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THE CRYSTALLIZATION OF TERNARY FELDSPARS: A STUDY FROM NATURAL ROCKS

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ABSTRACT. Composition of coexisting alkali and plagioclase feldspar phenocrysts and groundmass feldspars in trachytes from the Island of Ischia have been used to study the crystallization behavior of feldspars in the ternary system. The plagioclase feldspars invariably show textures that can be interpreted as due to resorption. Using Greig's (unpub.) graphical construction it is shown that the plagioclase feldspars in this suite of rocks would be expected to be resorbed when their composition is about An_{40-35} under conditions of perfect equilibrium cooling. Partial fractionation will tend to delay resorption to a later stage of crystallization.

INTRODUCTION

As part of a study of the ternary feldspar system a number of samples of two-feldspar trachytes, one phonolite, and one latite from the Island of Ischia in the Bay of Naples, were selected for study. The memoir by Rittmann (1930) on the geology of Ischia gives a very complete account of the chemistry and petrography of the rocks. The present paper is a study of the chemistry of the feldspars from these rocks and an interpretation of their course of crystallization.

Theoretical studies have been made of the phase relations in the ternary feldspar system, among these being the works of Tuttle and Bowen (1958), Turner and Verhoogen (1960), Stewart and Roseboom (1962), and Carmichael (1963); in addition a beginning has been made on experimental studies in the system An–Ab–Or by Franco and Schairer (1951) and An–Ab–Or–H_2O at P_{H_2O} = 5000 bars by Yoder, Stewart, and Smith (1957) and at P_{H_2O} = 1000 bars by Iiyama (1966).

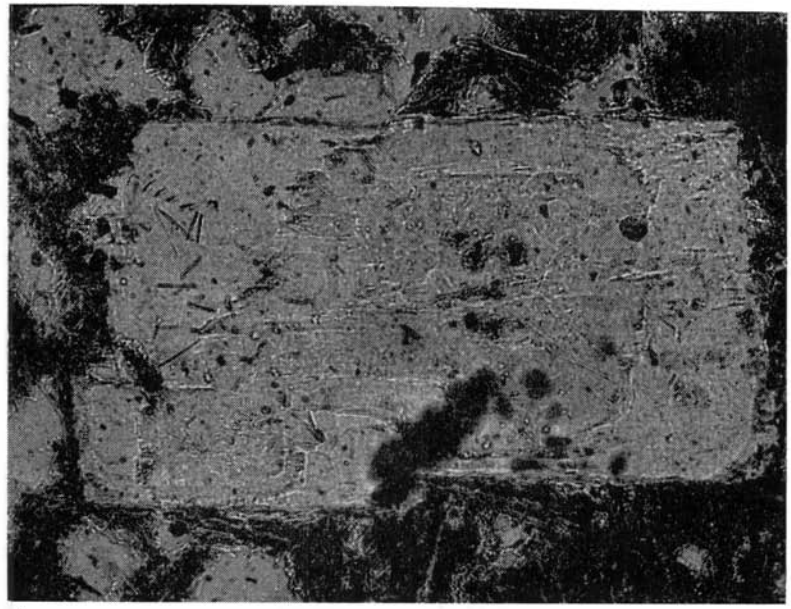
The ten specimens were selected because each of them contained three generations of feldspars—phenocrysts, microphenocrysts, and groundmass—and each contained both plagioclase and alkali feldspar. In addition to the feldspars, pyroxene, biotite, and iron ore were present in almost all the specimens. The Arso trachyte 63/4 is distinctive in that it contains olivine. The most common accessory minerals in all specimens are apatite and sphene.

THE FELDSPARS AND METHODS OF SEPARATION

Sanidine forms phenocrysts varying from about 1.5 to 6 mm in length occurring as disseminated crystals in the more compact rocks and as irregular clusters of crystals in the vesicular rocks. Within many of the sanidine phenocrysts are cores of plagioclase and in some cases only lamellae of plagioclase. (pl. 1-A, B, C). Plagioclase does not occur as separate phenocrysts outside sanidine crystals, but in some of the rocks it forms microphenocrysts.

The various feldspars were separated in the following manner: part of the hand specimen of rock was cut into thin slices, and the phenocrysts broken out from the rock. This phenocryst fraction was separated by hand-picking the fairly large fragments of feldspar which were then crushed to pass through a 120-mesh sieve and purified by passing through

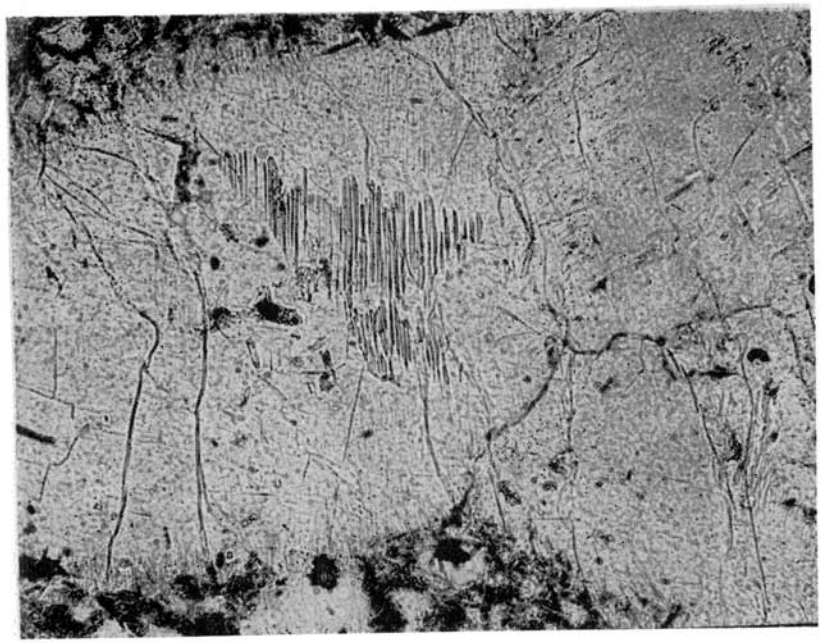
PLATE 1



A.

B.

PLATE 1 (Continued)



C.

A. Plagioclase within alkali feldspar phenocryst from trachyte near top of Monte Tabor spine (specimen 16). X70.

B. Plagioclase fragments within alkali feldspar phenocryst from Zara trachyte (specimen 1). X25.

C. Lamellae of plagioclase within alkali feldspar phenocryst in trachyte from Monte Posta Lubriania (specimen 6). X70.

an electro-magnetic separator. From this feldspar fraction the plagioclase was removed by repeated centrifuging in heavy liquids, and a final purification of the alkali feldspar portion was made by passing through the electro-magnetic separator again. A pure plagioclase fraction was obtained by repeated centrifuging, but only the heaviest fraction could be obtained pure; the lightest fraction was contaminated by alkali feldspar in almost every case and was not suitable for chemical analysis because of this. The remaining phenocrysts were removed from the rock slices, using a small diamond drill, and the rock crushed to pass through a 40-mesh sieve. Any remaining parts of phenocryst were removed by hand picking. The sample was then passed through a 120-mesh sieve, and the microphenocrysts removed by an electro-magnetic separator; microphenocryst feldspars were the only non-magnetic material whereas the groundmass feldspars had magnetic material adhering to them. Two of the rocks contained microphenocrysts of both plagioclase and alkali feldspar, and these were separated by heavy liquids. The groundmass was

finally separated by crushing and seiving through a 200-mesh sieve and repeated centrifuging in heavy liquids.

All samples with the exception of the groundmass were judged to be 99.5 percent pure—the impurities in the groundmass were mainly ore minerals and some sodalite or analcite or glass which it proved impossible to remove and impossible to make allowance for in calculating the composition of the feldspar.

As mentioned above two of the samples have microphenocrysts of plagioclase, and from the partial analyses they are found to be very basic, An_{70-75}. One is from the Arso olivine trachyte (no. 4) and the other from the Molara latite (no. 31). These crystals are very strongly zoned, and the analyses are probably representative of the cores of the crystals rather than the bulk composition since the rims may have been lost during crushing of the rock. Within the sanidine phenocrysts, the plagioclases in some of the rocks have cores of plagioclase of even higher refractive index included, and these may be as basic as the microphenocrysts mentioned above. It has been assumed that these very basic plagioclases are evidence of the evolution of these rocks by fractional crystallization and that only the rims were in equilibrium with the alkali feldspars and liquid in the rock at the time of consolidation. The two analyzed microphenocryst plagioclases are plotted in figure 1 where they are represented by asterisks, but they will not be considered further here.

ANALYTICAL METHODS

Complete chemical analyses were undertaken on feldspars (alkali feldspars) where the amount of isolated and purified sample was sufficient for this purpose. In the other cases only Na_2O, K_2O, and CaO were determined.

The following methods were adopted. Gravimetric determinations of SiO_2 and R_2O_3 were followed by a photometric determination of Fe_2O_3, MnO, TiO_2, residual SiO_2 (UNICAM spectro-photometer), Na_2O and K_2O (EEL flame photometer), and rapid determination of CaO and MgO (EEL Quantitrator). In the case of complete analyses the amount of SiO_2 was determined by a combined gravimetric and colorimetric method (Jeffrey and Wilson, 1960).

Complete or partial analyses of the feldspars are in tables 1 and 2 together with the calculated weight percentages of the feldspar molecules Or, Ab, and An. It can be seen that the analyses generally calculate to within 2 percent feldspar, and these are only recalculated when they deviate by more than 1 percent.

SOLID SOLUTION IN TERNARY FELDSPARS

The extent of solid solution of anorthite in alkali feldspars and orthoclase in plagioclase feldspars depends mainly on the temperature of crystallization and whether or not another feldspar is present.

The greatest amount of ternary solid solution may be expected in feldspars from assemblages consisting of two feldspars and liquid, and

it is assumed by most authors that the feldspars from trachytes will show larger amount of calcium in the alkali feldspars than the corresponding phenocrysts in phonolites and rhyolites where liquidus temperatures are lowered by additional components. The effect of pressure on the limits of solid solution has not yet been evaluated.

The form of the feldspar diagram has been indicated by the studies of Yoder, Stewart, and Smith (1957), Tuttle and Bowen (1958), Stewart and Roseboom (1962), and Carmichael (1963). All these studies make it clear that, when a liquid lies on the field boundary, a stage in cooling may be reached during equilibrium crystallization where one of the previously precipitated feldspars begins to dissolve. Stewart and Roseboom's very detailed theoretical treatment of the low temperature termination of the three-phase region considers the various possibilities and in one of these (case C) the two feldspars approach each other in composition and become identical at the same temperature as the liquid reaches the end of the field boundary. Even in this rather idealized situation, one of the feldspars may be resorbed for certain bulk compositions.

The position of the intersection of the solvus and the solidus for this suite of rocks from Ischia has been obtained by plotting the compositions of the *phenocryst* alkali feldspars and plagioclases in figure 1. Coexisting feldspars are joined by tie lines. All the compositions have not been plotted to avoid confusion of the diagram; all the microphenocrysts of alkali feldspar, for example, are not plotted, but in each case the microphenocrysts are more sodium-rich than the phenocrysts, as might be expected. The slope of the tie lines is very different from those obtained by Yoder, Stewart, and Smith (1957) for the synthetic system, but their data pertained to temperatures of 700° to 740°C at $P_{H_2O} = 5000$ bars whereas the temperatures in the natural assemblages are likely to have been much higher because of the lower pressure of water. The slopes of the tie lines are similar to those found by Carmichael (1965) for undersaturated trachytes.

From the brief description of the textural relationships of the feldspars given above it is perhaps unjustifiable to join the compositions of phenocrysts plagioclase to those of the alkali feldspars, and some explanation is warranted here. The plagioclases described as phenocrysts are in all cases mantled by alkali feldspar and so are unlikely to be in equilibrium with the outer part of the alkali feldspar crystals or with the liquid that crystallizes to form the groundmass. However most of these rocks have a rather low CaO content, and so their liquids will meet the feldspar field boundary after a rather short period of plagioclase crystallization and thereafter will crystallize plagioclase and alkali feldspar together. At some stage the plagioclase may begin to dissolve, and it is possible that this is the period at which the mantles of alkali feldspars are deposited on the plagioclase crystals—this is anticipating the arguments to be put forward at a later stage in this paper.

The position of the field boundary separating the plagioclase field from the alkali feldspar field has been obtained from the plot of the

TABLE 1

Alkali feldspars

A. Phenocrysts

Sample no.:	1	2	4	6	7	13	14	16	25	31
SiO_2	65.16	65.10	65.03			65.22	64.89		65.77	65.07
TiO_2	0.09	0.09	0.15			0.11	0.13		0.11	0.08
Al_2O_3	19.57	20.06	20.06			20.76	19.99		19.43	19.58
Fe_2O_3 (with FeO)	0.31	0.32	0.30			0.29	0.29		0.43	0.28
MnO	n.d.	n.d.	n.d.			n.d.	n.d.		n.d.	n.d.
MgO	0.08	0.13	0.13			0.12	0.13		0.13	0.08
CaO	0.83	1.15	1.02	1.17	1.18	1.00	1.14	1.36	0.93	1.15
Na_2O	5.38	4.79	4.54	4.78	4.58	5.24	4.74	4.61	6.73	4.76
K_2O	8.30	8.97	9.49	8.82	9.01	8.40	9.20	8.97	6.46	9.11
Total	99.72	100.61	100.72			101.14	100.60		99.99	100.11
Or	49.04	53.00	56.07	52.12	53.24	49.63	54.36	51.94	38.17	53.83
Ab	45.52	40.53	38.41	40.44	38.75	44.33	40.10	39.00	56.94	40.27
An	4.12	5.70	5.06	5.80	5.85	4.96	5.65	6.75	4.61	5.70
Total feldspar	98.68	99.23	99.54	98.36	97.84	98.92	100.11	97.69	99.72	99.80
Recalculated to 100%:										
Or	49.70			52.99	54.42	50.17		53.17		
Ab	46.13			41.11	39.60	44.81		39.92		
An	4.17			5.90	5.98	5.02		6.91		

B. Microphenocrysts

Sample no.:	1	2	6	7	13	14	16	25
SiO_2		64.91				64.86		
TiO_2		0.13				0.21		
Al_2O_3		18.93				18.66		
Fe_2O_3		0.47				0.47		
MgO		0.13				0.25		
CaO	1.43	0.94	1.54	1.30	1.08	0.98	1.27	0.84
Na_2O	6.50	6.00	4.88	4.53	5.99	5.81	4.69	7.06
K_2O	6.46	7.65	8.40	8.80	7.74	7.82	8.60	6.30
Total		99.16				99.18		
Or	38.17	45.20	49.64	52.00	43.73	46.21	50.82	37.22
Ab	54.99	50.76	41.29	38.33	50.68	49.16	39.68	59.73
An	7.09	4.66	7.64	6.45	5.36	4.86	6.30	4.16
Total feldspar	100.25	100.62	98.57	96.78	99.77	100.23	96.80	101.11
Recalculated to 100%:								
Or			50.36	53.73			52.50	36.81
Ab			41.89	39.61			40.99	59.07
An			7.75	6.66			6.51	4.12

TABLE 1 (continued)

	C. Groundmass							
Sample no.:	1	2	4	6	7	13	14	16
CaO	0.97	0.98	n.d.	1.67	1.65	1.02	1.13	1.44
Na_2O	7.09	6.57	6.00	5.90	6.34	6.24	6.55	6.15
K_2O	6.22	6.89	7.10	6.85	6.48	7.36	6.45	6.89
Or	36.75	40.71	41.95	40.48	38.29	43.49	38.11	40.71
Ab	59.99	55.95	50.76	49.92	53.64	52.79	55.42	52.04
An	4.81	4.86		8.28	8.19	5.06	5.60	7.14
Total feldspar	101.55	101.16		98.68	100.12	101.34	99.13	99.89
Recalculated to 100%:								
Or	36.19	40.24	41.95	41.02		42.92	38.44	
Ab	59.07	54.95	50.76	50.59		52.09	55.91	
An	4.74	4.61	7.29	8.39		4.99	5.65	

1. Trachyte, Zara lava flow, Villa Cigliano, Monte Caruso (0.2 percent normative Q).
2. Trachyte, Zara lava flow, 1/4 mile northeast of specimen 1 (0.2 percent normative Q).
4. Olivine trachyte, Arso lava flow (1.75 percent normative ne).
6. Trachyte, Monte Posta Lubriania, south of Monte Maschiatta.
7. Trachyte, Fondo Ferraro, south of Monte Maschiatta.
13. Trachyte, 200 yards west of Monte Tabor spine.
14. Trachyte, Monte Tabor spine (0.98 percent normative ne).
16. Trachyte, near top of Monte Tabor spine.
25. Phonolite, San Angelo dome (4.26 percent normative ne).
31. Latite, Molara Crater (no normative Q or ne).

groundmass compositions in figure 2, in which it is assumed that the groundmass feldspars are representative of the feldspathic components of the liquids, and that the liquids lie on the field boundary. The field boundary can only be located very approximately because of the scatter of points representing groundmass feldspar. This may be partly due to the difficulty of obtaining pure samples of groundmass feldspar for analysis and partly due to the fact that some of the natural liquids may not in fact lie on the field boundary. If the plagioclase is completely mantled by alkali feldspar, then two feldspars are not in equilibrium with the liquid, and the liquid cannot remain on the field boundary. In addition preferential fractionation of one feldspar could cause the liquid to leave the field boundary and subsequently return to the boundary. In figure 3, three-phase triangles have been drawn for only four of the rocks. It is clear from figure 1 that a number of the two-feldspar tie lines will intersect so that the three-phase triangles do not represent a series of temperatures in the same system. Such discrepancies are to be expected from a suite of natural rocks.

EQUILIBRIUM CRYSTALLIZATION IN THE FELDSPAR SYSTEM

We are interested in trying to determine the course of equilibrium crystallization in this system with the data we have available from these

TABLE 2

Plagioclase

A. Phenocrysts

Sample no.:	1	2	4	6	7	14	16	31
CaO	9.34	9.33	10.45	9.57	10.07	10.31	9.03	12.20
Na_2O	5.67	5.79	5.25	5.49	5.34	5.28	5.69	4.45
K_2O	0.92	1.16	0.95	1.01	0.81	0.81	0.87	0.82
Or	5.44	6.85	5.61	5.97	4.79	4.79	5.14	4.84
Ab	47.97	48.99	44.42	46.45	45.18	44.67	48.14	37.65
An	46.36	46.29	51.84	47.48	49.96	51.15	44.80	60.52
Total feldspar	99.75	102.13	101.87	99.90	99.93	100.61	98.08	103.01
Recalculated to 100%:								
Or		6.71	5.51			4.76	5.24	4.70
Ab		47.97	43.60			44.40	49.08	36.55
An		45.32	50.89			50.84	45.68	58.75

B. Microphenocrysts

Sample no.:	4	31
CaO	15.59	14.67
Na_2O	2.64	2.99
K_2O	0.56	0.63
Or	3.31	3.72
Ab	22.34	25.30
An	77.34	72.78
Total feldspar	102.99	101.80
Recalculated to 100%:		
Or	3.22	3.66
Ab	21.69	24.87
An	75.09	71.49

rocks. We are much indebted to Dr. J. W. Greig of Pennsylvania State University for drawing our attention to a graphical construction he has evolved for determining the change of mass of the phases in a ternary system involving ternary solid solutions. Dr. Greig has very generously permitted us to use his notes on this subject in which he deals with the most general case, but we have chosen to apply his construction only to the system under discussion. The present authors are alone responsible for any lack of rigor in the treatment given here.

The range of temperature covered by the three-phase triangles drawn from the present data is insufficient to illustrate this construction clearly, and so we have drawn in figure 4 part of a hypothetical phase diagram for the ternary feldspar system, the shape of the highest temperature three-phase triangles being based on those of figure 3, but the lower temperature triangles are only possible shapes of these triangles.

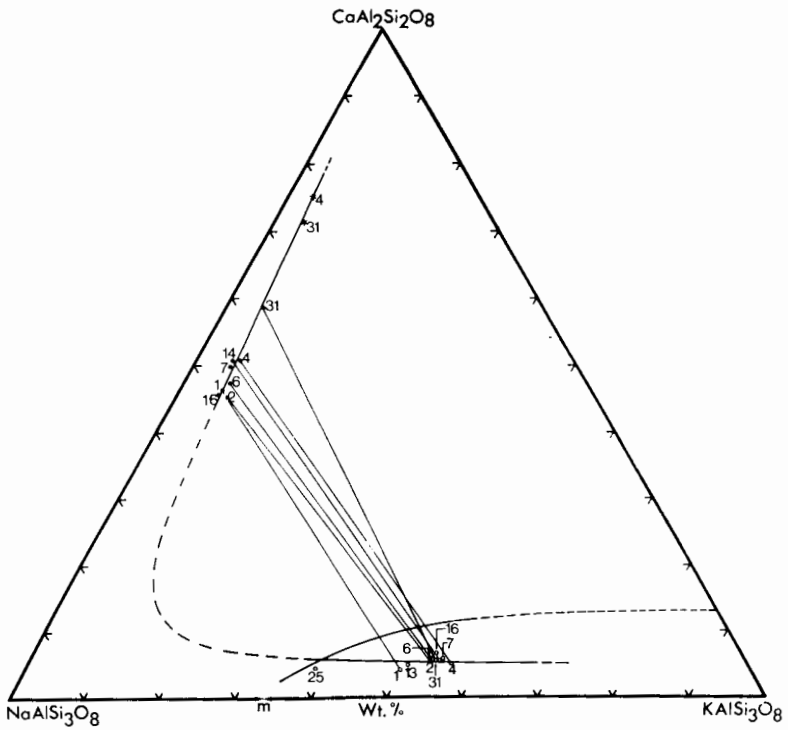


Fig. 1. Plot of compositions of feldspar phenocrysts from Ischia lavas. Coexisting feldspars are joined by tie lines, and the curve representing the intersection of solvus and solidus is drawn to pass through the feldspar compositions. The alkali feldspar phenocrysts from a phonolite (no. 25) and the microphenocryst plagioclases from an olivine trachyte (no. 4) and a latite (no. 31) are plotted for completeness.

The field boundary is drawn in figure 4 as also is the path of the alkali feldspar composition in equilibrium with liquid and plagioclase feldspar. Liquid compositions are represented by the letter "l", alkali feldspar by the letter "a", and plagioclase by the letter "p"; to permit enlargement of the critical area of the diagram the plagioclase corners have been omitted. A bulk composition B is chosen, and through this point, lines are drawn from the plagioclase apex of each three-phase triangle to meet the liquid-alkali feldspar side of the corresponding triangle. These intersections are marked z_3, z_4, z_5 and z_6. For each instant of temperature represented by a three phase triangle, the point z represents the composition of alkali feldspar + liquid that together with plagioclase make up the bulk composition.

Whether the change of mass of the plagioclase (p) is increasing, decreasing, or zero can be obtained for any given temperature interval from this diagram. In figure 4 a line is drawn through z_4 parallel to p_4p_5 to meet Bz_5 in the point σ. (The inset shows this relationship in a different scale).

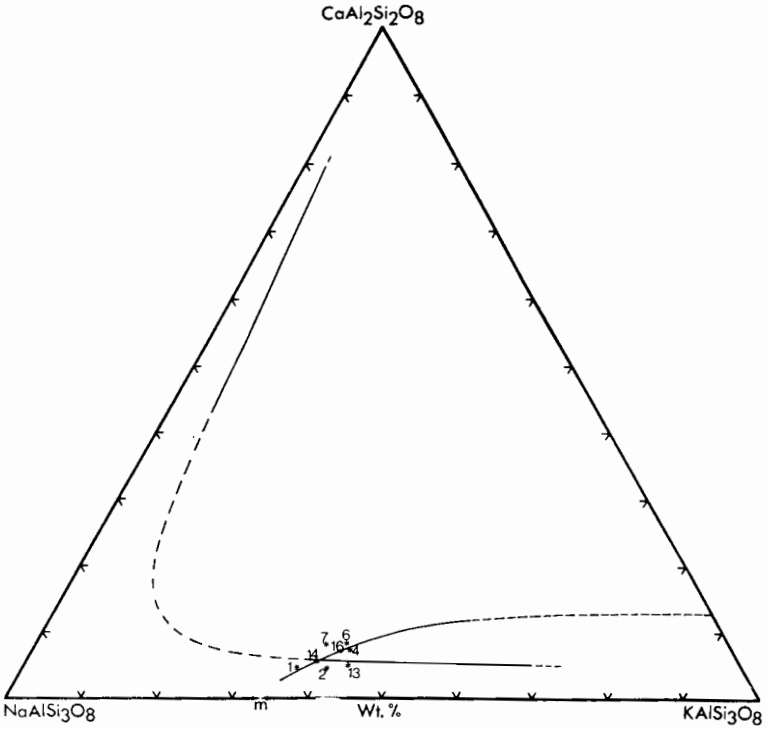


Fig. 2. Plot of the composition of the groundmass feldspars from Ischia trachytes. The field boundary is drawn to pass through the groundmass feldspar compositions.

At the temperature represented by point 4,

$$\frac{\text{mass } p_4}{\text{mass } l_4 + \text{mass } a_4} = \frac{Bz_4}{Bp_4} = \frac{B\sigma}{Bp_5} \quad \text{(similar triangles)}$$

At the temperature represented by point 5,

$$\frac{\text{mass } p_5}{\text{mass } l_5 + \text{mass } a_5} = \frac{Bz_5}{Bp_5}$$

Since Bz_5 is greater than $B\sigma$, the ratio of plagioclase to alkali feldspar + liquid has increased between temperature 4 and temperature 5, and so in this range of temperature, plagioclase must be crystallizing. If z_4 did not intersect Bz_5 but met the prolongation of Bz_5, the ratio of plagioclase to alkali feldspar would be decreasing, and plagioclase would be dissolving in this temperature range.

The locus of z has been drawn in figure 4, and from this can be obtained the critical temperature at which plagioclase is neither crystallizing nor dissolving. This occurs when the tangent to the locus of z is parallel

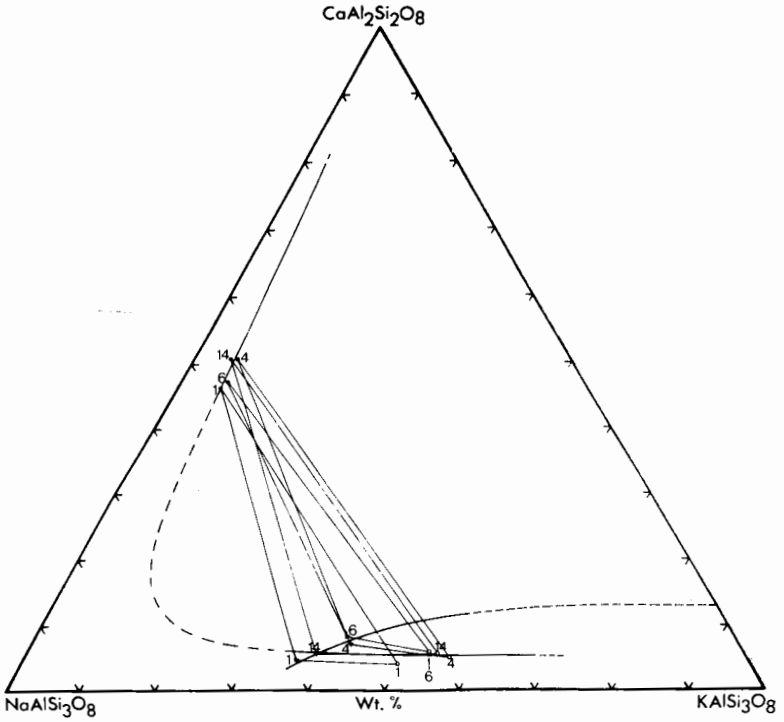


Fig. 3. Three-phase triangles drawn from the compositions of feldspar phenocrysts and the composition of groundmass feldspars. Only four triangles are shown to avoid confusion.

to the path of the plagioclase composition line[1]. The composition of the plagioclase at this critical temperature can be obtained by drawing a line from the point of tangency through the bulk composition to meet the plagioclase composition line. It can readily be seen that the composition of the alkali feldspar and of the liquid at this temperature can be obtained by using similar constructions. For the bulk composition represented by the point B, Or_{35} Ab_{55} An_{10} (table 3), the plagioclase ceases to crystallize and begins to dissolve when its composition is Or_6 Ab_{54} An_{40}.

Figure 5 has been constructed to illustrate the effect of a change in bulk composition on the resorption of plagioclase. The three phase triangles are identical with those in figure 4, and the bulk composition B is also identical. Four bulk compositions have been chosen, and the locus of z has been drawn in each case. Lines that are parallel to the plagioclase path are drawn tangent to the loci of z, and from the points of tangency, the composition of plagioclase when resorption begins can be obtained.

[1] In the more calcic plagioclases the change in composition is represented very closely by a straight line, in this case parallel to Or_6, but in more sodium-rich compositions it must curve due to increasing solubility of the orthoclase component.

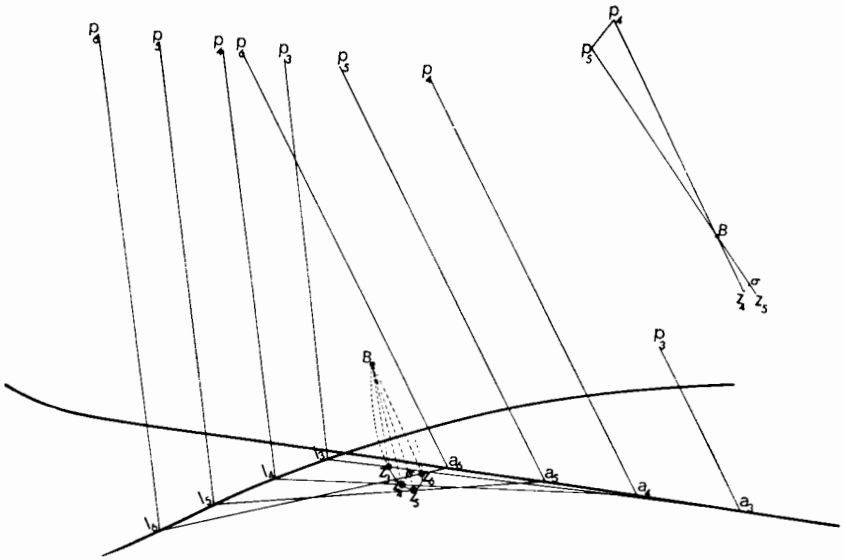


Fig. 4. Part of the feldspar diagram showing the field boundary and the alkali feldspar path. B is a bulk composition, the crystallization of which is discussed in the text.

Table 3 shows that as the bulk composition becomes more albite-rich so also does the composition of the plagioclase at which resorption takes place.

TABLE 3

	Bulk composition			Approximate composition of plagioclase when resoprtion begins		
	Or	Ab	An	Or	Ab	An
A	37.5	52.2	10	6	53	41
B	35	55	10	6	54	40
C	32.5	57.5	10	6	55	39
D	30	60	10	6	57	37

Since we are dealing with a suite of natural rocks, the compositions of which do not fall in the feldspar system, some approximations have to be made if we are to consider the course of crystallization of a given rock composition. We can either plot the C.I.P.W. normative constituents, or we can calculate the feldspar constituents from the total Na_2O, K_2O, and CaO. As has been noted above, the three-phase triangles are only approximations, and the lower temperature triangles we have drawn are purely hypothetical, and in consequence we cannot discuss rigorously the course of crystallization of any of the rocks in this suite. Nevertheless the construction described above enables us to obtain an approximate idea of the compositions at which plagioclase feldspar will begin to dissolve and provides a possible explanation of the textures, which have been described briefly here, of plagioclase with embayed edges or relict plagioclase lamellae within alkali feldspar.

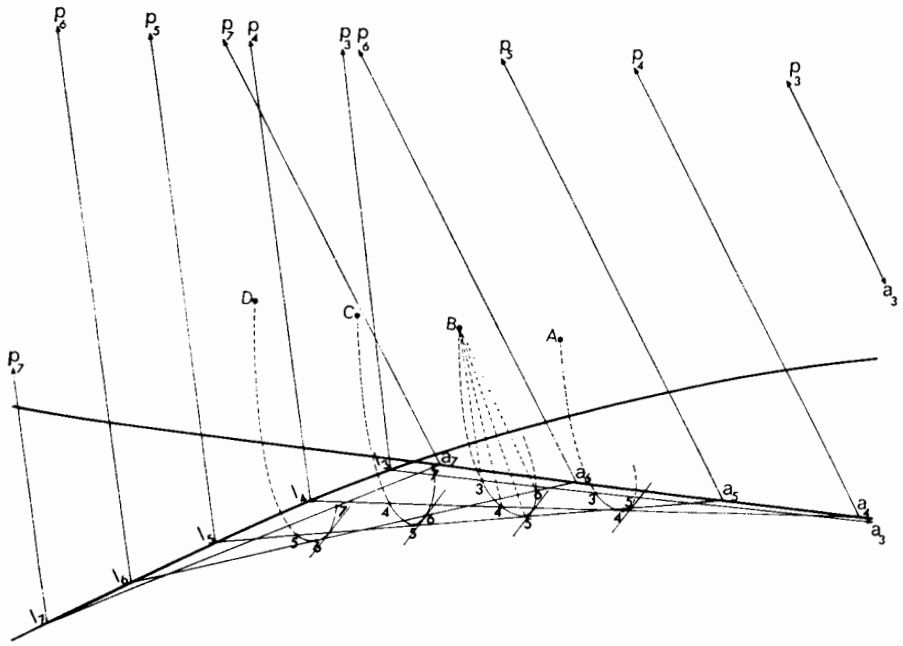


Fig. 5. Part of the feldspar diagram as in figure 4 with four bulk compositions plotted. See text for discussion of crystallization of these bulk compositions.

If perfect equilibrium were attained it can be seen that, for compositions similar to that of a trachyte magma, the plagioclase will begin to dissolve when its composition is about An_{40}-An_{35} but if partial fractionation of the solid phases takes place, the bulk composition will become more sodium-rich, and the stage at which resorption of plagioclase occurs will be delayed. The mantling of the plagioclases has undoubtedly preserved the evidence for their previous existence (see pl. 1-c).

CONCLUSIONS

From the above discussion it can be seen that the course of crystallization of feldspathic liquids cannot be discussed rigorously from the feldspar diagram until the exact relations between the shape of the field boundary and the solvus-solidus intersection are known from experimental studies in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$. In addition, water pressure undoubtedly affects the shapes of these curves, but perhaps equally important is the effect of other components, particularly SiO_2, on the system so that it would be desirable also to know the phase relations in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2.

It was noted previously that in this suite of rocks, the plagioclase feldspars were not in equilibrium with the alkali feldspars and the liquid at the time of consolidation of the rocks. The feldspar tie lines were however drawn on the assumption that the departure from equilibrium was

slight. Further justification for this assumption is provided by comparison of the feldspar tie lines with those of rocks of similar composition and by contrasting them with tie lines from rocks of different composition. Figure 6 has been drawn for this purpose. In three of the four feldspar pairs from the present study the bulk compositions of the rocks are known: specimen 1 has 0.2 percent normative quartz, and specimens 4 and 14 have 1.75 and 0.98 percent normative nepheline respectively. The feldspar pairs from two other trachytes are represented in figure 6 by open circles, and these have 3.98 and 6.53 percent normative nepheline (Carmichael, 1965). These trachytes show tie lines having a similar slope to those of the Ischia rocks. The points on figure 6 that are represented by filled circles are feldspar pairs from oversaturated trachytes and rhyolites. The normative quartz values in the two oversaturated trachytes are 10.68 and 11.82 percent (Carmichael, 1965), and the remaining filled circles represent rhyolite feldspar pairs.

It appears from figure 6 that these tie lines form two distinct groups and that the slope of the tie lines depends to a large extent on the degree of silica saturation of the magma. This difference is undoubtedly due to the lower temperature of crystallization in magmas containing considerable amounts of excess silica over that required to form feldspars. Sobolev (1959) noted the difference in the slope of feldspar tie-line in undersaturated rocks as compared with saturated rocks, and Carmichael (1965) remarked on the difference in the trend of the two feldspar tie lines in saturated and oversaturated rocks.

The difference in the slope of feldspar tie-lines from rocks of differing composition appears to merit further consideration. The plagioclase feldspars in rhyolites may become apparently very rich in the Ab component and, in some cases, show no evidence of resorption as has been noted in the suite of trachytes just described. If it is assumed that rhyolites may result from fractional crystallization of a slightly oversaturated trachytic magma then the fractionation of feldspar, required to produce the excess SiO_2 in the liquid, may be sufficient to inhibit the resorption of plagioclase. On the other hand it may be that in melts containing excess SiO_2 there is no tendency for the plagioclase to be resorbed even under conditions of perfect equilibrium crystallization. With regard to the alkali feldspars, the average An content of those from rhyolites and oversaturated trachytes is lower than that of the saturated or just undersaturated trachytes (fig. 6), indicating a lower temperature of crystallization as might be expected, and yet the former are richer in the Or component. Assuming again that rhyolites may result from fractional crystallization of trachytes, the alkali feldspars, which at an earlier stage of crystallization were becoming more sodium-rich, must subsequently become more potassium-rich. That this is possible in the case of liquids crystallizing only an alkali feldspar can be seen in the later stages of crystallization in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–SiO_2–H_2O (Tuttle and Bowen, 1958).

Stewart and Roseboom (1962) have presented a very thorough theoretical account of the possible end stages of crystallization in the system

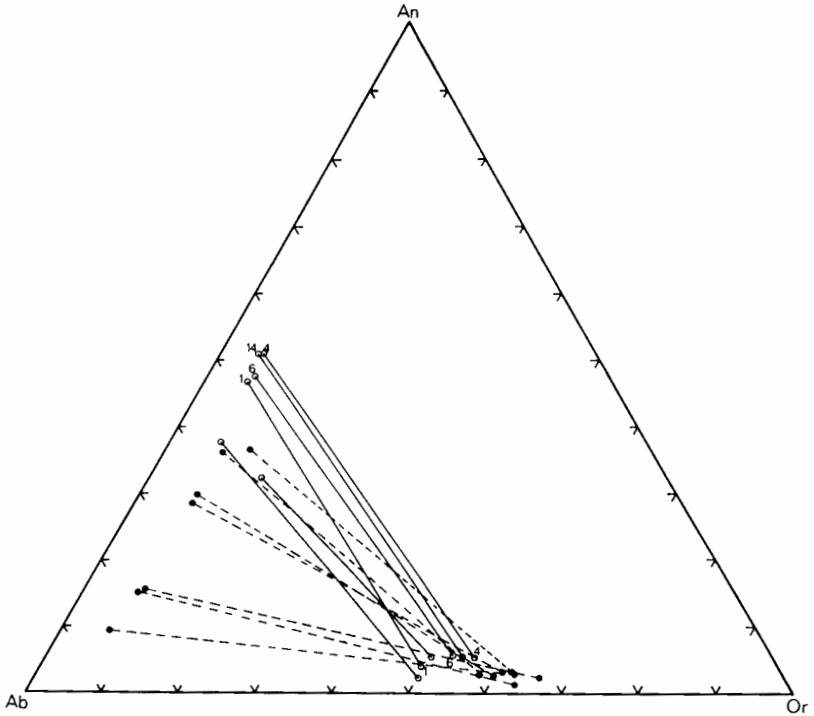


Fig. 6. Plot of compositions of coexisting feldspars from volcanic rocks. Open circles represent feldspars from undersaturated and just saturated trachytes and filled circles represent feldspars from oversaturated trachytes and rhyolites.

$KAlSi_3O_8$–$NaSlSi_3O_8$–$CaSl_2Si_2O_8$. The present study cannot be used to indicate which of the possible terminations of the three phase region applies to this suite of rocks, although a few of the cases described by Stewart and Roseboom may be excluded as incompatible with the chemical data presented here.

It is clearly very desirable that the phase relations in the system $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$ and $KAlSi_3O_8$–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–SiO_2 should be determined experimentally before further progress can be made in the understanding of the more complex natural systems. The discussion above takes no account of the possibility that the feldspars from oversaturated rocks may be non-stoichiometric as has been suggested recently by Carman and Tuttle (1967). If this is the case a further complexity is introduced into discussion of the slope of the feldspar tie lines.

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