ADVANCED METHODS TO CHARACTERIZE THERMAL PROPERTIES OF QUARTZ

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ABSTRACT

Six different types of quartz and quartzites used as raw materials by ferroalloy plants have been investigated with respect to their thermo mechanical properties. In order to investigate the effect of the thermal shock caused by the rapid heating of quartz when it enters the furnace, the following techniques have been used for both in situ investigations and investigations of pre-heated quartz:

- *Heating stage microscopy for in situ observation of heating effects.*
- *Shock heating of quartz in an induction furnace*

An optical microscope-mounted heating stage was used for in situ observations of the microscopic effects of heating up to 1300 ºC. The effects of heating were observed at different temperature intervals in different samples. The main temperature intervals were below 573 ºC and above 1000 ºC. The cause of the observed effects is interpreted as fluid inclusion decrepitation for T<573 ºC and structural implications (micro cracks, grain boundaries and remaining fluid inclusions) at T>1200 ºC.

Shock heating of the samples was carried out in an induction furnace to 1300 ºC for ten minutes. The effects of the heating were studied with different techniques such as direct observation during and directly after heating, optical microscopy and XRD. Combined transmitted and fluorescence light microscopy shows that the heated quartz show an opening of the grain boundaries and evenly distributed micro cracks that were not present in the unheated reference samples. In some of the heated samples, weak generation of cristobalite was detected by XRD.

1. INTRODUCTION

The mineral quartz (SiO_2) is the raw material for Si in the silicon and ferrosilicon ((Fe)Si) production. Quartz is built up of one Si bound to four O atoms such that in a SiO_4 tetrahedron where all the O-atoms are shared between neighboring tetrahedrons. α-quartz is the SiO_2 polymorph that is most stable at room temperature. The phase diagram for the silica system is shown in Figure 1. The phase transformation from α- to β-quartz has been described as a spontaneous and reversible reaction. The transformation from β-quartz to tridymite usually needs a catalyst, like alkali elements, to occur. Therefore, β-quartz probably transforms directly to cristobalite, a reaction that may start as low as 1100 °C [1]. This phase transformation is more time demanding than the β-quartz formation. Therefore, combined with the temperature span of the direct transformation from β-quartz to β-cristobalite, this results in only partial β-cristobalite formation in the quartz material during the experiments described in this paper and also most probably in the real (Fe)Si process. The amount of β-cristobalite in the real furnace is probably also depending on the retention time of the quartz, especially the time at high temperatures (>1470 °C).

Pure quartz suitable for the (Fe)Si process, occurs in nature as hydrothermal quartz, pegmatite quartz and quartzite. In metallurgical terms, quartz is often classified as rock quartz or gravel quartz. Gravel means

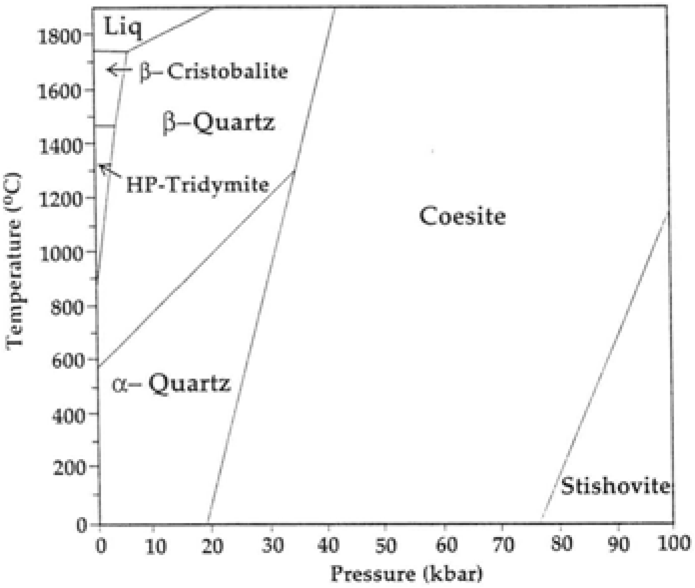


Figure 1: Phase diagram for the silica system [2]

quartz mined from fluvial deposits by excavations of unconsolidated material and rock quartz means quartz mined from bedrock by blasting operations.

This paper presents the results from two experiments where the thermal properties of quartz were investigated, both microscopically in-situ and by using secondary analytical techniques on heated material. By using a Linkam heating stage (Linkam TS 1500), the heating sequence was simulated and the mineralogical response to the heat could be observed. The main response to the heating was observed in two temperature intervals, between 180 and 573 °C and above 1200 °C.

To investigate the effects of the thermal shock, quartz samples were introduced to an induction furnace at 1300 ºC and heated for 10 minutes. After cooling in room temperature optical microscopy and XRD investigations were carried out on the heated samples and the unheated reference samples.

1.1 The Process

The metallurgical (carbothermic) production of (Fe)Si is described by e.g. Schei et al. [3]: Quartz and carbon materials react at high temperatures to form silicon metal. In ferrosilicon production, also iron ore is added. The temperature at the top of the charge burden of the furnace is 700 – 1300 ºC and the temperature in the hottest parts of the furnace is more than 2000 °C. The ideal reaction can then be written as:

$$SiO_2 + 2C = Si + 2CO \tag{1}$$

In a real furnace, the process is much more complicated and consists of several sub-processes, which may be affected by the quality of the raw materials.

The ferroalloy industry has a set of requirements to the quartz used as a raw material [3]:

- Chemistry (e.g. Al, Ti, B, P, Fe, Ca)
- Lump size (typical 10 – 150 mm)
- Mechanical strength
- Thermal strength
- Softening properties

Chemistry and size are the most common specifications used by all (Fe)Si producers. Some (Fe)Si producers focus on or measure mechanical- and thermal strength although these are not included in the specifications to the supplier, and a few (Fe)Si producers focuses on the softening properties or properties and measurements related to the softening properties. Further, additional requirements may be defined by the individual (Fe)Si producer, according to what is most optimal for the specific operation.

The raw materials are experiencing an extreme thermal shock as it enters the furnace and "bad" quartz respond quite different to the extreme thermal gradient compared to the "good" quartz. The raw materials are continuously fed by gravity on top of the furnace, such that all the raw materials are directly exposed to the hot charge material, and experience the highest thermal gradient. Otherwise, the raw materials are charged in cycles, such that the material lands on top of the charge burden in piles. Then the material in the center of the pile will be "isolated" from direct contact with the hot material and experience a slightly more gradient heating. The temperature on top of the charge burden might be as high as 700 – 1300 ºC. This means that the temperature interval is between room temperature and 1300 ºC, within seconds or minutes. The retention period for quartz in the furnace has been calculated by SiMod for a 25 MW Si furnace [4], and is on average 5.70 hrs but may be as low as 1 hour.

1.2 Previous Work

Birkeland and Carstens [5] reported results from a high temperature microscopy investigation where 1 mm thick and 6 mm circular samples of quartzite and single-crystal quartz were heated in a microscope heating stage (Leitz 1350 heating stage mounted on a Leitz Ortholux transmitted light microscope) to 1300 °C during 5 to 10 minutes and visual observations were recorded. Birkeland and Carstens [5] demonstrated that cracking occurred in most samples at around 300 – 400 °C and increasing with raising temperature up to the α-to β-quartz transition at 573 °C. Between 600 and 900 °C Birkeland and Carstens [5] see no activity related to the heating. Regenerated activity is seen between 900 and 1000 °C in several samples. This activity was reported as explosions that destroys the samples.

Birkeland and Carstens [5] also reported results from an experiment where samples from each of different quartzites were heated in a furnace to 1000 ºC with different heating rate. Two samples for heating were prepared as pieces measuring 1x5x5 cm: One sample was introduced to the furnace at room temperature and heated to 1000 ºC during 20 min, while the other sample was introduced directly to the furnace at 1000 ºC. Both samples were slowly cooled (2-3 hours), however, there are no specifications of how long the samples were kept at 1000 ºC. A third sample was used as an unheated reference. Some interesting observations were made by optical microscopy: The authors are surprised that the fluid inclusions planes did not seem to be important for the fracturing of the sample. Deformation structures like undulate extinction, sub-grain segmentation, deformation lamellae and deformation bands, and most of the inclusion planes, seem unaffected by the heating.

Geiss [6] reported an XRD investigation of heated quartz. The temperature that the heating was carried out to was not reported. The results from this experiment showed that only high-quartz was detected. Geiss [6] relates the lack of phase transformations other than β-quartz is related to the crushing of the samples and the effect this has on the lattice properties.

2. MATERIALS AND METHODS

2.1 Sample Material

The samples consist of six different types of quartz used as raw materials for the metallurgical production of (Fe)Si in Norway. The samples are both gravel- and rock quartz. Table 1 shows the different samples, listed with both metallurgical and geological type as described by Moen and Malvik [7].

Table 1: List of sample material and sample type. Metallurgical type = the differentiation that are used by metallurgists

Name	*Metallurgical Type*	*Quartz Type*
Sample A	Gravel	Hydrothermal/pegmatite
Sample B	Gravel	Hydrothermal/pegmatite
Sample C	Rock	Hydrothermal
Sample D	Rock	Pegmatite
Sample E	Rock	Meta-sandstone (quartzite)
Sample F	Gravel	Hydrothermal

A study performed by Elkem Research [8] describes the thermo-mechanical and mechanical properties of the samples used in these experiments. The thermo mechanical and mechanical properties varies between fairly good to good for all the samples.

2.2 High-Temperature Micro Thermometry

2.2.1 Equipment

The equipment used for the high-temperature micro thermometry is the Linkam TS1500 system. The stage is controlled by the temperature programmer via computer (PC) software (Linksys 32 DV (digital video)). The size of the sample cup is 7 mm in diameter and 3 mm deep. The heating stage is mounted on a Nikon Eclipse ME600 polarized and transmitted light microscope. A PixeLink firewire camera (1280x1024 pixel resolution) is mounted on the microscope and connected to the PC and is also controlled by the Linksys 32 DV software.

The temperature is controlled by the TMS94/1500 programmer via the S-type Pt/Rh thermocouple. After the end of a sample run, the images that were collected are stored together with temperature and light intensity

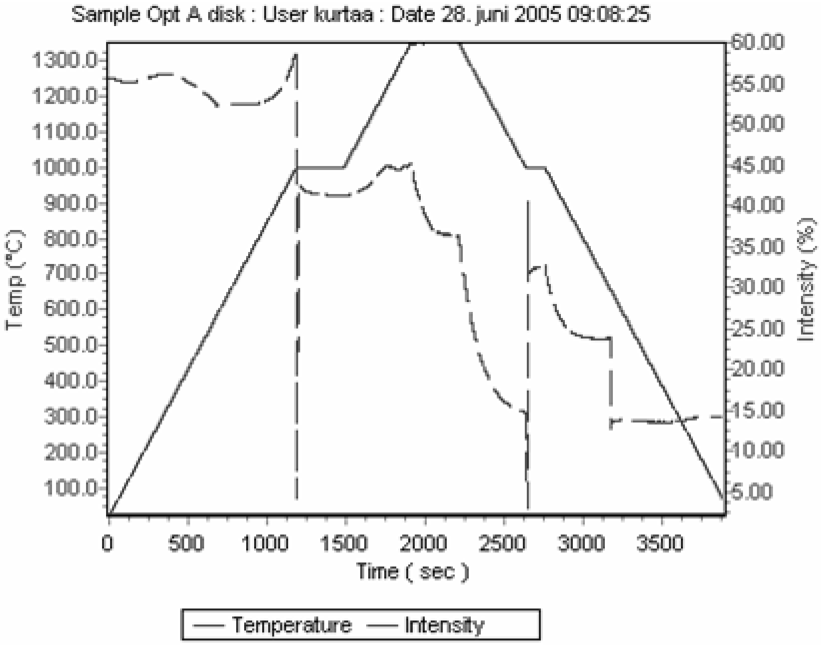


Figure 2: Example of temperature profile from the high-temperature micro thermometry investigation of Sample A.

(to the camera CCD) data in a project database. The images can later be saved and compressed into different image formats (jpeg, TIFF, etc) or into movie files (avi). The heating sequence is presented as a graph showing the temperature progress together with the intensity of the light (Figure 2). The experiments were carried out in a dark room to prevent unnecessary, unwanted light reaching the camera.

The temperature profile used for the experiments was 50 °C/min to 1350 °C with a five minutes hold at the current temperature at 1000 °C and at 1350 °C. Pictures was taken automatically every five seconds. The investigated part of the heating experiments was between the start of the temperature profile until the end of the five min. hold at 1350 °C. The cooling part of the experiments was not studied, because, in the real silicon process, the temperature never returns to room temperature.

2.2.2 Sample Preparation

The samples for the heating stage investigations were prepared as polished thick sections. The thickness of the samples was between 200 and 250 µm. The polished thick sections had to be broken to smaller pieces in order to fit the samples inside the sample cup.

2.3 Shock Heating of Quartz in Induction Furnace

2.3.1 Equipment

The furnace used for the shock heating experiments of quartz was an ASEA induction furnace from ca. 1950 working at 3830 Hz and with a capacity of 50 kg of steel. To monitor the temperature, a thermo element type S was used. A graphite crucible was used to hold the samples in the furnace.

Prior to placing each sample in the crucible, the furnace was heated to 1300 ºC. To avoid unnecessary breaking of the quartz, the samples were handled by using an appropriate pair of large tweezers. After the insertion the temperature was brought back to 1300 ºC (a small decrease in temperature was observed when the top cover was removed and the extra mass of the sample was introduced in the crucible). The sample was kept in the furnace for ten minutes to ensure homogeneous temperature distribution (1300 ºC). After ten minutes, the sample was removed by lifting the crucible and “pouring” the sample into a graphite bowl where it was left to cool at room temperature for a few minutes before they were transferred to tin cups for further cooling. The samples had cooled after approximately one hour, except Sample F, which was much less defragmented, and brought back to room temperature after more than two hours.

2.3.2 Sample Preparation

The samples were cut by diamond saw to cubes approximately 40 mm x 40 mm x 40 mm as seen in Figure 3. Due to the relatively small size of the sample material, Sample D was cut to a cube of 30 mm x 30 mm x 30 mm.

Polished Thin Sections

One polished thin section (PTS) from each of the heated samples and the corresponding unheated reference samples were prepared for polarized light optical microscopic investigations. The PTS were also impregnated with fluorescent epoxy for investigations in fluorescent light microscopy.

The optical microscopic investigations were carried out on a Nikon Eclipse E600 polarization microscope (transmitted light) equipped with a 2 megapixels digital camera (*Spot Insight Color* from Diagnostics Instruments). The fluorescence equipment (Nikon Super High Pressure Mercury Lamp) is connected to the same microscope.

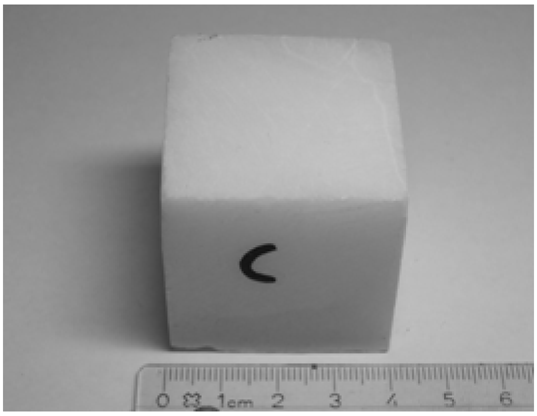


Figure 3: Example of sample preparation of quartz for shock heating in the induction furnace

XRD Analyses

Preparation of samples for XRD investigations were carried out in a laboratory disc mill. The samples were milled to approximately 40 μm grain-size. The milling time for each sample was 60 – 70 seconds at 710 rpm. The analyses were carried out on a Philips PW 1830 XRD.

3. RESULTS

3.1 High-Temperature Micro Thermometry

The typical observation for the samples was an activity related to decrepitation of fluid inclusions that started weakly around 180 °C and increasing with temperature up to the temperature for α-/β-quartz transition at 573 °C. This activity seems to be related mostly to the decrepitation of fluid inclusions but the opening of inter granular micro cracks are also observed. It is not possible to see if these micro cracks are related to fluid inclusions that lay beyond the focus depth. Further, from 600 to 1000 degrees, nothing happens within most of the samples. The exception is Sample F where all the experiments shows a moderate to high activity in the temperature interval from just below 900 °C to 1000°C. Also, one experiment of Sample D shows moderate activity around 900 – 1000 °C. In the temperature interval from 1200 – 1350 °C, most of the samples show a moderate to high activity. This is probably related to grain boundaries and existing cracks in the sample. In addition, possible remaining fluid inclusions will decrepitate in this interval. No minerals other than quartz were observed in the samples that were investigated by high-temperature micro thermometry.

The observations during the experiments are based on the observations of emerging cracks seen as dark lines in the image. Fluid inclusion decrepitation was seen as dark foggy areas probably related to the escaping fluids. In some samples, the sample was suddenly moving out of place during heating, as if it was defragmented explosively. Some samples were seen moving in one or the other direction in small steps, this were probably related to thermal drifting.

The results were after the initial in-situ observations, further checked by using the video and image options to confirm the observations. Also, the resulting temperature and intensity graphs could be used to verify the observations. Typically the intensity are steeply declining in the temperature interval of high activity of reactions while it is increasing or more stable for temperature intervals of low or no activity as seen in Figure 4 a) and b) and Figure 5 a) and b). Table 2 shows the results from the high-temperature experiments within the main intervals. Each sample is placed in a category according to the intensity of response to the heating within each interval. Here Category 0 means little or no activity observed, and Category 3 means high activity observed. The results are based on the visual observations and study of the data material after the experiments.

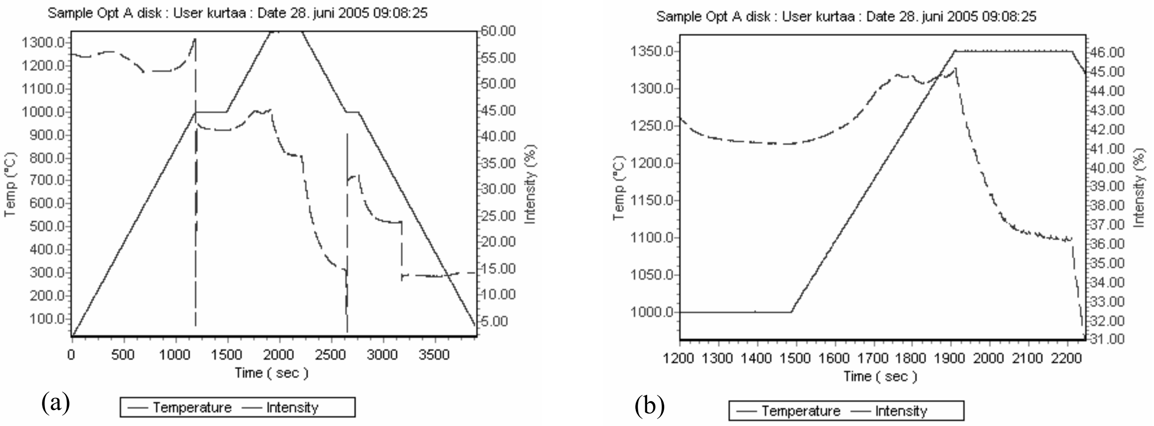


Figure 4: Temperature (line) and intensity (dashed) graphs of Sample A-2. a) Shows the entire experiment; b) shows the temperature interval 1000 °C to 1350 °C+ 5 min

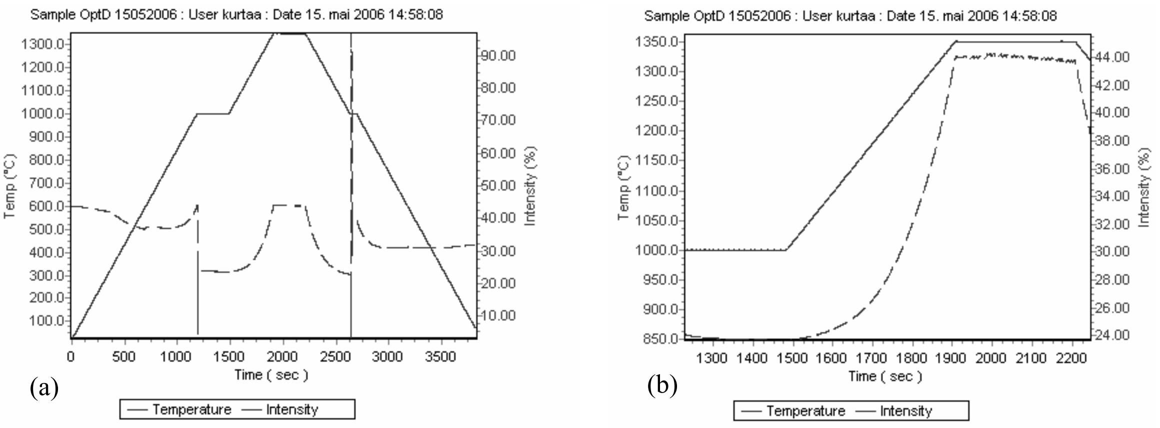


Figure 5: Temperature (line) and intensity (dashed) graphs of Sample D-3. a) Shows the entire experiment; b) shows the temperature interval 1000 ℃ to 1350 ℃+ 5 min

Table 2: Results from investigations in the Linkam heating stage. Category 0 = little activity; Category 1 = some activity; Category 2 = moderate activity; Category 3 = high activity.

Sample		<573 °C	573-1000 °C	1000-1200 °C	1200-1350 °C
A	1	0	0	0	3
	2	3	0	0	3
	3	2	0	0	3
	Average	**1.7**	**0.0**	**0.0**	**3.0**
B	1	3	0	0	3
	2	2	0	0	3
	3	2	1	1	3
	Average	**2.3**	**0.3**	**0.3**	**3.0**
C	1	2	0	0	2
	2	2	0	0	2
	3	1	0	0	2
	Average	**1.7**	**0.0**	**0.0**	**2.0**
D	1	1	0	0	2
	2	2	2	0	2
	3	2	0	0	0
	Average	**1.7**	**0.7**	**0.0**	**1.3**
E	1	2	1	0	2
	2	1	0	0	2
	3	1	0	0	2
	Average	**1.3**	**0.3**	**0.0**	**2.0**
F	1	1	2	0	3
	2	1	1	0	1
	3	1	2	0	2
	Average	**1.0**	**1.7**	**0.0**	**2.0**

3.1.1 General

The phase transformation from α- to β-quartz always occurs at 573 °C. This is also easily seen in the samples at this temperature. The effects vary from extreme to slight, but the rule of thumb is that it will always be seen during heating beyond this temperature. The intensity of the light in the samples will also usually show this effect as a sudden drop in intensity close to 573 °C and an increase in the intensity just after 573 °C (Figure 6).

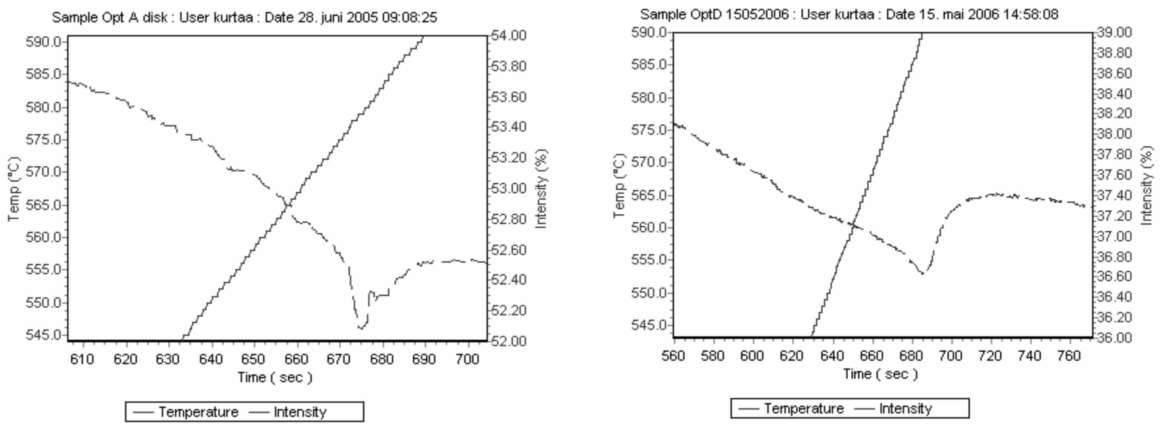


Figure 6: Examples of the intensity response to the phase transformation from - to -quartz in Samples a) A-2 and b) D-3.

3.2 SHOCK HEATING OF QUARTZ IN INDUCTION FURNACE

Prior to heating, each of the cubes was weighed and the weights are presented in Table 3, together with the weights of the +1.651 mm and -1.651 mm fractions obtained from the sample after heating.

Table 3: Weights of the prepared cubes for heating. The heated samples where weighed before and after heating

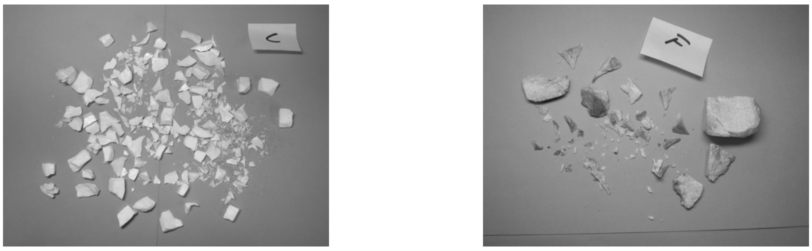
Sample	*Weight (g) Total sample*	*Weight (g) heated -1.651 mm*	*Weight (g) heated +1.651 mm*
Sample A	166.9	2.35	139.64
Sample B	167.0	1.67	163.76
Sample C	165.0	1.74	161.83
Sample D	82.0	0.58	78.69
Sample E	161.2	1.77	153.44
Sample F	160.0	1.83	121.60

3.2.1 Visual (and audible) observations during and after heating

Some of the samples had quick and "violent" response to the heat in the crucible. One could hear the crackling from some of the Samples (A, C and minor in D and E). Sample C responded so violent that one could hear the pieces of rock flying within the crucible. Table 4 lists the visual and audible observations during and after the heating of the quartz and Figure 7 shows microphotographs of Samples Warm C and Warm F after heating.

Table 4: List of visible and audible effects from heating

Sample No	*Visible effects*	*Audible effects*
Sample A	Many medium and small pieces.	Some crackling just after started heating
Sample B	Few but large pieces. Some small.	No
Sample C	Many medium and small pieces. Not as fine as expected.	Intense crackling immediately after started heating.
Sample D	Few but large pieces. Some small.	Minor
Sample E	Color changed from reddish to grey. Few but large pieces. Some small.	Minor
Sample F	One large piece and only few small.	Minor



(a) (b)

Figure 7: Example of the resulting material after heating and removal of the -1.651 mm fraction. The fragmentation is due to the thermal shock. a) Warm C; b) Warm F.

3.2.2 Fines Generation

Sieves were used to find the amount of fine material (fines) in the sample material after heating (see Table 3). The samples were sieved on 1.651 mm screens and the + and - fractions were weighed. As the original sample material was of uniform size (except Sample D), the fines content of the heated sample is expected to say something about the thermal strength of the material. Table 5 shows the percentage fines in the sample after heating (fines index). This index is not the same as the heat index (HI) as described by i.e. Birkeland [8], since the heat index is based on other definition of sample material size used for the heating and are a measure of sample material +20 mm.

Table 5: Fines index of sample materials after shock heating to 1300 °C for ten minutes. Index is % fines (-1.651 mm) material of total sample before heating

Sample	*Fines Index*
A	1.41
B	1.00
C	1.05
D	0.71
E	1.10
F	1.14

3.2.3 Optical Microscopic investigations and fluorescent light microscopy

Polarized light microscopy

The fresh, unheated reference samples (e.g. Cold A), and the heated samples (e.g. Warm A), were investigated by optical microscopy to search for changes in the material as a result of the heating. As described above (see Table 1), the quartz raw materials are from different geological origin. The rock quartz is relatively easy to describe and relate to the genesis of the rocks, both macro- and microscopically: Samples C to E is typically well-defined quartzes of hydrothermal, pegmatitic and quartzite types, respectively. The gravel quartzes are macroscopically more difficult to classify because of the weathered surface of the boulders. Microscopically, Sample F can also be classified as typical hydrothermal quartz based on the irregular grain shape and –size. The gravel quartz in Samples A and B are microscopically very similar to Sample C and must therefore be classified as hydrothermal quartz, as well.

Trace amounts of other minerals than quartz are seen in Samples B, E and F, while Samples D shows one mica grain and Sample C has some very small unidentified mineral inclusions, probably mica. Fluid inclusions are present in vast amounts and in a wide size interval in Samples A to D. The fluid inclusions are of several generations seen by the cross cutting fluid inclusion planes. Samples E and F show only minor amounts of fluid inclusions. Table 6 summarize the samples with type, relative grain size, content of other minerals (type) and position of these minerals.

Table 6: List of sample types, relative grain size, content and position of other minerals

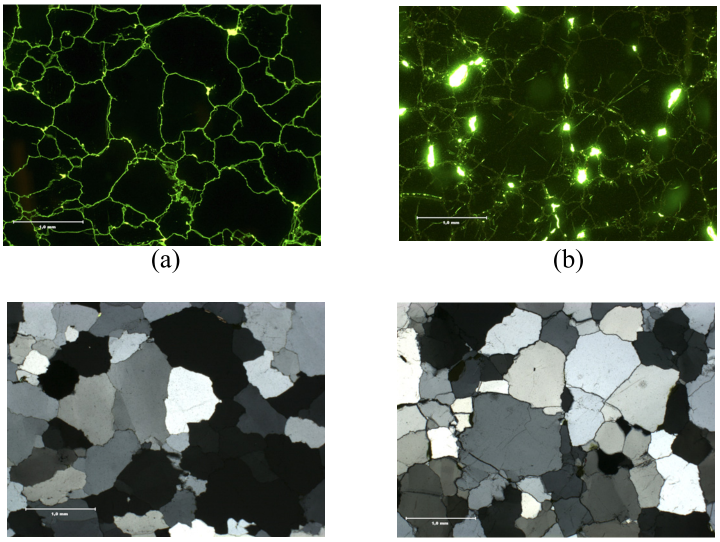
Sample	Type	Rel. grain size	Other minerals	Pos. of trace minerals
A	Hydrothermal	V. coarse	None	-
B	Hydrothermal	V. coarse	Chlorite/mica	Grain boundaries
C	Hydrothermal	V. coarse	(mica)	Scattered
D	Pegmatite	Fine-coarse	(mica)	Scattered
E	Quartzite	Medium	Zircon; monazite; mica; tourmaline?	Scattered
F	Hydrothermal	Medium-coarse	Mica (or tourmaline)	Grain boundaries

Mineralogical properties such as undulate extinction and sub-grains are not affected by the shock heating. The fluid inclusion planes are still visible and seem unaffected in low magnification, however, in higher magnifications, it is obvious that most of the inclusions have decrepitated and thin micro cracks are often visible along these planes. The fluid inclusions in Samples Warm A to Warm D show an absence of bubbles. This is probably an indication of decrepitation of the fluid inclusions. However, the smallest inclusions in all samples and several inclusions in Sample D still contain bubbles, and thus seem to have survived the heating.

The heated samples usually show a more diffuse appearance of the quartz grains, which is probably related to micro cracks that have been induced in the rock as a result of the extreme heat. There are no evidence of the cause of these random micro cracks. Opening of the grain boundaries were also seen in some of the samples, especially Samples Warm D to Warm F. Figure 8 c) and d) show microphotographs (x-nichols) of Sample Cold F and Warm F respectively. It is easy to see that the grain boundaries have become more pronounced as a result of the high temperatures.

Fluorescent light microscopy

The Samples Cold A to Cold C show dense grain boundaries and low content of micro cracks that were filled with fluorescent epoxy.



(a) (b)

(c) (d)

Figure 8: Examples of fluorescence image of Sample a) Cold F and b) Warm F. The respective polarized light microphotographs (x-nichols) are shown in c) Cold F and d) Warm F. The scale bar is 1 mm

Regular optical microscopy showed some significant differences between the fresh and the heated samples. When studying the samples with fluorescent light, all the samples showed a significant increase in the intensity of the light reflected by epoxy in the grain boundaries. The intensity of the micro cracks has also increased in most samples. For some samples i.e. Warm F, the intensity of pores and micro cracks suppressed the high intensity from the grain boundaries that were already present in the unheated Sample Cold F (Figure 8).

3.2.4 XRD investigations

XRD investigations were carried out on the unheated reference samples and on the heated samples. The results shows that for some of the quartz types, the heating to 1300 °C for ten minutes results in a beginning phase transition into β-cristobalite (Table 7). This is seen as emerging small peaks at the 2θ values related to β-cristobalite accompanied by a lowering of the intensity of some of the 2θ peaks for quartz. No HP-tridymite was seen in the XRD investigations.

Table 7: List of cristobalite formation in the different types of quartz. The "peak change" reflects the change in the quartz peaks

Result\Sample	*A*	*B*	*C*	*D*	*E*	*F*
Cristobalite formation	No	Minor	Minor	No	Major	Minor
Peak change	Major	No	Major	Minor	No	Minor

4. DISCUSSION

The high-temperature micro thermometry shows that there are two main temperature intervals that are important during heating of quartz samples. These are the interval between ca. 180 °C up to 573 ° C and the interval from ca 1200 °C to the end of the experiment at 1350 °C. There were also observed some activity in some samples around 900-1000 °C. Since almost all samples display high activity in response to the heating at the high temperatures, this is probably not a crucial type of activity. There should be more concern about the activity that happens at slightly lower temperatures around 900 to 1000 °C. Malvik and Lund [9] related this temperature interval to mica impurities. However, no mica minerals were seen in the investigated samples that were used for the experiments. The low temperature interval below 573 °C can also be significant for the thermal properties. If the decrepitation of the fluid inclusions takes place over a short temperature interval for several planes, this could contribute to a severe fracturing of the quartz.

Shock heating of the quartz shows by observation of the heating experiments that there are vast differences in the behavior of the different quartz types. The most extreme behavior was displayed by Sample C, where the crackling was very intense as judged by the sounds from inside the heating furnace and the fragmenting of the sample was also intense. Sample F had only minor fracturing. Further investigations by microscopic methods showed that the heating of the samples introduced an opening of the grain boundaries in most samples accompanied by the development of micro cracks, either as short disconnected cracks in a dense pattern or as a network of connected micro cracks. The fluid inclusion planes also show networks of micro cracks that are probably a result of the decrepitation of the fluid inclusions. This is in contrast to the observations made by [5], which concluded that the fluid inclusion planes were not important for the fracturing of the samples.

The mica seen along grain boundaries in Samples Cold B and Cold F, which were not seen at all in the heated Samples Warm B and Warm F, indicates that mica is responsible for the fracturing of the samples. This is also supported by the high-temperature micro thermometry investigations, especially for Sample F, where moderate activity was seen at the temperature interval around 900 - 1000 °C, which is also the conclusion by Malvik and Lund [9].

The HP-tridymite formation seems to be ruled out as a cause of the effect seen around 900 – 1000 °C as no HP-tridymite were seen from the XRD investigation. The lack of HP-tridymite formation is probably related to the purity of the quartz samples, as well as the short retention time at 1300 °C. This is also supported by the investigations by Geiss [6] who reported only β-quartz from similar investigations.

5. CONCLUSION

The high-temperature micro thermometry investigations shows that the thermal effects in quartz are related to fluid inclusions and intra grain micro cracking at low temperatures (<573 °C). The high temperature effects are related to existing cracks and grain boundaries as well as the decrepitation of remaining fluid inclusions, while the effects seen at moderate temperature between 900 – 1000 °C is probably related to mica minerals in grain boundaries, although no mica was observed in the investigated areas of the samples. The importance of mica for the effects in the interval 900 – 1000 °C were supported by the effects of the shock heating in Samples D and F where mica were observed along grain boundaries in the unheated samples and a resulting wide opening of these grain boundaries in the heated samples.

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