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EXPLODED FLUID INCLUSIONS IN QUARTZ FROM ALPINE FISSURES AND THEIR SIGNIFICANCE

(Figs. 5)

Abstract: From the published geochronological data (K-Ar dating of biotite, apatite fission tracks ages) and thermodynamic conditions of origin of the alpine type veins is deduced, that the rate of uplifting of the Veporides in the Upper Cretaceous was at least 0.3 mm/year. In quartz from alpine veins near Kokava and Klenovec exploded primary inclusions of metamorphic solutions were discovered. The process of dehermetization is in conditions of regional metamorphism improbable, therefore the presence of these inclusions is interpreted as a result of postmetamorphic heat flow action.

Резюме: Из опубликованных геохронологических данных (K-Ar датирование биотита, возрасты следов после расщепления урана в апатитах) и термодинамических условий формирования жил альпийского типа вытекает, что скорость поднятия вепоридов в верхнем меле была по крайней мере 0,3 мм/год. В кварцах из альпийских жил близ с. Кокава и с. Клеповец были определены взорванные первичные включения метаморфических растворов. Процесс дегерметизации неправдоподобный в условиях регионального метаморфоза, поэтому наличие этих включений интерпретировано как результат влияния постметаморфического теплового потока.

Introduction

One of the characteristic marks of the Veporide crystalline rocks and their mantle series is the intensive Alpine metamorphism. The result of activation of metamorphic solutions was crystallisation of alpine type veins with a simple mineral association (quartz, adular, albite, chlorite, calcite, pyrite, rutile, more rarely actinolite, anatase, apatite, tourmaline, pyrrhotite and chalcopyrite).

Hurai (1983) has studied fluid inclusions in quartz from twenty — two occurrences of alpine veins in the Veporide crystalline rocks. From the ratio K/Na in metamorphic solutions, which is the function of temperature, and from microthermometric measurements, thermodynamic parameters of quartz crystallisation on the basis of the method, introduced by Poty et al. (1974) were calculated.

In granitoids of the Kráľova hoľa subzone, quartz has crystallized at temperatures 420—555 °C and pressures 205—345 MPa from highly concentrated solutions (14—20 weight % NaCl eq.). In metamorphites of the Kohút subzone mostly metamorphic solutions with a high portion of CO_2 (up to 50 weight %) have circulated, whereas the content of salts have attained 2—3.5 spec-grav. % NaCl eq. The K/Na ratio indicates the temperature of origin 330—415 °C.

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These values must be considered as minimum, because the presence of HCO^-_3 disturbs the equilibrium in the system two alkali feldspars — solution of alkalies, lowers the K/Na ratio in solution and also the established temperatures of origin (Iiyama ex Poty et al. l. c.). The filling temperatures of the inclusions CO_2 — rich solutions vary mostly between 300—360 °C. The pressure in the moment of homogenization, determined by the method of Naumov and Malinin (1968), attains 104—126 MPa. By graphite thermometer Šengelija—Miko—Bezák (1978) established maximum of temperature alteration of rocks of the Hron complex in the Kohút subzone at 400 to 450 °C. On the basis of linear extrapolation can be estimated the maximum pressure of CO_2 — rich metamorphis fluids to 150—200 MPa provided that 450 °C is their highest possible temperature.

In mylonite zones of granitoids of the Kráľova hoľa subzone, there were found quartzes with inclusions of heterogeneous solutions. In inclusions CO_2 concentration changes from zero to 80 weight % and the content of dissolved salts from 6 to 15 wt. % NaCl eq. These solutions probably arose by mixing of both types of metamorphic fluids in a later stage of the metamorphism during formation of tectonic structures in NE—SW direction.

Fluid inclusions microthermometry of alpine type veins in the Western, Central (Poty et al. l. c.) and Eastern Alps (Luckscheiter—Morteani, 1980) provided similar results as the one in the Veporide crystalline complexes. In many cases the homogenization tempertures and composition of the inclusions as well as the temperatures and pressures are coincident.

Exploded inclusions

In quartz from four occurrences of alpine veins was possible to observe exploded primary inclusions. Such quartzes was found to occur in the Kohút subzone of the Veporides in the Sinec (836.1) and Ostrá (1101.4) massifs near Klenovec and Kokava.

The difference between destroyed and understroyed inclusions is shown in Fig. 1 and Figs. 2—4, respectively. At the margin of the exploded inclusions, there are to be seen the micro-fissures, which are around negative crystall-shaped inclusions parallel to prism surfaces {11$\bar{2}$0}. The fissures are healed up by hydrothermal solutions, which were traped in secondary daughter inclusions. The exploded inclusions are not of equal composition. They contain water solution or solution enriched in carbon dioxide. In places of transition of the microfissures into enclosure are sometimes developed II. nd generation of quartz crystals, mobilized by secondary recrystallization processes.

Only in one sample were dehermetized all inclusions. In the majority of cases zones with exploded as well as original inclusions are observed. In the original inclusions the maximum content of CO_2 attains 45 wt. %, the water phase takes up 40 vol. % of the cavity. The maximum volume of the water phase is 50 vol. %, the concentration of CO_2 does not exceed 35 wt. %.

Theory

With theoretical aspects of dehermetization of inclusions are dealing Vozňak—Kaľužnyj (1976). Breaking of the inclusion takes place when its inner

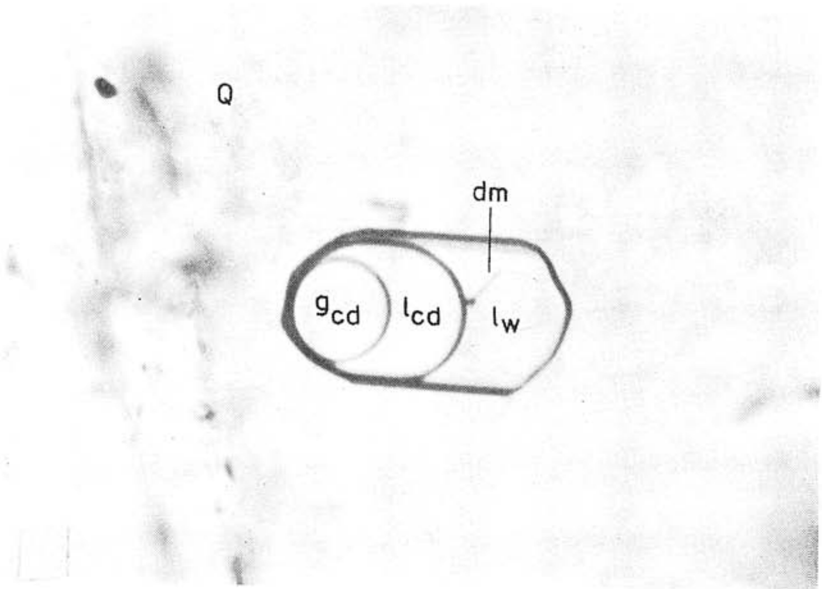

Fig. 1. Original inclusion of metamorphic solution in quartz from the talc quarry near Kokava.
Explanations: g_{cd} — gaseous carbon dioxide; l_{cd} — liquid carbon dioxide; l_w — water-rich liquid phase; d_m — daughter minerals; Q — host quartz.

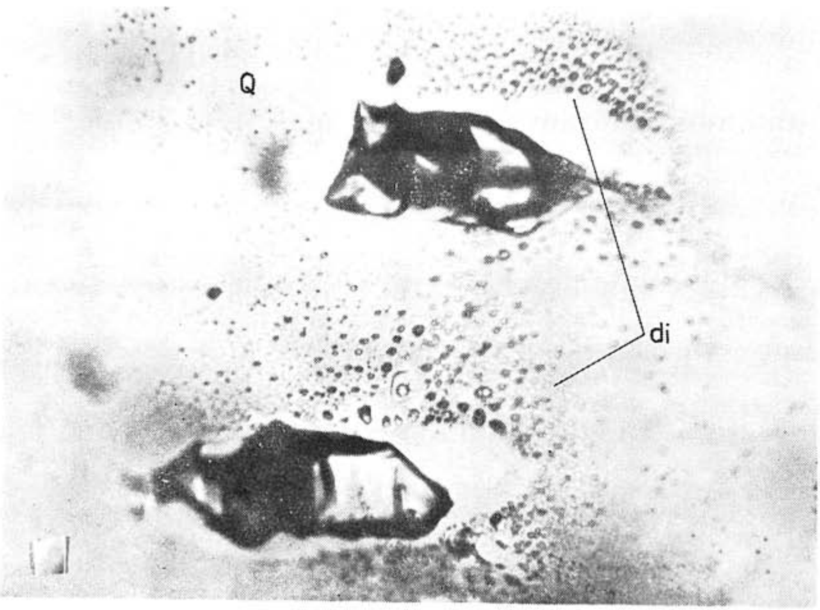

Fig. 2. Exploded inclusions of metamorphic solutions in quartz from the talc quarry near Kokava. In healed fissures are trapped daughter inclusions (di).

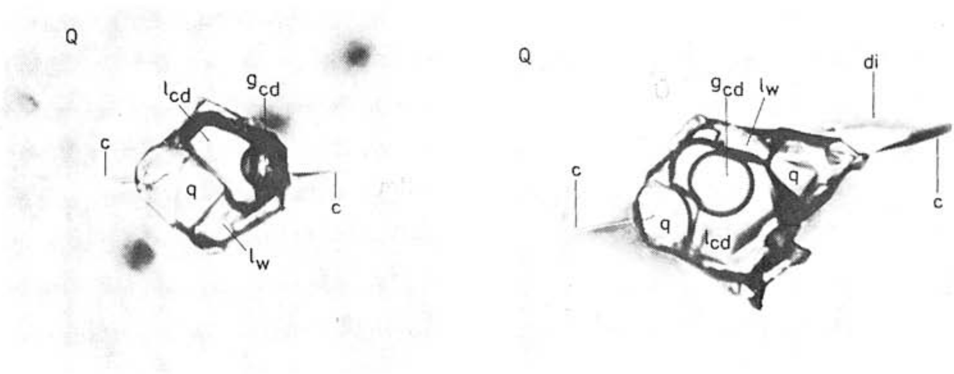

Fig. 3, 4. Exploded inclusions in quartz from the locality Klenovec.
Explanations: q — secondary mobilized quartz; c — healed fractures containing small daughter fluid inclusions. The size of inclusions is around 0.1 mm.

pressure exceeds the pressure of the surrounding environment by certain value. Chetčikov et al. (1968) and Tugarinov—Naumov (1970) mention the pressure gradient about 85 MPa for quartz grains with a diameter up to 1 mm and the size of inclusions up to 0.5 mm. Disturbing of inclusion walls under natural conditions can be caused by decreasing pressure or rising temperature of the mineralization environment. The process of dehermetization of the inclusions is influenced by their size, material composition, distance from the margin of the grain or crystal. Thus within the scope of one sample all inclusions cannot be dehermetized.

The exploded inclusions were described in its, which genesis is connected with magmatic activity. Vozňak—Kaľužnyj (1977) reported such inclusions in quartz from Volhynian pegmatites (Ukraine) and interpreted their origin as a result of penetration of hot solutions from deeper parts of granite body during formation of contraction fissures.

Discussion

The presence of dehermetized inclusions in quartz from alpine fissures in the Veporides indicates a sudden change of thermodynamic properties of the surrounding environment. Clearing up of the cause of this change requires the recapitulation of knowledge about the place of alpine fissures in the process of metamorphism and their importance for reconstruction of the thermal history of the given region.

The age of alpine fissures, depth of origin, uplift rate of the Veporides

The temperatures and pressures in crystallisation of alpine type veins testify that they originate during the main metamorphic phases. This is confirmed by the results of the oxygen and hydrogen isotopes study (Friedrichsen—Morteani, 1979) also by geochronological data (Arnold, 1972; Leutwein et al.; Purdy—Stalder; Purdy—Jäger; Jäger et al. ex Poty et al., 1974). The fissures in the Alps originated during the Neoalpine phase of metamorphism as a consequence of tectonic movements, induced by general uplift and updoming of the area (Luckscheiter—Morteani l. c.). The published results of K/A and Rb/Sr mineral dating of the alpine veins, summarized by Poty et al. (l. c.), provided values from 8 to 18 mil. years.

The age of alpine veins in the Veporides has not been proved by radiometric dating until now. The apatite fission tracks ages of uranium from metamorphosed granitoids of the Veporides are varying around 75 mil. years (Kráľ, 1977, 1982). The K/Ar dating of biotites from metamorphites of the Kráľova hoľa and Kohút subzones provided the values between 90—110 mil. years. (Bagdasarjan et al., 1977). Regarding the possible cooling rate of the granitoid rocks the uranium fission tracks ages in apatite record very low temperatures — around 100 °C (Kráľ l. c.). On the contrary, "blocking temperature" of biotite is much more higher. It varies around 300 °C for the system Rb-Sr (Arnold l. c.). The uplift of the Veporides after the Alpine metamorphism and cooling of the rock complexes could have begin already before the Upper Cretaceous and therefore the radiometric age of the alpine veins should vary around the value of 100 mil. years.

The CO_2 — free metamorphic solutions with a high concentration of soluble salts are connected with granitoid and gneiss complexes of the Alps and West Carpathians. Poty et al. (l. c.) established in granitoids of Mont Blanc 6—10.5 wt.% NaCl eq. and 11 wt.% NaCl eq in the Aar central massif. Luckscheiter—Morteani (l. c.) observed increased contents of salt (up to 9 weight % NaCl eq.) in quartz from fissures in orthogneiss complexes of the Tauern Window. In a similar way highly concentrated solutions are connected with granitoid rocks of the Kráľova hoľa subzone of the Veporides.

On the contrary, the solutions enriched in CO_2 are bound to volcanic-sedimentary complexes, affected by lower-grade progressive metamorphism (ibid.). The carbon dioxide in the course of metamorphism originates mainly by decarbonatization reactions or oxidation of graphite and hydrocarbons under the presence of water (Hoefs—Stalder, 1977; Hoefs—Morteani, 1979). This origin of CO_2 is real also in Veporide crystalline rocks, because in inclusions of metamorphic solutions traces of hydrocarbons were established (Hurai l. c.) and variegated volcanic-sedimentary complexes with graphite and carbonate layers are also often represented here.

CO_2 metamorphic solutions can penetrate into granitoid complexes along faults, fissures and mylonite zones, which have been already formed after sufficient releasing of pressure in decompression phase of metamorphism. The inclusions of salt-rich solutions without CO_2 in fissure quartz from granitoids represent remnants of older metamorphic fluids, which existed in relatively closed systems. This conclusions is also supported by the results of stable isotope study of hydrogen and oxygen in metamorphites of the Penninicum of the Central Alps. There was no penetration of juvenile and vadose waters in course of Alpine metamorphism and metamorphic recrystallization took place in a closed system (Hoernes — Friedrichsen, 1980).

From the records about pressure of metamorphic fluids can be derived the depth of the mineralization process. Bloch (1981) mentions that in the macroscopic pores and fissures of rocks the pressure of the metamorphic solution is lesser or equal to the pressure of overlying rocks. It is evident from the above mentioned, that in closed systems the pressure of fluids can approach the pressure of overlier. In open systems at shallow depths the pressure of fluids can be equal to the pressure of the column of mineralizing solution.

The pressure of salt-rich solutions without CO_2 in granitoids of the Kráľova hoľa subzone attained 205—345 MPa. The corresponding depth is 10 ± 2.5 km assuming the average rock density 2.7 g . cm^{-3}. The geothermal gradient 44—58 °C . km^{-1} corresponds, for example, to conditions in the East Slovakian lowland, which Ďurica (1982) considers as a region of recent metamorphism.

The inclusions of CO_2 -metamorphic solutions in the Veporides were observed in quartz from mylonite zones and fissures, which are copying NE-SW direction of the main tectonic lines of this region. In such structures, the pressure of the metamorphic solution will be somewhat lower than the pressure of overlying rocks. In this case the equation P (fluid) = P (rock column) misrepresents the data on the depth of the mineralization process. As a matter of fact, regarding little differences in temperature between both metamorphic phases, it is possible to suppose that thickness of the overlying rocks was approximately equal in spite of different pressures of the metamorphic fluid.

Supposing that the uplift of the Veporides began 100 mil. years ago, we must admit an uplift rate of at least 0.3 mm per year, so that into reconstruction of thermal history of the Veporides the uranium fission tracks ages in apatites should fall, determined by Kráľ (l. c.). But this means, that the considered thickness 10 km of rocks had already been denuded during the Upper Cretaceous and the transgression of the Paleogene sea encroached the smoothed and consolidated surface. This presumption was expressed by Lukniš (1964), who described from the northern margin of the Slovenské rudohorie Mts. levelled surfaces with islands of Eocene basal conglomerates. The occurrences of bauxites in the Upper Hron valley also exclude the existence of a dissected surface in the pre-Eocene period (ibid.).

A high rate of uplift of the Veporides in the Alpine epoch is also supposed by Vrána (1980) in orded to clear up the distinct retrogressive zonality of garnets, which crystallized in the postkinematic stage of the Alpine metamorphism.

The origin of exploded inclusions

Dehermetization of inclusions in quartz from the alpine veins could have taken place

— during crystallisation of quartz as a consequence of suddenly sinking pressure of metamorphic solutions or their rising temperature,

— after crystallisation of quartz by the influence of postmetamorphic thermal flow.

The variation of pressure of the metamorphic fluids within a range greater than 85 MPa in course of the decompression phase of metamorphism is possible, but when not connected with heat supply, cannot cause dehermetization of inclusions. With decreasing pressure namely a part of carbon dioxide escapes from the solution, contemporaneously leading to cooling of the mineralization environment surrounding the quartz crystal. Such a process of degassing of the metamorphic solution was observed, for example, during crystallisation of quartz in an alpine fissure at a stone quarry near Klenovec, about 1 km NE from the site of occurrence of quartz with exploded inclusions. The heterogenized solution was trapped in quartz so that some inclusions contained a water rich phase and some a CO_2 rich phase. Temperatures of homogenization of this kind of inclusions are equal as the trapping temperatures (S m i t h — L i t l e,

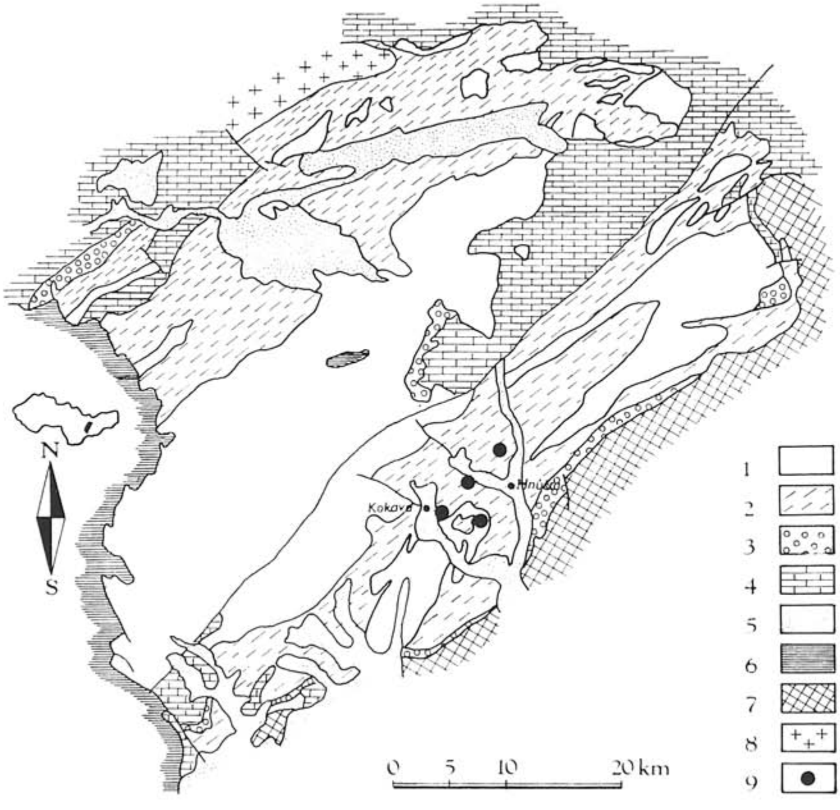

Fig. 5. Location of occurrences of exploded fluid inclusions in quartz from alpine veins. Simplified geological map compiled according to the Geological map of Czechoslovakia 1:500 000 (K o d y m — F u s á n — M a t ě j k a, 1967).
Explanations: 1 — metamorphosed granitoids of the Veporide crystalline complex; 2 — metasedimentary series of the Veporide crystalline complex; 3 — Late Paleozoic; 4 — Mesozoic; 5 — Paleogene and Quaternary sediments; 6 — neovolcanics; 7 — Paleozoic of the Gemerides; 8 — Ďumbier massif; 9 — occurrences of exploded inclusions.

1959). On the basis of the method of K a ľ u ž n y j (1955) it was calculated that the pressure of mineralization environment decreased already to 20 MPa. This value is in fact somewhat higher, because it includes only the sum of partial pressures of CO_2 and H_2O, not taking into consideration their non-ideal mixing in the mixture and influence of dissolved salts. Decreasing of pressure was accompanied by that of temperature to 310 °C. At this locality dehermetized inclusions have not been found. Thus not even such changes of temperatures and pressures of metamorphic solution have called forth the process of dehermetization.

Improbability of dehermetization of the inclusions under conditions of regional metamorphism is also supported by the fact, that exploded inclusions have not been found in alpine veins of the Kráľova hoľa subzone so far.

On the basis of the above mentioned it may be supposed that the presence of exploded inclusions in quartz from alpine types veins indicates the heat flow action after crystallization of alpine type veins. The lowest possible temperature, necessary for dehermetization of inclusions of this type, was 270—300 °C, supposing the process has ein taken place at minimum depth. Regarding to the limited area of the occurrence of exploded inclusions and their position in proximity of faults of NW direction (Fig. 5) it is possible, that the thermal flow could have been a result of penetration of an intrusion of Alpine age or its post-magmatic products in weakened places of the earth crust.

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