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Melt inclusions in quartz from the Karkonosze granitoids

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Abstract: Melt inclusions study has been done in quartz grains from the Karkonosze granitoids. The quartz crystals selected for the investigations were apparently a product of relatively early magma crystallization. The melt composition in the inclusions was variable, from tonalitic through granodioritic to granitic. Water content in the melt changed in broad ranges, from *ca*. 9 wt. % for silica-poor high-temperature inclusions to *ca*. 4-5 wt. % for silica-rich low-temperature ones. Homogenization temperatures of the inclusions were from 998 to 837°C. The obtained data point to different melt properties in various parts of the massif: probably in certain volumes the magma was homogeneous, but there should exist spaces, in which the magma inhomogeneity is strongly suggested by melt inclusions of variable chemical composition. The time span of the changes of chemical composition of magma is difficult to estimate, however, at least in one case found such change should be very fast in geological sense.

Key words: melt inclusion, water, silicate, granite, granodiorite, tonalite, homogenization, temperature, magma, Karkonosze, Sudetes

THE KARKONOSZE MASSIF

The Karkonosze massif in Sudetes is a Variscan intrusion about 70 km long and 8 to 20 km wide. Its geotectonic position and the relation to the overriding large geological structure of the Bohemian massif have been discussed extensively and since long time. An exhaustive and up-to-date presentation of the geo-structural problems and ideas concerning this area, its development since Precambrian inclusively, was recently given by Mazur *et al*. (2007).

Karkonosze massif is a composite intrusion. The earliest outline of its structure were made by Cloos (1922, 1925) on the basis of his studies of the schlieren, aplite veins, joints and feldspar megacrysts distribution and orientation throughout the massif. The present-day opinion on the massif building may be obtained on the basis of the publication by Mierzejewski (2007) and the references gathered therein. The structural considerations yielded the conclusion, that the pattern of intruding of the magma portions was complex and generally it is impossible, what variety of the Karkonosze granite is younger, and which one – older. In a number of outcrops the sequence of the granite varieties is different. This is consistent with the regime of formation of a shallow intrusion like the Karkonosze massif, where the consolidating portions of magma were broken, fractured and intruded by subsequent inflows of magma. The process of magma entering most probably was accompanied by regional tectonic movements and possible rotation, thus the complexity of the massif formation is understandable. However, in general a regional pattern of the distribution of the granitoid varieties do exists, though the boundaries between them are frequently difficult to tracing.

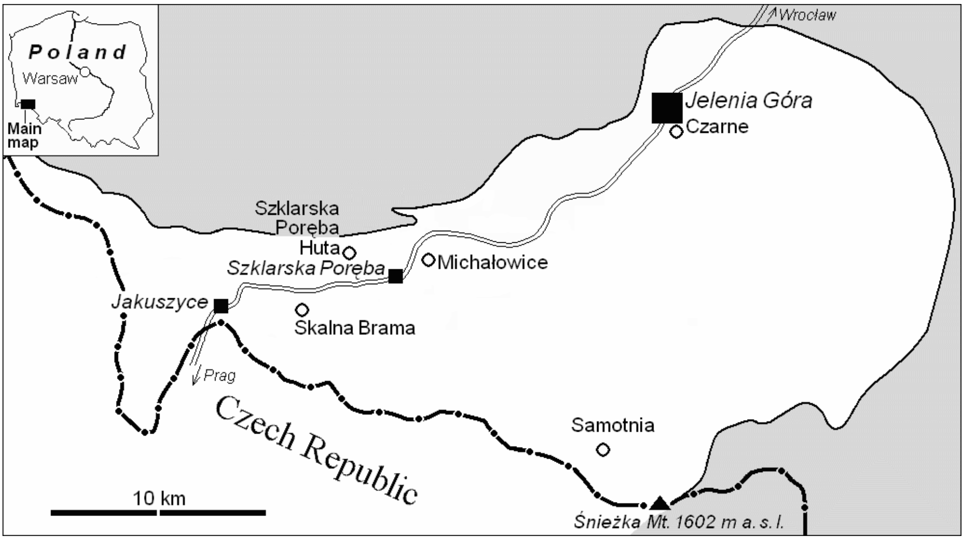

Fig. 1. Polish part of the Karkonosze massif with the sampling places marked by circles.

Almost whole massif consists of biotite granite or granodiorite; Borkowska (1966) distinguished four granitoid varieties which occupy various parts of the massif area: porphyritic coarse-grained granite with oligoclase- or albite-mantled potassium feldspar phenocrysts and with subordinate hornblende, equigranular granite composed of fine to medium crystals of potassium feldspar, acid plagioclase, quartz and biotite, medium-grained granite containing the same components as the previous variety, and granophyric granite with scarce hornblende. The equigranular varieties build mostly the main range of Karkonosze, and the hypsometrically lower parts of the massif in its northern and north-eastern terrains consist of porphyritic granite. The granophyric granite occurrence is essentially limited to the northern part of the massif, where the massif outline has characteristic stricture.

SAMPLES

In the recent study six samples of granite, bearing various contents of early, usually euhedral bipyramidal quartz grains, were used. Three of them, one collected near the Samotnia mountainous shelter and other two taken to the south from Skalna Brama, were the samples of the equigranular granite. Two further samples were collected from porphyritic granite at Czarne in Jelenia Góra in the abandoned quarry, and at Michałowice in the quarry temporarily out of operation. The sixth sample was taken in the operating quarry at Szklarska Poręba Huta (Fig. 1) from the granophyric granite. Though more samples were investigated for melt inclusions in quartz, only the six samples contained appropriate material for the inclusion studies.

The samples from Skalna Brama were different: one was typical biotite granite without hornblende, and the second sample was in fact taken from a 70 cm thick schliere with diffused borders; the schliere occurred in the biotite granite. Granodiorite from the schliere was richer in biotite than the host biotite granite, and it contained subparallel arranged 2-5 mm long prisms of hornblende, macroscopically black and under microscope displaying dark green colour. The habits of hornblende was euhedral or almost euhedral.

Quartz grains used for the melt inclusion studies were bipyramidal, from 2 to 7 mm in size, medium grey and frequently fractured, most probably due to the high → low quartz phase transition. They contained small inclusions of biotite and in the outer zones – inclusions of plagioclase and potassium feldspar. Melt inclusions occurred rarely.

METHODS

The preparations of quartz for the thermometric investigations were doubly polished ~0.5 mm thick slices cut through the centre of the quartz grains. The homogenization temperatures were measured by means of the quenching method (Kozłowski 1981, 2003) with the accuracy ±5ºC at temperatures close to 1000ºC. Careful approaching to the homogenization temperature was necessary to avoid water loss from the inclusions during heating at high temperatures (Kozłowski 1985). Thus, when the last crystal phase was near to melt, the formal temperature increments were minimized even to 3ºC due to application of a special thermostating electric circuit and a thermo-isolating chamber of the micro-oven. Multiple heating-quenching runs resulted, however, in the loss of several preparations, in which the inclusions were destroyed by the repeating thermal shocks.

Composition of the melt in inclusions was determined by use of the Cameca sx100 electron microprobe in the Inter-Institution Laboratory of Microanalysis of Minerals and Synthetic Substances at the Faculty of Geology of the Warsaw University, the analysts L. Jeżak and Dr. P. Dzierżanowski. A set of artificial glasses was used as the standards, because the analysed silicate melt was in the state of glass. Preparations for the microprobe analyses were made from the quartz slices previously used for the homogenization temperature determinations. The completely molten inclusion filling was rapidly cooled (quenched) to obtain glass in the inclusion. Next the inclusion was opened by careful polishing with diamond abrasive compound till the sufficiently large surface of the inclusion filling was obtained. Voluminous (*i.e.* not flat) inclusions were selected for this procedure to avoid the contamination of the analytical results by the influence of the underlying quartz host. The inclusions should be at least 10 µm in diameter in the preparation plane.

Water content in the melt inclusion was determined by heating of the molten inclusion filling at temperature slightly higher than the temperature of solidus of the inclusion (*i.e.* a little higher than temperature of crystallization of the last melt portion). Under these conditions majority of water dissolved in the silicate melt migrated to the contraction bubble as vapour, though some water might have been bound in aqueous mineral phases like micas. On quick cooling after such heating run the rest of melt converted into glass and the contraction bubble retained its original shape. The perfect case is, when the bubble is either spherical or circular between two parallel and close vacuole faces. Thus, the volumetric calculations are simple and relatively precise; if the habit of the inclusion and the bubble is far from a clear geometric shape, the precision of the calculations is low. Additional and difficult to estimation error is caused by the limited solubility of water in the silicate melt at the temperature of separation of water from the melt. Unfortunately, the melt saturation by water here is rather difficult to estimation, but probably the error caused by this factor does not exceed 10 % of the total water content.

INCLUSIONS

The investigated magmatic quartz contained melt inclusions scarcely. The size of the investigated inclusions was from 5 to 15 µm; the smaller inclusions were difficult for identification of the phases occurring in, the larger ones frequently decrepitated on heating. The studied inclusions occurred in the central parts of the quartz grains, and were filled by crystal phases and contraction bubble, in natural state of the inclusion strongly deformed (Fig. 2A). In most of the inclusions the filling consisted of the crystals of potassium feldspar, plagioclase, quartz, biotite and mixture of fine grains of these minerals, and bubble of volatiles (water and CO_2). Only some inclusions from the sample of the schliere from Skalna Brama contained tiny needles of hornblende and two of them – grains of pyroxene, most probably a sodium-bearing clinopyroxene.

During heating the first signs of melting were discernible at ca. 600ºC. Usually total melting of the daughter crystals in inclusion appeared at temperature 20-30ºC lower than temperature of bubble disappearance (Figs. 2B and C), and the last melting crystal was potassium feldspar, biotite or plagioclase, the latter probably with incongruent melting. In the inclusions in quartz grains from the schliere from Skalna Brama, if hornblende or pyroxene were present, these minerals were the last ones to melt. The same quartz grains contained in the outer rims melt inclusions, which usually did not yield consistent data (homogenization temperatures and melt compositions) till present. Some of them were probably trapped aggregates of small mineral grains rather than true melt inclusions.

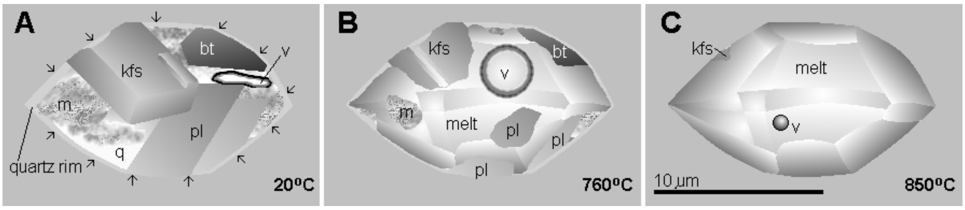

Fig. 2. Melt inclusion in quartz from the Samotnia granite before heating (**A**) and at elevated temperatures (**B** and **C**). Note the rim of quartz that crystallized from the inclusion volume, outlined by arrows, and the presence of small portion of the potassium feldspar (image C), which melted completely at temperature few degrees below homogenisation temperature of the inclusion (876ºC); kfs – potassium feldspar, pl – plagioclase, q – quartz, bt – biotite, v – volatile bubble, m – mixture of fine grains of silicates.

Homogenization temperatures were between 825 and 920ºC (Table 1), what agrees with the data for quartz from granitoids published elsewhere (*e. g.* by Sobolev and Kostyuk 1975). This was typical of all the studied inclusions but those in the quartz grains from the samples from Skalna Brama. Homogenization temperatures of the latter inclusions split into two groups: the values for the inclusions in quartz from the schliere was in the ranges from 990 to 998ºC, and the inclusions in quartz from biotite granite – from 880 to 920ºC with on exception, when the homogenization temperature was 979ºC (Table 2).

The differences occurred in the chemical composition of the melt in inclusions as well. Most of the inclusions yielded silicate melt compositions typical of granite or granodiorite (Table 1, and quartz from the granite sample from Skalna Brama in Table 2). However, three analysed inclusions in quartz from the schliere (Table 2) had lower silica and alkalis contents, and higher total iron, magnesium and calcium contents than the other inclusions. Their chemical composition may be recalculated to tonalite normative mineral composition.

These two differences, *i.e.* temperature and composition, are accompanied by the third one. The repeated microprobe analyses gave constantly low total values, the missing fraction was as high as *ca.* 9 to 11 wt. %. Normally systematic low total in analysis of the inclusion glass is interpreted as presence of water (volatiles) dissolved in the melt. In most inclusions from the investigated quartz the missing fraction equals *ca.* 4-5 wt. %.

Table 1. Chemical composition of the silicate melt in inclusions and homogenization temperatures

Component, wt. %	Michałowice, quarry			Szklarska Poręba Huta, quarry			
	1	2	3	4	5	6	7
SiO_2	62.4	62.8	65.0	66.7	66.0	68.1	68.4
TiO_2	0.3	0.4	0.3	0.3	0.3	0.3	0.2
Al_2O_3	15.5	15.6	14.6	13.7	14.0	13.9	14.0
FeO (tot)	4.3	4.1	3.9	3.1	3.3	3.4	3.1
MnO	0.2	0.1	0.2	0.1	0.1	0.1	0.1
MgO	1.8	1.7	1.4	0.7	0.6	0.8	0.7
CaO	4.5	4.2	3.4	1.5	1.3	1.4	1.3
Na_2O	3.7	3.9	3.5	3.5	3.7	3.9	3.6
K_2O	3.0	3.1	3.8	4.2	4.4	4.5	4.3
P_2O_5	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Total	95.9	96.0	96.3	94.0	93.9	96.6	95.9
Th, °C	865	863	850	843	847	825	840

Table 1. continued.

Component, wt. %	Samotnia shelter			Czarne, old quarry			
	8	9	10	11	12	13	14
SiO_2	63.3	64.1	64.8	62.3	60.9	65.2	66.1
TiO_2	0.5	0.3	0.3	0.3	0.5	0.3	0.3
Al_2O_3	16.1	14.7	14.8	15.1	15.7	14.6	14.3
FeO (tot)	4.1	3.6	4.0	3.9	5.3	3.8	3.8
MnO	0.1	0.1	0.1	0.2	0.1	0.2	0.1
MgO	1.5	1.3	1.5	1.6	2.1	0.9	0.8
CaO	4.4	4.0	4.0	4.4	4.8	1.8	1.5
Na_2O	3.3	3.5	3.6	3.9	3.2	3.7	3.8
K_2O	3.2	3.2	3.0	3.3	2.6	4.4	4.5
P_2O_5	0.1	0.2	0.1	0.2	0.2	0.2	0.2
Total	96.7	95.0	96.2	95.1	95.4	95.1	95.4
Th, °C	889	876	880	890	920	843	837

Table 2. Chemical composition of the silicate melt in inclusions and homogenization temperatures, the sample from Skalna Brama

Component, wt. %	Schliere sample			Granite sample			
	15	16	17	18	19	20	21
SiO_2	55.6	56.0	55.1	63.0	66.5	66.9	67.2
TiO_2	0.7	0.6	0.8	0.2	0.1	0.2	0.1
Al_2O_3	14.9	14.6	14.1	15.3	15.9	14.0	14.1
FeO (tot)	4.6	4.9	4.2	4.1	2.7	3.0	3.2
MnO	0.1	0.2	0.1	0.1	0.1	0.1	0.1
MgO	2.2	2,7	3.0	1.3	0.7	0.8	0.9
CaO	5.5	5.9	5.9	4.2	1.7	1.8	1.6
Na_2O	3.5	3.5	3.6	3.3	3.2	4.0	3.9
K_2O	2.0	2.3	2.1	3.1	4.1	3.5	4.0
P_2O_5	0.1	0.3	0.2	0.1	0.2	0.1	0.2
Total	89.2	91.0	89.1	94.7	95.2	94.4	95.3
Th, °C	995	998	992	979	911	902	886

The procedure of water determination in melt inclusions, described in the chapter “Methods”, was applied to check whether the low total values in the microprobe analyses really mean a presence of water. Several calculations for the inclusions with total oxides of *ca*. 95-96 % yielded water amount separated from melt equal 3-4 % of the melt mass (the used specific gravity of the melt was 2.65). However, the inclusions of “tonalitic” compositions had water contents 8-9 wt. %, when determined by the heating and volume calculation method. Thus, the "tonalitic" melt was water-rich, if compared with the granitic melt.

FINAL REMARKS

The preliminary communication on the melt inclusion studies in quartz from the Karkonosze granite (Kozłowski, Słaby 2004) suggested that on the basis of the melt inclusion studies one may conclude that the parent magma of the Karkonosze granite was homogeneous. This is probably true for a major part of the massif. However, more detailed sampling and investigations yielded additional data.

The prevailing part of the Karkonosze massif granitoid rocks formed from melts of granite or granodiorite composition, bearing *ca*. 4-5 wt. % dissolved water. Temperature of this magma was roughly 880-920ºC. However, traces of more calcic and mafic melts were found; the melts occurred locally. It is necessary to investigate other schlieren samples to recognize melt inclusions in the minerals forming them (if the inclusions are present). These melt portions had high temperature, approaching 1000ºC. This temperature, especially under few-kbar pressure, allows high quartz to crystallize (Presnall 1995), thus the melt inclusions should preserve safely from their isolation conditions.

Another problem is connected with the high water content in the "tonalitic" inclusions. Two possible cases: a) the melt came from the depth as a water-rich medium, and b) the originally rather dry melt "gathered" water from the surrounding environment, presently cannot be evaluated on the basis of the studies of the massif rocks. Nevertheless, the experimental data (Carroll, Wyllie 1990) indicate, that the tonalitic melt to be above the liquidus at *ca*. 1000 ºC, requires the water content of about 10 wt. %, otherwise, if water content is lower, its liquidus temperature increases strongly. Hence, if the "tonalitic" melt in the inclusions at the temperature *ca*. 1000 ºC was in liquid state, it had to have high water content.

The role of the "tonalitic" melt in forming the variety of the granitoid rocks of the Karkonosze massif should be investigated. However, high content of water at least in one of the mixing silicate melts undoubtedly facilitates the process of the mixture formation (Wenner, Coleman 2001). If the "tonalitic" melt brought water to the forming intrusion, this should explain, at least in the local scale, the mixing of (or with) rather dense and viscous magma of the granite or granodiorite composition.

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REFERENCES

Borkowska M. Petrography of the Karkonosze granite. *Geologia Sudetica*, 2, 7-119.

Carroll M. R., Wyllie P. J. 1990. The system tonalite-H_2O at 15 kgar and the genesis of calc-alkaline magma. Amer. Mineralogist, 75, 345-357.

Cloos H. 1922. Tektonik und Magma: Untersuchungen zur Geologie der Tiefen. *Abh. preuss. geol. Landesanst.*, 89, 1–18.

Cloos H. 1925: *Einfűhrung in die tektonische Behandlung magmatischer Erscheinungen (Granittektonik)*. Verlag von Gebrűder Borntraeger, Berlin, 194 pp.

Kozłowski A. 1981. Melt inclusions in pyroclastic quartz from the Carboniferous deposits of the Holy Cross Mts., and the problem of the magmatic corrosion. *Acta Geol. Polon.*, 31 (3-4), 273–284.

Kozłowski A. 1985. Do melt inclusions lose volatiles during homogenisation studies? *Fluid Inclusion Research – 8th Symp. On Current Research*, Götingen, 88–89.

Kozłowski A. 2003. Methods of investigation of melt inclusions. *Prace Specjalne (Special Papers) PTMin.*, 22, 119–122.

Kozłowski A., Słaby E. 2004. Melt inclusions and evolution of parental magma of the Karkonosze granite. *Prace Specjalne (Special Papers) PTMin.*, 24, 247-250.

Mazur S., Aleksandrowski P., Turniak K., Awdankiewicz M. 2007. Geology, tectonic evolution and Late Palaeozoic magmatism of the Sudetes – an overview. In: *Granitoids in Poland, AM Monograph No. 1*, eds. A. Kozłowski, J. Wiszniewska, Publ. by KNM PAN-WG UW, Warszawa, 59-87.

Mierzejewski M. P. 2007. A general view on the Karkonosze granite. In: *Granitoids in Poland, AM Monograph No. 1*, eds. A. Kozłowski, J. Wiszniewska, Publ. by KNM PAN-WG UW, Warszawa, 111-122.

Presnall D. C. Phase diagrams of Earth-forming minerals. *Mineral physics and crystallography*. Amer. Geophys. Union, 248-268.

Sobolev V. S., Kostyuk V. P. 1975. *Magmatic crystallisation as based on the study of melt inclusions*. “Nauka”, Novosibirsk, 232 pp. [in Russian]

Wenner J. M., Coleman D. 2001. The role of basaltic water content in facilitating magma mixing by reducing density and viscosity contrasts. *Abstracts with Programs – Geol. Soc. America*, 33 (6), 375.

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