From classic inclusions to neutrons:
A 'fresh' look at modern gemmology

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The 'Ratnaraj' Ruby, 10.05 ct, sold at Christie's HK December 2016
From Geology to Gemmology

Mogok Gemstone Tract
Metamorphic rocks (mainly marbles and gneisses) closely in contact with magmatic rocks (mainly granite and syenite).

Inclusion paragenesis

Inclusion suite in ruby from Mogok
Inclusion studies

Inclusion paragenesis

What microscopically looks as one inclusion is quite often a mixture (integrowth) of several mineral phases.

Inclusion studies

Baddeleyite $\text{ZrO}_2$

Tiny baddeleyite ($\text{ZrO}_2$) as accessory inclusions indicate magmatic contribution to gemstone formation in metamorphic marbles.

Raman spectrum of baddeleyite $\text{ZrO}_2$
Inclusion studies

Zircon ZrSiO₄

Zircon inclusions (at the surface) enable us to carry out U-Pb age dating of gemstones, using the GemTOF (LA-ICP-TOF-MS).

Granitoid zircon (zoned)

Figure (modified) from Chew et al. 2017

Zircon at girdle of sapphire

Figure H.A.O. Wang, SSEF 2016

Age dating of zircon inclusions

Zircon at girdle of sapphire

Figure (modified) from Chew et al. 2017

Granitoid zircon (zoned)
A new figure is attached, including two analyses of Zircons on SriLanka and kasmir sapphires.

Wang, Hao; 25.09.2017
**Inclusion studies**

**Zircon ZrSiO₄**

Raman spectra show the effect of heat treatment on the crystallinity of zircon inclusions in pink sapphires (from Ilakaka, Madagascar).

**Inclusion studies**

**Zircon ZrSiO₄**

High-temperature heating results in melting of zircon and precipitation of baddeleyite in silica glass matrix.
**Zircon ZrSiO$_4$**

**Kashmir**

Prismatic zircon inclusions in **Kashmir** sapphires, often slightly corroded.

**Ambatondrazaka, Madagascar**

Tiny prismatic zircon inclusions in sapphires from Bemainty near **Ambatondrazaka (Madagascar)**, visually quite similar to zircons in Kashmir sapphire.
Inclusion studies
Zircon ZrSiO$_4$

Analysis of Raman spectra (position and peak width of $1008$ cm$^{-1}$ peak) of zircon inclusions of corundum (ruby/sapphire) specimens from different origins.

Raman spectra of zircon inclusions

‘Kashmir-like’ sapphires of excellent quality from new deposit at Bemainty near Ambatondrazaka, Madagascar.
**New instrument**

**Time of Flight : GemTOF**

**Basic principle of laser ablation ICP mass spectrometry**

- **Material ablation**: at surface using pulsed laser of high energy
- **Transport of particles**: by carrier gas (e.g. helium)
- **Ionisation of particles**: in inductively coupled argon plasma (ICP)
- **Injection into mass spectrometer**: of singly charged isotopes (and some complexes)
- **Mass separation**: two main principles
- **Isotope/mass detection**: magnetic field e.g. quadrupole, time of flight of isotopes
New instrument

Time of Flight: GemTOF

Through this process, low-MR variations and unique mineral compositions were identified.
Inclusion studies

**Kashmir sapphire**

The Richelieu sapphires, sold at Sotheby’s Geneva for US$ 8.35 mio.

Pargasite (amphibole) in sapphire from Kashmir
Rubies from amphibolite (metamorphic rock) are characterised by a distinct iron concentration, thus contributing to their colour and UV fluorescence reaction.
Inclusion studies

**Amphibole in ruby**

- Montepuez, Mozambique
- Didy, Madagascar
- Montepuez, Mozambique
- Andilamena, Madagascar

Ruby, fancy sapphires (ruby-sapphire mix) and sapphires from Winza, near Dodoma (Tanzania).
Inclusion studies

Amphibole in ruby

Local change of the Ti⁴⁺ - Fe²⁺ intervalence charge transfer (IVCT) presumably caused by a reaction with the amphibole inclusion results in spesial color „hole” around these amphiboles.

Amphibole in emerald

Emerald sample – LABc_1144
Sandawana (Zimbabwe)

X-ray μ-tomography section
Inclusion studies

Using Neutrons and X-rays (PSI)

3D visualisation of inclusions and organic fillers in emeralds
Project in collaboration with the Laboratory for Neutron Scattering and Imaging at PSI

Inclusion studies

Using neutrons and X-rays (PSI)

Neutron μ-tomography  X-ray μ-tomography

Emerald sample – LABc_1209 Colombia

<table>
<thead>
<tr>
<th>Neutron μ-tomography section</th>
<th>X-ray μ-tomography section</th>
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</thead>
<tbody>
<tr>
<td>White</td>
<td>a not seen</td>
</tr>
<tr>
<td>Grey</td>
<td>white</td>
</tr>
<tr>
<td>Black</td>
<td>black</td>
</tr>
<tr>
<td>Weak greyish lines</td>
<td>not seen</td>
</tr>
</tbody>
</table>

3D visualisation of inclusions and organic fillers in emeralds
artificial resin
X-ray CT
Conclusions

Inclusions in gemstones are highly important clues for a better understanding of (coloured) gemstones.

They reveal important information about formation processes, geological setting, and treatments.

The analysis of gemstones and their inclusions is based on a large range of methods from basic microscopy to advanced methods using laser light, X-rays, electrons and neutrons.

The aim is to characterize their chemical, isotopic, and structural state as far as possible.

Until today, meticulous microscopic examination of gemstones and their inclusions remains crucial, as it not only unveils their beauty, but also provides a wealth of information to gemmologists.

Thank you for your attention