FEATURES OF PHENACITE MINERALIZATION FROM THE URAL EMERALD MINES

M. P. Popov, A. G. Nikolaev

The authors consider the problems of development of phenacite mineralization at the Ural Emerald Mines, which is rather well developed and described in the Marinsky (Malyshevsky) and Sretensky (Sverdlovsky) emerald-beryllic deposits. Phenacite is widely spread in many beryllic deposits, but crystals of jewelry quality, with such large sizes as at the Emerald Mines, form rare. Despite the description of the discovery in 1833, and because of the rare occurrence of jewelry quality of crystals, and the presence of more expensive and valuable stones – emeralds and alexandrites – in deposits of the Emerald Mines, phenacite remains almost unknown in the precious stones market, and especially abroad. Phenacite mineralization mostly occurs in the micaceous veins represented by grey and greenish-gray phlogopite. Distribution of phenacite in the micaceous veins is extremely uneven. Mineralization is typically nesting. High content of phenacite appears in the micaceous veins, mineral composition of which is mostly phlogopite, veins and concretions of beryllium-containing margarite (B-margarite) and chlorite. Content of phenacite in the micaceous veins is very unstable, and often, beautifully colored during growth, it often passes off as topaz or even as a diamond. However, the color of phenacite is very unstable, and often, beautifully colored during mining, stone completely fades after a few months under the sunlight, what is one of its disadvantages [1].

Phenacite is a beryllium mineral (Be2SiO4). A. V. Kokovin discovered phenacite at the Ural Emerald Mines at the Sretensky field of the Mariinsky (Malyshevsky) and Sretensky (Sverdlovsky) emerald-beryllic deposits. Phenacite is widespread in many beryllic deposits, but crystals of jewelry quality, with such large sizes as at the Emerald Mines, form rare. Despite the description of the discovery in 1833, and because of the rare occurrence of jewelry quality crystals, and the presence of more expensive and valuable stones – emeralds and alexandrites – in deposits of the Emerald Mines, phenacite remains almost unknown in the precious stones market, and especially abroad. Phenacite mineralization mostly occurs in the micaceous veins represented by grey and greenish-gray phlogopite. Distribution of phenacite in the micaceous veins is extremely uneven. Mineralization is typically nesting. High content of phenacite appears in the micaceous veins, mineral composition of which is mostly phlogopite, veins and concretions of beryllium-containing margarite (B-margarite) and chlorite. Content of phenacite is low in the micaceous veins that include phlogopite, plagioclase, beryl, fluorite, smoky quartz and corundum [1].

On the territory of the Ural emerald mines, phenacite mineralization is rather well developed and is described in the Marinsky (Malyshevsky) and Sretensky (Sverdlovsky) emerald-beryllic deposits. According to the exploration results of the Marinsky deposit, phenacite is extremely rare there. Phenacite mineralization mostly occurs in the micaceous veins represented by grey and greenish-gray phlogopite. Distribution of phenacite in the micaceous veins is extremely uneven. Mineralization is typically nesting. High content of phenacite appears in the micaceous veins, mineral composition of which is mostly phlogopite, veins and concretions of beryllium-containing margarite (B-margarite) and chlorite (Fig. 1). Content of phenacite is low in the micaceous veins that include phlogopite, plagioclase, beryl, fluorite, smoky quartz [1].

One can observe both growth of emerald over phenacite and overgrowth of phenacite around beryl crystals (Fig. 2). In all cases, there are induction faces.

During exploration and development at the Sretensky deposit, a few phenacite crystals in the mica complexes were among the finders of emerald.
ings. In 1994, in the “Yuzhny” quarry, in the lying (western) side of the ore zone of the Sretensky deposit, researchers discovered a plagioclase vein with thin phlogopite ridges, characterized by an exceptionally high (not less than 30% of the volume) concentration of large-grained (and intergrowths) phenacite. This vein belongs to a new type of ore bodies of chrysoberyl-phenacite composition, bedded in ultrabasic rocks. Unlike emerald-bearing micaceous veins that have a northwest-ern spread, the chrysoberyl-phenacite ore bodies are oriented in the near-latitudinal direction and have a northern incidence at an angle of 75–80°. The length of the veins of the new type does not exceed 5–6 m, and their thickness varies from 20 to 50 cm [2]. In the vein, there are two generations of phenacite. The first is a granular, fractured milk-white aggregate. The second grows on the first in the form of idiomorphic crystals (Fig. 4). The contact between them is clear smooth.

**Shape of the crystals and properties of the mineral**

The most common form of phenacite crystals on the Emerald Mines is rhombohedral and short columnned. Crystals have a large number of faces. The usual shapes are a hexagonal prism and rhombohedrons. Twin crystals are common, druses, columnar aggregates, and spherulites are characteristic. The facets may be specular, covered with growth bumps or dissolution pits [1]. Sometimes one can observe hatching of joint growth on them (Fig. 5).

Phenacite usually is in the form of crystals grown into the rock, sometimes in the form of druses in voids. The size of crystals varies

from small (fractions of mm) to large (up to 10–15 cm). Individual crystals can be up to 20 cm in length.

Phenacite can be colorless or slightly colored in wine yellow, sometimes pinkish, light gray, white, rarely brown (Fig. 6). The color in the crystal can spread non-uniformly. Wine-yellow coloration is not stable; it completely disappears in the light.

**Inclusions**

Phenacite from the Ural emerald mines contains mineral, gas-liquid and mechanical inclusions that affect the transparency of the crystals.

The most frequent inclusion in phenacite is chlorite in the form of singular scales (1–6 mm) or aggregates of idiomorphic crystals, 0.6 × 0.5 cm in size. The authors present chlorite compositions in Table 1 (analyzes 3 and 4). After converting (the content of H₂O is 11.65% according to the data of wet chemistry), the authors obtained the following crystallochemical formulas:

\[
\begin{align*}
(Mg_{3.88}Fe_{0.81}Cr_{0.01}Mn_{0.01})_{4.71}Al_{1.23}[Si_{2.75}Al_{0.24}O_{10}](OH_{7.96}F_{0.21})_{7.97} & \quad \text{– an. 3.} \\
(Mg_{3.92}Fe_{0.81}Mn_{0.01})_{4.75}Al_{1.21}[Si_{2.82}Al_{1.20}O_{10}](OH_{7.96}F_{0.21})_{7.97} & \quad \text{– an. 4.}
\end{align*}
\]

By results of the analysis, it is clear that chlorite belongs to the clinochlore group.

A rather common mineral inclusion in phenacite is ilmenite, which occurs in the form of thin plates of gray-black color (Fig. 7) or small isometric inclusions. The size of the mineral is from 1–2 mm up to 2 cm. One can see the compositions of the mineral in Table 1 (analyzes 1 and 2), and their recalculated crystallochemical formulas are:

\[
\begin{align*}
(Fe_{0.90}Mg_{0.03}Mn_{0.08})_{1.01}Ti_{0.99}O_3 & \quad \text{– an. 1.} \\
(Fe_{0.89}Mg_{0.03}Mn_{0.08})_{1.00}Ti_{0.99}O_3 & \quad \text{– an. 2.}
\end{align*}
\]

Rarely, phenacite contains pyrrhotite grains (diagnosed by X-ray diffraction), 1–2 mm in size. They have an irregular shape and a bronze-yellow color.

**Gas-liquid inclusions** in the phenacite have a tubular, isometric and elongated shape (Fig. 8). Tubular inclusions usually have sub-parallel orientation in the form of small clusters. Their dimensions do not exceed a tenth of a millimeter.

Isometric and elongated inclusions occur together. They often are oriented in the plane of healed cracks. The ratio between water and gas in the inclusions is from 3 : 1 to 5 : 1. Composition of the inclusions was mainly two-phase, with no detected three-phase inclusions.

Most phenacite crystals have numerous mechanical inclusions – cracks. There are two types (Fig. 9):

- small cracks (type A) – have a strictly sustained strike, are formed due to plastic deformations when crystals are formed in a plastic medium (micaceous material);
– large cracks (type B) have different directions and much greater power, are formed during the extraction of crystalline raw material under the influence of impact loads.

Formation of numerous cracks leads to a deterioration in the transparency of the phenacite crystals and formation of “blockiness”. In the center of the crystal there are large transparent blocks, about 15–30 mm in size, and closer to the periphery, the block size decreases, leading to the decrease of transparency degree.

**Infrared spectroscopy**

The authors surveyed infrared spectra of phenacites from the Mariinsky deposit using a spectrophotometer “Spectrum Two perkin-elmelmer”, in the “reflection” mode. The shooting range was 450–4500 cm\(^{-1}\), the spectral resolution was 0.5 cm\(^{-1}\). One can see the characteristic infrared spectrum of colorless phenacite below (Fig. 10).

Weak vibrational bands of up to 660 cm\(^{-1}\) relate to deformation vibrations associated with BeO\(_4\) and SiO\(_4\) complexes in the phenacite structure. Bands in the range of 690–800 cm\(^{-1}\) relate to the valence vibrations of BeO\(_4\) complexes, and above 800 cm\(^{-1}\) – to SiO\(_4\) structures in the mineral [3]. For the study authors by infrared spectroscopy selected samples of colorless phenacites and phenacites having different colors, from yellow to light brown. There were no fundamental differences in the oscillation lines in infrared spectra of colorless and colored phenacite samples. The main oscillation lines of the structural complexes BeO\(_4\) and SiO\(_4\) in colorless and colored phenacites have the same wavelengths and have minor differences in the optical density. From this, we can draw the following conclusions: the coloring of phenacites has an electron-hole nature, and, due to it, the color appearance mechanism does not affect the symmetry of local structural units in the crystal structure of the mineral.

**Optical spectroscopy**

The authors recorded optical absorption spectra on a specialized SHIMADZU UV-3600 spectrophotometer in the wavelength range of 185–3300 nm, at room temperature. The authors obtained optical absorption spectra of colorless and light brown phenacite from the Mariinsky deposit. On both spectra of the mineral in the range of 2900–3200 nm are oscillations associated with the presence of OH group. There are peaks in the range of phenacites of yellow color in the interval of 250–286 nm (Fig. 11).

In the transparent colorless phenacites, there was no absorption in ultraviolet range (Fig. 12). Other low-intensity absorption bands in optical spectra are noises related to the survey conditions.
The nature of the phenacite coloration currently is not studied in detail in optical adsorption spectroscopy. Many authors agree on only one thing, that the nature of coloration is associated with electron-hole centers. Disappearance of color in phenacite upon expose to either ultraviolet radiation or high temperatures indicates it. According to one of the theories, these absorption lines are associated with the oxygen vacancies that have captured an electron [4]. Other researchers believe that these absorption lines are associated with bridged electron centers of the \( \text{Al}^{3+} - \text{O} - \text{Al}^{3+} \) type [4]. They are formed due to the isomorphic occurrence of aluminum ions in the crystal lattice of phenacite, in an amount up to 0.5% [5]. In addition, the presence of paramagnetic centers affects the color in the EPR spectra of the impurity radical \( \text{PO}_{4}^{4-} \) in the light brown mineral [6–10]. Thus, during the study on paramagnetic resonance in irradiated phenacite \( \text{Be}_2\text{SiO}_4 \), a widespread phenomenon, for example, disintegration of properties in barite [11].

**Gemmology**

Phenacite as a precious stone is quite rare in the modern jewelry market. Color differences (pink and wine-yellow) are still popular, but due to the rapid fading in the sunlight, do not have much demand in jewelry stores. Due to a sufficiently high refractive index (higher than that of topaz, beryl, tourmaline) it was of interest in the Urals in a role of an “Ural diamond”; before diamonds finding. Current works aim to strengthen and fixate the color in the phenacite.

Currently, the world jewelry market receives phenacite mainly from Brazil and Sri Lanka (see Table 2).

From the materials provided one can see that the gemmological characteristics of the phenacites from the Ural Emerald Mines are similar to the characteristics of the phenacites from Sri Lanka. They have similar formation conditions.

<table>
<thead>
<tr>
<th>Table 2. Comparison of gemmological characteristics of phenacite from different countries.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics</td>
</tr>
<tr>
<td>Refractive index</td>
</tr>
<tr>
<td>Birefringence</td>
</tr>
<tr>
<td>Shine</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
</tr>
<tr>
<td>Fluorescence:</td>
</tr>
<tr>
<td>LWUV</td>
</tr>
<tr>
<td>SWUV</td>
</tr>
</tbody>
</table>

**REFERENCES**

2. Zolotukhin F. F., Zhernakov V. I, Popov M. P. 2004, Geologiya i zakono-
mernosti raspredeleniya dragotsennych kamenny Malyshevskogo mesto-
zeniya (Ural’skie izumrudnye kopi) [Geology and regularities of distribution of precious stones of Malyshevsky deposit (Ural Emerald Mine)], Ekaterinburg, 75 p.
10. Platoven A. N. 1976, Priroda okraski mineralov [Nature of color of mineral-
als], Kiev, 264 p.

**Mikhail Petrovich Popov, popovm1@yandex.ru**

**Institut geologii i geofiziki**

im. академика А. Н. Заварницкого УрО РАН

Россия, Екатеринбург, ул. Академика Вонсовского, 15

**Анатолий Германович Николаев, Anatolij-nikolaev@yandex.ru**

Казанский (Приволжский) федеральный университет

Россия, Казань, ул. Кремлевская, 18


**EARTH SCIENCES**