

THE AMERICAN MINERALOGIST, VOL. 47, JANUARY-FEBRUARY, 1962

THE Mg AND Fe²⁺ CONTENTS OF PYROXENES FROM THE PENNSYLVANIA AND DELAWARE PIEDMONT PROVINCE: A RE-INTERPRETATION

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A paper appeared on these pyroxenes, in *The American Mineralogist*, over two years ago (Norton and Clavan, 1959, *Am. Mineral.* **44**, 844-74). From that time, the present writer has been concerned about the manner in which conclusions were reached, regarding the genesis of the rocks from this province, which were based on certain erroneous mineralogical concepts. This note points out some of these errors in case other investigators are tempted to use the same methods of reasoning.

To begin with, the authors of the paper state (p. 868) that "When dealing with the crystallization of igneous rocks it is to be expected that, as the series olivine→orthopyroxene→clinopyroxene progresses, both Fe²⁺/Mg and Mg/Ca ratios will simultaneously decrease." While this is obviously so for the latter ratio (almost by definition), it is not so for the former; providing the order is one of crystallization with falling temperature, and that equilibrium is maintained with the cooling magma, then the Fe²⁺/Mg ratio will *increase*. The fact that, in the pyroxenes of this Province, the Fe²⁺/Mg ratio is higher in hypersthene than in augite is not, therefore, proof that these pyroxenes are of igneous origin simply by analogy with a somewhat theoretical crystallization sequence, but proof either that the two pyroxenes crystallized together (and in equilibrium) from a magma, or that the hypersthene crystallised after the augite (such poikilitic relations are not unusual in igneous rocks), or that subsequent metamorphism has resulted in equilibrium being attained between the two pyroxene phases. A textural description of each rock would indicate whether, in certain cases, the metamorphism had reversed or modified the Fe²⁺/Mg ratios, as would be likely if a preserved igneous texture showed hypersthene enclosed by augite. The result of equilibrium being attained is that the tie-lines joining co-existing pyroxene pairs will intersect the Wo-En-Fs triangle on the Wo-En join, but this applies equally to both igneous and metamorphic pairs, between which no obvious distinction can, at present, be drawn from this type of diagram.

The authors also consider, in some detail, the fact that the Mg/Ca ratios of their augites and hypersthene are very different. It has long been known that monoclinic augites contain much calcium and hypersthene very little, so it is not clear why these ratios are tabulated and considered relevant to the genesis of these rocks. The variation noted in the Mg/Ca ratio, between different pyroxene pairs, is in fact influenced by the varying Fe²⁺/Mg ratios, the large Ca difference being almost constant.

In the concluding section (p. 870) it has been proposed that the complex evolution of these rocks may be demonstrated through the recognition that Mg has been introduced during metamorphism and concentrated in the orthopyroxene rather than in the clinopyroxene. This conclusion, if valid, would be of great petrological interest. Unfortunately, however, it cannot be accepted on the evidence presented. The authors examined the Mg and Fe²⁺ contents of orthopyroxenes and clinopyroxenes from the same rock and concluded that, because Mg is higher in the former than in the latter mineral (despite the important fact that the Mg/Fe²⁺ ratio is *lower* in the orthopyroxene), then Mg must have been introduced, preferentially, into the orthopyroxene. It is surely apparent that, in contrasting two rather magnesian minerals such as hypersthene and augite, one of which contains 5% Ca and the other 45% Ca (of total Ca + Mg + Fe²⁺), the former will contain much more Mg (as a ratio of total cations) than the latter. By recalculating the formulae on a Ca-free basis or according to equal Ca contents, or even by examining the Fe²⁺/Mg ratios, it becomes apparent that the orthopyroxene is the more ferriferous of each pair and that no evidence exists for the selective introduction of Mg into this mineral during metamorphism. The authors suggest that equilibrium was established by this introduction of Mg into the hypersthene. As the pyroxene pairs from this province show a distribution of Fe²⁺ and Mg between hypersthene and augite similar to that found in igneous pairs which have attained equilibrium, this cannot be so. Should the igneous pairs *not* have attained equilibrium, then the introduction of Fe²⁺, rather than Mg, into the hypersthene would be necessary in order to produce the observed Fe²⁺/Mg relationships.

As the Fe²⁺/Mg ratios of the hypersthene are greater than those of co-existing augites in this Province, it would be expected that their refractive indices would also be greater, providing the Ca differences do not offset slight Fe²⁺/Mg differences. This is so, but it leads Norton and Clavan to conclude (pp. 871 and 873) that "The optical properties of one or both pyroxenes have been modified by their metamorphic evolution." The optical properties certainly reflect the chemistry of the minerals, in this case in terms of contrasted Fe²⁺/Mg ratios, but do not signify an introduction of Mg into the hypersthene, which would produce a modification or reversal of the optical property differences between pyroxene pairs. In any case, modification of the optical properties of minerals during thermal metamorphism is not, when accompanying the appropriate chemical changes, proof of complexity of metamorphic evolution, and should not be confused with polymorphic modifications which involve changes in physical properties without, necessarily, changes in chemical composition.