Sapphire of the Naryn-Gol Creek Placer Deposit (Buryatia, Russia)

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Abstract. A new occurrence of gem corundum was discovered in the vicinity of Naryn-Gol Creek, on the Dzhida volcanic field, Russia. Sapphires were found in both alluvial deposits of the Naryn-Gol Creek and pyroclastic rocks of the nearby Cenozoic alkali basalt volcano Barun-Hobol Pravyi. These rocks contain, in addition to sapphire, large crystals of garnet, spinel, augite, olivine, enstatite, ilmenite, and feldspar. Chemical composition of the sapphires overall is typical for corundum from basalt: rich in Fe, low in Ti and Cr. The oxygen isotopic compositions of corundum and associated minerals show δ18O values ranging between 4.6‰ and 6.8‰ that is attributed to magmatic rocks. Study of impurities reveals the great role of volatiles, CO2, in particular, during the formation process.

1. Introduction

Sapphires, jewellery varieties of corundum, as well as garnet, zircon, spinel, sanidine and augite sometimes occur as megacrysts (up to 5-7 cm or more) in alkali basalts. Their size, beautiful colouring and transparency make it possible to use them in the jewellery industry. Such sapphires are found and mined in placers related to intraplate alkaline basalts in Australia, Southeast Asia, Mongolia, Russia and other provinces of the world [1, 2, 3, 4]. The genesis of such deposits has been debatable, as basalts are not corundum-normative rocks [4, 5, 6, 7]. Furthermore, the impossibility of crystallising corundum directly from a basaltic melt has been proven experimentally [8].

However, in-situ, finds of sapphires, as well as other minerals of megacryst assemblage, there have been made in lava and pyroclastics of Cenozoic alkaline basalts [9, 10]. It is this unique manifestation that was discovered in the vicinity of Naryn-Gol Creek, in the Dzhida volcanic field, Russia. To be more precise, it has been rediscovered. In fact, the first discovery of bright blue transparent corundum here took place in 1988. Geologists had just begun to study this placer, but due to the collapse of the USSR, research data were archived and forgotten until 2016.

Megacrysts of sapphires, garnets, spinel, augite and other minerals were found in the Naryn-Gol Creek placer and nearby Paleovolcano Barun-Hobol Right, providing an opportunity to shed some light on the problem of this disequilibrium assemblage forming. This work aimed at the studying of mineralogy, geochemistry and isotopic composition of sapphires from this unique deposit as well as inclusions in sapphire.
2. Geological setting
The explored area is located on the southern edge of the Dzhida flood basalts belonging to the Baikal rift zone. Volcanogenic formations are represented by remnants of the Neogene-Quaternary alkali basalt stratovolcano (Barun Hobol Pravyi), small lava-slag cones, residual lava flows, and basaltic and pyroclastic strata (Figure 1). Some of these rocks contain megacrysts and ultramafic xenoliths. The Upper Ordovician Dzhida Formation, which is composed of metamorphosed sandstones, siltstones, limestones, and dolomites interbedded with breccia, conglomerate and shale, is intruded and covered by volcanic rocks. These, in turn, are overlain by Quaternary alluvial river and lake deposits in which most of the sapphires were found.

The territory under consideration, despite the monotony of its composition, has an extraordinarily complex history. It is located in the cup-shaped swampy valley of the Naryn-Gol Creek. At the time the volcanic activity began, the river network had already formed, so erupting basalts covered the ancient river terraces first. Each subsequent eruption added lava layers and the valleys became nested in one another.

To identify the structural features of the sapphire-bearing placer, three trenches and several test pits were excavated in different locations revealing a considerable variety in the placer structure. Enrichment with sapphire and garnet was observed at the junction of Naryn-Gol Creek and the Darhintuy River and further upstream in Naryn-Gol Creek, in layers predominantly composed of basalts, irrespective of the size and distribution of the material in the placer. Alluvial-diluvial deposits at the foot of the Barun-Hobol Pravyi volcano are characterised by the permafrost in the subsoil layer and a thick heavy residual layer composed mainly of spinel, ilmenite, garnet, and iron oxides/hydroxides. Corundum here is rare, but a few crystals were found in situ in weathered basalt (Figure 1) and weathered pyroclastic sediments. In addition, multiple finds of sapphires in massive grey basalts have been reported by local people.

![Figure 1. “In situ” sapphire in weathered basalt from Root Trench.](image1)

![Figure 2. The 22-stone collection of Naryn-Gol placer sapphires.](image2)

3. Mineralogy
Alluvial placers associated with weathered alkali basalts are the most commercially important types of sapphire-bearing deposits. Such deposits are widely exploited throughout the eastern margin of the Pacific Ocean, from Australia to Russia [1, 11]. The sapphires of these placers are identified as
belonging to the Blue-Green-Yellow (BGY)-type [12, 13] involving predominantly blue, green, and yellow gems which are characterised by spotty colouration, zoning, and abundance of inclusions. Not long ago, a BGY-type deposit (placer of the Kedrovka River) and several other BGY occurrences (Podgelbanochnyi, Levyi Zolotoi, Kitscha) were discovered in the Far East of Russia [2, 10, 14]. We consider that the studied Naryn-Gol Creek occurrence also belongs to this type.

The Naryn-Gol corundum is light blue, blue, green, yellow, grey, brown, and even dirty pink, though rare. The range of colour, clarity and transparency were previously studied based on a collection of 22 stones (Figure 2). The stones are mostly blue and light blue, often with zonal and spotty coloration, and transparent to translucent in diaphaneity. The size of the sapphires is generally in the range of 3-7 mm, sometimes reaching 15 mm or more. Barrel-shaped crystals and their fragments are most common, while bipyramids are rare. Corundum does not have crystal cleavage but separates along parting planes into hexagonal.

3.1. Chemical and trace element composition

The corundum of the Naryn-Gol occurrence contains only one major impurity - iron. Its concentrations vary from 0.5 to 2 wt. % (Table 1) which is typical for “magmatic” BGY-sapphires. Concentrations of Ti, Cr, V, Ni, Mg, Mn, and Ga were determined, as it was revealed they are also characteristic for BGY-sapphires. The trace-element distribution (Table 1) is typical for “magmatic” sapphires [4, 16, 17].

Table 1. Chemical, trace element compositions and isotopy of the Naryn-Gol Creek corundum.

| Method | Isotopy, ‰ | Microprobe, wt. % | Ion probe, ppm |
|--------|-----------|-------------------|---------------|
| N      | δ¹⁸O SMOW | Al2O3             | FeO           | Mg  | Mn  | Cr  | Fe  | Ti  | V   | Ni  | Ga  |
| J8     | 6.2       | 98.35             | 1.23          | 27.4| 5.34| 0.07| 6538| 56  | 7.87| 5.57| 210 |
| J1     | 4.6       | 96.76             | 0.61          | 19.7| 3.51| 5.37| 2499| 92  | 12.78| 9.60| 267 |
| J3     | 6.4       | 98.12             | 1.93          | 16.4| 3.11| 0.25| 3701| 121 | 8.67| 14.36| 197 |

Isotopy. MAT-252 dual inlet mass spectrometer. Oxygen was extracted while heating the sample by an infrared laser (10.6 μm) in the steam of BrF5 (~ 210 Torr). The method has been tested on international (NBS - 28) and internal standards. The measurement accuracy for δ18O = ± 0.2 ‰.

Microprobe. JXA – 8100 microanalyser (JEOL, Japan) with three wave spectrometers equipped with INCAx-sight energy dispersive spectrometer (Oxford Instruments, UK). FEGI FEB RAS.

Ion probe. Cameca IMS – 4F ion microprobe. IPPE, RAS, Yaroslavl.

3.2. Inclusions in sapphires

The clarity of the sapphire samples from the Naryn-Gol Creek occurrence varies from VS (very slightly included) to I3 (heavily included). In some samples, inclusions are visible to the naked eye (Figure 3). Most examined samples contain inclusions, monophase (Figure 3 A1) and multiphase (Figure 3 A1). Among these inclusions, both mineral, fluid and melt were found.

3.2.1. Mineral inclusions. According to preliminary estimates, mineral inclusions in the corundum study are mainly fluorapatite (Figure 3 A1, B1), sometimes zircon (Figure 3 B4), less frequently feldspar (sanidine) and Fe-spinel (pleonaste).

3.2.2. Melt inclusions. Primary melt inclusions are rare in the Naryn-Gol sapphires, while the secondary ones, in contrast, are abundant and consist mainly of iron oxides and hydroxides (Figure 3 B2,3).
3.2.3. Fluid inclusions. Fluid inclusions are represented by both individual vacuoles and plumes of inclusions. Liquid or gaseous carbon dioxide usually prevails in their composition. Quite common are fingerprint fluid inclusions (Figure 3 A3), caused by the healing of cracks.

3.2.4. Multiphase inclusions.

Sometimes inclusions are present together in the same areas, consisting of several phases with varying volume ratios. For example, Figure 3 A2 shows such an inclusion where one side of apatite crystal has a fluid inclusion with a gas cavity inside (CO₂).

![Figure 3. Mineral, fluid and melt inclusions in the Naryn-Gol Creek sapphires.](image)

3.3. Isotopic characteristics

The genetic identity of corundum can be determined by its oxygen isotopes [6, 16]. These δ¹⁸O isotopes fractionate differently according to conditions of mineral growth. Thus, δ¹⁸O values for metamorphic minerals are depleted relative to V-SMOW, while the δ¹⁸O values for corundum of magmatic origin are enriched, varying from +4 to +8.

The isotopic values for the Naryn-Gol Creek corundum are presented in Table 1 and lie within a narrow range of 4.5 - 6.5‰, placing them within the field of magmatic rocks.

3.4. Mineral assemblage

In both placers and pyroclastic rocks, corundum co-exists with beautiful large crystals of garnet, feldspar, augite, enstatite, olivine, and other minerals (Figure 4).

Garnet is represented by pyrope–almandine Prp 0.545, Alm 0.312, Grs 0.118 (Figure 4A); feldspar by sanidine (Figure 4B); olivine by forsterite with Mg # 90.27 (Figure 4C); spinel by pleonaste with low chromium (0.57 wt.%) and titanium (0.81 wt.%) (Figure 4D); orthopyroxene by enstatite (Figure 4E); and clinopyroxene by Ti-augite (Figure 4F). Large silver-black ilmenite resembles spinel overall but is distinguished by a flinty fracture (Figure 4G). In addition, ferric oxide/hydroxide pseudomorphs after pyrite (‘devil’s dice’) were found in large numbers (Figure 4H).

Since the surfaces of the megacryst assemblage minerals bear traces of melting and dissolution, they are in disequilibrium with their host basalts. However, oxygen isotopic compositions of the megacrysts demonstrate δ¹⁸OSMOW values ranging between 4.8‰ to 5.7‰ that is characteristic of magmatic rocks. One unusual aspect of the mineral gem suite should also be emphasised: it is the
apparent lack of zircon megacrysts that typically accompany such magmatic sapphire suites [17], which probably may indicate a rarer combination of pressure, temperature and volatile component in the crystallisation conditions.

4. Discussion

Study of the corundum and megacryst association minerals of the Naryn-Gol vicinity reviled that, first of all, corundum from the placer is identical to the corundum from the Paleovolcano Barun-Hobol Right, which is the source for the placer. Secondly, the corundum belongs to an assemblage of alkali basalts megacrysts (large crystal size, identical features of the crystal growth, and the same $\delta^{18}O$ values); garnet, augite, spinel, and olivine are also part of this association. Minerals of the megacryst assemblage, including corundum, have similar $\delta^{18}O$ values and are undoubtedly related to basalts. Nevertheless, corundum megacrysts are in disequilibrium with host basalts (quenching rims, corrosion, and xenomorphic habitus of crystals); in other words, they are non-cogenetic. Next, the abundance of the fluid inclusions and high content of the volatile components in some mineral phases reflect the significant role of volatiles and, in particular, CO$_2$ during the process of the corundum formation. Thus, the relationship between alkali basalts and corundum megacrysts is evident but, at the same time, it indicates disequilibrium of the corundum and the hosting basalt.

5. Conclusions

The following conclusions can, therefore, be drawn. Sapphires found in the alluvial deposit Naryn-Gol Creek are identical to gems from the pyroclastic rocks erupted from the nearby Cenozoic Barun Hobol Pravyi alkali basalt volcano. Sapphires of both occurrences belong to the BGY-type. In both cases, the sapphires associate with other megacryst minerals (garnet, spinel, augite, olivine, enstatite, ilmenite, magnetite, and feldspar). The chemical, trace-element and oxygen isotopic composition of the corundum, olivine, garnet and spinel megacrysts indicate their magmatic origin; yet, at the same time, the etched and corroded surfaces of the sapphire and other megacrysts indicate disequilibrium with their host alkali basalts. Study of impurities reflects the significant role of volatiles, CO$_2$, in particular, during the formation process.

6. References

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