A new suite of inclusions in spinel from Mogok (Myanmar) - a study using Raman microspectroscopy and scanning electron microscopy

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This is the first detailed study of spinel inclusions from different marble-type gem localities within the Mogok area, Myanmar, using optical microscopy, Raman microspectroscopy and scanning electron microscopy (SEM) equipped with an energy dispersive spectroscopy EDS. For this study we analysed 100 gem-quality spinels of pink to red, orangey, and purplish grey colour, which were collected from six different localities of the Mogok area. 87 alluvial samples were collected by the first author directly from mining sites (Yadanar Kadae Kadar, Bawlongyi, Kyauksin, Kyauksaung, Pyaungpyin and Mansin) and 13 samples were collected from local markets.

Initially, the surfaces of all gem-quality spinel crystals were polished to get an overview on their inclusions. Afterwards, all mineral inclusions were investigated with the polarization microscope and with the Raman spectrometer. Problematic and particularly interesting mineral inclusions were brought to sample surfaces by polishing and finally these mineral inclusions were identified with SEM using secondary electron images (SE), back-scattered electron images (BSE) and energy dispersive spectroscopy (EDS).

The following 17 new minerals were identified for the first time as inclusions in spinel from Mogok (in alphabetical order): amphibole (pargasite), anatase, baddeleyite, boehmite, brucite, chlorite, clinohumite, clinopyroxene, diaspore, goethite, geikielite, gypsum, halite, marcasite, molybdenite, periclase and pyrrhotite. Furthermore, we found anhydrite, apatite, carbonate (calcite, dolomite and magnesite), graphite, chondrodite, phlogopite and zircon, which were already known as mineral inclusions in spinel from Mogok. Particularly interesting is the first discovery of geikielite (MgTiO$_3$) in spinel from the Mogok area. It forms tiny, colourless flakes of maximum 20 µm diameter oriented along the (111) crystallographic direction of spinel. Their regular orientation – presumably as epigenetic precipitates – is related to the spinel structure. This inclusion is similar to geikielite-rich ilmenite exsolution lamellae described from chromite-chrome spinel from metacarbonates of the Oetztal-Stubai complex in Austria (Mogessie et al. 1988). Furthermore, exsolutions of dolomite in calcite inclusions were identified by SEM- BSE and detected with EDS. Numerous solid inclusions consisted of different mineral phases (e.g. calcite intergrown or aggregated with various primary and secondary mineral phases such as dolomite, apatite, anhydrite, gypsum). These intergrowths, however, were
beyond the resolution of the Raman microspectroscopy and could only be detected by SEM microscopy.

In conclusion, we found that spinels of gem quality from the six sampled localities within the Mogok area have significantly different populations of mineral inclusions, which are shown in Figure 1. The findings of the present study sheds light on the formation of spinel in the Mogok area and possibly will enable gemmologists to better separate Mogok spinels from those originating from other marble-related spinel deposits worldwide.

![Figure 1. The population of inclusions found in spinel in different localities of spinel mines and the gem market in Mogok, Myanmar.](image)

REFERENCES