In late 2016, a new sapphire-producing mine was discovered at Bemainty, near Ambatondrazaka and Didy in Madagascar (Figure 5). The mine produced a considerable amount of large sapphires, including Padparadscha and yellow sapphires (Figures 4a, c). The mining area has now been closed. The Bemainty mine lies north of the Didy mine (Figure 5) in a slightly different geological setting within a so-called Imorona-Htsindro Series.

The formation of sapphire at the Didy mine is believed to be related to Nb-Ta pegmatites that are mapped in the area south of Didy. Niobite inclusions found within sapphires from Didy suggest a connection to these pegmatites (Peretti and Hahn, 2013). The geology of the new Bemainty mine and its surrounding does not indicate such Nb-Ta pegmatites, yet niobite inclusions in one of the samples from the new mine have been found. Currently fieldwork in the area is not being undertaken due to elevated security risks (Figures 1a, b).

Spectacular inclusion features have been found in sapphires from Bemainty and they resemble textbook Kashmir (India) sapphire inclusions (Figures 6 to 11). As a consequence, a certain degree of misinterpretation of these sapphires seems to exist in the market, and a series of stones from Madagascar has possibly been falsely classified as Kashmir sapphires (Krzemnicki 2013). Kashmir sapphires have seen an unprecedented rise in value with prices that can reach well over $100,000 per carat, while their counterparts from Madagascar are ten times less expensive. This offers a great potential for fraud and the correct identification is thus an important part of the challenge of internationally recognized gem-testing laboratories.

In order to distinguish the sapphires from the new mine in Madagascar from those from Kashmir, we have prepared a Master Set of more than 50 reference samples from both mines, carefully selected to cover the entire range of inclusion features (Figures 4a, b, c).

The GRS Kashmir-Ambatondrazaka Master Set

The Kashmir Master Set of was prepared from the GRS reference collection, comprised of hundreds of sapphire reference samples from Kashmir, collected over the last 20 years. Many of those samples have been cut in our own facility and then categorized according to different inclusion features, covering all the literature-published features of Kashmir sapphires.

The Ambatondrazaka Master Set includes samples that we received from two commissioned independent agents that we have sent to the new mines, as well as cut and polished stones from more than five different reliable sources Figure 2. Countries with sapphire deposits of commercial importance. The Kashmir sapphire mine in northern India has been exhausted for decades and does not produce significant amounts of sapphire besides isolated single findings. Madagascar is the major sapphire producer dominating the world market supply. Madagascan sapphires are occasionally misrepresented as originating from Myanmar, Sri Lanka or Kashmir. InColor/ICA Figure 1a Figure 1b in the Bangkok market, all reported of being from the new deposit. Among the samples are more than two dozen sapphires that contain typical Kashmir inclusions (e.g. Figure 6). These types of inclusions were found in rough samples that we obtained directly from the mine and kept as rough. Sizes range from 2 to 10 carats. Approximately 20% of our a very particular and unique way (Peretti et al, 1990). In the high Himalayas, pegmatites intruded into a series of amphibolite and ultramatic rocks (Figure 3b). During that process, the pegmatite was depleted of silica and a reaction rim of tourmaline was formed around the pegmatites (Peretti et al, 1990).

This process has become known as de-silification and it ultimately leads to the formation of sapphires within the pegmatites. The sapphires either formed within the pegmatite or in the reaction zone. There are different types of sapphires with varying inclusions such as tourmaline, plagioclase and amphibole, depending on the spot where the sapphire was formed.
Figure 2. Countries with sapphire deposits of commercial importance. The Kashmir sapphire mine in northern India has been exhausted for decades and does not produce significant amounts of sapphire besides isolated single findings. Madagascar is the major sapphire producer dominating the world market supply. Madagascan sapphires are occasionally misrepresented as originating from Myanmar, Sri Lanka or Kashmir.

Below: Figure 3a. The Kashmir sapphire deposit is an isolated spot at an elevation of 4600 meters within the Himalayan mountain range. One of the authors (Adolf Peretti) studies the primary deposit at the site in the early 1990s. Only a few gemologists in the world made it to the Kashmir sapphire mine. (Photo: Rainer Kündig).

Figure 3b. The geology of the formation of Kashmir sapphires at this primary deposit. A pegmatite intrudes rocks of peridotite and amphibolite and produces a tourmaline reaction zone (Peretti et al, 1990).
### Sedimentary and Volcanic Rocks (and metamorphic equivalents)

<table>
<thead>
<tr>
<th>Legend</th>
<th>Description</th>
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<tr>
<td>Qa</td>
<td>Non-specified alluvial rocks</td>
</tr>
</tbody>
</table>

#### Betsimisaraka Zone

- **Rocks**: Sedimentary, Volcanic, and Metamorphic Rocks
- **Formation**: Sakaraha

#### Mananpotsy Complex

- **Rocks**: Migmatic hornblende + biotite + garnet-orthoamphibolite

#### Antananarivo Zone

- **Rocks**: Structural features

### Plutonic rocks (and metamorphic equivalents)

<table>
<thead>
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<th>Description</th>
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<tbody>
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<td>Anatectic granite, idiomorphic K-felspar Facies</td>
</tr>
<tr>
<td>ЄAgr</td>
<td>Anatectic granite/migmatized, not differentiated</td>
</tr>
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</table>

#### Tsaratanana Complex

- **Rocks**: Migmatic plagioclase gneiss with biotite + hornblende and garnet-gneiss with amphibolite lenses and porphyroblastic gneisses

#### Antananarivo Zone

- **Rocks**: Mafic biotite gneiss with clinopyroxene and amphibolite boudins; local charnockitisation

#### Mananpotsy Complex

- **Rocks**: Mafic granofels/mafic rocks with gabbro-like composition

#### Betsimisaraka Zone

- **Rocks**: Migmatic hornblende + biotite gabbro-orthoamphibolite

### Antananarivo Zone

- **Rocks**: Migmatic plagioclase gneiss with biotite + hornblende and granitogneiss with amphibolite lenses and porphyroblastic gneisses

### Betsiboka Series

- **Rocks**: Mafic biotite gneiss with clinopyroxene and amphibolite lenses and porphyroblastic gneisses

### Betsimisaraka Zone

- **Rocks**: Mafic granofels/mafic rocks with gabbro-like composition

### Antananarivo Zone

- **Rocks**: Migmatic biotite + hornblende and gneiss with intercalated layers of older gneiss rocks

### Plutonic rocks (and metamorphic equivalents)

<table>
<thead>
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<th>Legend</th>
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</tr>
<tr>
<td>Cu</td>
<td>Nickel-bearing laterite</td>
</tr>
<tr>
<td>Nb-Ta</td>
<td>Wolframite-bearing non-specified pegmatite</td>
</tr>
<tr>
<td>Sn</td>
<td>Nickel-bearing laterite</td>
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<tr>
<td>REE</td>
<td>Rare earth element</td>
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<td>Fe</td>
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<td>Ni</td>
<td>Rare earth element</td>
</tr>
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<td>REE</td>
<td>Rare earth element</td>
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</table>

### Figure 4a

- Parts of the GRS reference collection with sapphires from the new deposit near Bemainty in Madagascar

### Figure 4b

- The GRS Kashmir reference Master Set.

### Figure 4c

- A selection of padparadscha sapphires in a lot from the new mine in Madagascar for the GRS reference collection.

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Below: Legend for Figure 5, opposite page.
Figure 5. Map showing the “Geology” for the Didy (Madagascar) mine. The Didy mine is situated in the metamorphic rock suite of gneiss, amphibolite, quartzite, intercalated sillimanite-gneiss (complex of Mananpotsy), migmatite garnet and biotite-bearing ortho-amphibolite. The Ambalavao rock suite surrounds the Didy mining area and contains quite different rock types including anatetic granites and migmatites. They are partially melted rocks typical for a lower high-metamorphic continental crust. The new mine is located in the kiangara series (in the Legend, nPKLsg, with alcali granites and syenite rocks) bordering the Imorona-Istindro Series (in the Legend, nPIIom, with granites and gneisses).

Figure 6. Inclusion features found in a high-value sapphire over 10 cts, originating from the new Bemainty sapphire mine in Madagascar as seen under 60x magnification and oblique fiber optic illumination. The minuscule details resembling clouds, streamers and striae, possess all the hallmarks of Kashmir sapphires. Only the study of minute details reveals differences (Figure 7). (Photo: Matthias Alessandri)

Figure 7. Sketch of the Madagascar sapphire inclusion details (Figure 6) revealing subtle differences to similar inclusions found in sapphires from Kashmir (Figures 15 and 17), e.g. development of small rutile needles around clouds. This phenomenon is absent in Kashmir sapphires.

Figure 8. Oscillating color zoning in a sapphire from the new mine in Madagascar. Note the occasional appearance of yellow color zoning. Such color zones have not been found in Kashmir sapphires of the GRS Master Set.

Figure 9. Fluid feathers containing yellow infillings. This is due to the late hydrothermal alteration and weathering process found in sapphires from Madagascar. This alteration within fluid inclusion feathers is absent in Kashmir sapphires. (Photo: Willy Bieri)

Figure 10. Clusters of long zircons included in the sapphires from Madagascar. The zircons have extensive tension cracks and are often corroded and milky. They are distinctly different from the zircon inclusions found in Kashmir sapphires (Figure 16).
Figure 11. Oscillating milky and blue zones and streamers perpendicular to the growth zones are found in this gemquality cornflower blue sapphire from the new mine in Madagascar (viewed under fiber optic illumination). At first glance, it resembles the inclusion features of a Kashmir sapphire. Only the study of minor details allows a distinction from features observed as inclusions in Kashmir sapphires.

Figure 12a. Two examples of Kashmir sapphires that are part of the GRS Kashmir reference Master Set. On the left is a crosssection through a 20-ct gem-quality Kashmir sapphire with a polished window. On the right is a 100+ ct Kashmir sapphire carving by Glenn Lehrer, California. The carved Kashmir contains a 5-mm dravite tourmaline overgrowth, proving its Kashmiri origin. All the samples were obtained before the opening of the new deposit in Madagascar.

Figure 12b. The same two Kashmir sapphires as in Figure 12a are exposed to long-wave ultraviolet light and exhibit distinctive fluorescence. Left: Core of a Kashmir sapphire shows yellow-orange fluorescence, followed by a zone of inert reaction to UV-light and an outer rim of red fluorescence. Right: The Kashmir sapphire shows red fluorescence throughout its body and possesses a distinctive zone of intense red fluorescence, restricted to a growth zone within the crystal. Yellow fluorescence was exclusively found in Kashmir sapphires, while red fluorescence can also be observed in sapphires from the new deposit in Madagascar.
Preliminary Comparison Study

We have compared the following properties of the samples for this preliminary report:

A) Solid inclusions  
B) Fluid inclusions  
C) Age of zircon inclusions  
D) Color zoning  
E) Inclusion features indicative of Kashmir sapphires  
F) UV-fluorescence analysis

Further analysis is currently focused on oxygen isotopes, zircon ages, LA-ICP-MS analysis and SEM-EDS. We will report further on our findings in the near future. For the first report, we focused on sapphires that are potentially at risk for being mixed up with Kashmir sapphires. We have found the following results.

A) Zircon habit: both origins may contain long zircon crystals (Figures 10, 16). They can, however, be easily distinguished from each other. Uraninite crystals are only present in Kashmir sapphires. Tourmaline inclusions of dravite compositions are exclusive to Kashmir sapphires as of now (Figure 14).

B) Kashmir sapphires contain a special type of pseudo secondary fluid inclusion features. These types of inclusions are largely absent in our master stones from the new deposit in Madagascar (Figure 15).

C) Isolated yellow color zones were found in samples from the new mine in Madagascar (Figure 8). These yellow color zones are not present in Kashmir sapphires.

D) The age of Kashmir sapphire zircons was found to be 23 million years old. The sapphires from the new deposit in Madagascar are older than 200 million years as can be concluded from the geological set-up of the rock formations. This can be established using LA-ICP-MS analysis.

E) Al-hydroxide inclusion features, often referred to as Kashmir-type inclusions, show small differences. These differences can be seen, if the inclusion features are sketched and analyzed in detail (example Figure 7).

F) Fluorescence analysis has shown that UV-fluorescence criteria reported earlier (Krzemnicki 2013) cannot be applied (Figures 12a, b).

Implications for the Market

The surfacing of new gemstone deposits is proving to be a serious challenge for gemological laboratories. A solution to this problem is to have a reference collection that has been established over a period of more than 20 years. It took us some time to collect the different types of Kashmir sapphires with different inclusion properties. Only two to three Kashmir sapphire samples per year could be purchased from reliable sources between 1994 and 2015.

Finding reference samples of the new mine from Madagascar was especially difficult, since traders did not cooperate in selling samples to the laboratory, particularly those with Kashmir-like inclusion features. It was necessary for us to get the samples in 2016 anonymously, pretending to be serious buyers through agents and paying high market prices.

Based on our Master Sets, we can confirm that comparing the minute details of the sapphires makes it possible to distinguish the two different origins. Re-checking is recommended for sapphires in the market between 2016 and 2017, which are claimed to be from Kashmir.

Warning About Potential Origin-Misinterpretation of Padparadscha Sapphires from the Bemainty Deposit

Remarkably large and beautiful padparadscha sapphires have been found in this new deposit with sizes that can exceed 20 carats. We came across cases where they have been misinterpreted in the trade as originating from Sri Lanka.

The padparadscha from Bemainty can be identified based on their characteristic color zoning (Figure 19) in combination with their distinctive FTIR spectrum (Figure 20). The FTIR spectrum though is not exclusive to this origin.

We have encountered situations where clients confirmed a padparadscha’s origin as from this new deposit in Madagascar, but declined to accept our gemstone report since the stone came with other gemstone reports stating a Sri Lankan origin as the most probable provenance. This requires a “Trade Alert” to the public in addition to the that previously published about the new Kashmir-like sapphires from Madagascar.

Figure 13. An amphibole inclusion in a Kashmir sapphire is accompanied by a fluid inclusion feather. The singly isolated fluid inclusion voids are arranged in a distinct flat area. When illuminated with an oblique fiber optic light, the fluid inclusion tubes reflect simultaneously. This type of fluid incisions is typically found in Kashmir sapphires.

Figure 14. Opaque cubic inclusions found in Kashmir sapphires, identified as uraninite. They are generally absent in sapphires from the new deposit in Madagascar, but can be found in sapphires from Adranondambo in southern Madagascar (Gübelin and Peretti, 1997, 1998). For the purpose of distinguishing sapphires from Kashmir from sapphires from the new deposit in Madagascar, these crystals are helpful, although not always present, but serve as an important distinction criteria.

Figures 15 and 17. Clouds of Al-hydroxide are often found in gem-quality Kashmir sapphires. These inclusions were generally believed to be exclusive to Kashmir sapphires until the arrival of sapphires from the new sapphire mines in Madagascar.

Figure 16. A cluster of long needle-shaped zircons without any tension cracks, found in a sapphire from Kashmir. The inventory of zircon habits is relatively complex and includes various types of different zircon inclusions. Comparing zircon habits, corrosion features, growth zoning inside the zircons and geometry of the tension cracks around zircons provides a key feature for distinguishing the Madagascan sapphires from their Kashmir counterparts.

Figure 18. Dravite inclusions in a sapphire from Kashmir are still considered a strong indication for their origin (see their occurrence at the primary deposit, Figure 3b). Further inclusion analysis in sapphire from the new deposit is currently underway to test this argument.
References


8) Peretti, A. et al., 2017. Gems from Mogok (including spinel) and Kashmir and identification against their natural counterparts, textbook with 558 pages, more than 900 figures (release September 2017, Hong Kong Jewellery and Gem Fair, GRS Seminar).


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Figure 19. Microphotograph taken of the interior structure of a padparadscha sapphire (over 20 cts in size) from the new mine in Madagascar. Pink, yellow and orange color zoning is revealed with occasional isolated blue zones that are not shown in this picture (40x microscope magnification using transmitted light). These features, in combination with the infrared spectrum (Figure 20) as well as additional chemical and spectroscopic data, are characteristic of padparadscha sapphires from this new deposit. This allows the determination of the origin of this new type of padparadscha sapphire from the Bemainty deposit near Ambatondrazaka.

Figure 20 FTIR-transmission spectra of an unheated Padparadscha sapphire from the new mine in Madagascar (Bemainty, Ambatondrazaka). Note the prominent line at 3160 cm⁻¹. Similar spectra were described for rubies from Winza, Tanzania (Peretti 2008).