

AN EVALUATION OF THE CHEMICAL DISTINCTIONS BETWEEN IGNEOUS AND METAMORPHIC ORTHOPIROXENES

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ABSTRACT

Chemical analyses of orthopyroxenes from igneous rocks (67) and metamorphic rocks (158) have been evaluated in order to determine possible distinctions between them. Plots of percent $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ vs. percent Al_2O_3 demarcate between the igneous (excluding volcanic) and metamorphic fields. Orthopyroxenes having $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ higher than 44.3 percent are metamorphic. With lower values of this parameter the Al_2O_3 content indicates metamorphic or igneous origin. It has also been found that MgO , FeO , or SiO_2 content distinguishes between igneous and metamorphic orthopyroxenes. The reliability of these chemical distinctions has been supported, with some reservations, by checking an additional 172 analyses of orthopyroxenes from igneous and metamorphic rocks.

INTRODUCTION

Hess (1941) observed that the tie-lines of Ca-rich and Ca-poor pyroxenes from igneous rocks intersects, approximately, at the point $\text{Wo}_{75}\text{En}_{25}$ of the triangle Wo-En-Fs . Muir and Tilley (1958) have shown that chemically analyzed coexisting pyroxene pairs from igneous and metamorphic rocks do not show any significant departure from this point. On the other hand, Wilson (1960) reached the conclusion that "differences (in tie-line intersection points) did exist—not only between igneous and metamorphic assemblages, but also between metamorphic assemblages of differing genetic histories". Wilson's conclusion was criticised by O'Hara (1960), Kretz (1961b), and Brown (1961), and the validity of determining chemical composition of pyroxene from optical data was also questioned. Kretz (1961a) showed for the first time for granulite-facies metamorphic pyroxene pairs from the Madras charnockite series, that the Mg-Fe^{2+} distribution coefficient (K_D) is 0.54, while from the Skaergaard igneous differentiation series, it is 0.73. Thus, a quantitative basis for distinction between igneous and metamorphic pyroxenes was developed.

During an investigation of charnockitic rocks from the Eastern Ghats of Srikakulam district, India, I felt that a chemical frame of reference should be established for the distinction between igneous and metamorphic pyroxene-bearing rocks, from a single pyroxene analysis. The fact that clinopyroxene is comparatively rare in the Srikakulam charnockites, and also that Binns (1965) has already shown three different trends for igneous, granulite, and amphibolite facies rocks from the Ca-Mg-Fe plot of their analyzed *clinopyroxenes*, prompted a study of the available chemical data of *orthopyroxenes* from igneous and metamorphic rocks.

SELECTION OF ANALYSES

In the present study, only superior analyses of orthopyroxenes from rocks of undoubted origin have been used. The specimen numbers, source of orthopyroxene analyses, and brief notes about the rocks are given in Tables 1 and 2.* Altogether, 225 wet chemical analyses of orthopyroxenes have been used in Figure 1 to develop a reliable distinction between igneous and metamorphic orthopyroxenes, and the conclusions in this regard have been supported by 172 additional analyses of orthopyroxenes (including both wet and microprobe analyses) from various rocks. The main object of the study is to distinguish between igneous and metamorphic orthopyroxenes occurring only in *medium and coarse-grained rocks* (e.g., rocks of noritic composition) where textural evidence fails to differentiate between the igneous or metamorphic nature of the rocks. Therefore, volcanic orthopyroxenes, which are certainly from unambiguously igneous rocks, have not been considered in this paper.

IGNEOUS AND METAMORPHIC ORTHOPYROXENES

Figure 1 plots percent $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ versus percent Al_2O_3 of orthopyroxenes from igneous and metamorphic rocks. From the figure it is obvious that the igneous and metamorphic orthopyroxenes are distinctly concentrated in the two fields. The line of demarcation between the two fields has been drawn by eye. No analysis of an orthopyroxene from rocks of undoubted origin is available for the region where the Al_2O_3 content is less than 1 percent and where $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ lies between 43 to 45 percent.

The choice of MgO and FeO in the above figure is due to the following reason: During metamorphism of igneous orthopyroxene, Mg^{2+} is easily replaced by heavier Fe^{2+} available in the rocks from iron oxide or other iron-bearing minerals, resulting in the increase of $(\text{MgO} + \text{FeO})$ weight percent in the orthopyroxene. Addition of Fe_2O_3 to $(\text{MgO} + \text{FeO})$ reduces to a small amount the discrepancy in a few of the plots. Al_2O_3 has been used so that the effect of pressure which has been shown to cause higher alumina content in metamorphic than in igneous orthopyroxene (cf. Hess, 1952; Boyd and England, 1960), would be reflected in the diagram. This diagram clearly demonstrates a distinction between igneous and metamorphic orthopyroxenes. Certainly some discrepancies exist, but it will be shown in a separate publication that most of them can be explained.

* These two tables along with the relevant reference list may be ordered as NAPS Document 01315 from National Auxiliary Publications Service of A.S.I.S., c/o. CCM Information Corporation, 909 Third Avenue, New York, N.Y. 10022; remitting in advance \$2.00 for microfiche or \$5.00 for photocopies, payable to CCMIC—NAPS.

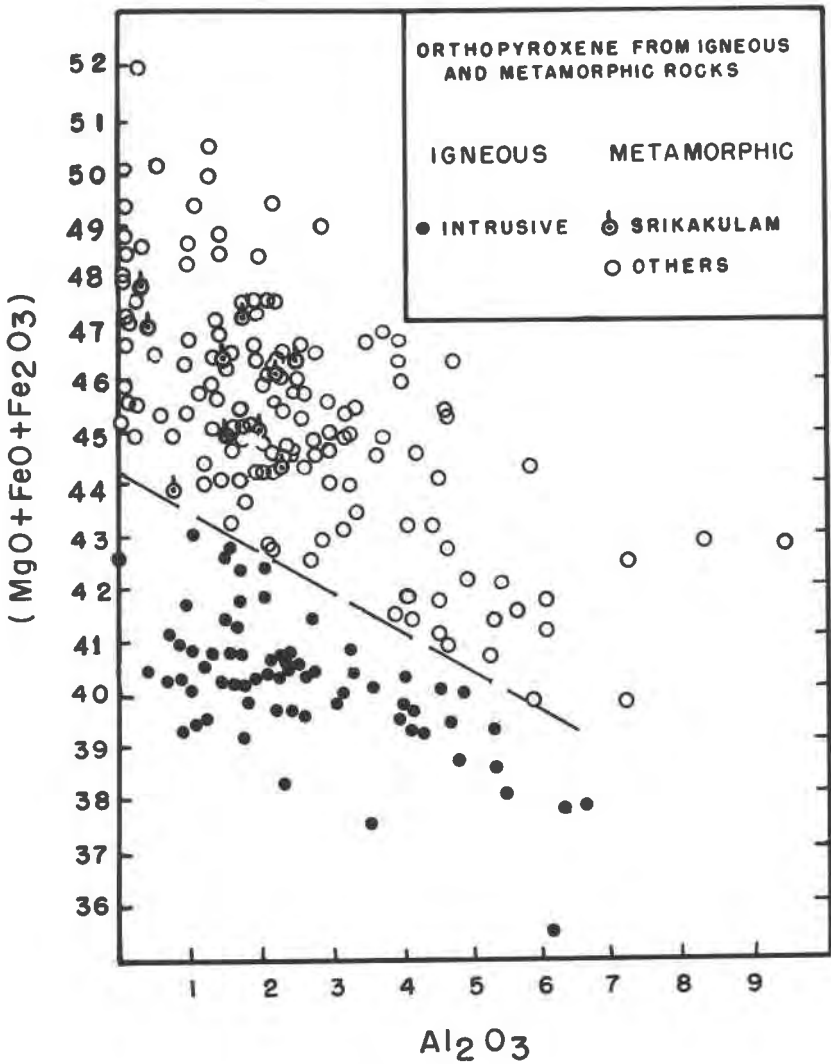


FIG. 1. Fields for igneous and metamorphic orthopyroxenes. The demarcation of the two fields is based on the plots from 225 analyses of orthopyroxenes. The source of the data is given in Tables 1 and 2.

The demarcation line between the igneous and metamorphic fields intersects the ordinate at a point near 44.3 percent (MgO+FeO+Fe₂O₃); orthopyroxenes having (MgO+FeO+Fe₂O₃) content higher than this are metamorphic. For values lower than this, the Al₂O₃ content must be considered in assessing the igneous or metamorphic nature of orthopyrox-

enes as is evident in Figure 1. The equation of the demarcation line is useful in this regard:

$$(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3) + 0.775 \text{Al}_2\text{O}_3 = 44.304$$

Three spectrographically analyzed orthopyroxenes (De Vore, 1955, numbers 131, 691, 699) and three pigeonites (Brown, 1957, numbers 4385A, 4341, 4430) from Skaergaard gabbros, five pigeonites and orthopyroxenes inverted from pigeonites in plutonic and hypabyssal igneous rocks (Hess, 1960, p. 28), and one ferropigeonite from Bushveld ferrodi-orite (Atkins, 1965, quoted from Brown, 1968) have not been included in Figure 1. If plotted, all but two (*i.e.*, Hess, 1960, EB89; Brown, 1968, SA616) are seen to lie in the igneous field, which is in conformity with their suggested origin. The specimen EB89 (Hess, 1960) is a dolerite hornfels, but the orthopyroxene from it falls well inside the igneous field. Similarly, orthopyroxene from pyroxene hornfels described by Challis (1965, number 94305) falls in the igneous field. An explanation for these inconsistencies is discussed later. Five analyses of orthopyroxene from two-pyroxene gneisses and amphibolites of the Eastern Sayan Archaean Complex (Nikitina, *et al.*, 1967) could not be used in this paper, because the analyses came to the notice of the writer too later. All of them, however, agree with their metamorphic nature since the $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ content in each is higher than 44.3 percent.

MgO, FeO, AND SiO₂ AS INDICATORS OF IGNEOUS AND METAMORPHIC ORTHOPYROXENES

It has been shown in Figure 1 that igneous and metamorphic orthopyroxene can be clearly distinguished by the plots of their $(\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3)$ content versus Al₂O₃ content (in weight percent). To see how far a single major component can indicate the igneous or metamorphic nature of orthopyroxene, a histogram of the FeO percent of orthopyroxenes was drawn (Figure 2). It is seen that igneous orthopyroxene can contain up to 16 percent FeO, and moreover there is a transition zone between 8 to 16 percent FeO, wherein lie both igneous and metamorphic orthopyroxenes. The results obtained from the histograms of FeO as well as of MgO and SiO₂ are shown in Table 3.

The above observation that igneous orthopyroxenes can contain up to a maximum of 16 percent FeO has strong support from 167 recently published chemical analyses of orthopyroxenes for FeO (total iron as FeO) from the Lower Critical Zone of western part of the Bushveld igneous complex (McDonald, 1967). The FeO content in these orthopyroxenes varies from 6.63 to 12.83 percent, the greater majority being within 9 to 12 percent. The FeO and MgO contents of a single more recently avail-

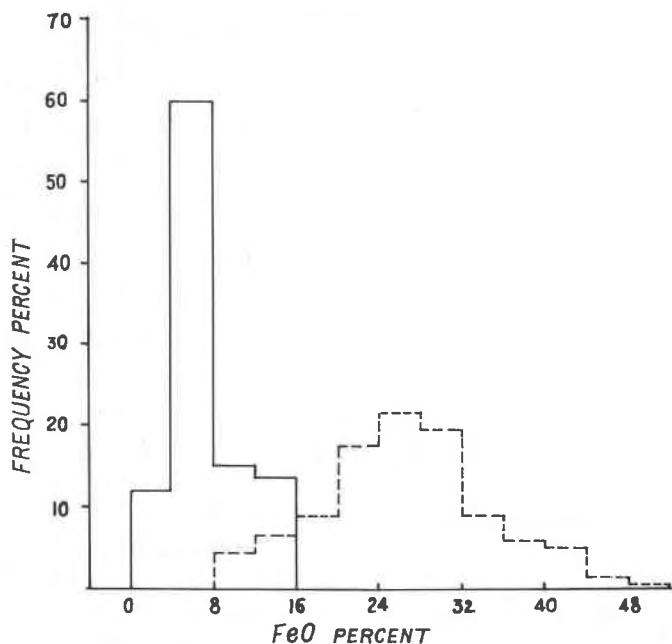


FIG. 2. Histogram showing the frequency distribution of FeO content of igneous and metamorphic orthopyroxenes. Solid line indicates igneous and dashed line indicates metamorphic orthopyroxenes. Data from Tables 1 and 2.

able analysis of orthopyroxene from the Main Zone gabbro of Bushveld intrusion (Brown, 1968, number SA722) agrees with the prescribed limit.

Electron probe analyses of igneous orthopyroxenes from Sudbury area, Ontario, show variation of FeO (total iron as FeO) from 10.4 to 23.1 percent and that of MgO from 19.7 to 30.6 percent (calculated value from weight percent FeSiO_3 and MgSiO_3 (Naldrett and Kullerud, 1967). The majority of these orthopyroxenes have FeO (total iron as FeO) of less than 20 percent and MgO of greater than 24 percent. Whether these deviations of FeO and MgO content from the expected range, (FeO less

TABLE 3. FeO, MgO, and SiO_2 WEIGHT PERCENTS AS INDICATORS OF IGNEOUS AND METAMORPHIC ORTHOPYROXENES

Nature of Orthopyroxene	FeO	MgO	SiO_2
Most probably igneous	<8.00	>30.50	>55.75
Igneous and/or metamorphic	8.00 to 16.00	30.50 to 24.00	55.75 to 50.00
Most probably metamorphic	>16.00	<24.00	<50.00

than 16 percent, MgO greater than 24 percent), reflect an original compositional effect, thereby raising the probability that a larger variation range of FeO and MgO should be used to distinguish between igneous and metamorphic orthopyroxenes, cannot be judged at this moment. It is, however, true that the act of setting the upper limit of FeO content and lower limit of MgO content for igneous orthopyroxenes is based on wet chemical analyses, and the Sudbury orthopyroxenes were analyzed by electron probe. Since the actual FeO content of Sudbury orthopyroxenes is not known, it is not possible at present to modify the limit of FeO percent characteristic for igneous or metamorphic orthopyroxenes.

Limitations. There is no theoretical reason why an igneous orthopyroxene (*i.e.*, orthopyroxene crystallized from a melt) would not fall in the metamorphic field of Figure 1, because the composition of the mineral under consideration will depend on various factors such as the composition of the melt, temperature, total pressure, water pressure, and oxygen pressure. For example, eulite from Rubideaux granite, California, (Larsen and Draisin, 1950) would fall in the metamorphic field of Figure 1 (not shown), though it is from a rock which has not probably undergone any metamorphism subsequent to crystallization from a melt. Deer, *et al.* (1963, Table 2, p. 19) list this with the igneous orthopyroxene. This is an exceptional case, and, therefore, does not invalidate the use of Figure 1 for distinction between igneous (volcanic excluded) and metamorphic orthopyroxene from common rocks.

It has been mentioned above that orthopyroxene from thermally metamorphosed rocks such as pyroxene hornfels (Challis, 1965, number 94305) and dolerite hornfels (Hess, 1960, p. 28, number EB89) fall in the igneous field. This suggests that ionic redistribution in orthopyroxene in a thermally metamorphosed igneous rock is not sufficient to shift the plot into the metamorphic field. In regionally metamorphosed rocks the Fe^{2+}/Mg ratio of orthopyroxene is generally higher than that from the igneous rocks. The physical significance of this is the progressive replacement of Mg by Fe^{2+} with increasing pressure of regional metamorphism. This is consistent with the conclusion of Olsen and Mueller (1966, p. 623) that the qualitative effect of adding MgO to the system $Fe_2SiO_4-SiO_2$ is to depress the equilibrium pressure.

From the foregoing discussion, the limitations for the use of Figure 1, or the values of MgO, FeO or SiO_2 , of orthopyroxene in determining the igneous or metamorphic nature of the rock may be summarized as follows:

(i) Original composition of the melt or sediments from which orthopyroxene has crystallized may affect the interpretation. For example,

orthopyroxene from Rubideaux granite (Larsen and Draisin, 1950) or that from Guadalupe igneous complex (Best, 1963), though occurring in igneous rocks, fall in the metamorphic field of Figure 1.

(ii) Departure from the ion-exchange equilibrium during regional metamorphism of a pyroxene-bearing igneous rock may cause the igneous pyroxene composition to be retained. In that case, in spite of the fact that the rock is associated with a metamorphic assemblage, its orthopyroxene composition will have the characteristics expected from unmetamorphosed igneous rock.

(iii) In thermally metamorphosed igneous rocks orthopyroxenes may retain the composition characteristic for igneous rock.

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