Compositional variations of the pyroxenes from three flows of Faeroe Islands basalts

AAGE JENSEN

Jensen, Aa.: Compositional variations of the pyroxenes from three flows of Faeroe Islands basalts. *Bull. geol. Soc. Denmark*, vol. 27, Special Issue, pp. 63-78, Copenhagen, July 30th, 1978.
https://doi.org/10.37570/bgsd-1978-SI-08

The pyroxenes from one flow from the lower lava series, one from the middle, and one from the upper lava series of the Faeroe Islands have been investigated by microprobe.

The flow from the lower series has augite as the only pyroxene, the flow from the middle series has bronzite as phenocrysts and augite and pigeonite, and the flow from the upper series has augite and pigeonite. 30 analyses of these pyroxenes are presented, comprising eight elements: Si, Ti, Al, Fe, Mn, Mg, Ca and Na, and the formulae based on four cations are calculated. Variations in major elements are shown in figs. 2-8; in these diagrams are also used the results of 116 partial analyses, comprising only Mg, Fe and Ca. The variations in minor elements and their distribution between augites and Ca-poor pyroxenes are discussed.

In a MnO-TiO_2-Na_2O diagram (Nisbet & Pearce 1977), the augites plot mainly in the ocean-floor basalt field, but a number of analyses fall in the field common to all the basalt types. F_1-F_2 values (Nisbet & Pearce 1977) correspond partly to the field where ocean-floor basalts and within-plate tholeiites overlap, and partly to the field where ocean-floor and volcanic arc basalts overlap.

Aage Jensen, Institute of Mineralogy, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark. January 16th, 1978.

The Faeroe Islands consist exclusively of flood-basalt lavas poured out subaerally in the earliest Tertiary and forming a pile 3000 m thick (Noe-Nygaard & Rasmussen 1968, Rasmussen & Noe-Nygaard 1969). This pile 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 basalts and is separated from the middle series by a 15 m thick sedimentary coal-bearing series. The average thickness of single lava flows in the lower series is about 20 m, whereas the single flows of the middle series, which comprises 1350 m of mainly porphyritic basalts, are considerably thinner, having thicknesses down to 10 cm. The upper series comprises 675 m of mainly olivine-bearing basalts, the single flows being about 10 m in thickness.

The pyroxenes from one flow from each of these three lava series have been investigated by microprobe analyses.

The flow investigated from the lower series is the second uppermost flow. The sampling was carried out on Syderø at the road tunnel between Tverå and Kvalbø, where the second uppermost flow is probably 17 m thick, of which 13½ m are accessible. Two samples were investigated: 63016 taken about 2 m above the lower contact of the flow, and 63023 taken about 9 m above the lower contact.

The flow from the middle series was sampled on Bordø in the quarry at Klaksvig, where an 11 m thick flow is exposed in full thickness, a thickness which is unusually large for a flow from the middle series. The samples investigated, 63135 and 63141, were collected 25 cm and 5 m respectively above the lower contact of the flow.

The samples from the upper series were collected from the flow ocurring along the quay of Torshavn, Strømø. This flow is an 18½ m thick plagioclase-porphyritic basalt. The samples investigated, 63171, 63176 and 63182, were taken immediately above the lower contact, 4 m above and 9 m above the lower contact respectively.

Sample description

63016. Fine-grained grey basalt with intersertal texture. Augite is the only pyroxene present. The larger grains of plagioclase and augite are occasionally clustered into glomeroporhyritic aggregates with a diameter about 1 mm. The analysed grains of augite vary in size from 30×40 μm to 330×600 μm. The Fe-Ti-oxides mainly have oxidation indices (Watkins & Haggerty 1967) 2 and 3, but some grains have reached 4.

63023. Fine-grained grey basalt with intersertal to intergranular texture. Augite is the only pyroxene present. The larger grains of plagioclase and augite are occasionally clustered into glomeroporphyritic agregates with diameter about 1 mm. The analysed grains of augite vary in size from 30×30 μm to 300×450 μm. The Fe-Ti-oxides represent all stages of oxidation from index 2 to index 6.

63135. Fine-grained grey basalt with phenocrysts of orthopyroxene up to 2 mm, they are to some extent clustered in glomeroporphyritic aggregates up to 4 mm. The texture is intergranular to intersertal. The groundmass pyroxenes comprise pigeonite as well as augite. The analysed grains of augite vary in size from 15×20 μm to 40×90 μm. The analysed grains of pigeonite vary from 20×20 μm to 30×90 μm. The Fe-Ti-oxides have oxidation indices 1 and 2.

63141. Fine-grained grey basalt with phenocrysts of orthopyroxene up to 1 mm, they are occasionally clustered in glomeroporphyritic aggregates up to 2 mm. The texture is intergranular to intersertal. The groundmass pyroxenes comprise pigeonite as well as augite. The grain size of the groundmass is slightly larger than in 63135. The analysed grains of augite vary in size from 30×45 μm to 35×140 μm. The analysed grains of pigeonite vary from 30×60 μm to 60×75 μm. The Fe-Ti-oxides have oxidation indices 1 and 2.

63171. Redbrown plagioclase-porphyritic basalt with fine-grained groundmass, the texture of which is intergranular to intersertal. The plagioclase phenocrysts are to a large extent clustered into glomeroporphyritic aggregates up to 5 mm in diameter. The basalt is somewhat vesicular with rounded vesicles, the diameter of which can reach 5 mm. Augite is the only pyroxene present, and the analysed grains vary in size from 90×120 μm to 450×450 μm. The Fe-Ti-oxides all have oxidation index 6.

63176. Grey plagioclase-porphyritic basalt with fine-grained groundmass, the texture of which is intergranular to intersertal. The plagioclase phenocrysts are to a large extent clustered into glomeroporphyritic aggregates up to 5 mm in diameter. The grain size of the groundmass is less than in 63171. The pyroxene is mainly augite, but pigeonite is present in sparse amount. One grain of pigeonite, 30×60 μm in size, was analysed. The analysed grains of augite vary in size from 30×45 μm to 300×390 μm. The Fe-Ti-oxides mainly have oxidation index 3, but some grains have index 4.

63182. Grey plagioclase-porphyritic basalt with fine-grained groundmass, the texture of which is intergranular to intersertal. The plagioclase phenocrysts are to a large extent clustered into glomeroporphyritic aggregates up to 5 mm in diameter. The grain size of the groundmass is intermediate between 63171 and 63176. The pyroxenes comprise pigeonite as well as augite. Pigeonite is much more frequent than in 63176 and occurs often as rather large grains. The analysed grains of augite vary in size from 30×45 μm to 150×200 μm, and analysed grains of pigeonite from 30×45 μm to 225×600 μm. The Fe-Ti-oxides mainly have oxidation index 3, but some grains have index 4.

Rock analyses

The rock samples have been analysed in the laboratory of the Geological Survey of Greenland by Ib Sørensen. H_20^+ was determited 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 with XRF on glass discs. The results of the analyses are given in table 1 together with the calculated C.I.P.W. weight norms. The norms are calculated with the ratio $Fe_20_3/Fe0$ as found by analyses (first column) as well as with this ratio adjusted to 0.15 (second column).

With the ratio $Fe_20_3/Fe0$ as found by analyses the samples are all quartz tholeiites (Yoder & Tilley 1962). But whereas the samples from the lower and middle series remain quartz tholeiites also with the adjusted ratio, the use of this ratio turns two of the samples from the upper series into olivine tholeiites, while a small amount of normative quartz remains in the third.

Compared to the average quartz basalt by Manson (1967) the samples from the lower series are low in Si, Al and K, and high in Ti, Fe, Mn, Ca and P, and they have a somewhat higher ratio of $Fe_20_3/Fe0$ than the average quartz basalt.

Table 1. Chemical analyses of rock samples

		Lower series				Middle series				Upper series					
Sample number		63016		63023		63135		63141		63171		63176		63182	
SiO_2		48.14		48.09		53.94		53.68		48.06		49.54		49.33	
TiO_2		3.30		3.20		1.45		1.49		2.64		2.97		2.66	
Al_2O_3		13.48		13.20		12.85		12.78		14.92		13.80		14.26	
Fe_2O_3		5.66		5.79		1.99		1.38		10.05		4.83		3.88	
FeO		8.90		8.64		7.70		8.48		2.97		8.74		8.94	
MnO		0.22		0.21		0.08		0.01		0.16		0.22		0.29	
MgO		5.63		5.70		8.83		8.96		5.88		5.91		6.16	
CaO		10.48		10.58		8.60		8.76		10.84		10.47		10.60	
Na_2O		2.54		2.49		2.35		2.43		2.73		2.69		2.92	
K_2O		0.23		0.30		0.93		0.69		0.26		0.41		0.40	
H_2O		0.95		0.96		0.90		0.78		1.57		0.64		0.84	
P_2O_5		0.38		0.37		0.14		0.13		0.20		0.23		0.23	
Sum		99.91		99.53		99.76		99.57		100.28		100.45		100.51	
C.I.P.W. weight norms															
Q		5.05	0.75	5.16	0.69	5.16	4.33	4.15	4.04	5.11		3.91	0.41	1.02	
or		1.36	1.36	1.77	1.77	5.50	5.50	4.08	4.08	1.54	1.54	2.42	2.42	2.36	2.36
ab		21.49	21.49	21.07	21.07	19.89	19.89	20.56	20.56	23.10	23.10	22.76	22.76	24.71	24.71
an		24.70	24.70	23.96	23.96	21.77	21.77	21.93	21.93	27.69	27.69	24.37	24.37	24.62	24.62
wo	di	10.36	10.36	10.90	10.91	8.35	8.34	8.63	8.63	10.35	10.35	10.89	10.89	11.05	11.05
en		6.59	4.78	7.08	5.07	5.32	5.09	5.30	5.27	8.94	5.17	6.76	5.26	6.52	5.49
fs		3.11	5.48	3.09	5.72	2.48	2.79	2.85	2.89	0.00	4.96	3.48	5.45	3.98	5.34
en	hy	7.44	9.24	7.12	9.12	16.66	16.90	17.02	17.04	5.70	6.97	7.95	9.46	8.82	6.96
fs		3.51	10.59	3.10	10.28	7.77	9.28	9.14	9.34	0.00	6.70	4.09	9.79	5.38	6.75
fo	ol										1.75				2.03
fa											1.86				2.17
hm										8.37					
mt		8.21	2.68	8.39	2.65	2.89	1.82	2.00	1.86	2.44	2.30	7.00	2.51	5.63	2.38
il		6.27	6.27	6.08	6.08	2.75	2.75	2.83	2.83	5.01	5.01	5.64	5.64	5.05	5.05
ap		0.88	0.88	0.86	0.86	0.32	0.32	0.30	0.30	0.46	0.46	0.53	0.53	0.53	0.53

The samples from the middle series have an unusual composition as MgO is higher than CaO. Compared to the average quartz basalt the samples are low in Al, Mn, Ca and P, and high in Si and Mg. The ratio of Fe_2O_3/FeO is considerably lower for the samples than for the average quartz basalt.

Concerning the samples from the upper series, 63171 (in which the Fe-Ti-oxides all have oxidation index 6) is so rich in Fe_2O_3 that it cannot pass the screen for rocks of basaltic composition by Manson (1967). 63182 has the same ratio of Fe_2O_3/FeO as the average quartz basalt, whereas 63176 has a somewhat higher ratio. Compared to the average olivine tholeiite of Manson (1967) the samples from the upper series all have high values of the ratio Fe_2O_3/FeO.

In relation to the average quartz basalt as well as the average olivine tholeiite the samples are low in Al and K, and high in Ti, Fe, (Mn), Ca and Na, whereas Si and Mg for the samples are intermediate between the values of the two average basalts.

It can be noted that in all three flows the contents of Mg is higher in the interior of the flow than at the contact. In the upper series also Na and K are higher in the interior of the flow, whereas in the middle series K is highest at the contact.

Noe-Nygaard (1966) pointed out that the Faeroes-Iceland-Greenland basalts differ from the mid-ocean ridge basalts in that they are higher in Fe, Ti and P, and lower in Al and Mg. Brooks & Jakobsson (1974) introduced the designation FETI for the Fe-Ti-rich type. On the basis of rare-earth evidence, Schilling & Noe-Nygaard (1974) suggested that the Fe-Ti-rich basalts of the lower and middle series were plume-derived, whereas the upper series is more akin to normal mid-ocean ridge basalts. This idea was further elaborated by Bollingberg, Brooks & Noe-Nygaard (1975) who suggest that the lower series was erupted under vigorous plume activity, the middle series erupted during the waning phase of plume activity, and the upper series erupted by typical ocean tholeiite magmas without influence from plume activity.

The two samples from the lower series, 63016 and 63023, correspond well with the average of the lower series (Rasmussen & Noe-Nygaard 1969, Bollingberg, Brooks & Noe-Nygaard 1975) and could be classified as FETI-basalts characteristic of plume activity.

The flows from the middle and upper series investigated here, however, cannot be taken as representative for their respective series, and the samples deviate beyond the standard deviation for the average composition of the series given by Bollingberg, Brooks & Noe-Nygaard (1975).

Although they have a deviating composition the samples from the middle and upper series may support the idea of Schilling & Noe-Nygaard (1974), as they reflect a development away from the plume-derived FETI-basalts of the lower series towards more normal mid-ocean ridge basalts.

Thus in the flow from the middle series the elements Ti, Fe, Mn and Mg are present in amounts corresponding to mid-ocean ridge basalts, whereas the remaining elements (except P, see below) still show FETI-characteristics.

In the flow from the upper series such a division of elements cannot be made, but the composition is in many respects intermediate between mid-ocean ridge basalt and FETI-basalt, and the samples certainly are less FETI than the samples from the lower series.

The comparisons between basalt types by Bollingberg, Brooks & Noe-Nygaard (1975) are based on analyses recalculated to 100 % H_2O-P_2O_5-free, but Noe-Nygaard (1966) found Faeroe Islands basalts to be richer in P than mid-ocean ridge basalts, and it is clearly seen that the samples from the upper series and specially the samples from the middle series are lower in P than the samples from the lower series.

Pearce, Gorman & Birkett (1975) used TiO_2, K_2O and P_2O_5 to discriminate between oceanic and non-oceanic basalts. Plotted in the TiO_2-K_2O-P_2O_5 diagram (fig. 1) the samples from the lower and upper series fall well within the oceanic field, trending towards the non-oceanic field from contact to-

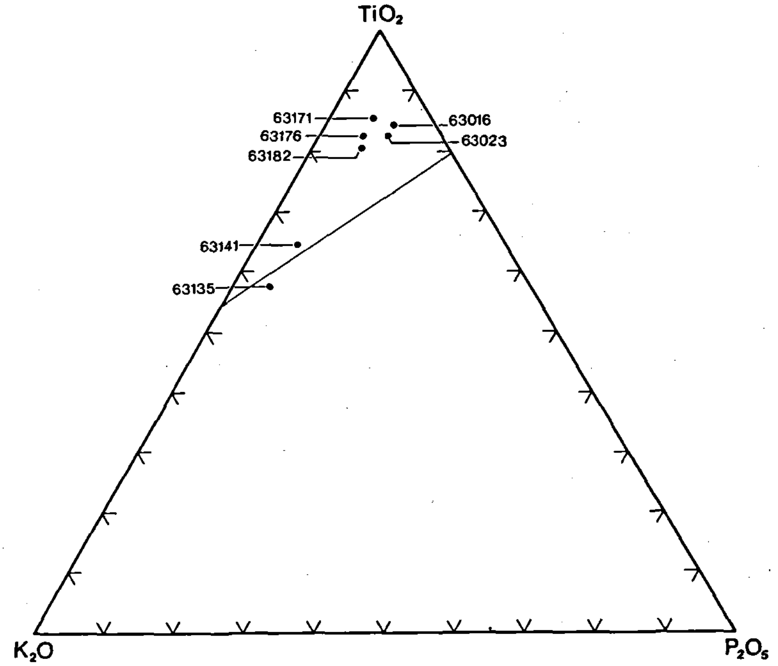

Fig. 1. TiO_2-K_2O-P_2O_5 diagram (Pearce, Gorman & Birkett 1975). Oceanic field above and non-oceanic field below dividing line.

wards interior of flow. The samples from the middle series fall on either side of the dividing line between oceanic and non-oceanic basalts with the contact sample on the non-oceanic side.

Values of the discriminant functions of Pearce (1976) are given in table 2. In an F_1-F_2 diagram the lower and upper series both plot in the within-plate basalt field, the upper series lying closer to the ocean-floor basalt field than the lower series. The middle series plot in the field of volcanic arc basalts, the sample from the flow interior lying closer to the field of ocean-floor basalts than the contact sample. In an F_2-F_3 diagram the middle series plot in the field of low-potassium tholeiites, but the sample from the flow interior is very close to the border of the field of ocean-floor basalts.

Table 2. Values of discriminant functions calculated after Pearce (1976)

Sample number		F_1	F_2	F_3
Lower series	63016	0.199	—1.537	
	63023	0.202	—1.525	
Middle series	63135	0.381	—1.508	—2.397
	63141	0.373	—1.536	—2.397
Upper series	63171	0.243	—1.537	
	63176	0.232	—1.543	
	63182	0.248	—1.554	

63016 and 63023 have indicator ratios (Coombs 1963) 0.34 and 0.32 respectively. 63171 and 63182 both have the indicator ratio 0.28, and 63176 has 0.32. This means that the flows from the lower and upper series have indicator ratios in the range where hypersthene appears to be unknown and pigeonite rare or absent. Hypersthene is not found in either flow, and the flow from the lower series is also without pigeonite, whereas pigeonite in the flow from the upper series is only absent in the contact sample 63171, occurs sparse in 63176, and is abundant in 63182.

The flow from the middle series have indicator ratios 0.52 (63135) and 0.51 (63141). The values thus are just above the limiting value of 0.50, below which hypersthene is seldom found.

Pyroxene analyses

The pyroxenes were analysed with a Hitachi XMA-5B electron microprobe using 15.0 kV accelerating voltage and a sample current on a Faraday cage of 20.0 nA. Stoichiometric oxides and silicates were used as standards. The correction programme used, EMSKOR, is based on the programme made by Springer (1967), but modified by Rønsbo, Institute of Mineralogy, University of Copenhagen, in accordance with the suggestions of Sweatman & Long (1969). Total iron has been divided between ferrous and ferric iron by the method suggested by Finger (1972). The distribution of elements between Z- and M-positions is in accordance with the method outlined by Hess (1949).

In this paper are presented 30 pyroxene analyses comprising the elements Si, Ti, Al, Fe, Mn, Mg, Ca and Na. Furthermore the results of 116 partial analyses, comprising only Fe, Mg and Ca, are used in some of the plots, but are not given in tables. For these partial analyses an amount of Mn, obtained by interpolation from the two nearest analyses with determination of Mn, was allotted to Fe in the calculation of atomic percentages of Ca, Mg and Fe, and the Fe-values in these calculations comprise total iron and manganese.

Table 3 gives the results of 19 analyses of augite, and table 4 gives the Ca-poor pyroxenes: 8 bronzites and 3 pigeonites.

Variations in major elements

The augites from the contact sample of the flow from the upper series are plotted in fig. 2. If the three ringed plots, which represent the rim part of relatively large grains, are left out of consideration, the augites here seem to represent a quench trend comparable to the findings of Smith & Lindsley (1971) for a flow from the Columbia River basalt.

The three ringed plots would fit better in fig. 3 where the augites from the interior of the flow are plotted. The augites here show a normal trend with a position intermediate between the Skaergaard trend (Brown 1957) and the Thingmuli trend (Carmichael 1967). This is in contrast to the flow of Columbia River basalt where Smith & Lindsley (1971) found the normal trend from the interior of the flow to be more calcic than the Skaergaard trend. The reason for the lower Ca contents in the augites from the Faroe Islands flow might be that this flow is plagioclase-porphyritic, and the plagio-

Table 3

Microprobe analyses of augites

	Lower series			Middle series									Upper series						
Sample no.	63016	63016	63016	63135	63135	63135	63135	63135	63135	63135	63141	63135	63182	63176	63182	63176	63176	63176	63176
Analysis no.:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	49.5	50.5	49.6	51.0	50.7	51.0	50.9	50.7	51.8	51.1	51.1	51.8	50.7	50.8	50.3	50.3	49.7	50.1	50.0
TiO_2	1.45	1.12	1.05	0.97	1.03	0.97	0.97	1.03	0.89	0.96	0.92	0.89	1.03	0.93	1.06	1.02	1.48	0.90	1.12
Al_2O_3	3.54	1.76	1.74	2.55	3.24	2.55	2.23	3.24	2.15	2.22	2.58	2.15	1.89	1.65	1.93	1.75	2.36	1.67	2.27
Fe_2O_3	1.88	1.05	1.38	1.90	1.89	0.37	2.31	0.04	0.74	2.31	2.60	0.00	2.28	1.21	2.23	2.14	1.37	0.93	0.44
FeO	8.71	14.7	15.6	7.96	9.20	11.2	9.03	12.1	11.7	10.4	10.5	14.9	10.3	13.0	13.1	12.9	14.3	15.3	15.8
MnO	0.22	0.46	0.27	0.26	0.27	0.26	0.28	0.27	0.26	0.27	0.26	0.26	0.28	0.43	0.34	0.36	0.45	0.32	0.36
MgO	14.5	14.2	12.0	17.4	16.5	16.1	16.2	15.9	15.3	15.2	15.1	13.7	14.9	14.5	13.7	13.5	13.0	12.7	12.4
CaO	19.1	15.6	17.0	16.9	16.9	16.2	17.3	15.5	17.6	17.5	17.7	16.8	18.3	16.6	17.2	17.5	16.8	16.8	16.5
Na_2O	0.27	0.21	0.27	0.21	0.22	0.21	0.30	0.22	0.20	0.38	0.35	0.20	0.22	0.22	0.26	0.29	0.29	0.21	0.30
Total	99.17	99.60	98.91	99.15	99.95	98.86	99.52	99.00	100.64	100.34	101.11	100.70	99.90	99.34	100.12	99.76	99.75	98.93	99.19
Total iron as FeO	10.4	15.6	16.8	9.67	10.9	11.5	11.1	12.1	12.4	12.5	12.8	14.9	12.3	14.1	15.1	14.8	15.5	16.1	16.2
Atomic percentages (Mn calculated with Fe)																			
Ca	40.2	32.6	36.2	34.6	34.8	33.9	35.5	32.8	36.1	36.0	36.2	35.2	37.5	34.5	35.6	36.4	35.5	35.5	35.3
Mg	42.4	41.2	35.5	49.5	47.2	46.9	46.3	46.8	43.6	43.5	42.9	40.0	42.4	41.9	39.4	39.0	38.2	37.4	37.0
Fe	17.4	26.2	28.3	15.9	18.0	19.2	18.2	20.4	20.3	20.5	20.9	24.8	20.1	23.6	25.0	24.6	26.3	27.1	27.7
Formulae based on 4 cations																			
Si	1.864	1.921	1.920	1.898	1.882	1.918	1.902	1.906	1.925	1.906	1.894	1.946	1.905	1.927	1.905	1.912	1.896	1.930	1.921
Al	0.136	0.079	0.079	0.102	0.118	0.081	0.098	0.094	0.075	0.095	0.106	0.065	0.084	0.073	0.086	0.078	0.104	0.070	0.079
Ti																			
Fe^{+++}			0.001										0.011		0.009	0.010			
Z	2.000	2.000	2.000	2.000	2.000	1.999	2.000	2.000	2.000	2.001	2.000	2.011	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al	0.021			0.010	0.024	0.032		0.050	0.019	0.003	0.007	0.030		0.001			0.002	0.006	0.024
Ti	0.041	0.032	0.031	0.027	0.029	0.027	0.027	0.029	0.025	0.027	0.026	0.025	0.029	0.027	0.030	0.029	0.042	0.026	0.032
Fe^{+++}	0.053	0.030	0.039	0.053	0.053	0.010	0.065	0.001	0.021	0.065	0.073		0.054	0.034	0.054	0.051	0.039	0.027	0.013
Fe^{++}	0.274	0.466	0.504	0.248	0.286	0.351	0.282	0.379	0.365	0.325	0.324	0.468	0.322	0.413	0.415	0.409	0.455	0.492	0.508
Mn	0.007	0.015	0.009	0.008	0.008	0.008	0.009	0.009	0.008	0.009	0.008	0.008	0.009	0.014	0.011	0.012	0.015	0.010	0.012
Mg	0.814	0.805	0.692	0.965	0.913	0.903	0.902	0.891	0.847	0.845	0.834	0.767	0.834	0.820	0.773	0.765	0.739	0.729	0.710
Ca	0.770	0.636	0.705	0.674	0.672	0.653	0.693	0.625	0.701	0.699	0.703	0.676	0.737	0.675	0.698	0.713	0.687	0.694	0.679
Na	0.020	0.015	0.020	0.015	0.016	0.015	0.022	0.016	0.014	0.027	0.025	0.015	0.016	0.016	0.019	0.021	0.021	0.016	0.022
M	2.000	1.999	2.000	2.000	2.001	1.999	2.000	2.000	2.000	2.000	2.000	1.989	2.001	2.000	2.000	2.000	2.000	2.000	2.000
% Al in Z	6.8	4.0	4.0	5.1	5.9	4.1	4.9	4.7	3.8	4.7	5.3	3.2	4.2	3.7	4.3	3.9	5.2	3.5	4.0
% Ti in Z																			
% Fe^{+++} in Z			0.1										0.6		0.5	0.5			
% Al in M	1.1			0.5	1.2	1.6		2.5	1.0	0.2	0.4	1.5		0.05			0.1	0.3	1.2

Table 4

Microprobe analyses of Ca-poor pyroxenes

	Bronzites								Pigeonites		
	Middle series								Middle series	Upper series	
Sample no.	63135	63135	63135	63141	63135	63135	63135	63141	63141	63181	63181
Analysis no.	20	21	22	23	24	25	26	27	28	29	30
SiO_2	55.8	56.0	56.1	55.0	55.0	55.1	54.7	53.5	51.6	52.9	51.4
TiO_2	0.20	0.20	0.20	0.27	0.33	0.33	0.32	0.53	0.63	0.53	0.60
Al_2O_3	0.85	1.07	0.99	1.39	1.19	1.16	1.28	1.10	1.46	0.76	0.72
Fe_2O_3	0.43	0.02	0.00	0.89	0.00	0.23	0.41	0.91	1.23	0.04	2.03
FeO	10.9	11.3	11.6	10.8	11.6	12.5	15.4	17.6	22.2	21.9	20.8
MnO	0.23	0.18	0.21	0.24	0.28	0.27	0.26	0.32	0.32	0.50	0.56
MgO	29.5	29.4	29.1	28.9	28.2	28.1	26.1	24.3	18.9	20.0	19.0
CaO	2.34	2.38	2.23	2.45	2.66	2.39	2.36	2.31	4.41	4.14	4.91
Na_2O	0.04	0.05	0.06	0.07	0.09	0.06	0.10	0.06	0.09	0.09	0.11
Total	100.29	100.60	100.49	100.01	99.35	100.14	100.93	100.63	100.84	100.86	100.13
Total iron as FeO	11.3	11.3	11.6	11.6	11.6	12.7	15.8	18.4	23.3	21.9	22.6
Atomic percentages (Mn calculated with Fe)											
Ca	4.5	4.5	4.3	4.7	5.2	4.6	4.6	4.6	9.0	8.4	9.9
Mg	78.4	78.3	77.9	77.5	76.7	75.8	70.9	66.6	53.5	56.2	53.5
Fe	17.1	17.2	17.8	17.8	18.1	19.6	24.5	28.8	37.5	35.4	36.6
Formulae based on 4 cations											
Si	1.973	1.974	1.983	1.954	1.971	1.966	1.962	1.951	1.936	1.971	1.942
Al	0.027	0.026	0.023	0.046	0.031	0.034	0.038	0.047	0.064	0.027	0.032
Ti										0.002	0.001
Fe^{+++}								0.002			0.025
Z	2.000	2.000	2.006	2.000	2.002	2.000	2.000	2.000	2.000	2.000	2.000
Al	0.008	0.018	0.018	0.012	0.019	0.015	0.016		0.001	0.006	
Ti	0.005	0.005	0.005	0.007	0.009	0.009	0.009	0.015	0.018	0.013	0.016
Fe^{+++}	0.011			0.024		0.006	0.011	0.023	0.035	0.001	0.033
Fe^{++}	0.323	0.333	0.343	0.321	0.348	0.373	0.463	0.536	0.696	0.681	0.656
Mn	0.007	0.005	0.006	0.007	0.008	0.008	0.008	0.010	0.010	0.016	0.018
Mg	1.554	1.544	1.533	1.530	1.506	1.494	1.395	1.321	1.057	1.111	1.070
Ca	0.089	0.090	0.084	0.093	0.102	0.091	0.091	0.090	0.177	0.165	0.199
Na	0.003	0.003	0.004	0.005	0.006	0.004	0.007	0.004	0.007	0.007	0.008
M	2.000	1.998	1.993	1.999	1.998	2.000	2.000	1.999	2.001	2.000	2.000
% Al in Z	1.4	1.3	1.1	2.3	1.5	1.7	1.9	2.4	3.2	1.4	1.6
% Ti in Z										0.1	0.1
% Fe^{+++} in Z								0.1			1.3
% Al in M	0.4	0.9	0.9	0.6	1.0	0.8	0.8		0.05	0.3	

clase phenocrysts could have depleted the magma in Ca relative to Mg and Fe.

Considering the augites from the flow from the lower series, the values obtained for the interior of the flow (fig. 5) conform to the Skaergaard trend, whereas the values from the outer part of the flow (fig. 4) show a rather scattered picture. In the interpretation it must be remembered that the sample from the outer part of this flow is about 2 m above the contact, and thus a quench trend cannot be expected to show as clearly as in samples closer to the contact. The ringed values are all from the central part of rather large grains, and it is believed that the trend shown by these values represent a quench trend.

Concerning the values of the augites from the

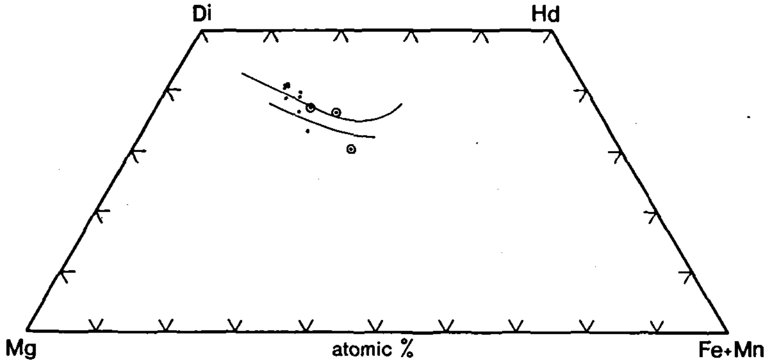

Fig. 2. Augites from the contact sample (63171) of the flow from the upper series. Ringed values represent analyses of rim of large grains. Upper line is the Skaergaard trend (Brown 1957), lower line is the Thingmuli trend (Carmichael 1967).

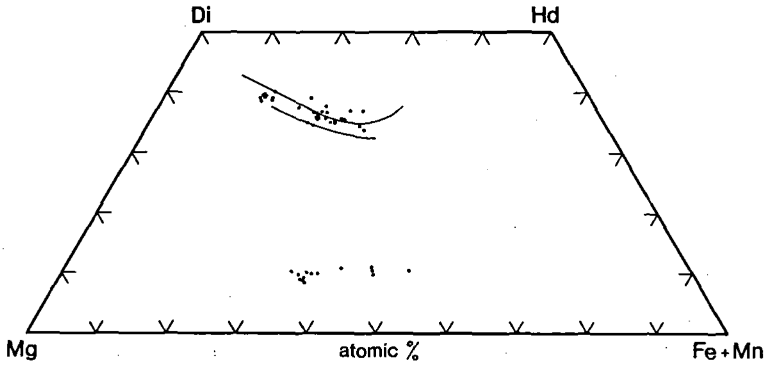

Fig. 3. Augites and pigeonites from the interior of the flow from the upper series (63176 & 63182). Lines as in fig. 2.

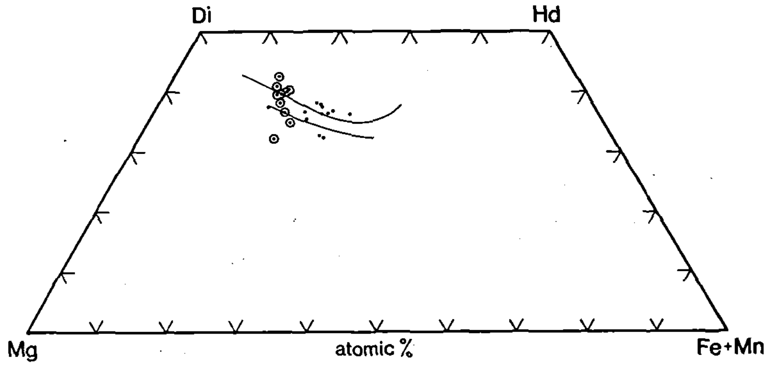

Fig. 4. Augites from near the contact (63016) of the flow from the lower series. Ringed values represent analyses from the central part or large grains. Lines as in fig. 2.

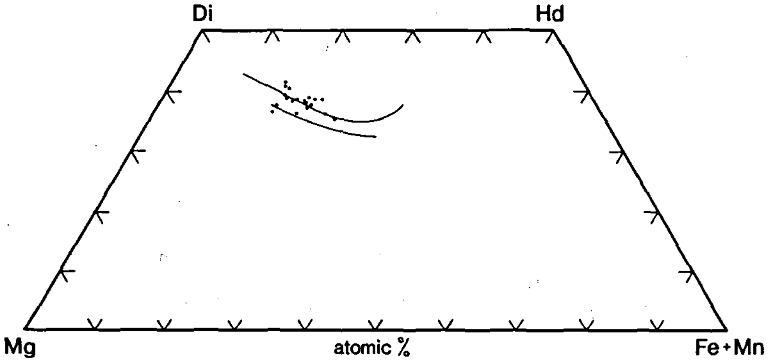

Fig. 5. Augites from the interior of the flow from the lower series (63023). Lines as in fig. 2.

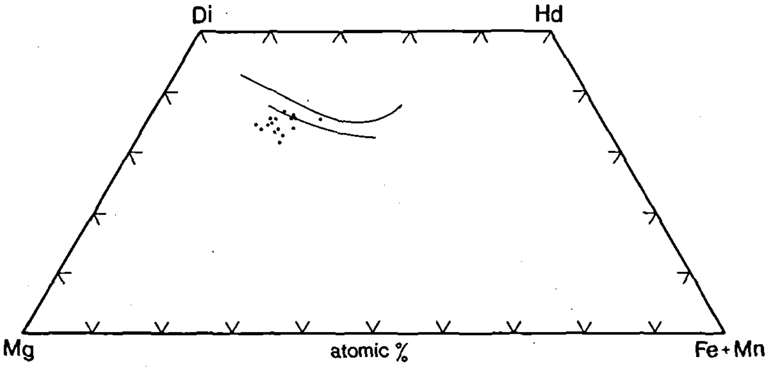

Fig. 6. Augites from the contact sample (63135) of the flow from the middle series. Lines as in fig. 2.

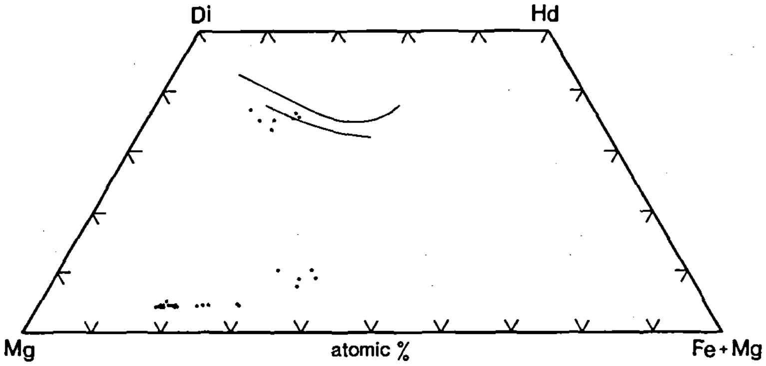

Fig. 7. Bronzites and pigeonites from the flow from the middle series (63135 & 63141), and augites from the interior of the flow (63141). Lines as in fig. 2.

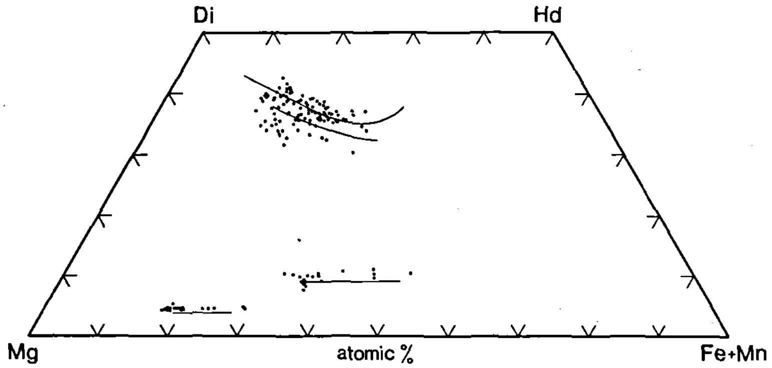

Fig. 8. Total plot of the Faeroese pyroxenes. The upper trend line for augites and the trend lines for Ca-poor pyroxenes are the Skaergaard trends (Brown 1957). The lower trend line for augites is the Thingmuli trend (Carmichael 1967).

flow from the middle series (figs 6 and 7) it is the opinion of the author that these are too scattered to show any trend, the larger scattering of the values from the contact sample might however be explained as due to the influence of a quench trend. The position of the plots is remarkable by being rather poor in Ca, lying mainly below the Thingmuli trend. The explanation is probably that the flow as such is rather low in Ca (table 1).

The bronzites, found only in the flow from the middle series, cover a range from Ca$_{4.5}$ Mg$_{78.4}$Fe$_{17.1}$ to Ca$_{4.6}$M$_{66.6}$Fe$_{28.8}$, and the whole range can be found as zoning within a single grain. The trend of the bronzites is about the same as found for the Skaergaard bronzites (Brown 1957) and the Bushveld bronzites (Atkins 1969), but whereas the Bushveld bronzites deviate from the Skaergaard bronzites in being slightly lower in Ca, the Faeroese bronzites are slightly higher in Ca than the Skaergaard bronzites.

The five analysed pigeonites from the middle series (fig. 7) range from Ca$_{10.1}$ Mg$_{58.3}$Fe$_{31.6}$ to Ca$_{10.1}$ Mg$_{53.5}$Fe$_{36.4}$, but between these two end-members the Ca-values reach a minimum of 7.5 %.

From the flow from the upper series 14 pigeonite analyses are available, they cover a range from Ca$_{10.1}$Mg$_{57.0}$Fe$_{32.9}$ to Ca$_{10.4}$Mg$_{40.1}$Fe$_{49.5}$, with Ca-values fluctuating between 8.4 and 11.0 %.

The trend is about the same as for the Skaergaard pigeonites (Brown 1957) and the Bushveld pigeonites (Atkins 1969), but as was the case for the bronzites, the pigeonites from the Faeroe Islands are slightly higher in Ca, and the Bushveld pigeonites sligtly lower in Ca than the Skaergaard pigeonites. The amounts of Ca in the Faeroese pigeonites correspond to the amounts found in the Thingmuli pigeonites (Carmichael 1967) and in the Tasmanian pigeonites from the dolerite at Red Hill (McDougall 1961), but whereas the Ca-contents in as well the Thingmuli pigeonites as the Tasmanian pigeonites increase with fractionation, the Faeroese pigenoites must be characterised as rather steady for higher values of Fe although they fluctuate for lower values of Fe. Investigations of the Makaopuhi lava lake by Evans & Moore (1968) have shown that increase in Ca with Fe-enrichment of pigeonite is connected with chilled rocks, whereas with slower cooling the pigeonite trend is nearly horizontal.

Fig. 8 shows all the Faeroese pyroxenes plotted in the same diagram.

Distribution of minor elements between augites and Ca-poor pyroxenes

It is generally accepted that augites are enriched in Al and impoverished in Mn relative to Ca-poor pyroxenes. As far as Al is concerned this is also the case with the Faeroese pyroxenes. Concerning Mn, however, it holds true only for augites and pigeonites, whereas Mn in the bronzites varies from below the corresponding augites in the low fractionation stages (central part of grains) to above augites in the highest fractionation stage (rim part of grains).

It is frequently stated that the distribution of Mn between augites and Ca-poor pyroxenes is a consequence of Mn following Fe^{++}. In the present investigation there seems to be no correlation between Mn and Fe^{++}, and it is noteworthy that in the augites of the middle series FeO varies from 7.96 to 14.9% while MnO remains constant at 0.26%.

Also Na is enriched in augites relative to Ca-poor pyroxenes, as has been found for the Skaergaard pyroxenes (Brown 1957) and the Thingmuli pyroxenes (Carmichael 1967).

Concerning Ti and Fe^{+++} there are different opinions. Brown (1957) found Ti and Fe^{+++} enriched in augite, Carmichael (1967) found Ti enriched in augite, and Atkins (1969) found Ti, and with a single exception also Fe^{+++}, to be enriched in augite, whereas McDougall (1961) found pigeonite enriched in Ti and Fe^{+++} relative to augite in the Tasmanian dolerite from Red Hill. In the Faeroese pyroxenes Ti is clearly enriched in augites relative to Ca-poor pyroxenes. Concerning Fe^{+++}, the values are not analytically determined in the Faeroese pyroxenes, but calculated, and the calculated Fe^{+++} values show large scattering, however, the highest values are obtained for the augites, and the view of Atkins (1969) that Fe^{+++} behave sympathetically with Fe^{++} gets no support from the calculated values of Fe^{+++} from the Faeroese pyroxenes.

Fractionation trends of the minor elements

Na

The Na_2O contents of the augites from the Faeroe Islands basalts vary from 0.21 to 0.38%, which are relatively low values as LeBas (1962) gives the average value of Na_2O for tholeiitic basalts as 0.35%. With the exception of two analyses (0.35 and 0.38%) the values from the Faeroe Islands are all below this average. The Na_2O values, however, correspond to the values found for the Thingmuli augites (Carmichael 1967).

In the flow from the lower series there is no significant variation in the Na content with fractionation. In the flow from the middle series the highest Na values are obtained in the middle of the fractionation range represented, that is about $Fe/Fe+Mg+Ca = 20–21\%$. In the flow from the upper series Na shows a slight increase with fractionation. Na is frequently stated as decreasing with fractionation (Brown 1957, Atkins 1969, Walker, Ware & Lovering 1973), but the increase in Na found in the flow from the upper series of the Faeroe Islands basalts is in agreement with Le Bas (1962) who states that Na decreases in augites of the high-alumina series and increases in the tholeiite series.

In the bronzites Na remains steady, and although the values of table 4 might indicate an increase in Na of the pigeonite, the author believes that Na also in the pigeonites remains steady (this belief is based on the evidence from several other analyses of pigeonite, not published because their sum exeeds 101%).

The amounts of Na present in the Ca-poor pyroxenes correspond to the amounts of Na in the Ca-poor pyroxenes from Bushveld and the Palisades Sill. Atkins (1969) found Na steady in the orthopyroxenes and a slight increase in the pigeonites of Bushveld. Walker, Ware & Lovering (1973) state that there appears to be a tendency to increase for the orthopyroxenes as well as the pigeonites of the Palisades Sill.

Mn

The values of MnO of the augites from the Faeroe Islands basalts lie in the middle of the range generally reported for MnO in augites. In the flow from the lower series Mn is fluctuating without any trend. In the flow from the middle series Mn is remarkably constant throughout the whole fractionation range represented. In the flow from the upper series Mn is also fluctuating, but shows a slight increase with fractionation.

MnO values of the bronzites are rather low compared to the values generally reported for orthopyroxenes, but they correspond to the values of the Bushveld bronzites found by Atkins (1969), and like the Bushveld bronzites the Faeroese bronzites show an increase in Mn with fractionation.

The pigeonite from the flow from the upper series has MnO values corresponding to the values generally reported for pigeonites, whereas the content of MnO in the pigeonite from the flow from the middle series is considerably lower. MnO in the pigeonite from the flow from the middle series is similar to the MnO content of the bronzite of this flow. Besides the analysis of pigeonite given in table 4 this statement is confirmed by several unpublished analyses of pigeonite.

Al and Ti

The Al_2O_3 values for the augites lie within the range generally reported for augites, whereas the TiO_2 values are rather high as LeBas (1962) states that non-alkaline clinopyroxenes commonly have less than 1% TiO_2. However, similar high values of TiO_2 are reported from augites from Kap Edvard Holm by Elsdon (1971), and almost as high values of TiO_2 are found in the Skaergaard augites (Brown 1957) and the Thingmuli augites (Carmichael 1967).

In the augites from the lower series Al_2O_3 as well as TiO_2 decreases with fractionation, the augites from the middle series show rather fluctuating values of Al_2O_3 and TiO_2 but both tend to show a decrease with fractionation. In the upper series no trend can be found for either Al_2O_3 or TiO_2.

In the bronzites Al_2O_3 and TiO_2 increase in the earliest fractionation stages, remain steady in the middle fractionation stages, and in the latest fractionation stages Al_2O_3 decreases while TiO_2 again increases.

The pigeonites from the middle series have about the same amount of TiO_2 as the pigeonites from the upper series, whereas they have considerably more Al_2O_3, but the same relationship holds true for the corresponding augites.

With the exception of Himmelberg & Ford (1976) who found no obvious trend for Al and Ti in the pyroxenes from the Dufek intrusion, Antarctica, authors generally agree that Al_2O_3 decreases with fractionation, whereas the opinions on TiO_2 differ. In the Skaergaard Ti hardly varies (Brown 1957), in the Tasmanian dolerite at Red Hill Ti increases with fractionation (McDougall 1961). LeBas (1962) stated that Ti rises in augites from non-alkaline as well as alkaline rocks, however, LeBas did not consider augites with Fe/Fe + Mg + Ca exceeding 18%. Carmichael (1967) found that Ti tends to decrease in augites from Thingmuli. Atkins (1969) found Ti to increase in the Bushveld pyroxenes. Walker, Ware & Lovering (1973) found that Ti in augites from the Palisades Sill increases until Fe/Fe + Mg + Ca reaches 35.6%, whereafter Ti decreases.

In the Faeroese augites Al_2O_3 as well as TiO_2 decrease in the flows from the lower and middle series, most markedly for the lower series, whereas no trends were found in the flow from the upper series. However, in all three flows it is striking that the variations in Al_2O_3 are followed closely by TiO_2 in the augites, whereas the correlation between Al_2O_3 and TiO_2 is considerably weaker or non existent in the bronzites.

A close correlation between Al and Ti is to be expected, as it is generally supposed that the substitution of Al^{3+} for Si^{4+} in Z-positions is counterbalanced by introduction of Ti^{4+} in the otherwise mainly divalently occupied M-positions.

The values of the Faeroese pyroxenes clearly follow the equation: $Al_Z + Fe_Z^{+++} = Al_M + Fe_M^{+++} + 2Ti_M - Na$ which must be obeyed in order to maintain balance of charges. (Any Ti which might be present in Z-positions will not influence the charge balance, but K, when determined, should be subtracted on the right side of the equation like Na). In the following section the variation relationships between Ti and Al as distributed between Z- and M-positions shall be dealt with.

Relationships between Ti and Al as distributed between Z- and M-positions

In the augites from the lower series Ti, and Al_Z as well as Al_M decreases until the disappearence of Al_M, whereafter Ti and Al_Z remain steady.

In the augites from the middle series Ti remains rather steady, but Al_Z, Al_M and Fe^{+++} (and to some extent also Na) all fluctuate so heavily that it is difficult to observe any pattern in most of the fractionation range. However, in the latest stage Fe^{+++} disappears and Al_Z decreases markedly, while Al_M shows a corresponding increase.

In the augites from the upper series there is no obvious trend for Ti and Al_Z, whereas Al_M clearly increases in the later stages of fractionation, but this increase is compensated by a corresponding decrease in Fe_M^{+++} (and to some extent also by the variation in Na).

In the bronzites Ti increases slightly in the earliest fractionation stages while Al_Z and Al_M fluctuate, in the middle fractionation stages Ti, Al_Z and Al_M all remain rather steady, but in the latest fractionation stages Ti and Al_Z increase, whereas Al_M decreases to zero, the decrease in Al_M being compensated by increase in Fe^{+++}.

The variations in Ti, Al_Z, Al_M, Fe^{+++} and Na thus obviously are very complicated, but it is a common feature that Ti generally behave sympathetically with total Al. Exceptions to this rule only occur in cases where a decrease in total Al is combined with an increase in Al_Z, or an increase in total Al is combined with a decrease in Al_Z. These combinations are found three times in the eight bronzite analyses, but only once in the 19 augite analyses.

For the Skaergaard pyroxenes Brown (1957) found that Al in augites as well as in Ca-poor pyroxenes decreases steadily during fractionation, both in Z- and M-positions, the decrease being more marked for the augites. For the Bushveld pyroxenes Atkins (1969) found that Al as percentage of Z-positions as well as M-positions were greater in the augites than in the coexisting orthopyroxenes, and that the ratio between the pairs were strikingly consistent: the ratio of Al_Z in augite to Al_Z in orthopyroxene expressed as percentages of Z-positions was 1.1 - 1.2, and the corresponding ratio for M-positions 2.1 - 5.1. The Al-enrichment in the augites thus is most pronounced for M-positions in the Bushveld pyroxenes.

For sample 63135 the ratio for Al_Z varies from 1.9 to 5.4, and for Al_M from 0 to 6.3. If only the rim of bronzites is considered to be coexisting with the augite, the range for Al_Z is narrowed to 1.9 – 3.9, and for Al_M to 0 – 3.1.

For sample 63141 the ratio for Al_Z varies from 2.2 to 2.8, and for Al_M from 0.5 to 0.4/0. If only the rim of bronzites is considered to be coexistent with augite the value 2.2 is obtained for Al_Z and 0.4/0 for Al_M.

Thus for the Faeroese pyroxenes there is no consistency of the ratios, but they show clearly that compared to the Bushveld pyroxenes the Faeroese augites are considerably more enriched in Al_Z, relative to the bronzites, whereas the augites concerning Al_M can be as well enriched as impoverished. In this respect the Faeroese pyroxenes compare better with the Skaergaard pyroxenes, as Brown (1957) found that whereas the augite always contains more Al in the Z-positions than the Ca-poor pyroxene from the same rock, the augite contains about the same or slightly less in the M-positions.

For 63141 the ratio between augite and pigeonite for Al_Z is 1.7 and for Al_M 8.0, compared to pigeonite the augite is thus preferentially enriched in Al in M-positions.

In 63182 from the flow from the upper series the augite has no Al in M-positions, this holds true for one of the pigeonite analyses too, whereas the other has a small amount of Al in M-positions. The ratio for Al in Z-positions varies from 2.6 to 3.1. Thus, while Al in M-positions is absent, the enrichment in Al in Z-positions of the augite compared to pigeonite is considerably more pronounced in the flow from the upper series than in the flow from the middle series.

Determination of magma type based on pyroxene composition after Nisbet & Pearce (1977)

Values of the discriminant functions of Nisbet & Pearce (1977) are given in table 5. In an F_1–F_2 diagram two of three augites from the lower series plot in the field where ocean-floor and volcanic arc basalts overlap, and the third plots in the field where ocean-floor basalts and within-plate tholeiites overlap.

Of the nine augites from the middle series four fall in the field where ocean-floor and volcanic arc basalts overlap, three in the field where ocean-floor basalts and within-plate tholeiites overlap,

Table 5. Values of discriminant functions calculated after Nisbet & Pearce (1977)

	Sample number	Analysis number	F_1	F_2
Lower series	63016	1	—0.858	—2.465
	63016	2	—0.824	—2.533
	63016	3	—0.837	—2.443
Middle series	63135	4	—0.785	—2.506
	63135	5	—0.795	—2.515
	63135	6	—0.790	—2.515
	63135	7	—0.807	—2.495
	63135	8	—0.784	—2.530
	63135	9	—0.820	—2.528
	63135	10	—0.825	—2.501
	63141	11	—0.822	—2.504
	63135	12	—0.826	—2.540
Upper series	63182	13	—0.833	—2.477
	63176	14	—0.820	—2.511
	63182	15	—0.835	—2.487
	63176	16	—0.840	—2.478
	63176	17	—0.871	—2.521
	63176	18	—0.822	—2.461
	63176	19	—0.842	—2.494

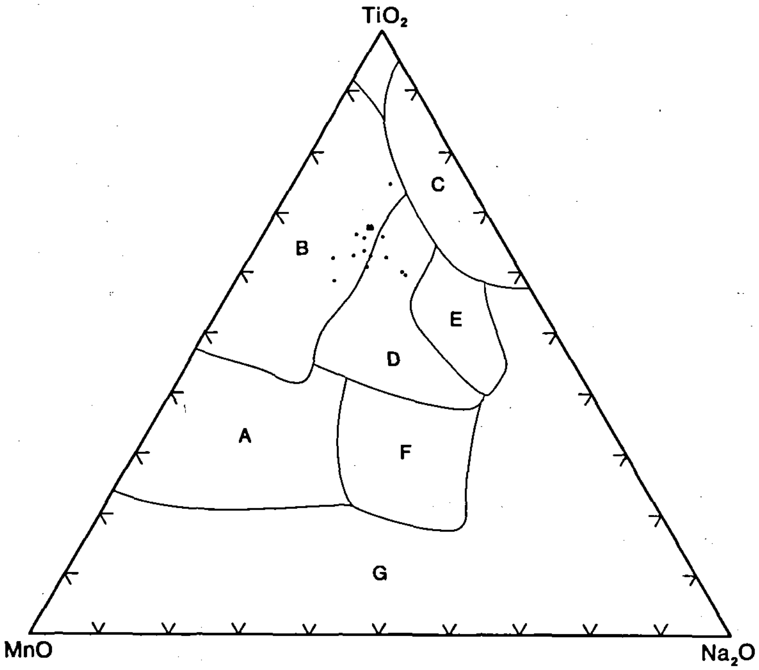

Fig. 9. TiO$_2$-MnO-Na$_2$O diagram (Nisbet & Pearce 1977). A is a field of volcanic arc basalts, B a field of ocean-floor basalts, C and G are fields of within-plate alkali basalts. F is a field where volcanic arc basalts and within-plate alkali basalts overlap, E is a field where volcanic arc basalts, within-plate tholeiites and within-plate alkali basalts overlap, and D is a field where all the basalt types overlap.

and the remaining two on the border between these two fields.

Of the seven augites from the upper series three fall in the field where ocean-floor and volcanic arc basalts overlap, three in the field where ocean-floor basalts and within-plate tholeiites overlap, and the last one on the border between these two fields.

Fig. 9 shows the augites plotted in a TiO$_2$-MnO-Na$_2$O diagram (Nisbet & Pearce 1977). Two of the augites from the lower series plot within the field of ocean-floor basalts, the third in the field common to all the basalt types. Six of the nine augites from the middle series plot within the field of ocean-floor basalts, and three in the field common to all basalt types. Five of the seven augites from the upper series plot inside the ocean-floor basalt field, and two on the border between this field and the field common to all basalt types.

In a SiO$_2$-TiO$_2$ diagram (Nisbet & Pearce 1977) all the augites will plot inside the ocean-floor basalt field, except one which falls just on the borderline.

Summary of conclusions

Concerning the major elements, Mg, Fe, Ca, the Faeroese augites show a quench trend, or at least show a scattering due to quench influence in the contact samples, whereas the augites in the samples from the interior of flows show a more normal trend, comparable to the Skaergaard trend, but the augites from the middle and upper series are generally somewhat lower in Ca.

The trends for bronzites and pigeonites are also comparable to those of the Skaergaard intrusion, but contrary to the augites these Ca-poor pyroxenes are slightly higher in Ca than the Ca-poor pyroxenes from the Skaergaard intrusion.

The augites are enriched in Al, Ti and Na, and probably also in Fe^{+++} relative to the Ca-poor pyroxenes of the same rock. Concerning Mn the augites are impoverished in relation to pigeonites, but hold about the same amount of Mn as the bronzites.

Na and Mn remain steady or show a slight increase with fractionation.

The relationships between Ti, Al_Z and Al_M are complicated. They are linked by the equation $Al_Z + Fe^{+++}_Z = Al_M + Fe^{+++}_M + 2Ti_M - Na$, but the only rather simple trend (decrease in Ti, Al_Z and Al_M until the disappearance of Al_M, whereafter Ti and Al_Z remain steady) is obtained for the augites from the lower series, and the simple relationships might very well be due to the fact that only three analyses are available. No matter how complicated the relations between Ti, Al_Z, Al_M, Fe^{+++} and Na are, it appears that Al_2O_3 and TiO_2 behave sympathetically, except when a decrease in total Al is combined with an increase in Al_Z, or an increase in total Al is combined with a decrease in Al_Z. These combinations are relatively frequent in the bronzites, but seldom in the augites.

The evidence on magma type from the pyroxene compositions consistently shows oceanic affinities, whereas the evidence from whole rock analyses shows oceanic affinities in a TiO_2-K_2O-P_2O_5 diagram, but plots in the field of within-plate basalts or the field of volcanic arc basalts in a F_1-F_2 diagram.

Acknowledgement. Thanks are due to the Danish Natural Science Research Council for providing the electron microprobe facilities.

Dansk sammendrag

Pyroxenerne fra en lavabænk fra hver af de tre lavaserier på Færøerne er blevet analyseret med mikrosonde. Lavabænken fra den nedre serie har augit som eneste pyroxen. Bænken fra mellemste serie har bronzit som strøkorn og augit og pigeonit i grundmassen. Bænken fra øvre serie har augit og pigeonit, pigeonit findes dog ikke ved kontakten, men dukker op et par meter fra kontakten og tiltager indefter i bænken.

Bjergartsanalyser af de undersøgte prøver er vist i tabel 1, og analyser af pyroxenerne er vist i tabel 3 og 4. Foruden de 30 analyser i tabellerne er resultaterne fra 116 partielle pyroxen-analyser, omfattende Mg, Fe og Ca, benyttet i diagrammerne fig. 2–8. Udviklingen i pyroxenerne svarer stort set til den der kendes fra Skærgårdsintrusionen i Østgrønland, men augiterne i mellemste og øvre serie fra Færøerne er fattigere på calcium, og bronziterne og pigeoniterne er lidt rigere på calcium end de tilsvarende pyroxener fra Skærgårdsintrusionen. Endvidere er udviklingen af augiterne fra kontaktprøverne tydeligt prægede af den hurtige afkøling.

Augiterne er rigere på Al, Ti og Na end bronziter og pigeoniter fra samme prøve. Augiterne er fattigere på Mn end pigeoniterne, men har omtrent samme indhold af Mn som bronziterne.

Indholdet af Mn og Na er ret konstant eller viser en svag stigning med stigende jernindhold. Variationerne i Al og Ti med stigende jernindhold er ret komplicerede, men det er tydeligt at disse to grundstoffer følges ad i udpræget grad i augiterne, men væsentlig mindre udpræget i bronziterne.

F_1-F_2 værdierne (Nisbet & Pearce 1977) svarer dels til det felt, hvor oceanbundsbasalter og pladetholeiter overlapper hinanden, og dels til det felt, hvor oceanbundsbasalter og basalter fra vulkanbuer overlapper hinanden. I et TiO_2-MnO-Na_2O diagram (Nisbet & Pearce 1977) falder Færø-pyroxenerne overvejende i feltet for oceanbundsbasalter, men nogle falder i det felt, der er fælles for alle basalttyperne.

References

Atkins, F.B. 1969: Pyroxenes of the Bushveld intrusion, South Africa. *J. Petrology* 10: 222–249.

Bollingberg, H., Brooks, C.K. & Noe-Nygaard, A. 1975: Trace element variations in Faeroese basalts and their possible relationships to ocean floor spreading history. *Bull. geol. Soc. Denmark* 24: 55–60.

Brooks, C.K. & Jakobsson, S.P. 1974: Petrochemistry of the volcanic rocks of the North Atlantic ridge system. *In* Kristjansson, L. (editor): *Geodynamics of Iceland and the North Atlantic Area* 139–154, (N.A.T.O. Advanced Study Institute Series) Reidel: Dordrecht.

Brown, G.M. 1957: Pyroxenes from the early and middle stages of fractionation of the Skaergaard intrusion, East Greenland. *Mineralog. Mag.* 31: 511–543.

Carmichael, I.S.E. 1967: The mineralogy of Thingmuli, a Tertiary volcano in eastern Iceland. *Am. Miner.* 52: 1815–1841.

Coombs, D.S. 1963: Trends and affinities of basaltic magmas and pyroxenes as illustrated on the diopside-olivine-silica diagram. *Min. Soc. Am. Special Paper* 1: 227–250.

Elsdon, R. 1971: Clinopyroxenes from the Upper Layered Series Kap Edvard Holm, East Greenland. *Mineralog. Mag.* 38: 49–57.

Evans, B.W. & Moore, J.G. 1968: Mineralogy as a function of depth in the prehistoric Makaopuhi tholeiitic lava lake, Hawaii. *Contrib. Mineral. Petrol.* 17: 85–115.

Finger, L.W. 1972: The uncertainty in the calculated ferric iron content of a microprobe analysis. *Carnegie Inst. Wash. Yearb.* 71: 600–603.

Hess, H.H. 1949: Chemical composition and optical properties of common clinopyroxenes, Part 1. *Am. Miner.* 34: 621–666.

Himmelberg, G.R. & Ford, A.B. 1976: Pyroxenes of the Dufek intrusion, Antarctica. *J. Petrology* 17: 219–243.

LeBas, M.J. 1962: The role of aluminum in igneous clinopyroxenes with relation to their parentage. *Am. Jour. Sci.* 260: 267–288.

Manson, V. 1967: Geochemistry of basaltic rocks: major elements. *In* Hess, H.H. & Poldervaart, A. (editors): *Basalts* 1: 215–269. Interscience: New York.

McDougall, I. 1961: Optical and chemical studies of pyroxenes in a differentiated Tasmanian dolerite. *Am. Miner.* 46: 661–687.

Nisbet, E.G. & Pearce, J.A. 1977: Clinopyroxene composition in mafic lavas from different tectonic settings. *Contrib. Mineral. Petrol.* 63: 149–160.

Noe-Nygaard, A. 1962: The geology of the Faeroes. *Quart. J. geol. Soc. Lond.* 118: 375–383.

Noe-Nygaard, A. 1966: Chemical composition of tholeiitic basalts from the Wyville-Thompson ridge belt. *Nature* 212: 272–273.

Noe-Nygaard, A. & Rasmussen, J. 1968: Petrology of a 3000 metre sequence of basaltic lavas in the Faeroe Islands. *Lithos* 1: 286–304.

Pearce, J.A. 1976: Statistical analysis of major element patterns in basalts. *J. Petrology* 17: 15–43.

Pearce, T.H., Gorman, B.E. & Birkett, T.C. 1975: The TiO_2-K_2O-P_2O_5 diagram: a method of discriminating between oceanic and non-oceanic basalts. *Earth Planet. Sci. Lett.* 24: 419–426.

Rasmussen, J. & Noe-Nygaard, A. 1969: Beskrivelse til Geologisk Kort over Færøerne. Danmarks geol. Unders. (1), 24, 370 pp. (English edition: Geology of the Faeroe Islands. *Danmarks geol. Unders.* (1), 25: 142 pp.).

Schilling, J.-G. & Noe-Nygaard, A. 1974: Faeroe-Iceland plume: rare-earth evidence. *Earth Planet. Sci. Lett.* 24: 1–14.

Smith, D. & Lindsley, D.H. 1971: Stable and metastable augite crystallization trends in a single basalt flow. *Am. Miner.* 56: 225–233.

Springer, G. 1967: Die Berechnung von Korrekturen für die quantitative Elektronenstrahl-Mikroanalyse. *Fortschr. Mineral.* 45: 103–124.

Sweatman, T.R. & Long, J.V.P. 1969: Quantitative electron-probe microanalysis of rock-forming minerals. *J. Petrology* 10: 332–379.

Walker, K.R., Ware, N.G. & Lovering, J.F. 1973: Compositional variations in the pyroxenes of the differentiated Palisades Sill, New Jersey. *Bull. geol. Soc. Amer.* 84: 89–110.

Watkins, N.D. & Haggerty, S.E. 1967: Primary oxidation variation and petrogenesis in a single lava. *Contrib. Mineral. Petrol.* 15: 251–271.

Yoder, H.S. & Tilley, C.E. 1962: Origin of basalt magmas. *J. Petrology* 3: 342–532.