Cupriferous pseudobrookite in a Tertiary basalt from the Faeroe Islands

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Forty-five electron microprobe analyses have been carried out on pseudobrookite occurring in a basalt from the Faeroe Islands. It is shown that pseudobrookite formed after ilmenite contains between 1 and 3% CuO, whereas pseudobrookite formed after titanomagnetite does not contain Cu. This difference in Cu content is not inherited from the original ilmenite and titanomagnetite, but arises during the formation of the pseudobrookite.

The pseudobrookite in this basalt, regardless of whether it formed from ilmenite or from titanomagne-tite, is richer in Ti than in the formula Fe_2TiO_5, the surplus Ti^{4+} being balanced by the presence of divalent ions such as Mg, Mn, Fe and Cu. Mg and Cu dominate in pseudobrookite after ilmenite, Fe and Mg domi-nate in pseudobrookite after titanomagnetite. Pseudobrookite after titanomagnetite is richer in Ti than pseudobrookite after ilmenite.

The pseudobrookite is not homogeneous. Both pseudobrookite formed from ilmenite and that formed from titanomagnetite contain small blebs of hematite and rutile, and furthermore pseudobrookite after ti-tanomagnetite is intergrown with larger coherent areas of hematite. The hematite blebs in pseudobrookite after ilmenite can contain up to more than 5% CuO, but there is virtually no copper in either type of he-matite in the pseudobrookite after titanomagnetite, nor do the rutile blebs contain copper.

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Introduction

The petrology of the 3000 m thick sequence of early Tertiary basalt lavas that make up the Faeroe Islands has been described by Noe-Nygaard & Rasmussen (1968), and a geological map of the Faeroe Islands was issued in 1969 (Rasmussen & Noe-Nygaard 1969). The 3000 m pile of basaltic lava is divided into three series: the lower series, the middle series and the upper series (Noe-Nygaard 1962). The lower series comprises 900 m of mainly aphyric quartz tholeiitic basalts and is separated from the middle series by a 15 m thick sedimentary coal-bearing sequence. The average thickness of single lava flows in the lower series is about 20 m, whereas individual flows in the middle series, which comprises 1350 m of mainly porphyritic quartz tholeiitic basalts, are considerably thinner, having thicknesses down to 10 cm. The upper series comprises 675 m of mainly olivine tholeiitic basalts; single flows are about 10 m in thickness.

Mineralogical and geochemical variations across single lava flows (one flow from each of the three series) were investigated by Jensen (1978, 1980) and the same author investigated the distribution of Cu across the same three flows (Jensen 1982). Two of the flows contain about 200 ppm Cu, whereas the third contains about 100 ppm Cu. A negligible amount of Cu is bound in sulphides, somewhat more occurs as native Cu, but most of the Cu content is either loosely bound in material with ion-exchange properties such as zeolites, or lattice-bound mainly in Fe-Ti-oxides.

The amount of lattice-bound Cu is largest where the oxidation has reached stage 6 or 7 (Haggerty 1976) and the Fe-Ti-oxides are represented by pseudobrookite-hematite-rutile intergrowths. The Cu preferentially occurs in pseudobrookite and the amount of Cu present can be as high as 2.4%. These results were obtained with a Hitachi XMA-5B electron microprobe. Pseudobrookite has long been known to contain varying amounts of Ti^{4+}, Fe^{3+}, Al^{3+}, Fe^{++} and Mg^{++} – for example Smith (1965) reported pseudobrookite with up to almost 8% Al_2O_3 – but Jensen (1982) was the first to report pseudobrookite containing a substantial amount of Cu. This cupriferous pseudobrookite has now been further investigated with a Jeol Superprobe JCXA 733 which has the necessary scanning equipment to allow one to see exactly what is being analysed in the pseudobrookite-hematite-rutile intergrowths.

Analytical results

The electron microprobe analyses were carried out with 15.0 kV accelerating voltage and a sample current of 20.0 nA using hematite, TiO_2, MgO, Al_2O_3, Mn, Cu and Cr as standards (Cr was not determined in all the analyses). Total iron was divided between ferrous and ferric iron by the method suggested by Finger (1972). The detection limit for Cu is 0.01% CuO.

Pseudobrookite formed from previous titanomagnetite can be recognised by the presence of larger areas of hematite in the grains and frequently also by the presence of relic {111} planes after ilmenite lamellae (fig. 1), whereas pseudobrookite formed from previous ilmenite results in grains consisting almost entirely of pseudobrookite containing only small blebs of hematite and rutile (fig. 2).

The analyses were all carried out on a sample taken seven metres above the lower contact of the approximately 18½ m thick flow from the upper series described by Jensen (1978, 1980, 1982). Table 1 shows four analyses from each of three different grains of pseudobrookite after ilmenite, and table 2 shows eight analyses of pseudobrookite after titanomagnetite.

The Cu content of the pseudobrookite can be seen to be highly variable, and there is a striking difference between pseudobrookite after titanomagnetite and pseudobrookite after ilmenite. Pseudobrookite after titanomagnetite contains

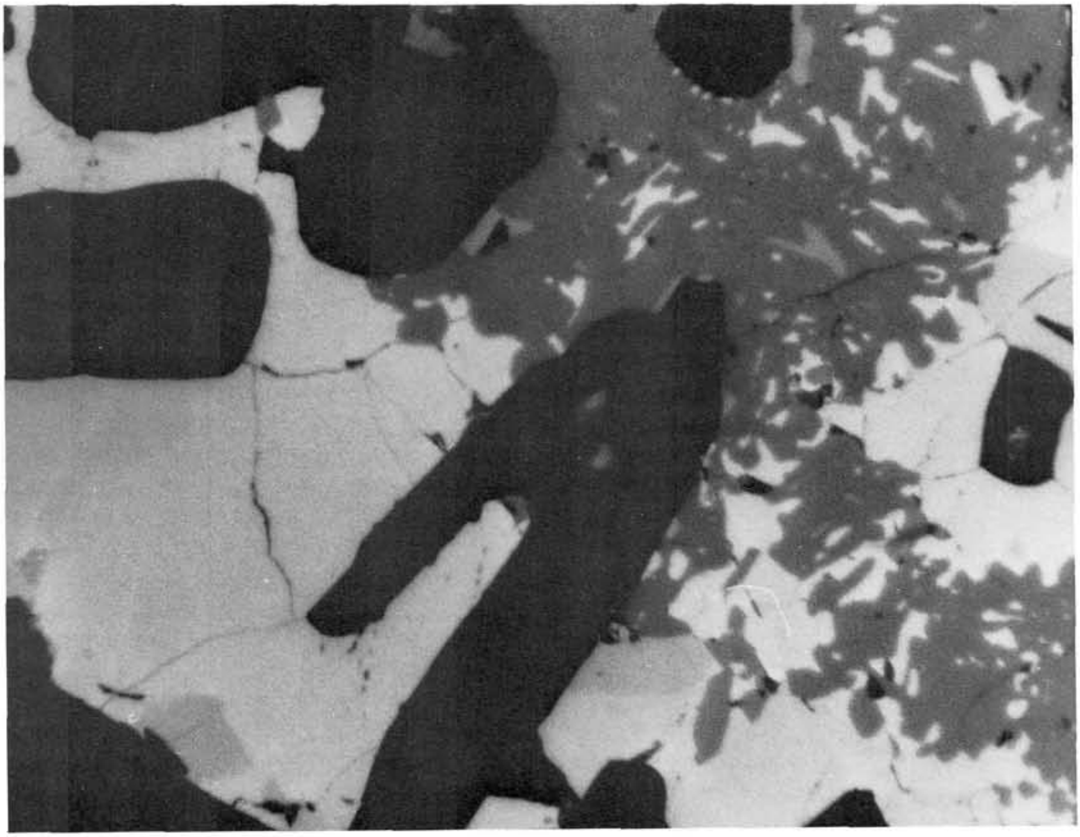

Fig. 1. Polariser only. ×1000. Oil immersion. Pseudobrookite formed after titanomagnetite (dark grey), hematite in larger coherent areas and as small blebs in pseudobrookite (white), and rutile blebs in pseudobrookite (medium grey).

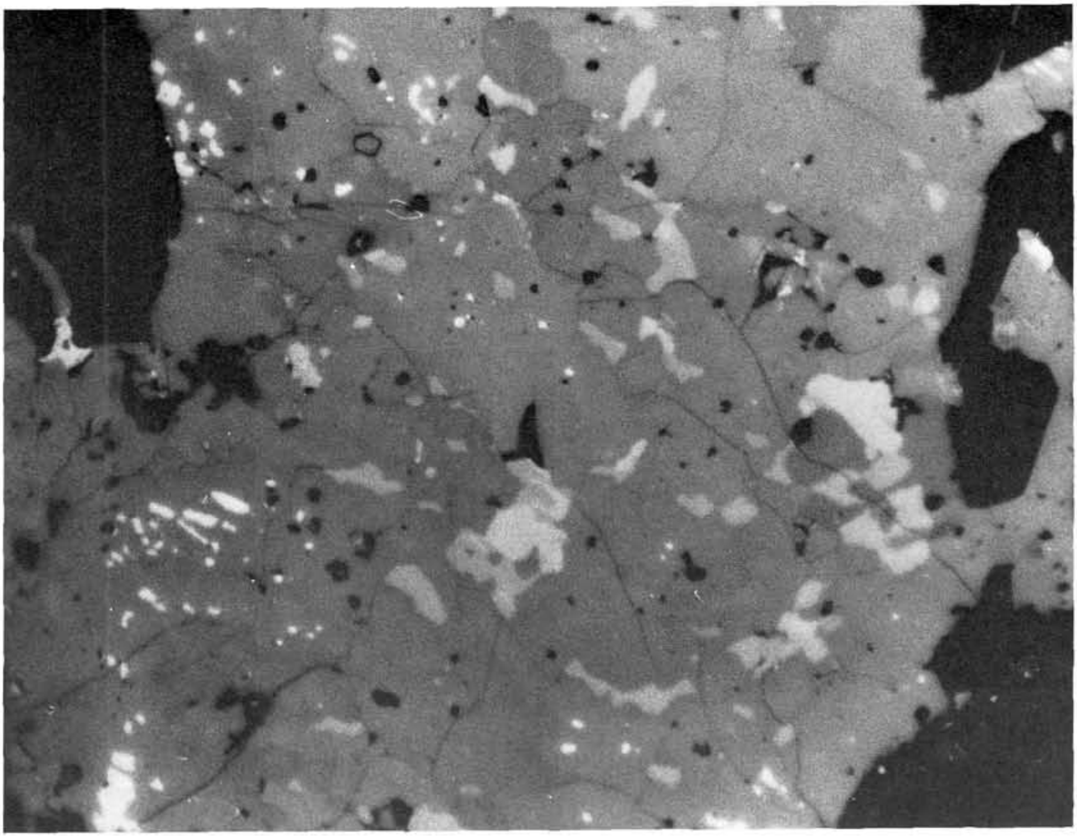

Fig. 2. Polariser only. ×1000. Oil immersion. Pseudobrookite formed after ilmenite (dark grey) with small blebs of hematite (white) and rutile (medium grey).

only small, frequently not detectable, amounts of Cu, whereas pseudobrookite after ilmenite contains between 1 and 3% CuO. The Cu content differs between grains but is rather constant within single grains.

The pseudobrookite in the Faeroe Islands basalt, whether developed from ilmenite or from titanomagnetite, is richer in Ti^{4+} than in the formula Fe_2TiO_5. The surplus Ti^{4+} is balanced by the presence of divalent ions such as Mg, Mn, Fe and Cu. Mg and Cu dominate in pseudobrookite after ilmenite, and Fe and Mg dominate in pseudobrookite after titanomagnetite. The surplus of Ti^{4+} is considerably greater in pseudobrookite after titanomagnetite than in pseudobrookite after ilmenite. As Fe^{++} is the dominant divalent ion in pseudobrookite after titanomagnetite, this means that this pseudobrookite is richer in $FeTi_2O_5$ than pseudobrookite after ilmenite. This is in contrast to the finding of Haggerty (1976, p. 55).

Al_2O_3 is considerably higher in pseudobrookite after titanomagnetite than in pseudobrookite after ilmenite. MnO is somewhat higher in pseudobrookite after ilmenite than in pseudobrookite after titanomagnetite.

Pseudobrookite is usually considered a solid solution series of the four end members Fe_2TiO_5, $FeTi_2O_5$ (ferropseudobrookite), $MgTi_2O_5$ (karrooite) and Al_2TiO_5 (tielite/tialite), but in the light of the analyses presented here it seems reasonable to include also a Cu compound. The writer believes that the Cu is present as Cu^{++}, although a compound $CuTi_2O_5$ is not known while $Cu_2Ti_2O_5$ has been synthesised.

The pseudobrookite is not homogeneous. Both pseudobrookite after ilmenite and pseudobrookite after titanomagnetite contain small blebs of hematite and rutile from less than 1 μm to about 10 μm in size, and pseudobrookite after titano-

Table 1
Electron microprobe analyses of pseudobrookite after ilmenite.

Grain	1	1	1	1	2	2	2	2	3	3	3	3
Analysis	1	2	3	4	5	6	7	8	9	10	11	12
Weight %												
MgO	2.29	1.83	1.97	2.27	2.18	2.26	1.95	1.74	2.06	2.03	2.33	2.44
Al_2O_3	0.09	0.13	0.13	0.19	0.09	0.10	0.07	0.07	0.10	0.13	0.08	0.14
TiO_2	41.61	40.18	40.84	41.65	41.63	41.34	40.72	39.45	39.77	39.96	40.47	40.76
Cr_2O_3									0.00	0.04	0.02	0.03
MnO	0.54	0.47	0.36	0.46	0.38	0.38	0.35	0.39	0.56	0.58	0.53	0.50
FeO	0.34	0.00	0.52	0.00	0.86	0.79	0.61	0.09	0.00	0.34	0.00	0.00
Fe_2O_3	52.35	54.45	53.66	51.73	52.81	52.68	53.59	56.31	55.76	55.62	54.82	54.85
CuO	2.15	2.29	2.08	2.88	1.78	1.73	1.98	1.62	1.27	1.10	1.32	1.25
	99.37	99.35	99.56	99.18	99.73	99.28	99.27	99.67	99.52	99.80	99.57	99.97
Number of cations on the bais of 3 cations and 5 oxygens												
Ti	1.226	1.190	1.205	1.229	1.223	1.219	1.205	1.166	1.173	1.179	1.190	1.192
Fe^{+++}	1.544	1.613	1.584	1.528	1.552	1.555	1.587	1.665	1.646	1.633	1.613	1.606
Al	0.004	0.006	0.006	0.009	0.004	0.005	0.003	0.003	0.005	0.006	0.004	0.006
Cr									0.000	0.001	0.001	0.001
ΣM^{+++}	1.548	1.619	1.590	1.537	1.556	1.560	1.590	1.668	1.651	1.640	1.618	1.613
Mg	0.134	0.107	0.115	0.133	0.127	0.132	0.114	0.102	0.121	0.119	0.136	0.141
Mn	0.018	0.016	0.012	0.015	0.013	0.013	0.012	0.013	0.018	0.019	0.017	0.017
Fe^{++}	0.011	0.000	0.017	0.000	0.028	0.026	0.020	0.003	0.000	0.011	0.000	0.000
Cu	0.063	0.068	0.061	0.086	0.052	0.051	0.059	0.048	0.038	0.033	0.039	0.037
ΣM^{++}	0.226	0.191	0.205	0.234	0.220	0.222	0.205	0.166	0.177	0.182	0.192	0.195

magnetite is intergrown furthermore with larger coherent areas of hematite (figs 1, 2).

Table 3 shows three analyses of hematite blebs from each of the three pseudobrookite grains from table 1. It is seen that these hematite blebs are even richer in Cu than the pseudobrookite in

Table 2
Electron microprobe analyses of pseudobrookite after titanomagnetite.

Analysis	13	14	15	16	17	18	19	20
Weight %								
MgO	2.52	2.04	2.39	2.42	2.07	1.50	1.24	1.14
Al_2O_3	1.06	1.05	1.03	1.07	1.35	0.96	0.78	0.80
TiO_2	50.51	45.19	46.72	46.46	41.39	43.74	42.70	41.34
Cr_2O_3					0.11	0.04	0.08	0.08
MnO	0.27	0.21	0.22	0.31	0.27	0.33	0.30	0.28
FeO	9.60	6.07	6.72	6.27	2.43	5.59	5.32	4.32
Fe_2O_3	35.51	44.92	42.01	42.72	51.73	47.04	49.23	51.44
CuO	<0.01	<0.01	0.05	<0.01	0.01	<0.01	<0.01	0.01
	99.47	99.48	99.14	99.25	99.36	99.20	99.65	99.41
Number of cations on the basis of 3 cations and 5 oxygens								
Ti	1.462	1.319	1.362	1.353	1.211	1.287	1.256	1.221
Fe^{+++}	1.028	1.312	1.226	1.245	1.515	1.385	1.449	1.521
Al	0.048	0.048	0.048	0.049	0.062	0.044	0.036	0.037
Cr					0.003	0.001	0.003	0.002
ΣM^{+++}	1.076	1.360	1.274	1.294	1.580	1.430	1.488	1.560
Mg	0.144	0.118	0.138	0.140	0.120	0.087	0.072	0.067
Mn	0.009	0.007	0.007	0.010	0.009	0.011	0.010	0.009
Fe^{++}	0.309	0.197	0.218	0.203	0.079	0.183	0.174	0.142
Cu	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
ΣM^{++}	0.462	0.322	0.365	0.353	0.208	0.281	0.256	0.218

Table 3
Electron microprobe analyses of hematite blebs in pseudobrookite after ilmenite.

Grain	1	1	1	2	2	2	3	3	3
Analysis	21	22	23	24	25	26	27	28	29
Weight %									
MgO	0.86	0.75	0.84	1.05	1.08	1.12	0.91	0.90	1.01
Al_2O_3	0.33	0.16	0.04	0.06	0.08	0.06	0.09	0.06	0.08
TiO_2	9.25	9.41	12.17	7.59	9.40	13.59	12.50	8.56	13.35
Cr_2O_3							0.05	0.05	0.08
MnO	0.76	1.27	0.72	0.83	0.56	0.44	0.55	0.72	0.60
FeO	3.13	0.99	5.12	1.45	3.26	7.72	7.73	3.90	8.43
Fe_2O_3	83.33	80.93	76.30	85.49	83.27	74.25	77.25	84.58	74.97
CuO	3.24	5.48	4.01	3.00	2.87	2.37	1.33	1.62	1.31
	100.90	98.99	99.20	99.47	100.52	99.55	100.41	100.39	99.83
Number of cations on the bais of 2 cations and 3 oxygens									
Ti	0.181	0.188	0.242	0.151	0.184	0.267	0.244	0.168	0.262
Fe^{+++}	1.628	1.617	1.515	1.696	1.632	1.462	1.510	1.661	1.472
Al	0.010	0.005	0.001	0.002	0.002	0.002	0.003	0.002	0.002
Cr							0.001	0.001	0.002
ΣM^{+++}	1.638	1.622	1.516	1.698	1.634	1.464	1.514	1.664	1.476
Mg	0.033	0.030	0.033	0.041	0.042	0.044	0.035	0.035	0.039
Mn	0.017	0.029	0.016	0.018	0.012	0.010	0.012	0.016	0.013
Fe^{++}	0.068	0.022	0.113	0.032	0.071	0.169	0.168	0.085	0.184
Cu	0.063	0.110	0.080	0.060	0.056	0.047	0.026	0.032	0.026
ΣM^{++}	0.181	0.191	0.242	0.151	0.181	0.270	0.241	0.168	0.262

which they occur. The writer believes that here also the Cu is present as Cu^{++}. The hematite blebs are also richer in FeO and MnO (and probably Cr_2O_3), but poorer in MgO than the pseudobrookite in which they occur.

Table 4 shows eight analyses of hematite in

Table 4
Electron microprobe analyses of hematite in pseudobrookit after titanomagnetite.

Analysis	30	31	32	33	34	35	36	37
Weight %								
MgO	0.37	0.38	0.42	0.32	1.35	1.47	1.02	1.11
Al_2O_3	0.52	0.56	0.62	0.69	0.74	0.65	1.06	0.91
TiO_2	13.38	13.21	13.24	13.54	15.76	16.30	13.63	14.81
Cr_2O_3	0.33	0.29	0.26	0.22	0.33	0.17	0.13	0.12
MnO	0.76	0.24	0.15	0.22	0.42	0.44	0.27	0.43
FeO	10.75	10.82	10.92	11.39	11.51	11.78	10.22	10.88
Fe_2O_3	74.07	73.64	73.49	72.94	69.55	68.65	73.59	70.85
CuO	<0.01	<0.01	0.02	<0.01	0.02	0.04	0.08	0.03
	100.18	99.14	99.12	99.32	99.68	99.50	100.00	99.14
Number of cations on the basis of 2 cations and 3 oxygens								
Ti	0.262	0.261	0.262	0.267	0.307	0.317	0.265	0.290
Fe^{+++}	1.451	1.457	1.454	1.440	1.354	1.338	1.432	1.389
Al	0.016	0.017	0.019	0.021	0.023	0.020	0.032	0.028
Cr	0.007	0.006	0.005	0.005	0.007	0.004	0.003	0.003
ΣM^{+++}	1.474	1.480	1.478	1.466	1.384	1.362	1.467	1.420
Mg	0.014	0.015	0.016	0.012	0.052	0.057	0.039	0.043
Mn	0.017	0.005	0.003	0.005	0.009	0.010	0.006	0.009
Fe^{++}	0.234	0.238	0.240	0.250	0.249	0.255	0.221	0.237
Cu	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.001
ΣM^{++}	0.265	0.258	0.259	0.267	0.310	0.323	0.268	0.290

Table 5
Electron microprobe analyses of rutile blebs in pseudobrookite, the first four after ilmenite, the last four after titanomagnetite.

Analysis	38	39	40	41	42	43	44	45
Weight %								
MgO	0.00	0.00	0.01	0.00	0.03	0.04	0.03	0.00
Al_2O_3	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.02
TiO_2	97.46	99.33	97.75	98.55	97.32	95.21	96.07	96.44
MnO	0.05	0.03	0.07	0.08	0.01	0.04	0.00	0.01
FeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	1.48	0.98	1.36	1.40	2.82	4.04	3.08	3.31
CuO	0.14	0.05	0.05	<0.01	<0.01	0.01	<0.01	0.02
	99.13	100.39	99.24	100.03	100.20	99.36	99.19	99.80

pseudobrookite after titanomagnetite; the first four are from blebs inside pseudobrookite, and the last four are from larger coherent areas of hematite. It is seen that the hematite blebs do not contain more Cu than the pseudobrookite, whereas hematite in larger coherent areas appears to be very slightly richer in Cu than the pseudobrookite. The hematite blebs as well as the hematite in larger coherent areas are richer in FeO (and probably in MnO and Cr_2O_3), but poorer in MgO and Al_2O_3, than the pseudobrookite. However, the differences in MgO and Al_2O_3 are not as prominent for the hematite in larger coherent areas as for the hematite blebs.

Table 6
Average of 8 electron microprobe analyses of ilmenite and average of 13 partial electron microprobe analyses of titanomagnetite.

	Ilmenite	Titanomagnetite
Weight %		
MgO	1.90±0.10	1.41±0.32
Al_2O_3	0.08±0.03	0.07±0.02
TiO_2	50.88±0.36	
MnO	0.32±0.03	0.46±0.08
FeO	41.97±0.50	
Fe_2O_3	4.67±0.94	
CuO	0.03±0.03	0.01±0.01
	99.85±0.35	
Number of cations on the basis of 2 cations and 3 oxygens		
Ti	0.956±0.008	
Fe^{+++}	0.088±0.017	
Al	0.002±0.001	
ΣM^{+++}	0.090±0.017	
Mg	0.071±0.003	
Mn	0.007±0.001	
Fe^{++}	0.877±0.012	
Cu	0.000±0.001	
ΣM^{++}	0.954±0.009	

Table 5 shows four analyses of rutile blebs in pseudobrookite after ilmenite, and four of rutile blebs in pseudobrookite after titanomagnetite. Apart from a varying amount of Fe_2O_3, the rutile blebs are practically pure TiO_2. Blebs in pseudobrookite after titanomagnetite are free of Cu, whereas blebs in pseudobrookite after ilmenite appear to contain just a trifle Cu.

The oxidation stages of the sample on which the pseudobrookite analyses were carried out vary between C4 and C7 for the cubic phases and between R3 and R7 for the rhombohedral phases. Accordingly the composition of the original ilmenite and the original titanomagnetite could not be obtained from this sample.

In order to see whether the difference in Cu content between pseudobrookite after ilmenite and pseudobrookite after titanomagnetite could be inherited from the original ilmenite and titanomagnetite, the composition of the latter were investigated in a sample taken three metres lower in the same flow. In this sample the oxidation stages for the cubic phases vary between C2 and C3 and the oxidation stage of the rhombohedral phase is invariably R1. This attempt to establish the composition of the original ilmenite and titanomagnetite was however only successful with ilmenite (table 6), as the relations between Ti, Fe^{+++} and Fe^{++} could not be established for the titanomagnetite because of maghemitisation. Hence only partial electon microprobe analyses of this titanomagnetite are presented in table 6. It can be seen, however, that the amounts of Cu in both ilmenite and titanomagnetite are very small.

Table 7 presents whole rock analyses of the samples on which the pseudobrookite analyses

Table 7
Chemical analyses of rock samples.

Sample number		63181 7 metres above lower contact		63176 4 metres above lower contact
SiO_2		49.12		49.54
TiO_2		2.75		2.97
Al_2O_3		14.14		13.80
Fe_2O_3		6.16		4.83
FeO		6.93		8.74
MnO		0.18		0.22
MgO		6.14		5.91
CaO		10.69		10.47
Na_2O		2.62		2.69
K_2O		0.36		0.41
H_2O		0.38		0.64
P_2O_5		0.30		0.23
		99.77		100.45
Total Fe as FeO		12.47		13.09
C.I.P.W. weight norms				
Q	5.19	0.10	3.91	0.41
or	2.13	2.13	2.42	2.42
ab	22.17	22.17	22.76	22.76
an	25.76	25.76	24.37	24.37
wo (di)	10.57	10.57	10.89	10.89
en (di)	7.81	5.29	6.76	5.26
fs (di)	1.75	5.06	3.48	5.45
en (hy)	7.49	10.00	7.95	9.46
fs (hy)	1.68	9.56	4.09	9.79
mt	8.93	2.39	7.00	2.51
il	5.22	5.22	5.64	5.64
ap	0.70	0.70	0.53	0.53
	99.40	98.95	99.80	99.49

were carried out. The rock samples were analysed in the laboratory of the Geological Survey of Greenland by Ib Sørensen. H_2O^+ was determined by the Penfield method and Fe^{++} by wet chemistry. Mg was determined by complexometric titration, Na by flame photometry, and the remaining elements were analysed by XRF on glass discs. CIPW weight norms were calculated with the ration Fe_2O_3/FeO found by analysis (first column) as well as with this ratio adjusted to 0.15 (second column).

Deviations from the formula Fe_2TiO_5

The transformation of ideal ilmenite $FeTiO_3$ to ideal pseudobrookite Fe_2TiO_5 results in loss of 19.30% TiO_2 (by weight), oxidation of 47.35% FeO to 52.62% Fe_2O_3, and addition of a further 14.03% Fe_2O_3.

Comparing the analyses of ilmenite (table 6) with those of pseudobrookite after ilmenite (table 1), we see that the transformation of ilmenite to pseudobrookite in the Faeroe Islands basalt has resulted in the loss of only 10% TiO_2, and addition of only 3% Fe_2O_3. The transformation, however, has also resulted in the addition of 1–2% CuO, whereas the values for MgO, Al_2O_3 and MnO are very similar, but might indicate a slight increase. Thus it is seen that in the transformation of ilmenite to pseudobrookite in the Faeroe Islands basalt only about half of the expected amount of Ti has been lost, and a correspondingly smaller amount of Fe has been added.

The transformation of titanomagnetite of the composition $\frac{1}{2}Fe_3O_4 \cdot \frac{1}{2}Fe_2TiO_4$ to ideal pseudobrookite Fe_2TiO_5 results in loss of 18.96% FeO, oxidation of the remaining 28.40% FeO to 31.56% Fe_2O_3, and addition of 15.80% TiO_2. The transformation of titanomagnetite of the composition $2/10Fe_3O_4 \cdot 8/10Fe_2TiO_4$ to ideal pseudobrookite Fe_2TiO_5 results in loss of 10.21% FeO, oxidation of the remaining 47.22% FeO to 52.47% Fe_2O_3, and addition of 4.96% TiO_2.

The transformation of titanomagnetite of the composition $\frac{1}{2}Fe_3O_4 \cdot \frac{1}{2}Fe_2TiO_4$ to the pseudobrookite compostion given by the analyses of pseudobrookite after titanomagnetite (table 2) is accomplished by addition of 27% TiO_2 and a correspondingly large loss of FeO (32%). Thus it is seen that if the titanomagnetite in the Faeroe Islands basalt had the composition $\frac{1}{2}Fe_3O_4 \cdot \frac{1}{2}Fe_2TiO_4$, about twice as much TiO_2 as expected has been added, and a correspondingly larger amount of FeO has been lost. If the original titanomagnetite in the Faeroe Islands basalt was richer in Fe_2TiO_4 than $\frac{1}{2}Fe_3O_4 \cdot \frac{1}{2}Fe_2TiO_4$, the discrepancy is even greater. Thus if the original titanomagnetite had the composition $2/10Fe_3O_4 \cdot 8/10\ Fe_2TiO_4$, more than three times the expected amount of Ti has been added, and correspondingly more FeO has been lost.

Whereas ilmenite is more or less completely altered to pseudobrookite, the formation of pseudobrookite from titanomagnetite is always accompanied by the formation of larger areas of hematite. The FeO lost in the titanomagnetite $\rightarrow$ pseudobrookite reaction was probably mostly used to form these hematite areas.

When the partial electron microprobe analysis of titanomagnetite (table 6) is compared with the analyses of pseudobrookite after titanomagnetite (table 2), it is seen that the transformation of titanomagnetite to pseudobrookite has resulted in addition of Al_2O_3, and to some extent also in addition of MgO and loss of MnO.

Conclusions

It has been shown that besides the four end members Fe_2TiO_5, $FeTi_2O_5$, $MgTi_2O_5$ and Al_2TiO_5, a Cu compound is needed to describe the pseudobrookite formed from previous ilmenite in a Faeroe Islands basalt.

The pseudobrookites here, whether formed after ilmenite or after titanomagnetite, are considerably richer in Ti than in the formula Fe_2TiO_5. The enrichment in Ti is balanced by divalent ions such as Mg, Fe, Mn and Cu.

The Fe-Ti exchange required by pseudobrookite-forming reactions is less than expected in pseudobrookite after ilmenite, and greater than expected in pseudobrookite after titanomagnetite. Pseudobrookite after titanomagnetite is somewhat richer in Ti than pseudobrookite after ilmenite, which contrasts with the pseudobrookite in a basalt from Oregon (Haggerty 1976). Furthermore, contrary to the finding of Haggerty (1976), pseudobrookite after ilmenite in the Faeroe Islands basalt has less $FeTi_2O_5$ than pseudobrookite after titanomagnetite.

Pseudobrookite after ilmenite is richer in Cu and Mn (and total Fe) and poorer in Al (and Cr) than pseudobrookite after titanomagnetite. In the formation of pseudobrookite from titanomagnetite Fe is lost, whereas the formation of pseudobrookite from ilmenite is accompanied by addition of Fe, and the only explanation that can be offered for the difference in Cu content between the pseudobrookites is that Cu (and Mn) follows Fe.

The high concentration of Cu in the hematite blebs in pseudobrookite after ilmenite is considered evidence for the blebs not being relics, but the result of incomplete formation of pseudobrookite, because of local lack of Ti in the hematite blebs and local lack of Fe in the rutile blebs.

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Dansk sammendrag

I et tidligere arbejde (Jensen 1982) er det blevet påvist at de oxiderede Fe-Ti-oxider i Færøbasalterne, repræsenterede af pseudobrookit-hæmatit-rutil sammenvoksninger kan indeholde op til 2.4% Cu, og at kobberet fortrinsvis sidder i pseudobrookit.

Denne kobberholdige pseudobrookit er nu blevet nærmere undersøgt ved hjælp af den nyanskaffede Jeol JCXA 733 mikrosonde, hvis gode scanning udstyr har gjort det muligt præcist at afgøre, hvilken fase i de tætte pseudobrookit-hæmatit-rutil sammenvoksninger der analyseres.

Pseudobrookit der er opstået ved oxidation af oprindelige ilmenitkorn består næsten udelukkende af pseudobrookit, dog med en del 1–10 μm store indeslutninger af hæmatit og af rutil, medens pseudobrookit der er opstået ved oxidation af oprindelige titanomagnetitkorn kun delvis udgøres af pseudobrookit (med 1–10 μm store indeslutninger af hæmatit og af rutil), idet der tillige er store sammenhængende partier af hæmatit. Pseudobrookiten kan som regel ses fortrinsvis at være opstået hvor der i den oprindelige titanomagnetit har været ilmenitlameller efter {111}.

Pseudobrookiten i Færøbasalterne er, uanset om den er dannet af oprindelig ilmenit eller oprindelig titanomagnetit, betydeligt rigere på Ti end svarende til formlen Fe_2TiO_5. Den overskydende Ti modsvares af tilstedeværelsen af divalente ioner såsom Mg, Fe, Mn og Cu. Mg og Cu dominerer i pseudobrookit efter ilmenit, og Fe og Mg dominerer i pseudobrookit efter titanomagnetit. Pseudobrookit efter titanomagnetit indeholder mere Al end pseudobrookit efter ilmenit.

Udvekslingen af Ti- Fe ved pseudobrookitdannelsen er mindre end forventet for pseudobrookit dannet af oprindelig ilmenit og større end forventet for pseudobrookit dannet af oprindelig titanomagnetit, og pseudobrookit efter titanomagnetit er noget rigere på Ti end pseudobrookit efter ilmenit. Endvidere er pseudobrookit efter ilmenit i Færøbasalterne fattigere på $FeTi_2O_5$ (ferropseudobrookit) end pseudobrookit efter titanomagnetit, hvilket er i modsætning til de pseudobrookitanalyser der anføres af Haggerty (1976).

Pseudobrookit efter titanomagnetit indeholder næsten ikke Cu (tabel 2), medens pseudobrookit efter ilmenit har et indhold varierende fra godt 1% CuO til knap 3% CuO (tabel 1). De små indeslutninger af hæmatit i pseudobrookit efter ilmenit er endnu rigere på Cu end pseudobrookiten, og indholdet kan overstige 5% CuO (tabel 3). Tabel 4 viser analyser af hæmatit i pseudobrookitkorn efter titanomagnetit. De første fire analyser er af hæmatitindeslutninger i pseudobrookit, de sidste fire er af større sammenhængende hæmatitområder i pseudobrookitkorn. Hæmatitindeslutningerne har lige så lidt Cu som pseudobrookiten, medens de større sammenhængende hæmatitområder ser ud til at indeholde en lille smule mere Cu. Tabel 5 viser at rutilindeslutningerne i pseudobrookit, såvel efter oprindelig ilmenit som efter oprindelig titanomagnetit, bortset fra et varierende indhold af Fe_2O_3, er næsten ren TiO_2. Rutil i pseudobrookit efter ilmenit indeholder en lille smule Cu, medens rutil i pseudobrookit efter titanomagnetit er praktisk taget uden Cu.

Tabel 6 viser sammensætningen af den oprindelige ilmenit og delvis af den oprindelige titanomagnetit. Det ses klart at forskellen i Cu indhold mellem pseudobrookit efter ilmenit og pseudobrookit efter titanomagnetit ikke hidrører fra udgangsmaterialet af ilmenit og titanomagnetit, men må være fremkommet i forbindelse med pseudobrookitens dannelse.

Ved dannelsen af pseudobrookit fra titanomagnetit afgives der Fe, medens dannelsen af pseudobrookit fra ilmenit er ledsaget af tilførsel af Fe, og den eneste forklaring på forskellen i Cu-indhold mellem pseudobrookit efter ilmenit og pseudobrookit efter titanomagnetit der kan gives er at Cu (og Mn) følger Fe.

Den høje koncentration af Cu i hæmatitindeslutninger i pseudobrookit efter ilmenit tages som indicium for, at disse indeslutninger ikke er ureagerede rester, men repræsenterer ufuldstændig omdannelse til pseudobrookit på grund af lokal mangel på Ti for hæmatitindeslutningerne, og lokal mangel på Fe for rutilindeslutningerne.

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