Irradiation methods for removal of fluid inclusions from minerals

Iradiacijske metode odstranjevanja tekočinskih vključkov iz mineralov

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Abstract: Methods for removal of fluid inclusions, using gamma quantum and high energy proton irradiation, microwave radiation and electromagnetic impulse treatment, were studied. The effects investigated directly decrease the number of fluid inclusions in minerals and change their temperature spectrum. Radiation methods differ from thermal treatment in that they are not connected with direct heating of a mineral, are less expensive, use background radiation and can be combined with other technologies.

Izvleček: Preučene so bile metode za odstranjevanje tekočinskih vključkov z gama-kvantno in visokoenergijsko protonsko iradiacijo, mikrovalovno radiacijo ter z elektromagnetno impulzno obdelavo. Preučeni efekti neposredno zmanjšujejo število tekočinskih vključkov v mineralih in njihov temperaturni spekter. Radiacijske metode se razlikujejo od termalne obdelave v tem, da niso povezane z neposrednim segrevanjem minerala, so cenejše, uporabljajo radiacijo naravnega ozadja, lahko pa jih tudi kombiniramo z drugimi tehnologijami.

Key words: fluid inclusions, removal of minerals, gamma quantum, high energy proton, microwave radiation, electromagnetic impulses, water extracts

Ključne besede: tekočinski vključki, odstranjevanje mineralov, gama- kvanti, visokoenergijski proton, mikrovalovna radiacija, elektromagnetni impulzi, vodni izvlečki

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INTRODUCTION

As pure materials are in demand, attempts are made to develop efficient methods to remove impurities from minerals. A common type of inclusions that are hard to remove, that disturb the homogeneity, deteriorate the characteristics and limit the use of minerals are fluid inclusions (ROEDDER, 1984). Such inclusions are removed by heating a mineral to a high temperature that destroys inclusions (DOLGOV, ERMAKOV, 1971; KRAVETS, 1995). As a lot of energy is needed to heat minerals, more economic methods to destroy fluid inclusions are being sought (BELASHEV, SKAMNITSKAYA, LEBEDEVA, OZEROVA, 2001; SKAMNYTSKAYA, KAMENEVA, BELASHEV, 2004).

The paper deals with methods for removal of fluid inclusions from minerals by gamma quantum, high energy particle and microwave irradiation and by treatment with strong electromagnetic impulses.

The mechanism of the effect of radiation on fluid inclusions has not been thoroughly studied. Well-known impacts of radiation on a mineral, such as the formation of colour centres, structural rearrangements, weakening of bonds, redistribution of defects and loosening of a sample (SHEVYAKOVA, LIFSHITZ, POLYASCHENKO, 1980), indirectly contribute to removal of fluid inclusions from a mineral but do not cause their destruction. The study of the effect of various fields on a mineral is expected to cast light on inclusion destruction mechanisms.

The goal of the study is to acknowledge the destructive effect of irradiation on fluid inclusions and to assess its quantitative characteristics.

MATERIAL AND METHODS

The problem was approached by studying initial fluid inclusions in the sample, their disintegration products or inclusions that were not removed by treatment. As the first step it was important to estimate the influence of radiation on all kinds of fluid inclusions in minerals.

Quartz, microcline, plagioclase, kyanite, apatite and tourmaline samples were collected from various deposits in Karelia (DANILEVSKAYA, SKAMNITSKAYA, SHIPTSOV, 2004) and the morphology of fluid inclusions and their spatial distribution in the sample were studied under optic microscope.

At the initial stage of removal of inclusions, the mineral was ground to reveal coarse inclusions and inclusions at grain boundaries. The samples were subjected to gamma quantum irradiation with an energy of 4 MeV on a defectoscopic installation provided by Tyazhbummash Plant (Petrozavodsk). A bundle of protons with an energy of 2 GeV, produced by the Nuclotrone at the Joint Institute of Nuclear Research (Dubna), was also used. The samples were subjected to UHF treatment in a domestic Samsung microwave oven. The minerals were affected by strong electromagnetic impulses with an amplitude of 40–50 kV and a pulse frequency of 125 Hz and 200 Hz on a plant at the Institute for Integrated Development of Mineral Resources (Moscow) designed for disintegration of refractory auriferous raw materials (Skamnitskaya, Kameneva, Belashev, 2004). The efficiency of removal of fluid inclusions was controlled by an acoustic decrepitograph, recording impulses from the disruption of inclusions left after treatment (Belashev, Skamnitskaya, Lebedeva, Ozerova, 2001). It was also controlled by the water extract method used by studying inclusion disintegration products that passed into aqueous solution (Moskalyuk, 1973). The relative error of this method of measurement is 10 %.

Results and discussion

Fluid inclusions, 10–50 μm in size, are distributed in minerals either chaotically or along the internal fractures of grains (Figure 1). The number and composition of fluid inclusions in min-

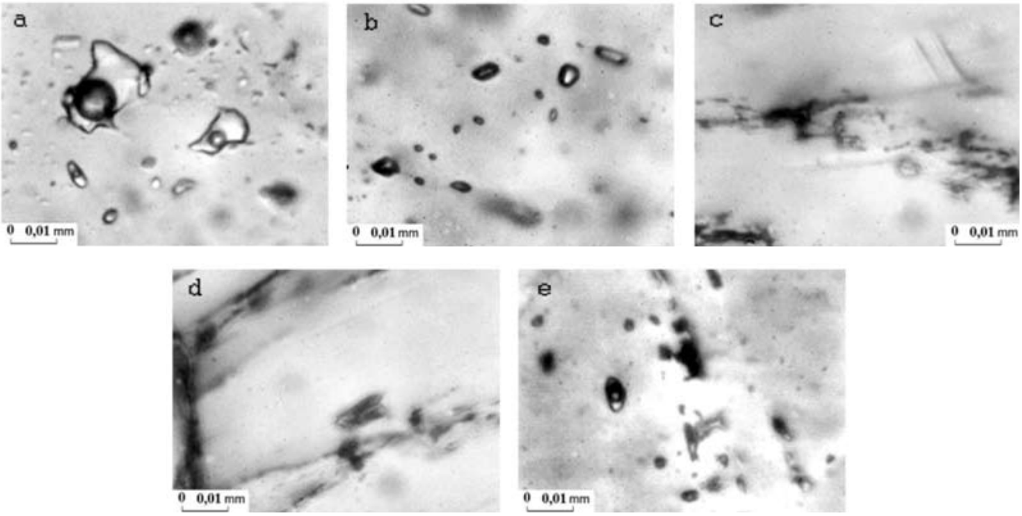

Figure 1. Fluid inclusions in minerals: quartz, Kyrjala deposit, secondary fluid inclusions (a), kyanite, Khizovaara deposit, primary fluid inclusions (b), microcline, Kyrjala deposit, primary fluid inclusions (c), plagioclase, Kyrjala deposit, primary fluid inclusions (d), tourmaline, Kyrjala deposit, primary fluid inclusions (e).

Table 1. Number of fluid inclusions in samples of quartz decrepited in temperature ranges

Temperature ranges, T/°C	Sample 9/98, pegmatitic, Kyrjala deposit	Sample 3/94, veined, Khizovaara deposit
	Number of inclusions	
100–200	711	796
200–300	4569	406
300–400	3939	1160
400–500	9159	992

Table 2. Concentration and species composition of initial fluid impurities

Mineral	Extract	Concentration, c/(mg/L)										
		pH	Fe	Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	Li^{1+}	HCO_3^-	SO_4^{2-}	Cl^-	$C_{org.}$
Quartz, Kyrjala deposit	1	7.62	0.15	1.4	0.4	2.5	2.4	0.19	16.4	4.4	5.5	2.7
	2	6.97	2.70	1.0	0.2	2.3	0.9	0.08	6.8	5.2	4.6	2.7
Microcline, Kyrjala deposit	1	8.43	0.19	7.4	1.2	05	114	3.9	166	10.0	29.4	0.5
	2	8.43	0.05	7.4	0.5	0.5	55	3.6	138	7.3	6.7	0.5

erals depend on the parameters of mineral-forming solutions and vary with deposit, sector of deposit and temperature range (Table 1). The density of fluid inclusions varied considerably with quartz type (Belashev, Skamnitskaya, Lebedeva, Ozerova, 2001).

The sulphate-chloride-bicarbonate composition of fluid inclusions was determined by the water extract method (Table 2). Ion concentration in the inclusions is 1.43 times that in solutions produced by dissolving the minerals. For fluid inclusions in feldspars, a pH of 7.5–8.5 suggests an oxidation-reduction medium. The cations that play the leading role are sodium, potassium and calcium. In microcline, small-sized Na and Ca ions are more easily replaced by H^+ ions than K ions. Impurities in feldspars, such as lithium, magnesium etc., pass into aqueous solution as a result of hydrolysis. Anions are acid residues or the dissolution products of the solid-phase components of fluid inclusions.

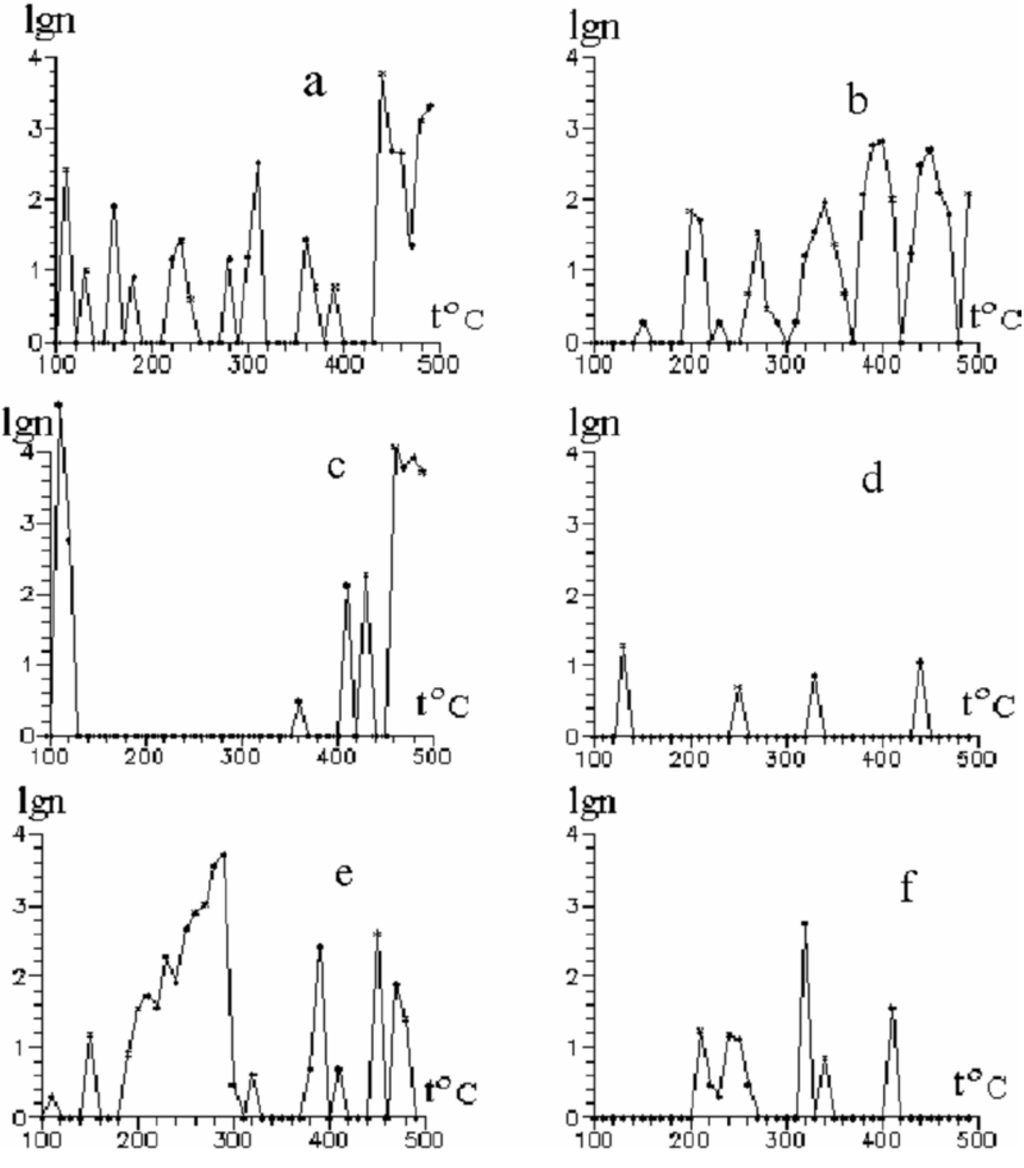

Figure 2. Decreptograms of quartz, microcline and plagioclase of powders from Kyrjala deposit before (a, c, e) and after irradiation (b, d, f) with a bundle of gamma-quanta (*E* = 4 MeV) for 1 h.

The results of 1 h gamma-quantum irradiation of the minerals are shown in Figure 2. The effect of proton irradiation on fluid inclusions in quartz is shown in Figure 3. Figure 4 shows the influence of UHF irradiation on quartz samples. The results obtained corroborate the effect of irradiation of minerals on the concentration of fluid inclusions. Figure 2–4 shows that as irradiation dose and mineral treatment time increase, the number of fluid inclusions decreases and their temperature spectrum changes qualitatively: the peaks of the initial decreptograms decrease in amplitude, split up and are shifted to the medium and low temperature range.

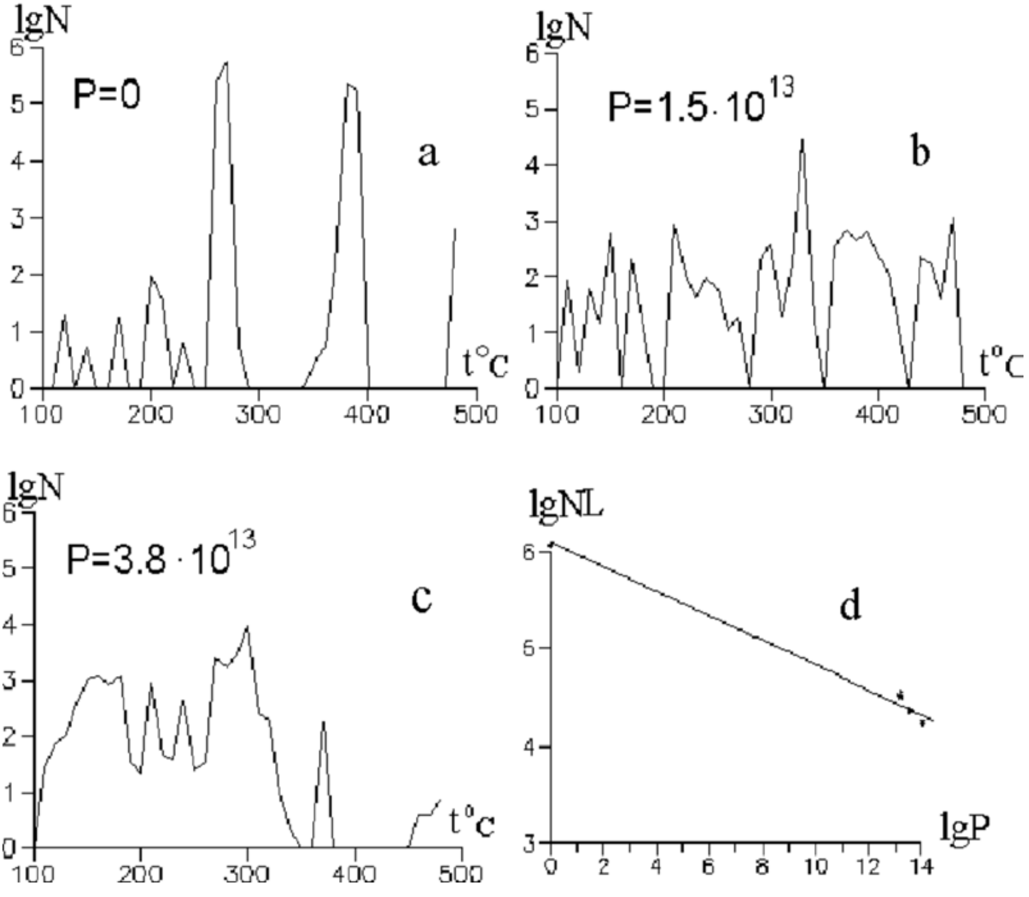

Figure 3. Effect of proton irradiation dose on the number of fluid inclusions in quartz from Kyrjala deposit (a) initial decreptogram not subjected to irradiation; (b, c) decreptograms of quartz subjected to increasing irradiation doses; (d) dependence of the number impulses NL on the decreptogram on the number of protons P that passed through the sample.

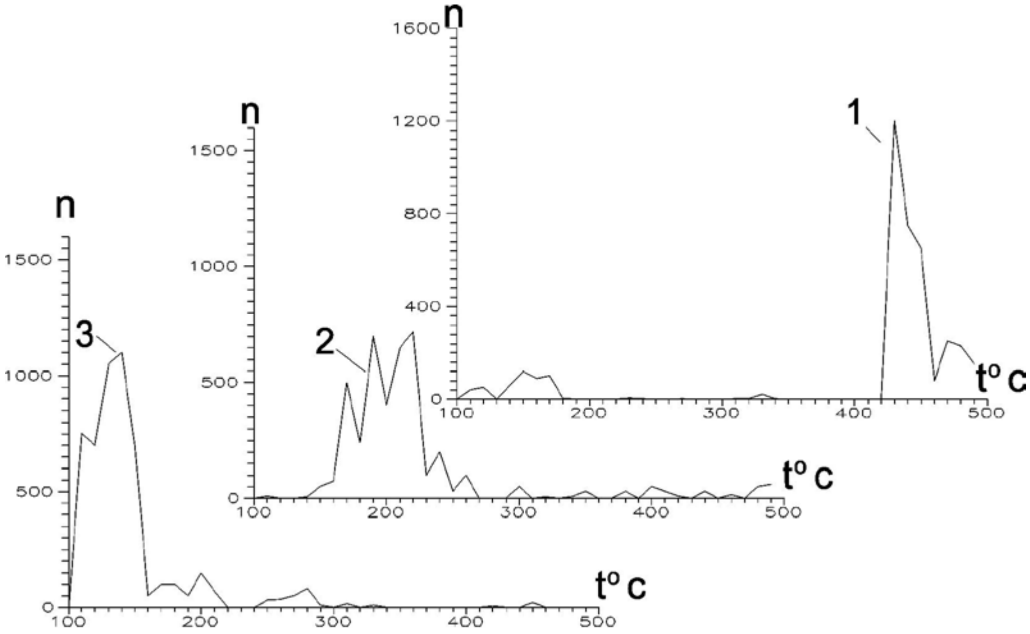

Figure 4. Decreptogram of vein quartz from the Mursula deposit: 1- initial sample, 2 - UHF irradiation for 5 min, 3 - UHF irradiation for 10 min

The compositions of water extracts from the minerals after electromagnetic impulse treatment are shown in Table 3. The regimes used to reveal fluid inclusions vary with mineral. In microcline, treatment with electromagnetic impulses for 60 s reveals a maximum number of inclusions, and the greatest number of HCO^{3-}, SO_4^{2-}, Cl anions pass into water extracts, the number of SO_4^{2-} anions being five times that observed when treatment time is less than 10 s. A maximum number of inclusions is found when treatment time is 15 s for kyanite and 180 s for apatite. The data obtained show that long treatment leads to local heating and destruction of organic impurities and their decreased concentration in water extracts.

The effect on fluid inclusions observed could be explained by mechanisms that act with regard for the composition of inclusions and the characteristics of irradiation. An inclusion is destroyed by a rise in internal pressure caused by ionization and heating of inclusions upon dissipation of particle energy. An inclusion can be heated selectively by protons because of mass equality; they efficiently supply energy and impulse to the water protons of inclusions. UHF irradiation is absorbed in a resonance manner by the rotational fluctuations

Table 3. Composition of extract from minerals after electromagnetic impulse irradiation

Mineral	Treatment time, t/s	pH of extract	Concentration, c/(mg/L)								
			Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	Li^{1+}	HCO^{3-}	SO_4^{2-}	Cl^-	Corg
Microcline, Kyrjala deposit	0	7.16	1.4	0.3	0.6	0.4	0.03	5.1	0.4	1.2	2.7
	10	7.27	2.2	0.4	0.4	0.9	0.05	7.9	1.8	1.3	10.8
	30	7.28	2.3	0.4	0.4	0.8	0.04	7.9	1.6	1.3	0.5
	60	7.36	3.4	0.6	0.7	1.0	0.06	11.1	2.2	1.5	2.7
	300	7.20	3.3	0.2	0.5	0.9	0.05	7.03	0.6	1.3	2.7
Kyanite, Khizovaara deposit	15	4.65	3.4	0.51	1.4	0.38		0	76.8		35.8
	30	4.57	3.5	0.52	1.4	0.38		0	50.6		22.8
	60	4.50	3.6	0.51	1.4	0.40		0	54.4		6.5
	180	4.52	3.4	0.48	1.4	0.36		0	58.2		21.6
Apatite, Tikshozero deposit	15	5.17	0.92	0.17	0.77	0.23		0	30.9		19.8
	30	5.10	0.92	0.18	0.77	0.24		0	29.1		21.2
	60	5.04	0.84	0.17	0.77	0.22		0	27.2		27.0
	180	5.26	0.92	0.17	0.85	0.26		0	26.2		6.4

of inclusion water molecules. Electromagnetic impulses create in minerals numerous channels that expose fluid inclusions or create high pressure and decompression zones in close proximity to them (Chanturia, Bunin, Ivanova, Skamnitskaya, Pylova, 2004).

Some of the mineral treatment regimes used are far from being optimum. The energy of gamma quanta does not correspond to the energy of their resonance absorption by the water of inclusions. As the ability of protons to cause maximum destruction at the end of their travel in matter is not used, the efficiency of different methods cannot be compared experimentally, and radiation technology should further be improved. An example of UHF irradiation (Figure 4, curve 3) shows that the resonance transmission of field energy to inclusions makes the destruction of high temperature inclusions more efficient. For low temperature peaks, this statement requires additional checking because of masking by an intense peak of adsorbed water.

CONCLUSIONS

- Irradiation of minerals and their treatment with electromagnetic impulses at the optimal conditions change the number of fluid inclusions and their temperature distribution, decreasing the number of high temperature fluid inclusions.
- The radiation destruction of fluid inclusions and their treatment with electromagnetic impulses are not connected with direct heating of a mineral, are less expensive, use background irradiation and can be combined with other technologies.
- As dressing continues, the destruction products of fluid inclusions pass into pulp, change its ion composition and affect flotation processes and the composition of return water (SKAMNITSKAYA, KAMENEVA, 2005).

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