CHEMISTRY OF SOME GARNET-BEARING ROCKS FROM SOUTH NORWEGIAN PERIDOTITES

By

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Abstract. Chemical analyses (7 new) of nine garnetiferous rocks from the peridotites of Tafjord and Almklovdalen are presented and discussed.

The geochemistry of garnetiferous peridotites and garnet-pyroxene rocks within the peridotites of Tafjord and Almklovdalen, Norway, does not compare closely with that of eclogites in gneisses, nor with that of the suite of eclogites and garnet-peridotites in kimberlite diatremes, nor with that of any extrusive magma type, nor with that of the products of igneous crystal accumulation and crystal sorting obtainable at low pressures where the C.I.P.W. norm closely represents the actual minerals likely to be present.

Introduction

Garnet-wehrlites, garnet lherzolites, garnet-websterites, and garnet-clinopyroxene rocks form layers interleaved with dunites and saxonites in the large, deformed peridotite masses among the gneisses of the Tafjord and Almklovdalen regions, South Norway (ESKOLA 1921, O'HARA and MERCY 1963). These rocks contain a magnesian olivine, alumina-poor magnesian orthopyroxene, alumina-poor chrome diopside, and a pyrope-rich garnet. Petrographic and mineralogical data for these rocks are given elsewhere (O'HARA and MERCY 1963, MERCY and O'HARA, in preparation).

Knowledge of the bulk chemical compositions of the garnet-peridotites and garnet-pyroxene rocks is essential for any discussion of the origin of the composition variation in these peridotite masses. The analyses are also important in characterizing the geochemistry of a group of rocks which may in some way be connected with the origin and evolution of basalt magmas, and some of the rocks here described belong to one of the types of eclogite occurrence distinguished by most authors (e.g. ESKOLA 1939, DAVIDSON 1943, O'HARA and YODER 1963). The first mentioned aspect of these rocks is being studied in detail by Mr. D. A. Carswell and will not be considered further in this communication.

Chemical Analyses

New chemical analyses and C.I.P.W. norms of seven specimens of garnet-peridotite and associated rocks from the Norwegian province are presented in Tables 1 and 2 together with a few analyses quoted from the literature. Petrographic data for these samples are given in Table 1A and by O'HARA and MERCY (1963, Table II). The analyses represent the chemical composition of hand specimens taken from layered sequences and may not, individually, represent the bulk composition of any substantial volume of rock.

Discussion

The remarkable paucity of K_2O and P_2O_5, low Na_2O, relatively high MgO, Cr_2O_3, and prominent NiO in the analyses distinguish these, both individually and as a group, from the majority of analyses of eclogite bodies in gneisses (cf. BRIÈRE 1920, ESKOLA 1921, ALDERMAN 1936, YODER and TILLEY 1962, and a host of analyses referenced by ANGEL 1957), and from analyses of any extrusive magma-type (cf. TURNER and VERHOOGEN 1960). The olivine-eclogite from Lyngenes, Sörpol, Selje, described by ESKOLA (1921) on the basis of an imperfectly located specimen collected 35 years previously, allegedly from a body in gneiss, is apparently related chemically to the group of rocks under discussion. As Eskola remarks, the Lyngenes eclogite is petrographically very similar to material from the mass at Rödhaugen, but in the CMF projection (Fig. 1) it falls far apart from the rocks discussed here.

There is a geochemical hiatus between the garnet peridotites and garnet-pyroxene (eclogite) nodules in kimberlite (O'HARA and MERCY 1963, Fig. 26 and p. 301) which is evidence in favour of the origin of these eclogites through a partial melting process operating on garnet peridotite with subsequent precipitation of eclogite accumulates (O'HARA and YODER 1963). There is no such geochemical hiatus be-

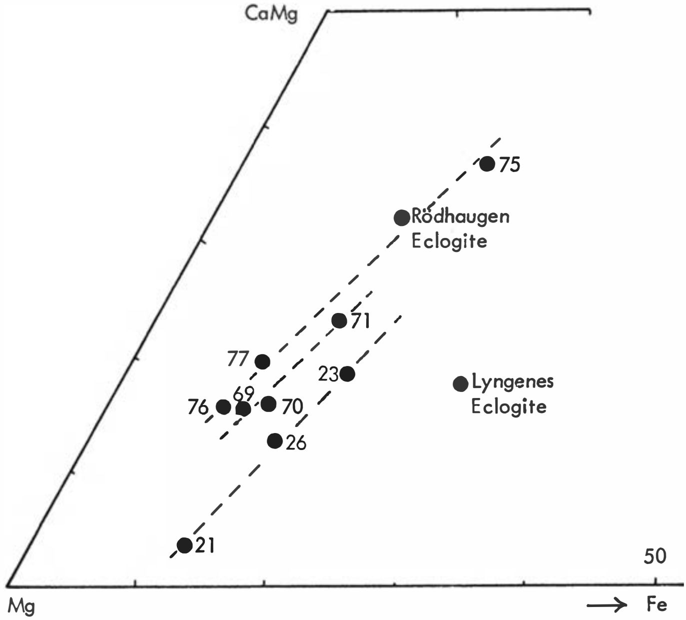

Fig 1. Atomic ratios Ca : Mg : total Fe plot of garnetiferous rocks in Norwegian peridotites. Points are identified by the field numbers given in Tables 1 and 2. The plots of the eclogites from Rödhaugen and Lyngenes (ESKOLA 1921) are also shown. This diagram should be compared with the plot of garnet peridotite and eclogite nodules from kimberlite (O'HARA and MERCY 1963, Fig. 26) when it will be seen that most of the Norwegian specimens fall in a field intermediate and transitional between those of the garnet-peridotite and eclogite nodules in kimberlite, a field which is virtually unoccupied by eclogite facies materials from kimberlite sources. The broken lines in Fig. 1 represent an apparent linear correlation between samples from the same locality implying that samples from Rödhaugen are systematically richer in Ca relative to Mg and Fe, at any chosen Fe/Mg ratio, than are samples from Lien, and these in their turn than samples from Kalskaret.

tween the garnet peridotites and garnet-pyroxene rocks in the peridotites of the Norwegian province (Fig. 1), but true bimineralic eclogites, geochemically comparable to the materials in kimberlite, are not found within the Norwegian peridotites. Quartz-bearing eclogites, similar to the eclogites occurring in the country rocks, have been found, however, in the Norwegian peridotites at Kaldhussæter (personal communication, D. A. Carswell) and Hornindal. Transitional relationships, such as exist among the rocks described here, have not been

Table 1. *Chemical Analyses, Weight %*

Collection No. Field No.	10268 N.21	10273 N.26	10316 N.69	10270 N.23	10323 N.76	10317 N.70	10318 N.71	10324 N.77	10322 N.75	Röd- haugen Eclogite
SiO_2	42.95	44.26	47.58	48.83	48.10	47.46	46.68	47.32	44.42	48.7
TiO_2	0.04	0.34	0.19	0.45	0.28	0.11	0.17	0.17	0.14	t.r.
Al_2O_3	0.88	5.81	6.68	8.55	9.92	10.65	12.23	13.29	18.59	11.7
Cr_2O_3	0.40	0.34	0.43	0.21	0.63	0.49	0.32	0.40	0.109	0.2
Fe_2O_3	2.63	2.66	0.69	1.71	1.22	2.34	0.52	1.22	2.23	1.4
FeO	7.82	8.16	6.51	8.53	4.32	5.34	7.75	4.58	7.06	6.8
MnO	0.15	0.16	0.14	0.19	0.18	0.19	0.22	0.22	0.18	0.2
NiO	0.32	0.21	0.33	0.104	0.139	0.113	0.13	0.075	0.031	—
MgO	40.97	29.54	27.50	21.72	25.64	24.69	19.80	22.40	12.09	16.7
CaO	2.20	6.88	7.94	8.46	7.32	7.62	10.15	8.65	13.69	13.9
Na_2O	0.19	0.72	0.82	0.84	0.79	0.63	0.58	0.78	1.41	0.4
K_2O	<0.02	0.02	0.02	<0.01	0.04	0.01	0.02	<0.01	<0.01	0.2
P_2O_5	<0.003	0.005	0.003	<0.003	<0.003	0.004	0.003	0.011	0.014	—
H_2O+	1.20	1.09	1.08	0.57	1.18	0.79	1.04	0.98	0.19	0.1
Totals	99.75	100.19	99.91*	100.16	99.76	100.44	99.61**	100.10	100.15	100.3

* also contains CoO 0.007%
** also contains CoO 0.004%

Analyses listed in order of Al_2O_3 content, excepting Eskola's specimen.
All analyses made on material dried at 110° C for 2 hours.

Analyst: E. L. P. Mercy.

Methods: Classical procedures for SiO_2, FeO, H_2O. Colorimetric methods for Ti (tiron), Mn (permanganate), P (heteropoly blue), Total Fe (thioglycollic acid), Al (8-hydroxy quinoline), Cr (chromate or S-diphenyl-carbazide), and Ni (dimethyl-glyoxime). Titrimetric for Ca and Mg (by E. D. T. A.) Flame photometric for Na and K.

The sensitivity of a method of chemical analysis depends to some extent on the amount of material available. The usual routine for the flame photometric determination of K enables us to detect positively an instrumental response corresponding to 0.015% or 0.02%. Hence, no response is recorded as <0.01%. Similar remarks apply to the colorimetric determination of P with a lower limit of detection at <0.003%. An investigation of the exact K contents of these rocks and minerals would be of scientific interest but would require very special techniques in the sampling, preparation, and analysis of the materials.

Table 1A. *Estimated Volume Proportions of Minerals in Analysed Rocks*

	10268 N.21	10273 N.26	10316 N.69	10270 N.23	10323 N.76	10317 N.70	10318 N.71	10324 N.77[1]	10322 N.75	Röd-haugen
Olivine	80	55	35	—	10	25	—	5	—	—
Orthopyroxene	—	tr	10	20	10	5	15	20	—	—
Clinopyroxene	—	25	30	40	30	40	35	20	55	55*
Garnet	10[2]	15	20	30	15	25	40	35	45	45*
Amphibole	10	5	5	10	30	5	10	20	tr	tr
Chlorite	tr	—	—	—		—	—	—	—	tr
Rest {rutile, opaques, serpentine}	tr	tr	tr	tr	5	tr	tr	tr	tr	tr

Proportions estimated to nearest 5 % on the basis of point counting on thin sections cut from hand specimens with very variable grain size and of inhomogeneous character with respect to the distribution of minerals.

[1] Estimated from mineral separation.
[2] Includes amphibole, ore, kelyphite after garnet.
* Calculated (Eskola 1921).

Table 2. *C.I.P.W. norms of*

	10268 N.21		10273 N.26		10316 N.69		10270 N.23	
Or	—		0.12	18.77	0.12	21.55	—	
Ab	1.61	3.16	6.09		6.94		7.00	26.62
An	1.55		12.56		14.49		19.62	
Ne	—		—		—		—	
Di	6.66	7.38	14.83	17.04	17.06	19.57	14.56	17.81
Hd	0.72		2.21		2.51		3.25	
En	14.47	16.26	8.02	9.39	15.83	18.50	25.05	31.47
Of	1.79		1.37		2.67		6.42	
Fo	59.19	67.26	41.12	48.88	31.35	37.17	15.62	20.03
Fa	8.07		7.76		5.82		4.41	
Mt	3.81		3.86		1.01		2.48	
Ilm	0.08		0.65		0.36		0.85	
Cr	0.59		0.50		0.63		0.31	
Ap	—		0.01		0.01		—	
Rest	1.20		1.09		1.08		0.57	
Total	99.74		100.19		99.88		100.14	
$\frac{Fe + Mn + Ni}{Fe + Mn + Ni + Mg}$ **	0.09		0.11		0.11		0.16	
Ab/Ab + An **	0.52		0.34		0.34		0.27	

* Quoted from Eskola 1921.
** Molecular ratios in normative silicates. Norms calculated using accurate

Key to Tables

Lab. No.	Field No.	
10268	N.21	Garnet-dunite, Kalskaret, Tafjord
10273	N.26	Garnet-wehrlite, Kalskaret, Tafjord
10316	N.69	Garnet-lherzolite, Lien, Almklovdalen
10270	N.23	Garnet-websterite, Kalskaret, Tafjord
10323	N.76	Garnet-lherzolite, Rödhaugen, Almklovdalen
10317	N.70	Garnet-lherzolite, Lien, Almklovdalen
10318	N.71	Garnet-websterite, Lien, Almklovdalen

rocks in Table 1 (in weight per cent)

10323 N.76	10317 N.70	10318 N.71	10324 N.77	10322 N.75	Rödhaugen Eclogite*
0.23 6.69 23.40 } 30.32	0.06 5.33 26.21 } 31.60	0.12 4.91 30.71 } 35.74	— 6.60 32.77 } 39.37	— 7.34 44.40 } 51.74	1.11 3.14 30.02 } 34.27
—	—	—	—	2.49	—
9.33 0.83 } 10.16	8.21 0.91 } 9.12	12.60 3.06 } 15.66	7.13 0.82 } 7.95	14.21 4.61 } 18.82	} 30.98
26.29 2.67 } 28.96	25.94 3.30 } 29.24	15.69 4.37 } 20.06	21.30 2.79 } 24.09	— —	} 18.06
23.29 2.61 } 25.90	22.24 3.12 } 25.36	19.52 6.00 } 25.52	21.85 3.16 } 25.01	16.48 6.75 } 23.23	} 14.70
1.77 0.53 0.93 —	3.39 0.21 0.72 0.01	0.75 0.32 0.47 0.01	1.77 0.32 0.59 0.03	3.23 0.27 0.16 0.03	2.09
1.18	0.79	1.04	0.98	0.19	
99.75	100.44	99.57	100.11	100.16	100.10
0.07	0.09	0.18	0.09	0.22	
0.23	0.18	0.15	0.18	0.15	

atomic weights.

1, 1A, and 2

Lab. No.	Field No.	
10324	N.77	Garnet-olivine-websterite, Rödhaugen, Almklovdalen
10322	N.75	Garnet-chrome-diopside rock (eclogite of Rödhaugen type in ESKOLA 1921), Rödhaugen, Almklovdalen
Rödhaugen eclogite.		Calculated composition from mineral analyses, (ESKOLA 1921, p. 30).

All the rocks contain secondary amphibole and/or chlorite (see O'HARA and MERCY 1963, Table II).

proved to exist between the peridotite and these quartz-bearing eclogites. Their status is not yet clear.

These relationships give a clear indication of different modes of origin for the Norwegian materials and for nodules in kimberlite, and they may afford a positive distinction between the suite of garnetiferous peridotites which could be obtained as xenoliths from crustal sources, such as the Norwegian garnetiferous peridotites, and the suite of garnetiferous peridotites which actually appears in kimberlite diatremes. The latter point bears adversely on DAVIDSON's (1964) claim that the suite of eclogites and garnetiferous peridotites found in kimberlite is identical with that obtained from crustal sources.

The C.I.P.W. norms of the Norwegian garnetiferous peridotites and associated rocks are characterized by abundant olivine and the presence of hypersthene in all but one case. The amounts of felspar and olivine in the norms vary greatly. The most sodic normative felspars are found in those rocks with least felspar present, but there is no convincing correlation between the amount of ferromagnesian phases present in the norm and their iron/magnesium ratios. It does not seem possible that these rocks have been formed by the eclogite facies metamorphism of layered ultrabasic rocks showing a sorting of olivines, pyroxenes, and felspars having compositions close to those of the ideal molecules calculated in the C.I.P.W. norm, although the behaviour of the normative felspars might reflect the operation of an interprecipitate liquid effect.

The appearance of nepheline in the norm of specimen 10322 from Rödhaugen requires comment. This rock contains primary garnet and chrome-diopside with scarce secondary amphibole. The norms of some garnet-chrome diopside mixtures from garnet peridotites have been calculated, and the mineral pair from 10316 (N. 69) (O'HARA and YODER 1963, Fig. 6) may be taken as representative. Olivine and hypersthene would have been expected in the norm of the garnet-chrome diopside mixture from 10322 (N. 75), and the presence of some primary olivine or enstatite would only increase the amounts of these molecules in the norm and could not lead towards the appearance of nepheline in the norm. The appearance of nepheline in the norm of this rock cannot be attributed to the later introduction of excess soda because the amount of secondary amphibole is altogether too small to explain the effect. It is deduced, therefore, that the clinopyroxene of this rock contains appreciably more Na_2O, probably as the jadeite molecule, than any of the clinopyroxenes analysed in our previous study (O'HARA and MERCY 1963, Table VIII). The proportion of clinopyroxene in this rock is about 55%, implying that the pyroxene contains about 2.5% Na_2O. It also appears, from a comparison of Fig. 1 with O'HARA and MERCY (1963) Fig. 22, that the clinopyroxene and garnet of this rock are appreciably richer in iron relative to magnesium than Eskola's Rödhaugen eclogite or any analysed in our previous study.

We have previously discarded the idea that the bulk compositions of these rocks result from igneous sorting of the phases now present (O'HARA and MERCY 1963, pp. 276–77) and this conclusion is strengthened by reference to the present mineral compositions of the three specimens N. 21, N. 26, and N. 23 from Kalskaret (O'HARA and MERCY 1963).

These results do not support the view that these garnetiferous materials are unaltered igneous rocks (ESKOLA 1921) nor do they support the view that they are no more than metamorphosed gabbroic lenses within the peridotites (DAVIDSON 1943).

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