Clarification of the petrology and occurrence of garnet lherzolites, garnet websterites and eclogite in the vicinity of Rødhaugen, Almklovdalen, West Norway

DENNIS ANTHONY CARSWELL

Carswell, D. A.: Clarification of the petrology and occurrence of garnet lherzolites, garnet websterites and eclogite in the vicinity of Rødhaugen, Almklovdalen, west Norway. *Norsk Geologisk Tidskrift,* Vol. 61, pp. 249–260. Oslo 1981. ISSN 0029-196X.

Re-examination of the so-called Rødhaugen eclogite specimens analysed by Eskola (1921) and Mercy & O'Hara (1965), together with new field observations, demonstrate that these specimens were not petrographically analogous nor from precisely the same locality. Eskola apparently overlooked the presence of appreciable orthopyroxene in his specimen. New microprobe mineral analyses are presented both for these earlier specimens and for a further suite of eight associated garnet lherzolite, garnet websterite and eclogite samples from the Rødhaugen area. The petrogenesis and tectono-metamorphic evolution of these rocks are discussed with reference to the differing compositions of porphyroclast cores and rims, and recrystallised matrix grains. New pressure/temperature equilibration estimates for these assemblages are taken to indicate that these rocks shared a common eclogite facies metamorphic event with the surrounding eclogite bearing gneiss complex.

D. A. Carswell, Department of Geology, University of Sheffield, Mappin Street, Sheffield S1 3JD. England.

In his classic early paper on the eclogites of Norway, Eskola (1921) described and presented chemical analyses for co-existing garnet and clinopyroxene in an eclogite from within one of the large peridotite masses in Almklovdalen near Åheim in Sunnmøre. He made it clear that his analysed specimen, previously unnumbered but hereon referred to as sample ESK 75, was from the collection in the Mineralogisk-Geologisk Museum at Oslo and was simply labelled 'Almklovdalen'. However, comparison with specimens which he later collected himself convinced him that it was from the hill called Rødhaugen about 500 metres to the north-east of Hellebust (Fig. 1). According to Eskola this eclogite contained rounded 'phenocrysts' of a pyropic garnet and a diopsidic pyroxene set in an evenly granular millimetre-sized groundmass of the same pyroxene. Small amounts of pale green amphibole were noted at the contacts between garnet and clinopyroxene and traces of chlorite and rutile were also observed. From the measured specific gravity of the rock, Eskola calculated a mode which he then used to calculate a bulk rock chemical composition for this eclogite from the garnet and pyroxene analyses (see Table 2). In his Fig. 5, Eskola sketched the Rødhaugen eclogite as occuring as 5–70 cm wide bands within olivine-rock which sometimes contains garnets and calcic pyroxenes as in the eclogite.

In their much later papers on Norwegian garnetiferous peridotites, O'Hara & Mercy (see both O'Hara & Mercy 1963 and Mercy & O'Hara 1965) presented petrographic data and a bulk rock analysis of what was claimed to be a petrographically similar porphyroclastic textured garnet-chrome diopside rock (field no. N75). They likewise indicated the locality for this rock to be at Rødhaugen within the Eikremsæter peridotite mass in Almklovdalen and implied that this was essentially the same eclogite as studied by Eskola. However, they did observe that their analysed eclogite sample was appreciably more ferriferous and must have contained a more sodic clinopyroxene than Eskola's Rødhaugen eclogite.

In order to resolve this confusion over the so-called Rødhaugen eclogite, it seemed desirable to undertake a reinvestigation of the samples analysed by these earlier workers in the light of my own field observations of the garnetiferous rocks within the Eikremsæter peridotite mass on, and in the vicinity of, the hill called Rødhaugen. It is apparent from this study that not only were the Eskola and O'Hara & Mercy

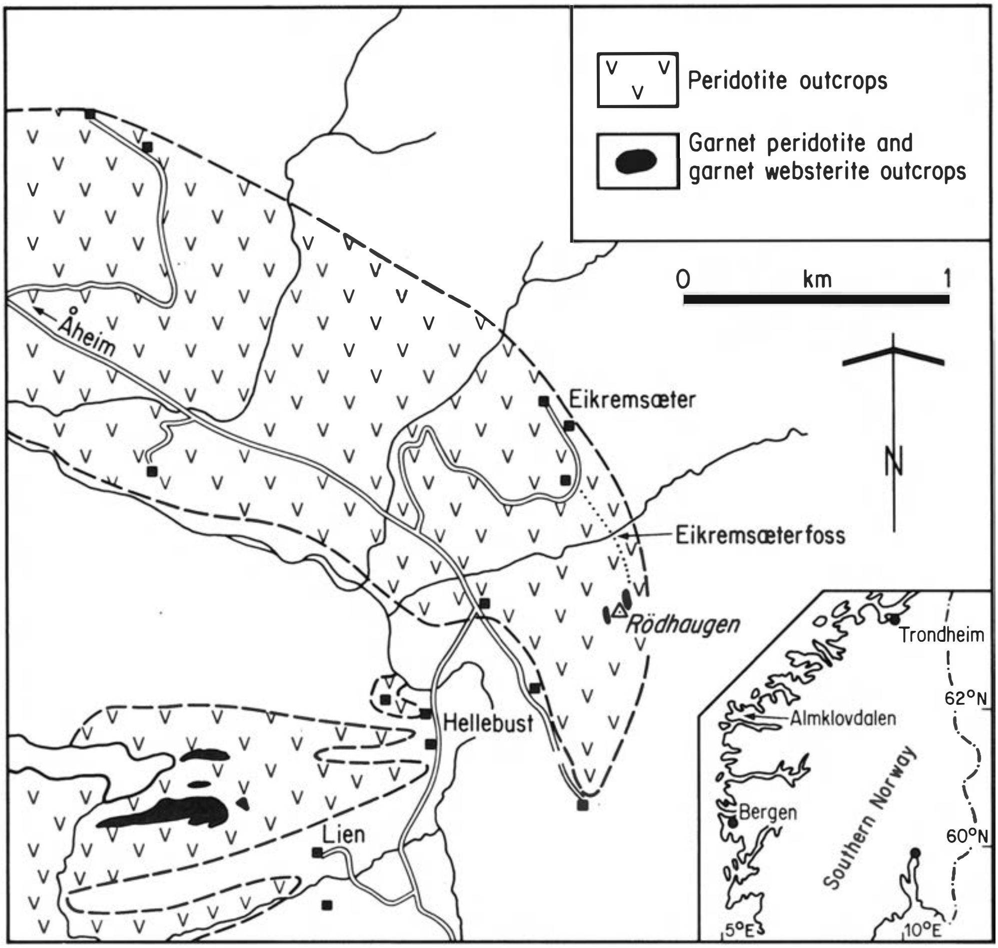

Fig. 1. Geological sketch map showing the locality for the analysed eclogite samples in relation to the garnet peridotite and garnet websterite outcrops in the Rødhaugen and Lien areas of Almklovdalen.

samples not identical petrographically, as well as chemically, but that they cannot have come from the same locality.

Field locations and petrography

It is now clear that the O'Hara & Mercy sample N75, though a true eclogite, did not come from the outcrops on the flanks of Rødhaugen but rather from a locality, perhaps best referred to as Eikremsæterfoss, about 250 metres north of Rødhaugen (see Fig. 1). Here a 130 cm wide lens of eclogite is exposed within chloritic peridotite on the eastern bank of a minor stream just below a small waterfall and above the rough track from Eikremsæter to Rødhaugen.

The eclogite at Eikremsæterfoss is indeed an essentially bimineralic red garnet-green clinopyroxene rock except for traces of both rutile and sulphide and the development of increasing amounts of secondary darker green amphibole towards the contact with the adjacent peridotite. Much of this eclogite is of relatively uniform grain-size with garnets 3–5 mm across and slightly smaller clinopyroxenes. However, it has a strikingly porphyroclastic texture in places, especially in pyroxene rich portions, with large strained clinopyroxene porphyroclasts up to 1 cm in length, set in a mosaic of strain-free recrystallised 0.3–0.5 mm sized clinopyroxenes.

TABLE 1 MODAL ANALYSES (VOL. %) OF ANALYSED SAMPLES

SAMPLE NUMBER	ROCK TYPE	% OLIVINE	% ORTHOPYROXENE	% CLINOPYROXENE	% GARNET	% AMPHIBOLE	% CHLORITE
A41	Eclogite	-	-	32	56	12	-
A84	Eclogite	-	-	67	28	7	-
ESK 75	Garnet Websterite	-	10	56	26	8	-
A33	Garnet Websterite	-	21	25	38	16	-
A49	Garnet Websterite	-	26	22	14	38	-
A6	Garnet Lherzolite	41	11	14	21	13	-
A7A	Garnet Lherzolite	47	9	19	17	8	-
A7B	Garnet Lherzolite	25	18	15	26	16	-
ESK 76	Garnet Lherzolite	17	22	21	32	8	-
ESK 77	Garnet Lherzolite	55	17	8	6	11	3

Mineral analyses are presented in this paper for two new samples of eclogite from this locality. Sample A41 is essentially identical to the original N75 sample of O'Hara & Mercy, whilst sample A84 is of the associated porphyroclastic textured variant.

By contrast, Eskola's analysed sample (ESK 75) was not a bimineralic eclogite as described by him. Re-examination of a residual piece of this sample retained in the Mineralogisk-Geologisk Museum at Oslo confirmed my earlier suspicions that this rock contains a minor, though significant, amount of orthopyroxene (see Table 1). This orthopyroxene takes the form of both rare large strained porphyroclasts and more abundant smaller recrystallised grains. This rock is thus strictly a garnet websterite and as such is indeed more akin to the rocks exposed on Rødhaugen, where garnet and clinopyroxene rich rocks occur interbanded with garnet and clinopyroxene free peridotite in the manner illustrated by Eskola. I myself have observed that at Rødhaugen there are in fact no true bimineralic eclogites and that the most garnet and clinopyroxene rich rocks are garnet websterites – in other words they invariably contain orthopyroxene.

In an attempt to confirm whether or not Eskola's specimen came from Rødhaugen, new petrographic and mineral composition data on the original Museum specimen have been obtained and compared with data on a further suite of garnetiferous samples from this locality. Two of these samples, ESK 76 and ESK 77, were also from Eskola's original collection housed in the Museum at Oslo, but in both cases specifically labelled as being from Rødhaugen. Sample ESK 76, recorded as *Eclogite in dunite*, in fact contains both orthopyroxene and olivine (Table 1). Sample ESK 77, recorded as *Garnet dunite*, likewise has a 4-phase garnet lherzolite assemblage but with much scarcer garnet and clinopyroxene, and the former heavily kelyphitised. In addition, the following five specimens were selected for analysis out of my own field collection from the Rødhaugen locality. Samples A33 and A49 are both olivine free but orthopyroxene bearing, and are therefore garnet websterites. Of these, sample A33 is petrographically the closest in appearance to Eskola's original Rødhaugen

TABLE 2 ANALYSES OF BULK ROCKS AND MINERAL SEPARATES

SAMPLE	BULK ROCK ANALYSES		ANALYSES OF MINERAL SEPARATES				
			GARNET		CLINOPYROXENE		AMPHIBOLE
	N75	ESK 75	A41	ESK 75	A41	ESK 75	A41
SiO_2	44.42	48.7	40.61	41.52	54.14	54.49	45.07
TiO_2	0.14	tr.	0.01	tr.	0.11	tr.	0.35
Al_2O_3	18.59	11.7	22.50	23.01	8.26	2.50	16.19
Cr_2O_3	0.11	0.2	0.10	0.22	0.15	0.20	0.08
Fe_2O_3	2.23	1.4	0.43	1.22	0.78	1.63	0.15
FeO	7.06	6.8	12.30	12.86	1.57	1.98	4.91
MnO	0.18	0.2	0.29	0.33	0.01	0.06	0.04
NiO	0.03	n.d.	0.00	0.00	0.05	0.03	0.11
MgO	12.09	16.7	11.56	16.64	12.72	16.74	16.06
CaO	13.69	13.9	11.92	4.71	19.31	21.40	11.59
Na_2O	1.41	0.4	0.06	0.00	2.68	0.83	3.10
K_2O	<0.01	0.2	0.02	0.00	0.02	0.40	0.08
P_2O_5	0.01	n.d.	0.02	n.d.	0.06	n.d.	0.01
H_2O	0.19	0.1	n.d.	0.16	n.d.	0.12	n.d.
TOTAL	100.15	100.3	99.82	100.67	99.86	100.38	97.74

ESK 75: Analyses of mineral separates and calculated bulk rock analysis from Eskola (1921)

N75: Bulk rock analysis from Mercy & O'Hara (1965)

A41: New analyses of mineral separates from the Eikremsaeter eclogite, performed by a combination of gravimetric, colometric and titration techniques in the Geology Department, University of Sheffield, U.K.

'eclogite' sample ESK 75, and is from the widest (approx. 75 cm.) olivine free layer observed at Rødhaugen. By contrast, sample A49 shows more extensive secondary amphibolitisation. As overall there are considerable variations in the proportions of primary garnet, pyroxenes and olivine in the various garnetiferous layers within the peridotite mass at Rødhaugen, the remaining three analysed samples, A6, A7a and A7b, were selected to span the gap between the olivine free garnet websterite samples and the relatively garnet impoverished lherzolite sample ESK 77.

All the analysed garnet websterite and garnet lherzolite samples have strikingly porphyroclastic textures with highly strained clasts of garnet, pyroxenes and olivines (in lherzolites only) up to 1 cm. in maximum dimension, set in a recrystallised matrix, consisting of a mosaic of small (typically 0.2–0.5 mm.) strain-free grains (neoblasts) of garnets, pyroxenes, olivines and amphiboles. Secondary amphibole has clearly formed at the expense of both primary garnets and clinopyroxenes and in certain samples, notably A49 and ESK 77, is intergrown with fine-grained chrome spinel as pronounced kelyphite rims around the garnets.

Mineral chemistry

Eikremsæterfoss eclogite

As might be predicted from comparison of the bulk rock analyses, the new mineral analyses confirm that all the clinopyroxene in the Eikremsæter eclogite is substantially more jadeitic than in Eskola's sample (ESK 75), and that garnets and clinopyroxenes both have higher Fe/Mg ratios (compare Tables 2–4). In addition the garnets in the Eikremsæterfoss eclogite are very much more calcic, reflecting the bimineralic eclogite paragenesis (Fig. 2). On the other hand, comparison with other analysed eclogite, garnet websterite and garnet lherzolite assemblages (O'Hara & Mercy 1963, Lappin 1974, Lappin & Smith 1978, Carswell 1968, 1973 and Medaris 1980) indicates that the limitation of the CaO content in the garnet in Eskola's sample to only 4.71 wt.% reflects equilibration within an orthopyroxene bearing assemblage (as indeed has been confirmed by the petrographic reinvestigation of this sample).

There is no interbanding of this eclogite with olivine bearing rocks, but instead sharp contacts between the eclogite and peridotite, adjacent to

TABLE 3 MICROPROBE ANALYSES OF MINERAL PHASES IN SAMPLES OF THE EIKREMSÆTER ECLOGITE

Sample No.	A41	A41	A41	A41	A84	A84	A84	A84	A41	A41
Description	Gnt Cores	Gnt Rims	Cpx Cores	Cpx Rims	Gnt Unzoned	Cpx Clast Cores	Cpx Clast Rims	Cpx Recryst.	Amph Adj. to Gnt	Amph Remote From Gnt
SiO_2	41.12	41.46	54.49	54.65	41.32	54.92	55.01	54.55	41.78	45.05
TiO_2	0.04	0.02	0.16	0.11	0.04	0.18	0.16	0.16	0.15	0.44
Al_2O_3	22.83	22.91	7.42	7.40	22.62	8.40	8.04	7.87	20.18	14.25
Cr_2O_3	0.13	0.07	0.12	0.16	0.14	0.14	0.17	0.16	0.07	0.17
^{T}FeO	12.19	12.61	1.97	1.96	12.69	2.08	2.14	2.22	7.17	5.06
MnO	0.26	0.27	0.02	0.02	0.29	0.02	0.02	0.01	0.06	0.00
NiO	0.00	0.00	0.03	0.08	0.00	n.d.	n.d.	0.07	0.11	0.15
MgO	11.57	11.53	12.47	12.40	10.69	11.75	11.74	12.06	13.39	16.13
CaO	12.25	12.13	19.18	19.35	13.20	18.37	18.65	18.37	12.33	10.81
Na_2O	0.02	0.02	3.39	3.44	0.02	4.16	4.03	4.06	1.55	3.39
TOTAL	100.41	101.02	99.25	99.57	101.01	99.95	99.96	99.53	96.79	95.45
Cation Proportions										
Si	3.016	3.024	1.962	1.963	3.027	1.960	1.966	1.960		
Ti	0.002	0.001	0.004	0.003	0.002	0.005	0.004	0.004		
Al	1.974	1.970	0.315	0.313	1.953	0.353	0.339	0.333		
Cr	0.008	0.004	0.003	0.004	0.008	0.004	0.005	0.004		
Fe	0.748	0.769	0.059	0.059	0.774	0.062	0.064	0.067		
Mn	0.016	0.017	0.001	0.000	0.018	0.001	0.001	0.000		
Ni	0.000	0.000	0.001	0.002	0.000	-	-	0.002		
Mg	1.264	1.253	0.669	0.664	1.167	0.625	0.625	0.646		
Ca	0.963	0.948	0.740	0.745	1.036	0.702	0.714	0.707		
Na	0.003	0.003	0.237	0.240	0.003	0.288	0.279	0.283		
TOTAL	7.993	7.989	3.992	3.994	7.992	4.000	3.997	4.008		
O	12.0	12.0	6.0	6.0	12.0	6.0	6.0	6.0		

T:- All Fe expressed as FeO

Microscan IX wavelength dispersion analyses performed in Department of Geology, University of Sheffield, U.K.

which the eclogite is heavily amphibolitised. This secondary amphibole develops at the expense of both garnet and clinopyroxene and varies in composition depending on location. The two electron microprobe analyses given in Table 3 represent the extremes of the composition range observed in the amphibole grains, whilst the pargasitic amphibole separate analysis (Table 2) represents an average composition.

Despite the lack of interbanding of this eclogite with the adjacent peridotite, the fact that its bulk rock composition (N75 in Table 2) lies on the continuation of the linear composition trend shown on the Ca:Mg:Fe plot of Mercy & O'Hara (1965) for the interlayered garnet websterites and lherzolites from Rødhaugen suggests that this eclogite may well be genetically related to the associated peridotitic rocks rather than that it represents a tectonic inclusion of eclogite of the type found in the nearby gneisses. Such an interpretation is further supported by the relatively magnesian and chromiferous nature of the garnets and clinopyroxenes in this eclogite,

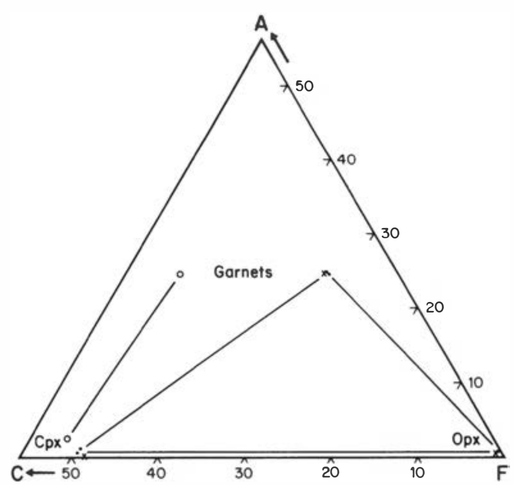

Fig. 2. ACF diagram showing a comparison of mean garnet, clinopyroxene and orthopyroxene porphyroclast core compositions in both the Rødhaugen garnet lherzolite and garnet websterite samples (filled circles) with the corresponding mineral compositions in Eskola's original 'eclogite' specimen (crosses) and in the Eikremsæterfoss eclogite (open circles).

TABLE 4 MICROPROBE ANALYSES OF PRIMARY MINERAL PHASES IN GARNET WEBSTERITE SAMPLES

Mineral Description	Garnet Clast Cores			Garnet Clast Rims & Recryst. Grains		Clinopyroxene Clast Cores			Clinopyroxene Clast Rims & Recryst. Grains			Orthopyroxene Clast Cores			Orthopyroxene Clast Rims & Recryst. Grains		
Sample No.	ESK 75	A33	A49	ESK 75	A33	ESK 75	A33	A49	ESK 75	A33	A49	ESK 75	A33	A49	ESK 75	A33	A49
SiO_2	42.19	43.67	41.92	42.18	43.75	55.16	55.50	55.80	55.48	55.88	55.36	56.89	58.30	57.72	57.78	59.37	57.73
TiO_2	0.04	0.02	0.02	0.02	0.02	0.08	0.15	0.15	0.06	0.11	0.11	0.18	0.03	0.04	0.02	0.02	0.02
Al_2O_3	22.59	23.22	23.08	24.47	22.90	2.85	3.06	3.38	2.26	2.65	3.08	0.77	0.76	0.72	0.41	0.34	0.40
Cr_2O_3	0.16	0.46	0.62	0.18	0.46	0.18	0.41	0.62	0.14	0.39	0.55	0.02	0.09	0.09	0.01	0.03	0.05
^{T}FeO	14.70	8.59	9.56	15.29	9.51	2.53	1.38	1.51	2.52	1.28	1.54	8.67	4.80	4.91	9.27	4.68	5.14
MnO	0.37	0.38	0.45	0.43	0.44	0.03	0.02	0.03	0.03	0.02	0.03	0.05	0.06	0.10	0.06	0.05	0.07
NiO	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.04	0.02	0.02	0.14	0.05	0.04	0.11	0.04	0.06
MgO	16.08	20.40	20.00	15.70	19.74	15.28	15.51	15.41	15.59	15.02	16.00	32.64	35.67	35.65	32.64	35.85	35.82
CaO	4.33	4.26	4.19	4.47	4.21	21.92	22.23	22.02	22.44	22.51	22.53	0.30	0.18	0.14	0.11	0.07	0.06
Na_2O	0.00	0.00	n.d.	0.00	0.00	1.86	1.80	1.87	1.52	1.56	1.64	0.02	0.03	0.01	0.01	0.01	0.00
TOTAL	100.46	101.02	99.84	100.74	101.03	99.91	100.08	100.81	100.08	99.44	100.86	99.68	99.97	99.42	100.42	100.46	99.35
Cation Proportions																	
Si	3.054	3.057	2.993	3.055	3.073	1.995	1.994	1.990	2.004	2.017	1.978	1.986	1.992	1.986	2.004	2.014	1.996
Ti	0.002	0.001	0.001	0.001	0.001	0.002	0.004	0.004	0.002	0.003	0.003	0.005	0.001	0.001	0.001	0.001	0.001
Al	1.928	1.916	1.942	1.919	1.896	0.122	0.130	0.142	0.096	0.113	0.130	0.032	0.031	0.029	0.017	0.014	0.002
Cr	0.009	0.026	0.035	0.010	0.026	0.005	0.012	0.018	0.004	0.001	0.016	0.001	0.002	0.002	0.000	0.001	0.002
Fe	0.890	0.503	0.571	0.926	0.559	0.076	0.042	0.045	0.076	0.039	0.046	0.253	0.137	0.141	0.269	0.133	0.149
Mn	0.023	0.023	0.027	0.026	0.026	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.003	0.002	0.001	0.005
Ni	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.004	0.001	0.001	0.003	0.001	0.002
Mg	1.735	2.128	2.128	1.695	2.067	0.824	0.830	0.819	0.839	0.808	0.852	1.699	1.817	1.828	1.687	1.812	1.846
Ca	0.336	0.320	0.320	0.347	0.317	0.849	0.856	0.842	0.868	0.871	0.863	0.011	0.007	0.005	0.004	0.002	0.002
Na	0.000	0.000	0.000	0.000	0.000	0.130	0.125	0.129	0.106	0.109	0.114	0.001	0.002	0.001	0.001	0.001	0.000
TOTAL	7.976	7.972	8.018	7.979	7.965	4.005	3.994	3.990	3.998	3.972	4.003	3.993	3.992	3.998	3.987	3.980	4.002
O	12.0	12.0	12.0	12.0	12.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0

T:- Total Fe as FeO

Microscan IX wavelength dispersion analyses performed in Department of Geology, University of Sheffield, U.K.

compared with those in eclogites directly enclosed in the gneisses at the nearby Lien locality (Medaris 1980).

Both Krogh (1977) and Medaris (1980) have interpreted mineral compositional zoning in eclogite lenses directly enclosed in the gneisses to indicate a prograde metamorphic evolution of such rocks. This contrasts and converges with the retrograde metamorphic P./T. trend defined on mineral zoning evidence by Medaris (1980) for interbanded garnet peridotite and pyroxenites in the Lien mass at Almklovdalen. However, probe analyses of the different samples of the Eikremsæterfoss eclogite (Table 3) indicate only minimal overall compositional zoning. Indeed mineral composition differences between the two samples (A41 and A84) are greater than the within grain variations observed in either sample. What little compositional zoning there is in the garnets and clinopyroxenes in sample A41 indicates a slight increase in the K_D partition co-efficient

$$[=(Fe^{2+}/Mg^{2+})\ \text{garnet}/(Fe^{2+}/Mg^{2+})\ \text{clinopyroxene}].$$

On the other hand, no significant zoning was detected in garnets in sample A84, and even the composition differences between the large strained porphyroclasts and the smaller recrystallised grains of clinopyroxene in that sample are surprisingly small.

Garnet websterite samples

Electron microprobe analyses of the primary mineral phases in the two garnet websterite samples (A33 and A49) from Rødhaugen are given in Table 4, where they can be compared with the new analyses for Eskola's original 'Rødhaugen eclogite' sample (ESK 75). All three samples lack modal olivine. It is noticeable that whilst the mineral compositions in Rødhaugen samples A33 and A49 are fairly similar, those in Eskola's sample are much less magnesian and chromiferous. For example, orthopyroxenes in ESK 75 are En_{86-87}, compared with En_{92-93} in the other two samples. In view of this, and the fact that I have been unable to match closely in appearance Eskola's original sample with any sample which I have collected at Rødhaugen, it is thought that Eskola's sample may not have come from that locality. Instead it is suspected that it may have originated from the nearby Lien locality, where Medaris (1980) has found that the

TABLE 5 GARNET AND CLINOPYROXENE ANALYSES IN GARNET LHERZOLITE SAMPLES

Min. Descrip.	Garnet Cores					Garnet Rims				Clinopyroxene Clast Cores					Clinopyroxene Clast Rims & Recryst. Grains				
Sample No.	A6	A7A	A7B	ESK 76	ESK 77	A6	A7A	A7B	ESK 76	A6	A7A	A7B	ESK 76	ESK 77	A6	A7A	A7B	ESK 76	ESK 77
SiO_2	41.91	42.44	43.01	42.40	41.98	41.74	42.09	42.84	41.94	55.29	55.52	54.58	55.19	55.39	55.49	55.18	54.48	55.52	54.72
TiO_2	0.08	0.04	0.05	0.05	0.02	0.07	0.05	0.02	0.02	0.17	0.20	0.19	0.16	0.09	0.13	0.07	0.07	0.15	0.06
Al_2O_3	21.92	22.76	22.74	22.87	22.08	21.61	22.62	22.68	22.80	3.72	3.49	3.35	3.42	3.32	2.94	2.65	1.48	3.34	2.67
Cr_2O_3	1.97	0.87	0.60	1.09	1.92	2.04	0.91	0.70	0.98	1.72	0.76	0.60	0.96	1.45	1.82	0.78	0.61	0.89	1.43
^{T}FeO	9.08	9.23	8.25	8.67	9.44	11.34	9.77	9.47	9.83	1.73	1.76	1.58	1.61	1.54	1.76	1.81	1.35	1.57	1.60
MnO	0.41	0.43	0.39	0.33	0.48	0.55	0.47	0.49	0.49	0.03	0.04	0.03	0.03	0.06	0.06	0.03	0.03	0.05	0.05
NiO	n.d.	n.d.	0.00	n.d.	n.d.	n.d.	n.d.	0.00	n.d.	0.04	0.02	0.02	0.05	0.02	0.00	0.03	0.02	0.02	0.03
MgO	19.52	19.72	20.30	20.09	19.24	18.36	19.41	19.60	19.52	14.65	15.26	15.50	15.43	15.27	14.98	16.37	16.88	15.31	15.48
CaO	4.27	4.08	4.40	4.05	4.27	4.23	4.03	4.47	4.19	21.13	22.12	21.94	21.94	21.43	21.69	22.77	23.84	22.19	22.23
Na_2O	n.d.	n.d.	0.00	n.d.	n.d.	n.d.	n.d.	0.00	n.d.	2.38	1.88	1.67	1.90	2.17	2.09	1.24	0.71	2.02	1.80
TOTAL	99.16	99.57	99.74	99.55	99.43	99.94	99.35	100.27	99.77	100.86	101.05	99.46	100.69	100.74	100.96	100.93	99.47	101.06	100.07
Cation Proportions																			
Si	3.018	3.030	3.050	3.021	3.019	3.016	3.022	3.042	3.003	1.978	1.980	1.977	1.976	1.982	1.986	1.975	1.985	1.981	1.978
Ti	0.004	0.002	0.003	0.003	0.001	0.004	0.003	0.001	0.001	0.004	0.005	0.005	0.004	0.002	0.004	0.002	0.002	0.004	0.002
Al	1.861	1.916	1.901	1.921	1.872	1.841	1.914	1.899	1.924	0.157	0.147	0.143	0.144	0.140	0.124	0.112	0.064	0.140	0.114
Cr	0.112	0.049	0.034	0.061	0.109	0.116	0.052	0.039	0.056	0.049	0.021	0.017	0.027	0.041	0.052	0.022	0.018	0.025	0.041
Fe	0.547	0.551	0.489	0.517	0.568	0.685	0.587	0.562	0.589	0.052	0.053	0.048	0.048	0.046	0.053	0.054	0.041	0.047	0.048
Mn	0.025	0.026	0.023	0.020	0.029	0.034	0.029	0.030	0.030	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002
Ni	-	-	0.000	-	-	-	-	0.000	-	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001
Mg	2.095	2.098	2.145	2.133	2.062	1.977	2.077	2.074	2.083	0.781	0.811	0.837	0.823	0.814	0.799	0.873	0.917	0.814	0.834
Ca	0.330	0.312	0.334	0.309	0.329	0.328	0.310	0.340	0.321	0.810	0.846	0.851	0.842	0.822	0.832	0.873	0.931	0.848	0.861
Na	-	-	0.000	-	-	-	-	0.000	-	0.165	0.130	0.117	0.132	0.151	0.145	0.086	0.029	0.140	0.126
TOTAL	7.991	7.985	7.980	7.985	7.989	8.001	7.992	7.988	8.006	3.998	3.995	3.997	4.000	4.000	3.996	3.999	3.987	4.002	4.006
O	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0

T:- Total Fe as FeO

Microscan IX wavelength dispersion analyses performed in Department of Geology, University of Sheffield, U.K.

mineral assemblages in comparable rocks extend to similarly more ferriferous compositions (e.g. orthopyroxenes are En_{87-92}).

In all three analysed garnet websterite samples, porphyroclasts of garnet and both pyroxenes are compositionally zoned. The most obvious features are an increase in Fe/Mg ratio from cores to rims in garnets, a decrease in Al and Na from cores to rims in clinopyroxenes, and a decrease in Al, Cr and Ca from cores to rims in orthopyroxenes. It was found that the compositions of the smaller recrystallised matrix grains of these phases are essentially the same as the rims of the large porphyroclasts. It was not possible to obtain a realistic garnet rim analysis in sample A49 because of the extensive kelyphitisation, but in the other two samples the change in Fe-Mg partitioning between garnets and clinopyroxenes is reflected in an increase in the K_D value from grain cores to rims (see Table 7).

The electron microprobe analyses for the garnets in ESK 75 are broadly similar to Eskola's original analysis (cf. Tables 2 and 4) for the garnet mineral separate. However, the new analyses for the clinopyroxenes in this rock are, significantly different from Eskola's original analysis. In particular, they indicate lower Fe and Mg, and higher Ca, Al and Na contents. From this it is concluded that Eskola's analysed clinopyroxene mineral separate may well have been contaminated with about 10% of orthopyroxene, the presence of which he appears to have overlooked in this rock sample. That said, it is still difficult to reconcile Eskola's value for Na_2O in the clinopyroxene with the roughly doubled values determined in the electron microprobe analyses.

Garnet lherzolite samples

The range of mineral compositions determined in the five garnet lherzolite samples from Rødhaugen (Tables 4 and 5) is fairly limited. The olivines are Fo_{90-91} and the orthopyroxenes En_{91-92} in all samples. Overall the garnets and pyroxenes have broadly similar Fe/Mg ratios to those determined in the associated garnet websterite samples from Rødhaugen, but are generally more chromiferous. Indeed, the chrome contents appear in general to increase in sympathy with decreasing modal contents of these minerals, relative to olivine.

There are again some significant composition differences between the cores and rims of porphyroclasts, with the smaller recrystallised matrix grains having essentially the same compositions as the porphyroclast rims. Moreover, the nature of these differences is much the same as in the olivine-free garnet websterites. K_D values are again consistently somewhat higher for clast rims than for cores (Table 7). Likewise, clinopyroxene clast rims and recrystallised grains have generally lower Al and Na (i.e. jadeite) contents and equivalent orthopyroxenes lower Al, Cr and Ca contents than corresponding clast cores.

Equilibration conditions and petrogenetic implications

Medaris (1980) has reported that core and rim compositions of minerals in garnet lherzolite and garnet pyroxenite assemblages from the nearby Lien locality (Fig. 1) define a retrograde metamorphic trend from 820° C., 28.1 Kbars. to 645° C., 17.6 Kbars. By contrast, eclogite lenses directly enclosed in the adjacent gneisses were reported to record a prograde metamorphic trend, which converges with the retrograde trend observed in the ultramafic rocks.

For comparison, calculated equilibration temperature-pressure estimates for respective core and rim (+neoblast) assemblages in the various analysed rocks are given in Table 7. All pressures have been calculated through use of the garnet-orthopyroxene geobarometer as formulated by Wood (1974), with substitution of Cr for Al in the octahedral sites taken into account in the manner which he proposed. Only results obtained from those geothermometers judged to give fairly consistent and reliable values have been included in Table 7. For example, results based on Fe^{2+}–Mg^{2+} partitioning between garnet and olivine in garnet lherzolite assemblages as experimentally calibrated by O'Neill & Wood (1979, 1980) vary from 706° C./21.6 Kbars. to 1086° C./48.4 Kbars. for grain cores alone, and have therefore been excluded. More detailed discussion of the likely validity of the various available mineralogical thermometers and barometers, especially those applicable to garnet lherzolite assemblages, have been given elsewhere (Carswell & Gibb 1980 a & b). It should, however, be noted here that in the case of the Wells (1977)/Wood (1974) and Ellis & Green (1979)/ Wood (1974) combinations, the paired temperature/pressure values have been obtained through simultaneous solution of two temperature and pressure dependent equations. Hence in these instances the temperature and pressure values given are interdependent, and each susceptible to errors in the other. For the other paired temperature/ pressure values given in Table 7, temperatures were calculated before pressures. Thus these pressure values are susceptible to any temperature errors but not vice-versa.

Both the Wells (1977) and Mori & Green (1978) calibrations of the two pyroxene solvus geothermometer give closely similar and encouragingly consistent temperature estimates for porphyroclast core assemblages. The mean values are 724° C./23 Kbars. and 732° C./23.5 Kbars. for the respective temperature/pressure pairings. However, it seems necessary to attach uncertainties of at least ±50° C. to these particular temperature estimates, in view of the relative temperature insensitivity of the two pyroxene solvus at such low temperatures. Co-existing pyroxene clast rims and recrystallised matrix grains yield much less consistent temperature estimates by this method, although the mean values are fortuitously similar to those for co-existing pyroxene clast cores.

Fe^{2+}–Mg^{2+} partitioning between co-existing garnet and clinopyroxene, usually expressed by the distribution co-efficient $K_D = (Fe^{2+}/Mg^{2+})$ garnet/(Fe^{2+}/Mg^{2+}) clinopyroxene, is much more temperature sensitive. It is therefore reasonable to expect that the temperature/pressure values obtained from this geothermometer in combination with the garnet-orthopyroxene geobarometer should be the most reliable. However, results calculated in this manner are critically dependent on whether or not all the iron in the co-existing garnet-clinopyroxene mineral pairs is taken to be divalent. If it is all taken as Fe^{2+}, the mean K_D values for the combined garnet lherzolite and garnet websterite samples are 4.51 and 5.40 for clast core and rim (+neoblast) assemblages, respectively. However, if one assumes equivalent $Fe^{2+}/(Fe^{2+}+Fe^{3+})$ ratios in the garnets and clinopyroxenes to those determined in analysis of bulk mineral separates from comparable assemblages (Table 2 and O'Hara & Mercy 1963), the mean K_D values are raised to 6.22 and 7.46, respectively. Consequently, calculated equilibration temperatures (Table 7) are on average around 100° C. lower.

The fact that the Mori & Green (1978) calibration of the K_D geothermometer involved some experiments on mineral assemblages separated from Norwegian garnet lherzolites of much the same composition as those being considered in this study, encourages one to consider that it should be more directly applicable to the present garnet lherzolite and garnet websterite assemblages than the Ellis & Green (1979) experimental calibration, which was based on garnet-clinopyroxene mineral pairs, in generally more siliceous and ferriferous basaltic compositions. However, it should be appreciated that Mori & Green's formulation of the K_D geothermometer was based on experiments run at either 30 or 40 Kbars. pressure and, unlike the Ellis & Green calibration, does not include a pressure dependence factor. There were also important differences in the experimental procedures employed, which have a bearing on the crucial question as to whether or not all the iron in the garnets and clinopyroxenes should be taken as Fe^{2+} when calculating K_D values. As pointed out by Medaris (1980), the garnets and clinopyroxenes produced in Mori & Green's experiments almost certainly contained small amounts of Fe^{3+}, as do the natural mineral pairs in these Norwegian rocks. However, since Mori & Green formulated their K_D geothermometer from microprobe mineral analyses in which all the iron was taken as Fe^{2+}, it seems desirable to make the same assumption when dealing with the natural assemblages in question. On the other hand, Ellis & Green carefully controlled the oxygen fugacity in their experiments on synthetic rock compositions in order to ensure that all iron remained divalent. Hence application of their K_D calibration to natural garnet-clinopyroxene pairs should take account of the presence of any Fe^{3+}.

With these considerations in mind, the temperature/pressure values based on the Mori & Green K_D calibration (assuming all Fe as Fe^{2+}) in combination with the garnet-orthopyroxene geobarometer of Wood (1974) are judged to be the most reliable as far as the garnet lherzolite and garnet websterite samples are concerned. On this basis, the averaged 'best' temperature/pressure estimates for the porphyroclast core assemblages in these rocks are 770° C. and 25.8 Kbars. Such values are very much in line with those obtained by Medaris (1980, Table 3) for comparable samples from the Lien locality on the same calculation basis, and are compatible with experimental evidence (O'Hara et al. 1971, Jenkins & Newton 1979) on the temperature/pressure conditions necessary for stability of such garnet lherzolite assemblages.

The consistently higher K_D values for co-existing garnet and clinopyroxene porphyroclast rims and recrystallised matrix grains, compared with the values for porphyroclast cores, suggests that cataclasis and attendant recrystallisation occurred as temperatures were falling. If, as seems likely, this took place as these rocks were being thrust towards the surface, subsequent to the metamorphic 'high', one would reasonably expect that pressures would also be lower. However, it is apparent from Table 7 that in many cases the calculated equilibration pressures for porphyroclast rim and neoblast assemblages are actually higher than those for corresponding porphyroclast cores. This is a consequence of the consistently lower Al contents of orthopyroxene porphyroclast rims and neoblasts compared with the porphyroclast cores (Tables 4 and 6). However, it is considered that the low Al contents in such orthopyroxenes at least in part reflect the uptake of Al in associated secondary amphiboles, a feature also noted in partly amphibolitised orthopyroxene eclogite assemblages (Carswell et al. 1981). Hence it is probably invalid to calculate equilibration pressures for such clast rim and neoblast assemblages using the garnet-orthopyroxene geobarometer based on anhydrous assemblages (Wood 1974, MacGregor 1974) and considered unlikely that the temperature/pressure estimates (Table 7) calculated in that manner for the porphyroclast rim and neoblast assemblages are geologically meaningful. Thus, although the K_D variation suggests recrystallisation in a falling temperature (and pressure?) environment, it is not possible to confirm the actual values indicated by Medaris (1980) for the retrograde metamorphic trend in garnetiferous assemblages in the nearby Lien peridotite.

The absence of primary plagioclase and quartz means that it is not possible to estimate the equilibration pressures for the Eikremsæterfoss eclogite sample from the jadeite content of its clinopyroxene (Kushiro 1969). The lack of orthopyroxene similarly rules out use of the garnet-orthopyroxene geobarometer. However, if one assumes a pressure value of 25.8 Kbars. (taken to be the 'best' pressure estimate for the garnet lherzolites and websterites), then from the Ellis & Green (1979) K_D calibration, which encompasses broadly comparable rock compositions, calculated equilibration temperatures for

TABLE 6 ORTHOPYROXENE AND OLIVINE ANALYSES IN GARNET LHERZOLITE SAMPLES

Mineral Description	Orthopyroxene Clast Cores					Orthopyroxene Clast Rims & Recryst. Grains					Olivines				
Sample No.	A6	A7A	A7B	ESK 76	ESK 77	A6	A7A	A7B	ESK 76	ESK 77	A6	A7A	A7B	ESK 76	ESK 77
SiO_2	57.84	57.57	58.37	57.89	57.33	57.99	57.84	58.54	57.72	58.70	40.53	40.62	41.18	40.62	40.24
TiO_2	0.04	0.03	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	n.d.	n.d.	n.d.	0.00	n.d.
Al_2O_3	0.81	0.84	0.62	0.66	1.00	0.48	0.60	0.53	0.61	0.46	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	0.22	0.17	0.08	0.12	0.25	0.11	0.08	0.05	0.09	0.07	n.d.	n.d.	n.d.	0.00	n.d.
^{T}FeO	6.07	5.63	5.86	5.33	6.00	6.36	5.93	5.15	5.69	6.15	9.34	8.57	9.45	8.56	9.27
MnO	0.13	0.11	0.12	0.10	0.14	0.14	0.07	0.08	0.11	0.13	0.11	0.12	0.18	0.15	0.12
NiO	0.04	0.06	0.05	0.05	0.08	0.05	0.06	0.05	0.04	0.07	0.41	0.42	0.31	0.38	0.42
MgO	34.42	34.93	35.10	35.74	34.41	34.64	35.07	35.52	35.21	34.78	49.33	50.01	48.90	49.96	49.26
CaO	0.18	0.10	0.10	0.10	0.18	0.09	0.10	0.09	0.09	0.09	0.00	0.00	0.00	0.00	0.00
Na_2O	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	n.d.	n.d.	n.d.	0.00	n.d.
TOTAL	99.78	99.44	100.33	100.01	99.42	99.89	99.41	100.07	99.59	100.47	99.72	99.74	100.02	99.69	99.31
Cation Proportions															
Si	1.993	1.987	1.996	1.984	1.983	1.997	1.987	2.000	1.989	2.006	0.996	0.994	1.007	0.995	0.993
Ti	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	-	-	0.000	-
Al	0.033	0.034	0.025	0.027	0.041	0.020	0.024	0.021	0.025	0.018	0.000	0.000	0.000	0.000	0.000
Cr	0.006	0.005	0.002	0.003	0.007	0.003	0.002	0.001	0.002	0.002	-	-	-	0.000	-
Fe	0.175	0.162	0.168	0.153	0.174	0.183	0.171	0.147	0.164	0.176	0.192	0.176	0.193	0.175	0.191
Mn	0.004	0.003	0.004	0.003	0.004	0.004	0.002	0.002	0.003	0.004	0.002	0.002	0.004	0.003	0.002
Ni	0.001	0.002	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.002	0.008	0.008	0.006	0.008	0.008
Mg	1.767	1.796	1.789	1.825	1.774	1.778	1.807	1.809	1.808	1.771	1.806	1.825	1.782	1.824	1.812
Ca	0.007	0.004	0.004	0.004	0.007	0.003	0.004	0.003	0.003	0.003	0.000	0.000	0.000	0.000	0.000
Na	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	-	-	-	0.000	-
TOTAL	3.988	3.993	3.989	4.001	3.993	3.991	3.999	3.989	3.997	3.983	3.004	3.006	2.993	3.005	3.007
O	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	4.0	4.0	4.0	4.0	4.0

T:- Total Fe as FeO

Microscan IX wavelength dispersion analyses performed in Department of Geology, University of Sheffield, U.K.

garnet-clinopyroxene grain cores average out at 879° C (if all Fe is taken as Fe^{2+}) or 778° C. (if analytical $Fe^{2+}/Fe^{2+} + Fe^{3+}$ ratios are taken into consideration). The latter value is clearly to be preferred both in the light of earlier discussions on the iron valency state problem and its similarity with the preferred mean value of 770° C. for porphyroclast core assemblages in the garnet lherzolites and websterites. Whilst the close agreement between these two values is encouraging, concern over the disparity in the various individual temperature estimates listed in Table 7 and doubts over the accuracy of the garnet-orthopyroxene geobarometer, when applied to chromiferous garnet lherzolite assemblages (Carswell & Gibb 1980 a & b), demand that fairly wide error brackets should be attached to the favoured temperature/pressure estimates.

In my opinion the most judicious though still somewhat subjective, interpretation which can be placed on the available temperature/pressure estimates is that the equilibration conditions for the porphyroclast core assemblages in the rocks described are probably encompassed by the values 740 ± 50° C. and 22 ± 5 Kbars. These values are compatible with several other estimates for the metamorphic 'high'-responsible for the development of eclogite facies assemblages enclosed both within other peridotite bodies and directly in the surrounding gneisses throughout much of Møre and Romsdal (Krogh 1977, Medaris 1980, Carswell & Gibb 1980a, Carswell et al. 1981) – but are significantly lower, especially in pressure terms, than the values of 700–850° C. and 30–45 Kbars. given by Lappin & Smith (1978). They are also in line with the temperature/presure estimates derived by Krogh (1980) for relict high grade assemblages occasionally preserved in the quartzofeldspathic gneisses themselves.

The available evidence therefore points to such temperature/pressure conditions having been operative on a regional scale, and indicates that the emplacement of the peridotite bodies into a lower crustal gneiss sequence occurred prior to the regional metamorphic 'high' (Carswell & Gibb 1980a). Since geochemical considerations (e.g. Carswell 1968, Brueckner 1977) suggest an ultimate mantle origin for the peridotite bodies, a possible scenario is that tectonic intercalation of these sub-Moho rocks occurred in the nose of a continental lithospheric plate as it was being temporarily subducted beneath another such plate with which it had collided

TABLE 7 CALCULATED TEMPERATURE-PRESSURE ESTIMATES FOR THE VARIOUS ANALYSED SAMPLES

Samples		Methods	Two Pyroxene Solvus				GNT—CPX $^1K_DFe^{2+}—Mg^{2+}$					GNT—CPX $^2K_DFe^{2+}—Mg^{2+}$				
			T°C Wells (1977)	P. Kbars Wood (1974)	T°C Mori & Green (1978)	P. Kbars Wood (1974)	^1K_D	T°C Ellis & Green (1979)	P. Kbars Wood (1974)	T°C Mori & Green (1978)	P. Kbars Wood (1974)	^2K_D	T°C Ellis & Green (1979)	P. Kbars Wood (1974)	T°C Mori & Green (1978)	P. Kbars Wood (1974)
Garnet Websterites	ESK 75	CLAST CORES	691	19.7	711	20.9	5.52	729	22.0	693	19.8	7.31	642	15.5	608	13.5
		CLAST RIMS	722	28.1	749	29.8	6.02	726	28.3	665	24.2	7.94	642	21.4	585	17.7
	A33	CLAST CORES	693	20.9	693	20.9	4.73	783	26.4	747	24.2	6.31	687	20.5	651	18.3
		CLAST RIMS	699	29.6	699	29.6	5.65	751	33.3	685	28.7	7.48	660	26.1	601	22.1
	A49	CLAST CORES	747	25.2	751	25.4	4.88	773	26.7	736	24.5	6.47	677	20.0	643	18.0
Garnet Lherzolites	A6	CLAST CORES	719	21.7	728	22.2	3.94	856	30.0	820	27.8	5.57	724	21.5	690	19.4
		CLAST RIMS	704	26.0	713	26.6	5.26	763	29.9	710	26.4	7.44	652	22.4	603	19.2
	A7A	CLAST CORES	719	22.4	725	22.8	4.06	840	29.8	808	27.8	5.74	711	21.4	680	19.6
		CLAST RIMS	802	30.7	817	31.6	4.55	805	30.8	762	28.1	6.45	682	22.5	644	20.0
	A7B	CLAST CORES	759	27.6	770	28.3	3.99	869	34.6	815	31.2	5.65	733	25.5	685	22.4
		CLAST RIMS	816	31.9	828	32.6	6.04	715	25.4	664	22.1	8.56	612	18.3	566	15.4
	ESK 76	CLAST CORES	731	25.6	736	25.9	4.14	843	32.7	800	30.0	5.86	712	24.0	674	21.6
		CLAST RIMS	621	18.9	620	18.9	4.91	779	29.0	734	26.1	6.91	664	21.1	623	18.6
	ESK 77	CLAST CORES	735	20.7	745	21.3	4.86	764	22.4	737	20.8	6.85	653	15.4	626	13.9
Mean Values		CLAST CORES (n = 8)	724	23.0	732	23.5	4.51	807	28.1	770	25.8	6.22	692	20.5	657	18.3
		CLAST RIMS (n = 6)	727	27.5	738	28.2	5.40	757	29.4	703	25.9	7.46	652	22.0	604	18.8
Eclogite	A41	CLAST CORES					6.67	861				9.37	770			
		CLAST RIMS					6.92	846	25.8 Kbars. P. assumed			9.74	756	25.8 Kbars. P. assumed		
	A84	CLAST CORES					6.71	878				9.40	787			

^1K_D—all Fe taken as Fe^{2+} in calculation.
^2K_D—calculation takes account of $Fe^{2+}/(Fe^{2+} + Fe^{3+})$ ratios in garnets and clinopyroxenes as follows:
0.924 and 0.656 in garnet lherzolite assemblages
0.879 and 0.660 in garnet websterite assemblages
0.921 and 0.574 in the Eikremsaeterfoss eclogite

(see Cuthbert et al. 1981). It does not seem unreasonable to expect that the sorts of temperature/pressure conditions deduced above for the metamorphic 'high' were established within the overridden plate, prior to its rapid upwards recovery which led to the eventual exposure of such high grade assemblages at the earth's surface.

Acknowledgements.– Access to Eskola's original specimens housed in the Mineralogisk-Geologisk Museum at Oslo was kindly arranged by I. Bryhni. Financial support was provided by a grant from the Natural Environment Research Council. F. G. F. Gibb and V. A. Somogyi are thanked for their assistance with the electron microprobe and 'wet' chemical analyses, respectively.

Manuscript received August 1981

References

Brueckner, H. K. 1977: A crustal origin for eclogites and a mantle origin for garnet peridotites: strontium isotopic evidence from clinopyroxenes. *Contrib. Mineral. Petrol. 60*, 1–15.

Carswell, D. A. 1968: Possible primary upper mantle peridotite in Norwegian basal gneiss. *Lithos 1*, 322–355.

Carswell, D. A. & Gibb, F. G. G. 1980a: The equilibration conditions and petrogenesis of European crustal garnet lherzolites. *Lithos 13*, 19–29.

Carswell, D. A. & Gibb, F. G. F. 1980b: Geothermometry of garnet lherzolite nodules with special reference to those from the kimberlites of northern Lesotho. *Contrib. Mineral. Petrol., 74*, 403–416.

Carswell, D. A., Griffin, W. L. & Krogh, E. J. 1981: Petrogenetic implications of calculated equilibration conditions for Norwegian orthopyroxene eclogites. *Proceedings of the 1981 Uppsala Caledonide Symposium* (in preparation).

Cuthbert, S. J., Harvey, M. A. & Carswell, D. A. 1981: A plate tectonic model for the metamorphic evolution of the basal gneiss complex in western Norway. *Proceedings of the 1981 Uppsala Caledonide Symposium* (in preparation).

Ellis, D. J. & Green, D. H. 1979: An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibrium. *Contrib. Mineral. Petrol. 71*, 13–22.

Eskola, P. 1921: On the eclogites of Norway. *Skr. Norske Vidensk. – Akad. i Oslo, Mat. – naturv. Kl., no. 8*, 1–118.

Jenkins, D. M. & Newton, R. C. 1979: Experimental determination of the spinel peridotite to garnet peridotite inversion at 900°C. and 1000°C. in the system CaO-MgO-$Al_2O_3SiO_2$ and at 900°C. with natural garnet and olivine. *Contrib. Mineral. Petrol. 68*, 407–420.

Krogh, E. J. 1977: Evidence of Precambrian continent-continent collision on western Norway. *Nature 267*, 17–19.

Krogh, E. J. 1980: Compatible P-T conditions for eclogites and surrounding gneisses in the Kristiansund area, Western Norway. *Contrib. Mineral. Petrol. 75*, 387–393.

Kushiro, I. 1969: Clinopyroxene solid solutions formed by reactions between diopside and plagioclase at high pressures. *Mineral. Soc. Am. Spec. Pap. 2*, 179–191.

Lappin, M. A. & Smith, D. C. 1978: Mantle-equilibrated orthopyroxene eclogite pods from the Basal Gneisses in the Selje district, western Norway. *J. Petrol 19*, 530–584.

MacGregor, I. D. 1974: The system MgO-Al_2O_3-SiO_2: Solubility of Al_2O_3 in enstatite for spinel and garnet peridotite compositions. *Am. Mineral. 59*, 110–119.

Medaris, L. G. Jr. 1980: Petrogenesis of the Lien peridotite and associated eclogites, Almklovdalen, Western Norway. *Lithos, 13*, 339–353.

Mercy, E. L. P. & O'Hara, M. J. 1965: Chemistry of some garnetbearing rocks from south Norwegian peridotites. *Nord. Geol. Tidsskr. 45*, 323–332.

Mori, R. & Green, D. H. 1978: Laboratory duplication of phase equilibria observed in natural garnet lherzolites. *J. Geol. 86*, 83–97.

O'Hara, M. J. & Mercy, E. L. P. 1963: Petrology and petrogenesis of some garnetiferous peridotites. *Trans. Roy. Soc. Edinb. 65*, 251–314.

O'Hara, M. J., Richardson, S. W. & Wilson, G. 1971: Garnet peridotite stability and occurrence in crust and mantle. *Contrib. Mineral. Petrol. 32*, 48–67.

O'Neill, H. St. C. & Wood, B. J. 1979: An experimental study of Fe-Mg partitioning between garnet and olivine and its calibration as a geothermometer. *Contrib. Mineral. Petrol. 70*, 59–70.

O'Neill, H. St.C. & Wood, B. J. 1980: An experimental study of Fe-Mg partitioning between garnet and olivine and its calibration as a geothermometer: corrections. *Contrib. Mineral. Petrol. 72*, 337.

Wells, P. R. A. 1977: Pyroxene thermometry in simple and complex systems. *Contrib. Mineral. Petrol., 62*, 129–139.

Wood, B. J. 1974: Solubility of alumina in orthopyroxene coexisting with garnet. *Contrib. Mineral. Petrol. 46*, 1–15.