Senior Thesis

MEASUREMENTS OF THE WATER CONTENT OF BASALT FROM PATMOS ISLAND, GREECE

Presented in Partial Fulfillment of the Requirements for
the Degree of Bachelor of Science in the
Department of Geological Sciences

by

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SPO-1993

ABSTRACT

The focus of this study was the examination of basalt samples from Patmos Island, Greece. The samples were examined using microprobe analysis and the relative concentrations of the elements present determined. It was hoped that through this analysis it could be determined whether or not the magma from which the rock formed was generated by the interaction of a subducting slab and a mantle source. The concentrations of calcium and sodium in the plagioclase phenocrysts was plotted against whole rock concentrations. These values were then compared against known values of the distribution coefficient and an estimate of the water content was made.

From the plots made, it was determined that the source of the parent magma *was* a mantle source interacting with a subducting slab. However, one of the samples had anomalously low amounts of water and calcium. It is suggested that further study of this sample be conducted to determine if the data used in this study was in error, or to determine the possible causes for these low abundances

INTRODUCTION

Patmos is a small island of the Hellenic arc, Greece. The island is located approximately fifty kilometers east of Turkey and 200 kilometers northwest of Crete in the Southern Aegean Sea. Like several islands of the Aegean Sea, Patmos is made of extrusive igneous rocks, mainly basalt. The examination of these basalt with the use of geothermometers and geobarometers give geologist an idea of the conditions of temperature and pressure that the magma was under while it crystallized. Another important factor determined in analyzing these rocks is the water content of the rock. Knowing the water content of a basalt is important for several reasons, including what effects the water may have had on the magma. Among the effects that water content has on magma are reduction of melt viscosity, increase of diffusion rates, and the decrease of the crystallization temperature. Water content can also indicate the source of the magma that formed the rock. A high water content is a strong indicator that the magma was derived from a mantle source interacting with a subducting slab. A low water content or no water indicates that the possible source of the magma was from the mantle.

The focus of this paper is to estimate the water content of various basalt samples from Patmos Island. Several samples of Patmos basalt were analyzed with the electron microprobe, these samples have been labeled Pat 167, Pat 97, and Pat 26. The data collected was then analyzed and an approximate water content was found. In doing this, it was hoped that the source of the magma that created Patmos would be determined.

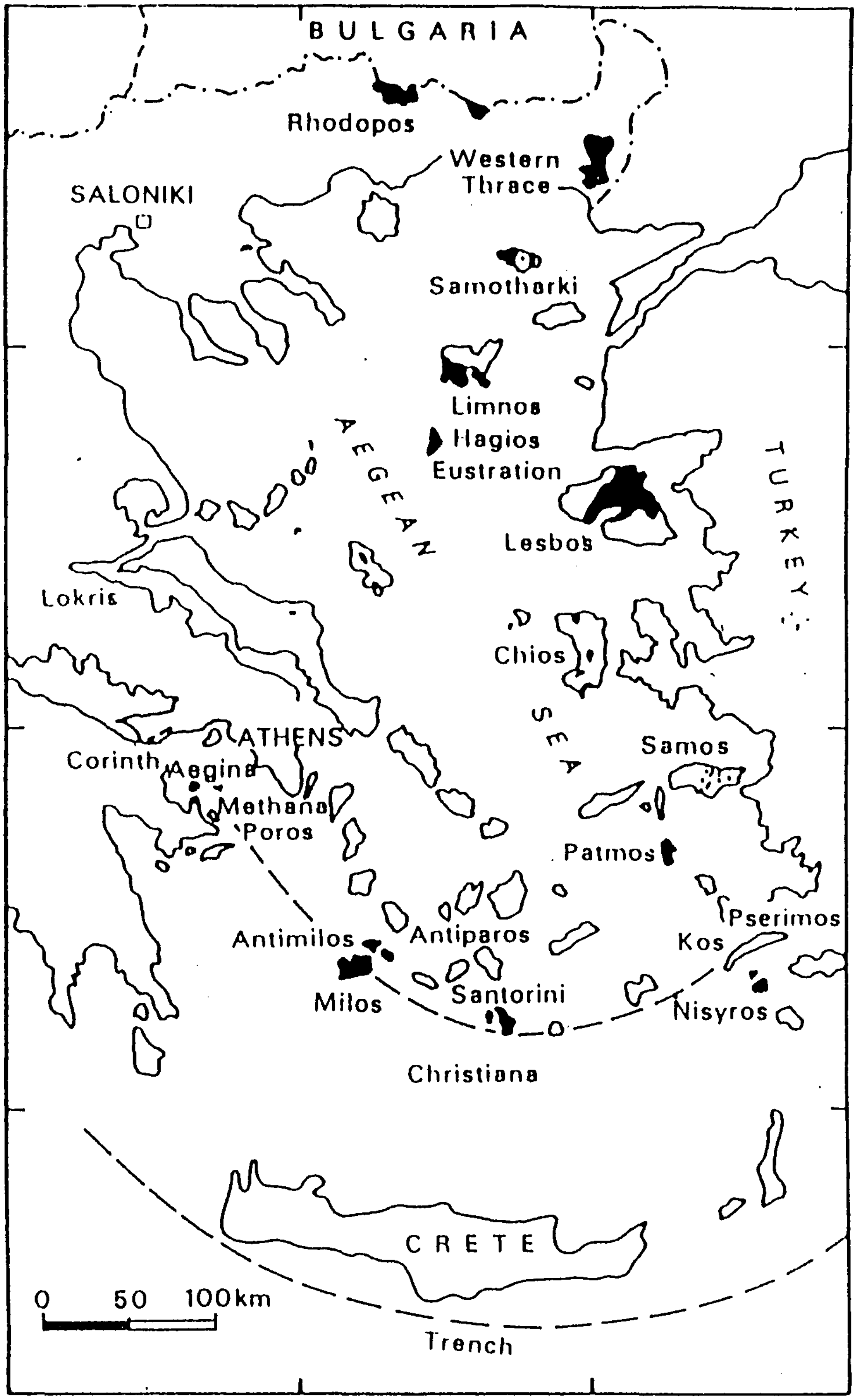


Figure 1

Map of the Aegean Sea showing major outcrops of volcanic rocks
The dashed lines mark the Hellenic Trench and the Hellenic Arc.
(From Barton and Wyers, 1991)

GEOLOGY

The geology of Patmos Island is described in Wyers and Barton (1986). The basalts of Patmos are alkaline in nature, that is they have high concentrations of alkalies (Na, K) relative to silica. Several phases of volcanic activity are recognized on Patmos, including the eruption of ne-trachybasalts, hy-trachybasalts and Q-trachytes which occured 5.5 - 5.7 million years ago; and the eruption of ne-trachybasalts which occured 4.5 - 4.6 million years ago (Barton and Wyers, 1991). These basalts account for a large amount of the rock that makes up the island (fig. 2) Other rock types found on Patmos include rhyolite, phonolite, pyroclastics and marble. With the possible exception of zircon, major and trace element data for the ne-trachybasalts, hy-trachybasalts, trachyandesites and the trachytes are consistent with an evolutionary model involving fractional crystallization in an intermediate depth (about 8 kilometers) magma chamber (Wyers and Barton, 1986).

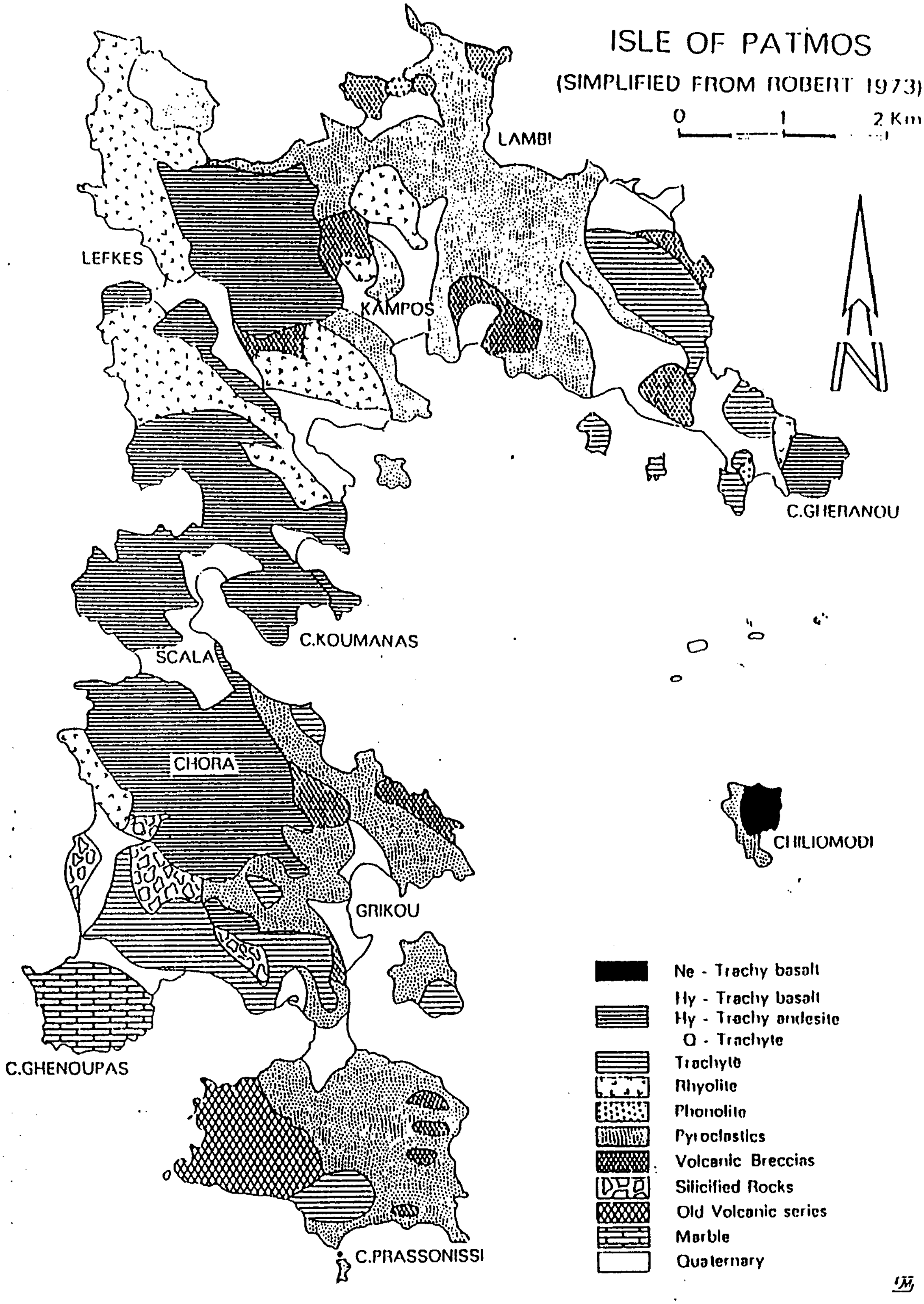


Figure 2

Simplified geologic map of Patmos Island, Greece (from Barton and Wyers, 1986)

METHODS

Three samples collected from Patmos Island were examined for this study, Pat 26, Pat 97, Pat 167. The samples were made into thin sections and then analyzed with the electron microprobe. The microprobe analyzes the sample by bombarding a specific part of the thin section with electrons. X-Rays are produced as a result of this bombardment. Using the wavelength and intensity of the lines in the X-ray spectrum the elements present in the thin section may be identified and their concentrations estimated.

The analysis of the samples involved scanning the thin sections for plagioclase phenocrysts. When the phenocrysts were located, a probe analysis of the grain's core and rim was conducted. The evolution of the magma that the basalt formed from is be reflected by the change in composition, or zonation that takes place from the core of the grain to it's rim. This will give the researcher an idea of the conditions that exsisted as the magma cooled.

Given that:

$$K_D = \frac{(Ca/Na)_{plag}}{(Ca/Na)_{liquid}}$$

Values of $[Ca/Na]_{plag}$ were calculated for all three samples by calculating the molar values of the CaO and Na_2O concentrations that were determined by the microprobe analysis. The values for $[Ca/Na]_{liquid}$ were calculated from whole rock analysis of the three samples conducted previous to this study (Barton and Wyers, 1991). The results of these calculations are displayed in Tables 1 and 2.

It should be noted that the K_D analysis of the plagioclase phenocryst was limited to the more Anorthitic (more calcic) phenocryst. Very calcic plagioclase ($>An_{90}$) form in basaltic melts with high water content, but cannot form from dry melts with normal arc Na_2O and CaO concentrations (Sisson and Groves, 1992). Since no plagioclase phenocryst with $>An_{90}$ were found in these samples, the more calcic phenocryst present were examined. Since very calcic plagioclase will not form in dry melts, it was believed that examination of the most calcic phenocryst would be the best to study to confirm water was indeed present. The [Ca/Na] ratios tabulated were then plotted and compared against known values of K_D, and an estimate of water content was made.

SAMPLE	GRAIN #	CORE/RIM	$[Ca/Na]_{plag}$
PAT 167	4	CORE	8.2583
PAT 167	7	CORE	7.7456
PAT 167	9	CORE	12.293
PAT 167	9	RIM	7.9796
PAT 167	24	CORE	15.39
///////	/////////	//////////	////////////
PAT 26	1	CORE	10.186
PAT 26	2	CORE	18.29
PAT 26	2	RIM	12.55
PAT 26	4	RIM	10.18
PAT 26	6	CORE	10.03
PAT 26	8	CORE	9.51
PAT 26	8	RIM	16.21
PAT 26	9	CORE	12.92
PAT 26	9	RIM	11.36
PAT 26	10	CORE	11.68
PAT 26	11	RIM	9.253
///////	/////////	//////////	////////////
PAT 97	---	CORE	7.41

TABLE 1
[Ca/Na] Ratios for Plagioclase Phenocryst for Basalt Samples, Patmos, Greece

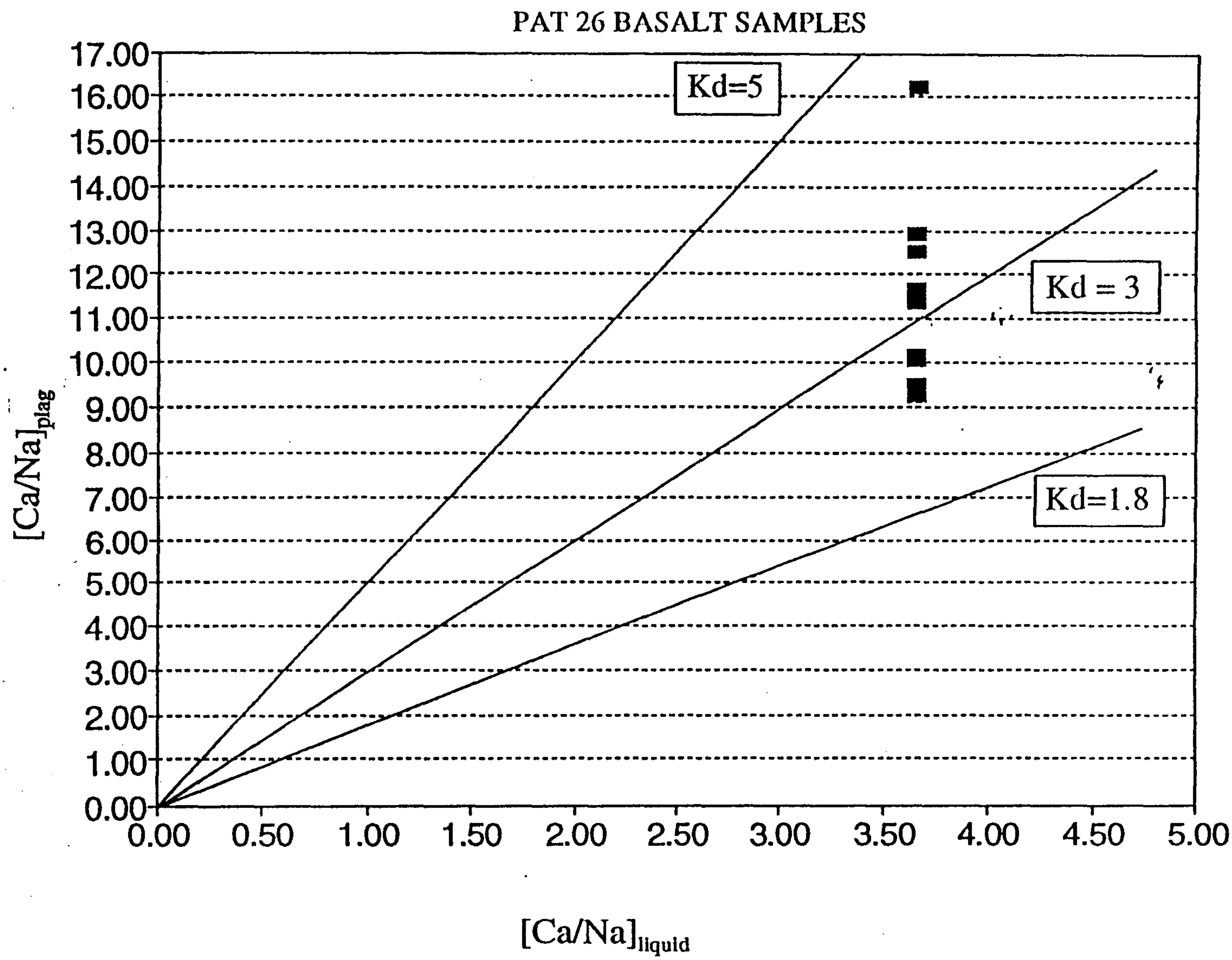
SAMPLE	$[Ca/Na]_{liquid}$
PAT 26	3.66
PAT 97	2.31
PAT 167	2.535

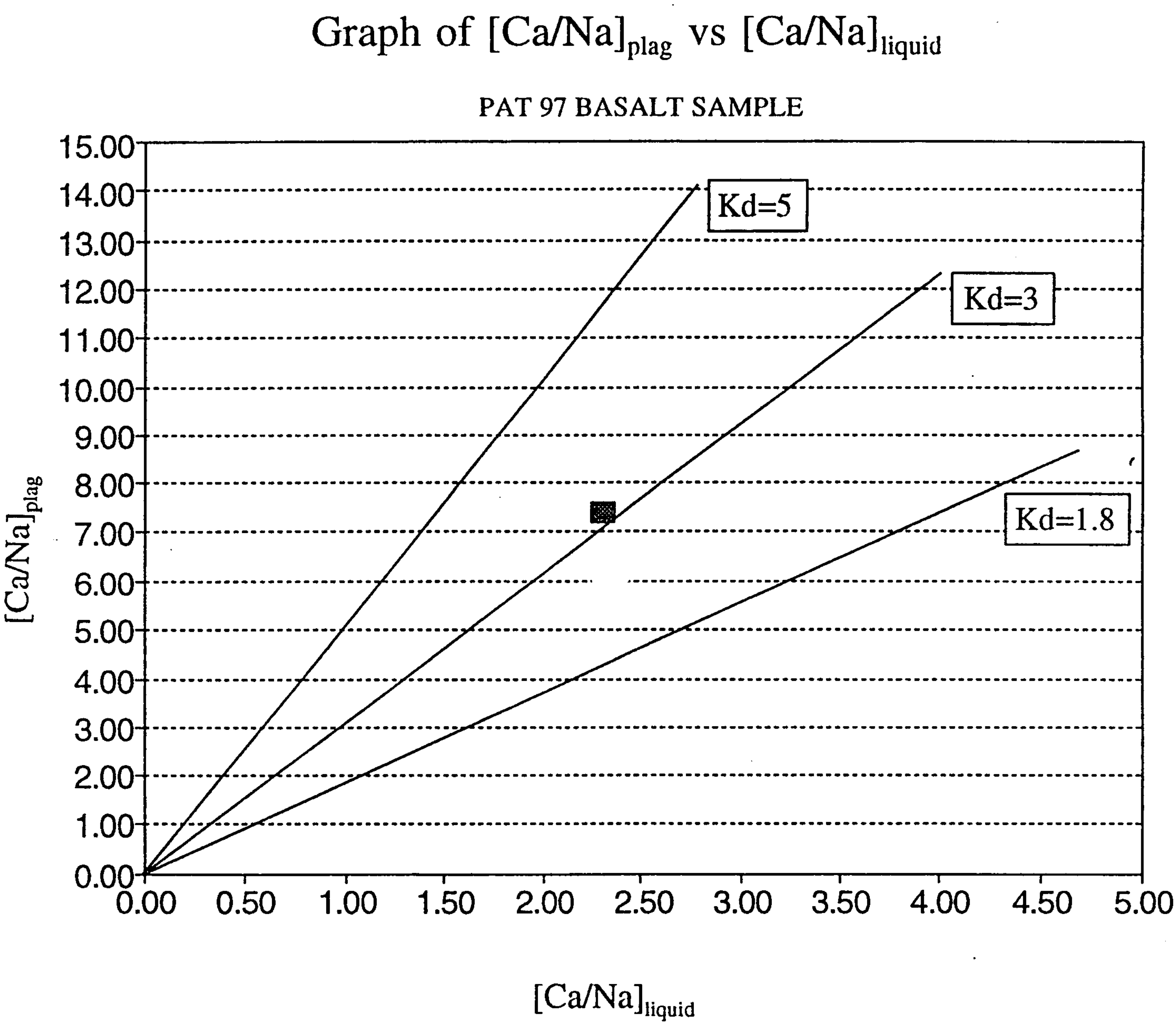
TABLE 2
[Ca/Na] Ratios for magma Basalt Samples Patmos, Greece

RESULTS

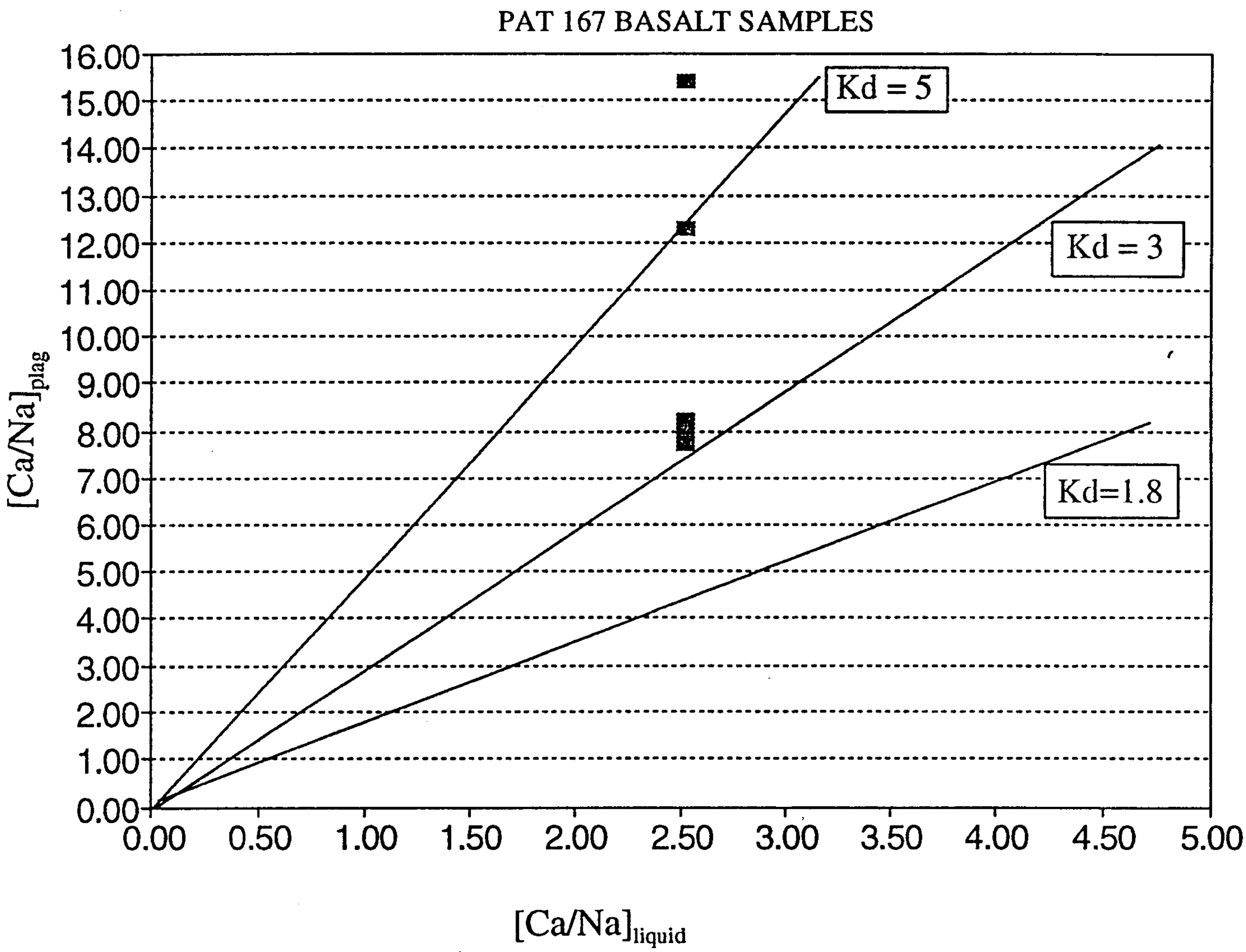
The data for the three samples was plotted against three known values of K_D. From the plots (see pp. 9-11) it was determined that the samples did indeed contain various amounts of water. Given that K_D values of 1.8, 3, and 5 roughly correspond to water percentages of 2, 4, and 6, the water weight percentage of the samples was estimated. The sample PAT 26 possessed phenocryst with water content varying from about 2% H_2O to 6% H_2O. Sample PAT 97 possessed a water content of about 4% and PAT 167 had a water weight percentage that varied from 4% to values greater than 6%.

Graph of $[Ca/Na]_{plag}$ vs $[Ca/Na]_{liquid}$




Graph of [Ca/Na]$_{plag}$ vs [Ca/Na]$_{liquid}$
PAT 97 BASALT SAMPLE
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Kd=5
Kd=3
Kd=1.8
[Ca/Na]$_{plag}$
[Ca/Na]$_{liquid}$

Graph of $[Ca/Na]_{plag}$ vs $[Ca/Na]_{liquid}$



DISCUSSION

The data collected and calculated seem to have shown that water was indeed present in the magmas that formed these rocks. Samples PAT 167 and PAT 26 have many high calcic plagioclase phenocryst present. From these two samples it appears that there is enough evidence to suggest that plate subduction did indeed play a part in the genesis of the magma. The problem arises when the data for PAT 97 is examined. Of all the plagioclase cores and rims examined in this sample, only one core was very calcic (An_{78}). The other phenocryst had calcium concentrations ranging from An_5 to An_{63}. A calculation of water content for the low calcic plagioclase, An_5, revealed that even though small amounts of calcium were present, there was still water present in the sample (≈1% H_2O).

The decreasing water content and low calcium content of PAT 97 may indicate that the magma from which this sample originated crystallized later than the parent magmas which produced PAT 26 and PAT 167. As the magma crystallized perhaps the water and calcium present in the magma was depleted early. As a result, later cooling of the magma produced rocks that were depleted in water and calcium relative to the earlier crystallized basalts. This would also explain why the rims of the plagioclase phenocryst in sample PAT 97 show a large change in calcium and water content from the cores to the rims.

CONCLUSIONS

The water content of these samples of basalts from Patmos Islands strongly suggest that the original magma from which these samples originated was derived from a mantle source interacting with a subducting slab. Water content in the samples from Patmos Island ranges from 2% H_2O to >6% H_2O. Sample PAT 97 has anomalously low percentages of calcium and water relative to the other samples. This may be a result of fractional crystallization. It might be worthwhile re-examine this sample for a future study. This would have to involve a very rigorous and detailed study of the sample with the electron microprobe, to determine if the sample possesses any amounts of highly anorthitic plagioclase.

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APPENDIX I

Pat 107 Plagioklaas op basis van 8 O   zaf-corr - 15.000 kV - driftfact. 1,000 - 30 sec count-time.

	plag 18-C	plag 18-R	plag 19-gr-man	plag? 20-i midden	plag 20-R	plag 20-C	plag 21-C	plag 21-R	plag ind 22-C	plag 2 22-C	plag 23-R	plag 24-C	plag 24-R	plag 25-C	plag 26-C	plag 27-C	plag 27-R	plag (lang ..) 20-C rand
SiO_2	50,01	50,53	51,77	50,56	50,14	50,01	48,56	49,66	50,41	49,70	49,08	46,89	50,04	52,02	50,57	48,01	48,48	50,76
Al_2O_3	31,08	31,65	30,84	31,07	31,87	31,04	33,52	32,48	31,50	31,77	31,61	33,41	31,61	30,94	29,92	33,78	32,46	30,88
Cr_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TiO_2	,16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FeO	,52	,86	,72	,90	,62	,50	,63	,64	,84	,38	,71	,91	,57	,97	,91	,95	,58	1,01
MnO	-	,15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MgO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CaO	13,89	14,20	13,60	13,67	14,48	14,23	16,57	15,20	13,96	14,89	14,48	17,27	14,03	13,89	13,35	16,61	15,85	13,89
Na_2O	2,58	3,22	4,17	3,11	3,44	2,44	2,20	2,74	3,17	2,55	2,75	1,24	2,80	3,14	3,28	2,01	1,92	3,11
K_2O	,95	,33	0,55	,27	,30	,29	,19	,39	,36	,44	,41	,13	,46	0,61	,51	,24	0,97	,45
Total	99,21	100,98	101,68	99,60	100,89	99,83	101,69	101,13	100,27	99,73	99,78	99,88	99,53	101,60	98,36	101,63	100,29	100,12

	18-C	18-R	19-gr-man	20-i midden	20-R	20-C	21-C	21-R	22-C ind	22-C 2	23-R	24-C	24-R	25-C	26-C	27-C	27-R	20-C rand
Si	2,304	2,291	2,331	2,316	2,276	2,285	2,195	2,251	2,298	2,277	2,206	2,163	2,299	2,339	2,339	2,176	2,225	2,318
Al	1,688	1,692	1,637	1,670	1,706	1,715	1,787	1,736	1,693	1,716	1,703	1,817	1,709	1,640	1,639	1,806	1,756	1,663
Cr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ti	,006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe	,020	,033	,027	,035	,024	,019	,024	,024	,032	,015	,028	,035	,022	,037	,036	,036	,023	,039
Mn	-	,006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca	,686	,690	,656	,671	,704	,721	,803	,738	,682	,731	,711	,854	,689	,669	,665	,807	,780	,680
Na	,231	,283	,364	,277	,303	,217	,193	,241	,280	,227	,245	,111	,249	,274	,296	,177	,171	,276
K	,056	,019	,032	,016	,018	,017	,011	,023	,021	,026	,025	,008	,027	,035	,030	,014	,057	,026
Som	4,990	5,014	5,008	4,992	5,031	4,974	5,013	5,015	5,006	4,992	4,997	4,988	4,990	4,995	5,004	5,016	5,011	5,002

	18-C	18-R	19-gr-man	20-i midden	20-R	20-C	21-C	21-R	22-C ind	22-C 2	23-R	24-C	24-R	25-C	26-C	27-C	27-R	20-C rand
Ca*	71	70	63	70	69	75	80	74	69	74	72	88	71	68	67	81	77	69
Na*	24	29	35	29	30	23	19	24	28	23	25	11	26	28	30	18	17	28
K*	6	2	2	2	2	2	1	2	2	3	3	1	3	4	3	1	6	3

PAT 97 Plagioklaas op basis van 32 O.

	PA kern	PA rand	PB kern (PL 2)	PB rand	PC kern (PL 1)	PC rand	PD kern (plagioklaas/K-veldspaat)	PD rand	PE kern (PL 3)	PE rand (SAN)
	53.0^5	54.0^5	52.2^5	54.8	47.1	51.2^5	53.7^5	64.6^5	54.5^5	65.0
	28.7^5	28.2	29.7^5	27.6^5	34.8^5	30.5	27.9	20.3^5	27.9^5	20.2^5
	.5	.7	$.5^5$	.6	$.4^5$	.5	.8	.4	$.0^5$	$.3^5$
	–			$.0^5$	–				$.0^5$	$.0^5$
	11.3	10.7^5	12.3^5	10.3	15.7^5	12.8	10.9	1.8^5	10.7^5	$.9^5$
	4.6^5	5.2^5	4.2	5.3^5	2.3^5	4.0	5.1	6.6^5	5.2	6.7
	.4	$.4^5$	$.3^5$	.5	.1	$.2^5$	$.5^5$	5.4^5	$.4^5$	6.9
Σ	99.6^5	99.4	99.4^5	99.2^5	100.6	99.3	99.0	99.3^5	99.6	99.5^5
	9.74	9.86	9.54	10.00	8.60	9.40	9.86	11.66	9.92	11.72
	6.18	6.06	6.42	5.94	7.50	6.58	6.09	4.32	6.00	4.30
	.08	.10	.08	.10	1.30	.08	.12	.06	.10	.06
				(< .02)					(< .02)	(< .02)
	2.30	2.10	2.42	2.00	3.08	2.52	2.14	.36	2.10	.18
	1.64	1.84	1.48	1.86	.84	1.42	1.82	2.32	1.84	2.14
	.10	.10	.08	.12	.02	.06	.12	1.26	.10	1.60
	20.04	20.06	20.02	20.02	20.10	20.06	20.10	19.98	20.06	20.00
	57	52	61	50	78	63	52	9	52	5
	41	46	37	47	21	36	45	59	46	55
	2	2	2	3	1	2	3	32	2	41

Recalc.

PAT. 26 PLAGIOCLASE ON THE BASIS OF 8 O

(1) over 1^C, (2) over 2^C, (8) over 6^C, (3) over 6^R

	1^C	2^C	2^R	3^C	3^R	4^C	4^R	5^C	5^R	6^C	6^R	8^C	8^R	9^C	9^R	10^C	10^R	11^C	11^R	12^B	13^B
O₂	46,02	47,71	47,50	49,21	52,08	48,53	46,94	50,82	50,73	47,72	50,12	46,87	45,69	46,26	45,94	46,56	49,04	47,90	48,45	51,09	50,07
₂O₃	33,26	34,43	34,51	32,95	31,05	33,64	33,20	31,49	31,67	33,79	30,99	33,13	34,30	33,51	33,26	32,90	31,23	32,34	32,71	29,65	30,61
eO	0,79	0,65	0,82	0,74	0,75	0,95	0,58	0,83	0,44	0,48	0,69	0,47	0,47	0,56	0,82	0,85	0,87	0,46	0,40	0,94	0,70
gO	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
aO	16,32	17,08	15,47	16,34	13,93	16,21	16,83	14,52	14,78	16,80	14,36	√16,87	√17,46	√17,55	√16,97	√16,71	14,70	15,98	√15,91	12,82	[illegible]
₂O	1,77	1,08	1,45	2,53	3,24	2,40	1,76	3,02	3,01	1,86	3,34	√1,96	√1,19	√1,50	√1,65	√1,58	2,91	2,19	√1,98	3,72	2,88
₂O	0,32	0,22	0,79	0,28	0,37	0,16	0,00	0,45	0,37	0,16	0,45	0,18	0,07	0,19	0,00	0,11	0,23	0,31	0,24	0,38	0,62
Σ =	99,26	102,03	101,55	102,08	101,44	101,02	99,33	101,16	101,03	100,92	99,97	100,02	99,20	99,59	98,66	98,74	99,00	99,10	99,72	98,63	[illegible]
Si	2,172	2,153	2,157	2,218	2,341	2,215	2,173	2,300	2,295	2,174	2,297	2,164	2,121	2,144	2,147	2,171	2,271	2,217	2,225	2,362	2,312
Al	1,809	1,833	1,845	1,751	1,645	1,753	1,812	1,680	1,629	1,815	1,675	1,804	1,877	1,831	1,833	1,809	1,705	1,765	1,771	1,617	1,566
Fe	0,031	0,025	0,031	0,028	0,028	0,036	0,023	0,032	0,017	0,018	0,027	0,038	0,018	0,022	0,032	0,033	0,031	0,018	0,016	0,037	0,027
Mg	0,012	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
Ca	0,812	0,865	0,800	0,789	0,671	0,792	0,835	0,704	0,717	0,824	0,705	0,835	0,869	0,872	0,850	0,835	0,730	0,793	0,783	0,635	0,702
Na	0,159	0,095	0,128	0,222	0,282	0,212	0,158	0,265	0,264	0,165	0,297	0,176	0,108	0,136	0,150	0,143	0,262	0,197	0,177	0,334	0,258
K	0,019	0,013	0,046	0,016	0,021	0,010	0,000	0,023	0,022	0,010	0,026	0,011	0,004	0,011	0,000	0,007	0,014	0,018	0,014	0,023	0,037
Σ =	5,013	4,984	5,007	5,025	4,984	5,014	5,000	5,006	5,004	5,005	5,027	5,028	4,997	5,015	5,012	4,999	5,014	5,008	4,985	5,007	5,003
An	82,3	88,9	82,1	75,8	68,9	78,1	84,1	70,7	71,5	82,5	68,6	81,7	88,6	85,6	85,0	84,8	72,6	78,6	82,4	64,1	70,4
Ab	16,1	9,8	13,1	21,6	29,0	20,9	15,4	26,6	26,4	16,5	28,9	17,2	11,0	13,3	15,0	14,6	26,0	19,6	19,2	33,7	25,9
Or	1,9	1,3	4,7	1,6	2,2	1,0	0,0	2,3	2,2	1,0	2,6	1,1	0,4	1,1	0,0	0,7	1,4	1,8	1,4	2,3	3,7

DP

(9)

POINT N : 17 X= -5596 Y= 31998 Z= -6 FELDSPAR
PAT/

ELT.	PEAK POS.	PEAK (C/S)	BACKGR. (C/S)	I.X./I.STD.	K.RATIO	SIG/K	BEAM
							20.
Na	46367	144.14	11.90	0.16851	0.00609	2.7	
K	42723	27.70	10.70	0.01053	0.00113	6.0	
Si	27742	6678.02	74.81	0.69420	0.16800	0.5	
Al	32454	5676.83	86.02	0.96069	0.14061	0.5	
Ca	38379	1845.08	15.80	0.88849	0.10731	0.9	
Mg	38488	22.70	20.00	0.00277	0.00009	6.7	
Fe	48078	19.80	5.90	0.06124	0.00357	7.3	
Ba	31715	18.50	18.10	0.00011	0.00005	7.4	

FELDSPAR CATIONS ON 8. <O> BASIS

			WT.%	CATIONS
SiO2	48.2645	Si	22.5610	2.1725
Al2O3	34.4771	Al	18.2474	1.8290
MgO	0.0215	Mg	0.0130	0.0014
CaO	16.9507	Ca	12.1148	0.8175
FeO	0.5650	Fe	0.4392	0.0213
BaO	0.0091	Ba	0.0081	0.0002
Na2O	1.5234	Na	1.1301	0.1330
K2O	0.1581	K	0.1312	0.0091
TOTAL	101.9693			4.9840

AB: 13.86 OR: 0.95 AN: 85.20 FM: 0.94

POINT N : 18 X= -5594 Y= 32024 Z= -10 FELDSPAR
PAT/167, R-#9

ELT.	PEAK POS.	PEAK (C/S)	BACKGR. (C/S)	I.X./I.STD.	K.RATIO	SIG/K	BEAM
							20.
Na	46367	205.08	15.50	0.24177	0.00873	2.3	
K	42723	34.60	8.70	0.01606	0.00173	5.4	
Si	27742	6926.65	72.51	0.72055	0.17438	0.4	
Al	32454	5461.21	83.02	0.92412	0.13526	0.5	
Ca	38379	1709.93	16.50	0.82247	0.09933	0.9	
Mg	38488	20.20	19.10	0.00113	0.00004	7.1	
Fe	48078	20.10	4.70	0.06785	0.00396	7.2	
Ba	31715	22.50	17.40	0.00141	0.00069	6.7	

FELDSPAR CATIONS ON 8. <O> BASIS

			WT.%	CATIONS
SiO2	49.9218	Si	23.3357	2.2390
Al2O3	33.2851	Al	17.6165	1.7595
MgO	0.0088	Mg	0.0053	0.0006
CaO	15.7121	Ca	11.2296	0.7550
FeO	0.6262	Fe	0.4868	0.0235
BaO	0.1154	Ba	0.1033	0.0020
Na2O	2.1770	Na	1.6150	0.1893
K2O	0.2421	K	0.2010	0.0139
TOTAL	102.0886			4.9828

AB: 19.76 OR: 1.45 AN: 78.80 FM: 0.98

POINT N : 19 X= -7809 Y= 31361 Z= -11 FELDSPAR
PAT/167, C-#10