

Πρακτικά		3ου Συνεδρίου	Μάιος 1986
Δελτ. Ελλ. Γεωλ. Εταιρ.	Τομ. XX/2	σελ. 293-303	Αθήνα 1988
Bull. Geol. Soc. Greece	Vol.	pag.	Athens

## DISTRIBUTION OF ELEMENTS BETWEEN COEXISTING PHENGITE AND CHLORITE FROM LOW GRADE ROCKS FROM SKYROS ISLAND, GREECE

E. BALTATZIS\*

Abstract.

Distribution of  $Fe^{2+}$  and Mg between coexisting phengite and chlorite shows a linear trend. The distribution coefficient  $K_D(Fe)$  is influenced in part by  $X_{Fe}$  of phengite. The tie lines for the mineral pairs on the triangular diagram show a subparallel trend. The  $Mg/Mg + Fe^{2+}$  of chlorite varies sympathetically with the  $Mg/Mg + Fe^{2+}$  of the rock.

### Introduction

No prior determination of partition coefficient among coexisting phases for low grade metamorphic rocks from Greece is known to the writer, hence the reason for the present study. This study was undertaken in low grade rocks from Skiros island. Details on the geology of the island of Skiros, may be found in Melentis (1973) and Jacobshagen and Skala (1976).

The mineral assemblages observed in the rocks studied include the following:

albite +white mica ± epidote

albite +white mica + chlorite ± epidote

albite +epidote

All the above assemblages ± quartz, ± calcite ± Fe-oxides.

This paper discusses the distribution of element between coexisting phases in rocks of greenschist facies metamorphism from Skiros island, Greece (Fig. 1).

---

\*DEPARTMENT OF GEOLOGY

SECTION OF MINERALOGY, PETROLOGY AND ECONOMIC GEOLOGY

PANEPISTIMIOPÓLIS, ANO ILISIA, GR- 157 01 ATHENS



Fig 1. Map showing the locality (hatched) of the collected samples.

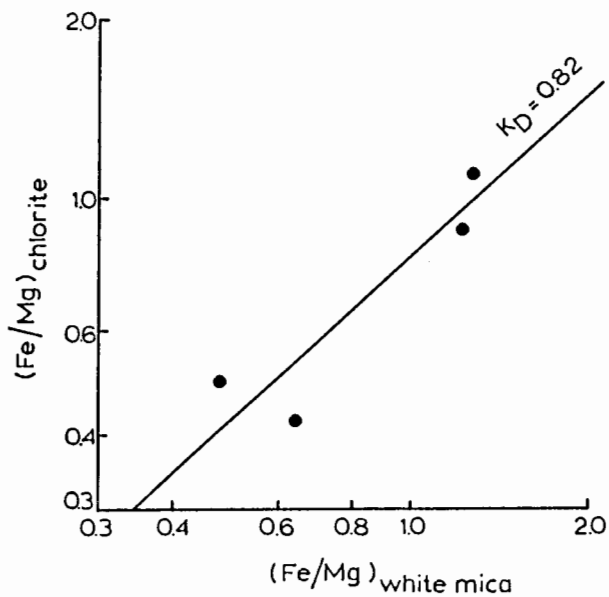


Fig. 2. Major element fractionation of  $Fe^{2+}$  versus Mg in coexisting chlorite + white mica pairs.

## Mineral and rock chemistry.

XRF major element analyses of representative samples, computed on a volatile free basis, are given in Table 1, together with their mineral assemblages.

Mineral analyses (Table 2), were performed at the University of Manchester, using a Cambridge Instrument Geoscan fitted with a Link Systems model 290-2KX energy-dispersive spectrometer and ZAF-4/FLS quantitative analysis software system. Operating conditions were 15 kV accelerating voltage and 3nA specimen current on cobalt metals. Accuracy, precision and detection limits of energy-dispersive electron-microprobe analyses of silicate used are given by Dunham and Wilkinson (1978).

### Chlorite

According to Hey's (1954) classification scheme, the chlorites from the quartzfeldspathic rocks (samples 205,511, Table 2) fall into the epidolite field, whereas the chlorite from metabasic rocks (samples 30,35, Table 2) lie within the pycnochlorite field. Chlorites from samples 205, 511 tend towards relatively more Al- and Fe- rich compositions, whereas metavolcanic chlorites (samples 30,35) are more magnesian. Similar ranges in compositions are reported by Ernst (1983). The analysed chlorites show replacement of silica by aluminium within the range  $\{Si_{3.02} Al_{0.98}\}$  to  $\{Si_{2.67} Al_{1.33}\}$  which is close to that observed in chlorites from other areas of similar or little higher metamorphic grade (Kawachi, 1975; Baltatzis and Katagas, 1984). The small variable amounts of K, Na and Ca, observed which are consistent within a single thin section, suggest the possibility that some of the analysed chlorites may be represent regular submicroscopic intergrowth with phengite paragonite and margarite (Ernst, 1983).

### Muscovite

Atomic proportions for O=22 per formula unit, computed as if all Fe is present as  $Fe^{2+}$  are listed in Table 2. All are clearly phengitic with Si/Al in their tetrahedral sites much higher than 3:1. Thus, the white micas analysed are comparable with phengites from low temperature metamorphic terrains (Brown, 1967; Coombs et al; 1976; Ra0, 1977; Katagas and Panagos; 1979; Baltatzis and Katagas, 1984). Furthermore, in the metabasic rocks (samples 30,35), the white micas are richer in celadonitic molecule (~32-33%), whereas in the quartzfeldspathic rocks (samples 205,511), the celadonitic molecule in the white micas are lower (~12-17%). This relationship reflects the difference in the bulk rock composition (Table 1) and is reported by Liou et al, (1981), Baltatzis and Katagas (1984).

Table 1. XRF Bulk Rock analyses of representative samples and their mineral assemblages

	205	511	30	35
SiO <sub>2</sub>	68.49	68.86	47.67	48.73
Al <sub>2</sub> O <sub>3</sub>	15.37	14.81	16.46	13.60
Fe <sub>2</sub> O <sub>3</sub>	4.32	5.64	9.18	11.06
MgO	1.90	4.13	10.87	11.96
CaO	4.26	0.91	6.80	9.46
Na <sub>2</sub> O	2.81	3.22	2.96	3.18
K <sub>2</sub> O	2.03	1.68	2.50	0.13
TiO <sub>2</sub>	0.64	0.67	2.45	1.45
MnO	0.02	0.02	0.19	0.20
P <sub>2</sub> O <sub>5</sub>	0.16	0.23	0.57	0.20
Total	100.00	100.17	99.65	99.97
Quartz	x	x	x	x
Albite	x	x	x	x
Chlorite	x	x	x	x
Muscovite	x	x	x	x
Epidote			x	
Clpx(relicts)				x

Table 3. Relationship between  $X_{Mg}$  for muscovite (phengite) and the distribution coefficient ( $K_D$ ) for the co-existing mineral pairs.

Sample	musc-chl	musc
	$K_D(Mg)$	$X_{Mg}$
205	0.099	0.052
511	0.121	0.075
30	0.188	0.202
35	0.234	0.217

Table 2. Analyses of coexisting chlorite - phengite.

	205		511		30		35	
	Chlorite	Phengite	Chlorite	Phengite	Chlorite	Phengite	Chlorite	Phengite
SiO <sub>2</sub>	25.37	47.05	25.77	47.16	29.12	50.86	30.08	51.24
TiO <sub>2</sub>	-	0.48	-	0.37	-	-	-	-
Al <sub>2</sub> O <sub>3</sub>	22.49	33.49	21.78	30.57	18.24	23.47	17.68	23.83
FeO	26.01	2.39	24.08	3.33	16.83	4.73	18.66	3.78
MgO	13.23	1.06	15.10	1.50	22.54	4.13	21.17	4.43
MnO	0.26	-	-	-	0.41	-	0.30	-
CaO	-	-	-	-	-	-	0.17	-
Na <sub>2</sub> O	0.53	0.43	-	0.78	0.36	0.27	0.34	-
K <sub>2</sub> O	0.14	9.82	-	9.24	-	10.21	-	11.10
Total	88.02	94.72	87.10	92.95	87.40	93.68	88.39	94.36
	14(0)	22(0)	14(0)	22(0)	14(0)	22(0)	14(0)	22(0)
Si	2.67	6.30	2.71	6.46	2.94	6.99	3.02	6.98
Al <sup>iv</sup>	1.33	1.70	1.29	1.54	1.06	1.01	0.98	1.02
Al <sup>vi</sup>	1.46	3.50	1.42	3.40	1.11	2.78	1.11	2.81
Ti	-	0.05	-	0.04	-	-	-	-
Fe <sup>+2</sup>	2.29	0.27	2.12	0.38	1.42	0.54	1.57	0.43
Mn	0.02	-	-	-	0.04	-	0.03	-
Mg	2.08	0.21	2.37	0.31	3.39	0.34	3.17	0.90
Ca	-	-	-	-	-	-	0.02	-
Na	0.11	0.11	-	0.21	0.07	0.07	0.07	-
K	0.02	1.68	-	1.62	-	1.79	-	1.93
Ce1%		11.65		16.71		33.17		32.13
Fe <sup>+2</sup> / <sub>Mg</sub>	1.101	1.286	0.895	1.226	0.419	0.643	0.495	0.478
$K_D = \frac{(Fe/Mg)_{chl}}{(Fe/Mg)_{phen.}}$	0.856		0.730		0.652		1.036	

## Partitioning of elements among coexisting phases.

In recent years considerable attention has been devoted to the development of geothermometers based on temperature - dependent Fe- Mg partitioning between coexisting ferromagnesian phases. The general phenomenon of element fractionation between coexisting minerals was systematically treated first by Ramberg and de Vore (1951). Subsequently, the partitioning of cations between coexisting minerals has been investigated by numerous authors; an up to date summary of the theory and some natural examples were provided by Saxena (1973). Partitioning is a function of temperature, to a minor extent, pressure and for non-ideal solutions, the compositions of the participating phases. For major element distribution involving exchange of the type:

$Fe_{\text{biotite}} + Mg_{\text{chlorite}} = Fe_{\text{chlorite}} + Mg_{\text{biotite}}$ , an equilibrium constant may be defined for fixed variables (P,T) as  $K_D = \frac{(Fe/Mg)_{\text{chlorite}}}{(Fe/Mg)_{\text{biotite}}}$ .

No prior determination of partition coefficient among coexisting phases for low- grade metamorphic rocks from Greece is known to the writer, hence the reason for the present study. In addition, similar studies on low-grade metamorphic rocks are very few (Ernst, 1964; McNamara, 1965; Brown, 1967; Ra0, 1977; Ernst, 1983).

Although a moderate number of microprobe analyses of minerals was obtained in the present study, few data were determined from any specific rock. Thus, the number of analysed coexisting phases is not large, conclusions must be regarded as tentative. Table 2 gives the values of  $Fe^{2+}/Mg$  for phengite and chlorite and the distribution coefficient for the 4 coexisting mineral pairs from the Skiros island rocks. The partitioning of ferrous iron and magnesium between coexisting pairs chlorite white mica are illustrated in Fig.2, on which the best fit straight line is shown. The equation of the straight line in Fig.2 is  $Y=0.7536x+0.043$ . The average  $K_D(Fe/Mg)$  value of this study ( $K_D=0.82$ ) is higher than those of Ra0 (1977) and lower than those of Ernst (1983). This suggests that the rocks of this study have formed at temperatures higher than those of Ra0 (1977) and lower than those of Ernst (1983).

In the analysed minerals,  $K_{D(Mg)}^{\text{musc-chl}}$  values (Table 3) shows a systematic variation with the content of tetrahedral Al or octahedral Al of either chlorite or phengite (Tables 2 and 3). On the contrary, Ra0 (1977) has been observed no systematic variation between these parameters. In addition, Table 3 gives the values of  $K_{D(Mg)}^{\text{musc-chl}}$  and  $X_{Mg}^{\text{musc}}$  for coexisting phengite and chlorite from Skiros island rocks, where the expression  $X_{Mg}$  stands for  $Mg/Y$ , where Y is the octahedral cation total.

The  $K_{D(Mg)}^{musc-chl}$  ranges from 0.009 - 0.234 with an average of 0.161. Fig.3 is a plot of  $K_{D(Mg)}^{musc-chl}$  versus  $X_{Mg}^{musc}$ . The plot shows a generally sympathetic variation between the two parameters. Similar variations though not highly regular, has been reported by Ra0 (1977)

#### Approach to equilibrium

Inspection of the S- A -F diagram (Fig 4 ), where the three coordinates represented are S=Si, A=Al and F=Fe<sup>2+</sup>+Mg, shows that the tie lines between coexisting chlorite -phengite of this study do not cross each other suggesting attainment of equilibrium (Greenwood, 1967; Saxena, 1969). The generally subparallel nature of the tie lines between the coexisting phengite and chlorite (Fig 4 ) suggests that the variations in the composition of the minerals are governed by the change in bulk composition of the rocks (Table 1). McNamara (1965) found two families of the lines between potassium mica and chlorite from greenschist facies rocks of the Scottish Highlands and attributed this to coarse and fine grain size of the mineral pairs. Ra0 (1977) studying coexisting phengite and chlorite pairs from the greenschist facies of the Tennant Creek area, Central Australia, observed a subparallel trend. He suggests that the variation in the mineral composition is governed either by the bulk composition of the rocks or by the variation in P and T in the Tennant Creek area.

#### P- T conditions of metamorphism

In the rocks studied some of the metamorphic mineral assemblages encountered in this island such as quartz-albite- chlorite-white mica ± epidote are not considered diagnostic of P - T conditions being common in both regional greenschist facies and the albite hornfels. In the absence of mineralogic geothermometers/geobarometers, the assignment of specific conditions of metamorphism is difficult indeed. In spite of, Velde (1964) has given a temperature of 300°C with  $P_{H_2O} = 2Kb$  for the first appearance of the greenschist assemblage of quartz-potassium mica and chlorite, while a higher temperature ( 400°C) is favoured by Winkler (1979) as the lower limits for the greenschist facies. Judging from other well studied, similar parageneses, a provisional estimation for the rocks studied would involve temperature of  $320 \pm 10^\circ C$ , with lithostatic pressure on the order of 3 kbar. This estimate takes into account the absence of biotite and garnet from the rocks studied.

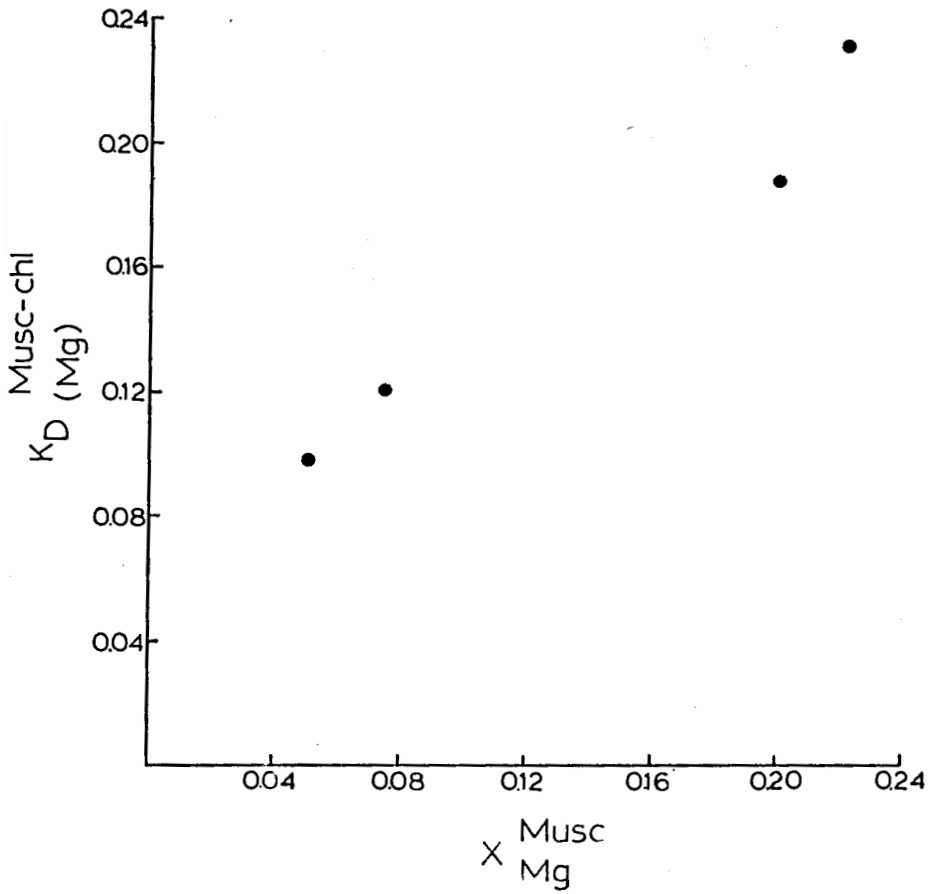


Fig. 3. Plot of  $x_{Mg}^{Musc}$  and  $K_D(Mg)^{Musc-chl}$  from Skiros island.



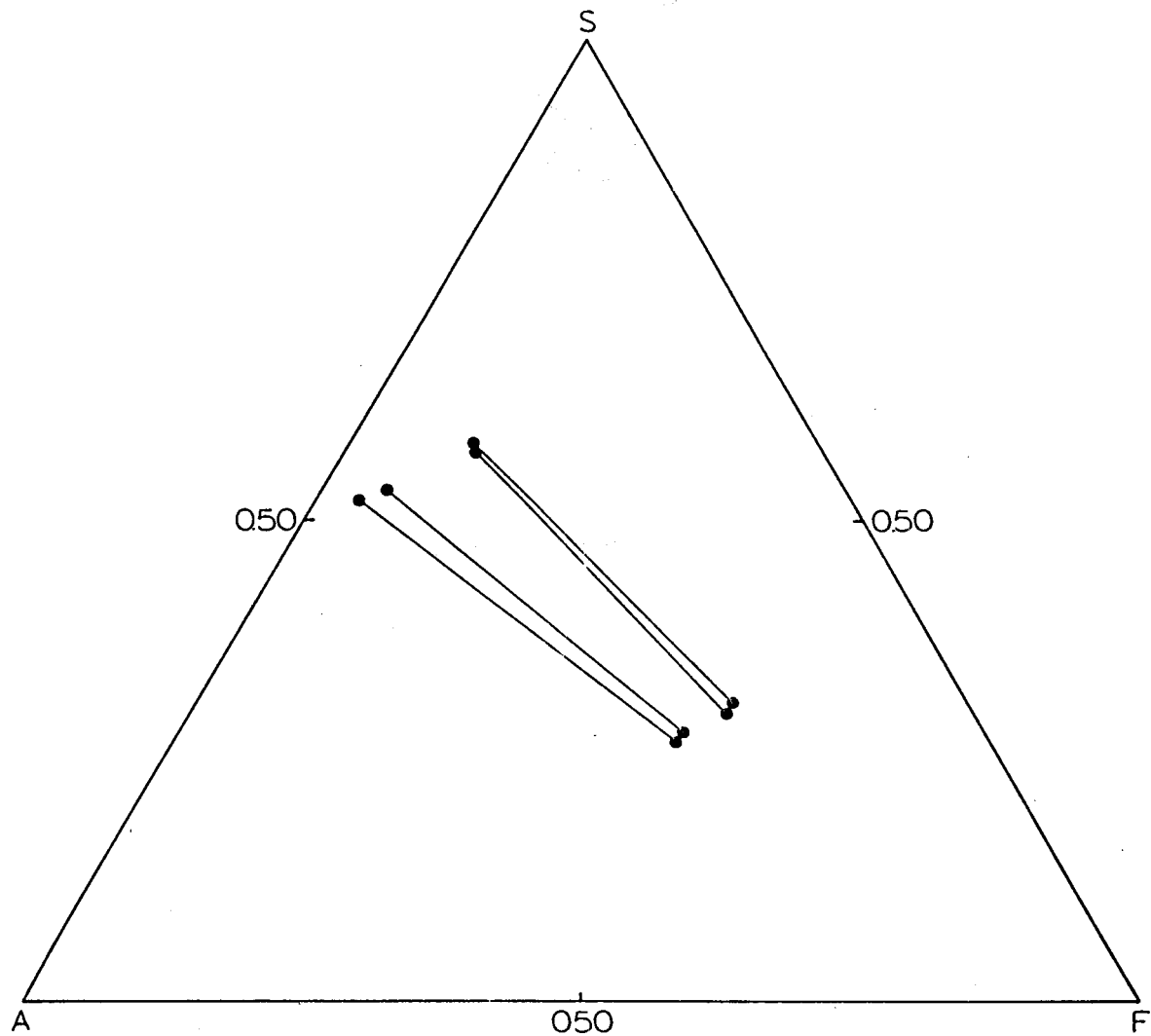


Fig. 4. S.A.F. diagram of the analysed coexisting chlorites and phengites.

## References

- Baltatzis, E.G and Katagas, C. (1984). The pumpellyite- actinolite and contiguous facies in part of the Phyllite- Quartzite Series, central Northern Peloponnesus, Greece. *J. metamorphic Geol.* 2, 349-363.
- Brown, E.H. (1967) . The greenschist facies in part of eastern Otago, New Zealand. *Contr. Miner. Petr.* 14, 259-292.
- Coombs, D.S., Nakamura, Y, and Vuagnat, M. (1976). Pumpellyite- Actinolite facies schists of the Tayeyanne formation near Loeche, Valais, Switzerland. *J. Petr.* 17, 440-471.
- Dunham, A.C. and Wilkinson, F.C.F. (1978). Accuracy, precision and detection limits of energy-dispersive electron-microprobe analyses of silicates. *X-ray spectrometry*, 7, No 2, 50-56.
- Ernst, W.G. (1964). Petrochemical study of coexisting minerals from low grade schists, Eastern Shikoku, Japan. *Geochim. et Cosmochim. Acta* 28, 1631-1668.
- Ernst, W.G. (1983). Mineral parageneses in metamorphic rocks exposed along Tailuko Gorge, Central Mountain Range, Taiwan. *J. metamorphic Geol.*, 1, 305-329.
- Greenwood, H.J. (1967). The N-dimensional tie-line problem. *Geochim et Cosmochim. Acta* 31, 465-490.
- Hey, M.H. (1954). A new review of the chlorites. *Miner. Mag.*, 30, 257-292.
- Jacobshagen, W. and Skala, W.(1976). Observations sur le développement tectonique des Sporades du Nord. *Bull. Soc. Geol. France*, 18, 281-286.
- Katagas, C and Panagos, A.G (1979). Pumpellyite- Actinolite and Greenschist facies metamorphism in Lesvos island (Greece). *Tschermaks. Min. Petr. Mitt.*, 26, 235-254.
- Kawachi, Y., (1975). Pumpellyite-actinolite and contiguous facies metamorphism in part of the upper Wakatipu district, South island, New Zealand. *N.Z.J. Geol. Geophys.*, 18, 401-441.
- Liou, J. G., Ernst, W.G. and Moore, D.E. (1981). Geology and petrology of some poly-metamorphosed amphibolites and associated rocks in northeastern Taiwan. *Bull. geol. Soc. Am.* 92, Part I, 219-224, Part II, 609-748.
- McNamara, M.J. (1965). The lower grade greenschist facies in the Scottish Highlands. *Geol. Foren. I Stockh. For.* 87, 347-389.
- Melentis, J. (1973). The geology of Skiros. *Bull. Geol. Soc. Greece*, X(2), 298-322.
- Ramamohana Rao, T, (1977). Distribution of elements between coexisting phengite and chlorite from the greenschist facies of the Tennant Greek area, Central Australia. *Lithos* 10, 103-112.

- Ramberg, H and de Vore, G.W. (1951). The distribution of  $Fe^{++}$  and  $Mg^{++}$  in coexisting olivines and pyroxenes. J. Geol. Chicago., 59, 193-210.
- Saxena, S.K. (1969). A statistical approach to the study of phase equilibria in multi-component systems. Lithos, 3, 25-36.
- Saxena, S.K. (1973). Thermodynamics of Rock-forming crystalline solutions. Springer-Verlag, New York, 188pp.
- Velde, B. (1964). Low-grade metamorphism of micas in pelitic schists. Carnegie Inst. Wash. Yearb. No 63, 142-147.
- Winkler, H. G. F. (1979). Petrogenesis of metamorphic rocks. (Fifth Edition). Springer-Verlag. N.Y.