

## 32. SECONDARY K-FELDSPAR IN BASALTS AT DEEP SEA DRILLING PROJECT HOLE 504B AND THE PROBLEM OF K-FELDSPATHIZATION IN OCEANIC BASALTS<sup>1</sup>

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### ABSTRACT

Basalts from some holes of the Deep Sea Drilling Project contain secondary K-feldspar which forms pseudomorphs after calcic ( $\geq 76\%$  An) plagioclase cores, whereas plagioclase of rims and microlites (68–74% An) remains unaltered. In basalts of Hole 504B two such grains with relics of plagioclase in the central parts of phenocrysts were recovered. The composition of the plagioclase rims and of non-replaced phenocrysts is  $An_{79-81}$ ; the composition of relics is  $An_{83}$ . The An and Ab contents of the K-feldspar is higher than in K-feldspar from altered basalt in Hole 418A in the Atlantic Ocean near the Bermuda Rise. Replacement of plagioclases by K-feldspar evidently is caused by oxygen-rich near-bottom sea water penetrating into basalts. The temperature interval of K-feldspathization is probably in the range 30 to 80°C, more-calcic plagioclase being replaced by K-feldspar at higher temperatures.

### INTRODUCTION

The problem of formation of secondary K-feldspar during alteration of certain basalts sprang up as a result of ocean drilling. This mineral has been found in several holes drilled by *Glomar Challenger* in the Atlantic and Pacific Oceans (DSDP Legs 14, 16, 17, 19, 22, 31, 32, 35, 38, 39, 51, 52, and 53). Simanovich (1979) made a survey of this problem and analyzed the data available on the conditions of formation of secondary K-feldspar in oceanic basalts. He pointed out that because of diagnostic difficulties investigators could easily miss the mineral. This occurred at DSDP Site 155. Generalization of the data permitted Simanovich to formulate certain regularities of the formation of the mineral in altered basalts. The type of K-feldspar under consideration does not occur at mid-ocean ridges and in young rift zones. The age of basalts with secondary K-feldspar is not less than 20 to 25 m.y. (usually it is much older). Almost all investigators report that the secondary K-feldspar forms pseudomorphs in more-calcic cores of plagioclase phenocrysts, often preserving twin structure. It differs from plagioclase by having low relief and low birefringence. The external, more-sodic zones of plagioclase, as well as microlites, usually are not replaced; thus, K-feldspar usually is rimmed by a thin zone of plagioclase. Only in the most-altered rocks are external rims and microlites replaced.

Examination of DSDP Holes 417A, 417D, and 418A (Legs 51 to 53) supplied extensive material on secondary K-feldspar (Pertsev and Rusinov, 1980). The secondary aspect of the mineral in this case cannot be doubted because the K-feldspar in pseudomorphs often contains relics of replaced plagioclase and is accompanied by small aggregates of calcite, colorless montmorillonite, and a zeolite of the phillipsite type. Study of the distri-

bution of this mineral in Holes 417 and 418 showed that it occurs in the most-oxidized units of basalt along cracks and breccia zones. It is restricted to the upper 300 to 350 meters of basaltic basement (Pertsev and Rusinov, 1980). The location of the mineral is naturally accounted for by sea water rich in oxygen, which penetrates into the upper part of the basalts as a result of late-stage faulting. The radiometric age of K-feldspar mineralization turned out to be considerably younger than that of basalts proper, about 70 m.y., against 108 m.y. for the basalts (Rusinov et al., 1980). Literature analysis shows that of K-feldspar mineralization typically is younger by some tens of millions of years than the basalts.

We also note that in Holes 417A, 417D and 418A K-feldspar selectively replaced plagioclase ( $\sim 76\%$  An), whereas more-sodic plagioclase of rims and microlites usually remained unaffected by the process. The total content of  $K_2O$  in intensively K-feldspathized basalt could reach 9% (Pertsev and Rusinov, 1980).

### OCCURRENCE OF K-FELDSPAR IN HOLE 504B BASALTS

When we examined the basalt cores from Hole 504B during DSDP Leg 69, we attempted to find secondary K-feldspar in oxidized zones of the upper part of the basalt basement, but discovered none. This was in agreement with the general absence of K-feldspar in young basalts, but in one of the sections from the material obtained from the Hole during Leg 70, K-feldspar was unexpectedly detected. It occurs within a basalt pillow near a quenched margin (504B-34-2, 16–20 cm, Piece 240), approximately 250 meters beneath the sediments. It was found only in two grains, representing typical core pseudomorphs of plagioclase phenocrysts (Fig. 1). Most puzzling is the fact that in the neighboring phenocrysts of plagioclase there is no K-feldspar. Nor does it occur in other thin-sections of this sample. Chemical analysis of the oxidized section of basalt revealed a small increase of  $K_2O$  content (Table 1).

<sup>1</sup> Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, S. M., et al., *Init. Repts. DSDP, 69*: Washington (U.S. Govt. Printing Office).

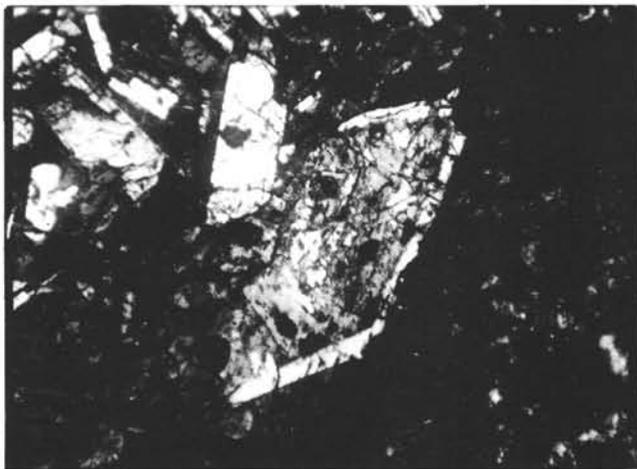


Figure 1. Plagioclase phenocryst with a core almost entirely replaced by K-feldspar. Relics of plagioclase (white) remain in the core. The plagioclase rim is also well preserved. 504B-34-2, 16–20 cm, Piece 240. Crossed Nicols,  $\times 70$ .

Table 1. Chemical analysis of basalt from brown zone bearing K-feldspar.

SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO				
45.38	1.01	15.56	5.79	3.63	0.22	8.01				
CaO	Na <sub>2</sub> O	K <sub>2</sub> O	H <sub>2</sub> O(105°C+)	H <sub>2</sub> O(105°C-)	P <sub>2</sub> O <sub>5</sub>	Total				
11.90	2.01	0.25	2.99	2.74	0.068	99.56				

Analyst: I. V. Basalayeva, Central Chemical Laboratory, Institute of Ore Deposit Geology, U.S.S.R. Academy of Sciences.

## MINERAL COMPOSITIONS

We studied the composition of plagioclases and K-feldspar from this sample (Table 2) and for comparison analyzed K-feldspars from a basalt with secondary K-feldspar taken during the Bermuda Rise "megaleg" (418A-35-3, 94–98 cm, ~462 m beneath the sea floor and 142 m beneath the sediments).

The difference in composition between the K-feldspars of these samples lies in the significantly higher values of albite and anorthite in K-feldspar from Hole 504B. Earlier, from Hole 417D, Pertsev and Rusinov (1980) revealed K-feldspar which contained neither CaO nor Na<sub>2</sub>O (Table 2, analysis 17).

We were surprised to find high K<sub>2</sub>O contents in plagioclase rims, and especially in relics in the analyzed phenocrysts from Hole 504B. We discovered that phenocrysts of plagioclase unaffected by K-feldspar do not contain significant amounts of K<sub>2</sub>O. To reveal the pattern of distribution of potassium, we determined profiles by microprobe analysis across a relic of plagioclase in K-feldspar and across the adjacent plagioclase rim (Fig. 2). The amount of K<sub>2</sub>O in plagioclase increases toward the contact with K-feldspar. Evidently, the process of K-feldspathization was accompanied by gradual enrichment of plagioclase with potassium without destruction of its lattice. Destruction of the lattice with

Table 2. Electron-microprobe analyses of K-feldspars and associated plagioclase phenocrysts and rims.

Analysis	Component						Total	An	Or	Ab
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	K <sub>2</sub> O	Na <sub>2</sub> O					
1	63.29	19.29	0.88	14.90	0.37	98.73	4.6	92.0	3.4	
2	50.20	32.49	17.51	0.48	1.91	100.68	81.3	2.7	16.0	
3	49.71	30.39	16.23	0.35	2.06	98.74	79.7	2.0	18.3	
4	50.83	30.13	15.82	0.06	2.17	98.51	79.8	0.3	19.9	
5	48.43	31.86	17.26	0.84	1.48	99.87	82.4	4.8	12.8	
6	46.88	32.11	16.43	0.0	2.16	97.58	80.8	0	19.2	
7	49.18	30.71	15.75	0.0	2.41	98.05	78.3	0	21.7	
8	45.18	33.56	17.93	0.0	1.59	98.26	86.2	0	13.8	
9	46.17	33.60	16.89	0.0	1.94	98.60	82.3	0	17.2	
10	50.10	31.09	14.95	0.0	2.74	98.88	75.1	0	24.9	
11	43.94	37.33	19.46	0.0	0.81	101.54	93.0	0	7.0	
12	43.29	36.27	19.16	0.0	0.80	99.52	93.0	0	7.0	
13	47.66	31.79	16.52	0.0	2.13	98.10	81.0	0	19.0	
14	65.39	19.16	0.23	15.58	0.42	100.77	1.2	94.9	3.9	
15	52.32	31.18	14.98	0.68	2.55	101.71	73.4	4.0	22.6	
16	50.78	30.97	14.91	0.27	2.29	99.23	77.0	1.6	21.4	
17	63.4	19.2	0.0	16.1	0.0	98.7	0	100.0	0	
18	64.81	18.83	0.05	16.07	0.16	99.93	0.3	98.2	1.5	
19	65.06	18.19	0.12	15.65	0.22	99.12	0.6	97.3	2.1	
20	65.86	17.80	0.09	15.98	0.14	99.69	0.5	98.2	1.3	

Note: Calculation of mineral composition in percent was made on the assumption that the sum of atomic amounts of Ca, K, and Na is equal to 1.0. (Analyses 1–5: 504B-34-2, 16–20 cm, Piece 240; Analysis 1: K-feldspar; Analyses 2, 3: plagioclase rim; Analysis 4: plagioclase phenocryst not replaced by K-feldspar; Analysis 5: relic of plagioclase in K-feldspar; Analyses 6–8: plagioclase phenocrysts 504B-7-3, 116–120 cm; Analyses 9–10: plagioclase phenocrysts 505B-2-1, 29–33 cm; Analyses 11–13: plagioclase phenocrysts 505B-6-1, 112–114 cm; Analyses 14–16: 418A-35-3, 94–98 cm; Analysis 14: K-feldspar; Analysis 15: plagioclase rim; Analysis 16: microlith; Analysis 17: K-feldspar (Pertsev and Rusinov, 1980), 417-30-5, 67–73 cm; Analysis 18: K-feldspar (Stewart et al., 1973), 192A-5-1; Analysis 19: K-feldspar (Stewart et al., 1973), 192A-5-6; Analysis 20: K-feldspar (Stewart et al., 1973), 192A-6-3.

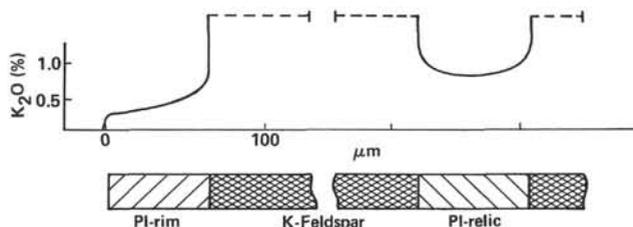


Figure 2. Schematic profile of K<sub>2</sub>O distribution in plagioclase rims and relics in K-feldspar, according to microprobe analyses.

formation of K-feldspar pseudomorphs took place upon introduction into plagioclase of over 1% by weight of K<sub>2</sub>O. It is likely that formation of K-feldspar after plagioclase is controlled by the An content of plagioclase, the composition of solutions, and temperature. Evidently these factors affect the contents of CaO and Na<sub>2</sub>O in K-feldspar as well. It is probable that (because of disequilibrium of the process) the duration of the process and intensity of circulation of solutions may also affect the composition of the formed K-feldspar, refining the latter becoming more pure with time. The higher content of admixtures in the considered K-feldspar probably testifies to a higher temperature of formation. Indeed, the temperature registered in this interval of the drill hole was approximately 80°C (Becker et al., this volume), whereas in Holes 417D and 418A the calculated temperature was about 40°C.

## DISCUSSION

The results of the study of plagioclases were quite unexpected. In the rims of phenocrysts replaced in the

cores by K-feldspar (Fig. 1), the content of the anorthite component is very high  $An_{79-81}$ . Relics of plagioclase among K-feldspar in the cores are more calcic ( $\sim An_{83}$ ). The content of anorthite in unreplaced phenocrysts of plagioclase is  $An_{79-81}$ , the same as the rims of the pseudomorphs. This circumstance suggests that in oxidized zones K-feldspar can replace only rare phenocrysts whose cores contain plagioclase with over 83% anorthite. Such phenocrysts are obviously rare, though in general plagioclase in basalts of Sites 501/504 and 505 are more calcic than usual, as revealed by our microprobe measurements (Table 2, analyses 6–13). In the studied sample from Bermuda Rise (Table 2, analyses 15 and 16) plagioclase is less calcic  $An_{74}$  in the rim and  $An_{77}$  in microlites.

Likely there is a very sensitive correlation between temperature and composition of plagioclase which can be replaced by K-feldspar under the effect of oxygen-rich bottom waters penetrating into basalt basement. Thermodynamic analysis shows that the relationship of chemical activities of potassium to sodium in sea water increases with decrease in temperature. The relative stability of K-feldspar should increase with a fall of temperature. Probably at very low temperatures (say, below 30°C) K-feldspar is unstable in sea water and is replaced by other potassium-bearing minerals (hydro mica, for example). Kelts and Mackenzie (1976) report that in contact with cold sea water authigenic low-temperature pseudomorphs of K-feldspars formed in volcanogenic sediments are replaced, though very slowly, by a film-like coating of products of post-depositional weathering.

It is also possible that at low temperature K-feldspar is not formed for kinetic reasons, because of high energy of activation. This circumstance may account for the typical absence of authigenic K-feldspar in young, cold basalts not covered by a thick layer of sediments. Though a rise in temperature will increase the rate of reaction, it may, however, shift this non-equilibrium reaction of replacement of plagioclase by K-feldspar into the region with a higher anorthite content (because of increase in stability of the albite component in sea water with increase in temperature). For this reason K-feldspathization does not manifest itself in basalts heated above 70 to 80°C.

The distinct occurrence of authigenic K-feldspar with oxidized basalt recovered in the Bermuda Rise "mega-leg" certainly proves the participation of oxygen-rich sea waters in this process. The reason for this evidently

lies in the increase of chemical activities of strong alkalis under oxidizing conditions (Korzhinskii, 1969, 1978).

Evidently, low-temperature K-feldspars in basalts may be analogous to K-feldspars detected in basalt sands, 800 meters below the sea floor during DSDP Leg 33 in the central Pacific. Kelts and Mackenzie (1976), who studied those samples in detail, came to the conclusion that K-feldspar formed as pseudomorphs after other feldspars in sediments, under the effect of hydrothermal solutions. This was followed by subordinate deposition of K-feldspar crystals in voids. In composition, their K-feldspars are similar to K-feldspars from the Bermuda Rise and other places discussed, i.e., it is considerably more pure than K-feldspar from Hole 504B.

In conclusion, we should like to state that if our suggestions are correct, it may be possible in the future to construct a paleothermometer based upon comparison of the composition of replaced plagioclase cores, and plagioclase rims in oceanic basalts.

#### ACKNOWLEDGMENTS

The authors are grateful to V. Kurnosov and I. Simanovich for their review of this paper and valuable advice which we followed during preparation of the manuscript.

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