THE VARIABLE INVERSION TEMPERATURE OF QUARTZ AS A POSSIBLE GEOLOGIC THERMOMETER

O. F. Tuttle, *Geophysical Laboratory, Washington, D.C.*

Abstract

The high-low inversion temperature of quartz has been found to vary as much as 1.90° C. The inversion temperature varies inversely with the temperature of formation and therefore may become a useful geologic thermometer.

Introduction

The high-low inversion temperature of quartz has been investigated by many observers. For a comprehensive review of these studies the reader is referred to Sosman[1] (1927). The most accurate measurements of the inversion temperature are those by Bates and Phelps[2] (1921) who suggested using the inversion temperature as a fixed point on the thermometric scale. They found the rising-temperature inversion to be $573.3 \pm 0.1°$ C.

The inversion temperature as a function of the geologic history of the quartz has not been investigated so far as the writer is aware, although Sosman suggested that such a study would be of considerable interest. The present report deals with a preliminary study of that relation.

Method

The quartz was crushed, sieved through a 35 mesh screen, and collected on a 200 mesh screen after which it was treated with boiling hydrochloric acid for 30 minutes, washed, and dried at 110° C. The high-low inversion temperature was measured by means of time-temperature heating curves using chromel-alumel thermocouples. The thermoelement junction was imbedded in 1.5 grams of powdered quartz.

Temperature measurements were made with a White potentiometer that gave readings on a standard quartz that were reproducible to $\pm .04°$ C. This degree of reproducibility could be obtained only by taking special care to place the charge and thermoelement leads in exactly the same position in the furnace for each experiment and to have the cold junction portion of the leads immersed to the same depth each time. All determinations were made by heating the powder at a uniform rate of 1° C. per minute through the inversion region and recording the temperature at 15-second intervals. The inversion temperature was taken as the

[1] Sosman, Robert B., The properties of silica: *Am. Chem. Soc., Monograph No.* **37** (1927).

[2] Bates, F., and Phelps, F. P., The new fixed point on the thermometric scale: *Phys. Rev.* (2) **18,** 115–116 (1921).

intersection of two straight lines drawn in the manner shown in Fig. 1.

The present investigation is concerned with differences in the inversion temperature and not the actual temperature of the transition, therefore

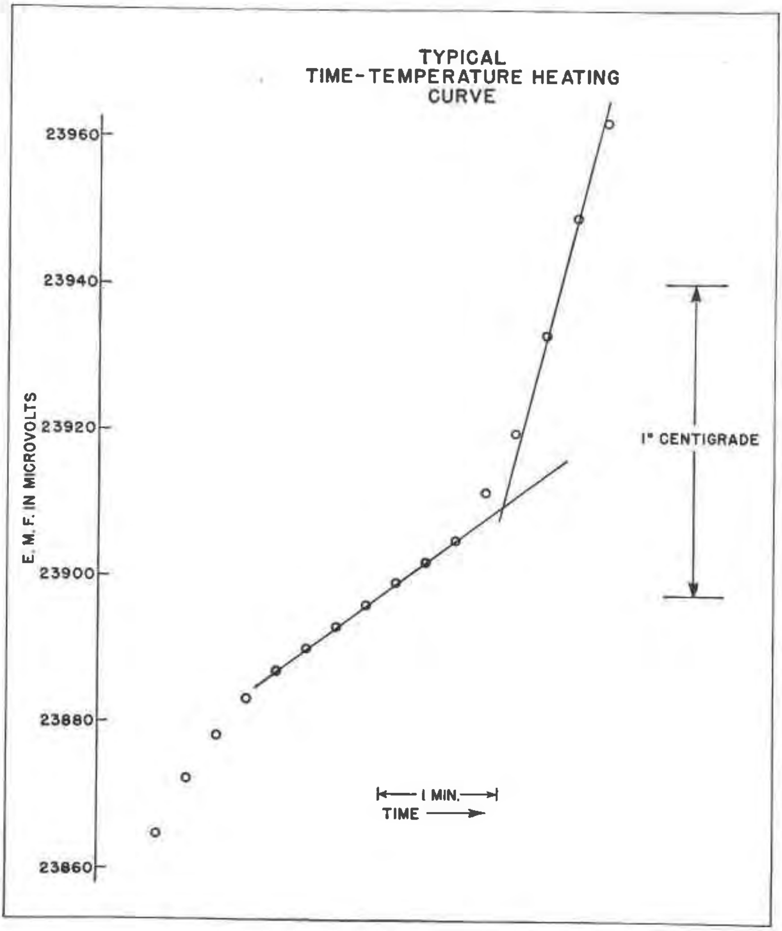

FIG. 1

no attempt has been made to fix the measurements on the thermometric scale.

All determinations reported are temperature differences between a "reference" quartz and the unknown. A large single crystal of quartz from Minas Gerais, Brazil, was selected as a reference. It is likely that the reference quartz used in this work has the same geologic origin as the material used by Bates and Phelps, therefore presumably has an inversion temperature of 573.3±0.1° C. One half of the crystal was crushed and used in the determinations, the remainder being saved for other investigations.

Each determination was made as follows: Three time-temperature heating curves were run on the reference quartz, the last two being made without cooling more than a few degrees below the transition. The reference quartz was then removed and the unknown immediately placed in-the furnace and three time-temperature curves were made as before. To check any drift in the potentiometer the reference quartz was again placed in the furnace and rerun three additional times. In all determinations the value of the third run of the second set of runs on the reference quartz was within 0.08° C. of the first, and the mean of the two values was accepted. A typical series of experiments is shown in Table 1.

TABLE 1. DETERMINATION OF DIFFERENCE IN INVERSION TEMPERATURE OF STANDARD AND UNKNOWN

Run	*Standard*	*Unknown*	*Standard*
1	23845.6	23829.9	23847.6
2	23842.0	23824.3	23842.0
3	23840.2	23823.0	23841.2

Standard	23840.7
Unknown	23823.0
	17.7 or 18 Microvolts difference

It was necessary to make three time-temperature curves for each determination because the first and second runs on a sample that had been cooled to room temperature were always somewhat higher than subsequent runs (one exception to this was found). After the third run through the transition the temperature of the inversion was constant within the experimental error and this value was accepted.

Investigations of the inversion by means of cooling and differential curves have not been carried out. The interrelations between heating, cooling, and differential curves should provide much useful additional information.

RESULTS

The inversion temperature of 36 quartz samples has been determined with respect to the reference quartz (Table 2). Inversion temperatures 0.60° C. above, and 1.30° C. below the reference have been found.[3]

[3] It should be pointed out that the value of quartz for calibration in routine thermal analysis as recently proposed by Dr. George T. Faust (*Am. Mineral.*, **33**, 337–345, 1948) is in no way affected by the variations in the inversion temperature reported here.

TABLE 2

No.	Type of Occurrence	Locality	Remarks	± ref. quartz
1	Novaculite	Missouri		+18
2	Euhedral crystals in solution cavities in limestone	Carrara, Italy		+17
3	Vein quartz	Brazil	Easily twinned by sawing	+15
4	Euhedral crystals from vug in limestone	Keokuk(?), Iowa	Pronounced lineage	+15
5	Quartz from Alpine-type vein	Switzerland	Smoky twisted	+14
6	Vein quartz	Brazil	Smoky, same crystal as spec. 9	+12
7	Vein quartz	Brazil	Easily twinned	+12
8	Euhedral crystals from vug in limestone	Herkimer Co., New York		+11
9	Vein quartz	Brazil	Clear, same crystal as spec. 6	+10
10	Euhedral crystal from vug in limestone	Herkimer Co., New York	Different source from 8	+10
11	Quartz vein in biotite gneiss	Washington, D. C.		+ 5
12	Quartz vein	Guanajuato, Mexico	Lineage present, amethyst	+ 5
13	Quartz-ankerite vein in marble	Medicine Bow Mts., Montana		+ 3
14	Quartz vein in mica schist	2 miles North of Keystone, S. D. on Hwy. 16		+ 2
15	Quartz vein	Hot Springs, Ark.		+ 1
16	Glassy white quartz core of pegmatite	New York Mine, Black Hills, S. D.		0
17	Quartz vein containing andalusite	Black Hills, S. D.		0
18	Harney Peak Granite	North of Mt. Rushmore, Black Hills, S. D.		0
19	Pegmatite in Harney Peak granite	North side of Sylvan, Lake, Black Hills, S. D.		− 2
20	Pegmatite in Harney Peak granite	South of Grizzly Bear Camp Grounds, Black Hills, S. D.		− 5
21	Graphic granite	Bradbury, Maine		−12
22	Rhyolite tuff	New Mexico		−14
23	Biotite granite	Wallace Cove, Head Harbor Island, Jones Port, Maine		−17
24	Probably pegmatite	Brazil	Citrine quartz	−19

TABLE 2—(*continued*)

No.	Type of Occurrence	Locality	Remarks	±ref. quartz
25	Gray quartz from quartz-spodumene zone of pegmatite	Helen Beryl Mine, Black Hills, S.D.		−21
26	Graphic granite	Minot, Maine		−23
27	Quartz core of pegmatite	Etta Mine, Black Hills, S. D.		−24
28	Rhyolite	New Mexico	National Mus. 102458	−26
29	Pegmatite	West of New York Mine, Black Hills, S. D.	Small offshoot (?) of N. Y. pegmatite	−26
30	Pegmatite	Jones Port, Maine	Specimen taken near 23	−28
31	Rhyolite	Colorado	Nevadite	−29
32	Rhyolite	Locality unknown	Euhedral crystal	−38
33	Epithemal (?) vein	Cripple Creek, Colorado		−40
34	Pegmatite	Probably Maine	Rose quartz	−52
35	Synthetic—grown in dilute NaOH solution at 300° C. and 1000 kg./cm.^{2} pressure			+24
36	Synthetic—grown in sodium tungstate melt at 800° C.			−12

Phenocrysts of quartz from five different rhyolites, presumably formed at high temperature, have transition temperatures below the reference quartz. Moreover one sample of quartz grown in the laboratory at 800° C. also inverted below the reference. On the other hand five samples believed to have grown at low temperature (from vugs in limestone) have inversion temperatures higher than the reference, as does one sample grown in the laboratory at 300° C. The relative temperature of formation of the remainder of the specimens is not known as they are from granites, pegmatites and quartz veins. Fig. 2 illustrates the relative temperatures of inversion of these samples.

Observations of geological significance may be summarized as follows:

(*a*) All quartz specimens whose geologic environment indicates low temperature of growth and one synthetic at 300° C. invert at higher temperatures than the reference quartz.

(*b*) All quartz from rhyolites and one synthetic at 800° C. invert at temperatures below the reference sample.

(*c*) All specimens whose morphology indicates low quartz invert at the same temperature as or at a higher temperature than the reference quartz.

(*d*) All specimens having recognizable lineage invert at higher temperatures than the reference. This inverse relation between lineage and tem-

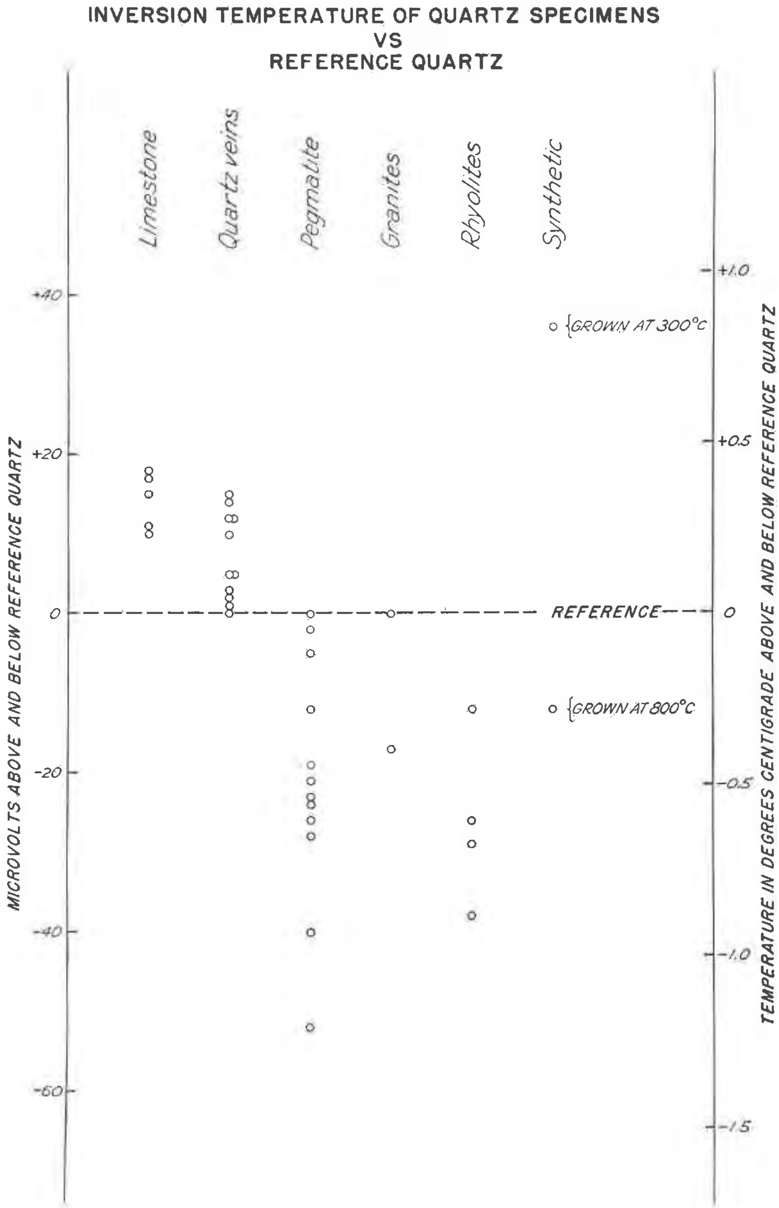
INVERSION TEMPERATURE OF QUARTZ SPECIMENS
VS
REFERENCE QUARTZ
Limestone
Quartz veins
Pegmatite
Granites
Rhyolites
Synthetic
+40
+20
0
-20
-40
-60
MICROVOLTS ABOVE AND BELOW REFERENCE QUARTZ
+1.0
+0.5
0
-0.5
-1.0
-1.5
TEMPERATURE IN DEGREES CENTIGRADE ABOVE AND BELOW REFERENCE QUARTZ
GROWN AT 300°C
REFERENCE
GROWN AT 800°C

FIG. 2

perature of formation has been reported for other crystals.[4] It is unfortunate that a quantitative method of evaluating the magnitude of lineage has not been devised.

(*e*) Two specimens of chert showed no break in the heating curve although *x*-ray analysis indicates that both samples are quartz.

(*f*) All specimens except number 24 inverted at a higher temperature on heating through the inversion from room temperature than on heating from a few degrees below the inversion temperature. In other words there appears to be some type of readjustment on cooling to room temperature that does not take place on cooling only a few degrees below the transition temperature. Much additional experimental work will have to be carried out to exclude experimental uncertainties before the significance of this observation can be evaluated.

Theoretical Considerations

Variability of the inversion temperature of quartz is probably the result of solid solution. Knowledge of the amount and kind of "impurities" must await careful spectrographic analysis.

Solid solution can raise the inversion temperature, lower it, or leave it unaffected, depending on the solubility relations between the two modifications of the crystal and the material entering into solid solution. If the solubility is greater in the high temperature modification, the inversion temperature will be lowered; whereas greater solubility in the low temperature form will raise the transition temperature.

The greater specific volume of the high temperature modification suggests that solid solution, especially of the interstitial type, would be greater in the high temperature form, with consequent lowering of the transition temperature. This is the relation actually found.

Quartz is a unique mineral in that it reputedly does not vary in composition despite its wide geologic distribution and the variability of the chemical environment in which it has grown. However, the possibility that small amounts of other elements may enter into solid solution cannot be excluded. A certain amount of interstitial solid solution seems probable, and substitutional solid solution does not appear to be improbable. Germanium, which is a likely candidate for substitutional solid solution, has been reported in small amounts in quartz.[5] Also, Ba, Al, and

[4] Smith, F. G., Lineage structure and conditions of deposition of pyrite: *Econ. Geol.*, **37**, 519 (1942).

Tuttle, O. F., and Twenhofel, W. S., Effect of temperature on lineage structure in some synthetic crystals: *Am. Mineral.*, **31**, 569–573 (1946).

[5] Goldschmidt, V. M., and Peters, C., Zur Geochemie des Germaniums: *Nachr. Ges. Wiss. Göttingen, Math.-Phys. Kl.*, **141** (1933).

Ti have been reported in quartz from granitic rocks in amounts up to 0.90%.[6] These impurities, if present in solid solution, might be sufficient to change the inversion temperature appreciably. Theoretically strain, such as may be present in the quartz from mylonitic rocks, could affect the inversion characteristics. An investigation of this possibility is being carried out.

Conclusions

The inversion temperature of quartz believed to have grown at low temperature is higher than specimens believed to have grown at high temperatures. The same contrast is shown by quartz grown in the laboratory at measured temperatures. If this inverse relation between inversion temperature and temperature of formation is found to be universally valid the quartz inversion will become a valuable geologic thermometer especially when calibrated by quartz grown at known temperatures and pressures in the laboratory. Solid solution is believed to be the most likely cause of the variable transformation temperature.

Acknowledgments

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[6] Bray, J. M., Spectroscopic distribution of minor elements in igneous rocks from Jamestown, Colorado: *Bull. Geol. Soc. Am.*, **53,** 765–814 (1942).