Variation in Perthitic Microcline From a Zoned Pegmatite

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Quantitative microscopic and chemical anaylses of 12 specimens of microcline, most of them perthitic, from the zoned Hugo pegmatite in the Black Hills near Keystone, South Dakota, have yielded data that can be used to estimate the temperatures of crystallization at successive stages in the formation of the pegmatite. The determined temperatures of crystallization range from 565°C in zone 3a, near the margin of the pegmatite, to 280°C in zone 7, the core.

More than half the world's crust is composed of feldspar. It has long been recognized that careful analyses of the chemical compositions of coexisting feldspars in an igneous or metamorphic rock can have value as a geothermometer. Because of the ubiquitous nature of feldspar and its potentialities as a geothermometer, much can be gained by determining the composition of each feldspar phase in a rock.

A study was made of microcline perthite from the Hugo pegmatite in the Black Hills near Keystone, South Dakota. Data will be presented on probable temperatures of crystallization and on the amount of albite still contained in solid solution in the microcline.

The Hugo pegmatite has been studied in detail by Norton, Page and Brobst (1962). It exhibits a well developed zonal structure consisting of seven generally concentric zones as well as two replacement units. It is Precambrian in age as are the other zoned and unzoned pegmatites of the Southern Black Hills (Norton and others, 1964; Orville, 1960), all of which are generally accepted as having been formed by crystallization of a magma-like fluid, somewhat rich in volatiles.

Theoretical Considerations

The microcline perthite can be considered to belong to the binary system $KAlSi_3O_8$–$NaAlSi_3O_8$ since the anorthite content of plagioclase has a maximum of only four tenths of one per cent (Norton, Page and Brobst, 1962:105), excluding zone one which was not included in this study. Therefore, a description of the various crystallization paths that can be followed in the Or–Ab system will be helpful in evaluating the experimental results.

In dry melts or those containing a low pressure of water vapor and other volatile components, a single alkali feldspar will crystallize from the melt and will continuously react with it to give a final crystalline composition equal to the original composition of the melt in a manner analogous to the continuous reaction series of the plagioclase feldspars [Figure 1-(a)]. The temperature then decreases from the point on the solidus curve to the point below on the solvus curve with no change in the nature of the single feldspar. As the temperature continues to decrease the single feldspar will gradually

unmix from its solid solution to give a perthitic intergrowth of two feldspars of the composition given by the solvus curve for each temperature. This exsolution continues, if the temperature is lowered slowly enough, until the final temperature is reached.

Under conditions of higher water vapor pressure, the liquidus and solidus curves are found at lower temperatures and the temperature range representing one feldspar between the solidus and the solvus is smaller [Figure 1(b)].

At some greater pressure of water vapor the solidus curve will intersect the solvus curve and truncate it [Figure 1(c)]. When a liquid under these conditions is cooled it will not be allowed to produce one homogeneous feldspar of a single composition but, rather, will produce two feldspars whose compositions are given by
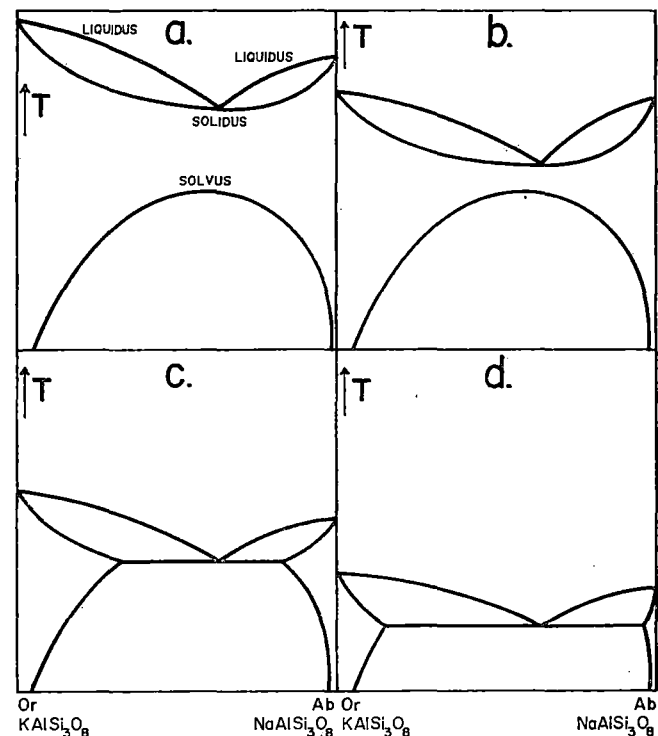

FIGURE 1. Schematic phase diagrams of $KAlSi_3O_8$–$NaAlSi_3O_8$ system: (a) low volatile content — one feldspar forms from melt; (b) higher volatile content—one feldspar form from melt; (c) still higher volatile content—two feldspar solid solutions form melt; (d) even higher volatile content—two feldspar solid solutions of greater purity form from melt.

the two halves of the solvus curve where they intersect the solidus.

Upon further cooling these two solid solutions of different composition may each exsolve to give perthite in one case and antiperthite in the other. Usually, however, the albite-rich solid solution does not unmix to form antiperthite due to the steepness of that half of the solvus.

At an even greater pressure of water vapor the liquidus and solidus curves are lowered still further and the two feldspar phases are formed at a lower temperature [Figure 1(d)]. The important point for the use of the feldspars as a geothermometer is that their compositions differ for different positions of the solidus, as a result of the inclination of the two limbs of the solvus. By measuring the amount of albite contained in the potassium-rich feldspar solid solution, the temperature of crystallization can be read from the solvus curve. Fortunately, the solvus changes position very little with increasing water pressure (Bowen and Tuttle, 1950: 449-500). Since the potassium-rich solid solution will often exsolve to perthite on a further lowering of temperature after crystallization, it is necessary to include the perthitic albite when calculating crystallization temperatures. It is, of course, also necessary to exclude any albite contained in the sample as inclusions that crystallized on the Ab side of the solvus. A factor that may often be more important in nature than the water vapor pressure in lowering the liquidus and solidus is the content of other volatiles such as fluorine (Norton, Page and Brobst, 1962:118). In the case of pegmatites formed at constant depth and thus nearly constant pressure, the volatile constituents would certainly seem to be important.

Procedure

Twelve samples of microcline, most of them perthitic, were taken through six of the seven zones in the south segment of the Hugo in an attempt to analyze the zonal variation of the microcline in terms of its albite content. The method used was to make both modal and chemical analyses of each sample and compare the modal percentages with the normative ones. Two thin sections of each sample were made parallel to the (010) cleavage and their mode was measured by using the improved Wentworth recording micrometer (integrating stage). The traverses were made at right angles to the perthitic bands. Nineteen flame photometric analyses for K_2O and Na_2O were also made, one a check on a National Bureau of Standards feldspar sample. Two samples were run by the Experiment Station of the Pennsylvania State University as a check on the writer's analyses.

In order of importance the mineral species present in the mode are, microcline, perthitic albite, poikalitic albite inclusions, muscovite and quartz. (In the central zone the mica is a lithia mica rather than muscovite.) Their average percentage magnitudes are, respectively: 80, 14, 4, 1-7/10 and 3/10 per cents. For this study the microcline and the perthitic albite are the two constituents of interest. Therefore, compensation must be made for the effect that the other three constituents have upon the chemical composition of the samples prior to a comparison between the mode and the norm. More specifically, there will be an appreciable contribution to the Na_2O content from the albite inclusions and a smaller contribution to the K_2O and Na_2O contents from the mica.

The calculations performed for each sample may be listed as follows:

1. Conversion of the average modal volume percentages to weight percentages.

2. Calculation of the small contributions to Na_2O and K_2O from the modal mica (Norton, Page and Brobst, 1962:106) and subtraction from the chemical percentages.

3. Calculation of the average normative microline and albite from the remaining alkali oxide percentages.

4. Recalculation of the total normative feldspar percentage to match the total modal feldspar percentage.

5. Subtraction of the modal albite inclusions' percentage from the normative albite percentage. The difference is the amount of albite of interest for use as a geothermometer and is either modal perthitic albite or albite remaining in solution in the microcline.

6. Recalculation of this albite as a percentage of total non-inclusion feldspar for finding the crystallization temperatures from a solvus curve.

7. Subtraction of the modal perthitic albite percentage from the difference obtained in number five. This new difference is the percentage of the rock that is albite remaining in solid solution in microcline.

8. Recalculation of this new difference as a percentage of the modal microcline. Ideally this should give the position of the Or-rich side of the solvus at room temperature and should be the same value for each sample.

Temperatures of Crystallization

Excluding the albite inclusions, the percentage of total feldspar as albite for each of the 12 samples is given in Table 1, as is the corresponding temperature of crystallization from a solvus published for that purpose by Barth (1962:336). The zones under which each are listed are those described by Norton, Page and Brobst (1962) with zone 2 the wall zone and zone 7, the core. The range in the albite percentages was calculated from the deviations found in multiple chemical analyses and between pairs of thin sections. Most of it is due to variations between different parts of the same sample rather than experimental error, although the latter factor was sometimes important. The range in the temperatures was read directly from the solvus using the extreme percentage values.

Five of the percentages and their temperatures are enclosed by parentheses to indicate that those values are considered unusable for various reasons. The sample from zone 2 or 3a had a relatively rapid cooling history since it is about five feet from the country rock. Therefore, it is possible that the early formed microcline did not have a chance to react with the remaining near-

TABLE 1.

Zone	Percent of total feldspar as albite (after inclusions)	Temperature of crystallization in °C	
2 or 3a	(17.9 ± 1.7)	(480	460-495)
3a (outer)	26.6 ± 6.4	565	510-610
3a (inner)	25.2 ± 2.5	555	525-575
3b	17.4 ± 1.4	475	455-490
3b (inner)	13.6 ± 2.4	420	390-455
4 or 5	10.9 ± 8.0	385	235-490
5 (inner?)	8.6 ± 1.1	345	330-365
5 (inner)	(1.8 ± 0.1)	(<200)	
6 (outer)	(4.8 ± 3.0)	(280.	<200-325)
6 (center?)	(21.9 ± 2.5)	(525	495-565)
6 (center?)	(20.9 ± 1.1)	(515	495-525)
7	4.8 ± 0.6	280	260-290

by melt and thus had a lower albite content than that which crystallized at the solvus curve. In any case, the fact that it had a more rapid cooling history, as shown by its position and relatively small crystal size, seems to warrant its being discounted because of probable lack of equilibrium. Three of the other values are discredited due to probable later alteration. The sample from zone 5 has definitely been affected by alteration following crystallization, indicated by fine grained muscovite replacing perthitic albite and by veins of muscovite and quartz throughout the sample. The two samples from near the center of zone 6 have a higher Na_2O content than would be expected by the steadily decreasing trend. These samples were collected near each other within about ten feet of the cleavelandite-microline-lithia mica replacement unit and it seems quite plausible that they were enriched in Na_2O by vapors that spread out from the replacement unit. Orville (1963) has done work on alkali ion exchanges between vapor and feldspar phases and his results indicate that fairly rapid exchange of Na^+ for K^+ in the alkali feldspars is possible by such means. The sample from the outer part of zone 6 has much less than two per cent Na_2O and, according to Dietrich (1961: 15), rocks containing less than two per cent Na_2O should not be used as geothermometers.

The remaining seven values should give reasonably reliable temperature values although a few cautions are necessary. The possibility of high-low modifications of the feldspars gives rise to some uncertainty in the interpretation (Norton, Page and Brobst, 1962: 111). According to Dietrich (1961: 15) the geothermometer has not been found to be susceptible to laboratory checking and is based upon natural feldspars. Hopefully, the history of the Hugo feldspars was similar to that of those used by Barth (1962) in drawing his solvus for which he makes no order-disorder qualifications. Those samples that seem to have been appreciably affected by deuteric

reaction have been discounted and the effect of exsolution has been accounted for, if it is assumed that only around the edges of the large crystals of perthite would there be any net loss of albite by exsolution. A remaining qualification that must be mentioned is that the microcline sample from zone 7 has well below two per cent Na_2O. However, zone 7 as a whole has four and four tenths per cent Na_2O (Norton, Page and Brobst, 1962: 112) and so the temperature should be usable if the sodium was available while the microline crystallized. Since zone 7 has some characteristics of a replacement body itself, this temperature is best regarded with caution.

Albite Content of Microcline

In Table 2 are presented the percentages of modal microcline which are normative albite—the amount of albite still in solid solution in microcline which did not exsolve to form perthite. As will immediately be seen, the probable range in values is of magnitude comparable to the actual values themselves. This is due to the fact that upon subtraction of large numbers the absolute error is carried along and becomes a much larger relative error. It is still possible to make some statements about the results, however. First of all, it will be seen that the values are not all the same, even allowing for the range in possible values. Second, the numbers are generally under ten per cent and most of them are under five per cent. Third, the median value of the albite content in four of the samples is very close to two per cent.

TABLE 2

Zone	Albite content of microcline, %
2 or 3a	2.1 ± 2.1
3a (outer)	10.0 ± 8.5
3a (inner)	9.7 ± 3.1
3b	1.9 ± 1.7
3b (inner)	−1.1 ± 3.0
4 or 5	0.5 ± 10.1
5 (inner?)	2.0 ± 1.3
5 (inner)	1.8 ± 0.2
6 (outer)	0.6 ± 3.4
6 (center?)	5.4 ± 3.2
6 (center?)	6.5 ± 1.4
7	4.8 ± 1.0

Ideally, the values should all be identical, as stated in a previous section. The number of real differences that exist cannot be determined, but for those that do the explanation must be either that the exsolution process did not reach equilibrium during cooling or that later alterations took place. For the high values near the outer margin of the pegmatite the former explanation may

fit best whereas the latter may best explain the high values in zones six and seven.

Goldsmith and Laves (1961: 92-93) have found by using X-ray data that the amount of albite in solid solution in highly ordered microclines is less than five per cent and that the more monoclinic the feldspar, the more albite it contains. The first part of this conclusion seems to be supported by the present study with the one exception of the sample from the inner part of zone 3a for which no definite explanation can be given. It is possible that this is a more monoclinic feldspar, but no other reason to suppose so is indicated. The possibility exists in any of these cases that the albite is not in true solid solution but rather exists as a cryptoperthite, which could explain the variation in the values.

The final point, that several of the values seem to be very near two per cent, needs further checking before any definite statement can be made. If it were found to withstand a number of more exacting measurements, this two per cent albite value might be termed the value of the solvus at room temperature on the $KAlSi_3O_8$ side of the binary phase diagram. A suggested method for more precise measurements made with the same general method is to take two thin sections parallel to each other and about an eighth of an inch apart, and use the small slab between them for the chemical analysis. This study has shown that the variation within a sample is too great to get precise values without such a close tie between the material used for the mode and the norm.

For a more complete description of the results and problems of the project see Tullis (1964).

Conclusions

After having dismissed some samples as unusable for temperature of crystallization calculations there remain a number that indicate a lowering of temperature as the crystallization of the pegmatite progressed inward. These values are often just above the minimum temperatures estimated by Norton, Page and Brobst, and are generally lower than the temperatures considered probable by them by about 50 degrees centigrade. The new results should probably be considered as supporting their conclusions rather than contradicting them since there are limitations to the method used.

No consistent value for the percentage of albite obtained in solid solution in microcline was found. More work would be required to evaluate the possibilities of either a complete range in values existing or a generally constant amount in the neighborhood of two per cent.

References

BARTH, T. F. W., 1962. The feldspar geologic thermometers. Norsk Geol. Tidsskrift, 42: 330-339.

BOWEN, N. L. and TUTTLE, O. F., 1950. The system $NaAlSi_3O_8$-$KAlSi_3O_8$-H_2O. Jour. Geology, 58:489-511.

DIETRICH, R. V., 1961. Comments on the "Two feldspar geothermometer" and K-feldspar obliquity. Inst. Lucas Mallada Cursillos y Conferencias, 8: 15-20.

GOLDSMITH, J. R. and LAVES, F., 1961. The sodium content of microclines and the microcline-albite series. Inst. Lucas Mallada Cursillos y Conferencias, 8: 81-96.

NORTON, J. J. and others, 1964. Geology and mineral deposits of some pegmatites in the southern Black Hills, South Dakota. U. S. Geol. Survey Prof. Paper 297-E: 293-341.

NORTON, J. J., PAGE, L. R. and BROBST, D. A., 1962. Geology of the Hugo pegmatite, Keystone, South Dakota. U. S. Geol. Survey Prof. Paper 297-B: 49-127.

ORVILLE, P. M., 1960. Petrology of several pegmatites in the Keystone district, Black Hills, South Dakota. Geol. Soc. America Bull., 71: 1467-1490.

ORVILLE, P. M., 1963. Alkali ion exchange between vapor and feldspar phases. Am. Jour. Sci., 261: 201-237.

TULLIS, T. E., 1964. Investigation of perthitic microcline from the Hugo pegmatite, Keystone, South Dakota. Unpublished Independent Study paper, Department of Geology, Carleton College, Northfield, Minnesota.