BLUE SILLIMANITE AND THE ORIGIN OF CRUSTAL XENOLITHS AT KILBOURNE HOLE, NEW MEXICO, USA, AND BOURNAC, HAUTE-LOIRE, FRANCE

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Crustal xenoliths of quartzo-feldspathic gneiss containing garnet and blue, colorless, or pale yellow sillimanite are found among the ejecta at Kilbourne Hole and Bournac. These xenoliths have been interpreted as fragments derived from granulite facies rocks at considerable depths in the earth's crust (Padovani and Carter, in press; Leyreloup, 1974). Similar quartzo-feldspathic gneisses containing only colorless or pale yellow sillimanite are common in granulite facies terrains exposed in deeply eroded metamorphic complexes. The aim of the present study is to compare the mineralogy and chemistry of sillimanite and ilmenite from these xenoliths with those from exposed granulite facies terrains. It is hoped that these relatively simple minerals will indicate: (1) differences in the physical conditions of formation of the two parageneses; and (2) the effect of the basaltic host on the xenoliths.

The granulite facies gneisses used for comparison are quartzo-feldspathic gneisses from the Precambrian shield of East Antarctica, most of which contain K-feldspar, plagioclase, garnet, biotite, sillimanite, and ilmenite. Some samples also contain cordierite, magnetite, spinel, rutile, or graphite.

Kilbourne Hole is located in the Rio Grande rift. The xenoliths form cores of basalt bombs in ejecta on bedded tuff overlying an alkaline olivine basalt flow in the Quaternary Afton Basalt (Hoffer, 1976). Depth to Precambrian basement is estimated to be about 6 km (Woodward et al., 1975). Precambrian rocks exposed 45 to 100 km distant include greenschist and amphibolite-facies metamorphic rocks and plutonic rocks, mostly granite (Denison and Hetherington, 1969). No granulite facies rocks have been reported from this area; but the basement in the down-dropped blocks of the rift itself has not been sampled near Kilbourne Hole.

At Bournac, the gneiss xenoliths are fragments in a tuff breccia resting on a gneissic basement and overlain by a "labradorite" (Boule, 1892). The "labradorite" is of alkali affinities (Brousse, 1971), and is one of the Miocene-Pliocene plateau basalts of east Velay, a volcano-tectonic horst (de Goer de Herve and Mergoil, 1971). The gneissic basement is an upper amphibolite facies terrain consisting of sillimanite-orthoclase gneisses, migmatites, and the Guéret-Velay granite containing biotite and cordierite (Chenevoy and Ravier, 1971).

The quartzo-feldspathic gneisses in the Kilbourne Hole and Bournac xenoliths are medium grained, friable, light-colored rocks; those at Kilbourne Hole have a sintered appearance. The gneisses at both localities contain the following minerals: quartz, perthitic K-feldspar (probably sanidine), plagioclase, garnet, prismatic sillimanite, ilmenite, rutile, biotite (Bournac only), and graphite. Glass, in places vesicular, is abundant in the Kilbourne Hole samples, generally as microveinlets or in pools surrounding garnet or orthopyroxene-spinel symplectite. Devitrified glass may be present in small amounts in some of the Bournac xenoliths. Garnet at Kilbourne Hole is partly replaced by the symplectite. Brown rutile is present at both localities; at Kilbourne Hole, some xenoliths also contain purple or blue rutile.

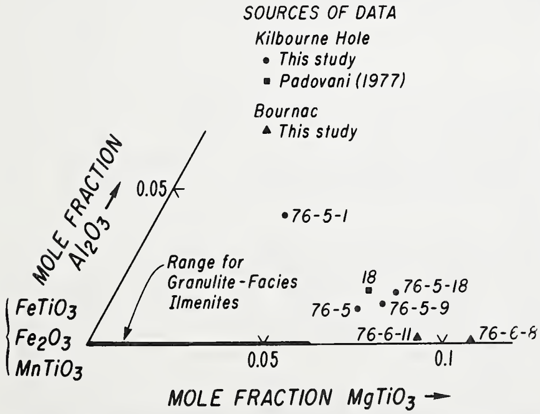
The xenolith ilmenite forms discrete grains free of hematite lamellae and contains 0.06 to 0.35 weight percent MnO, 0.96 to 2.90 weight percent MgO, 0.07 to 2.84 weight percent Al_2O_3, and 0 to 32 mole percent Fe_2O_3 (Figures 1 and 2). The xenolith ilmenites are richer in MgO than the granulite facies ilmenites from Antarctica (Figure 1). Those from Kilbourne Hole, moreover, are also richer in Al_2O_3. Sample 76-5-1 is richer in Fe_2O_3 than any of the granulite facies ilmenites.

Sillimanite in the xenoliths is pale yellow (sample 76-5-1 only), colorless, or blue. The pale yellow color is characteristic of iron-rich sillimanite in granulite facies rocks. Blue sillimanite, however, is reported from only 4 other localities in the world, and at none of these is information on the paragenesis available. The author has failed to obtain more information on Bank's (1974) report of blue sillimanite from Kenya, while the reported occurrence by Hattori (1967) in New Zealand appears to be blue kyanite misidentified as sillimanite. Blue sillimanite does occur as a detrital mineral in the gem gravels of Ceylon and Burma, but no information is available on the source rock.

The range in Fe_2O_3 contents for the Kilbourne Hole sillimanite (except for sample 76-5-1) is 0.35 to 0.99 weight percent, and, for Bournac, 0.17 to 0.87 weight percent, more or less within the ranges observed in granulite facies rocks from Antarctica (0.25 to 1.36 weight percent). The iron content of sillimanite in sample 76-5-1 (1.82 weight percent) is greater than that of any of the ilmenite-bearing rocks from Antarctica and is as great as that in sillimanite associated with hematite in granulite facies rocks. The iron content of blue sillimanite is less that that of the colorless. The upper limit for Kilbourne Hole is 0.94 weight percent. At Bournac, the upper limit is only 0.23 weight percent, and blue sillimanite is found only in graphite-bearing rocks.

The distribution of Fe_2O_3 between sillimanite and ilmenite is not regular. By comparison with granulite facies rocks, the xenolith ilmenites have a lower Fe_2O_3 content that would be expected from the composition of coexisting sillimanite (Figure 2).

The major mineralogical and chemical differences between the xenoliths and granulite facies rocks are the blue color of the sillimanite, structural state



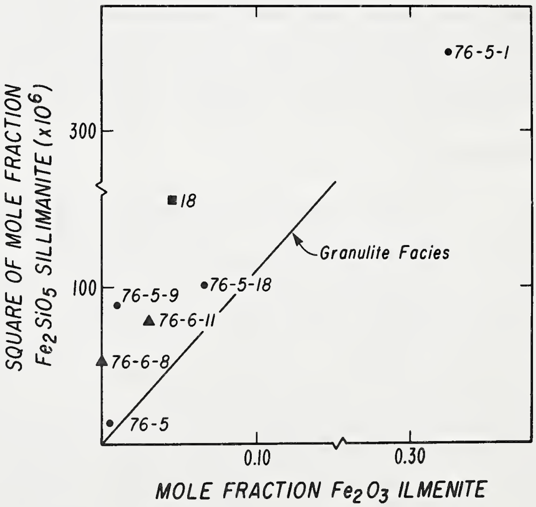


Figure 1. Compositions of ilmenite from crustal xenoliths and from Antarctic granulite facies gneisses.

Figure 2. Iron contents of associated ilmenite and sillimanite. Curve for granulite facies rocks based on 9 pairs from Antarctic granulite facies rocks, and one pair from an upper-amphibolite facies rock.

of the K-feldspar, and high MgO content in the ilmenite. The Kilbourne Hole samples, moreover, differ in the high Al_2O_3 content of ilmenite, replacement of garnet by symplectite, abundance of glass, and unusually high Fe_2O_3 content of some sillimanite and ilmenite. A few of these features in the xenoliths have been documented from rocks partially melted under high temperatures and low pressures. Examples are the conversion of microcline to sanidine (Butler, 1961) and partial melting of garnet to spinel, orthopyroxene, and liquid during shock-induced heating (Stähle, 1975). Thus the xenoliths must have been affected considerably by the heat treatment due to their incorporation into basalt. This heat treatment would alter the mineralogy and chemistry of the minerals, so that statements concerning the original source rock must be made with caution. For example, absence of biotite in the Kilbourne Hole xenoliths is probably no indication of its absence in the source rocks, for biotite breaks down early in the melting of rocks (Butler, 1961).

The composition of ilmenite probably was considerably changed by the heat treatment, although that of sillimanite may have remained relatively unaffected. Scatter in the distribution of Fe_2O_3 between associated sillimanite and ilmenite most likely is due to the heat treatment. The high Mg contents of the ilmenite in the xenoliths may be due to the high MgO/FeO ratio in the xenolith bulk composition. Differences in the Al_2O_3 content, however, probably reflect differences in the physical conditions of crystallization. As the high-Al_2O_3 ilmenites are found only in the Kilbourne Hole samples, the Al_2O_3 enrichment appears to be correlated with the intensity of the heat treatment and thus would not be due to unusual pressure-temperature conditions during the original metamorphism.

The greater extent of partial melting in the Kilbourne Hole samples is probably due to their having spent more time in the host basalt. Geologic evidence suggests that granulite facies source rocks were at greater depths at Kilbourne Hole than at Bournac.

The blue color in sillimanite is probably related to the heat treatment and quenching that occurred during the eruption that brought the xenoliths to the surface. Quenching may be critical in preserving the blue color; its absence in other metamorphic rocks may be explained by the fact that these rocks cooled sufficiently slowly for the color to be lost by annealing.

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