

Distribution of some elements among minerals of Norwegian eclogites

By

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Abstract. Coexisting clinopyroxene, orthopyroxene, and garnet from a lens of eclogitic rocks of Norway are analysed for their Mg, Ni, Co, Zn, Fe, and Mn contents. Examination of their distribution among these three phases reveals that: 1) in the pair orthopyroxene-clinopyroxene, the partition is essentially controlled by the size of the cations, so that, as far as the moderate-sized ions as listed above are concerned (except for Mn), the smaller ions prefer clinopyroxene, and 2) in the pair garnet-clinopyroxene, the partition is controlled by two factors, i.e. that the larger ions prefer garnet and that the less electronegative ions are excluded from garnet.

This note is a preliminary report on the distribution of certain cations among clinopyroxene, orthopyroxene, and garnet in the eclogitic rocks of Norway.

The petrology of the host rocks will be given elsewhere. The rocks are from a lens of eclogitic rocks enclosed in gneiss at Kolmanskog, Molde Peninsula, Norway (HERNES 1954). The major constituents of the rocks are clinopyroxene, garnet, and orthopyroxene together with subordinate hornblende and iron ores. The analysed minerals were separated by conventional methods to obtain a purity higher than 98%.

Chemical analyses were carried out by atomic absorption flame photometry using a Nippon Jarrel-Ash Model AA-1E flame photometer with H₂-air flame for Mn, Co, Ni, Cu, and Zn; by emission flame photometry after the standard addition technique for Ca in orthopyroxene; by chelatometric titration for Ca and Mg, and by colorimetry for Fe. Accuracy has been gauged from the analysis of the standard W-1 using similar techniques. Errors were estimated to be less than 5% relative.

Table 1. *Eclogite No. 2 (contents in ppm)*

	Garnet	Ortho- pyroxene	Clino- pyroxene	K'Gar · Cpx M · Fe	K'Opx · Cpx M · Fe
Mg	97,900	186,500	105,000	0.22	0.59
Ca	34,300	3,100	167,000
Mn	6,400	1,660	800	1.88	0.69
Fe	122,000	85,500	28,500	1.00	1.00
Co	119	177	77	0.36	0.77
Ni.....	28	330	190	0.034	0.58
Cu	1	1	40
Zn	29	102	30	0.23	1.13

Table 2. *Eclogite No. 3 (contents in ppm)*

	Ortho- pyroxene	Clino- pyroxene	K'Opx · Cpx M · Fe
Mg	179,400	103,000	0.58
Ca	5,700	163,000
Mn	1,800	830	0.73
Fe	90,700	30,400	1.00
Co	196	87	0.76
Ni.....	740	460	0.54
Cu	3	103
Zn	117	35	1.12

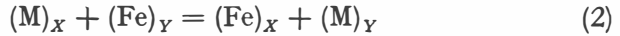
Results of the analyses are presented in Tables 1 and 2. It is notable that Cu is concentrated almost exclusively in clinopyroxene, suggesting the oxidation state of Cu(I). Therefore, in this case, the oxidation state of Fe can be supposed most plausibly to be + 2.

The apparent partition coefficients are also given in the Tables. They are defined as follows:

$$K' \frac{X \cdot Y}{M \cdot Fe} = (M/Fe)_X / (M/Fe)_Y \quad (1)$$

where symbols *X* and *Y* refer to the silicate phases under consideration and *M* denotes a divalent ion of the size similar to those of Mg and Fe. This way of presentation of partition coefficient has been discussed

elsewhere (BANNO and MATSUI 1965). In brief, the apparent partition coefficient $K' \frac{X \cdot Y}{M \cdot Fe}$ is approximately equal to the equilibrium constant in the exchange reaction:



Since the classical work of GOLDSCHMIDT (1926), it is widely accepted that ionic size plays a fundamental role in the processes of elemental distribution. Hence, it is interesting to see the relation between $\log K'$ values, which are approximately proportional to the exchange energies, and relevant ionic radii. Figs. 1 and 2 are such diagrams for the mineral pairs garnet-clinopyroxene and orthopyroxene-clinopyroxene, respectively. Pauling's radii are used in construction of the Figures (PAULING 1927). (The adoption of Pauling's set is a matter of convenience. Actually, choice of Ahrens' set results in little effect upon the trends discussed below.)

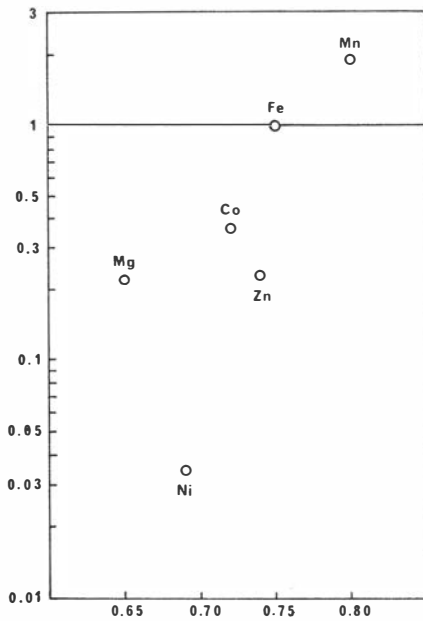


Fig. 1. Distribution pattern between garnet and clinopyroxene. Abscissa: Ionic radius Å. Ordinate: $K' \frac{\text{Gar} \cdot \text{Cpx}}{M \cdot \text{Fe}}$

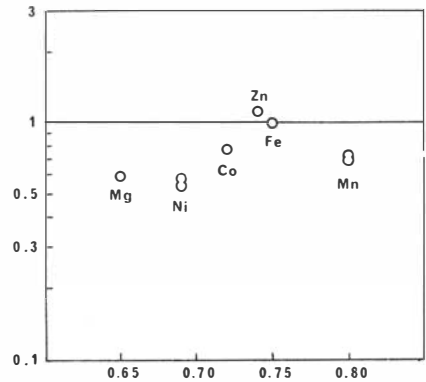


Fig. 2. Distribution pattern between orthopyroxene and clinopyroxene. Abscissa: Ionic radius Å. Ordinate: $K' \frac{\text{Opx} \cdot \text{Cpx}}{M \cdot \text{Fe}}$

In Fig. 1, the relation between $\log K'$ and ionic radius is not so simple. Though there is a general tendency that larger ions prefer garnet, and this can be understood considering the fact that garnet is essentially the mineral of relatively large cations such as Mn, it is obvious that Ni and Zn, and perhaps Co also, deviate from this tendency. As is noticed by some authors (NEUMANN 1949, WEDEPOHL 1953), the geochemical coherence of Zn and Fe is rather weak, despite the similarity in their ionic radii. This phenomenon is usually explained by the difference in their electronegativities or electron affinities. The degrees of deviation from the tentative join Mg-Fe-Mn in Fig. 1 are $\text{Ni} > \text{Zn} > \text{Co}$. This order coincides with that of their second ionization potentials, viz., Ni: 18.147, Zn: 17.959, and Co: 17.052 (in eV) (AHRENS 1964).

In contrast to the above pair, the pattern of partition between ortho- and clinopyroxenes (Fig. 2) is far more regular. The fact that the join Ni-Co-Fe is shifted to the right as compared to the join Mg-Zn is most probably due to the apparent shrinkage of the ionic size of the former group according to the crystal-field effect (CURTIS 1964). [Note, for example, that the lattice dimensions of $\text{CaNiSi}_2\text{O}_6$ are smaller than those of $\text{CaMgSi}_2\text{O}_6$ (GJESSING 1941).] Thus, in this pair it can be said that the smaller ions prefer clinopyroxenes. This is explained qualitatively as the mean size of the sites for cations of moderate size, i.e. exchangeable with Mg and Fe, is smaller in clinopyroxene than in orthopyroxene, which has large M_1 sites (GHOSE 1965). The departure of Mn is possibly due to the replacement of Mn for Ca in clinopyroxene.

As a conclusion, the following statement can be made: the partition of cations between minerals of similar anionic characters (such as ortho- and clinopyroxenes) is controlled by the size of cations irrespective of their chemical properties; this holds for both major and trace elements. The partition between minerals of different anionic characters is more complicated and reflects the type of individual chemical bonds. This sort of statement is, in fact, not novel. Nevertheless, we should like to emphasize that our conclusion has been derived purely from the analysis of the partition of the elements between coexisting minerals.

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Curved joints in gneiss

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In aerial photographs of the island of Justöy, on the Norwegian Skagerrack coast south of Lillesand, a pattern of long, almost rectilinear joints is a highly predominant feature (Fig. 1). The majority of them are very nearly vertical and at right angles to the main schistosity plane of the gneiss (OFTEDEAL 1956), i.e. directed with minor deviations