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A Test of Aluminum in Quartz as a Geothermometer

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Abstract

To test the partitioning of Al between quartz and an Al-saturated phase as a geothermometer, 18 quartz specimens from a wide range of temperature environments—as indicated by mineralogical and geologic criteria—were analyzed for Al by atomic absorption spectrophotometry. The plot of Al concentration in quartz against the assumed temperature range for the specimens analyzed is random. On the basis of this study, the usefulness of this partitioning system as an indicator of crystallization temperature is questioned.

Introduction

The obvious attractiveness of employing the partitioning of Al between an aluminous phase and quartz to determine temperature of crystallization—as suggested by Perry (1963) and Dennen and Blackburn (1970) and as part of a continuing study of temperature indicators in metamorphic rocks (Scotford, 1969, 1973)—led the writer to a test of this method before using it as part of an investigation of contact metamorphism of Belt quartzites.

The test was designed to determine if the apparent validity of this geothermometric method could be established by analysis of a number of quartz specimens from a wide range of temperature environments as indicated, or suggested, by their mineralogic association and geologic origin (Table 1). The particular aluminous mineral in assumed equilibrium with the quartz sample analyzed was not in every case obvious. However, aluminous minerals associated with the various groups of quartz samples are as follows: biotite, muscovite and alkali feldspar with the pegmatite samples, biotite and muscovite with the quartz from hydrothermal ore bodies, biotite and garnet with the vein quartz from metamorphic rocks, and clay minerals with the geode quartz.

A positive correlation between assumed temperature of crystallization based on geologic or other geothermometric grounds and the temperature predicted by the aluminum partitioning would strongly validate the method, while a lack of such a correlation, although not in itself discrediting the concept, would weaken its acceptability for routine geothermometric use and would suggest that the partitioning system may not be as simple as has been asserted.

Experimental Procedures

Samples selected for analysis were only those which could be treated so as to obtain a high degree of purity. In a few cases discrete crystals were used, and in all cases the quartz was coarse and not intimately associated with other finely disseminated silicate material. However, considerable care was exercised to assure that the analyzed samples were free of any aluminum-bearing minerals, as the analyses would have been considerably affected by even small amounts of such material.

Each sample, after crushing, was freed of non-quartz minerals by various combinations of the following methods: hand picking under the microscope, leaching in 6N HCl and washing in demineralized water to remove oxides, magnetic separation to remove opaque minerals, and gravity separation using heavy liquids to remove minerals heavier than quartz; in a few cases where small quantities of mica, clay minerals, or feldspars remained after hand picking, the sample was finely crushed and treated ultrasonically to assure a complete separation of minerals and then leached repeatedly in 1N HF after decanting the suspended very fine fraction. No

TABLE 1. Al Concentration in Quartz Specimens from Various Thermal Envirnoments

Spec. No.	Specimen Origin and Probable Temperature Environment	Duplicated Analyses of Al in Quartz in ppm	
1	β quartz crystal from rhyolite, Judith Mts., Montana. 573-867°C (Sosman, 1965, p. 38)	219	---
2	Pegmatite, Beryl Mt., N.H. 500-600°C most probable temperature range (Jahns and Burnham, 1969)	109	116
3	Pegmatite, Devils Hole, Colorado. (Jahns and Burnham, 1969)	438	442
4	Pegmatite, Meyers Ranch, Colorado. (Jahns and Burnham, 1969)	169	175
5	Pegmatite, Custer, S.D. (Jahns and Burnham, 1969)	513	549
6	Pegmatite, Albany, Maine. (Jahns and Burnham, 1969)	221	231
7	Hydrothermal ore body, Broken Hill, New South Wales. 400-630°C (Gustafson, et al., 1950 and Ramdohr, 1950)	273	269
8	Hypothermal ore body, Homestake, S.D. 300-600°C most probable temperature in upper portion of temperature range (Ridge, 1972)	393	370
9	Hypothermal ore body, Climax, Colo. 300-600°C (Ridge, 1972) Probably closer to lower end of temperature range (Singewald, 1933)	336	315
10	Quartz vein in garnet zone metamorphic rocks, Three Top Mt., N.C. 300-400°C, temperature estimated on basis of assumed segregation origin	75	70
11	Quartz vein in garnet zone metamorphic rocks, West Jefferson, N.C. 300-400°C, temperature estimated on basis of assumed segregation origin	166	179
12	Mesothermal ore body, Noranda, Quebec. Specimen from hydrothermal zone. 200-350°C (Ridge, 1972)	159	166
13	Mesothermal ore body, Butte, Montana. 200-325°C (Meyer, et al., 1968)	390	377
14	Hydrothermal quartz crystals in low grade metamorphic rocks near Little Rock, Arkansas. 100-300°C (Miser and Milton, 1964)	217.	220
15	Telethermal ore body, Galena, Kansas. 83-120°C, based on fluid inclusions in sphalerite (Schmidt, 1962)	404	414
16	Quartz crystals ("Herkermer Diamond") precipitated at near surface temperature, Herkermer, N.Y. (Frondel, 1962)	99	95
17	Quartz crystals in geode, Kentucky. Surface temperature (Jackson, 1970)	70	75
18	Quartz crystals in geode, Indiana. Surface temperature.	452	461

sample was accepted for analysis unless microscopic examination after treatment revealed no silicate impurity.

An additional test of purity was provided by the standard of reproducibility required before the analytical data were accepted for inclusion in this study. If the two aliquots of the same sample did not yield the same analytical result, it was assumed the inhomogeneity was probably due to impurity and the sample was discarded.

The Al content of the quartz was determined using a Perkin-Elmer Model 303 atomic absorption spectrophotometer with nitrous oxide as oxidant and acetylene fuel. Samples were analyzed in groups of three to six together with a contamination blank and the NBS (National Bureau of Standards) standard-198 Silica Refractory. To repress Al ionization, 500 ppm K was added to both sample and standard solutions.

The accuracy of the analyses was evaluated by comparing those here obtained for the NBS 198 standard with those quoted by the National Bureau of Standard from other laboratories. The average of 12 analyses quoted by NBS is 0.160 wt percent Al_2O_3. The mean of 11 analyses obtained in this study is 0.145, indicating a probable accuracy of better than ±10 percent.

The reproducibility of the analyses was established by duplicate analysis of all samples except one (No. 1) for which insufficient sample was available. The data (Table 1) show a maximum uncertainty of 7 percent, with most analyses agreeing within less than 5 percent of the amount present.

Results

The duplicate analyses of Al in the quartz specimens is shown in Table 1 together with the specimen origin and probable temperature range. These data are plotted graphically on Figure 1. The probable temperature range of each specimen is indicated by the vertical line while the crossing horizontal line is the error bar relating to the duplicate Al analyses. The intersection of the two lines represents the best temperature estimate for that sample.

Also plotted on Figure 1 is the curve of Dennen and Blackburn (1970) which relates temperature to Al in quartz. It is obvious that no linear relationship exists between the probable temperature of crystallization and Al concentration in the quartz samples analyzed in this study.

Conclusions

The lack of any linear relationship between the Al content of quartz and the apparent temperature of crystallization based on mineralogic and geologic evidence would seem to bring the utility of the Al-quartz geothermometer into question. Using 10 samples, Dennen and Blackburn (1970, p. 341)

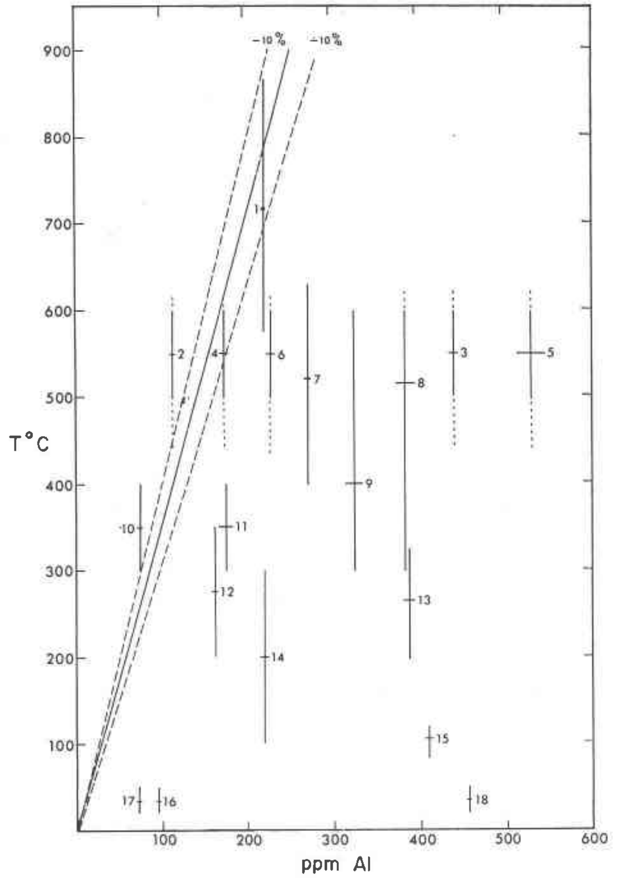

FIG. 1. Plot of the Al in numbered quartz specimens *vs* temperature (see Table 1). Error bars indicate probable limit of error for temperatue and Al concentation. Intersection of error bars is most probable temperatue and Al concentation. Sloping lines are from the least squares regression of Dennen and Blackburn (1970) for Al in quartz *vs* temperature.

found that four, all granitic rocks, did not fall at reasonable temperature values when their Al concentrations were plotted on the Al in quartz-temperature curve. They suggested that the consistently low temperatures obtained by this plot might reflect the late intergranular concentration or recrystallization of quartz in a subsolidus reaction. However, in this study only three or possibly four out of 18 analyses fall anywhere on the Dennen and Blackburn curve (Fig. 1).

Possible explanations of the discrepancies between the present study and that of Dennen and Blackburn are considered below. As all but four analyses have an Al content higher than can be plotted on the Dennen and Blackburn curve, the possible presence of a non-silica source of Al in the sample is suggested. However, as described above, considerable care was taken in the selection and preparation of the samples analyzed to assure their purity. An alternate explanation of the higher Al concentration found in this study may be the difference in analytical method. The analyses done in the Dennen and Blackburn study were by emission spectrography in which analytical precision, according to the writers, was not high, the coefficient of variation being about 20 percent, and no test of accuracy could be made. The atomic absorption spectrophotometric method used in the present study provided a reproducibility to within less than 7 percent and an accuracy evaluation established by comparison with an analyzed standard of ± less than 10 percent of the amount present.

The theory of Al partitioning between quartz and an Al-bearing mineral as a function of temperature requires the presence of an Al-saturated phase. The presence or absence of such a phase within the equilibrium domain during crystallization cannot always be established petrographically in a solidified rock. Thus, some quartz (*e.g.*, from geodes) employed in this study may not have acquired their Al content by participation in such an equilibrium.

To the writer the most reasonable conclusion to the present study is that the Al content in quartz is not simply a function of its temperature of crystallization and cannot be used as a reliable geothermometer. Instead this Al content may also be affected by the presence of other elements participating in the equilibrium of the system or by the substitution of Al not only into the tetrahedral sites of the quartz structure but also into the more open spaces in the structure.

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