

CRYSTALLIZATION HISTORY OF SOME POSTMETAMORPHIC DIABASES IN ÅLAND, HÄME AND SATAKUNTA, FINLAND. A THEORETICAL AND EXPERIMENTAL STUDY

HEIKKI MÄKIPÄÄ

MÄKIPÄÄ, HEIKKI 1979: Crystallization history of some post-metamorphic diabases in Åland, Häme and Satakunta, Finland. A theoretical and experimental study. *Bull. Geol. Soc. Finland* 51, 93—124.

The crystallization history of ten diabase dykes from three different sets in southern Finland are described.

The most primitive diabase magma can be derived from partially melted mantle. Evolving these magmas in the crust under different crystallization conditions the relationships between individual dykes can be explained.

The intrusion temperature has been derived to be about 1140—1170 °C and no clear distinction between individual sets can be made.

The results reveal that phenocrysts and megacrysts already were in the magma before intrusion. In the narrow dykes (width less than 3 m) the cooling was so rapid that the phenocrysts had not time enough to reequilibrate.

The mega- and phenocryst concentration in the middle of the dyke is explained by flowage differentiation.

*Heikki Mäkipää*¹: Nordic Volcanological Institute, University of Iceland, Geoscience Building, 101 Reykjavik. Iceland.

CONTENTS

Abstract	93
Introduction	94
General remarks	96
Experiments	96
Mineral composition of the dikes	96
Analytical results	
Åland diabases	
Husö	101
Bergskär, Betesö and Källsholm	101
Häme diabases	
Vehkajärvi	102
Orivesi I, II and III	103

<i>Satakunta diabases</i>	
Kiperjärvenoja	104
Hinnerjoki I and II	105
Discussion	
<i>Chemical compositions</i>	105
<i>Pressure-temperature relations</i>	106
<i>Phase-equilibrium</i>	109
<i>Cooling rate and crystallization history</i>	
Cooling rates	110
Contact phenomena	113
Duration of the solidification	115
Settling of the plagioclase crystals	116
Summary	118
References	119
Appendix 1	121
Appendix 2	122
Appendix 3	124

¹ Present address: Geological Survey of Finland
Box 237, SF-70101 Kuopio 10

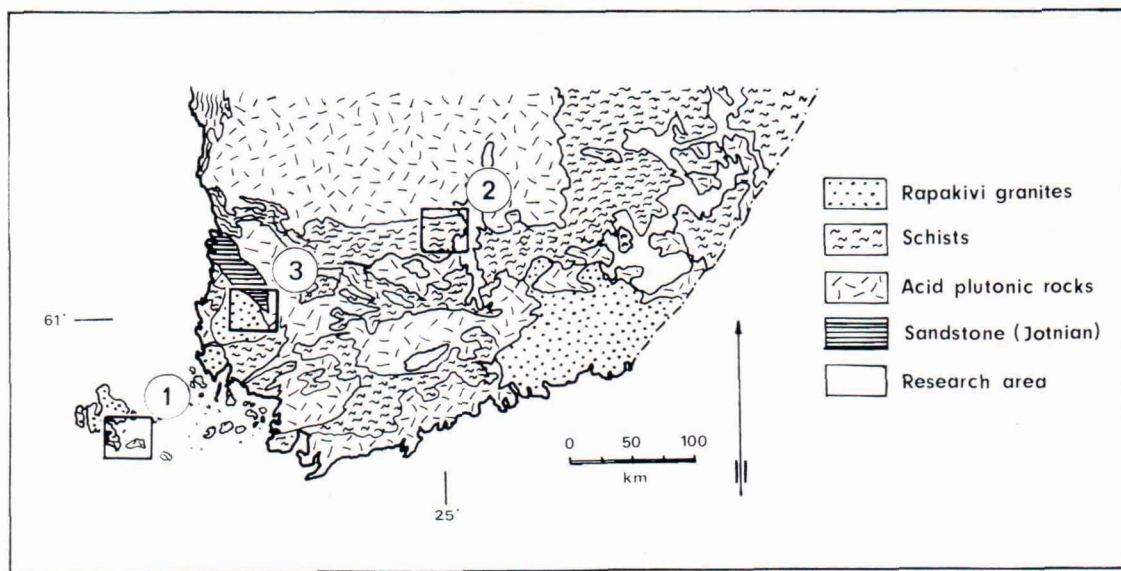


Fig. 1. Location of studied diabase sets and the bedrock of southern Finland (simplified after A. Simonsen 1959). 1 — Åland diabase set, 2 — Häme diabase set, 3 — Satakunta diabase set.

Introduction

The present paper describes the crystallization history of three different sets of diabase dykes in southern Finland (Fig. 1). The dykes are much younger than the last metamorphism in southern Finland, which took place about 1900 Ma ago. According to Ehlers and Ehlers (1977) the diabases of Åland archipelago are of the same age as the Åland rapakivi granite (1650 Ma according to Vaasjoki 1978). According to Laitakari, I. (1969) the

Häme diabase dykes are of the same age, while Satakunta diabases are much younger, about 1260 Ma (Haapala 1977). The alteration found in these dykes is a slight weathering near the margins, the occurrence of secondary minerals is scarce.

A general view of the geology of Åland area is presented by Sederholm (1934). The diabases are recently described by Ehlers and Ehlers (1977). All sites of collected samples are located east of the rapakivi area. The nearest dyke, Källsholm, is about 11 km from

Table 1. Localities and widths of the studied diabase dykes.

Diabase set	Map sheet ¹	Coordinates ¹	Name of locality	Width (m)
Åland	101411	6661.78—490.42	Bergskär	4.60
	101411	6661.70—490.12	Husö	0.17
	101408	6662.92—483.87	Betesö	1.00
	101404	6659.20—479.40	Källsholm	> 100
Häme	214205	6840.10—514.86	Orivesi I	0.26
	214204	6839.74—514.38	Orivesi II	1.20
	214204	6837.22—511.40	Orivesi III	5.10
	214303	6822.40—544.75	Vehkajärvi	3.10
Satakunta	113306	6765.26—553.86	Hinnerjoki I	0.25
	113306	6765.26—553.86	Hinnerjoki II	0.60
	113407	6874.18—562.00	Kiperjärvenoja	> 60

¹ Map sheet numbers and coordinates refer to the Finnish basic map system.

the rapakivi contact. The dykes form sharp, sometimes wriggling, contacts with the gneissic granodiorite country rock.

The width of the studied dykes (Table 1) varies from 17 cm to over 100 m. Husö dyke (Fig. 2) is the narrowest one, and it contains large plagioclase megacrysts (~ 1 cm) in the middle.

The Häme diabase set is about 150 km long and 20 km wide. According to Laitakari, I. (1966, 1969), more than one hundred individual dykes have been so far found in the area. The size of the dykes varies but most of them are 5–50 m wide and several kilometres long.

The Vehkajärvi dyke (Fig. 3) is situated in the middle of the diabase set and is only 3.1 m wide. It is ideally exposed in a road cutting. The diabase contains in the middle of the dyke large (up to 10 cm) white plagioclase megacrysts.

The Satakunta diabase set was studied intensively in the beginning of this century



Fig. 3. A general view of the 3.1 m wide diabase dyke in Vehkajärvi, Häme. Note the zone of megacrysts on the left of the hammer.

(e.g., Sederholm, 1911; Laitakari, A., 1925, 1928). It is about 100 km long and 50 km wide. The width of the dykes varies from centimetres to several hundred metres.

One sample set is collected in the northern end of the Lake Pyhäjärvi at Kiperjärvenoja. The Kiperjärvenoja diabase forms an wriggling contact with Jotnian sandstone. The contact zone is well exposed in an about 3–10 m deep drainage channel of Lake Kiperjärvi. The samples were collected beginning from the contact and extending 60 m into the dyke. The minerals found as phenocrysts or megacrysts are plagioclase and occasional completely altered olivine. The contact phenomena are described by Laitakari, A. (1925) and Kahma (1951).

The purpose of this paper is to answer the following questions: What is the origin of the diabase magma and can all the dykes be derived from the same parental magma? Is there a genetic relationship between the diabase magma and the associated rapakivis? Is the diabase dyke chemistry affected by melted country rock? How fast did the dykes cool? To answer these questions the temperature of the intruding magma and the equilibrium between liquids and crystals must be established.

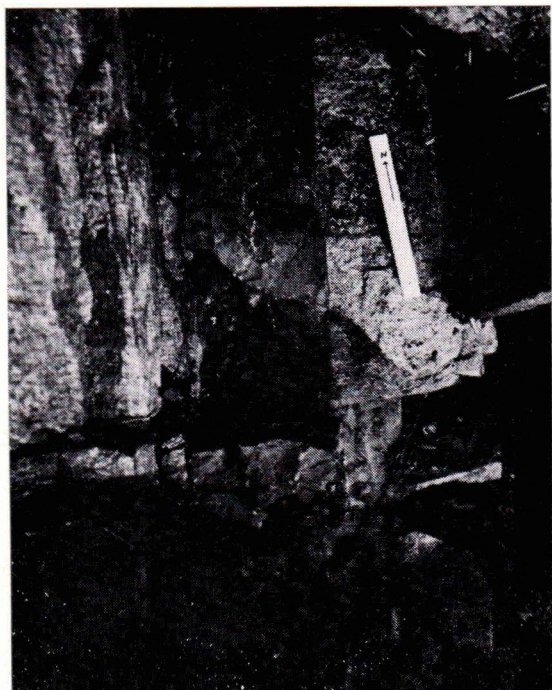


Fig. 2. Diabase dyke in Husö, Sottunga, Åland. Width 17 cm.

General remarks

Table 1 gives the locations of the studied dykes. Their width is given in smaller dykes with great accuracy but in the largest ones only approximately according to field observations. The length of the dykes is always uncertain, owing the scarcity of the outcrops, but it can vary from hundreds to several thousand metres.

All analyses were carried out on an automatic ARL-SEMQ microprobe and the analytical procedures are described e.g. by Mäkipää (1978a). The $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio is calculated using $\text{Fe}_2\text{O}_3/\text{FeO}-f_{\text{O}_2}$ relation (Mäkipää 1979).

According to the classification of Irvine & Baragar (1971) all the rocks are quartz or olivine normative tholeiites.

Experiments

Several experimental runs were conducted at 1 atm using the vertical quench furnace to test the cooling rates of the dykes. Also the contamination of the wall rock was studied using the method described by Yoder (1973). However, all the experiments were carried out under dry conditions.

All the cooling rate experiments were performed using one dyke material of each studied diabase set. The powdered sample

was suspended in a Pt loop at about 1200°C for 1 hour. The temperature, which is substantially higher than the liquidus of the dikes, was then decreased continuously and the rate of the cooling was varied between 2°C/h and 300°C/h . The cooling rate was then correlated with the width of the plagioclase (010) pinacoid.

For miscibility tests of basalt and country rock the same dyke materials were used. The platinum tubes, which were presaturated with the same material, were packed end-to-end by powdered material of the dyke and powdered or solid rock of the country rock in question.

The capsule was then suspended horizontally into the furnace at 1200°C for one to several hours depending on the width of the natural dike. Then the temperature was decreased gradually at different speeds below the solidus. The products were then analyzed on the microprobe.

Mineral composition of the dykes

The observed crystals were divided into four categories depending on size. All the dykes contain (1) megacrysts (including cognate crystals as well as fragments) ranging from several centimetres up to 30 centimetres along the longest axis. Phenocrysts (2) are usually 0.5–0.2 mm long. Some dykes contain

Table 2. Partial mineral composition of the studied diabases. (Determined by the point-counting method). Pl-plagioclase, Ol-olivine, Px-pyroxene, Amph-amphipole Biot-biotite, Opaq-opaque, Qz-quartz

Dike	Pl	Ol	Px	Amph	Biot	Opaq.	Qz	Acces.
Husö	49.1					9.0	4.9	
Betesö	36.1			52.4		4.4		7.1
Källsholm	53.6		32.8			7.2	6.1	0.3
Orivesi I	55.3	5.0						
Orivesi II	47.3	9.7	20.0			12.1		
Orivesi III	56.8	7.6	13.6		3.5	13.3		5.2
Vehkajärvi	61.9	3.1	11.8			9.9		
Hinnerjoki	56.1		19.5			6.4		
Kiperjärvenoja	58.7	15.6	11.1		2.7	6.9		5.0

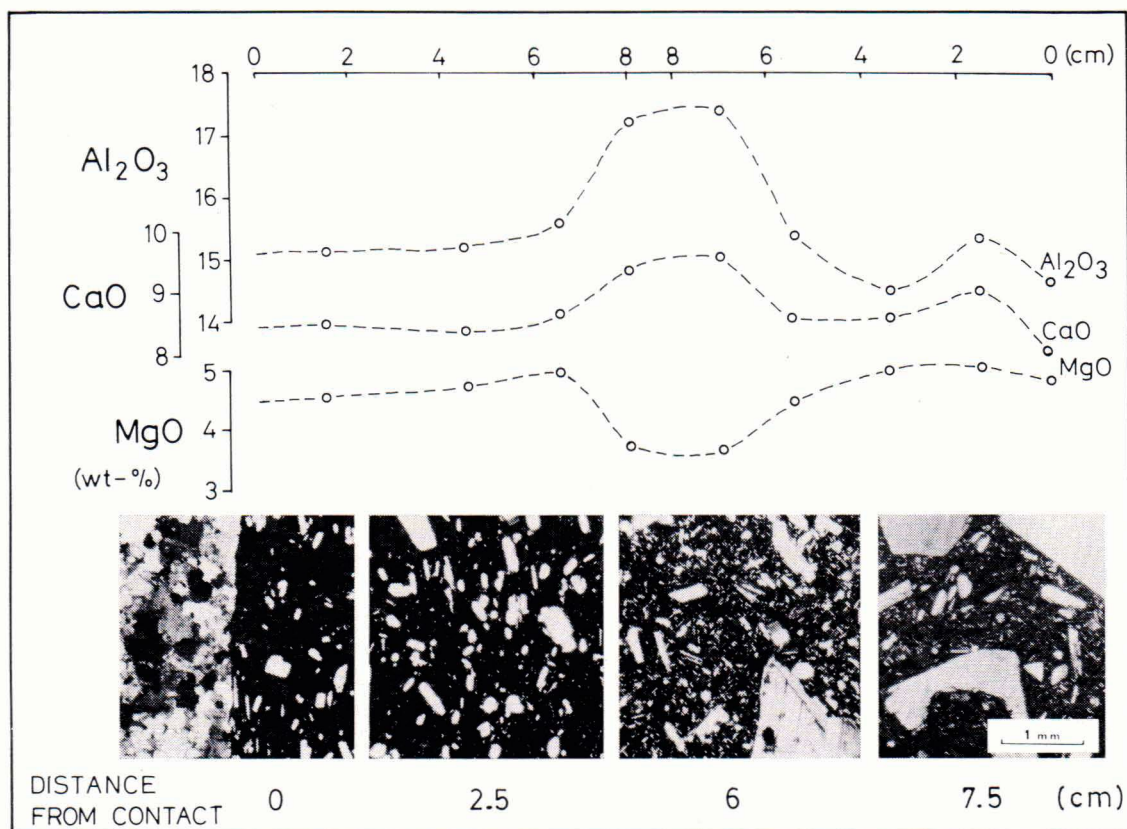


Fig. 4. Al_2O_3 , CaO and MgO variation (total analyses) and the variation of the grain size of the dyke in Husö, Sottunga, Åland. The numbers given below the photos refer to the distances from the contact. The scale is the same in all the photos.

also microphenocrysts (3) which are slightly larger than the groundmass minerals (4).

The partial modal compositions of the studied dykes are given in Table 2. Because of the narrowness of some dykes the groundmass was so glassy that the counting of the minerals was impossible, and therefore Table 2 gives rather the first primary phenocrysts found. The principal mineral is plagioclase, which comprises about 50 % of the total volume of the rocks.

The diabases of the Åland area have variable mineral composition. Källsholm dyke is a pyroxene diabase while Husö, Betesö and Bergskär dykes are amphibole diabases. Amphibole is the dominant mineral. It is partially a secondary product. The few

observed olivines are altered to opaque and serpentine, plagioclases to chlorite and epidote etc. This means that these three dykes, which are much older than the Källsholm dyke (V. Suominen, pers. comm.), have undergone a slight metamorphism. However, the contacts are still glassy and not recrystallized. In contrast the Källsholm diabase is rather fresh, although some secondary chlorite and amphibole occur.

The Häme and Satakunta diabases are olivine diabases. The dominant mineral is plagioclase, olivine occurs as idiomorphic grains sometimes with serpentine as alteration product. However, the occurrence of secondary minerals is very rare.

Table 3. Chemical composition and CIPW norms of the diabase studied dykes and some closely related rocks. Microprobe analyses.

Diabase set		ÅLAND								HÄME							
Dyke		Husö		Bergskär		Betesö		Källsholm		Orivesi I		Orivesi II		Orivesi III		Vehkajärvi	
Column No.		1	2	1	2	1	2 ¹	1	2	1	2	1	2 ²	1	2	1	2
SiO ₂		53.90	53.42	53.51	54.58	49.08	47.61	52.21	51.22	49.61	49.94	50.86	50.92	47.62	49.24	51.41	51.32
TiO ₂		1.87	1.75	1.53	1.57	1.10	0.91	1.71	1.62	2.43	2.74	2.38	2.58	3.51	2.68	3.01	2.56
Al ₂ O ₃		15.33	13.74	14.69	13.33	15.25	13.61	15.92	16.00	18.23	15.33	14.68	16.48	14.93	15.41	14.71	15.42
Fe ₂ O ₃		3.29	3.35	3.58	3.68	2.52	1.32	3.20	3.58	3.88	3.68	4.11	2.40	3.85	3.22	3.55	3.81
FeO		9.05	9.91	9.87	8.61	10.21	10.92	10.08	9.87	8.49	9.34	10.41	11.65	12.15	9.94	10.43	8.42
MnO		0.15	0.21	0.16	0.18	0.13	0.27	0.15	0.13	0.12	0.20	0.18	0.10	0.15	0.17	0.16	0.18
MgO		4.63	4.80	5.37	4.51	7.97	10.97	4.75	5.50	3.55	4.00	4.02	5.12	4.72	4.25	3.88	3.27
CaO		8.05	8.05	7.42	8.52	9.28	10.06	7.41	7.60	8.59	7.62	8.02	5.98	8.16	7.43	6.85	7.30
Na ₂ O		2.30	2.37	2.50	2.48	2.48	2.62	2.76	2.61	2.85	2.90	2.30	2.52	2.65	3.01	2.57	3.36
K ₂ O		0.97	0.93	0.78	1.11	1.32	1.26	1.46	1.52	1.82	1.78	2.16	1.51	1.74	2.04	2.23	1.99
P ₂ O ₅		0.48	0.43	0.45	0.39	0.27	0.40	0.43	0.60	0.49	0.76	0.64	0.78	0.76	0.73	0.88	0.84
Total		100.02	98.96	99.86	98.96	99.61	100.02	100.08	100.26	100.06	98.29	99.76	100.04	100.25	98.12	99.68	98.47
No. of anal.		12	154	10	14	6	18	10	10	12	16	11	8	9	10	14	109
CIPW norms (recalculated to 100 %)																	
Qz		10.72	9.91	9.05	11.19	—	—	4.31	2.99	1.53	3.65	4.98	5.25	—	0.58	6.05	4.32
Or		5.73	5.55	4.62	6.63	7.83	7.44	8.62	8.96	10.75	10.70	12.79	8.95	10.26	12.29	13.22	11.94
Ab		19.46	20.27	21.18	21.21	21.07	16.76	23.34	22.03	24.10	24.97	19.51	21.31	22.37	25.96	21.82	28.87
An		28.63	24.36	26.60	22.19	26.68	21.34	26.72	27.38	31.56	23.96	23.41	24.56	23.67	22.94	22.09	21.44
Di	Wo	3.41	5.49	3.06	7.49	7.42	10.83	3.01	2.64	3.27	3.94	5.13	—	4.92	4.08	2.60	4.08
	En	1.70	2.60	1.52	3.78	4.06	6.24	1.40	1.33	1.63	1.94	2.31	—	2.26	1.93	1.18	1.97
Hy	Fs	1.64	2.82	1.47	3.54	3.09	4.10	1.58	1.24	1.58	1.93	2.79	—	2.62	2.09	1.41	2.04
	En	9.83	9.48	11.87	7.57	6.40	—	10.42	12.33	7.21	8.20	7.73	12.75	8.62	8.86	8.52	6.30
Ol	Fs	9.46	10.25	11.48	7.08	4.87	—	11.74	11.46	7.01	8.20	9.36	15.33	9.98	9.61	10.18	6.51
	Fo	—	—	—	—	6.63	14.77	—	—	—	—	—	—	0.60	—	—	—
Mt	Fa	—	—	—	—	5.56	10.70	—	—	—	—	—	—	0.76	—	—	—
		4.76	4.91	5.20	5.39	3.67	1.92	4.63	5.18	5.62	5.43	5.98	3.48	5.57	4.76	5.16	5.61
Il		3.55	3.36	2.91	3.01	2.10	1.73	3.24	3.07	4.61	5.29	4.53	4.90	6.65	5.19	5.73	4.94
Ap		1.11	1.01	1.04	0.91	0.63	0.93	0.10	1.39	1.13	1.79	1.49	1.81	1.76	1.72	2.05	1.98

Table 3 (continued)

Diabase set					SATAKUNTA					SOME CLOSELY RELATED ROCKS					
Dyke		Kiperjärvenojo		Hinnerjoki											
Column	No.	1	2	1	2 ³	3	4	5	6	7	8 ⁴				
SiO ₂		47.45	47.89	47.38	47.06	52.69	46.20	47.73	48.84	51.46	47.36				
TiO ₂		2.91	2.59	2.75	2.46	1.14	1.90	1.96	3.78	1.95	1.00				
Al ₂ O ₃		16.99	17.49	18.81	18.39	14.12	17.20	15.06	12.70	15.35	19.70				
Fe ₂ O ₃		3.19	3.11	3.61	2.26	3.32	2.08	4.09	5.12	1.53	0.75				
FeO		10.52	8.56	9.93	8.52	9.49	11.95	10.40	9.47	12.39	10.46				
MnO		0.17	0.10	0.11	0.16	0.22	0.29	0.20	0.19	0.10	0.14				
MgO		5.13	4.90	5.54	4.86	5.53	7.10	4.23	4.32	4.42	8.34				
CaO		8.50	7.10	7.46	6.61	9.86	8.98	10.48	7.26	7.32	8.77				
Na ₂ O		3.07	3.07	2.94	3.09	2.51	2.88	2.74	2.76	2.94	2.68				
K ₂ O		1.37	1.36	1.37	1.04	0.64	0.89	1.46	1.96	1.64	0.63				
P ₂ O ₅		0.56	0.55	0.43	0.37	—	0.01	0.35	1.19	0.79	0.15				
Total		99.86	96.72	100.33	94.82	99.52	99.48	98.70	97.59	99.87	99.98				
No of anal.		10	15	8	14										
CIPW norms (recalculated to 100 %)															
Qz		—	0.11	—		5.36	—	—	6.02	1.23	—				
Or		8.05	8.31	8.07		3.80	5.29	8.74	11.87	9.70	3.72				
Ab		26.02	26.86	24.80		21.34	22.17	23.49	23.93	24.91	22.68				
An		28.60	30.94	33.97		25.49	31.54	24.80	16.88	23.87	39.87				
Di	{Wo	4.16	0.74	0.05		9.88	5.50	10.64	5.03	3.06	1.11				
	{En	2.08	0.41	0.03		4.94	2.70	4.77	2.87	1.16	0.59				
	{Fs	1.99	0.30	0.02		4.73	2.70	5.82	1.94	1.94	0.49				
Hy	{En	4.32	12.21	7.60		8.90	—	2.46	8.15	9.86	2.35				
	{Fs	4.12	9.07	6.02		8.54	—	3.00	5.51	16.50	1.95				
Ol	{Fo	4.48	—	4.29		—	10.56	2.41	—	—	12.50				
	{Fa	4.71	—	3.74		—	11.60	3.24	—	—	11.40				
Mt		4.63	4.66	5.21		4.84	3.03	6.01	7.61	2.22	1.09				
Il		5.53	5.09	5.21		2.18	3.63	3.77	7.36	3.71	1.90				
Ap		1.30	1.32	0.99		—	0.02	0.84	2.83	1.83	0.35				

COLUMNS:

1. Mean composition of the dyke.
 2. Average groundmass analysis.
 3. High Fe₂O₃ quartz normative dolerite (Weigand & Ragland, 1970).⁵
 4. Olivine diabase, Sorkka, Rauma (Kahma 1951). The total in the original paper is 100.72, containing 1.24 % H₂O^t.
 5. Olivine diabase, Suontaka, Laitila (Kahma, 1951). The total is in the original paper 100.15, containing 1.45 % H₂O^t.
 6. Quartz diabase, Möykynsaari, Lake Ladoga (Lokka, 1934). The total is in the original paper 100.27, containing 2.68 % H₂O^t.
 7. Quartz diabase, Kelesjärvi, Jaala (Savolahti, 1956). The total is in the original paper 100.47, containing 0.60 % H₂O^t.
 8. Olivine diabase, Ansio, Padasjoki (Savolahti, 1964). The total is in the original paper 100.44, containing 0.46 % H₂O^t.
- ¹ 3.25 % Ne in the norm.
² 1.69 % Co in the norm.
³ Norm is not calculated because of the low total.
⁴ 1.26 % Ne in the norm.
⁵ In the original paper total Fe reported as Fe₂O₃, ratio calculated using the method described in Appendix 1.

Table 4. Microprobe analyses of plagioclases, Husö, dyke, Åland.

	megacrysts					phenocrysts					groundmass plagioclase					
SiO ₂	58.98	54.53	53.57	55.03	53.95	54.28	56.12	54.48	53.66	55.21	54.30	52.24	55.26	53.67	53.39	54.20
Al ₂ O ₃	25.80	28.17	28.71	28.12	28.19	27.67	27.26	28.20	28.52	27.47	27.91	28.27	27.52	28.01	28.25	27.51
FeO ^t	.30	1.06	1.02	.37	.84	.78	.57	.73	1.12	.74	1.18	1.19	1.18	1.35	1.16	.62
CaO	7.59	10.16	12.05	10.88	11.82	11.21	9.55	11.81	11.98	10.86	11.49	12.26	11.08	11.24	11.95	11.30
Na ₂ O	6.78	5.32	4.64	5.29	4.93	5.20	5.11	4.75	4.65	5.23	4.84	4.40	5.01	5.05	4.53	5.10
K ₂ O	.62	.09	.17	.29	.10	.22	.59	.12	.19	.19	.18	.15	.18	.13	.16	.17
Total	100.07	99.33	100.16	99.98	99.93	99.36	99.20	100.09	100.12	99.70	99.90	98.51	100.23	99.45	99.44	98.90
An (mole-%)	36.8	51.3	58.4	52.3	57.0	54.4	49.0	57.5	58.1	53.4	56.8	60.1	55.0	55.2	59.3	54.5
No of anal.	4	2	3	3	4	8	2	4	4	4	5	3	4	6	2	7
Dist. from cont. (mm)	90	90	90	75	75	10	33	33	80	30	30	15	90	75	50	20
Calculated density	2.598	2.622	2.635	2.624	2.633	2.628	2.618	2.633	2.634	2.626	2.633	2.638	2.628	2.629	2.637	2.628
Notes	same crystal core → rim ← 4 mm →					same crystal core → rim ← 2 mm →		same crystal core → rim			same crystal core → rim					

Table 5. Microprobe analyses of plagioclases, Vehkajärvi dyke.

	megacrysts					phenocrysts					groundmass plagioclase						
SiO ₂	54.81	54.85	54.92	55.27	58.03	53.30	53.82	54.32	54.41	55.11	54.78	53.40	55.03	55.61	55.20	58.22	
Al ₂ O ₃	28.54	28.84	28.73	28.61	26.12	29.62	29.48	28.31	28.19	28.16	28.35	29.40	28.14	27.81	27.59	26.17	
FeO ^t	.39	.35	.43	.33	.77	.61	.66	.57	.73	.82	.48	.75	.54	.85	.82	.54	
CaO	11.12	10.73	10.67	10.69	7.66	11.83	11.13	10.80	11.33	10.28	10.55	11.24	10.48	10.38	9.94	8.12	
Na ₂ O	4.86	4.78	4.87	4.91	6.12	4.32	4.52	4.65	4.76	5.17	5.11	4.79	4.99	5.14	5.18	6.61	
K ₂ O	.66	.69	.64	.58	1.31	.49	.55	.67	.60	.65	.60	.52	.77	.68	.65	.60	
Total	100.38	100.24	100.28	100.39	100.00	100.17	100.16	99.32	100.02	100.19	99.87	100.10	99.95	100.47	99.38	100.26	
An (mole-%)	55.8	55.4	54.7	54.6	40.9	60.2	57.6	56.2	55.8	52.3	53.3	56.4	53.7	52.7	51.5	40.4	
No of anal.	2	2	2	2	2	4	2	4	4	2	2	6	3	3	2	2	
Dist. from cont. (cm)	152	152	152	152	152	0.1	0.1	1	34	50	152	0.1	35	50	152	152	
Calculated density	2.631	→ 2.628				2.603	2.638	2.633	2.632	2.631	2.625	2.627	2.632	2.627	2.626	2.623	2.603
Notes	core $\xrightarrow{\text{same crystal}}$ rim $\xleftarrow{\text{2 cm}}$					same crystal core $\xrightarrow{\hspace{1cm}}$ rim $\xleftarrow{\hspace{1cm}}$ 0.5 cm $\xrightarrow{\hspace{1cm}}$					core			same crystal core $\xrightarrow{\hspace{1cm}}$ rim $\xleftarrow{\hspace{1cm}}$ 0.01 cm $\xrightarrow{\hspace{1cm}}$			

Table 6. Microprobe analyses of plagioclases, Kiperjärvenojäa dyke, Satakunta.

	megacrysts			phenocrysts			groundmass plagioclase									
	51.23	56.76	50.41	51.49	50.89	58.91	51.95	51.52	57.30	50.61	51.93	51.70	53.40	55.09	56.88	
SiO ₂	30.57	26.58	30.48	30.72	30.57	25.06	30.39	30.75	26.70	20.71	29.53	29.87	28.10	27.26	25.62	
Al ₂ O ₃	.62	.37	.41	1.10	.61	.27	.44	.52	.91	.68	.60	.66	1.01	1.36	1.60	
FeO ^t	13.59	9.10	13.97	12.42	13.20	7.57	13.40	13.34	9.03	13.02	12.04	12.06	10.61	9.82	8.83	
CaO	3.90	6.80	4.10	4.12	3.67	7.07	3.78	3.64	6.32	4.08	4.96	5.21	5.81	6.31	6.55	
Na ₂ O	.24	.32	.26	.34	.25	.34	.20	.20	.33	.27	.40	.17	.30	.28	.33	
K ₂ O	100.15	99.93	99.63	100.19	99.19	99.21	100.15	100.17	100.58	99.37	99.46	99.67	99.23	100.12	99.81	
Total	65.8	42.0	65.3	62.5	66.5	37.2	66.2	67.3	44.1	63.7	57.3	56.1	50.2	46.2	42.7	
An (mole-%)	2	3	2	2	4	2	3	2	3	4	2	4	6	2	4	
No of anal.	6	6	10	10	10	10	400	400	30	30	400	400	600	600	300	
Dist. from cont. (cm)	2.648	2.605	2.647	2.642	2.649	2.597	2.649	2.650	2.605	2.643	2.633	2.632	2.620	2.613	2.606	
Calculated density																
Notes	same crystal core → rim ← 1 mm → same crystal core → rim															

Analytical results

Åland diabases

Husö

The mean chemical composition of the dyke is that of a quartz normative tholeiite (Table 3). However, the composition of the individual samples through the whole dyke varies considerably (Fig. 4 and Appendix 1). Due to the strong plagioclase concentration (40 %) samples near the center of the dyke show marked increase in CaO, Al₂O₃ and Na₂O, while MgO, FeO^t and TiO₂ decrease.

Composition of groundmass through the whole dyke shows variation only (Fig. 5) at the contacts, which will be discussed later. The analyses are given in Appendix 2.

The plagioclase composition is given in Table 4. Some of the megacrysts (An₃₈₋₅₃) are extremely homogeneous while others show strong compositional zoning. The large megacrysts usually have an inner and outer rim of An₅₀₋₅₃ and An₅₄₋₅₉, respectively.

Plagioclase phenocrysts (An₄₈₋₅₄) are homogeneous with a very thin reaction rim, An₅₄₋₅₉. The groundmass is wholly glassy about 8 mm from the contacts. The groundmass plagioclases (An₅₅₋₆₀) in the inner part of the dyke are extremely homogeneous laths.

Iron sulfides occur in 1–2 mm wide zones about 5 mm from the contacts. The concentration of sulfides in these zones is extremely high, up to 30 vol. %.

Bergskär, Betesö and Källsholm

The composition of the dykes are given in Table 3. The composition of individual dykes is very homogeneous except in the Källsholm dyke where variation can be observed.

The composition of Bergskär plagioclase phenocrysts and matrix plagioclases are An₅₂₋₅₃ (rim An₅₄₋₅₆) and An₅₃₋₅₉, respectively.

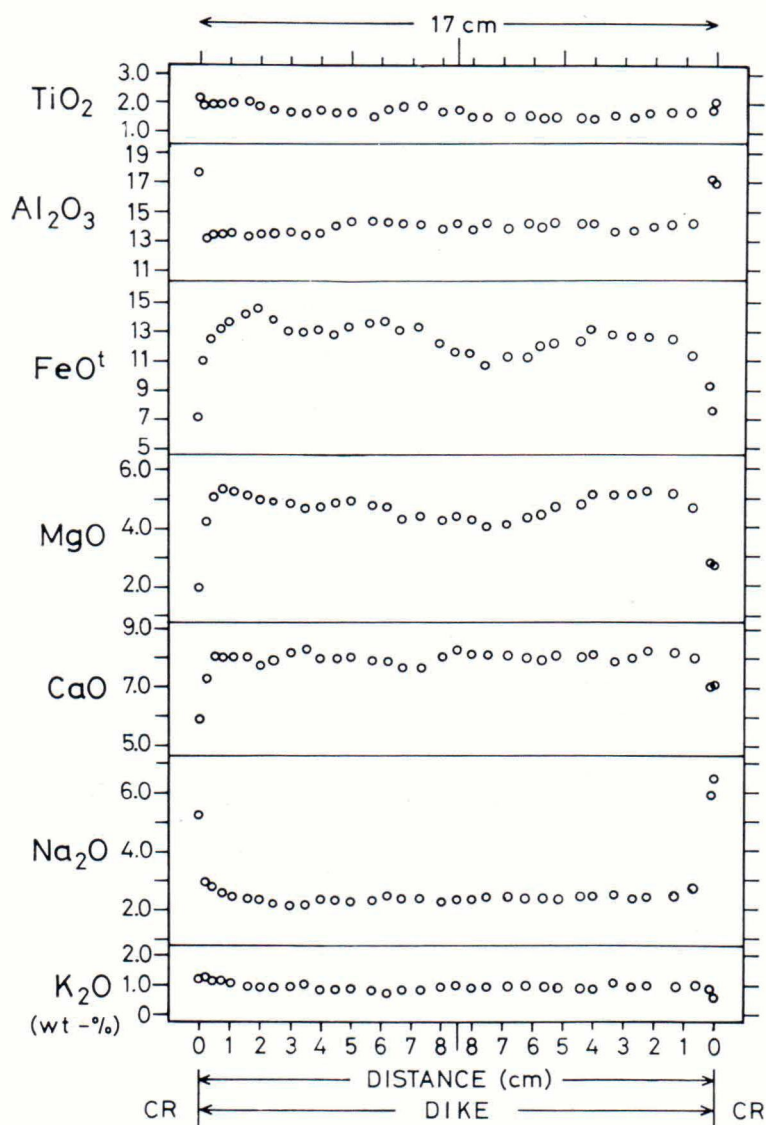


Fig 5. The groundmass chemistry variation (major elements) through the diabase dyke in Husö, Sot-tunga, Åland. Each circle is an average of many spot analyses given in Appendix 2. CR — country rock.

The corresponding values are An₃₅₋₄₅ (rim An₂₅₋₄₀), An₃₄₋₄₇ for Betesö and An₄₈₋₅₅ (rim An₄₅₋₅₅), An₄₇₋₇₇ Källholm plagioclase phenocrysts and matrix plagioclases, respectively. All the plagioclase compositions are tabulated in Appendix 3.

Häme diabases Vehkajärvi

The mean chemical composition of the dyke is that of a quartz normative tholeiite (Table

2). The variation in chemical composition through the dyke (Appendix 1) reflects concentration of plagioclase megacrysts, CaO, Al₂O₃ (Fig. 6) and Na₂O increase towards the middle of the dyke.

The groundmass chemistry (Table 3) is extremely homogenous until the plagioclase megacryst zone. Spot analyses of the groundmass through the whole dyke show strong variation in the megacryst zone (Fig. 7) re-

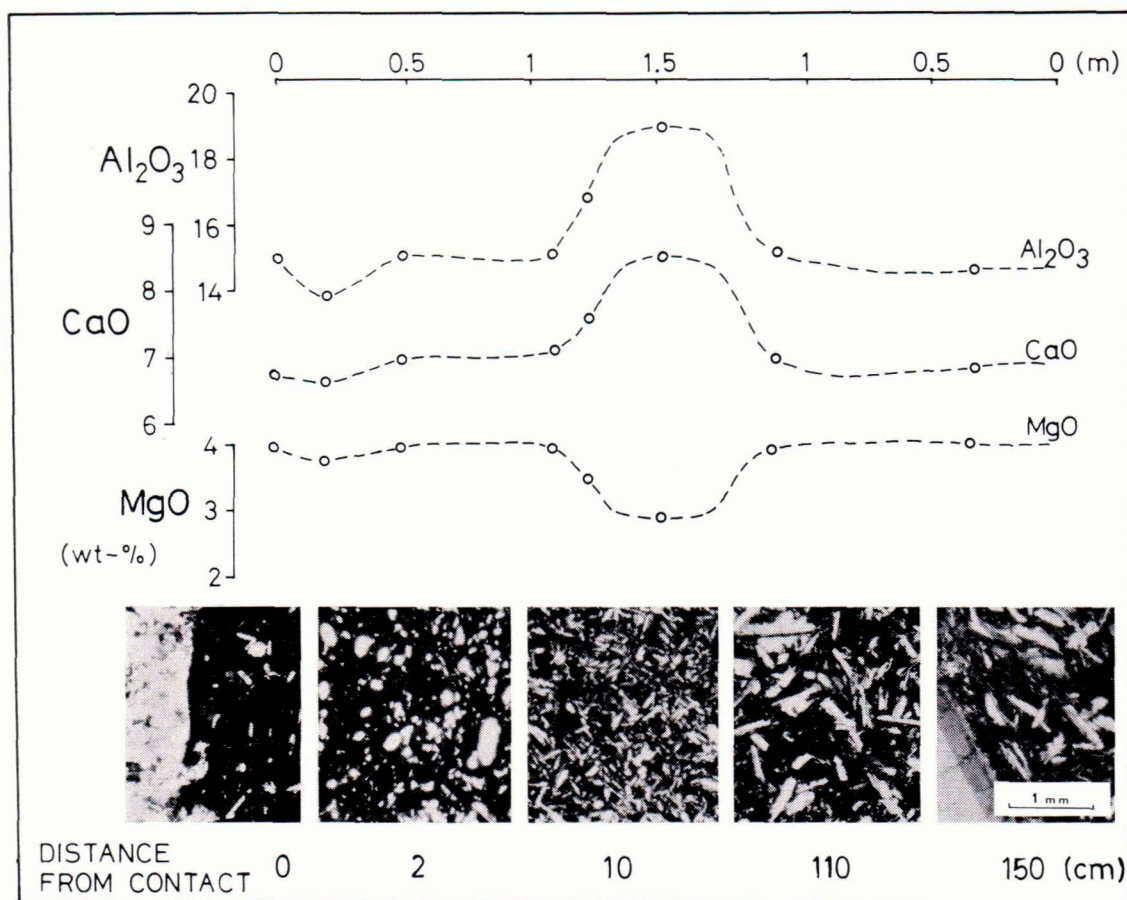


Fig. 6. Al_2O_3 , CaO and MgO variation (total analyses) and the variation of the grain size of the dyke in Vehkajärvi, Häme. The numbers given below the photos refer to the distances from the contact. The scale is the same in all the photos.

flecting intense reaction between the megacrysts and the groundmass.

The plagioclase composition is given in Table 5. The large megacrysts are extremely homogenous (An_{55-58}) with a rim of An_{40-42} . The crystallization of these 0.1 mm wide zones have caused significant in situ differentiation.

Plagioclase phenocrysts (An_{56-60}) are occasionally zoned with a thin reaction zone of An_{50-53} . The groundmass is wholly glassy to about 5 mm from the contact. The matrix plagioclase composition is usually An_{52-56} but in the megacryst zone the composition is variable down to An_{40} .

Orivesi I, II and III

The chemical composition of individual dykes is not the same (Table 3). Therefore it is assumed that they do not represent the same magmatic event.

The chemical composition through individual dykes is very constant and the dykes characteristically contain large plagioclase megacrysts (largest 10 cm). Phenocrysts are plagioclase and occasionally pyroxenes which are frequently altered. Olivine is very rare.

The composition of plagioclase phenocrysts and matrix plagioclases is An_{54-65} and

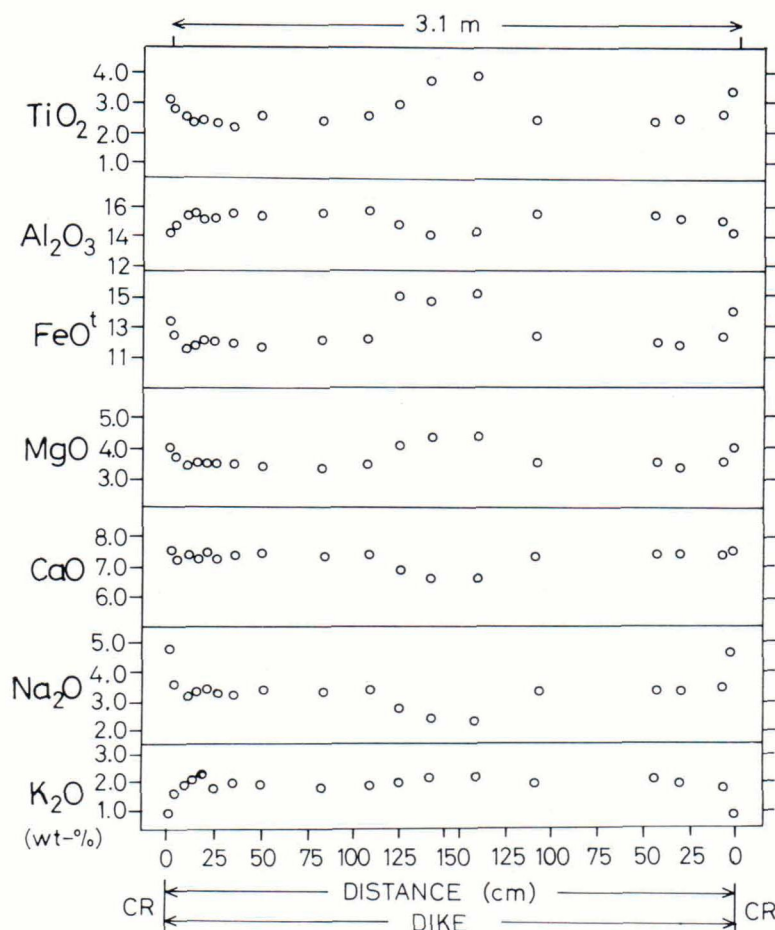


Fig. 7. The groundmass chemistry variation (major elements) through the diabase dyke in Vehkajärvi, Häme. Each circle is an average of many spot analyses given in Appendix 2. CR — country rock.

An₅₁₋₆₀, respectively. The plagioclase compositions of individual dykes are tabulated in Appendix 4.

Satakunta diabases Kiperjärvenoja

The mean composition of the dyke is quartz normative tholeiite (Table 3). Total chemical composition through the dyke shows variation (Appendix 1 and Fig. 8). Whether this is caused by a heterogeneous magma or concentration of phenocrysts, is not clear.

The groundmass analyses performed on the microprobe show no clear variation at the contact one. However, the groundmass is so

coarse-grained that microprobe analyses could only be carried out to about 10 cm from the contact.

Representative analyses of plagioclase phenocrysts are given in Table 6. Their composition at the fine-grained contacts is very homogenous, An₆₆₋₆₈. These crystals (about 0.1–0.3 mm wide) are strongly altered so that the determination of anorthite content in some cases was impossible. The large variation of rim chemistry An₃₅₋₆₇ might be caused by the alteration.

The matrix plagioclase composition is An₄₂₋₆₄ and some slight difference toward the centre of the dyke can be found.

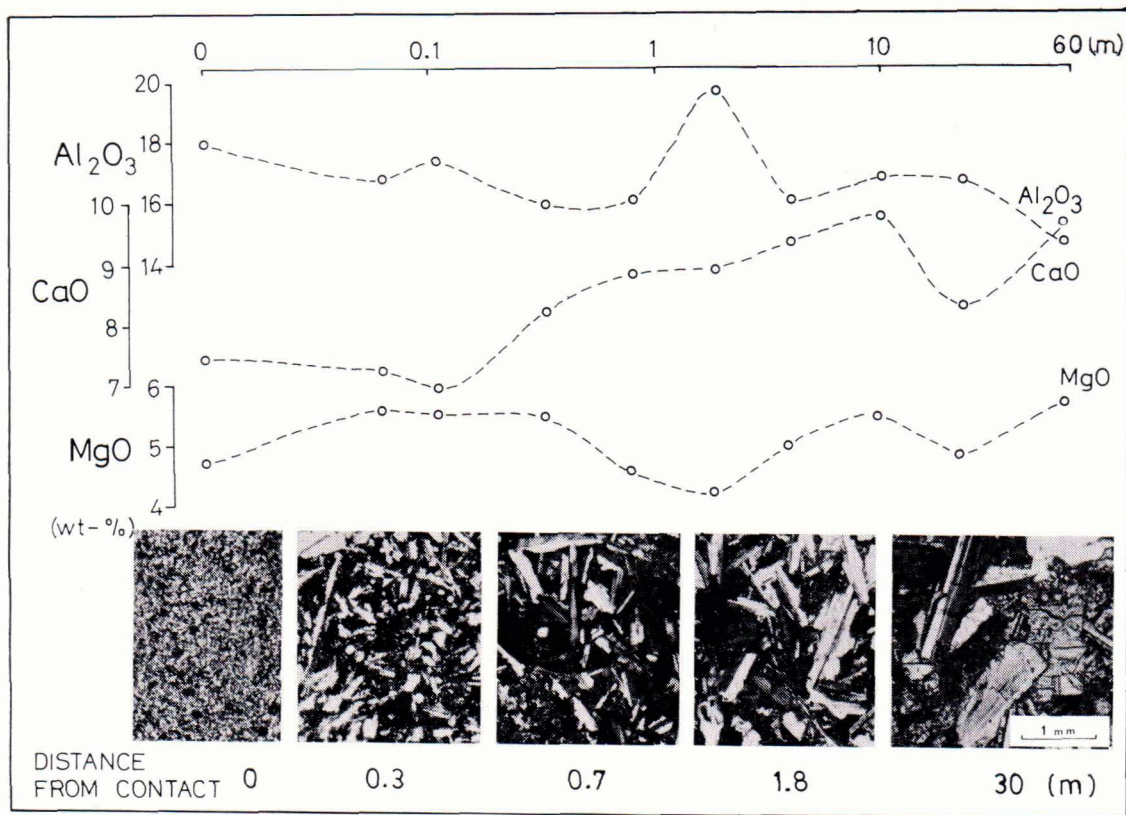


Fig. 8. Al_2O_3 , CaO and MgO variation (total analyses) and the variation of the grain size of the dyke in Kiperjärvenoja, Satakunta. The numbers given below the photos refer to the distances from the contact. The scale is the same in all the photos.

Hinnerjoki I and II

The two sample suites represent the same dyke and show identical composition (Table 3).

The whole dyke is considerably altered. The groundmass through the whole dyke contains very small chlorite grains. The groundmass analyses performed by microprobe gave always the sum of about 94 %. The rest (6 %) is assumed to be volatiles.

However, to get the original magma composition, the chlorites were separated from the material and the powder was melted and further analysed by microprobe. However, the original groundmass analyses show that the chemistry through the dyke is very homogenous. Only slight MgO decrease toward

the centre is observed, but this might be caused by smaller amounts of chlorites.

Discussion

Chemical compositions

Because of the different ages of the dyke sets it is unlikely that the magmas are derived from the same parental liquid. On the MgO-TiO₂ plot (Fig. 9) the different dyke sets plot separately. The Åland diabase set shows a variation trend towards MgO-poorer magma, so that the Husö, Källsholm and Bergskär magmas can be derived from the Betesö magma fractionating 21–24 % plagioclase and 15–17 % olivine. For Satakunta and Häme diabase sets relationships are more complicated.

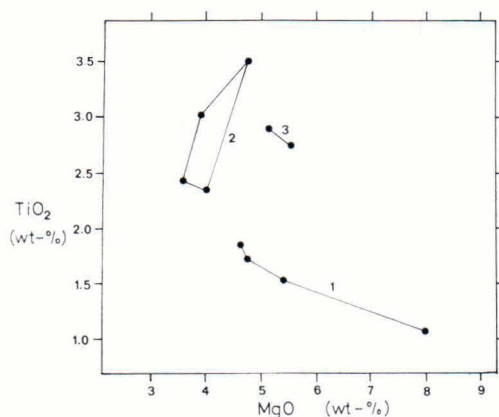


Fig. 9. MgO-TiO₂ variation diagram. 1) Åland set of diabase dykes. 2) Häme set of diabase dykes. 3) Satakunta set of diabase dykes.

To test possible genetic relationships the analyses were plotted on a TiO₂-P₂O₅ diagram in Fig. 10. In addition to the data presented here some more primitive diabases from the same areas were also plotted. These few plotted analyses show that the studied diabases were not derived from the same magma by simple fractionation. All three different groups show reasonable trends. If the most primitive magma in Häme diabase set is similar to the Ansio magma (Table 3), then it follows that deriving most evolved magmas,

Orivesi III and Vehkajärvi, from the same source the differentiation conditions (pressure, temperature and fO₂) must be different, otherwise the separate trends are difficult to explain. This can also be seen on the plagioclase phenocryst compositions. Vehkajärvi and Orivesi II both have plagioclase composition about An₅₅, while Orivesi I and III have An₆₂, which means that the crystallization conditions were different. Thus, from Ansio magma it is feasible to differentiate Orivesi I—Orivesi III and Orivesi II—Vehkajärvi in different ways.

The same holds for Satakunta diabases. We can not fractionate Kiperjärvi from Hinnerjoki, but both can be fractionated from a magma richer in MgO (Sorkka, Table 3). How to get such possible different parental liquids is discussed in the next chapter.

Pressure-temperature relations

The fact that most of the diabase dykes are geographically associated with the rapakivi intrusions does not necessarily mean that they are genetically and chemically related to the rapakivis, as widely has been argued. In some cases when the dikes are of the same age as rapakivi granite, the primary frac-

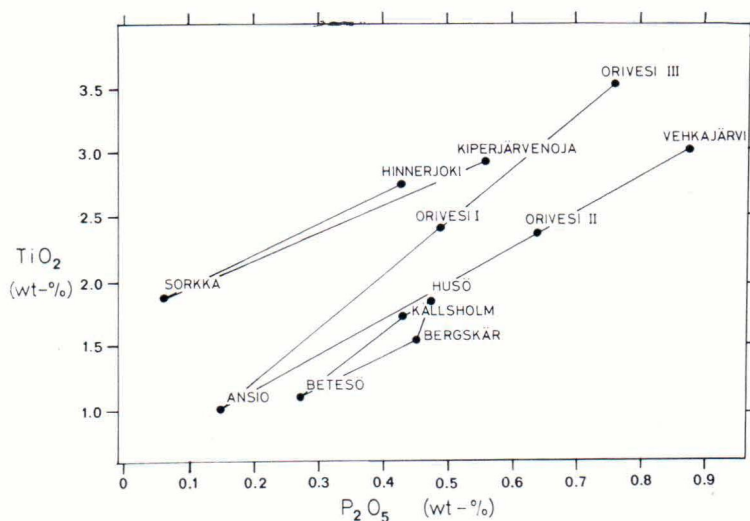


Fig. 10. P₂O₅-TiO₂ variation diagram showing the possible genetical relationships between the studied diabase dykes.

Table 7. Mixing calculations for deriving the Husö magma from partially melted garnet lherzolite.

Composition	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O
1. Garnet lherzolite	44.5	0.3	2.8	10.2	37.9	3.3	0.3	0.1
2. 20 % partial melting	50.3	1.1	12.3	10.4	10.0	12.0	1.5	0.7
3. Betesö magma	49.1	1.1	15.3	12.7	8.0	9.3	2.5	1.3
4. 72 % liquid 3. + 5 % olivine + 23 % clinopyroxene	50.2	1.0	12.2	10.8	10.0	12.2	1.8	0.9
5. Difference 2—4	0.1	0.1	0.1	0.4	0.0	0.2	0.3	0.2
6. Husö magma	53.9	1.9	15.3	12.4	4.6	8.1	2.3	1.0
7. 57 % liquid 6. + 19 % olivine + 24 % plagioclase	49.1	1.1	15.5	12.6	8.0	9.1	2.1	0.7
8. Difference 3—7	0.0	0.0	0.2	0.1	0.0	0.2	0.4	0.6

turing of the country rock is possibly due to the rising of rapakivi magma.

In a model constructed by Vormä (1977) the formation of rapakivi magma is due to the partial melting of the lower crust during the culmination of the svecofenno-karelian orogeny, about 1900—1800 Ma ago. During the first orogenic stages the basaltic magma from the mantle source possibly (discussed later) intruded and stored into the crust (Vormä, 1977).

At the subjotnian time, about 1700—1600 Ma ago, large-scale block movements took place in Fennoscandia (see e.g. Vormä, 1977). During that episode the rapakivi magma rose into the higher levels of the crust, accompanied by volcanic eruptions. The deep fractures and faults formed at the time may have extended into the mantle and at this time the basaltic magma may have erupted and the present diabase dike sets were left in the former conduits.

The parental mantle material of basalts is assumed to be garnet peridotite, which is stable in the upper mantle conditions. According to Kushiro (1973) the partial melting of the garnet lherzolite under the mantle conditions (1475°C, 20 kb) produces a liquid with composition given in Table 7. This liquid represents about 20 % melting of peridotite consisting mainly of pyroxenes and small amounts of olivine components.

The liquid is basaltic in character. Plagioclase can not be observed, because it is not stable at 20 kb. In order that this liquid could yield the most primitive basalt here (Betesö, Åland set) from it must first fractionate ferro-magnesian minerals and the liquid must be separated from the crystals. If the magma arrived into the lower crust during the orogeny, its temperature and pressure decreased, resulting in marked pyroxene and olivine crystallization. The Betesö magma can be derived from the partially melted peridotite (Table 7) by separating about 23 % clinopyroxene and 5 % olivine. The difference between the actual and calculated composition is very small. The more primitive magmas of Ansio (Häme set) and Sorkka (Satakunta set) can be derived in a similar away.

This process may be followed on a An-Di-Fo diagram. Although this diagram is very simple, it can be used to demonstrate pressure and crystallization relationships, see e.g. Pressnall et al. (1978) and Mäkipää (1978b). The extreme members (Betesö-Husö) of the Åland diabase dykes are plotted in Fig. 11. In spite of the paradox that Kushiro's (1973) 20 Kb experimental melted lherzolite does not lie on the 20 Kb cotectic line, the diagram shows the principal direction of crystallization. Assuming the partially melted peridotite to be the parental liquid, clinopyroxene and olivine starts to fractionate at about 20—

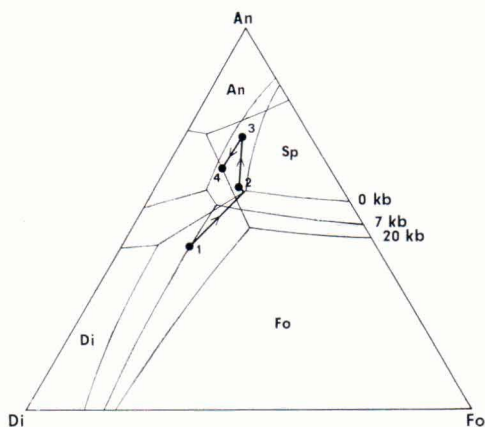


Fig. 11. The equilibrium diagram of the system Anorthite-Diopside-Forsterite. Different pressure lines drawn from Presnall et al. (1978). 1) Garnet lherzolite (Table 7). 2) Betesö magma (Table 3). 3) Husö magma (Table 3). 4) Husö groundmass (Table 3).

25 kb pressure. Separation and ascent into the lower crust would decrease the pressure and the composition of the magma lies within the spinel field. Because the spinel composition MgAl_2O_4 does not lie within the diagram, the fractional crystallization involving spinel cannot be described completely. However, the important feature is that the spinel reacts with the liquid, forming olivine and plagioclase. This part of evolution requires about 24 % plagioclase and 19 % olivine crystallization.

It should be noted that the tie lines in Fig. 11 are only to give the direction of crystallization on the basis of this diagram. During the ascent the pressure decreases and the composition of Husö magma now lies within the plagioclase field. Plagioclase is therefore the only mineral occurring as phenocrysts. As more plagioclase crystallize the composition of the liquid moves towards the cotecticum and finally eutecticum. This can be seen in the widest dykes where the crystallization is complete and the amount of olivine and pyroxene in the groundmass gradually increase towards the centre of the dyke.

The depth of the crystallization of the

matrix cannot be determined accurately. The fact that the magmas at this level are not cotectic, means that all the pressures derived are too high. However, all analyses (except Satakunta diabases) plot around 2 kb line (~ 6 km), which gives the maximum pressure. According to this diagram the Åland diabases represent the deepest erosion level.

The temperature of the magma that intruded into the joints can be estimated by the method described by Mäkipää (1979), and the results are tabulated in Table 8. Because of the very slight crystallization next to the contact, the magma is assumed to be at very near the liquidus temperature at the time of intrusion. The intrusion temperature appears not to be the same in all the dykes of the same set. Again the Vehkajärvi—Orivesi II and Orivesi I—Orivesi III magmas separate by different liquidus temperatures (difference $\sim 25^\circ\text{C}$) as well as different plagioclase equilibrium temperatures. So do also the Kiperjärvenoja and Hinnerjoki dykes. This indicates either lack of equilibrium or different conditions during the earlier evolution of these magmas.

The fact that plagioclase is the only phenocryst mineral in most of the studied dykes, sets a limit to the calculation of the accurate equilibrium temperatures, because the equilibrium depends on the prevailing water pressure. It seems most likely that the water pressure was around 1 kb or less. The results (Table 8) using the Kudo & Weill (1970) and Mathez (1973) plagioclase geothermometer show that the crystallization temperature of the matrix is about 50°C lower than the liquidus. It is noticeable that the phenocryst equilibrium temperatures are similar to the groundmass temperatures. This indicates that the magma was wholly in a liquid form during the arrival into the lower crust, where the phenocryst crystallization took place.

For testing the feasibility of these tem-

Table 8. Liquidus temperatures (calculated using the method described by Mäkipää 1979) and plagioclase equilibrium temperatures for megacryst-groundmass, phenocryst-groundmass and groundmass plagioclase-groundmass pairs.

mc-megacryst, pc-phenocryst, mc_{max} or min and pc_{max} or min refer to the calculated maximum and minimum temperatures, respectively, max or min refers to the groundmass plagioclase-groundmass maximum or minimum temperatures, respectively.

Sample			plagioclase equilibrium temperature					
			Kudo & Weill			Mathez		
			0 kb	1 kb	2 kb	0 kb	1 kb	2 kb
Husö	mc _{max}	1168	1172	1087	1010	1142	1114	1029
	mc _{min}		1081	1001	916	1064	1009	924
	pc _{max}		1173	1088	1003	1142	1115	1030
	pc _{min}		1157	1073	988	1129	1097	1012
	max		1175	1089	1004	1144	1117	1032
	min		1164	1080	995	1135	1105	1020
Bergskär	max	1151	1173	1087	1002	1142	1114	1029
	min		1149	1064	979	1122	1087	1002
Betesö	max	1250	1182	1101	1016	1152	1129	1044
	min		1114	1037	952	1093	1052	1067
Källsholm	max	1159	1226	1141	1052	1189	1177	1097
	min		1188	1105	1020	1156	1134	1049
Vehkajärvi	mc _{max}	1139	1227	1140	1051	1189	1177	1097
	mc _{min}		1158	1075	990	1130	1099	1014
	pc _{max}		1238	1150	1065	1199	1189	1109
	pc _{min}		1213	1126	1041	1177	1160	1080
	max		1228	1141	1052	1190	1178	1098
	min		1156	1073	988	1128	1096	1011
Orivesi I	max	1161	1222	1137	1052	1186	1172	1092
	min		1214	1129	1044	1178	1163	1083
Orivesi II	max	1147	1215	1129	1044	1179	1163	1083
	min		1206	1120	1035	1171	1153	1068
Orivesi III	max	1173	1240	1153	1068	1201	1192	1112
	min		1226	1140	1051	1189	1176	1096
Kiperjärvenoja	mc _{max}	1162	1267	1182	1106	1226	1224	1144
	mc _{min}		1208	1126	1041	1174	1158	1073
	pc _{max}		1265	1179	1099	1223	1221	1141
	pc _{min}		1183	1103	1018	1153	1130	1045
	max		1270	1184	1104	1228	1227	1147
	min		1208	1126	1041	1175	1159	1074
Hinnerjoki	max—min	1169	1287	1201	1121	1243	1246	1166

perature calculations, some crystallization experiments have been performed at the pressure of one atmosphere. The results so far indicate that reasonable approximations can be achieved by the method described above.

Phase-equilibria

The only method available to test the plagioclase equilibrium is the major element distri-

bution between plagioclase and liquid as a function of temperature.

Taking the plagioclase temperatures from Table 8 and supposing that they are equilibrium temperatures, all the microphenocrysts and the rim of the phenocrysts and megacrysts appear to be in a reasonable equilibrium (Fig. 12).

When attempting to clarify the mega- and phenocryst core equilibrium, the densities of

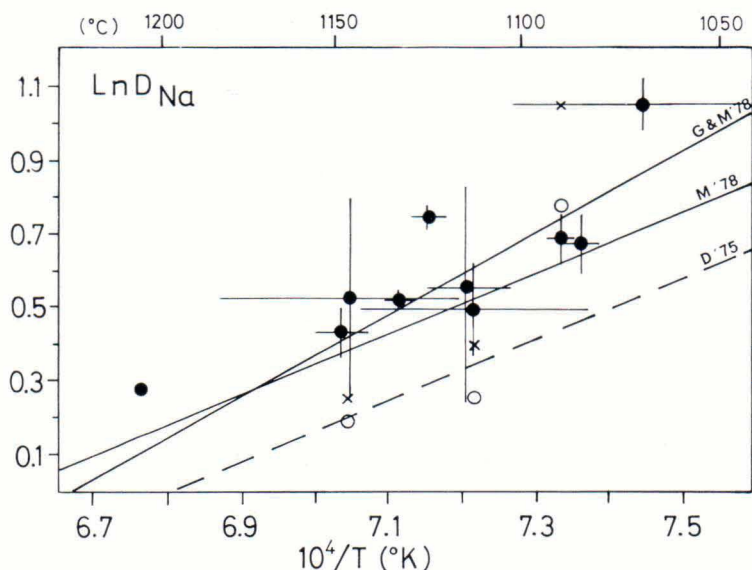


Fig. 12. Regression curve for $\ln D_{Na}$ versus $1/T$ ($^{\circ}K$), where $D_{Na} = (\text{weight of Na in plagioclase})/(\text{weight of Na in matrix})$. Solid circles refer to the groundmass, open circles to the phenocryst and crosses to the megacryst plagioclases (phenocryst and megacrysts only for Husö, Vehkajärvi and Kiperjärvenojä dykes). Dashed line (D'75) indicates equilibria in Drake's (1975) experiments. Solid lines are drawn from Mäkipää (1978) (M'78) and Grönvold & Mäkipää (1978) (G & M'78). Bars indicate the difference of maximum and minimum composition and temperatures.

the crystals play a most important role. For example, in Husö dyke large megacrysts could have been formed at greater depths and floated in the magma chamber into the liquid, where they are now found. Considering higher pressures, these crystals are in equilibrium with the groundmass and therefore formed in a similar or the same magma.

The reverse situation holds in Vehkajärvi dyke, where the mega- and phenocrysts were heavier than the surrounding magma. These crystals were in equilibrium with the groundmass, if lower pressures were postulated. However, according to the foregoing discussion about the crystallization history of these dykes, this model is an impossibility. Therefore the large megacrysts of the Vehkajärvi dyke cannot be crystallized from a magma corresponding the composition of the surrounding matrix.

Cooling rate and crystallization history

Cooling rates

The cooling rate of the magma in a dyke can be estimated using the results of experi-

ments by Grove & Walker (1977). They found that the size of plagioclase (width of the 010 pinacoid) correlates with the cooling rate as follows:

$$\log(\text{cooling rate}) = -1.71 \log(\text{width}) - 1.75$$

The derived rates can be used to give some estimations of cooling rates. The results of different dykes on the same set are fully comparable.

The Åland diabase dyke show a linear cooling rate with distance from the contact (Fig. 13). Because the country rock is the same in all the dykes, the influence of the width of the dyke is distinct, the wider the dyke the lower the cooling rate, because of the greater heat capacity.

The Satakunta diabbases show lowest cooling rates (Fig. 14), and the rate of cooling is almost constant up to about 10 cm from the contact. However, the temperature of the magma was so low that also contacts are completely crystallized even in the narrowest (20 cm) dykes. Further, the orientation of the groundmass plagioclases parallel to the dyke direction at contacts indicate that the magma was already partly crystallized before intrusion.

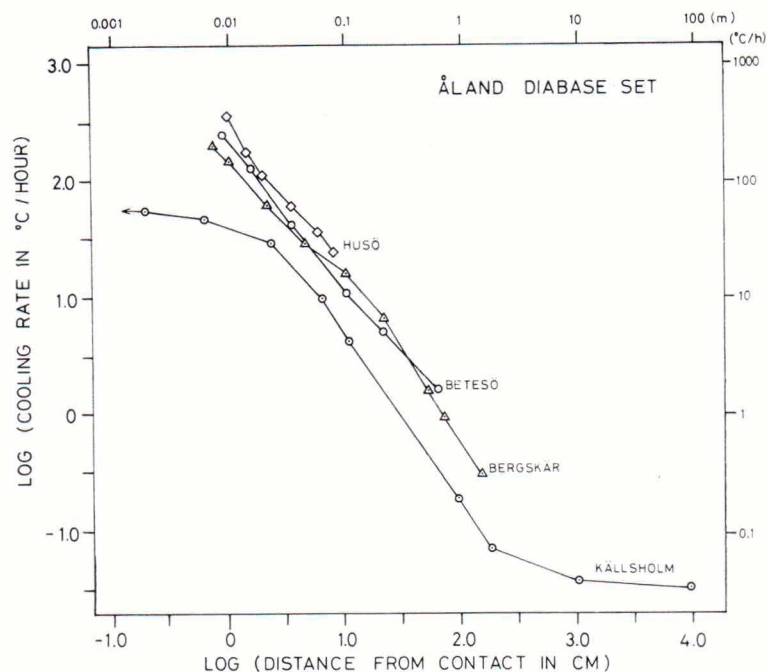


Fig 13. Cooling rate curves of the dykes in Åland diabase set.

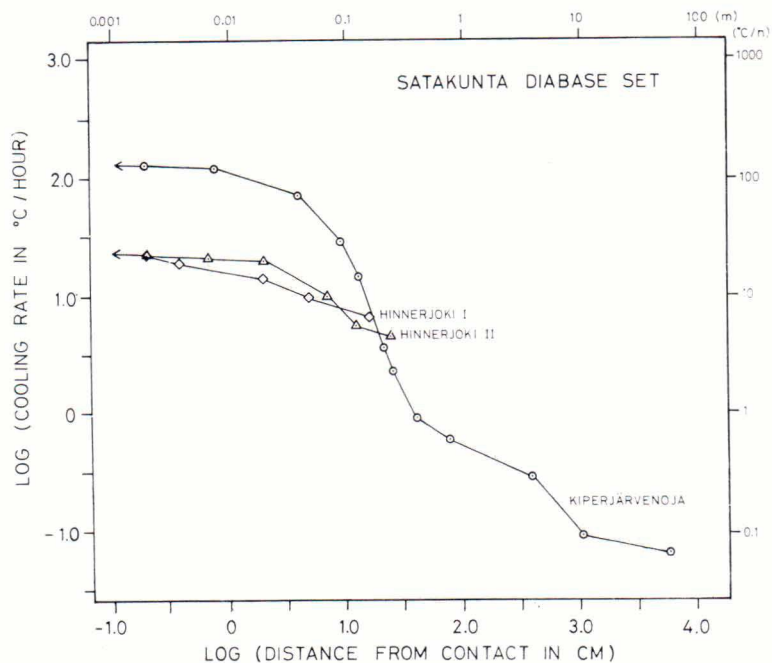


Fig. 14. Cooling rate curves of the dykes in Satakunta diabase set.

The Häme diabase set (Fig. 15) shows highest cooling rate at the contacts. However, the rates decrease rapidly and are lowest of all sets about 10 cm from the contact. This

might be caused by relative high intrusion temperature. The Vehkajärvi dyke, having the lowest temperature, shows not so rapid cooling rate. Further the width of the

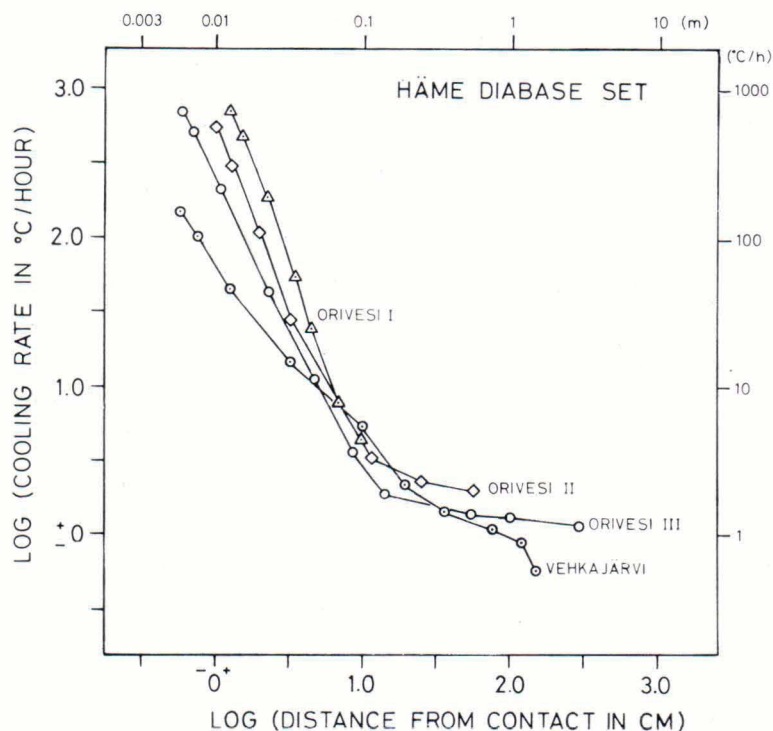


Fig. 15. Cooling rate curves of the dykes in Häme diabase set.

chilled margins decrease with increasing width of the dyke.

All the present cooling rate experiments show similar behaviour as the results of Grove & Walker (1977), i.e. the width of the plagioclase (010) pinacoid correlates lineary with the cooling rate, both in log scale (Fig. 16).

However, the slopes of the lines are very different. At higher cooling rates this can be caused by kinetic problems, but at lower rates there must be some other factor to control these individual experiments.

One important factor is the difference in the chemical composition. Grove & Walker (1977) used quartz-normative lunar basalts with pyroxene and small amounts of olivine and spinel as the first crystallization phase. Plagioclase was the last phase to crystallize. At the early stage in their cooling rate experiments the number of pyroxenes increased and their size decreased as a func-

tion of increasing cooling rate. They determined the pyroxene nucleation density and found it to correlate with the cooling rate. Then, during the late stages of crystallization the size of groundmass plagioclase increased at lower rate. So, applying this to the present experiments, the slope of the cooling rate line should be much steeper for early stage plagioclases than for late stage plagioclases. This is obvious. Does the line continue lineary at lower rates or turn parallel to late stage line is open to question.

However, another important result must also be pointed out. Three different dyke materials (Husö, Vehkajärvi and Kiperjärvenoja) were cooled simultaneously and the products reveal that the speed of the plagioclase growth differs in individual dykes, as shown in Fig. 16. This difference is small but noticeable. Applying this to Fig. 13 the discrepancy between the group Husö, Betesö

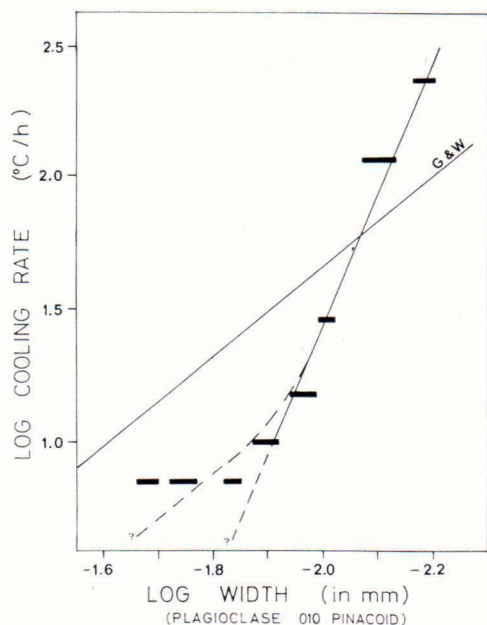


Fig. 16. Width of plagioclase phenocrysts measured in cooling rate experiments. Log of the width of plagioclase 010 pinacoid (in mm) is plotted against the cooling rate. G & W line represents late-stage cooling rates for lunar samples (Grove & Walker, 1977).



Fig. 17. A photomicrograph of the contact phenomena in Orivesi I diabase dyke. Note the partially melted country rock fragments in the dyke.

and Bergskär dykes (amphibole diabases) and the Källsholm dyke (pyroxene diabase) is easy to understand. So the width of the dyke is not the only and primary factor to control the cooling rate, but also the chemical composition of the magma plays an important role.

Contact phenomena

The heat capacity of the Husö dyke during the cooling was small and the partially melted contact zone only extended a few millimeters into the country rock. When magma is intruded into a country rock containing hydrous minerals, heat will be absorbed by vaporization and the whole system will be surrounded by a zone rich in water vapor. Because water can intrude into the magma, the contacts contain more water

than the rest of the dyke. The formation of very small, fine-grained and colourless chlorites at the contacts of Husö dike at high temperature is probably due to the activity of hydrothermal solutions intruded into the magma from partially melted granodiorite. Another explanation is thermal metamorphism, but then also the crystallization of the glassy groundmass should occur, which is not evident.

Because of this water-vapor phenomenon also the saussurization of the plagioclase feldspars can be understood. In the zone extending about 4–5 mm from the contacts plagioclases are altered to epidote.

In the Vehkajärvi dyke the partial melting of the country rock was very slight, in spite of the fairly large heat capacity of the magma. At the contacts only Na_2O , MgO and FeO increase slightly, while SiO_2 and Al_2O_3

decrease (Appendix 2). The altered zone is very narrow.

Extremely well the partial melting of the country rock occurs in some Orivesi dykes. The contact zones contain chlorites and even solution pubbles can be found (Fig. 17).

The contact zone is high in K_2O , MgO and FeO and low in SiO_2 and Na_2O . The average total of many microprobe analyses is as low as about 90 %.

After the crystallization cooling joints opened in the dykes. They were immediately filled up by hydrothermal deposits with average composition 12 % MgO , 30 % FeO , 13 % Al_2O_3 and 29 % SiO_2 . The rest 13–15 % is probably water.

The Kiperjärvenoja dyke has contact with an arkosic sandstone. According to Kahma (1951) its contact influence is low grade. »Approaching the contact the quartz grains in sandstone become toothed and the amount of fine-grained cement decrease. This fine-grained aggregate has almost entirely vanished at the contacts.»

The melted country rock material has flowed into the joint and mixed with contact magma. The mixing calculations show that about 35 % of the fluidal material has mixed with the magma at contact zone, MgO and FeO increased, while SiO_2 and Al_2O_3 decreased.

The present experiments show contact influence similar to those observed in the field. The partial melting of the country rock depends e.g. on the composition of dyke and country rock material, temperature, heating time and cooling rate. The degree of partial melting is directly comparable with the time used for preheating at high temperature (1150–1200°C). The contact zone is always richer in K_2O and FeO , and poorer in Na_2O , Al_2O_3 and SiO_2 than the rest of the dyke material in experimental capsule.

In one set of experiments powdered Husö

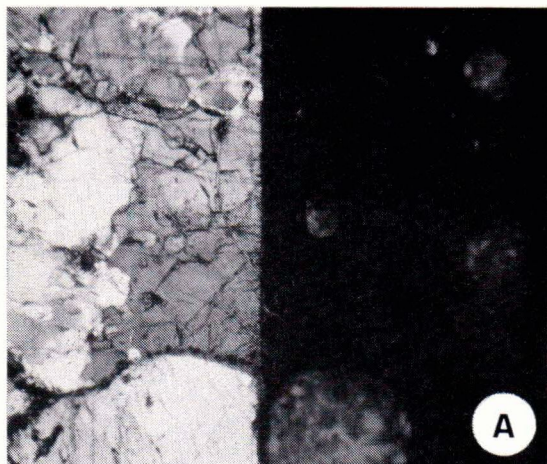


Fig. 18 A. A photomicrograph of products resulting from the experimental run of Husö diabase and granodiorite (left) at 1160°C for one hour.

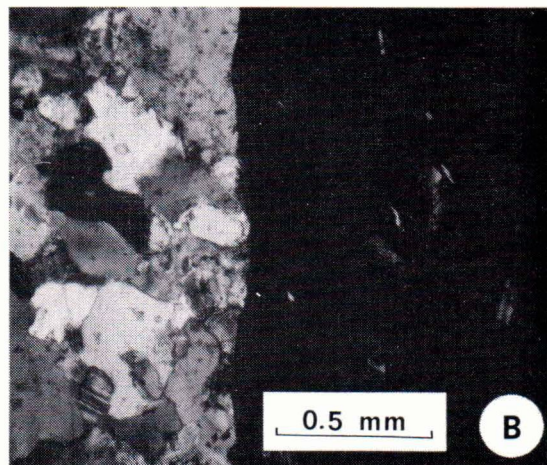


Fig. 18 B. A photomicrograph of Husö diabase — granodiorite contact.

diabase and solid granodiorite were packed in a platinum capsule and suspended in a furnace at 1160°C for one hour and cooled afterwards using the rate of 180°C/hour. Figure 18A shows the basalt-granodiorite contact after the experimental procedure. K_2O content of the diabase from the contact to the distance of about 1 cm decreases from 2.5 % to 0.8 %, while e.g. Al_2O_3 increases from 13.3 % to 15.3 %. This contact zone does

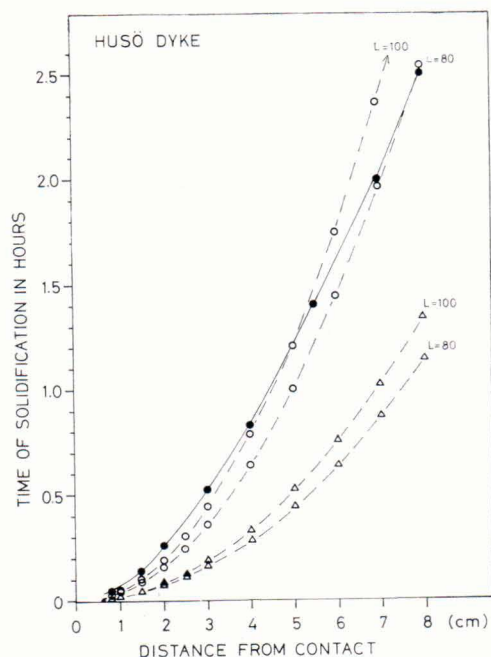


Fig 19. Time of the solidification as a function of the distance from contact in the Husö dyke. Solid circles — calculated using the experimental results of Grove & Walker (1977). Open circles — calculated using the method of Jaeger (1957) for intrusives. Triangles — calculated using the method of Jaeger (1957) for surface lava. $L = 100$ — latent heat 100 cal/g. $L = 80$ — latent heat 80 cal/g.

not extend more than a few millimeters to the diabase.

For comparison the natural contact of Husö dike is shown in Fig. 18 B.

Duration of the solidification

Jaeger (1957) studied the cooling rates of igneous rocks and introduced a method to calculate the time needed by a magma at a surface of known distance from the contact to solidify completely.

As discussed earlier the contact zone absorbed heat effectively and the corresponding heat loss must be accounted for in the calculation. In the Husö dyke the time for solidification is calculated using 1170°C as liquidus and intrusion temperature (derived using the

method by Mäkipää 1979) and 1120°C as solidus temperature (calculated plagioclase groundmass equilibrium temperature, Table 6). These temperatures agree well with the experimental results by Yoder & Tilley (1962). They found that rocks similar to those studied here are completely crystallized after the cooling of $40\text{--}60^{\circ}\text{C}$ from the liquidus.

In an attempt to account for the heat loss due to vaporization at the contacts, the temperature was assumed to be 30°C lower than the liquidus. The density of the magma was calculated using 1–2 kb pressure and 0.5 % H_2O content, which was assumed to be constant up to the contact zone where it was assumed to increase linearly up to 1.5 % H_2O .

The results (Fig. 19) with different latent heats 80 and 100 cal/g are compared with the results of the method by Grove & Walker (1977) and the cooling rates of the surface of a lava flow.

The agreement between the theoretical and experimental methods is good, and results may now be used quantitatively. According to these the solidification of Husö dyke was complete in 2–3 hours after the intrusion.

The case of the Vehkajärvi dyke is more complicated because of the differentiation in the dyke. The time of solidification was calculated using 1140°C as the liquidus temperature and 1090°C as the solidus temperature. Assuming similar conditions as quoted above, the cooling curves are shown in Fig. 20, which indicates slower cooling rate at the contact than calculated. This is caused by the graywacke schist country rock, which does not absorb heat well, and further, the chilled contacts were continuously in contact with the hotter magma intruded into the joint. When the contact zone (about 1 cm) is crossed, the cooling rate follows the calculated rate until it rapidly increases at the megacryst zone. Because of the very extensive crystallization the cooling rate is here

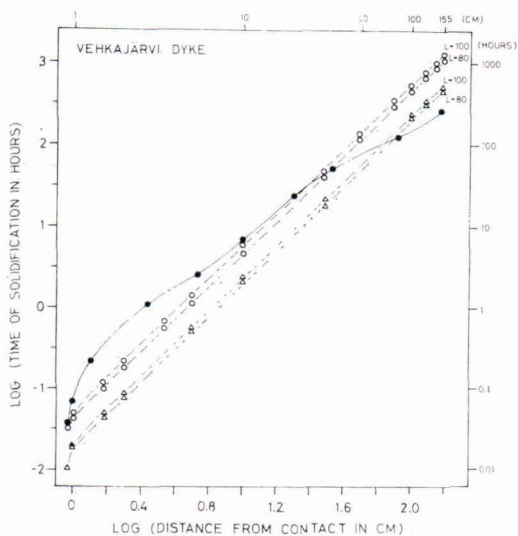


Fig. 20. Time of the solidification as a function of the distance from contact in the Vehkajärvi dyke. Symbols as in Fig. 20.

greater than calculated. However, according to the experimental results presented here, the cooling rate at the contact is not so rapid as calculated using the method of Grove & Walker (1977), and in addition, the megacryst zone shows slower cooling rate, so that the agreement between Jaeger's and this study is even better than presented.

According to these results, the solidification of the Vehkajärvi dyke was complete in 40–50 days after the intrusion. However, it seems to be more realistic to use the observed rate on the basis of plagioclase widths, which gives the result of two weeks.

The Kiperjärvenoja dyke is even more problematic, because of the differentiation and convection in the dyke during solidification. The time for solidification was calculated using 1170°C as intrusion temperature and 1120°C as solidus temperature. The comparison (Fig. 21) with the time derived from plagioclase widths shows marked difference. This is caused by at least three factors. Firstly, the effect of convection may play an important role. It seems certain that after the

marginal phase solidification the heat convection was increasingly dominating factor.

The author has made some experimental calculation to establish the effect of convection on the contact temperature and on the duration of solidification. In these the temperature at Kiperjärvenoja contacts has risen by an amount of tens of degrees from the initial contact temperature. Considering a very effective heat circulation, the duration of solidification decreases to half of the calculated value.

Secondly, the method to calculate the time of solidification using the plagioclase widths requires the assumption that the growth of the crystals is continuous and linear. In the studied dykes the width of the plagioclase crystals increase linearly only in dykes narrower than about 20 meters. For example the width of the plagioclase crystals in the 60 m wide Kiperjärvenoja diabase and 100 m wide Källsholm dyke seems to be constant (about 0.6 cm) from 25–30 m from the contact on.

Thirdly, according to the present early stage plagioclase cooling rate experiments, the agreement with the calculated rates is much better than presented but at lower rates it is now impossible to say if the growth continues linearly or not.

However, it seems unquestionable that the solidification time of Kiperjärvenoja dyke is in the order of a hundred years.

Settling of the plagioclase crystals

Using the Stokes' law it is possible to calculate the velocity required for a crystal rise or sink.

$$V = \frac{2 g a^2 (P_1 - P_2)}{9\mu}$$

where g is acceleration due to gravity ($\sim 10^3$ cm/sec²), a = radius of the crystal, P_1 = density of the crystal, P_2 = density of the melt,

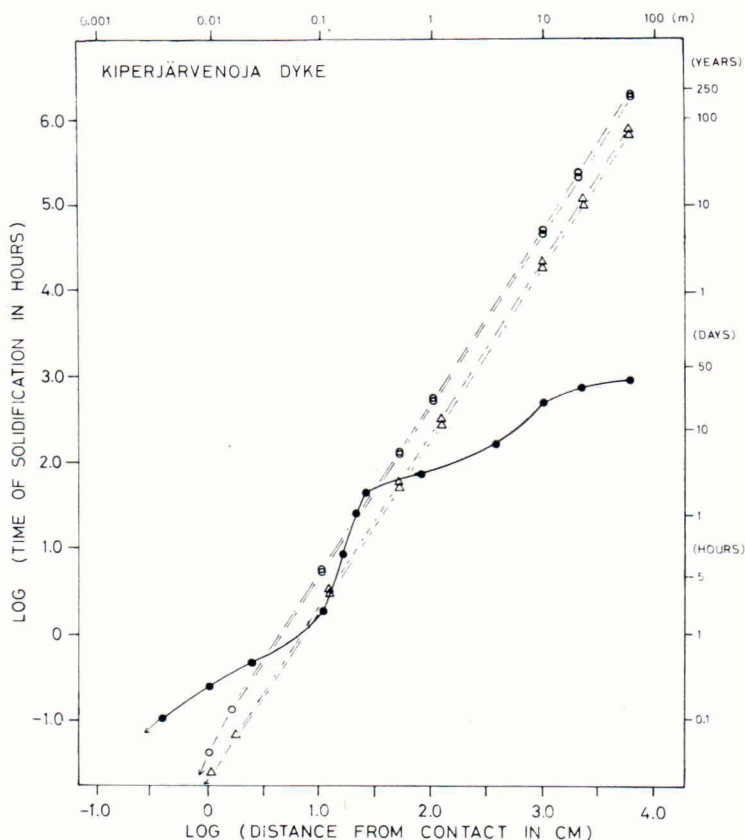


Fig. 21. Time of the solidification as a function of the distance from contact in the Kiperjärvenoja dyke. Symbols as in Fig. 20.

and μ = viscosity of the melt (calculated using the method of Shaw (1972)).

According to Bottinga & Weill (1970) the total range of the density of plagioclase at 1200°C is 2.53 to 2.71 (corresponding to An_0 — An_{100}). The calculated densities are given in the tables with plagioclase analyses of individual diabase sets.

The density of a magma can be calculated from partial molar volumes of oxide components (Bottinga & Weill, 1970).

Thus the density of the Husö plagioclase phenocrysts (Åland diabase set) varies from 2.615–2.625 (An_{48-54}). The density of the larger megacrysts can be considered to be between 2.600 and 2.625 (An_{38-53}). Assuming the pressure of 1–2 kb and water content of 0.5 %, the specific gravity of the Husö

groundmass at 1175°C is about 2.615. Considering the effective viscosity of the Husö magma to be about 1100 poises and the maximum radius of phenocrysts 0.2 mm the crystals should sink at the rate of 0.35 mm/day. This means that if the dyke is like a sill it takes half a year to remove the phenocrysts from the contact to the centre of the dyke. As discussed earlier the solidification of such a narrow dyke takes only hours.

Megacrysts can either sink or rise. Considering very common plagioclase megacryst composition (An_{40}) the crystals (max. 0.6 cm in diameter) should float at the rate of 0.8 cm/h.

On account of these velocities, the gravitational settling of plagioclases in Husö dyke is not a strong factor to move the crystals. The

concentration of the mega- and phenocrysts into the centre of the dyke must be understood to be due to the flowage differentiation.

Vehkajärvi plagioclase phenocrysts (Häme diabase set) show slight variation in composition toward the centre of the dyke. However, as an average their density varies from 2.625 to 2.635 (An_{53-60}). The density of the extremely homogenous, large megacrysts (\varnothing 2—3 cm) varies from 2.630 to 2.635 (An_{55-59}).

The density of the Vehkajärvi groundmass is 2.59 at 1139°C (other properties quoted above).

Vehkajärvi magma has a viscosity of about 1200 poises at 1140°C. The maximum radius of the phenocrysts is 0.1 mm, denoting sinking at the rate of 0.7 mm/day. The large megacrysts can move in the magma at the rate of 1.7 m/h and in this spirit the concentration of the plagioclase megacrysts in the middle of the dyke must be explained.

The first idea to rise is a simple model of magmatic chambers. Being much heavier than the magma, the megacrysts may have sunk to the bottom levels of the chamber. After the eruption the present megacryst zone may represent the last phase of the extracted material. However, this model should require a differentiation trend toward the centre of the dyke, which evidently does not occur. Further, the conditions during the eruption should be so ideal that the existence of this system is unlikely, and finally, as discussed earlier, the megacrysts are in equilibrium only if lower pressures are postulated.

Rather more probable is the existence of some mechanical sorting during the eruption. The only explanation worthy of consideration is the flowage differentiation. In such case the whole system is very stabil because of the higher viscosity of the concentration zone. This indicates that the less viscous magma on the both sides of the megacryst zone has flowed faster than the crystal-saturated

liquid in the mid-channel. On this basis the chemical difference between the matrix in the central part of the dyke and other parts is easy to understand.

Anyway in both cases the dyke must represent a more or less vertical joint or otherwise some gravitative settling should occur.

Kiperjärvenoja plagioclase phenocrysts (Satakunta diabase set) are homogenous and strongly altered. Their density varies between 2.645 and 2.650 (An_{66-68}). The density of the Kiperjärvenoja groundmass is 2.605 at 1165°C (other properties quoted above).

Kiperjärvenoja magma had a viscosity of 1150 poises at 1165°C. The maximum radius of the phenocrysts observed near the contacts is 0.2 mm, denoting sinking at the rate of about 3 mm/day.

Owing to the scarcity of the megacrysts such concentrations of the crystals as described in the Vehkajärvi dyke cannot be found. Because the distinction between the phenocrysts and groundmass minerals behind the contact zones is impossible under the microscope, the total analyses are the only facts relating possible crystal concentration during the intrusion.

Summary

The crystallization history of ten dykes from three different diabase sets in southern Finland has been described. The basaltic magma was formed by partial melting of the upper mantle during the Svecofennio-Karelian folding, and it intruded into the crust during this folding.

The intrusion temperature has been derived to be about 1140—1170°C and no clear distinction between individual sets can be made. The calculated equilibrium temperatures show that the dykes in most cases were

completely crystallized after a cooling of 40–60°C.

The magma at this temperature has partially melted the country rock. In the narrowest dykes the melted zone extends only a few millimeters into the country rock, but in the largest ones the zone is several tens of centimetres. The melting has also influenced the diabase chemistry up to 3–4 meters from the contact, as has been described by Kahma (1951). Also some differentiation in the dyke self occurs in the widest dykes.

The lack of any variation in the ground-mass chemistry around the mega- and phenocrysts indicates that they already were in the magma before intrusion. The homogeneity of the mega- and phenocrysts can be explained by magma chambers, which evidently existed for a long time beneath the diabase areas.

The cooling rate of the magma depends on the country rock, dyke chemistry, intrusion temperature and the width of the dyke. To generalize, the width of the chilled margins is the function of the width of the dyke. Further, the larger the dyke the slower is the cooling rate, and the higher the intrusion temperature the speedier is the cooling rate at the contacts.

The settling of the plagioclase mega- and phenocrysts in the centre of the dykes is explained here by a process of flowage differentiation. However, in most of the dykes in the studied areas the plagioclase crystals occur near the assumed upper or lower contact. Very popular explanation to this phenomenon is the gravitative differentiation in the dyke itself. However, this study shows that such conclusions must be made with great care.

Considering the plagioclase cell expansion at high temperature and the magma density variation with temperature and pressure, the density of the plagioclases in most dykes equals the density of the magma. In the narrowest dykes there has not been time enough to the gravitative separation of the crystals and therefore the origin of the crystal-concentration in one part of the dyke must be in magma chamber at a shallow depth or even deeper.

Acknowledgements — This study was carried out during the author's fellowship at the Nordic Volcanological Institute, Reykjavik. The author is indebted to Dr. Ilkka Laitakari and Mr. Veli Suominen, Phil.l.c., for their advice, help and hospitality during the field trip in Finland. Thanks are also due to them and Dr. Gudmundur Sigvaldason for valuable discussion during the work. Drs. Karl Grönvold and Atso Vormaa kindly read the manuscript and made a number of suggestions; this is gratefully acknowledged.

References

- Bottinga, Y. and Weill, F. (1970) Densities of liquid silicate systems calculated from partial molar volumes of oxide components. *Am. J. Sci.* 269: 169–183.
- Drake, M. J. (1975) Plagioclase thermometry and barometry in igneous systems. In *Extended abstracts: International Conference on Geothermometry and Geobarometry*, Pennsylvania State University, Pennsylvania.
- Ehlers, C. and Ehlers, M. (1977) Shearing and multiple intrusion in the diabases of Åland archipelago, SW Finland. *Geol. Surv. Finland, Bull.* 289, 31 p.
- Grove, T. L. and Walker, D. (1977) Cooling histories of Apollo 15 quartz normative basalts. *Proc. Lunar Sci. Conf. 8th*: 1501–1520.
- Grönvold K. and Mäkipää, H. (1978) Chemical composition of Krafla lavas 1975–1977. *Rapport Nordic Volcanological Institute* 78–16.
- Haapala, I. (1977) Petrography and geochemistry of the Eurajoki stock, a rapakivi-granite complex with greisen-type mineralization in south-

- western Finland. Geol. Surv. Finland, Bull. 286, 128 p.
- Irvine, T. N. and Baragar, W. R. A. (1971) A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci. 8: 523—549.
- Jaeger, J. C. (1957) The temperature in the neighbourhood of a cooling intrusive sheet. Am. J. Sci. 255: 306—318.
- Kahma, A. (1951) On contact phenomena of the Satakunta diabase. Bull. Comm. géol. Finlande 152. 84 p.
- Kudo, A. M. and Weill, D. F. (1970) An igneous plagioclase geothermometer. Contr. Mineral. Petrol. 25: 52—65.
- Kushiro, I. (1973) Partial melting of garnet lherzolites from kimberlite at high pressures. In: P. H. Nixon (ed.) Lesotho kimberlites, Lesotho National Development Corporation, Maseru, Lesotho, 294—299.
- Laitakari, A. (1925) Über das Jotnische Gebiet von Satakunta. Bull. Comm. géol. Finlande 73. 43 p.
- (1928) Palingenese am Kontakt des postjotnischen Olivindiabases. Fennia 50 (35). 25 p.
- Laitakari, I. (1966) Heinolan—Padasjoen—Oriveden seudun diabaasiuoniparvi. Thesis, Geological Institute, University of Turku. 157 p.
- (1969) On the set of olivine diabase dikes in Häme, Finland. Bull. Comm. géol. Finlande 241. 65 p.
- Lokka, L. (1934) Neuere Chemische Analysen von Finnischen Gesteinen. Bull. Comm. géol. Finlande 105. 64 p.
- Mäkipää, H. T. (1978 a) Petrological relations in some Icelandic basaltic hyaloclastites. Bull. Geol. Soc. Finland 50: 81—112.
- (1978 b) Mineral equilibria, geothermometers and geobarometers in some Icelandic hyaloclastites. Bull. Geol. Soc. Finland 50: 113—134.
- (1979) Contribution to the $\text{Fe}_2\text{O}_3/\text{FeO}$ determination in basaltic rocks. Bull. Geol. Soc. Finland 51: 125—129.
- Mathez, E. A. (1973) Refinement of the Kudo-Weill plagioclase thermometer and its application to basaltic rocks. Contr. Mineral. Petrol. 41: 61—72.
- Presnall, D. C., Dixon, S. A., Dixon, J. R., O'Donnell, T. H., Brenner, N. L., Schrock, R. L. and Dycus, D. W. (1978) Liquidus phase relations on the join Diopside-Forsterite-Anorthite from 1 atm to 20 kbar: Their bearing on the generation and crystallization of basaltic magma. Contr. Mineral. Petrol. 66: 203—220.
- Savolahti, A. (1956) The Ahvenisto massif in Finland. Bull. Comm. géol. Finlande 174. 96 p.
- (1964) Olivine diabase dike of Ansio in Padasjoki, Finland. Bull. Comm. géol. Finlande 215.
- Sederholm, J. J. (1911) Beskrifning till bergarts-kartan B 2, Tammerfors. Résumé en français. (General geological map of Finland) 1 : 400.000. 121 p.
- (1934) On migmatites and associated precambrian rocks of southwestern Finland. Part III. The Åland islands. Bull. Comm. géol. Finlande 107.
- Shaw, H. R. (1972) Viscosities of magmatic silicate liquids: an empirical method of prediction. Am. J. Sci. 272: 870—893.
- Vaasjoki, M. (1978) Rapakivi granites and other postorogenic rocks in Finland: their age and the lead isotopic composition of certain associated galena mineralizations. Geol. Surv. Finland, Bull. 294.
- Vorma, A. (1977) On the petrochemistry of rapakivi granites with special reference to the Laitila massif southwestern Finland. Geol. Survey of Finland, Bull. 285.
- Weigand, P. W. and Ragland, P. C. (1970) Geochemistry of Mesozoic dolerite dykes from eastern North America. Contr. Mineral. Petrol. 29: 195—214.
- Yoder, H. S. Jr. (1973) Contemporaneous basaltic and rhyolitic magmas. Am. Min. 58: 153—171.
- and Tilley, C. E. (1962) Origin of basalt magmas. J. Petrol. 3: 346—532.

APPENDIX 1

Total chemistry of the studied dykes.

Dist. from cont. (cm)	SiO ₂	TiO ₂	Al ₂ O ₃	FeO ^t	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
<i>Husö dyke</i>											
0	53.46	1.68	14.82	11.87	.17	4.73	8.09	2.35	1.50	.38	99.05
1	53.92	1.47	15.23	11.84	.18	4.60	8.44	2.24	1.11	.33	99.36
4	53.59	1.77	15.25	11.89	.21	4.79	8.36	2.24	1.04	.44	99.58
6	52.94	1.78	15.56	11.62	.14	4.96	8.51	2.28	1.22	.45	99.78
Centre	53.27	1.40	17.41	10.21	.14	3.74	9.56	2.59	1.22	.40	99.94
7.5	53.43	1.39	17.25	10.40	.14	3.75	9.30	2.61	1.20	.36	99.82
6	53.28	1.71	15.35	12.49	.13	4.55	8.51	2.28	1.01	.39	99.70
3	53.08	1.78	14.73	12.69	.13	5.00	8.59	2.31	.85	.37	99.53
1	53.79	1.77	15.30	11.21	.16	5.13	8.93	2.55	1.04	.42	100.30
<i>Vehkajärvi dyke</i>											
0	50.98	3.33	15.04	13.47	.17	3.95	6.84	2.67	2.27	.82	99.54
20	51.34	2.93	13.96	14.79	.16	3.77	6.68	2.40	2.30	.79	99.12
50	51.91	2.77	15.14	12.60	.16	3.92	7.03	2.65	2.12	1.03	99.33
110	51.48	2.75	15.26	13.10	.17	3.95	7.10	2.69	2.22	.98	99.70
125	50.37	3.48	16.88	11.82	.14	3.60	7.68	2.79	1.96	.73	99.45
Centre	50.80	2.60	19.02	10.69	.13	2.83	8.55	3.06	1.69	.57	99.94
110	50.98	2.81	15.38	13.40	.18	3.82	7.02	2.65	2.11	.88	99.23
30	51.21	2.91	14.86	14.10	.19	3.92	6.91	2.58	2.11	.76	99.55
<i>Kiperjärvenoja dyke</i> (metres)											
0	47.12	3.22	18.02	13.32	.19	4.76	7.44	2.96	1.44	.69	99.16
0.06	46.82	2.91	16.96	14.28	.11	5.58	7.34	2.98	1.72	.58	99.28
0.12	46.98	2.97	17.52	13.97	.16	5.56	6.99	2.85	1.36	.77	99.13
0.32	46.84	2.92	16.03	14.51	.17	5.48	8.29	3.16	1.26	.59	99.25
0.75	48.52	3.23	16.21	13.57	.18	4.61	8.87	2.92	1.26	.45	99.82
1.75	49.40	2.41	19.73	9.59	.19	4.28	8.89	3.33	1.30	.60	99.72
3.90	46.74	2.95	16.02	14.39	.18	4.96	9.45	3.13	1.21	.65	99.68
10	46.42	2.60	16.88	13.89	.13	5.44	9.83	3.15	1.13	.38	99.85
23	48.51	2.94	16.84	13.04	.15	4.87	8.23	3.16	1.55	.44	99.73
60	47.12	2.92	15.67	13.34	.20	5.72	9.66	3.08	1.42	.44	99.57

APPENDIX 2

Groundmass composition of the Husö diabase dyke (Åland diabase set).

Distance from cont. (mm)	No. of anal.	SiO ₂	TiO ₂	Al ₂ O ₃	FeO ^t	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
0	6	55.94	2.15	17.49	7.21	.28	1.96	5.99	5.25	1.18	.46	97.91
1	3	46.35	2.07	13.43	18.46	.37	6.87	4.87	.99	3.68	.46	97.55
2	6	56.63	1.92	12.88	11.12	.25	4.17	7.36	2.90	1.21	.41	98.85
4.5	5	53.43	1.97	13.25	12.68	.23	5.06	8.10	2.75	1.12	.43	99.02
7.5	4	53.18	1.96	13.17	13.20	.24	5.31	8.05	2.52	1.15	.43	99.21
11	3	52.42	2.00	13.40	13.66	.19	5.21	8.09	2.46	1.05	.43	98.91
16	3	52.07	2.12	13.18	14.12	.23	5.11	8.08	2.38	.95	.44	98.68
20	4	52.65	1.91	13.42	14.50	.21	4.97	7.79	2.38	.90	.43	99.16
25	6	53.18	1.61	13.42	13.82	.22	4.86	7.90	2.12	.98	.45	98.56
30	4	53.59	1.71	13.35	12.95	.22	4.85	8.21	2.05	.93	.44	98.29
35	4	53.86	1.70	13.16	12.95	.19	4.68	8.31	2.17	1.03	.32	98.37
40	3	53.36	1.77	13.24	13.19	.22	4.71	8.00	2.35	.85	.38	98.07
45	4	53.11	1.65	14.06	12.86	.20	4.87	8.01	2.31	.85	.41	98.39
50	4	52.57	1.71	14.24	13.38	.17	4.94	8.07	2.28	.88	.44	98.68
57	4	53.21	1.51	14.52	13.63	.20	4.77	7.92	2.32	.85	.40	99.33
62	4	52.15	1.84	14.24	13.71	.21	4.72	7.91	2.49	.74	.42	98.43
67	3	54.52	1.85	14.14	13.05	.22	4.26	7.70	2.35	.84	.40	99.33
73	4	53.92	1.95	14.15	13.24	.27	4.42	7.72	2.37	.84	.41	99.34
80	7	54.64	1.72	13.76	12.09	.19	4.29	8.06	2.23	.93	.44	98.35
Centre	7	54.09	1.79	14.06	11.64	.21	4.47	8.32	2.31	.96	.42	98.27
80	8	53.98	1.57	13.72	11.55	.21	4.30	8.14	2.36	.90	.45	97.18
75	7	56.23	1.55	14.14	10.77	.19	4.04	8.15	2.41	.96	.44	98.88
68	3	56.37	1.52	13.80	11.25	.22	4.19	8.13	2.41	.92	.40	99.21
62	4	55.86	1.47	14.21	11.18	.18	4.33	8.00	2.34	1.01	.41	98.99
56	3	55.58	1.50	13.82	12.00	.16	4.48	7.89	2.33	.91	.44	99.11
52	7	54.70	1.49	14.28	12.12	.19	4.70	8.15	2.31	.86	.42	99.22
44	5	54.06	1.46	14.11	12.31	.21	4.78	8.00	2.45	.80	.45	98.63
40	4	53.57	1.49	14.18	13.28	.18	5.17	8.18	2.43	.81	.47	99.76
33	3	53.78	1.56	13.40	12.68	.17	5.14	7.90	2.47	1.09	.46	98.65
27	4	53.26	1.58	13.56	12.66	.18	5.11	8.07	2.36	.89	.45	98.78
22	4	52.55	1.65	13.88	12.54	.18	5.28	8.29	2.39	.98	.48	98.16
13	6	53.79	1.63	14.04	12.41	.19	5.12	8.19	2.48	.81	.46	99.12
6	3	54.19	1.62	14.12	11.32	.22	4.61	8.03	2.72	.99	.41	98.23
1	6	53.62	1.73	17.09	9.24	.26	2.80	7.07	5.94	.81	.40	98.91
0	4	54.60	2.03	16.91	7.54	.23	2.74	7.15	6.50	.58	.47	98.64
Average	154	53.42	1.75	13.74	12.92	.21	4.80	8.05	2.37	.93	.43	98.62

APPENDIX 2 (continued)

Groundmass composition of the Vehkajärvi diabase dyke (Häme diabase set).

Distance from cont. (cm)	No. of anal.	SiO ₂	TiO ₂	Al ₂ O ₃	FeOt	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	Total
0	5	49.47	3.08	14.18	13.35	.26	3.82	7.40	4.43	.92	.87	97.78
0.2	3	50.11	3.34	14.43	10.90	.24	3.78	7.82	4.78	.68	.95	97.08
0.6	4	49.92	2.88	14.49	12.53	.22	3.74	7.26	3.66	1.76	.76	97.22
1.5	3	49.54	2.87	15.21	12.28	.19	3.48	7.45	3.47	1.93	.84	97.26
1.8	3	50.34	2.65	15.17	12.81	.21	3.24	6.89	3.35	2.14	.84	97.64
4	3	50.48	2.48	15.26	12.33	.18	3.31	6.99	3.26	2.01	.83	97.13
8	4	50.83	2.61	15.33	12.71	.19	3.18	7.12	3.41	2.26	.79	98.43
10	6	51.26	2.51	15.42	11.88	.22	3.22	7.33	3.22	1.97	.86	97.89
15	6	52.33	2.33	15.58	11.63	.18	3.16	7.21	3.40	2.06	.85	98.73
20	7	51.88	2.41	15.13	12.08	.19	3.43	7.42	3.45	2.25	.77	99.01
25	3	52.22	2.31	15.21	12.01	.21	3.33	7.13	3.31	1.88	.79	98.40
35	8	51.78	2.22	15.61	11.97	.18	3.35	7.28	3.16	2.00	.85	98.40
50	5	52.28	2.52	15.37	11.77	.18	3.13	7.39	3.47	1.90	.83	98.84
82	3	52.36	2.42	15.62	12.03	.19	3.36	7.18	3.37	1.80	.81	99.14
110	5	52.42	2.53	15.78	12.12	.19	3.41	7.32	3.41	1.92	.82	99.92
125	6	49.49	2.99	14.81	15.13	.16	4.07	6.98	2.72	1.96	.79	99.10
142	8	50.25	3.84	14.34	14.91	.17	4.14	6.77	2.41	2.17	.74	99.74
Centre												
148	9	50.12	3.92	14.21	15.08	.18	4.21	6.61	2.38	2.21	.72	99.64
110	5	52.30	2.42	15.61	12.28	.20	3.39	7.21	3.38	1.99	.88	99.66
42	5	51.31	2.38	15.48	12.01	.19	3.48	7.19	3.36	2.08	.93	98.41
30	3	52.23	2.48	15.12	11.81	.17	3.12	7.22	3.21	1.99	.86	98.21
28	3	51.62	2.41	15.13	11.97	.17	3.26	7.18	3.31	2.06	.87	97.98
6	4	50.82	2.59	15.11	12.38	.19	3.52	7.26	3.46	1.89	.79	98.01
2.5	3	50.22	2.78	14.98	12.29	.18	3.62	7.46	3.72	1.72	.81	97.78
2	3	49.36	2.63	14.89	12.37	.22	3.56	7.33	3.98	1.01	.82	96.97
0.8	4	48.72	2.92	15.01	12.08	.19	3.48	7.61	4.31	.81	.76	96.89
0.3	4	49.81	3.08	14.92	10.70	.29	3.76	7.90	4.72	.66	.90	96.74
0.1	6	50.12	3.31	14.48	11.02	.28	3.61	7.71	4.60	1.02	.92	97.08
0	7	48.81	3.28	14.36	13.92	.31	3.92	7.52	4.52	.92	.77	98.23
Average	109	51.32	2.56	15.42	11.85	.18	3.27	7.30	3.36	1.99	.84	98.09
Groundmass composition of the Kiperjärvenoja dyke (Satakunta diabase set)												
0	2	47.40	3.41	12.31	18.72	.17	6.55	2.10	1.41	2.38	.54	94.99
0.5	3	44.79	4.14	12.43	16.00	.18	8.33	3.09	1.56	3.27	.43	94.22
1	2	45.86	2.81	16.77	11.33	.09	4.86	6.48	2.92	2.86	.49	94.48
2	2	46.20	3.19	17.72	11.36	.10	5.16	6.10	3.08	2.78	.59	96.18
4	3	47.89	1.77	17.64	10.43	.09	5.14	6.60	3.39	1.24	.48	94.67
6	8	47.86	2.56	17.49	12.42	.09	5.08	6.90	3.42	1.96	.46	98.27
10	5	47.77	2.41	17.26	11.86	.17	4.89	7.21	3.47	1.14	2.10	98.17
Average	15	47.89	2.59	17.49	11.36	.10	4.90	7.10	3.42	1.24	.55	96.64

APPENDIX 3

Some representative microprobe analyses of plagioclase.

		SiO ₂	Al ₂ O ₃	FeO ^t	CaO	Na ₂ O	K ₂ O	Total	An
<i>Åland diabase set</i>									
Bergskär	pc _c	54.95	28.26	.75	10.72	5.29	.34	100.28	52.8
	pc _r	54.05	28.79	.76	11.21	5.15	.26	100.22	54.6
	pc _c	54.91	27.88	.53	10.35	5.27	.36	99.30	52.0
	pc _r	54.92	28.20	.81	10.78	5.09	.24	100.04	53.9
	gm	53.12	29.11	1.25	12.24	4.50	.38	100.60	60.1
	gm	53.87	28.49	1.26	11.49	4.81	.26	100.18	56.9
	gm	54.39	28.28	.86	10.70	5.25	.24	99.72	52.9
Betesö	pc _c	55.38	29.11	.16	8.42	6.04	.57	99.68	43.5
	pc _r	54.89	29.11	.19	7.69	6.20	1.86	99.94	40.7
	pc _c	58.38	25.75	.29	7.50	8.27	.10	100.29	33.4
	pc _r	60.03	24.73	.18	5.38	9.33	.15	99.80	24.2
	gm	57.26	25.92	.20	9.36	7.10	.06	99.90	42.1
	gm	55.37	27.81	.37	10.33	6.54	.01	100.34	46.6
	gm	59.04	25.69	.13	7.23	8.05	.01	100.15	33.2
Källsholm	pc _c	54.52	27.64	.59	10.68	5.83	.66	99.92	50.3
	pc _r	54.68	27.61	.60	11.53	5.37	.44	100.23	54.3
	pc _c	55.36	27.09	.42	11.05	6.25	.48	100.65	49.4
	pc _r	56.11	25.86	.32	10.12	6.82	.46	99.69	45.1
	gm	53.54	28.45	.66	11.60	5.03	.34	99.62	56.0
	gm	48.88	27.56	1.33	18.71	3.27	.16	99.91	76.0
	gm	55.15	27.39	.55	10.46	6.06	.63	100.24	48.8
<i>Häme diabase set</i>									
Orivesi I	pc _c	52.17	30.42	.50	12.77	3.84	.31	100.01	64.8
	pc _r	56.16	27.19	.68	9.72	5.21	1.06	99.92	50.7
	pc _c	53.95	29.31	.55	11.53	4.57	.50	100.41	58.2
	pc _r	55.89	28.02	.63	9.93	5.20	.82	100.49	51.3
	gm	54.47	28.26	.83	10.97	4.84	.74	100.11	55.6
	gm	54.43	28.42	.67	10.70	4.88	.59	99.69	54.8
	gm	54.86	28.37	.73	10.52	5.02	.43	99.93	53.5
Orivesi II	pc _c	53.06	28.26	.66	11.61	5.30	.76	99.65	54.6
	pc _r	55.50	27.60	.88	10.29	4.80	.82	99.89	54.1
	pc _c	52.40	28.65	.61	11.84	4.70	.92	99.12	58.1
	pc _r	55.19	28.00	.82	9.83	5.03	1.02	99.89	51.9
	gm	53.24	28.10	.73	11.36	5.32	.92	99.67	54.1
	gm	54.44	27.65	.79	10.65	5.51	.73	99.77	51.7
	gm	55.19	28.00	.63	9.83	4.83	1.02	99.50	52.9
Orivesi III	pc _c	54.02	29.71	.30	11.82	4.03	.40	100.28	61.7
	pc _r	55.13	27.92	.48	9.74	5.02	1.03	99.32	51.7
	pc _c	53.27	30.08	.27	12.31	3.96	.36	100.25	63.2
	pc _r	55.59	27.91	.64	9.92	5.12	1.02	100.20	51.7
	gm	53.04	29.88	.63	12.19	4.28	.47	100.49	59.5
	gm	53.92	28.92	.66	11.31	4.52	.62	99.94	57.9
	gm	54.38	28.66	.62	10.61	4.92	.72	99.91	54.4
<i>Satakunta diabase set</i>									
Hinnerjoki	mc	66.92	20.17	.02	.06	.10	11.65	98.92	—
I and II	mc	67.47	19.72	.15	.00	.10	12.43	99.87	—
	pc	50.92	30.57	.62	13.35	3.65	.19	99.30	66.9
	gm	50.65	30.17	.69	12.87	4.00	.21	98.59	64.0

mc — megacryst

pc_c — phenocryst corepc_r — phenocryst rim

gm — groundmass plagioclase