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Study of melt inclusions in the Nezametnoye corundum deposit, Primorsky region of the Russian Far East: Petrogenetic consequences

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Abstract

Any and all proposed theories regarding the origin of sapphires are still very much open to debate. Critical inconsistency arises on the magmatic petrogenesis mechanism of sapphire crystal formation. The Nezametnoye Deposit is one of the most prospective placer deposits of jewelry grade corundum (sapphire) and zircon (jacinth) in Russia, and is known for its native and alluvial gold–wolframite–tin deposits. We present new data obtained from mineral and primary melt inclusions that are syngenetic to corundum. Electron microprobe analysis indicates that rutile, zircon, albite, zinc-bearing hercynite, columbite, and fluorite represent syngenetic mineral inclusions. Silicate melt inclusions are almost always associated with carbon dioxide inclusions; this correlation suggests that a heterogeneous fluid–melt system was present during corundum crystallization. Distinctive features of chemical composition of the inclusions, along with their agpaitic coefficients, indicate that corundum crystallization occurred from granosyenite melts. Primary carbon dioxide-rich inclusions form random groups, or are associated with melt inclusions. P–T conditions for corundum crystallization have been calculated as 780–820 °C and 1.7–3 kbar, based on data from primary carbon dioxide and melt inclusions.
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1. Introduction

The study of the geological processes involving the construction of models of mineral formation and of phase diagrams for fluid conditions requires the application of thermobarogeochemical methods using fluid or melt inclusions. This approach makes it possible to obtain accurate information on the conditions of mineral crystallization. There are acknowledged disadvantages and restrictions to the method, but it is, nevertheless, recognized as the most reliable and precise scientific research tool available, particularly when employed in the development of methods that propose to analyze individual inclusions. These methods include the laser-spectrum analysis of inclusion

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fluid phases (IFP), proton-induced X-ray emission (PIXE), and laser ablation inductively coupled plasma-mass spectrometry (LA-ICPMS).

2. The Nezametnoye deposit

The Nezametnoye deposit is recognized as one of the most prospective placer deposits of precious corundum (sapphire) and zircon (jacinth) in Russia, and is known for its native and placer gold–tungsten–tin ores. It is located in the Samarka accretionary prism of the Sikhote-Alin. Igneous rock units, comprised primarily of granitoids of the Marev intrusive complex, are present in stocks and dikes composed of Early Cretaceous bi- otite granite, granite-porphyry, aplite, granosyenite, syenite and granodiorite. There are also examples of sparse, thin dikes comprising Late Jurassic gabbro, quartz–diorite, spessartite and vogesite, and of Neogene basalt and dolerite. All of the rocks in the deposit, with the exception of the Neogene basalt, are metasomatically variably altered. Metasomatite normally contains such accessory minerals as apatite, rutile, zircon, wolframite, scheelite and fluorite, but in some places monazite, columbite, corundum, and zircon are also present.

3. Corundum

Placer corundum occurs as abraded crystals and chips up to 20 mm in size; these are typically of beer-barrel or tabular appearance. Growth zones are observed in a sectional view parallel to a pinacoid. 'Silkiness,' a characteristic defined by the presence of rutile needle inclusions, is typical of these crystals, and there is occasional evidence of star asterism. There are three demonstrated types of inclusions in the placer corundum: mineral, melt, and fluid. Our genetic conclusions are based on the following information from the syngenetic mineral and primary melt inclusions in the corundum.

4. Methods and results

Results from X-ray fluorescence EDC analysis (JXA-8100, Jeol) reveal that syngenetic mineral inclusions are represented by rutile, zircon, albite, zinc-containing hercynite, columbite, monazite and fluorite (Khanchuk et al., 2003). There are two types of primary corundum-hosted inclusions: silicate melt inclusions (Fig. 1) and the more common carbon dioxide inclusions, which would seem to indicate that corundum crystallization occurred from granosyenite melts. An examination of glasses with primary heated melt inclusions was carried out by means of a JSM-5300 scanning electron microscope equipped with a LINK ISIS EDS-system, and a LEO 1430VP scanning electron microscope equipped with an INCA Energy energy dispersive spectrometer. Analyses revealed that the glasses are composed predominantly of SiO_2 (59–62 wt.%), Al_2O_3 (14–20 wt.%), and some alkalis. Na_2O (4–10 wt.%) predominates over K_2O (2–6 wt. %), and Fe_2O_3 (0.4–1.2 wt.%); some glasses also include CaO (0.3–3.7 wt.%), P_2O_5 (0.92–1.28 wt.%), Cl (0.18–0.66 wt.%) and V_2O_5 (0.2–1.5 wt.%). The agpaitic coefficient calculated for these inclusion glasses varies within a demonstrated range of 0.81 to 1.74, and is, in most cases, equal to 0.9. The chemical composition and agpaitic coefficient both seem to confirm that corundum crystallization occurred from granosyenite melts.

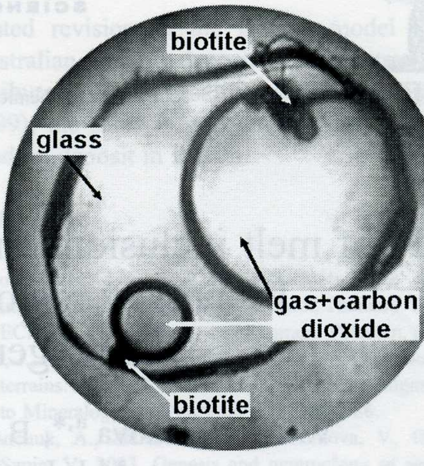

Fig. 1. Corundum primary melt inclusion: glass + gas + carbon dioxide + biotite.

Primary inclusions comprising mostly carbon dioxide form isolated azonal groups in the central parts of crystals, and accompany melt inclusions. Examination of the primary carbon dioxide inclusions (Fig. 2) using a Raman spectrometer (Dilor OMARS 89 with a cooled CCD detector; 514 nm line of an gaseous argon laser; at the JIGGM — Joint Institute of Geology, Geophysics and Mineralogy, Siberian Branch of Russian Academy of Sciences) has revealed a lack of methane, hydrogen sulfide, and nitrogen at the sensitivity level of the apparatus. The density of these inclusions, according to the temperature of fluid and gaseous carbon dioxide homogenization (31.2 °C of the fluid phase), is 0.46 g/cm^3. The temperature and pressure intervals for the onset of corundum crystallization were determined using the syngenetic

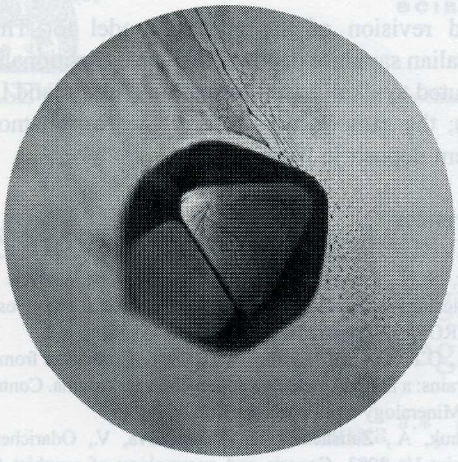

Fig. 2. Corundum primary carbon dioxide inclusion.

carbon dioxide and melt inclusions, and are 780 to 820 °C and 1.7 to 3 kbar, respectively.

5. Discussion

The most probable mechanism for formation of the corundum within the Nezametnoye deposit involves both magmatic and metasomatic processes. This probability is consistent with models that have been developed for primary corundum deposits.

Since the obtained results indicate that the corundum had its source in a granosyenite magma, the existence and location of similar magmatic rocks in the district becomes a primary exploration imperative. We have distinguished high-alumina differentiates of almandine–muscovite and almandine–biotite–muscovite rocks in the granite-porphyry of the Nezametnoye stock. Accessory garnet forms euhedral almandine–spessartine crystals; these crystals sometimes manifest in lattice structure. Corundum is represented by irregular, or sometimes scepter-shaped, grains that range in size from 0.3 to 0.16 mm, and by microaggregates that are 0.5–1.0 mm in size. In thin section, it is confined to areas composed of feldspar, muscovite and sericite, and is irregularly developed among the feldspar groundmass. Greisenization is developed everywhere in the granite-porphyry of the Nezametnoye stock, and contains muscovite, quartz, pyrite, scheelite, columbite and corundum neocrystallization.

Most of the Nezametnoye granitoid is represented by a normal potassium–sodium and very high-alumina leucogranite. This leucogranite hosts a normal potassium–sodium and very high-alumina granosyenite that contains accessory zircon and corundum (scepter-shaped crystals of up to 0.4 mm in largest dimension). The presence of high-alumina differentiates, accessory corundum, and associated metasomatite in the Nezametnoye stock granitoid would seem to suggest that such rocks are the main source of corundum.

Our initial hypothesis was that the corundum originated from alkali basalt, but this undeniably attractive working hypothesis was contradicted by five major geological and petrogenetic facts. These facts are as follows. (1) The placer coincides with areas of granitoid outcrops in the region. (2) The combined concentration of gold and precious stones in the alluvium and the absence of corundum in gold-free placers of the district. (3) The lack of olivine, pyroxene and other minerals that are typical of basalts among the corundum's mineral inclusions. However, the corundum does contain syngenetic mineral inclusions of rutile, zircon, albite, zinc-containing hercynite, columbite, monazite and fluorite, which are minerals that are accessory to metasomatite and granitoid greisen. This is significant support for a model in which the minerals are the result of processes that predate basalt flow. (4) The discovery of corundum in thin sections and in shattered pieces of high-alumina greisenized granite-porphyry and granosyenite. (5) The results of the analysis of primary melt inclusions in the corundum testify to its crystallization from a granosyenite melt that was enriched with volatile components.

We have, in short, obtained reliable evidence that alkali basalt, long considered the source of the Nezametnoye corundum, has no genetic relationship with the mineralization. This is a very important discovery, not only because it will further exploration for other such corundum-bearing bodies, but because it forces re-evaluation of the terms of solving problems concerned with corundum genesis and its place in the paragenetic sequence in ore deposits.

It is likely that corundum crystallization occurred under conditions similar to those established for natural crystals as shown by the corundum growth experiments according to the CTR (chemical-transport reactions) method (Rodionov et al., 1988).

Recent debate (Visotsky et al., 2002; Khanchuk et al., 2003; Odarichenko et al., 2004) on the origin of the Nezametnoye corundum are linked to the established opinion of the "basaltic" theory followers; that is, that quartz and corundum cannot occur together in nature. This theory is contradicted by the demonstrated presence in thin sections of associated corundum and quartz in the corundum-bearing rocks of Kalak-tasa, by the corundum quartzite phase and paragenesis (quartz+corundum+rutile+hematite or pyrite) discovered by Nakovnik (1968) and by Zharikov et al. (1998). Followers of the "basaltic" theory also fail to take note of the demonstrated conclusions of Guo et al. (1996); they studied more than 80 mineral inclusions from Australia, China, Kenya and USA from both alluvium and 'basaltic matrices,' and found that at least two of their sources were linked to the formation of corundum crystals – extremely differentiated granitoid and carbonaceous melts. There are no plausible geological conditions under which simple fractionation of a basaltic melt could account for the occurrence of accessories such as corundum and zircon among discrete nodules; nor could such a phenomenon account for the presence of minerals such as rutile, zircon, albite, zinc-containing hercynite, columbite, monazite, and fluorite among corundum inclusions.

These facts led Guo et al. (1996) and others to suggest that the alkali basalts acted as a 'conveyor' that delivered corundum and some other megacrystals to the Earth's surface from deep levels of the Earth's crust. Modern petrological and thermobarogeochemical methods, however, seem to suggest that, in fact, granosyenite melts enriched in volatile components were responsible.

6. Conclusion

During the past decade, progress in the investigation of the physical–chemical conditions of corundum formation and syenite magma petrogenesis has necessitated revision of the genetic model for Thai and Australian sapphire deposits that have traditionally been attributed to alkali basalt formation (Amour and Linnen, 1999); the same is now true of the Nezametnoye corundum deposit in Russia.

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