

Micro-Magma Chambers in Natural Rubies and Sapphires: The Behavior of Some Mineral Inclusions in Corundum At High Temperatures

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The behavior of certain fluid inclusions in natural corundum during high-temperature heat treatment processes has been examined before and is relatively well known (Koivula, 1986). From such studies and observations, the condition of fluid inclusions has become an extremely useful means of determining whether or not a particular ruby or sapphire was heat-treated to alter its color and/or clarity.

But when it comes to the behavior of *solid* mineral inclusions during the heat treatment of corundum, much less is actually understood. This leads to speculation and “best guessing” in the diagnosis of heat treatment in instances where solid inclusions are the determinant characteristics.

Many gemologists see glassy-looking melt-formed or melt-altered inclusions in heat-treated corundum and assume some form of flux healing has been done to the stone, with the fluxing agent forced into preexisting surface-reaching cracks, surface pits, and internal voids by some externally applied treatment technique. This has been widely written about and become generally accepted.

While this may be true in some instances, perhaps even many instances, it does not address the effect that high-temperature heat treatment actually has on some preexisting protogenetic and syngenetic solid mineral inclusions. To better understand other possibilities, gemologists must closely examine heat-treated rubies and sapphires for evidence that does not fit the commonly accepted “flux healing” model.

Following is an illustrated description of another possible cause for some of the damage we see in high-temperature heat-treated rubies and sapphires. This mechanism has been overlooked in the gemological literature.

To start with, we can examine large megascopic geological features seen on the earth’s surface and within the earth’s crust that are surprisingly similar to certain microscopic features observed in heated corundum. While many gemologists may not be familiar with the following terms (as defined in Jackson, 1997), those who have geological backgrounds will immediately recognize these terms and

understand their appropriate comparison to the microworld of heat-treated rubies and sapphires:

Magma Blister: A pocket of magma whose formation has raised the overlying land surface.

Magma Chamber: A reservoir of magma in the shallow part of the lithosphere (from a few kilometers to tens of kilometers), from which volcanic materials are derived.

Magma: Naturally occurring molten or partially molten rock material, generated within the earth and capable of intrusion and extrusion, from which igneous rocks are derived through solidification and related processes.

In this scenario, with regard to the above definitions, gem-quality corundum is the earth's crust. Magma is any solid inclusion that melts during a heat treatment process creating a hot pocket of expansive and explosive molten material in the gem being heated. What we are dealing with is the creation, expansion, and explosion of micro-magma chambers resulting from the virtual annihilation of solid mineral inclusions during high-temperature heat treatment.

Figure 1 shows a transparent brown, well-formed tourmaline crystal, approximately 0.27 mm long, in a Kashmir sapphire host. The overall condition of this mineral inclusion reveals no evidence that it has suffered any damage due to heat treatment, allowing us to conclude that the host sapphire was not heat-treated.

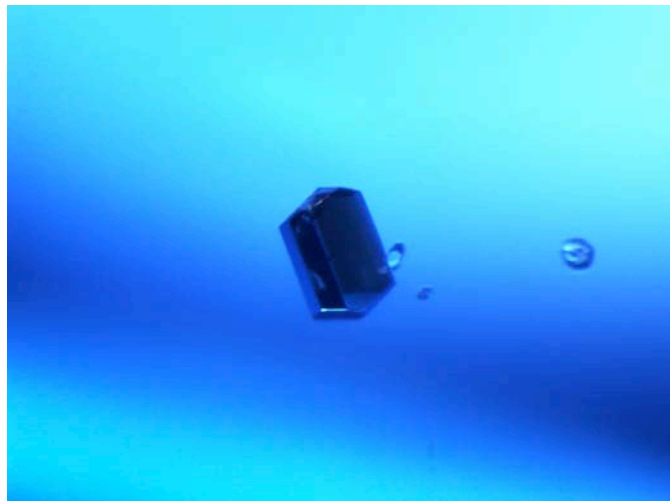


Figure 1

Moving up the treatment scale from no heat, figure 2 shows an apatite inclusion, in a blue sapphire host, that has minor cracking due to thermal expansion. This expansion either resulted from or was followed by partial melting of the apatite and leakage of that melt into the surrounding cracks. This in turn caused the formation of a few small bubbles in the melt due to loss of volume as the melt

leaked from the main inclusion mass into the surrounding cracks. The resulting bubbles were then trapped in fixed positions when the apatite melt resolidified. While this apatite inclusion is still generally recognizable in shape, it is logical to conclude that if the heat applied had been significantly higher, or of longer duration, then considerably more damage would have been done to the inclusion and the surrounding host. The field of view for this image is approximately 2.2 mm.



Figure 2

Figure 3 shows a dark inclusion situated just below the faceted pavilion surface in a heat-treated natural ruby. Cracks extending away from its center are caused by the expansion of the inclusion during the heat treatment process. If this inclusion were deeper within its host, with more corundum surrounding it on all sides, then its expansion would be more or less uniform in all directions. But since it is near the pavilion surface, there is much less corundum in that direction to confine the pressure generated during heat treatment. This is similar to the behavior of a magma chamber in the earth's crust. If it is near the surface, it will expand essentially upward toward the surface and relieve the built-up pressure in that direction. The field of view for this image is approximately 2.5 mm.



Figure 3

Comparing figure 3 to figure 4, we note that in surface-reflected light the dark-colored inclusion in figure 3 has caused the surface to swell, creating a raised blister on the otherwise flat facet. This is the micro-equivalent of a magma blister or dome on the surface of the earth's crust. Since the ruby host has only expanded, and not actually fractured or ruptured, this blister also shows that corundum heated to near its melting point becomes plastic before actually melting. If this inclusion had been polished flat again after heat treating, it would have been easily mistaken for an intentionally filled cavity. It would be surprising if this form of misinterpretation has not happened on more than one occasion.



Figure 4

Now, in figures 5 and 6 (field of view approximately 3.5 mm), we see the ultimate expression of micro-volcanism: an actual explosion or eruption of a micro-magma chamber onto the table surface of a heat-treated sapphire. In figure 5, taken in darkfield and fiber-optic illumination, the obviously melted inclusion is seen as a translucent to opaque white mass just beneath the table facet. A few smaller melt-formed features are also present.

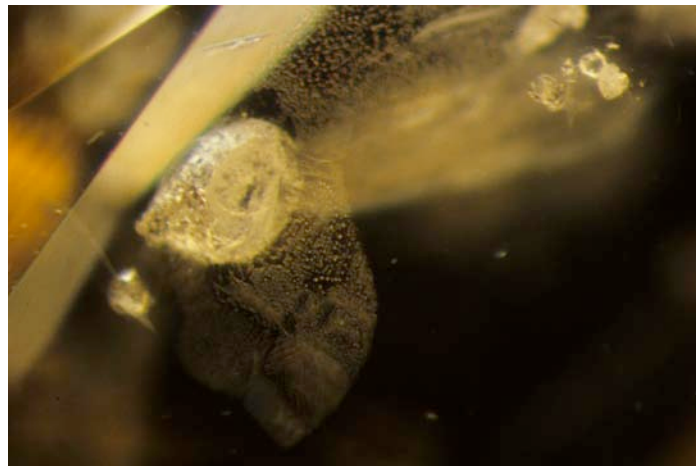


Figure 5

In figure 6, surface-reflected fiber-optic light shows that the heat-damaged inclusion has caused a raised blister to form near the edge of the sapphire's table facet. But unlike the micro-magma blister in figure 4, this raised dome has actually ruptured in the center, giving it the appearance of a micro volcano with a semicircular outline around its base and a low-profile conical shape and more or less centrally located crater.

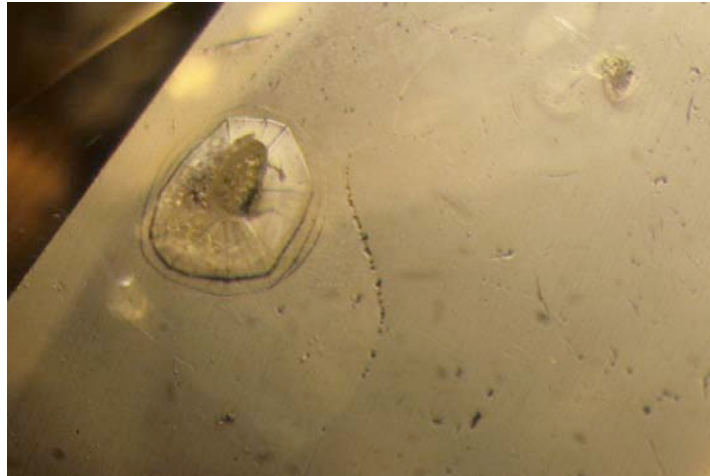


Figure 6

Interesting features revealed by Nomarski differential interference microscopy in figure 7 are the somewhat circular cracks in the table facet at the outer edge of the dome, surrounding and defining the uplifted blister, and the individual plates of sapphire with cracks separating them and extending from the base of the dome to the very edge of the crater. If the melt below had been of very low viscosity—for example, a liquid inclusion at room temperature such as water or carbon dioxide—the plates creating the dome of this micro-volcano would have been blown away, leaving only a hole in the table. But since the melted inclusion obviously had a high viscosity, it acted as a glue or adhesive, holding the major portion of the uplifted surface in place while the pressure vented through the central crater.

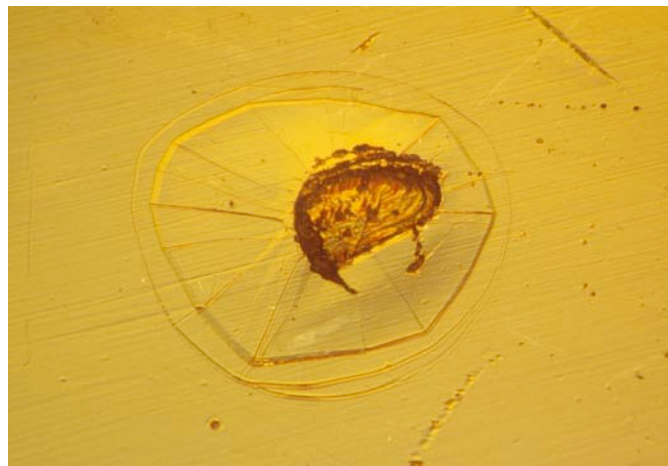


Figure 7

Just like the micro-magma blister in figure 4, if this table facet had been repolished after the sapphire was heat treated, then all of this telling information would have been permanently lost. If repolishing had occurred, it would also be easy to mistake this feature for an intentional filling.

In view of the existence of such features, any determination of flux healing or another form of artificial infilling must account for the possibility of a melted, expanded, and exploded mineral.

This can easily happen since the subsequent surrounding damage to a ruby or sapphire, caused by a molten mineral inclusion leaking into the very cracks it creates, while expanding explosively, can look very similar to the results of a flux agent or glass externally applied to preexisting surface-reaching cracks and pits.

Inclusions formed and captured at depth retain at least some of the original pressure signature under which they were sealed in their hosts. At great depths in the earth, in their original formational environment, gem minerals and their inclusions have a significant confining pressure surrounding them that compensates for their own internal pressure. At the earth's surface, however, under atmospheric pressure, the original confining pressure or compensating pressure is essentially negated, and the inclusions are now under significant positive outward pressure. This becomes an explosive environment when heat is applied during heat treatment. Such a scenario must be taken into account when we judge whether or not an intentional filling has been applied.

If melted-looking internal features do not reach the surface to some significant degree, or if they show evidence of outflow onto the host corundum's surface, as in figure 8, then they are probably the result of mineral inclusion melting and outward expansion, not the result of an externally applied filler. Both scenarios are possible. Care must be taken not to confuse the two when identifying rubies and sapphires.



Figure 8

References

- Jackson J.A., Ed. (1997) *Glossary of Geology*, 4th Ed. American Geological Institute, Alexandria, Virginia.
- Koivula J.I. (1986) Carbon dioxide fluid inclusions as proof of natural-colored corundum. *Gems & Gemology*, Vol. 22, No. 3, pp. 152–155.