

Leszek STOCH, Maria ŁACZKA*, Irena WACŁAWSKA*

THE ROLE OF IMPURITIES IN THE HIGH-TEMPERATURE TRANSFORMATIONS OF SiO_2

Abstract. The effect of impurities on the melting of vein quartz and rock crystal and on their transformation to cristobalite was studied. The change of quartz into cristobalite always occurs through a transitional phase. The presence of alkalis and alkaline earths promotes the formation of the transitional phase and subsequently, the crystallization of cristobalite. The isomorphous substitution of Al^{3+} for Si^{4+} accelerates the formation of the transitional phase, inhibiting simultaneously the crystallization of cristobalite. The higher the total content of impurities, the more rapid is the formation of silica melt and the lower is the temperature at which it forms.

INTRODUCTION

From the earlier studies of phase transformations of SiO_2 it is known that the formation of cristobalite proceeds through an amorphous transitional phase of a density of about 2.3 g/cm^3 . The content of this phase initially increases with the prolonged heating time and then decreases. This has been demonstrated by Roberts (1959, 1961), Chaklader (1963), Sanmoy Mitrā (1977) and other investigators who studied the kinetics of transformation of very pure rock crystal varieties to cristobalite at different temperatures.

Silica glass can be melted both from high-temperature cristobalite and directly from quartz, without its changing into cristobalite (Mackenzie 1960). According to Prianišnikov (1971), quartz does not pass into the melt directly but through an amorphous transitional phase.

It is generally known that both the mechanism and kinetics of the above phenomena depend on the kind, amount and distribution of structural impurities in quartz. Up till now, however, no systematic or extensive studies of this problem have been made.

The progress of high-temperature phase transformations of SiO_2 determines the quality and properties of silica glass (Stoch, Łączka, Kucharski 1981). The present authors investigated the factors affecting the crystallization of cristobalite and the formation of silica melt during the heating of natural quartzes showing varying degrees of chemical purity.

*Institute of Building Materials and Refractories, Academy of Mining and Metallurgy in Cracow (Kraków, al. Mickiewicza 30).

EXPERIMENTAL

The studies of high-temperature phase transformations of silica were carried out on rock crystals and vein quartzes. They were four varieties of rock crystal of the trade names of Angola, Watanabe and Telequartz — green and red varieties, and Polish quartzes from Lower Silesia (Wądroże Wielkie, Rozdroże Izerskie, Oleszna Podgórska, Taczalin, Leśna, Podgórzyn, Jarnottów).

The samples were first broken up by the method of thermal shocks, involving twice repeated calcination at 700°C, and then mechanically. The 0.1–0.5 mm fraction, as the one used for the melting of silica glass, was subjected to investigations.

In the case of vein quartzes, the 0.1–0.5 mm fraction was subjected to chemical treatment. The process involved hot treatment of samples in 18% hydrochloric acid for 6 hours and in oxalic acid for 3 hours.

All the quartz samples, both treated and untreated, were analysed for trace impurities, using AAS method. The results are presented in Tables 1 and 2.

The studies of transformation of high-temperature quartz to high-temperature

The content of impuri

Quartz variety	Impurities (in ppm)			
	CaO	MgO	Al ₂ O ₃	Na ₂ O
Angola	5.5	1.6	16.5	12.7
Watanabe	1.3	1.0	19.0	11.0
Telequartz green variety	8.0	1.0	34.0	16.0
Telequartz red variety	1.6	1.0	7.0	13.0

The content of impurities in untreated (a)

Quartz variety		Impurities (in ppm)		
		CaO	MgO	Al ₂ O ₃
Wądroże Wielkie	a	28	6	380
	b	14	3	113
Rozdroże Izerskie	a	28	32	570
	b	14	16	377
Oleszna Podgórska	a	84	33	180
	b	56	33	180
Taczalin	a	140	66	1900
	b	42	66	1140
Leśna	a	56	84	1880
	b	28	33	1300
Podgórzyn	a	14	8	190
	b	14	5	171
Jarnottów	a	140	100	188
	b	140	66	188

cristobalite were carried out at 1500°C in a superkhantal electric furnace. The samples were heated at this temperature for different lengths of time, from 0.5 to 16 hours.

The process of formation of silica melt was investigated by heating the samples at 1350, 1500, 1650 and 1750°C in a Baltzers vacuum furnace and "freezing" the stages corresponding to respective temperatures by rapid cooling.

The heating products were subjected to quantitative phase analysis for the content of quartz and cristobalite, using DTA method and calibration curves. Standard mixtures were made from the given quartz variety and standard cristobalite. The latter was obtained through crystallization of silica glass.

Thermal analysis was made with an F. Paulik Q-1500 derivatograph. The heights of DTA peaks of $\beta \rightarrow \alpha$ quartz transformation at 573°C and $\beta \rightarrow \alpha$ cristobalite transformation at 230–240°C were used to estimate the content of quartz and cristobalite.

Thin sections were made from selected samples and investigated in a polarizing microscope.

Table 1

ties in rock crystals

Impurities (in ppm)				R ₂ O+RO Al ₂ O ₃
K ₂ O	Li ₂ O	Fe ₂ O ₃	Total	
1.0	5.6	4.5	47.4	1.6
1.0	9.0	2.0	44.3	1.2
1.0	9.0	3.0	72.0	1.0
19.0	2.0	3.0	46.6	5.2

Table 2

and purified (b) vein quartzes

Impurities (in ppm)					R ₂ O+RO Al ₂ O ₃
Na ₂ O	K ₂ O	Li ₂ O	Fe ₂ O ₃	Total	
40	48	2	140	644	0.9
40	48	1	43	262	
135	60	6	28	859	0.4
54	48	10	14	533	
400	60	2	57	816	1.3
400	48	1	28	746	
810	240	64	100	2610	0.9
675	120	64	57	2164	
94	1200	6	285	3605	0.9
80	1080	8	28	2757	
13	24	21	14	284	0.2
13	12	21	14	240	
130	360	21	140	1079	2.9
130	240	21	71	859	

RESULTS

α quartz \rightarrow α cristobalite transformation

The phase analysis of samples heated at 1500°C shows that all the quartzes change into cristobalite, but the course and progress of this transformation differ widely for individual quartz varieties.

The results of phase analysis are presented graphically as a plot of the percentage of crystalline phases against heating time. In all cases the total content of quartz and cristobalite is less than 100%. As in earlier studies, it has been assumed that the complement to 100% is a phase failing to display DTA peaks, referred to as "transitional" phase. Changes in the content of this phase are indicated on the plots by a broken line.

The plots in Fig. 1 illustrate changes in the content of individual phases with heating time for rock crystals: Watanabe and Telequartz — green and red varieties. As is evident from the plots, the formation of cristobalite is always attended by the appearance of the transitional phase. In Watanabe and Telequartz (green variety quartzes) the content of this phase increases at the same rate as that of cristobalite, and after 10-hour heating the content of the two phases attains a value of a dozen or so per cent. A similar behaviour has also been observed for Angola rock crystal. It appears, therefore, that the degree of transformation to cristobalite is in these quartzes insignificant.

The transformation of Telequartz (red variety) proceeds differently. Its heating causes a rapid increase in the content of transitional phase, which attains its maximum after 8 hours. From this point, the content of cristobalite also begins to increase rapidly at the expense of the transitional phase. This shows that cristobalite forms through crystallization of the transitional phase.

A much greater amount of transitional phase forms during the heating of vein quartzes compared with rock crystal. However, the ability of the transitional phase to crystallize into cristobalite is different for individual quartzes. In this respect, the vein quartzes under study can be divided into three groups:

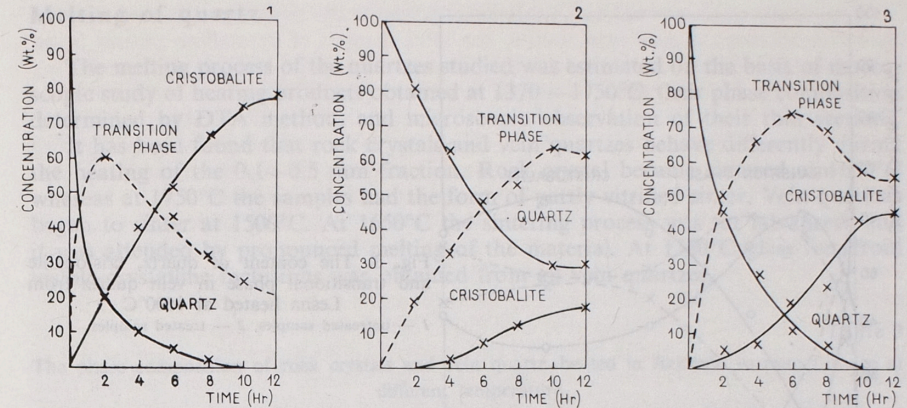


Fig. 2. The content of quartz, cristobalite and transitional phase in vein quartzes heated at 1500°C

1 — vein quartz from Wądroże Wielkie, 2 — vein quartz from Rozdroże Izerskie, 3 — vein quartz from Oleszna Podgórska

- quartzes showing a strong tendency to change into cristobalite (Wądroże Wielkie, Leśna, Jarnołtów);
- quartzes having a very weak tendency to change into cristobalite (Rozdroże Izerskie, Podgórzyn);
- quartzes showing intermediate behaviour (Oleszna Podgórska, Taczalin).

Plots of the content of phases vs. heating time, characteristic of the respective groups, are presented in Fig. 2. The plots were obtained for untreated vein quartz samples. As appears from plot 1 (quartz from Wądroże Wielkie), a substantial amount of transitional phase already forms after 2-hour heating. As the heating time is prolonged, the content of this phase decreases while the content of cristobalite increases rapidly, attaining a value of about 80%. The curve of the transitional phase content obtained for quartz from Rozdroże Izerskie (plot 2) attains its maximum after 10-hour heating. Even after 12 hours the amount of crystallized cristobalite is small, of the order of a dozen or so per cent, and does not show any tendency to increase. In the case of quartz from Oleszna Podgórska (plot 3), the maximum content of transitional phase has been noted after 6-hour heating, and the maximum amount of crystallized cristobalite is about 50%.

In quartzes showing a strong tendency to change into cristobalite, the partial removal of extra-structural impurities during acid treatment had an inhibiting effect on the crystallization of cristobalite. This is illustrated by plots in Figs. 3 and 4, showing changes in the content of phases during heating of quartzes from Leśna and Jarnołtów. In quartzes from Rozdroże Izerskie and Podgórzyn chemical treatment did not affect significantly the crystallization of cristobalite.

Microscopic observation of thin sections obtained from quartzes heated at 1500°C has shown that the transformation of quartz to transitional phase can be accomplished in two ways. It can proceed from the grain boundaries, which become melted during prolonged heating, or inside the grains, through cracks and fissures, along which an optically isotropic phase develops. The former way prevails in Watanabe and Angola rock crystals, the latter — in Telequartz varieties and vein quartzes. Quartz from Wądroże Wielkie shows the particularly advanced process of decomposition of grains through cracks and fissures.

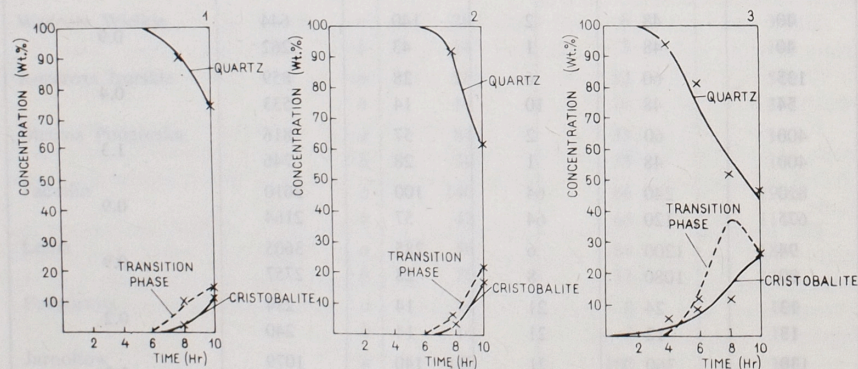


Fig. 1. The content of quartz, cristobalite and transitional phase in rock crystals heated at 1500°C
1 — Watanabe rock crystal, 2 — Telequartz rock crystal — green variety, 3 — Telequartz rock crystal — red variety

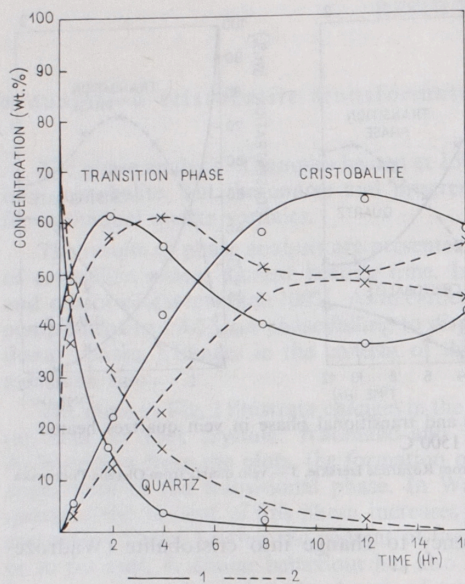


Fig. 3. The content of quartz, cristobalite and transitional phase in vein quartz from Leśna heated at 1500°C
1 — untreated samples, 2 — treated samples

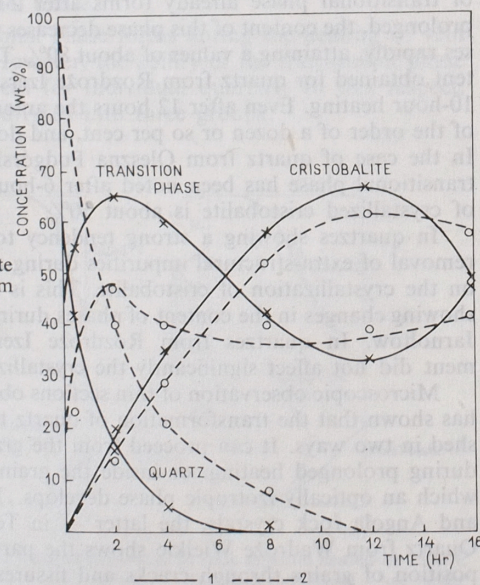


Fig. 4. The content of quartz, cristobalite and transitional phase in vein quartz from Jarnołtów heated at 1500°C
1 — untreated samples, 2 — treated samples

Melting of quartz

The melting process of the quartzes studied was estimated on the basis of macroscopic study of heating products obtained at 1370—1750°C, their phase composition determined by DTA method, and microscopic observation of their thin sections.

It has been found that rock crystals and vein quartzes behave differently during the heating of the 0.1—0.5 mm fraction. Rock crystal became sintered at 1650°C whereas at 1750°C the samples had the form of partly vitrified sinter. Vein quartzes began to sinter at 1500°C. At 1650°C the sintering process was far advanced and it was attended by pronounced melting of the material. At 1750°C glass free from visible crystalline inclusions was obtained from all vein quartzes.

Table 3

The phase composition of rock crystals and vein quartz heated in Baltzers vacuum furnace at different temperature

Quartz variety	Heating temperature (°C)	Content of phases (wt%)		
		quartz	cristobalite	phase failing to produce DTA effecte
Angola	1350	100	—	—
	1500	94	—	6
	1650	72	1	27
	1750	49	1	50
Watanabe	1350	100	—	—
	1500	89	—	11
	1650	72	—	28
	1750	66	—	34
Telequartz red variety	1350	100	—	—
	1500	91	2	7
	1650	90	6	4
	1750	33	5	62
Telequartz green variety	1350	100	—	—
	1500	96	—	4
	1650	30	2	68
	1750	3	1	96
Vein quartz Wądroże Wielkie	1350	67	10	23
	1500	20	23	57
	1650	—	66	34
	1750	—	—	100
Vein quartz Rozdroże Izerskie	1350	70	—	30
	1500	12	16	72
	1650	5	30	65
	1750	—	—	100
Vein quartz Oleszna Podgórska	1350	56	5	39
	1500	5	40	55
	1650	—	65	35
	1750	—	—	100

The results of phase analysis (Table 3) show that in the majority of heated samples quartz is accompanied by cristobalite, the total content of crystalline phases being less than 100. It has been assumed that the complement to 100% is a phase failing to produce DTA peaks which is mainly a melting product of quartz or cristobalite. The content of respective phases depends on temperature and the kind of quartz.

Rock crystals were transformed to cristobalite in an insignificant degree. During the heating of the purest of them (Watanabe), cristobalite did not practically crystallize while in the other varieties (Angola, Telequartz) it appeared in an amount of a few per cent. It follows therefore, that during the heating of rock crystals the melt forms directly from quartz, which begins to melt at about 1500°C. However, both phase analysis and microscopic studies show that the rock crystal varieties under study differ from one another in melting rate. Telequartz (green variety) appeared to melt most rapidly, so that at 1750°C the residue of crystalline phases was a few per cent only. The red variety of this quartz and Angola rock crystal melted at a somewhat slower rate, whereas Watanabe quartz showed the slowest melting rate.

The microscopic study of this sections revealed the following facts: In Telequartz (green variety), already at 1650°C the grains were covered with a dense network of cracks, sometimes passing into lenses filled up with an optically isotropic phase. At 1750°C the network of cracks became denser, and the resulting small fragments of grains were gradually melted and passed into the amorphous phase. Although slower, the process of melting was similar for Telequartz (red variety) and Angola. In Watanabe quartz, cracks filled up with an optically isotropic phase appeared at 1650°C on few grains only. At 1750°C the grains broke up along these cracks into smaller fragments that became melted at the edges. The amount of grains exhibiting thin cracks increased, yet the changes produced by heating were still insignificant. Such behaviour is characteristic of slow-melting quartz.

When heated, vein quartzes differ markedly from rock crystals in the degree of transformation to cristobalite and in melting rate.

The estimate of vein quartzes in respect of their transformation to cristobalite in the temperature range of 1350—1750°C agrees fairly well with the estimate made for 1500°C. Quartzes from Rozdroże Izerskie and Podgórzyn showed the weakest tendency to change into cristobalite, the amounts of crystallized cristobalite varying from a dozen or so to 30%. Simultaneously, already at 1350°C, i.e. at a temperature lower by 150° than in the case of rock crystals, quartz began to disappear. Glass free from crystalline inclusions was obtained at 1750°C, while only partially vitrified sinters were obtained at this temperature from rock crystal. From the above experimental data it appears that the mechanism of formation of silica melt from vein quartzes from Rozdroże Izerskie and Podgórzyn is similar to that of melting of rock crystal, but the melting point is lower by about 150°.

Compared with quartzes from Rozdroże Izerskie and Podgórzyn, the other vein quartzes showed a considerably higher degree of transformation to cristobalite. Cristobalite formed already at 1350°C, its content varying from 50 to 80%. The crystallization of cristobalite slowed down the process of formation of the melt. Despite this fact, the progress in melting of vein quartzes was faster than for rock crystals.

The partial removal of impurities during acid treatment slowed down markedly the process of melting.

Temperature (°C)	Watanabe	Angola	Telequartz (green)	Telequartz (red)
1750	100	100	100	100
1650	100	100	100	100
1500	100	100	100	100
1350	100	100	100	100
1200	100	100	100	100

DISCUSSION

The observed differences in the course of high-temperature phase transformations of silica in the quartzes studied were compared with the content of impurities (Tables 1 and 2). On this basis, the authors put forward certain hypotheses concerning the role of impurities in this process.

It seems that alkaline ions and alkaline earths present in quartz promote the formation of the transitional phase and then its crystallization into cristobalite because they weaken the bonds in the silicon-oxygen network and influence its depolymerization manifesting itself, among others, in the lower viscosity facilitating the migration of ions. All this accounts for the greater amount of transitional phase appearing upon heating of vein quartzes compared with rock crystal, and the higher degree of their transformation to cristobalite. The content of alkalis in vein quartzes is from some to several dozen times higher than in rock crystal. Other impurities only seem to facilitate the formation of the disordered transitional phase. At the same time, the foreign elements entering into the silicon-oxygen network as isomorphous substitution, e.g. Al³⁺ substituting for Si⁴⁺ in the SiO₄ tetrahedra, stabilize presumably the transitional phase, inhibiting the crystallization of cristobalite. This hypothesis is substantiated by the comparison of the progress of crystallization of cristobalite with heating time with the ratio of the total content of alkali oxides and alkaline earths (R₂O+RO) to the amount of Al₂O₃ in quartz samples after chemical treatment (Table 2). In the group of rock crystals, the value of $\frac{R_2O+RO}{Al_2O_3}$ was about 5 for Tele-

quartz (red variety), while for the other rock crystals it was about 1. Telequartz (red variety) showed the strongest tendency to change into cristobalite. In the group of vein quartzes, the value of $\frac{R_2O+RO}{Al_2O_3}$ varied from 1 to 3 for quartzes with a strong tendency to change into cristobalite, while for quartzes from Rozdroże Izerskie and Podgórzyn, which show the lowest degree of transformation to cristobalite, it was about 0.4 and 0.2, respectively.

From the analysis of the course of melting of the quartzes studied it can be inferred that impurities accelerate this process. Such an influence is presumably exerted both by structural and extra-structural impurities, as the former weaken the bonds and lower the melting point, and the latter promote the formation of melts with a lower melting point than that of pure silica at the grain boundaries. These facts account for the most rapid, in the group of rock crystals, melting rate of Telequartz (green variety), having the highest total content of impurities. They also explain the more rapid melting rate of vein quartzes compared with rock crystals, as well as the differences in the melting rate of treated and untreated quartzes.

Acknowledgement. The present study is a contribution to the research project No I-33 sponsored by the Ministry of Science, Higher Education and Technology. The authors express their thanks for the financial support for their investigations.

REFERENCES

- CHAKLADER A. C. D., 1963: X-ray study of quartz-cristobalite formation. *Jour. Amer. Cer. Soc.* 46, 2, 66—71.
 MACKENZIE J. D., 1960: Fusion of quartz and cristobalite. *Jour. Amer. Cer. Soc.*, 43, 12, 615—620.
 [PRIANISZNIKOW W. R.] ПРЯНИШНИКОВ В. Р., 1971: Система кремнезема. Изд. Литер. по Строительству. Ленинград.

- ROBERTS A. L., 1959: Kinetics of high-temperature processes (W. D. Kingery, editor), 222—227, Technology Press of M.I.T. and New York.
- ROBERTS A. L., CHAKLADER A.C.D., 1961: Transformation of quartz to cristobalite. *Jour. Amer. Cer. Soc.*, 44, 1, 35—41.
- SANMOY MITRA, 1977: Kinetics of quartz-cristobalite transformation. *Trans. Brit. Cer. Soc.*, 76, 4, 71—74.
- STOCH L., ŁĄCZKA M., KUCHARSKI J., 1981: The effect of isomorphous substitutions on the melting of quartz and its transformation to cristobalite. *Miner. Polon.* 12, 2, 57—68.

Leszek STOCH, Maria ŁĄCZKA, Irena WACŁAWSKA

WPLYW ZANIECZYSZCZEŃ NA WYSOKOTEMPERATUROWE PRZEMIANY SiO_2

Streszczenie

Zbadano wpływ zanieczyszczeń na przemianę w krystalobalit i topienie próbek kryształów górskich o nazwach handlowych: Angola, Watanabe, Telequartz — odmiana zielona i czerwona oraz kwarców żyłowych z siedmiu występowań na Dolnym Śląsku. Stwierdzono, że przemiana kwarcu w krystalobalit zachodzi poprzez fazę przejściową, nie dającą efektów DTA, przy czym stopień tej przemiany jest różny w zależności od rodzaju i ilości zanieczyszczeń w poszczególnych gatunkach kwarcu.

Z przeprowadzonych badań wynika, że obecność jonów alkalicznych i ziem alkalicznych sprzyja powstawaniu fazy przejściowej, a następnie jej przekształcaniu w krystalobalit. Stąd znacznie większe ilości fazy przejściowej, pojawiającej się przy ogrzewaniu kwarców żyłowych i ich wyższy stopień przemiany w krystalobalit w porównaniu z kryształem górskim, który w stosunku do kwarców żyłowych charakteryzuje się znacznie większą czystością chemiczną. Zanieczyszczenia wchodzące w formie podstawień izomorficznych do sieci krzemotlenowej, np. jony glinu Al^{3+} podstawiające w czworościanach (SiO_4) jony Si^{4+} , stabilizują przypuszczalnie fazę przejściową, hamując krystalizację krystalobalitu. Wskazuje na to porównanie stopnia przemiany w krystalobalit poszczególnych kwarców z obliczonymi na podstawie wyników analiz chemicznych wartościami stosunku sumy ilości tlenków alkalicznych i ziem alkalicznych ($\text{R}_2\text{O} + \text{RO}$) do ilości tlenku glinu Al_2O_3 . W grupie kryształów górskich dla kwarców o małej skłonności do przemiany w krystalobalit wartość $\frac{\text{R}_2\text{O} + \text{RO}}{\text{Al}_2\text{O}_3}$ wynosiła około 1, podczas gdy dla kwarcu najchętniej przechodzącego w krystalobalit (Telequartz — odmiana czerwona) — około 5. W przypadku kwarców żyłowych stosunek $\frac{\text{R}_2\text{O} + \text{RO}}{\text{Al}_2\text{O}_3}$ przyjmował wartości odpowiednio 0,4 i 0,2 dla kwarców z Rozdroża Izerskiego i Podgórzyna, których stopień przemiany w krystalobalit był najniższy, podczas gdy dla pozostałych kwarców żyłowych, wykazujących dużą skłonność do przemiany w krystalobalit wartości te mieściły się w przedziale od ok. 1 do 3.

Z analizy przebiegu procesu topienia wynika, że zanieczyszczenia wpływają przyspieszająco na ten proces. Wyjaśnia to największą w grupie kryształów górskich szybkość topienia kwarcu Telequartz — odmiana zielona, zawierającego największą sumaryczną ilość zanieczyszczeń. Tłumaczy to również większą szybkość topienia kwarców żyłowych w porównaniu z kryształami górskimi.

OBJAŚNIENIA FIGUR

- Fig. 1. Zawartość kwarcu, krystalobalitu i fazy przejściowej w próbkach kryształów górskich, wygrzewanych w temperaturze 1500°C
1 — kryształ górski Watanabe, 2 — kryształ górski Telequartz — odmiana zielona, 3 — kryształ górski Telequartz — odmiana czerwona
- Fig. 2. Zawartość kwarcu, krystalobalitu i fazy przejściowej w próbkach kwarców żyłowych, wygrzewanych w temperaturze 1500°C
1 — kwarc żyłowy z Wądroża Wielkiego, 2 — kwarc żyłowy z Rozdroża Izerskiego, 3 — kwarc żyłowy z Olesznej Podgórskiej
- Fig. 3. Zawartość kwarcu, krystalobalitu i fazy przejściowej w próbkach kwarcu żyłowego z Leśnej, wygrzewanych w temperaturze 1500°C
1 — próbki nieuszlachetnione, 2 — próbki uszlachetnione
- Fig. 4. Zawartość kwarcu, krystalobalitu i fazy przejściowej w próbkach kwarcu żyłowego z Jarholtowa, wygrzewanych w temperaturze 1500°C
1 — próbki nieuszlachetnione, 2 — próbki uszlachetnione

Лешек СТОХ, Марья ЛОНЧКА, Ирена ВАЦЛАВСКА

ВЛИЯНИЕ ЗАГРЯЗНЕНИЙ НА ВЫСОКОТЕМПЕРАТУРНЫЕ ПРЕВРАЩЕНИЯ

Резюме

Изучалось влияние загрязнений на превращение в кристобалит и плавление образцов горного хрусталя торговых наименований — Ангола, Ватанабе, Телекварц — зеленая и красная разновидности, а также жильных кварцев из семи местонахождений в Нижней Силезии. Обнаружено, что превращение кварца в кристобалит происходит через промежуточную фазу, не отражающуюся эффектами ДТА, причем степень этого преобразования различна в зависимости от рода и количества загрязнений в отдельных сортах кварца.

Из проведенных исследований следует, что присутствие щелочных и щелочноземельных ионов содействует образованию промежуточной фазы, а затем ее рекристаллизации в кристобалит. Отсюда и значительно большие количества промежуточной фазы, появляющейся при нагревании жильных кварцев и их более высокая степень превращения в кристобалит по сравнению с горным хрусталем, который в химическом отношении более чист чем жильный кварц. Примеси, входящие в виде изоморфных замещений в кремнекислородную решетку, например ионы алюминия Al^{3+} , замещающие в тетраэдрах (SiO_4) ионы Si^{4+} , по-видимому, задерживая кристаллизацию кристобалита, стабилизируют промежуточную фазу. На это указывает сравнение степени превращения в кристобалит отдельных кварцев с рассчитанными на основании химических анализов значениями соотношения суммы щелочных и щелочноземельных окислов ($\text{R}_2\text{O} + \text{RO}$) и содержания окисла алюминия Al_2O_3 . В группе горных хрусталей для кварцев с небольшой склонностью к превращению в кристобалит соотношение ($\text{R}_2\text{O} + \text{RO}$): Al_2O_3 составляло около 1, тогда как для кварца наиболее склонного к превращению в кристобалит (Телекварц — красная разновидность) — около 5. В случае жильных кварцев соотношение ($\text{R}_2\text{O} + \text{RO}$): Al_2O_3 принимало значение 0,4 и 0,2 соответственно для кварцев из Роздрожа Изерского и Подгужина, которые характеризуются самой низкой степенью превращения в кристобалит, тогда как для остальных кварцев,

обнаруживающих склонность к превращению в кристобалит, эти значения группируются в пределах от около 1 до 3.

Из анализа хода процесса плавления следует, что загрязнения влияют усложняющим образом на этот процесс. Это объясняет наибольшую в группе горных хрусталей скорость плавления зеленой разновидности Телекварца, содержащую в суммарном отношении наибольшее количество загрязнений. Это объясняет также большую скорость плавления жильных кварцев по сравнению с горными хрусталами.

ОБЪЯСНЕНИЯ К ФИГУРАМ

- Фиг. 1. Содержание кварца, кристобалита и промежуточной фазы в образцах горного хрустала, прогреваемых в температуре 1500°C
1 — горный хрусталь Ватанабе, 2 — горный хрусталь Телекварц — зеленая разновидность, 3 — горный хрусталь Телекварц — красная разновидность
- Фиг. 2. Содержание кварца, кристобалита и промежуточной фазы в образцах жильных кварцев, прогреваемых в температуре 1500°C
1 — жильный кварц из Вондрожа Велького, 2 — жильный кварц из Роздрожа Изерского, 3 — жильный кварц из Олешны Подгурской
- Фиг. 3. Содержание кварца, кристобалита и промежуточной фазы в образцах жильного кварца из Лесьны, прогреваемых в температуре 1500°C
1 — необлагороженные образцы, 2 — облагороженные образцы
- Фиг. 4. Содержание кварца, кристобалита и промежуточной фазы в образцах жильного кварца из Ярнотлова, прогреваемых в температуре 1500°C
1 — необлагороженные образцы, 2 — облагороженные образцы