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Electron Probe Microanalysis of Minor Elements in Plagioclase Feldspars

(Part II of Laboratory Investigations on Plagioclases)

By *M. Corlett* (Zürich)*) and *P. H. Ribbe* (Blacksburg, Va., USA)**)

With 3 figures in the text and 2 tables

Abstract

One hundred and fifty-seven plagioclase feldspars investigated by CORLETT and EBERHARD (this volume) have been analysed for potassium, strontium, barium, iron, titanium and phosphorus using microprobe X-ray emission methods. The average concentrations of these minor elements (using, in addition, 40 analyses from RIBBE and SMITH, 1966) are plotted as a function of anorthite content, showing that K, Ba and Sr are highest in the andesine composition range, Fe and Ti in the labradorite and P in the albite range, the last correlating directly with Si/Al ratio. The highest individual concentrations detected are: K 0.78, Sr 0.56, Ba 0.11, Fe 0.68, Ti 0.06 and P 0.33 wt. per cent.

Antiperthitic potassium feldspar is found to contain ca. 35% more Sr and orders of magnitude more Ba than the plagioclase host from which it is exsolved. Antiperthite occurs in more than two-thirds of the plagioclases examined and thus accounts for much of the discrepancy between previous chemical and spectrographic analyses of K and Ba and the microprobe analyses. Inclusions account for discrepancies between previous and present analyses of Fe and Ti in plagioclases. Phosphorus was detected in 62 of the 157 specimens, and all but a few with $P > 0.01\%$ are from pegmatites.

INTRODUCTION

The minor elements in feldspars are of interest because of their geochemical and structural implications. There already exists an extensive

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literature dealing with these elements (reviewed in detail by HEIER, 1962); but much of it must be interpreted with caution, because chemical and emission-spectrographic analyses are made on bulk specimens which very commonly contain impurities. However, x-ray emission microanalysis using the modern electron probe permits fast and accurate determination of elements in volumes smaller than ten cubic microns, and the spatial resolution necessary to avoid inclusions and exsolution and alteration products which would otherwise bias bulk analyses is now available.

RIBBE and SMITH (1966) present evidence that bulk analytical methods commonly show K, Ba, Fe and Ti in excess of that which is structurally combined in plagioclases. There is evidence of a similar nature for Ca, Fe and Ti in alkali feldspars (SMITH and RIBBE, 1966). However, since the purpose of these authors' studies was to test the microprobe methods of analysis and to devise suitable matrix corrections for the effect of one element upon another, they did not attempt an extensive study of the minor elements. The present investigation of many more plagioclases of generally, though not exclusively, low-temperature origin makes use of RIBBE and SMITH's data and employs certain of the techniques developed in the course of their work.

Although the microprobe data are clearly more reliable than bulk analytical data, attempts to formulate sweeping geochemical and crystal chemical conclusions concerning plagioclases have been restricted to the obvious ones in lieu of a forthcoming statistical study of variances of minor and major elements and a series of more specific petrologic investigations.

EXPERIMENTAL PROCEDURES

Specimens were prepared by epoxying small fragments of plagioclases into methacrylate holders. A fine polish was obtained using 0.25 micron diamond paste, and a conducting coat of Be was sputtered onto the polished surface before analysis commenced. A summary of microprobe techniques and analysing conditions appears in Table 1. Since attempts were made to discover reasons for discrepancies between bulk-chemical and microprobe analyses, specimens were frequently traversed to detect and identify impurities.

Complete elemental analyses were not attempted; Ca was used to determine anorthite content of the plagioclase. Potassium was carefully

measured only in regions of the crystal fragments which showed no antiperthite or other K-bearing impurity. The common occurrence of antiperthitic orthoclase was noted, and it was found to contain both Sr and Ba in excess of that in the plagioclase host from which it exsolved. For that reason K was monitored and avoided in Sr and Ba analyses. Note that Sr was measured on the 11″ LiF spectrometer, using Kα radiation. This technique, although somewhat less sensitive than that used by SMITH and RIBBE (1966) for SrLα is much faster and for the degree of accuracy desired, just as reliable. The background at the SrKα peak is gently sloping upwards from Ab to An, but pure synthetic plagioclases were used to establish the background correction and from then on no further measurements were necessary. This contrasts markedly with the Lα measurements which are made with difficulty because of an overlapping SiKβ' peak whose wavelength and intensity both vary as a function of the Si concentration.

Phosphorus was determined by two methods (see Table 1). The first measurements were made on an ADP crystal with an uncollimated detector; these show a strong dependence of background on Ca content (Fig. 1 a) since CaKβ peaks occur on either side of the PKα line. The effect of Ca is much less pronounced when an EDDT crystal with a detector slit of 0.2″ is used (Fig. 1 b). This method with its superior peak to background ratio is recommended for P determinations. Two standards were used: the early P analyses were referred to a large unanalysed fluorapatite single crystal from Durango, New Mexico which was assumed to be stoichiometric; the later analyses were calculated from synthetic $Ca_2P_2O_7$. The high-phosphorus specimens 187 and 190 (Table 2) were analysed by both methods; and after absorption and other corrections were made in the manner of SMITH (1965), the P analyses were found to agree within $\pm 3\%$, a negligible mismatch for such low-level concentrations.

Iron and Ti analyses were standardized using pure metals and were adjusted for matrix effects using correction factors listed by SMITH and RIBBE (1966, their Table 3). As expected, Fe- and Ti-rich impurities were detected during the specimen traverse, and these were carefully avoided during on-peak potentiometric readings. Absorption and atomic number effects of minor elements on one another are negligible, since the precision of the method is normally much lower than the correction factors, and for purposes of this general study better results are neither necessary nor useful.

The limits of detectability listed in Table 1 were determined wherever proportional counting methods were used (Ca, K, Ba, Sr, P) by assuming

that an on-peak reading greater than background plus three times the standard deviation of the background ($N_B + 3\sqrt{N_B}$) indicates that the trace element is definitely present (see LIEBHAFSKY et al., 1962). Only for Sr were the readings $> (N_B + \sqrt{N_B}) < (N_B + 3\sqrt{N_B})$ recorded as "trace" and used as 0.01 wt. % in calculating averages for the histogram (Fig. 2a).

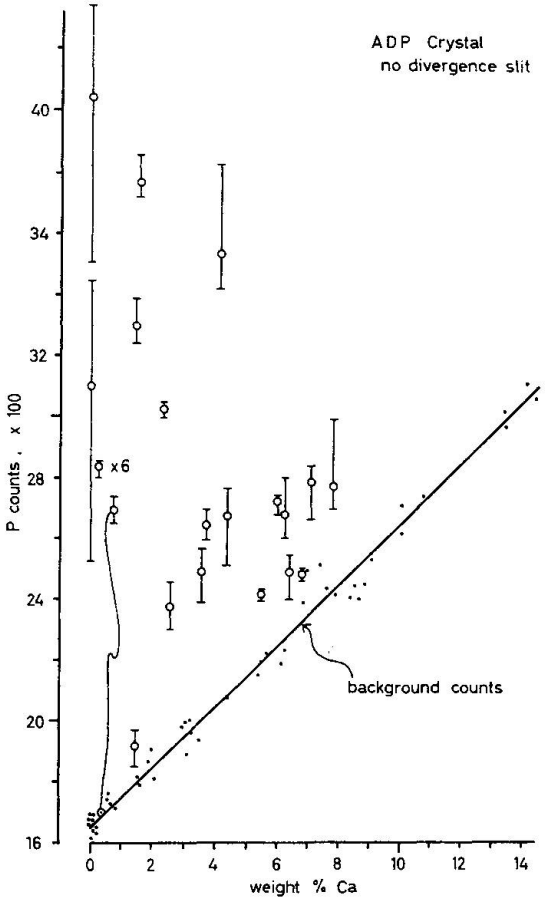


Fig. 1a. Phosphorus scaler readings plotted against Ca content of individual plagioclase grains. These data measured on an ADP crystal using an uncollimated detector. Notice the steeply sloping background due to second order CaKα peaks which occur on either side of the PKβ peak. Curved lines join data points from the same crystal; vertical bars show range of values recorded.

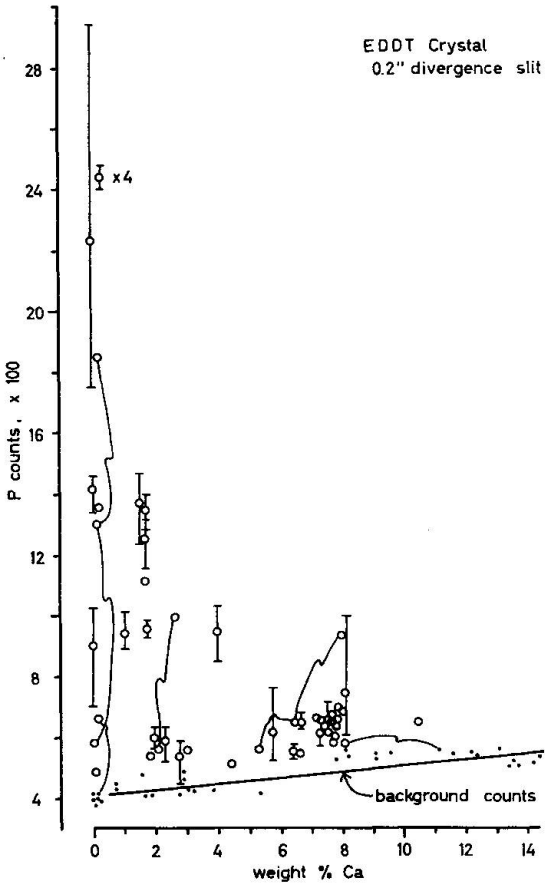


Fig. 1b. Phosphorus scaler readings plotted against Ca content of individual plagioclase grains. These data measured on an EDDT crystal using a 0.2″ collimator on the detector. Notice the slightly sloping background and the improved peak-to-background ratio (cf. Fig. 1a). Curved lines join data points from the same single crystal; vertical bars show range of values recorded.

DISCUSSION OF RESULTS

The results of the quantitative microprobe analyses of 157 plagioclases are listed in Table 2 along with data on 40 plagioclases from RIBBE and SMITH (1966). Wherever it was possible to be sure that more than one plagioclase came from the same hand specimen or — with a few exceptions — from the same locality, the analyses were averaged;

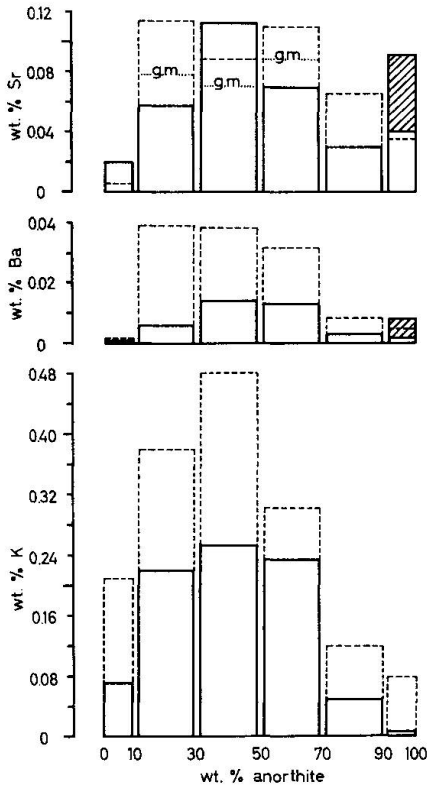


Fig. 2a. Histograms showing mean concentrations of K, Ba, and Sr as a function of anorthite content. The dotted bars represent arithmetic mean concentrations of the minor element data summarized by HEIER (1962). In the anorthite range, the open portion of the bar represents the Sr and Ba averages omitting one specimen from Vesuvius; the mean concentrations using this specimen are represented by the entire bar. g.m. = gravimetric mean from HEIER (1962).

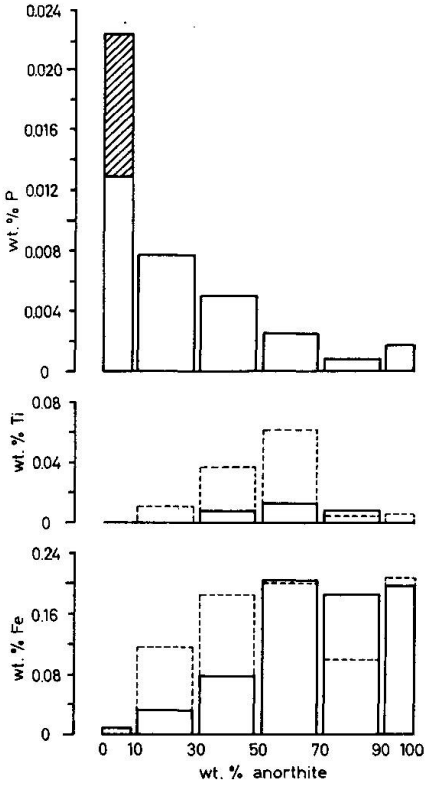


Fig. 2b. Histograms showing mean concentrations of Fe, Ti and P as a function of anorthite content. The dotted bars represent arithmetic mean concentrations of Fe and Ti from SEN (1960). In the albite range for P the open bar represents the average omitting Specimen 190 which contains ten times more P than the next highest specimen.

the averages are listed in the table and are used in determining the mean concentrations for the ranges An_{0-10}, An_{10-30}, An_{30-50}, An_{50-70}, An_{70-90} and An_{90-100} which appear in the histograms (Fig. 2). For purposes of comparison the mean concentrations of K, Ba and Sr from HEIER (1962) and of Fe and Ti from SEN (1960) are also shown; only three analyses for P were available but the An content of these feldspars was not reported (KORITNIG, 1965).

Potassium

As expected potassium is the most abundant minor element in the plagioclase structure. Fig. 2a shows the distribution of K as a function of An content. The highest mean concentration occurs in the andesine range where Sr and Ba (Fig. 2a) and Rb and Pb (HEIER, 1962) also appear to have their maximum concentrations. The nature of the geochemical association of these elements with K is uncertain, since there appears to be poor correlation between K and Sr and K and Ba for individual plagioclases. The reasons for the obvious correlation of the *mean* concentrations of K, Sr and Ba may very well be structural rather than geochemical. Perhaps strain associated with domain textures and exsolution phenomena in plagioclases of composition intermediate between the ordered albite and anorthite end-members produces favorable sites for these large cations.

Figure 2a clearly indicates the magnitude of the bias between chemical and microprobe determinations of K. Careful study of the polished surfaces of plagioclase grains show that at least two-thirds contain antiperthitic orthoclase or sericite. Such impurities can easily be detected by continuously scanning the specimen and monitoring K on the strip-chart recorder or by contrast between cathodoluminescence of impurity and plagioclase.

Barium

RIBBE and SMITH (1966) did not detect Ba at the 0.02 wt. per cent level; they used potentiometric profile methods, whereas our level of detection and sensitivity using proportional counting methods is somewhat better (0.01 wt. %). Barium is structurally combined in many plagioclases; the highest concentration, 0.11% was found in an oligoclase from Transvaal (Specimen 101). Pronounced discrepancies between chemical and microprobe analyses for Ba are most certainly due to

antiperthitic orthoclase. This is demonstrated in Fig. 3 which shows simultaneous recorder scans for K and Ba in an antiperthitic oligoclase from Seiland, Norway. The Ba level in the oligoclase is 0.035 wt. %, but it reaches ca. 1.2% in the exsolved orthoclase. The Transvaal oligoclase (Specimen 101) contains 0.11% Ba, but readings as high as 5% Ba were recorded in the antiperthite.

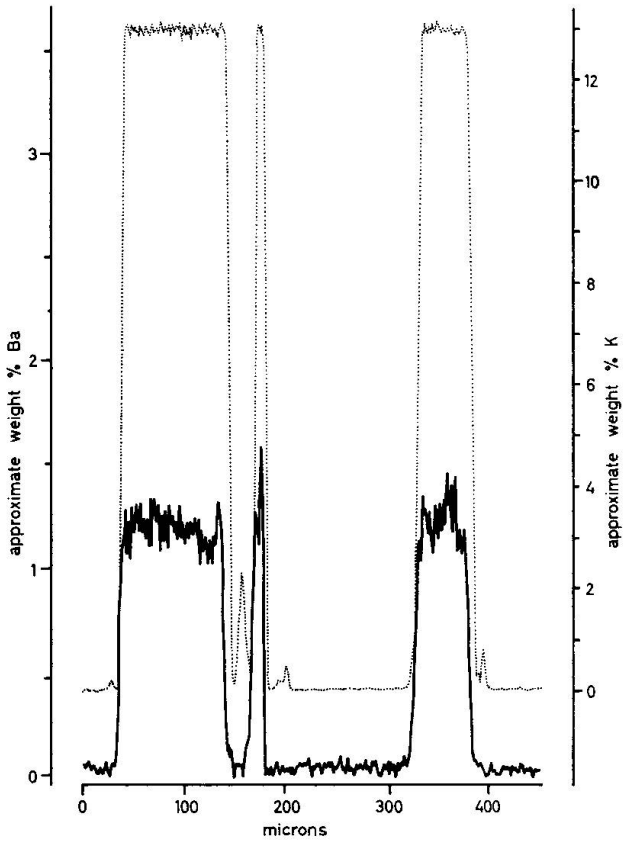


Fig. 3. Simultaneous Ba (solid line) and K (dotted line) scans across an antiperthitic oligoclase from Seiland, Norway. The Ba and K concentrations in the plagioclase are 0.035 and 0.10 wt. %.

Strontium

Strontium, like Ba, is a large cation and tends to concentrate in antiperthite, although it may not always do so. A few rough measurements of Sr in antiperthite indicate that there is ca. 35% more Sr in orthoclase than in the plagioclase host. The histogram (Fig. 2a) shows that Sr determined by chemical techniques does not differ substantially from

that measured on the electron microprobe. The small differences can easily be accounted for by antiperthite, analytical error and sampling.

There may be a positive correlation of Sr and Ba in plagioclases, but until a statistical investigation is completed, it is considered unwise to press this point.

Iron

Iron is the second most abundant minor element in plagioclases; the highest concentration recorded in this study is 0.68% Fe. RIBBE and SMITH (1966) came to the conclusion that Fe most likely occupies tetrahedral sites, substituting for Al. They suggest that the increase of Fe with increasing anorthite can be explained by (1) the generally higher temperature of crystallization of Ca-rich plagioclases and (2) the higher proportion of Al^{3+} sites into which Fe^{3+} may go. Although the histogram in Fig. 2b does not show the pronounced increase for anorthite in Fe that RIBBE and SMITH found in their specimens, there is no apparent reason to modify their conclusions.

The analyses of SEN (1960) show substantially more Fe in the range An_{10-50} and less in the range An_{70-90}; iron-rich impurities and sampling (all his specimens in the range An_{70-90} are from one locality) no doubt account for the differences in the mean concentrations.

Titanium

Titanium is present in the plagioclase structure only in small amounts. The highest concentration is 0.06 wt. % in a Skaergaard andesine (Specimen 239). The element was not detected at the 0.01 wt. % level in plagioclases An_{0-30} and An_{80-100}. From the microprobe analyses it is not possible to draw conclusions about the valence state of Ti or the site(s) it occupies in the feldspar structure. Most chemical analyses reporting Ti are in error because of Ti-rich impurities, and the explanation of the differences between our data and those of SEN (cf. Fig. 2b) is the same as that for Fe.

Phosphorus

About 40% of the analysed plagioclases contain phosphorus. There is a nearly perfect correlation of the mean P concentration with Si/Al ratio. This indicates, as expected, that P substitutes for Si in tetrahedral sites.

As with all minor elements, availability is an important factor in their incorporation into the feldspar structure. In the case of P it is obvious that this may be of first importance (as opposed to temperature and pressure) since all but a few plagioclases with $P > 0.01$ wt. % are from pegmatites and pegmatitic veins. The highest P concentration is 0.33% in an albite (An_2) from the Dolni Bory pegmatite.

Figures 1a and 1b contain plots of P as a function of An content for several specimens which were zoned or simply inhomogeneous. Some of these show that P increases with increasing Ca content within a single plagioclase grain. This is a curious phenomenon, since the histogram indicates the opposite trend and since most specimens show a random variation of P from spot to spot in the grain. This is not yet understood, but it may be that P is associated with the more Ca-rich volumes in the crystal (or vice versa) prior to exsolution of apatite, if indeed apatite exsolves from plagioclase. There is some microscopic evidence for this possibility in an albite from Auburn, Maine which shows micron-size apatite dispersed throughout the host plagioclase.

CONCLUSIONS

The success of electron microprobe analysis of minor elements in feldspars was demonstrated by RIBBE and SMITH (1966), and they showed that for most elements it is more reliable than bulk chemical or emission spectrographic methods which are commonly biassed by minute inclusions of one sort or another. Our work confirms this, and because a large number of specimens were studied, it is possible to understand more clearly the distribution of minor elements as a function of anorthite content. Unfortunately, because of an editorial deadline we were unable to complete a statistical analysis of the variances of minor and major elements, but this study is forthcoming.

The differences between chemical and microprobe analyses of K and Ba have been traced for the most part to antiperthitic orthoclase, and a small amount of Sr in excess of that chemically combined in the plagioclase structure may also be in the antiperthite. The mean P concentrations in plagioclases can be correlated with the proportion of Si sites. The pegmatitic feldspars contain by far the major proportion of P.

Several investigations of minor elements in coexisting alkali and plagioclase feldspars are currently under way, and it is hoped that these will provide information of petrologic importance.

Table 1. *Summary of microprobe techniques and analysing conditions*

Element	Spectral line	kV	μ A	Spectrometer radius	Analysing crystal	Limit of detection (wt. %)	Standard	Comments
Ca	K α	25	0.10	4″	Ge	0.01	synthetic An_{50}—An_{100} [1])	Specimen traversed; more than 10 analyses; simultaneous with K to avoid antiperthite and other impurities
K	K α	25	0.10	4″	EDDT	0.01	adularia, $Or_{97.6}$ Dorfgastein, Tyrol	Specimen traversed; more than 10 analyses; simultaneous with Ca to avoid antiperthite and other impurities
Ba	L α	25	0.10	4″	LiF	0.01	synthetic $BaAl_2Si_2O_8$ [2])	Specimen traversed; 5 analyses; K monitored to avoid antiperthite
Sr	K α	35	0.23	11″	LiF	0.02	synthetic $Sr_{0.1}Ca_{0.9}$-$Al_2Si_2O_8$ [2])	Two point analyses; if difference greater than 20 %, then 4 to 6 analyses; K monitored to avoid antiperthite
Fe	K α	25	0.40	4″	LiF	0.01	Fe metal	Wavelength scan to establish presence and background, than on-peak measurement using chart recorder while specimen traversed; K monitored
Ti	K α	25	0.40	4″	LiF	0.01	Ti metal	Same as Fe
P	K α	25	0.10	4″	ADP	0.003	Durango, N.M. apatite	Same as Sr, except that background readings taken on both sides of peak to correct for sloping background (see Fig. 1a)
			0.15	4″	EDDT	0.003	Synthetic $Ca_2P_2O_7$ [3])	Same as Sr (see Fig. 1b)

[1]) Provided by E. Eberhard, Zurich.
[2]) Provided by W. Hoffmann, Zurich.
[3]) Provided by U. Keppler, Karlsruhe.

Table 2. *Minor elements in plagioclase feldspars, listed in order of increasing anorthite content.* Data for RS specimens are from Ribbe and Smith (1966). ND = not detected

(Locality and description of sample may be found in Corlett and Eberhard, 1967)

Spec. No.	Weight per cent						
	Anorthite	K	Ba	Sr	Fe	Ti	P
62	0.0	0.05	0.00	0.00	0.00	0.00	0.065
RS-E1	0.0	0.04		0.00	0.00	0.00	0.11
Avg.	0.0	0.04_5	0.00	0.00	0.00	0.00	0.09
201	0.0	0.01	0.00	tr	0.00	0.00	ND
194	0.0	0.04	0.00	0.00	0.00	0.00	0.005
195	0.0	0.04	0.00	0.00	0.00	0.00	0.018

Spec. No.	Anorthite	Weight per cent K	Ba	Sr	Fe	Ti	P
146	0.1	0.02	0.00	0.02	0.00	0.00	ND
140	0.15	0.05	0.00	0.00	0.05_5	0.00	ND
RS-E 30	0.2	0.08		0.01	0.00	0.00	0.09
98	0.5	0.07	0.00	0.00	0.00	0.00	ND
150	0.0	0.02	0.00	0.00	0.00	0.00	ND
191	0.5	0.16	0.00	0.00	0.00	0.00	ND
RS-Amelia	0.1	0.11		0.00	0.00	0.00	ND
Avg.	0.3	0.09	0.00	0.00	0.00	0.00	ND
271	0.4	0.03	0.00	0.00	0.00	0.00	ND
184	0.4	0.03	0.00	0.00	0.00	0.00	0.031
112	0.4	0.04	0.00	0.00	0.00	0.00	ND
185	0.4	0.04	0.00	0.00	0.00	0.00	0.051
199	0.4	0.16	0.00	tr	0.00	0.00	0.036
188	0.5	0.02	0.00	0.06	0.00	0.00	ND
211	0.6	0.01	0.00	0.11	0.00	0.00	ND
197	0.65	0.15	0.00	tr	0.00	0.00	0.029
209	0.65	0.08_5	0.00	tr	0.00	0.00	ND
167	0.7	0.03	0.00	0.00	0.00	0.00	ND
4	0.8	0.06	0.00	0.00	0.03	0.00	ND
289	0.95	0.03_5	0.00	0.00	0.00	0.00	ND
192	1.0	0.04	0.00	0.03	0.00	0.00	ND
19	1.15	0.01	0.00	tr	0.00	0.00	ND
163	1.8	0.09	0.00	0.08	0.06_5	0.00	ND
190	2.0	0.18_5	0.00	0.02	0.01?	0.00	0.330
186	2.55	0.03_5	0.00	0.00	0.00	0.00	ND
178	3.95	0.04	0.00	0.00	0.00	0.00	0.011
196	1.5	0.06_5	0.00	0.00	0.00	0.00	0.034
Avg.	2.7	0.05	0.00	0.00	0.00	0.00	0.022
202	4.9	0.10	0.035	0.37	0.01	0.00	ND
137	4.2	0.17	0.055	0.13	0.01	0.00	ND
125	4.3	0.20	0.030		0.03	0.00	ND
110	4.3	0.20	0.065	0.13	0.02	0.00	ND
204	4.8	0.20	0.025	0.13	0.04	0.00	ND
Avg.	4.5	0.17	0.042	0.19	0.02	0.00	ND
99	5.2	0.11	0.00	0.00	0.00	0.00	ND
118	6.15	0.16	0.00	tr	0.00	0.00	ND
274	6.7	0.13_5	0.00	0.00	0.00	0.00	0.019
RS Monteagle	7.6	0.18		0.01	0.11	0.00	0.01
172	10.1	0.04	0.00	tr	0.02	0.00	0.003
RS Villeneuve	9.7	0.13		0.01	0.02	0.00	0.01
Avg.	9.9	0.08_5	0.00	0.01	0.02	0.00	0.007
RS-BM 1940, 27	10.0	0.09		0.03	0.03	0.00	tr
RS-E 2	10.4	0.05		0.02	0.03	0.00	ND
281	10.5	0.21_5	0.00	0.02	0.00	0.00	0.029
275	10.6	0.26_5	0.00	tr	0.00	0.00	0.034

Spec. No.	Anorthite	Weight per cent K	Ba	Sr	Fe	Ti	P
187	10.6	0.09	0.00	0.00	0.07	0.00	0.032
120	10.7	0.09	0.00	0.03	0.11	0.00	ND
287	11.3	0.25	0.00	0.02	0.00	0.00	0.019
285	11.3	0.27_5	0.00	0.02	0.00	0.00	0.025
129	11.4	0.24_5	0.010	0.17	0.08	0.00	0.043
293	12.3	0.17	0.00	0.02	0.00_5	0.00	0.004
RS Mont. valley	12.4	0.17		0.04	0.13	0.00	0.01
206	12.8	0.10	0.020	0.17	0.01	0.00	ND
135	13.0	0.06	0.020	0.17	0.00	0.00	ND
280	13.6	0.08_5	0.00	0.03	0.00	0.00	0.006
165	13.9	0.16	0.00	0.03	0.04_5	0.00	ND
46	14.4	0.10	0.00	0.00	0.01	0.00	ND
272	14.9	0.11	0.00	0.04	0.00	0.00	0.021
294	15.5	0.16	0.00	0.03	0.00	0.00	0.006
RS-E 3	15.5	0.13		0.02	0.05	0.00	ND
RS-E 4	16.0	0.18		0.02	0.00	0.00	ND
RS-KN 81822	17.0	0.28		0.06	0.03	0.00	0.01
RS-E 32	17.0	0.55		0.05	0.03	0.00	0.01
84	17.3	0.10	0.010	0.04	0.01	0.00	0.024
87	17.6	0.77	0.00	0.03	0.00	0.00	ND
277	17.7	0.18_5	0.015	0.05	0.00	0.00	0.015
171	18.1	0.09	0.00	tr	0.02	0.00	0.010
119	18.3	0.12	0.020	0.14	0.01	0.00	ND
2	18.5	0.13	0.00	0.00	0.01	0.00	ND
104	18.8	0.07_5	0.010	0.07	0.06	0.00	ND
282	18.9	0.24	0.00	0.07	0.01	0.00	0.004
291	20.6	0.16	0.00	0.06	0.00	0.00	0.005
Avg.	19.75	0.20	0.00	0.065	0.01	0.00	0.005
67	19.45	0.13	0.020	0.03	0.01	0.00	ND
RS-E 5	19.4	0.20		0.02	0.06	0.00	ND
Avg.	19.4	0.16_5	0.020	0.025	0.035	0.00	ND
86	19.4	0.45_5	0.00	tr	0.05	0.00	ND
279	19.8	0.12	0.010	0.05	0.00	0.00	ND
111	20.9	0.26	0.00	0.03	0.03	0.00	ND
RS-KN 80165	21.5	0.50		0.03	0.03	0.00	0.01
Avg.	21.2	0.38	0.00	0.03	0.03	0.00	0.005
162	21.2	0.55_5	0.00	0.03	0.02	0.00	ND
276	21.4	0.30_5	0.00	0.04	0.04	0.00	ND
183	21.7	0.18_5	0.010	0.11	0.05_5	0.00	ND
288	21.95	0.13	0.00	0.05	0.00	0.00	ND
166	22.5	0.17	0.00	0.00	0.08	0.00	ND
124	22.5	0.54	0.00	0.02	0.02	0.00	ND
34	22.5	0.54	0.00	0.09	0.03	0.00	ND
100	24.05	0.25	0.00	0.03	0.08_5	0.00	ND
114	25.0	0.04_5	0.00	0.04	0.00	0.00	0.010
170	26.4	0.14	0.00	0.02	0.08	0.00	0.014
262	26.5	0.16	0.00	0.00	0.04	0.00	ND

Spec. No.	Anorthite	Weight per cent K	Ba	Sr	Fe	Ti	P
193	26.7	0.14	0.00	0.03	0.05_5	0.00	0.019
RS-KN 97490	28.2	0.49		0.13	0.05	0.00	ND
31	29.0	0.33	0.00	0.04	0.05	0.00	ND
101	29.2	0.12	0.110	0.40	0.01	0.00	0.039
RS-Howie 2270	29.4	0.40		0.08	0.09	0.00	tr
109	30.2	0.06	0.015	0.13	0.02	0.00	ND
153	30.6	0.17	0.010	0.07	0.01	0.00	0.013
RS-RB 561	30.4	0.08		0.08	0.09	0.00	0.01
RS-RB 579	30.9	0.23		0.10	0.06	0.00	0.01
Avg.	30.65	0.15_5		0.09	0.08	0.00	0.01
RS-Howie S 347	33.6	0.24		0.06	0.08	0.00	0.01
136	36.7	0.06	0.010	0.22	0.00	0.00	ND
105	36.8	0.41	0.015	0.15	0.03_5	0.00	ND
RS-SK 4145	35.7	0.38		0.06	0.36	0.02	tr
RS-SK 4272	38.5	0.30		0.05	0.35	0.03	tr
Avg.	37.1	0.34		0.055	0.36	0.025	tr
158	37.2	0.08	0.040	0.12	0.00_5	0.00	ND
133	38.2	0.09_5	0.00	0.27	0.01_5	0.00	ND
5	39.6	0.54	0.010	0.02	0.06	0.00	0.005
173	39.3	0.11_5	0.00	0.15	0.01	0.00	0.006
RS-Howie 4642 A	41.4	0.25		0.02	0.05	0.00	0.04
83	41.6	0.78	0.060	0.42	0.24	0.05	0.011
38	42.8	0.01	0.00	0.05	0.00	0.00	ND
130	43.2	0.50_5	0.00	0.08	0.10	0.01	0.009
94	43.3	0.06	0.010	0.03	0.02	0.00	ND
239	44.3	0.32	0.015	0.05	0.22	0.06	0.003
37	44.5	0.24_5	0.015	0.11	0.16	0.01	0.0045
54	44.5	0.31	0.010	0.09	0.11	0.00	ND
212	44.7	0.06	0.035	0.18	0.02	0.00	0.007
126	47.5	0.62_5	0.00	0.10	0.17	0.03	0.003
RS-E 9	47.8	0.38		0.07	0.09	0.00	ND
144	47.8	0.22	0.00	0.08	0.03	0.00	ND
91	49.3	0.03_5	0.020	0.16	0.01	0.00	0.009
244	50.8	0.41	0.015	0.12	0.10	0.00	0.005
147	51.1	0.06	0.00	0.07	0.01	0.00	ND
243	51.1	0.43	0.015	0.10	0.10	0.00	0.007
50	51.1	0.37	0.015	0.09	0.07	0.00	ND
RS-EH 201	50.7	0.27		0.05	0.35	0.04	tr
RS-EH 20	52.5	0.26		0.04	0.32	0.04	ND
Avg.	51.6	0.27		0.045	0.34	0.04	tr
251	52.4	0.43	0.015	0.14	0.06	0.00	0.005
253	51.8	0.41	0.010	0.11	0.06	0.00	0.005
Avg.	52.1	0.42	0.013	0.125	0.06	0.00	0.005

Spec. No.	Anorthite	Weight per cent K	Ba	Sr	Fe	Ti	P
238	52.5	0.27	0.025	0.06	0.23	0.00	0.007
249	54.1	0.24_5	0.020	0.05	0.23	0.00	0.005
237	45.2	0.18	0.00	0.08	0.15_5	0.00	0.003
Avg.	50.6	0.23	0.015	0.06	0.205	0.00	0.005
261	54.1	0.31_5	0.020	0.09	0.23	0.00	0.007
260	50.6	0.34	0.025	0.07	0.22	0.00	0.007
Avg.	52.35	0.33	0.023	0.08	0.225	0.00	0.007
49	52.6	0.23	0.015	0.09	0.22	0.00	ND
55	53.6	0.30	0.015	0.08	0.21_5	0.00	ND
245	53.5	0.37	0.010	0.11	0.11	0.00	0.006
250	53.8	0.34	0.010	0.12	0.08	0.00	0.007
Avg.	53.65	0.35_5	0.010	0.115	0.095	0.00	0.007
268	53.8	0.37	0.025	0.07	0.20	0.00	0.004
24	53.3	0.23	0.020	0.08	0.09	0.02	ND
213	54.6	0.37	0.020	0.010	0.13	0.00	0.006
Avg.	53.95	0.30	0.020	0.09	0.11	0.01	0.003
53	54.1	0.31_5	0.015	0.08	0.24	0.00	ND
259	54.3	0.27	0.020	0.07	0.23	0.015	ND
48	54.3	0.20	0.015	0.09	0.06	0.01	0.008
97	54.8	0.30	0.030	0.10	0.22	0.05	ND
81	55.1	0.12	0.020	0.06	0.04	0.00	0.008
RS-E 12	55.2	0.05		0.06	0.13	0.00	0.01
Avg.	55.15	0.08_5	0.020	0.06	0.085	0.00	0.009
74	55.2	0.10_5	0.020	0.06	0.01	0.00	0.008
RS-E 13	55.5	0.07		0.06	0.06	0.00	0.02
Avg.	55.35	0.09	0.020	0.06	0.035	0.00	0.014
247	56.4	0.47	0.020	0.08	0.12	0.00	0.010
246	56.3	0.45_5	0.020	0.08	0.20	0.00	ND
267	56.7	0.31	0.010	0.07	0.22	0.00	ND
Avg.	56.5	0.38	0.015	0.075	0.21	0.00	ND
RS-E 14	56.9	0.05		0.08	0.18	0.00	tr
88	58.1	0.28_5	0.015	0.08	0.18	0.03	ND
RS-E 16	59.0	0.09		0.07	0.03	0.01	tr
96	59.5	0.18	0.015	0.07	0.21	0.00	ND
40	60.5	0.28_5	0.010	0.13	0.29	0.06	ND
11	61.2	0.03	0.00	0.03	0.27	0.025	ND
44	61.8	0.09	0.00	0.04	0.43	0.06	ND
43	62.1	0.07	0.00	0.05	0.46	0.06	ND
Avg.	61.95	0.08	0.00	0.045	0.445	0.06	ND

Spec. No.	Anorthite	Weight per cent K	Ba	Sr	Fe	Ti	P
RS-Clear Lake, Minn.	62.5	0.10		0.05	0.35	0.03	ND
263	62.6	0.10	0.00	0.05	0.50	0.06	0.003
175	63.25	0.16	0.015	0.06	0.40	0.03	ND
123	66.0	0.22_5	0.010	0.05	0.62	0.04	ND
68	67.4	0.08	0.00	0.07	0.34	0.00	ND
45	69.9	0.03	0.00	0.02	0.03	0.00	ND
103	70.2	0.11	0.010	0.07	0.06_5	0.00	ND
RS-Crystal Bay (KN)	70.3	0.05		0.00	0.29	0.02	ND
RS-E 23	72.1	0.00		0.07	0.13	0.00	tr
236	72.6	0.01	0.00	0.03	0.09	0.00	0.005
32	73.05	0.14	0.010	0.05	0.20_5	0.00	ND
61	74.7	0.09	0.010	0.04	0.24	0.02	ND
26	75.3	0.01	0.00	0.02	0.23	0.03	ND
RS-KN 7510	75.5	0.16		0.04	0.15	0.02	tr
7	78.2	0.07_5	0.00	0.04	0.16_5	0.02	ND
RS-H 92	81.1	0.04		0.03	0.53	0.02	
RS-G 98	80.1	0.03		0.03	0.50	0.02	
Avg.	80.6	0.03_5		0.03	0.515	0.02	
300	80.85	0.03	0.00	0.02	0.19	0.00	ND
36	78.0	0.04	0.00	tr	0.36	0.00	ND
RS-KN-EB 18	84.7	0.06		0.01	0.29	0.00	ND
Avg.	81.35	0.05	0.00	0.01	0.325	0.00	ND
299	81.9	0.00	0.00	0.04	0.05	0.00	ND
296	84.1	0.02	0.00	0.02	0.13_5	0.00	ND
308	85.0	0.00	0.00	0.02	0.13	0.00	ND
305	86.35	0.00	0.00	0.02	0.05	0.00	ND
302	90.75	0.00	0.00	0.03	0.11	0.00	ND
303	93.1	0.00	0.00	0.03	0.09_5	0.00	ND
113	93.4	0.07	0.050	0.56	0.30	0.00	ND
116	93.5	0.01	0.010	0.05	0.26_5	0.00	ND
304	93.9	0.01	0.00	0.02	0.22	0.00	ND
RS-Japan	94.3			0.04	0.49	0.00	
RS-Miyake 99	95.1	0.00		0.03	0.40	0.00	0.01
RS-Hakone 3	95.8	0.00		0.08	0.42	0.00	tr
10	95.75	0.00	0.010	0.03	0.39	0.00	ND
Avg.	95.25	0.00	0.010	0.045	0.425	0.00	0.003
301	95.3	0.00	0.00	0.03	0.07	0.00	ND
RS-Hakone 1	95.4	0.00		0.03	0.38	0.00	tr
115	98.6	0.00	0.00	0.06	0.04	0.00	ND
307	99.0	0.00	0.00	0.06	0.05	0.00	ND

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