RESEARCH OF DYNAMICS OF NATURAL MINERALS DISPOSITIONS AS DETECTORS OF FLUID SYSTEMS MIGRATION

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There is an active form of fluid migration in Tatar arch structure of the Central Volga-Ural anteclise. We studied quartz with gas-liquid inclusions which move on the dislocations of the crystal lattice. This form is associated with capillary-diffusion processes. There is a rupture of continuity of the crystal with the advent of the vacancies in its structure. Vacancies may be filled with mobile water molecules, simple hydrocarbons. Interstices may increase in volume and turn in voids of nucleate type and then in conducting channels. Migration of dislocations can occur at the stage of compression, in the decompression stage the movements of dislocations stop. As a result, large amounts of fluids are transferred to the sedimentary cover of the South Tatar arch.
Keywords: metamorphic rocks, quartz, gas-liquid inclusions, dislocation.

One form of fluid migration is migration in the form of small vesiculate gas-liquid inclusions in minerals. Such inclusions are widely developed in rock-forming minerals of crystal basement. Gas-liquid inclusions have the greatest distribution in quartz grains of rocks. According to the conducted research, such minerals may be detectors of fluid systems migration. It is shown that gas-liquid inclusions in minerals are connected with dislocational mechanism of their occurrence. They are shown during geomechanical processes of rock formation and its evolution.

The crystalline basement of the Tatarstan Arch is one of the central structures of the Volga-Ural anteclise. The performed studies indicate that the crystalline basement is an ever-evolving geological structure in the ever-changing field of geodynamic stress. Stress generation in the body of the crystalline basement of the Tatarstan Arch is associated with the formation of specific compression and decompression zones of destruction [(Sitdikova & Izotov, 2003; Sitdikova, 2005)]. Stress appears due to the constant movement of separate basement blocks pressed between platform troughs [(Sitdikova & Izotov, 1999)].

The active migration of fluid systems in crystalline rocks has been practically proven [(Marakushev, 1965)] but its forms and mechanisms are still under discussion. Most researchers link the migration of deep fluids to the deep faults in the Earth's crust that are considered the natural fluid-conducting channels.

However, the studies conducted in metamorphic areas indicate that fluid impact zones also widely occur within undisturbed geological sequences. Such strata contain metasomatite fields, diaphthorite beds and entire granite-gneiss bodies (domes) that could not be formed without the action of fluids.

One of the major factors of fluid migration within the Tatarstan Arch's hydrothermal systems is the constant geodynamic evolution of the basement [(Sitdikova & Izotov, 2006)]. This migration takes place in various forms depending on the geological conditions in the stress zone. The crystalline basement and its periphery contain various fault systems disrupting the integrity of basement rocks. Fluid migration through deep faults occurs in the form of the movement of hydrothermal systems in weak/low-coherence zones, resulting in the development of metasomatic processes and fields of hydrothermally altered rocks in the basement. In many cases, metasomatically altered rocks of the basement are not controlled by the fault tectonics, although it plays a major role in the formation of rocks with different degrees of alteration.

However, according to the author's data [(Izotov & Sitdikova, 2006; Sitdikova & Izotov, 2006)], the stress state of basement rocks constantly changes. In some portions of the basement with no disruption of the rock integrity, fluids can migrate in the form of hydrothermal inclusions along the dislocation planes in the crystalline lattice of minerals. This form of migration is very widespread and accounts for the formation of regional fields of metasomatites of granite-gneiss structures of the ancient shields and other geological regions within the deformed geological environments [(Sitdikova, 2005)].

The mechanism of fluid migration in the geological systems of this type will be explained below. As far back as 1957, D. S. Korzhinsky stated that the migration of hydrothermal fluids in such formations is associated with capillary diffusion [(Korzhinsky, 1957)].

The authors' research indicates that the corresponding capillary channels are formed within the dislocation systems of the crystalline lattice of minerals. Mineralogical and petrographic studies of metamorphic rocks of the crystalline basement rocks in the eastern portion of the Russian Plate based on core samples from deep and ultra-deep wells show that all studied types of rocks underwent various stages of tectonic stress, which resulted in the mylonitisation and brecciation in the destruction zones up to the formation of mineral blocks.

Raster electron microscopy shows that such crystals of metamorphic rocks can be channels for hydrothermal fluids carrying gas-liquid inclusions. Such inclusions are primarily found in quartz, a mineral with a viscous crystalline structure and no cleavage, which helps to preserve these inclusions in it. Quartz is known to have a framework crystalline structure with high viscosity at high pressures, which explains high-pressure plastic flow of quartz producing granulite structural forms with a wavy block structure indicated by the wavy and block extinction in thin sections.

Such a block structure of some minerals, e.g. quartz, has been studied in boreholes that penetrated the destruction zones of the crystalline basement – Minnibaevo-20000, Novo-Elkhovka-20009, Tlyanchi-Tamak-678, 20002, etc. – where the mosaic and wavy extinction is expressed in first-generation quartz grains [(Fig. 1, 2)].

Fig. 1. Dislocated quartz with mosaic and wavy extinction and chains of gas-liquid inclusions. Well 678 Tlyanchi-Tamak, 2470.2 m depth. Nicoli+. Magn. 125.

Fig. 2. Intersecting crack systems in quartz and plagioclase with gas-liquid inclusions. Well 678 Tlyanchi-Tamak, 2540.2 m depth. Nicoli+. Magn. 125x.

It is a well-known fact that various minerals contain fluid microinclusions but these have mainly been described for minerals of magmatic and hydrothermal crystallogenesis [(Balitsky *et al.*, 2006; Ermakov, 1972)]. However, the presence of these inclusions in metamorphic rocks and their dynamics are explained by other causes [(Cottrell, 1969)], as indicated by their morphology and position in crystals. The studies of microinclusions in quartz and other minerals conducted by the authors indicate that directed load in quartz produces deformation dislocations in nuclei with disrupted integrity of the crystal due to the appearance of vacancies in its structure. These vacancies can be filled with commensurate mobile molecules of water, simple hydrocarbons and oxides due to diffusion and other processes. Due to the growth of minerals, the volume of the vacancies increases and they turn into bubbly voids observed by microscopy. These bubbly voids in deformed quartz are thousandths and hundredths or, rarely, tenths of a millimetre in size. The inclusions are arranged in a linear-striate pattern within quartz crystals, in many cases without direct dependence on certain crystallographic directions of the mineral [(Fig. 3,4)].

Fig. 3. Subparallel chains of gas-liquid inclusions along dislocation lines in 1st-generation quartz. Well Novo-Elkhovo-20009, 1995,0 m depth. Magn. 1200x.

Fig. 4. Linear chains of gas-liquid inclusions. Partial fusion (enlargement) of inclusions with the formation of fluid-filled voids. Well 678 Tlyanchi-Tamak, 1965.0 m depth. Magn. 2500x.

The chains of gas-liquid inclusions can trend not along the crystallographic directions but along those perpendicular to stress, which is in many cases characterised by elongated wavy extinction blocks. The study of the arrangement of chains of gas-liquid inclusions in quartz allows the conclusion that they trace the planes of linear dislocations that appear in metamorphic processes and are associated with compression and decompression in the body of the basement [(Sitdikova, 2005)]. According to mineralogical and petrographic studies, chains of inclusions in many cases move from one quartz grain to another.

Normally, the inclusions are thousandths and hundredths of a millimetre in size with their flat and oblong voids greatly varying in shape, and the inclusions are elongated along their chains. Chains of gas-liquid inclusions generally trend along wavy extinction strips in quartz. According to petrofabric data acquired by the E. S. Fedorov's method, extinction zones are arranged sub-horizontally (perpendicular to the core axis), which indicates the sub-vertical stress gradient in rocks. The distance between such chains of inclusions varies from 0.n mm to 0.0n mm. Such an arrangement of inclusions in crystals indicates that they were formed during the post-metamorphic phase of the evolution of the Tatarstan Arch's basement.

Gas-liquid inclusions are characteristic of quartz from early metamorphic rocks (1st generation quartz) and are not present in pure quartz of hydrothermal veinlets (2nd generation quartz). Second-generation quartz was formed after the major stress action in the structure of the basement's metamorphic formations under study. Morphological features of gas-liquid inclusions in quartz of the crystalline basement rocks, studied by raster electron microscopy, confirm that these inclusions were produced by dislocations [(Sitdikova & Izotov, 2007)].

According to the dislocation theory [(Cottrell, 1969)], crystal damages of various types, created in solid bodies under stress gradient, migrate towards the minimum stress region according to the Burgers vector b:

$b = \int \frac{du}{ds} ds,$ where u – displacement vector in strained material, s – Burgers circuit / dislocation circuit.

In the process, the nano-sized disruption cavities created in nuclei of the moving dislocations and filled with rock fluids also migrate in the direction of the dislocation movement. According to the theory of elastic media [(Cottrell, 1969)], the migration rate of dislocations in crystals is comparable to the sound velocity that ranges between 3.5 and 6 km/s in the rocks under study. In the Tatarstan Arch's region the migration of dislocations occurs in the compression phase, stress relief leads to decompression and prevents further movement of dislocations, and the contained fluids cause partial recrystallisation of the walls of the inclusions and the appearance of drusy quartz in them or the formation of sheet silicate micro-extractions [(Fig. 5)].

Fig. 5. The internal structure of gas-liquid inclusion in quartz with the appearance of a drusy structure. Well 678 Tlyanchi-Tamak, 2083,0 m depth. Magn. 5000x.

Fig. 6. The internal structure of gas-liquid inclusion in quartz. Well 678 Tlyanchi-Tamak, 1965,0 m depth. Magn. 3100x.

Gas-liquid inclusions have also been studied in the other following rock-forming minerals of the basement: feldspars, amphiboles and pyroxenes. However, the described dislocation movement mechanism does not take place in these minerals as they are characterised by cleavage facilitating fluid movement through the weakest zones, i.e. their cleavage. In this case, the fluid movement is governed not by geodynamic stress fields but by other factors, i.e. the direction of cleavage planes in them [(Fig. 7, 8)].

Fig. 7. Biotite-plagioclase gneiss. Elongated voids with gas-liquid inclusions in cleavage planes and strain fractures crossing cleavage planes in orthoclase. Well 678 Tlyanchi-Tamak, 2392.0 m depth. Nicoli+. Magn. 125x.

Analysis has revealed many forms and ways of fluid migration in the crystalline basement rocks.

Fig. 8. Subparallel chains of gas-liquid inclusions along dislocation lines in 1st-generation quartz. Well Novo-Elkhovo-20009, 1810 depth. Nicoli+. Magn. 1200x.

Nano-size inclusions/dislocations in minerals, moving with a high speed within the crystalline medium, can carry large amounts of fluids accumulating in the sedimentary cover of the South Tatarstan Arch and other regions, which should be taken into account in geological exploration for hydrocarbons carried out within the sedimentary cover and the crystalline basement that have been proven to contain deep fluid pathways in the course of the implementation of the Deep Drilling Programme of the Republic of Tatarstan.

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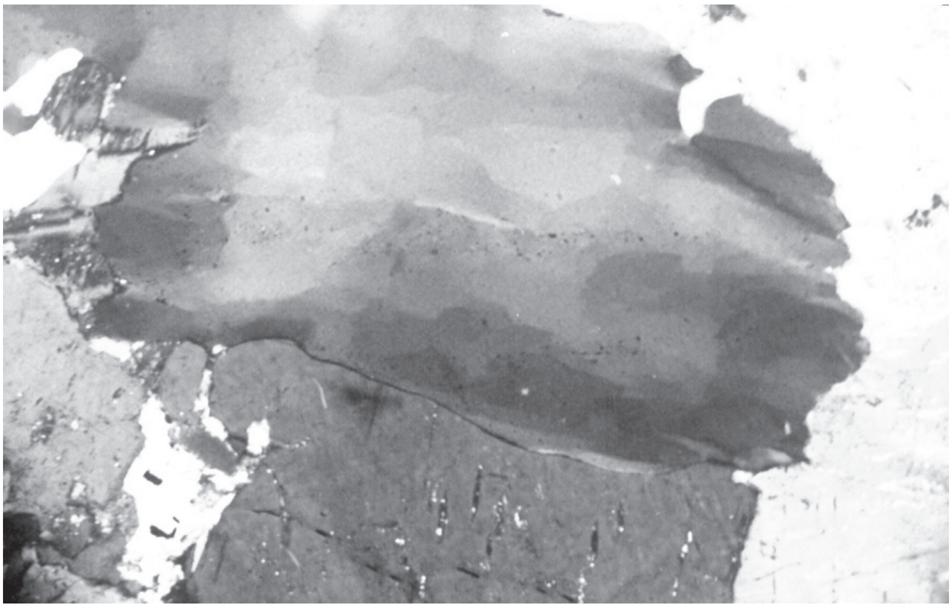

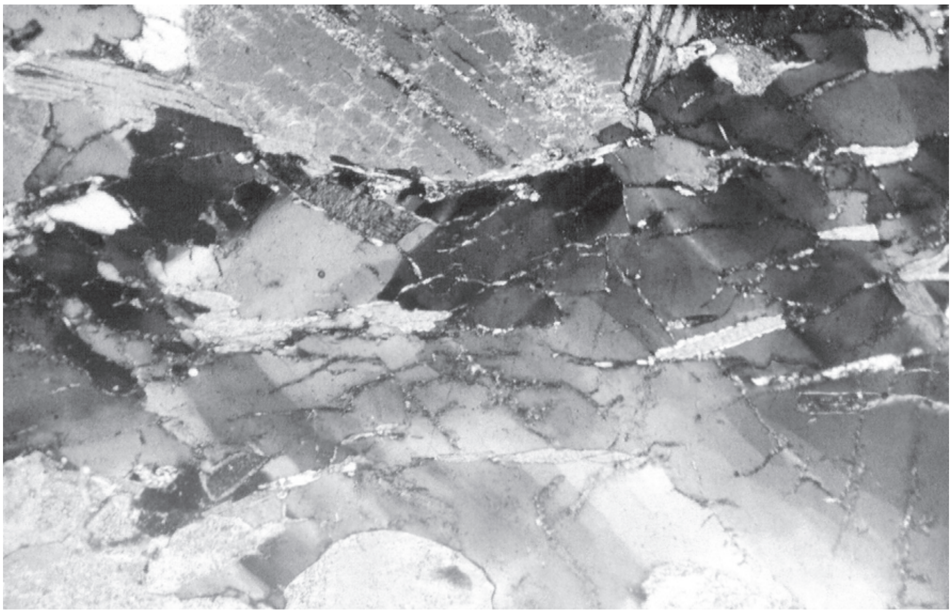

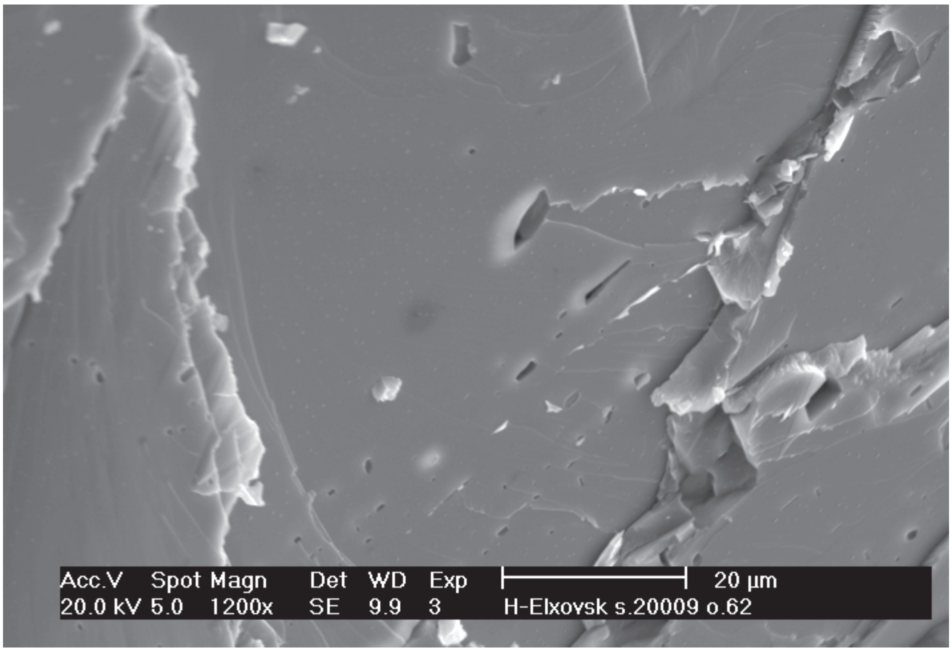
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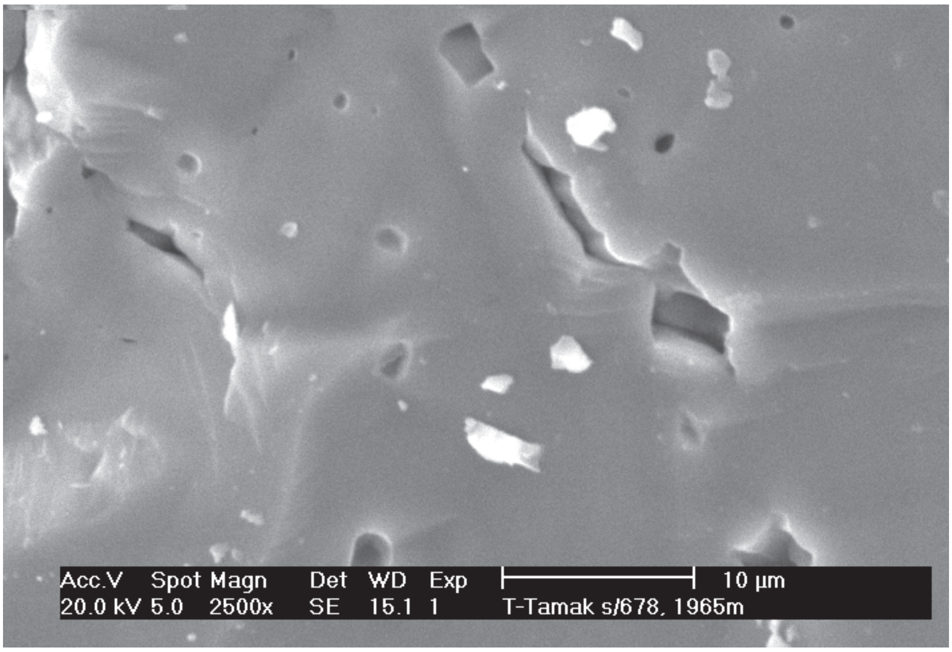
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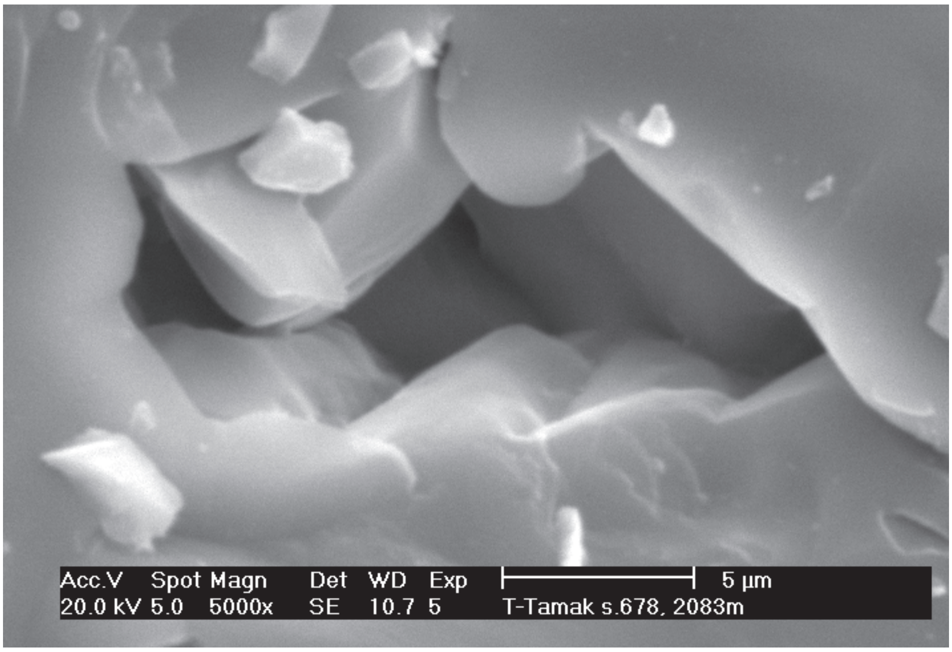
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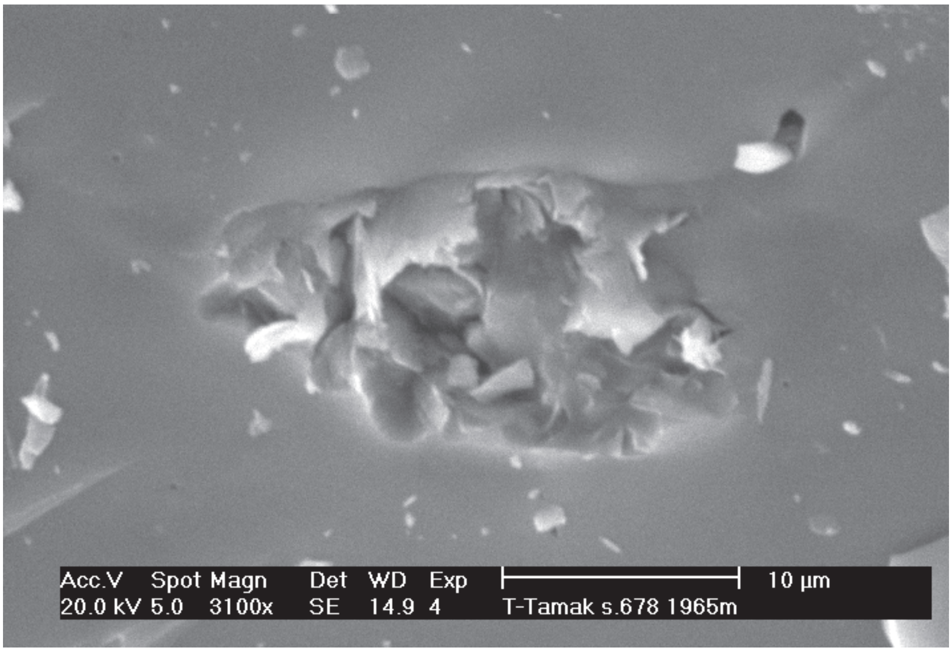
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