close association (usually as rims) with pleonaste and sometimes occurs with kyanite. Petrographic examination indicates the following reactions to be likely:

Al-orthopyroxene = spinel + sapphirine (V)
Al-pyroxene + spinel = sapphirine (VI)
orthopyroxene + spinel + (VII)
kyanite = sapphirine

with all three reactions proceeding to the right under high T, P conditions (Fig. 1; and see discussion in Woods, 1970) with the probable range in pressure being 12 to 20 kilobars. These reactions thus suggest a lowermost crustal or upper mantle site for formation of sapphirine.

In one area of a thin section (no. 3) of 1128d the assemblage orthopyroxene-pleonaste-kyanite-sapphirine-(grossular-rich) garnet is noted. This assemblage, if an equilibrium one, corresponds to an invariant point at approximately 13.5 kilobars and 700°C, according to the curves shown in Figure 1. These are minimum T, P conditions, however, as only the orthopyroxene and pleonaste are primary and the other minerals have formed by reactions as outlined earlier (reactions I-VII). Further, reaction (II) yields a minimum pressure of 17 kilobars according to Figure 1. Boyd and MacGregor (1964) further report that solid solution of enstatite in most clinopyroxenes from kimberlite nodules indicates temperatures in the range 900° to 1000°C, greater than the 700°C (with uncertain error limits) implied in Figure 1, but still well below most magmatic temperatures associated with ultramafic rocks.

DISCUSSION AND CONCLUSIONS

The crust-mantle boundary in northern Riley County lies at a depth of about 36 km, corresponding to a pressure slightly greater than about 11 kilobars (Brookins, 1969b). The high pressure reactions responsible for the formation of kyanite, sapphirine, and grossular-rich garnet in sample 1128d indicate a plausible range in pressure from 13.5 to 20 kilobars, corresponding to a depth range of 42 to 60 km. These minerals, except (possibly) some kyanite, have been formed from pre-existing minerals, which therefore must have crystallized at still greater depths. Some restraints on the maximum depth of formation of sample can be placed on sample 1128d, however. Boyd and MacGregor (1964) have demonstrated that at pressure corresponding to a depth of about 60 km the reaction

4 enstatite + spinel = (VIII)
forsterite + pyrope

occurs and, since no evidence for primary olivine is noted, this reaction presumably limits source material for 1128d to depths above 60 km.

The kimberlites themselves are thought to have crystallized at depths in the range 120 to 150 km (see summary of Riley County kimberlites in Brookins, 1970), but recent study of an ilmenite-pyroxene (intergrowth) nodule from the Monastery Mine kimberlite, South Africa, by Ringwood and Lovering (1970) has cast some doubt on this depth range. They propose that the parent for the ilmenite-pyroxene nodule was a Ti-rich garnet and that exsolution occurred at pressures near 100 kilobars, corresponding to an approximate depth of 300 km. If born out by further study, kimberlites may have crystallized at least twice as deep as previously thought. It should be pointed out, however, that Dawson and Reid (1970) have studied similar nodules from the same location and propose a parent

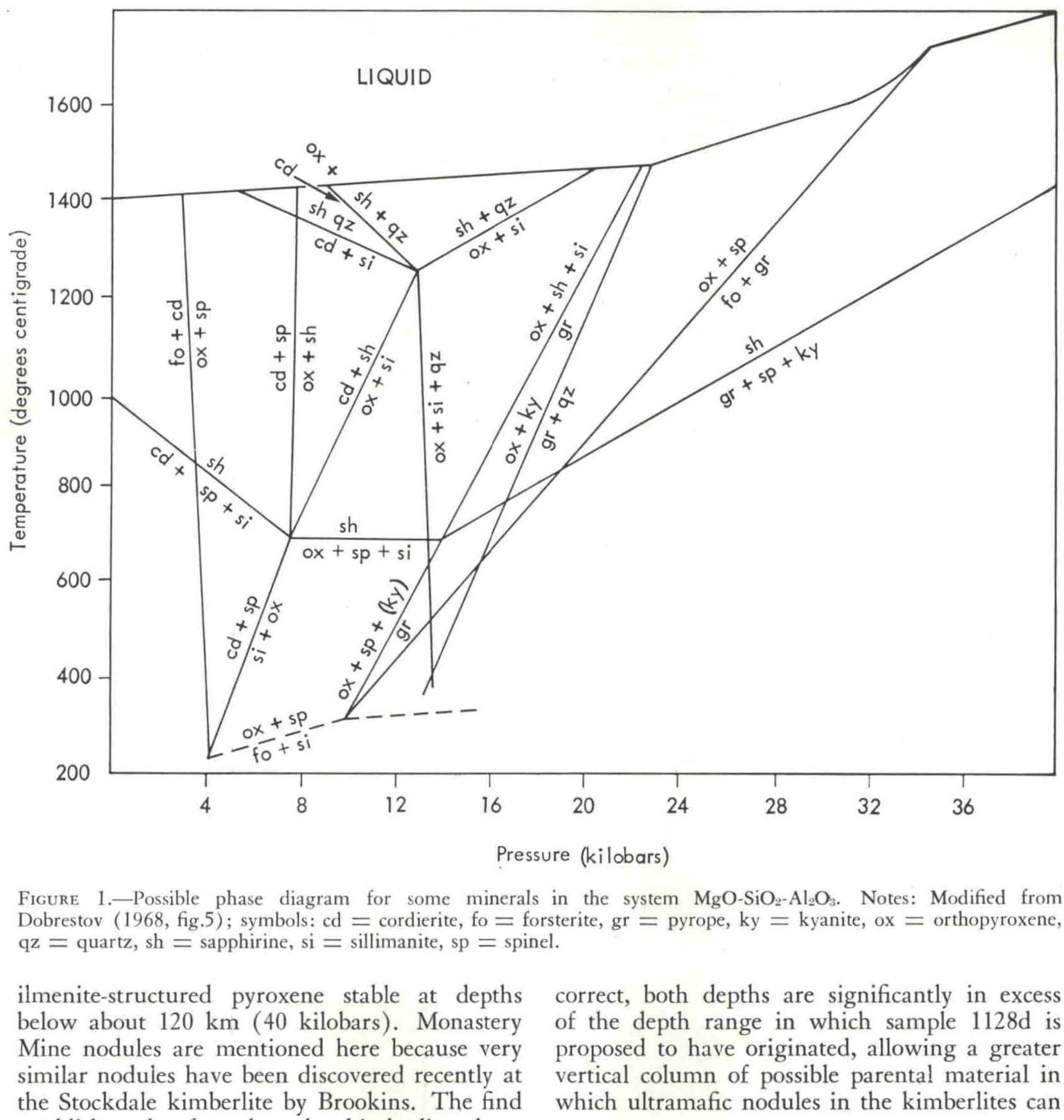

FIGURE 1.—Possible phase diagram for some minerals in the system $MgO-SiO_2-Al_2O_3$. Notes: Modified from Dobrestov (1968, fig.5); symbols: cd = cordierite, fo = forsterite, gr = pyrope, ky = kyanite, ox = orthopyroxene, qz = quartz, sh = sapphirine, si = sillimanite, sp = spinel.

ilmenite-structured pyroxene stable at depths below about 120 km (40 kilobars). Monastery Mine nodules are mentioned here because very similar nodules have been discovered recently at the Stockdale kimberlite by Brookins. The find establishes the fact that the kimberlites have indeed formed at least as deep as 120 km (as proposed by Brookins, 1970, by indirect evidence) and perhaps at much greater depths if the hypothesis of Ringwood and Lovering (1970) is substantiated. Regardless of which is correct, both depths are significantly in excess of the depth range in which sample 1128d is proposed to have originated, allowing a greater vertical column of possible parental material in which ultramafic nodules in the kimberlites can occur.

As a final note, sapphirine and kyanite are here reported for the first time from the Riley County, Kansas, kimberlites and these minerals should be added to the list prepared by Brookins (1969c).

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