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DIOPSIDE AND ACTINOLITE FROM SKARN, CLEARWATER COUNTY, IDAHO[1]

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ABSTRACT

Chemical and spectrographic analyses of coexisting actinolite and diopside from the metamorphosed dolomitic sandstone of the Precambrian Wallace Formation northwest of the Idaho Batholith indicate nearly equal distribution of all other elements except calcium. Calculated [Ca/(Fe+Mg)] in actinolite/diopside is 0.4. It is concluded that in the *PT* conditions of the amphibolite facies only diopside crystallizes in layers that have $[\mathrm{Ca}/(\mathrm{Fe}+\mathrm{Mg})]>1$; diopside+actinolite if $1>[\mathrm{Ca}/(\mathrm{Fe}+\mathrm{Mg})]>0.4$; and only actinolite if $[\mathrm{Ca}/(\mathrm{Fe}+\mathrm{Mg})]<0.4$, in which Ca is the excess after deduction of the amounts contained in plagioclase, sphene, and scapolite.

The mineral pair diopside-actinolite occurs with plagioclase and quartz or with plagioclase, scapolite, and quartz in metamorphosed dolomitic sandstones of the Precambrian Wallace Formation of the Belt Supergroup northwest of the Idaho batholith. It is most common in the gneissic layers in the kyanite-garnet and kyanite-sillimanite zones but also occurs in some layers in the sillimanite-muscovite zone and thus was stable under the pressure-temperature conditions of the amphibolite facies. Interbedded with the diopside-actinolite gneiss are layers that, in addition to plagioclase, quartz, ±scapolite, contain only diopside and still others that have only actinolite. On the basis of the theoretical formulas of the diopside, $\mathrm{Ca(Mg,Fe)Si_2O_6}$, and actinolite, $\mathrm{Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2}$, crystallization of diopside requires a higher concentration of CaO than does the crystallization of actinolite. Thus, the Ca/(Fe+Mg) ratio of the rock is certainly important in determining the ratio in which actinolite and diopside will crystallize from a given layer. This ratio may be further influenced by the amount of substitution of Mg by $\mathrm{Fe^{+2}}$ and Si by Al in each mineral. It is therefore important to find out the exact compositions of the coexisting diopside and actinolite.

General aspects of the occurrence of the coexisting diopside and actinolite from the Elk River-Clarkia area (Hietanen, 1963, p. C23–C25) and from the Mallard Peak area (Hietanen, 1968, p. 10–11) have already been described. The indices of refraction that were determined for these occurrences indicate a limited range in composition of each mineral: actinolite $\alpha=1.618$–1.622, $\gamma=1.642$–1.645; coexisting diopside $\alpha=1.673$–1.674, $\gamma=1.701$–704.

At the mouth of Collins Creek in the Mallard Peak area (Hietanen,

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1968, pl. 1), diopside and actinolite form monomineralic shells around calcite lenses in the Wallace Formation. Diopside crystallized next to the calcite (Fig. 1) and was enveloped by a shell of actinolite. Comparison with the low metamorphic equivalents of the Wallace Formation farther north suggests that these calcite lenses were originally dolomitic layers in shale and sandstone. During the metamorphism dolomite reacted with quartz to form diopside. The excess $CaCO_3$ seggregated into monomineralic lenses that were enveloped by diopside. Small grains of diopside in the surrounding gneiss are optically similar to the diopside in this shell. Actinolite crystallized in the dolomitic shaly layers that contained more Fe and Mg than the dolomite. The actinolite in the monomineralic shell is optically and presumably chemically similar to the actinolite in the gneiss. The monomineralic seams may have crystallized in response to concentration gradients resulting from local diffusion during the metamorphism but the distribution of these minerals in the primary thin layers (beds) certainly was controlled by the original composition of these layers.

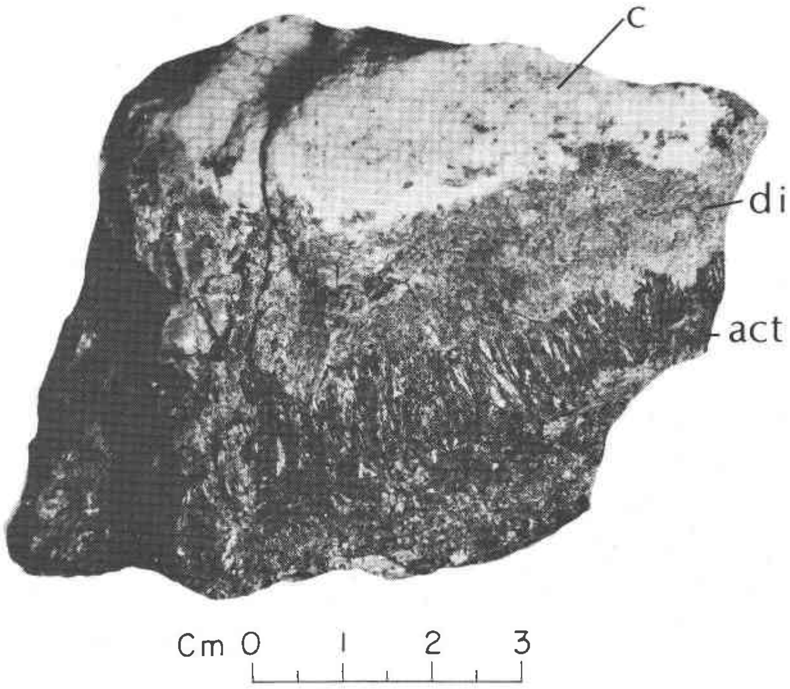

FIG. 1. Photograph of sample 2154, from which diopside (di) and actinolite (act) were separated. White part (c) consists of calcite.

TABLE 1. CHEMICAL COMPOSITION, CALCULATED FORMULAS, AND TRACE-ELEMENT CONTENT OF DIOPSIDE AND ACTINOLITE FROM SKARN (SAMPLE 2154), COLLINS CREEK CABIN, CLEARWATER COUNTY, IDAHO

Diopside					Actinolite				
Weight percent		Number of ions for 6 oxygens			Weight percent		Number of ions for 24 oxygens		
SiO_2	53.80	Si	1.99	2.00	SiO_2	54.84	Si	7.70	
Al_2O_3	0.47	Al	0.01		Al_2O_3	1.74	Al	0.29	8.00
		Al	0.01		Fe_2O_3	1.19	Fe^{3+}	0.01	
Fe_2O_3	0.93	Fe^{3+}	0.03				Fe^{3+}	0.12	
FeO	5.63	Fe^{2+}	0.17		FeO	6.95	Fe^{2+}	0.82	
MnO	0.35	Mn	0.01		MnO	0.29	Mn	0.03	4.88
MgO	14.15	Mg	0.78	1.98	MgO	18.64	Mg	3.90	
TiO_2	0.02	Ti	0.00		TiO_2	0.09	Ti	0.01	
CaO	24.46	Ca	0.97		CaO	12.97	Ca	1.95	
Na_2O	0.37	Na	0.01		Na_2O	0.58	Na	0.16	2.16
K_2O	0.004	K	0.00		K_2O	0.28	K	0.05	
F	—	F	0.00		F	0.66	F	0.29	1.98
H_2O	0.00	OH	0.00		H_2O^+	1.8	OH	1.69	
H_2O^-	0.04				Less O = F	0.28			
Total	100.22				Total	99.8			
ppm		End members (percent)			ppm		End members (percent)		
Ba	<4	Enstatite	39.59		Ba	4	Tremolite	73.01	
Be	4	Ferrosilite	9.14		Be	2	Ferrotremolite	9.73	
Co	40	Wollastonite	48.22		Co	48	Endenite	8.22	
Cr	32	Acmite	1.02		Cr	20	Hastingsite-	9.04	
Cu	8	$CaFe^{3+}AlSiO_6$	2.03		Cu	5	type molecule		
							$[Na_2Ca_2Fe_2^{2+}Mg_2Fe^{3+}(OH)_2Si_6Al_2O_{22}$		
Ga	7		100.00		Ga	12			
Ni	9	Indices of refraction			Ni	13	Indices of refraction		
Sc	46	$\alpha = 1.674 \pm 0.001$			Sc	40	$\alpha = 1.622 \pm 0.001$		
Sr	14	$\beta = 1.681 \pm 0.001$			Sr	14	$\beta = 1.634 \pm 0.001$		
V	100	$\gamma = 1.703 \pm 0.001$			V	95	$\gamma = 1.644 \pm 0.001$		
Y	30				Y	40			
Yb	3	$Fe^{2+}/Mg = 0.2234$			Yb	2	$Fe^{2+}/Mg = 0.2092$		
Zr	20	$Ca/Fe^{2+}+Mg = 1.016$			Zr	20	$Ca/Fe^{2+}+Mg = 0.414$		

$K_D(Fe_{2+}/Mg)$ Act/Di = 0.936; K_D $(Ca/Fe_{2+} + Mg)$ Act/Di = 0.407

Sample 2154, Collins Creek Cabin, Clearwater County, Idaho Analyses by C. O. Ingamells and Sarah T. Niell (chemical) and R. E. Mays (spectrographic), all of U S. Geological Survey.

Separation of the small grains of diopside and actinolite in the gneiss was not successful; therefore these minerals were separated from the monomineralic shells in sample 2154 and analyzed chemically (Table 1). In both minerals the percentage of MgO is about three times that of FeO. In the calculated formula the [Fe/Mg] ratio is 0.22 for the diopside and 0.21 for the actinolite, indicating an equal distribution of Fe and Mg between the diopside and actinolite. In Figure 2, where the percentages of major oxides in diopside are plotted along the abscissa and those in actinolite along the ordinate, plots for MgO, FeO and Al_2O_3 are slightly above the line drawn for the equal distribution, but the plot for CaO is much below it.

Trace-element content of analyzed diopside is very similar to that of the actinolite. Each contains 95–100 ppm V, 30–48 ppm each Co, Sc, and Y, and a small amount of Cr, Zr, Sr, Ni, Ga, Cu, Be, and Yb (Table 1). In Figure 3 all of these elements plot close to the equal distribution line; concentrations of Cr, Cu, Be, and Yb are only a little higher in the diopside than in the actinolite and Co, Y, Ni, and Ga a little lower.

In calculation of the percentages of end members of diopside (Table 1) all Mg was calculated as enstatite ($MgSiO_3$), Fe^{2+} as ferrosilite ($FeSiO_3$), Na as acmite ($NaFeSi_2O_6$) and Ca as wollastonite ($CaSiO_3$). A part of wollastonite was combined with Fe^{3+} and Al to form the molecule $CaFe^{3+}AlSiO_6$, which was derived from diopside by hypothetical substitution $Fe^{2+}+Si^{4+} \rightleftharpoons Fe^{3+}+Al^{3+}$, as has been suggested by Vogel (1966). The actinolite was first calculated as tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$) and ferrotremolite ($Ca_2Fe_5Si_8O_{22}(OH)_2$), then edenite ($NaCa_2Mg_5AlSi_7O_{22}(OH)_2$) and hastingsite-type molecules ($NaCa_2Mg_4Fe^{3+}Si_6Al_2O_{22}(OH)_2$) were formed from Na, Al, and a part of termolite.

Calculation of the chemical analyses shows that the coexisting diopside and actinolite contain about equal amounts of the iron end member, and differences in composition are mainly in the higher calcium content and

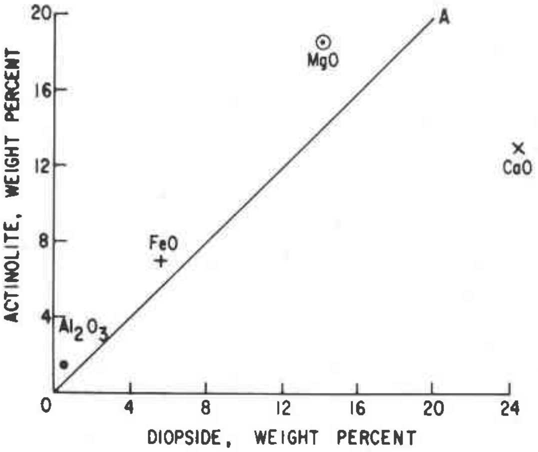

FIG. 2. Distribution of MgO, FeO, CaO, and Al_1O_3 between actinolite and diopside. Line OA is the line of equal distribution.

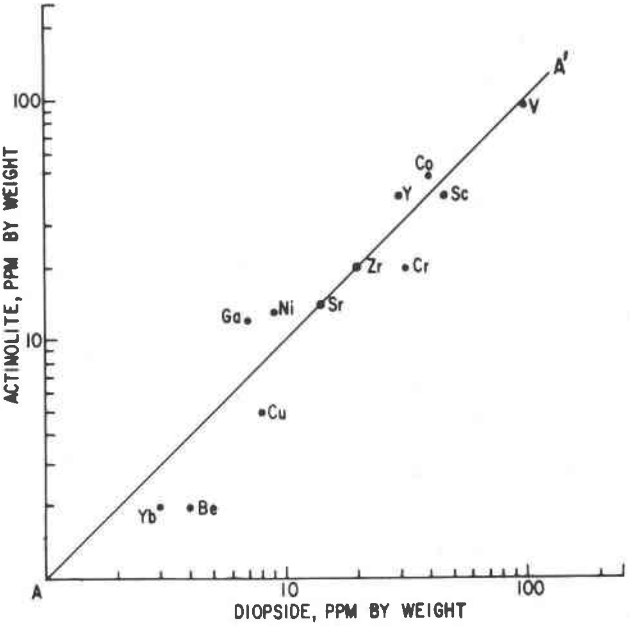

FIG. 3. Distribution of trace elements between actinolite and diopside. Line AA′ is the line of equal distribution.

slightly lower aluminum and alkali contents in the diopside. The distribution of [Fe/Mg] and [Ca/(Fe+Mg)] for diopside and actinolite is shown in Figure 4. K_D[Fe/Mg] for act/di is close to 1, whereas K_D[Ca/(Fe+Mg)] for act/di is 0.4. An important difference between the com-

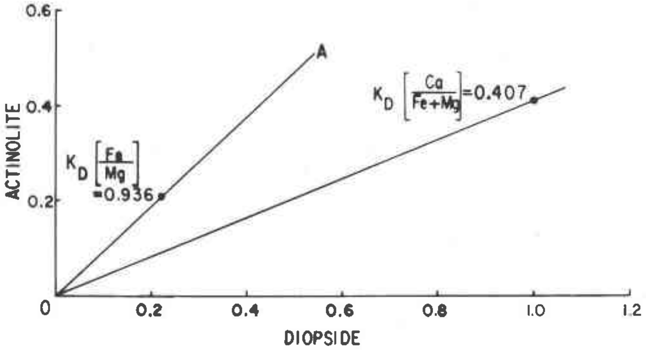

FIG. 4. Distribution coefficients for [Fe/Mg] and [Ca/Fe+Mg] in the analysed actinolite-diopside pair.

position of actinolite and diopside is the occurrence of $(OH)_2$ group in the actinolite. Therefore the initial CO_2/H_2O ratio of the individual primary layers may have influenced the preference of crystallization of either diopside (at high P_{CO_2}) or actinolite (at high P_{H_2O}). However, the common occurrence of calcite in each type of layers and the coexistence of biotite with diopside in thin interbedded layers (Hietanen, 1963, p. C30) indicate that this was not a determining factor. Rather the partial pressures of these volatiles were uniform on the scale of initial layer. The other differences in the chemistry of these minerals are minor; thus, crystallization of actinolite with diopside, and the ratio of these minerals in a given layer, depend mainly on the amount of CaO available, which can be calculated for each layer by deducting from the total CaO the amount that forms plagioclase (and scapolite) with Al_2O_3 and sphene with TiO_2. After these deductions are made, it is concluded that only diopside will crystallize in the layers that have $[Ca/(Fe+Mg)]>1$; diopside and actinolite will crystallize together if $1>[Ca/(Fe+Mg)]>0.4$; and only actinolite will form if $[Ca/(Fe+Mg)]<0.4$.

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