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## Sapphires from the gem rush Bemainty area, Ambatondrazaka (Madagascar)

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*Vincent Pardieu, Wim Vertriest, Vararut Weeramonkhonlert,  
Victoria Raynaud, Ungkhana Atikarnsakul and Rosey Perkins  
GIA Laboratory, Bangkok  
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Figure 1: Sapphire (about 15 carats size) reportedly from the gem rush near Ambatondrazaka seen at KV Gems office in Bangkok in Dec 2016. Stones courtesy KV Gems, Bangkok. Photo: Vincent Pardieu © GIA.

## Abstract:

A sapphire rush escalating to approximately 50,000 unlicensed small scale miners started in October 2016 about 35km East of Ambatondrazaka, Madagascar. It is taking place in the Corridor Ankeniheny-Zahamena (CAZ) which is a new protected area legally designated in 2015 and managed by “Conservation International”, one of the world’s largest conservation groups, on behalf of the Malagasy Government. The discovery of many fine quality sapphires in this area is opening a new chapter in the conflict between conservation and gem mining in northeastern Madagascar. The present report will introduce the new discovery, which was visited by author Rosey Perkins in Oct 2016 and provides a complete gemological description of these sapphires done at the GIA Laboratory based on samples acquired by author Vincent Pardieu. This preliminary study might enable GIA (and other gemological laboratories) to better identify stones produced from this new deposit.



Figure 2: Detail view of a fine, clean, faceted blue sapphire reportedly from the new deposit at Bemainty. The stone weight is about 7 carats. Stone courtesy: KV Gems, Bangkok. Photo: Vincent Pardieu, 2016 © GIA.

## Table of Contents

Abstract: .....	2
Introduction: .....	4
Location and access:.....	5
Brief description of the mines and mining methods:.....	7
Brief description of the stones seen at the mines and in the market: .....	11
About gem mining and conservation east of Ambatondrazaka: .....	14
Ruby and Sapphire mining in northeastern Madagascar: .....	17
Geology of the new sapphire deposit near Bemainty: .....	22
Global context: .....	22
Local context: .....	23
Gemstones in the geological context: .....	24
Part 1: Complete study of a blue sapphire reportedly from Bemainty area near Ambatondrazaka, Madagascar:.....	25
Materials and Methods: .....	25
Samples Selection: .....	25
Sample Fabrication: .....	26
Instrumentation: .....	26
Preliminary study of blue sapphire 100322689865 reportedly from the Bemainty area, Ambatondrazaka, Madagascar:.....	28
Microscopic examination:.....	29
UV-Vis-NIR and FTIR Spectroscopy: .....	29
Chemistry:.....	31
Discussion about the data collected from GIA reference sample 100322689865:.....	32
Part 2: The internal world and trace element chemistry of sapphires from Bemainty area near Ambatondrazaka, Madagascar: .....	33
Summary: .....	42
About the Authors:.....	42
Special Thanks:.....	42
Annex A: GIA Field Gemology cataloguing System.....	43
Bibliography: .....	44

## Introduction:

A sapphire rush escalating to possibly up to 50,000 unlicensed small scale miners started in September 2016 near Bemainty about 35km East of Ambatondrazaka, Madagascar and is still ongoing at the time that this report was published as author VP estimate that more than 20,000 people were still working there when he visited the area in February 2017.

Author Vincent Pardieu (VP) was informed of the rush by Marc Noverraz, a Swiss gem merchant based in Ilakaka, Madagascar on October 6<sup>th</sup> 2016. According to Noverraz, some large highly saturated blue and pinkish orange sapphires were found at a rainforest site in late September and soon a rush was on, attracting people from all over the island, as well as traders (mainly from Sri Lanka) who settled in the nearby town of Ambatondrazaka to buy gems.

On October 26<sup>th</sup> the author was sent a stunning photo of the mining area by Ashkar Ali Mubarak who shared in on Facebook. The photo (see Figure 3), taken few days before, was showing thousands of miners working and camping in a narrow valley between two forest covered hills.



Figure 3: Thousands of Malagasy people mining sapphires in the jungle east of Ambatondrazaka in Oct 2016. Photo by an unknown photographer shared by Ashkar Ali Mubarak.

British gemologist Rosey Perkins (RP) gained access to the mining site from 23-26th October 2017 (Perkins, 2016) about one month after the main discovery. When she arrived there, miners were working along a 2.5km long stretch of river, surrounded by forest. For more details, two short written reports and a short video about her expedition are available on [www.roseyperkins.com](http://www.roseyperkins.com)

Author VP visited Madagascar in Feb 2017 and was also able to visit the new mining site from Feb 7<sup>th</sup> to 10<sup>th</sup> 2017 in order to get a clear update about the situation at the mines. The following report will be based on that private expedition and the study at the GIA Laboratory in Bangkok of sapphire samples from Vincent Pardieu private collection.

## Location and access:

Access to the main mining site, called “*Tananarivo carrieres*” is mainly gained from Ansevabe, a village located about 1 hour journey from Ambatondrazaka by car or motorbike. To reach Ansevabe from Ambatondrazaka we drove on dirt roads over hills and in dry river beds. Many local people were seen travelling there by tractor, bicycle and on foot.

After a stop in Ansevabe to get some food and get ourselves organized with porters and security, we started walking. It took us 10 hours to walk from Ansevabe to the mine site with stops at *Depot 1* and *Depot 2*, two supply villages built in the jungle, and then at Bemainty village, where we spent a night. The track was tough as it was more or less going straight over steep hills with a positive gradient of 720m from Ansevabe to *Tananarivo carrieres*.



**Figure 4: Access to the mines from Ambatondrazaka to Tananarivo Carrieres. We used a car from Ambatondrazaka to Ansevabe and then walked from Ansevabe to Depot 1, Depot 2, Bemainty village and then Tananarivo Carrieres. Map © Vincent Pardieu, 2017**

On her return journey on 26th October RP counted 1,000 people travelling towards the mine while on Feb 7<sup>th</sup> VP counted 700 people returning from the mining site. Most of the people going to the mining site were actually carrying food and supplies for the miners. It seems that several supply routes were active in February 2017, mainly to avoid the police at Ansevabe.



Figure 5: Left and right: Miners on their way to the mining site carrying tools and supply. Photos © Vincent Pardieu, 2017

The mining area visited by RP in October 2016 was known as “*Tananarivo Carrieres*” when we visited it from Feb 7<sup>th</sup> to 10<sup>th</sup> 2017. Between these two visits, sapphire mining extended significantly (see Figure 6). In February 2017, it was still ongoing at “*Tananarivo Carrieres*” (17°59'45"S 48°41'07"E) but sapphire mining was also witnessed upstream at mining sites known as “*Milliard 1*” (17°59'17"S 48°40'53"E) and “*Milliard 2*” (17°59'07"S 48°40'44"E). Other mining sites called “*Milliard 3, Milliard 4 and Milliard 5*” were also reported further north up, possibly up to Zahamena National Park. Sapphire mining also extended north west of Bemainty village to “*Maladialina*” (17°57'50"S 48°38'26"E) and “*Bemainty Carrieres Vovo*” (17°59'13"S 48°39'01"E). Sapphire mining took place reportedly at *Maladialina* (meaning “the night falls rapidly”) in 2012 and 2014 without much success because the stones produced were mainly greenish, yellowish with a strong grey overtone.

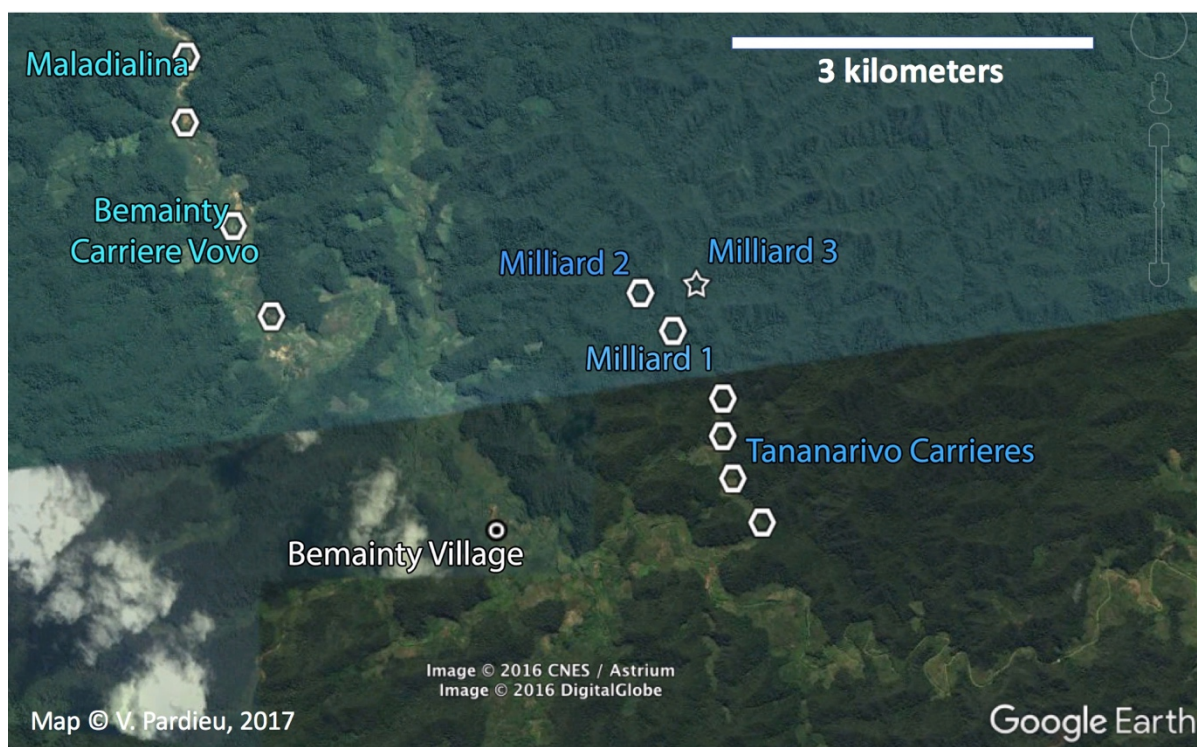


Figure 6: Detailed map of the Bemainty sapphire producing area based on GPS data collected by author VP in Feb 2017. The different mining site visited on the north west of Bemainty village were mainly producing dark greenish stones while the fine material reaching the trade in Oct. 2016 was mined at “*Tananarivo Carrieres*” and then later at *Milliard 1, 2, 3* and possibly from other mining site upstream. Map © Vincent Pardieu, 2017

## Brief description of the mines and mining methods:

The new deposit is clearly a secondary deposit: The long valleys in the west of Bemainty or at *Tananarivo Carrieres* have acted like a sapphire traps over the past million years. At *Tananarivo carrieres*, the valley is about 2 kilometers long north to south and sapphires showing some abrasion are found associated with gravels along streams and in the ground found on the flanks of the valley.



Figure 7: Panoramic view of "Tananarivo Carrieres" from south (left) to north (right). Photo: Didier Barriere Doleac.

Miners are digging pits up to a maximum of 2-3 meters deep in order to collect potentially gem rich gravels and to wash them in the nearby streams. If in October 2016, RP witnessed that all miners were using hand sieves to wash the gravels (see Figure 9), in February 2017 VP saw that most of them were now using water pumps, hoses and larger sieves (see Figure 8 and Figure 9). That new technique was reportedly introduced in November to the area and people worked again the whole mining area with it as it was found to be more efficient and less tiring that the traditional hand sieve.



Figure 8: Malagasy miners using a water pump and a hose at "Tananarivo Carrieres". Photo © Vincent Pardieu, 2017



Figure 9: Malagasy miners working at Tananarivo Carrières (left) using the traditional hand sieves commonly found in Madagascar and at Milliard 1 (right) using the new method recently introduced here where teams of miners are working with a water pump, a hose and a large sieve. Photos © Vincent Pardieu, 2017

The miners are working continuously except on Thursday. As in Bemainty, like many other places in Madagascar, digging the soil on Thursday is *fady* (meaning taboo in Malagasy culture). Thursday is usually spend around Bemainty resting or trading gems. If the weather is fine, many miners were reportedly working day and night using shifts. The miners we met were independent people working usually as team with other family members or friends. They were sponsored by investors and buyers (Malagasy or Sri Lankan mainly) based in town. Few traders were based at the mines, all of them were Malagasy except for a group of Guinean people.



Figure 10: Malagasy buyers selecting blue sapphires at Tananarivo Carrières using a powerful hand torch to check for inclusions and fractures and a bowl of water to be able to study better color zoning. Photos © Vincent Pardieu, 2017



Figure 11: Group of miners, all family related, from Milliard 1 enjoying some food on Thursday at Tananarivo Carrieres while trying to sell the production of the past 2 weeks: a small parcel composed of ten attractive small blue sapphires. Photo © Vincent Pardieu, 2017

Again like at Didy in 2012, we heard several unconfirmed stories that some buyers were actually working for powerful Malagasy officials. The main rumor we heard this time was about one buyer called Robin who bought from November to December more than one kilo of fine sapphires between 1 and 20 grams. A helicopter, reportedly owned by the son of Madagascar President Hery Rajaonarimampianina, came to collect the stones few days before Christmas.

Life at the mining site was very basic with some people living in huts but most in make-shift tents under a plastic roof. As in most jungle villages, there was no sanitation and clean water was not easily accessible. Nevertheless, if prices were about double or triple compared to Ambatondrazaka, bottled water, drinks and fresh or canned food were easily available in the numerous shops scattered around the mining site.



Figure 12: Left: Classic hut and tent used by miners at Tananarivo Carrieres. Right: a Malagasy lady selling fresh vegetable at Tananarivo Carrieres. Photo © Vincent Pardieu, 2017



Figure 13: Malagasy miner resting in his hut at Tananivo Carrieres. Photo © Vincent Pardieu, 2017

To estimate the number of people working at the mines was not an easy task. In Ambatondrazaka we heard numbers between 10,000 and 300,000. Based on the number of people we saw at Bemainty, Tananarivo, Milliard 1 and 2, and the number of people carrying rice, we could estimate that a maximum of 30,000 people were probably still living and working at the mines in Feb. 2017.

Regarding security, the situation at the mines was much better than expected, people were very friendly everywhere and everybody was busy working. 8 gendarmes (Malagasy military police) were present to keep peace and public order. Interestingly we found that the security situation at the mines was much better compared to what we saw in town in Ambatondrazaka. There each night houses were attacked by bandits. Our house in particular was attacked the night before our arrival. In Ambatondrazaka the authorities and the population were very worried as the rain was two months late. Because of that many people had nothing to do and no income. As the new sapphire mining site was providing some significant income to many otherwise jobless people, closing the mining site was not seen as a good option to maintain public order in these difficult times. In the meanwhile at Bemainty villages and at Tananarivo carrieres, the discovery was seen as something very positive by the local people. Nevertheless nothing is perfect and we were reported by the president of Bemainty village that the chief of the village was murdered in Bemainty village by bandits trying to rob a store beginning December 2016. It was very sad for the whole village as he was a wise good man appreciated by everybody.

## Brief description of the stones seen at the mines and in the market:

While the sapphires produced these days at “*Bemainty Carrieres Vovo*” are mainly greenish and yellow, like those from *Maladialina* in the past, the sapphires produced at “*Tananarivo carrieres*”, and at *Milliard 1, 2* are mainly blue, varying from light to a very desirable deep blue. Some of these blues are slightly green, most are milky or silky and they are often included. The sapphires are well received by traders because while the milky stones were reacting well to heat treatment, many stones were nice enough to be faceted without heat treatment despite the presence of inclusions.

“Polychromes” (Malagasy slang for parti-colored sapphires) with strong color zoning and pinkish orange sapphire, similar to those discovered at Mandraka near Toamasina in 2011 (Pardieu, 2012), are also found.

Interestingly if most of the stones were milky some blue stones we saw were probably silky enough to produce a star sapphire if cut as cabochon. Besides that, while going around and visiting gem buyers at *Tananarivo Carrieres*, we were also presented few synthetics and even a piece of blue glass, something that is not uncommon in mining areas.



Figure 14: Left a greenish sapphire probably from *Bemainty Carriere Vovo*, right: a small silky blue sapphire with a visible sheen that could be probably turned into a star sapphire if it was cut as cabochon. Photos © Vincent Pardieu, 2017



Figure 15: Left and right: a milky, geuda type, blue sapphire probably from “*Tananarivo carrieres*” area showing on the right some yellow diesel like color while seen in the direction of the light. This effect is due to light scattering from particles. Geuda type sapphires like this one are typically heat treated to increase both transparency and color. Photos © Vincent Pardieu, 2017

In Ambatondrazaka and Antananarivo, where Sri Lankan and Malagasy buyers are based, the authors saw some fine blue stones up to 75 carats and pinkish orange stones up to 10 carats.



Figure 16: Left fine blue sapphires over 40 carats seen in Ambatondrazaka in Oct 2016, Right: an attractive pinkish orange stone reportedly also from Bemainty, the stone was lighter in color when it was mined and gained in saturation after being exposed to strong sunlight for 2 hours. Photos: Marc Noverraz.



Figure 17: Fine rough blue sapphires reportedly from the new deposit at Bemainty near Ambatondrazaka. The stone on the left weighted 41 carats. But actually it was broken into 2 pieces and when it was discovered it was more than 70 carats. Photos © Vincent Pardieu, 2017

Fine clean blue stones over 100 carats and some attractive pinkish orange stones over 50 carats were reported and according to Marc Noverraz ( a Madagascar based Swiss gem merchant) and Mr. Ramzy (a Sri Lankan gem merchant), this new deposit produced more fine blue sapphires over 100 carats in the past 6 months than the whole Ilakaka / Sakaraha area during the past 15 years.

In the meanwhile, many fine quality sapphires started to appear in the main gem markets such as Beruwala, Ratnapura and Colombo (Sri Lanka) and also in Bangkok (Thailand) (see Figure 1, Figure 2 and Figure 18). In January 2017, a gem merchant visiting Bangkok from Sri Lanka reported the authors that it was unbelievable to see that a 10 carat unheated fine blue sapphire was not anymore such a rare sight in Colombo. Several buyers visiting the Tucson show in the US reported to the authors that they saw there many fine blue stones from the new Malagasy deposit.

It seems that nevertheless most of the production from this deposit is composed of included stones while fine, unheated, clean stones over 5 carats are actually rare.



Figure 18: Fine clean faceted blue sapphires reportedly from the new deposit at Bemainty near Ambatondrazaka. The stones weight is ranging from about 4 to 15 carats. Stones courtesy: KV Gems, Bangkok. Photo: Vincent Pardieu, 2016 © GIA.

## About gem mining and conservation east of Ambatondrazaka:

As new rubies and sapphires deposits have been discovered regularly in the region since 2000, a new sapphire discovery in that rainforest covered region was not a huge surprise (Pardieu, 2012).

It would be a blessing for the Malagasy gem industry if the area was not a protected one. In reality, the region East of Ambatondrazaka town is part of the Corridor Ankeniheny-Zahamena (CAZ) which is a new protected area legally designated in 2015. This new protected area links the established protected areas of Zahamena in the north and the Mantadia/Analamazoatra in the south. This area is managed by “Conservation International” on behalf of the Malagasy Government.

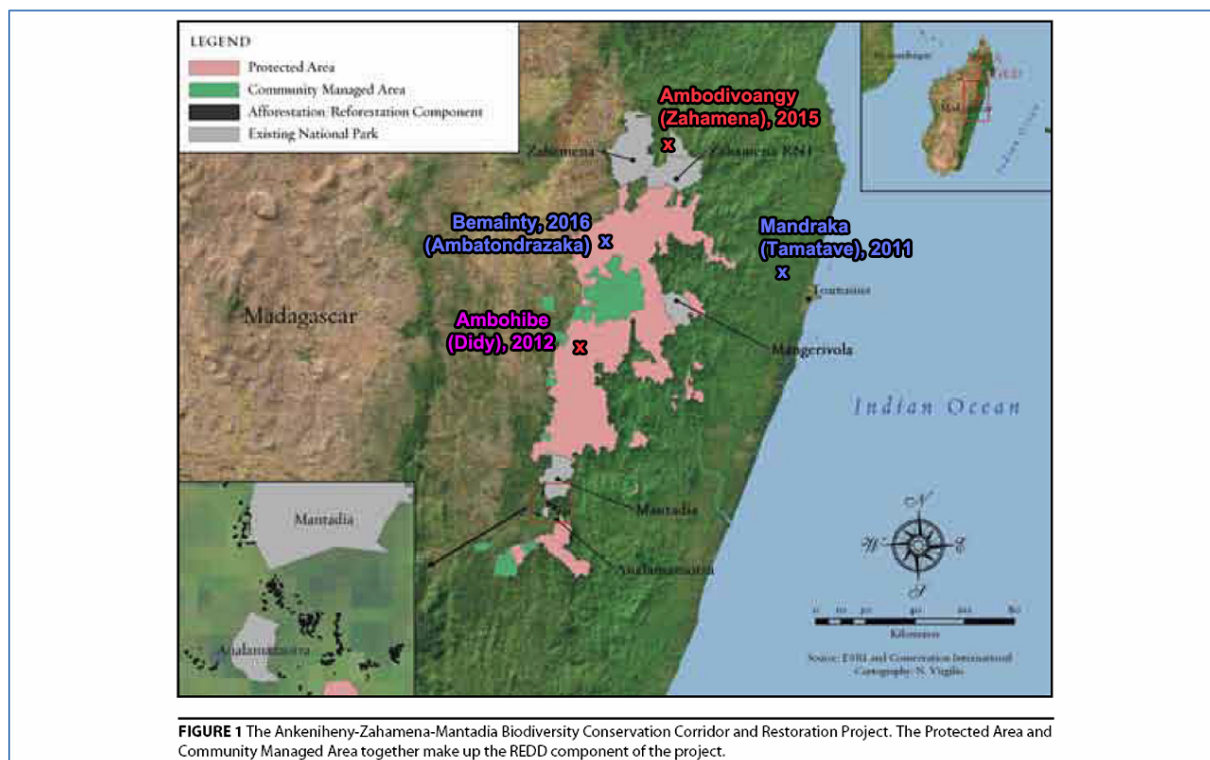


Figure 19: Map of the different recent gem discoveries near or inside the Corridor Ankeniheny-Zahamena (CAZ), a protected area linking different National Parks from Zahamena in the north to the Mantadia/Analamazoatra in the south. This area is managed by “Conservation International” on behalf of the Malagasy Government. Map modified from “Reducing Emissions from Deforestation and Degradation REDD”, © The Nature Conservancy, Conservation International and Wildlife Conservation Society, 2010

In such protected area gem mining is not allowed. It seems that the authorities were slow to respond to the gem rush. Until November 2016 most of the security resources were busy with an international event in Antananarivo, the Malagasy capital. Since then, foreigners in Ambatondrazaka were checked by the authorities, road blockades were reportedly set up on the way to the illegal mining site but it seems that these method had a limited effect: As we could see many Sri Lankan buyers were still active in Ambatondrazaka while many others moved their office to the capital Antananarivo. Regarding the supply for the miners, porters are simply avoiding road blockades using other tracks in the jungle and as we could see while visiting the mining site in Feb 2017, the number of diggers barely decreased since Rosey Perkins visit in Oct 2016.

Many were expecting that with the arrival of the rainy season the miners will leave and people will start again working in the paddy fields around Ambatondrazaka. But at the end of January 2017, the rains were yet to come and the local authorities in Ambatondrazaka were very worried as many people in the region had nothing to do and were not expecting much income that year. Thus in such difficult time for the local economy, the sapphire discovery was seen as a good way to keep out of town people without employment and provide them some income.

The regular discoveries inside the CAZ and the arrival of thousands of people inside protected area is creating a lot of trouble for people in charge of conservation in Madagascar. It is a serious issue for them as miners are usually creating some significant damage to the natural habitat. The main environmental issues being logging (people need wood for lodging and cooking), siltation in streams (washing gem rich soil releases fine sediments in the streams), finally littering and poaching are also additional issues to take into consideration. But actually as we could witness, gem mining is not the worst thing that can happen to protected areas: In Madagascar thousands of hectares are destroyed each year by “slash and burn” type agriculture locally called “tavy”. Actually the discovery of the sapphire deposit at Tananarivo carrieres happened in such a tavy where a local farmer burned some forest and was reportedly followed by gold prospectors who discovered sapphires instead of gold (see Figure 20)



Figure 20: View over the "Tananarivo Carrieres" mining area from the top of the tavy dominating it. Unlike what this photo could suggest, the forest over the mining site was not burned by the gem miners, it was burned by a farmer practicing “slash and burn” type farming before the discovery of the sapphires in the area. Photos © Vincent Pardieu, 2017

Nevertheless, the regular gem rushes in CAZ protected area is causing serious problems as the CAZ is seen by many as one of the key areas to protect the unique Malagasy flora and fauna including some rare type of lemurs and endemic plants.



**Figure 21: Slash and burn type agriculture (left) where the forest is burned in order to grow crops on his ashes is the main source of destruction for the natural habitat in Madagascar. Endemic species, such as this black-and-white-ruffed lemur we saw while on the way to the new mining site, have then less and less space to live and some of these species are critically endangered. Photos © Vincent Pardieu, 2017**

Obviously it will take time and many efforts for conservation and gem mining to benefit from each other in Madagascar. Most miners we met believe that a protected area is an area that some powerful people want to keep for themselves because it is rich in many treasure like gemstones. But everything is not negative as around Ambatondrazaka as the rains were never that late many people start to wonder about climate change, many believe that actually too many trees were cut and that somethings need to change for Ambatondrazaka to remain the rice bucket of Madagascar.

In a perfect world gem mining and conservation could help each other with gems helping to promote and support financially conservation. But these days around Ambatondrazaka with the elections coming next year, and the drought hitting hard the local economy, it seems that for the Malagasy authorities, public order and short term economic benefits are the priority. But in the author opinion, the issue is not to taken lightly as it is very likely that a major ruby and sapphire deposit is hidden in the forest covered mountains of North Eastern Madagascar as we will see in the next chapter:

## Ruby and Sapphire mining in northeastern Madagascar:

Corundum has been known in northeastern Madagascar since the French colonial times, when geologists like Lacroix (Lacroix 1922, 1923) and Besairie (Besairie, 1966) explored the island and described its mineral deposits. Rubies and sapphires, the gem varieties of the mineral corundum, have only recently been discovered. In October 2000, rubies (see Figure 22, left) were discovered in the jungle-covered mountainous region east of Andilamena (Leuenberger 2001). Over the next years, new ruby and sapphire discoveries (see Figure 29) occurred regularly in the region extending from Andilamena in the north west, to Ambatondrazaka in the south west, and up to the coast north of Toamasina in the east (Pardieu, 2012):

A particularly interesting discovery was that of blue sapphires at Andrebabe in 2002 (Hughes, Pardieu et al. 2006, Pardieu 2012) a small deposit that was for a while believed to be producing blue sapphires (Figure 22, right) associated with basalts as the stones were rich in iron, but after study in the lab, the author found out that these stones are in fact of metamorphic origin.



Figure 22: Left: A parcel of small fine quality rubies from the “Moramanga carriere” deposit seen in Andilamena town in 2005. Right: Blue sapphires parcel reportedly from Andrebabe seen in Andilamena in October 2005. Photos V. Pardieu / AIGS, 2005

At the end of 2004, the region experienced a new mining rush as the rubies produced at “Moramanga Carriere” (Figure 24) in the east of Andilamena became famous since they are highly suitable for the new lead glass treatment (Pardieu 2005; Pardieu and Wise 2005).



Figure 23: Left and right: Ruby crystals from Andilamena, Madagascar. This deep red but heavily fractured material, was used as the base material for the so called "Lead Glass Treatment" developed in Thailand after the discovery of the deposit near Andilamena between 2001 and 2004. Photos: V. Pardieu / AIGS, 2005.



Figure 24: View over the "Moramanga Carrieres" ruby mining village in October 2005. The mining area was located deep in the jungle-covered hills about one day walking distance east of Andilamena town. While visiting the area for the first time in July 2005 author VP witnessed approximately 15,000 miners living and working there, few months later in October 2005, when he visited the place for the second time with Richard W. Hughes, about 5,000 were still working there. Photo: Vincent Pardieu / AIGS (2005).

Visiting the area twice in 2005, author VP could find out that the deposit was not a secondary deposit as it was believed to be since its discovery in 2000, but a primary type deposit where rubies and sapphires were found in situ in their weathered host metamorphic rocks (Pardieu 2005, Rakotondrazafy 2008). Rubies were found in a weathered horizontal mica-rich layer while polychrome sapphires were found over the ruby rich layer in weathered kaolin-rich, lens-shaped pockets.

In January 2011, some new sapphire deposits were discovered in the north west of Toamasina, near the village of Mandraka, initiating the "Tamatave sapphire rush" that culminated with the intervention of the Malagasy military in April 2011 (Pardieu, 2012). The deposits in these areas were secondary type deposits producing mostly blue and pink-orange sapphires (see Figure 25) of the metamorphic type with high iron content very similar to the stones found in 2016 at the new deposit near Bemainty. Some purple stones with strong blue and pink to pinkish red color zoning were also found. As most stones were found to be very tumbled, and as the deposit near Mandraka and Bemainty are located in the same drainage basin, it is possible that the two deposits are actually related.

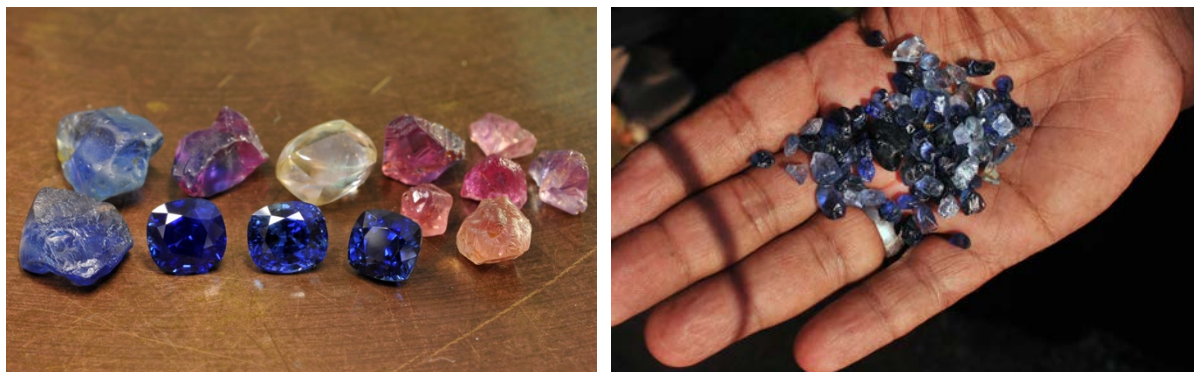


Figure 25: Left: Rough and faceted blue and pink orange sapphires and a diamond crystal believed to have been mined near Mandraka around April 2011, Right: Heat treated blue sapphires reportedly from the new deposit near Toamasina seen at the Ratnapura morning gem market (Sri Lanka) in January 2012. Photos Vincent Pardieu © GIA

The next important ruby and sapphire discovery happened at Ambohibe in the jungle south east of Didy village in April 2012 (see Figure 26). The presence of corundum near Didy is noted in a map by Rakotondrazafy (Rakotondrazafy 2008), but no serious mining activity was reported in the area before that rush. Nevertheless, in April 2012 author VP met a Sri Lankan gem merchant (“New Ricky Gems”) in Ambatondrazaka who had been based in the area for many years. He told the author that small quantities of rubies or blue sapphires were regularly coming from unknown deposits in the region for several years. At that time, author VP started to suspect that the whole jungle-covered region was actually hiding a very significant ruby and sapphire deposit.



Figure 26: Left: Malagasy miners working in the jungle at Ambohibe in the south east of Didy at the beginning of the rush in April 2012. Photo: Nirina Rakotosaona. Right: rubies and sapphires from Didy area. Photo: V. Pardieu © GIA

The discovery near Didy attracted several thousands of miners and many foreign buyers (mainly from Sri Lanka). The deposit produced many fine blue sapphires but more importantly it also produced some very clean, large rubies of a quality that had not been seen yet from Madagascar.

In July 2015, another significant ruby (see Figure 28) discovery happened near Ambodivoangy, a village located near Zahamena National Park (Hughes, 2015; Pardieu et al., 2015). Several thousands of miners from all over Madagascar went there to try their luck mining rubies (see Figure 27). Rapidly, photos of fine clean rubies over 10 carats started to get shared on social media, mainly by traders from Sri Lanka. The Malagasy authorities sent some soldiers, policemen and gendarmes to chase away the miners in August 2015. However, upon visiting the area in September 2015, author VP could witness that the miners had return and about 500 people were working the mining site that was partially located inside Zahamena National Park. A short video documentary about that field expedition is available at: <https://www.youtube.com/watch?v=OGO8ubjI9K4>



Figure 27: Left: Malagasy miners on their way to the mining site near Ambodivoangy village. Right: Miners working the gem rich gravels down the main mining site near Ambodivoangy village. Interestingly, the stream is the actual border between the Zahamena National Park (left) and the land used by people from Ambodivoangy (right), if these miners seen here are not inside the Zahamena National park, the main ruby mining site located uphill was inside the Zahamena National Park. Photos: V. Pardieu © GIA



Figure 28: Rubies from Zahamena area. The stones had an attractive red color reminding the aspect of fine rubies from Thailand/Cambodia or Mozambique. Photo by V. Pardieu © GIA

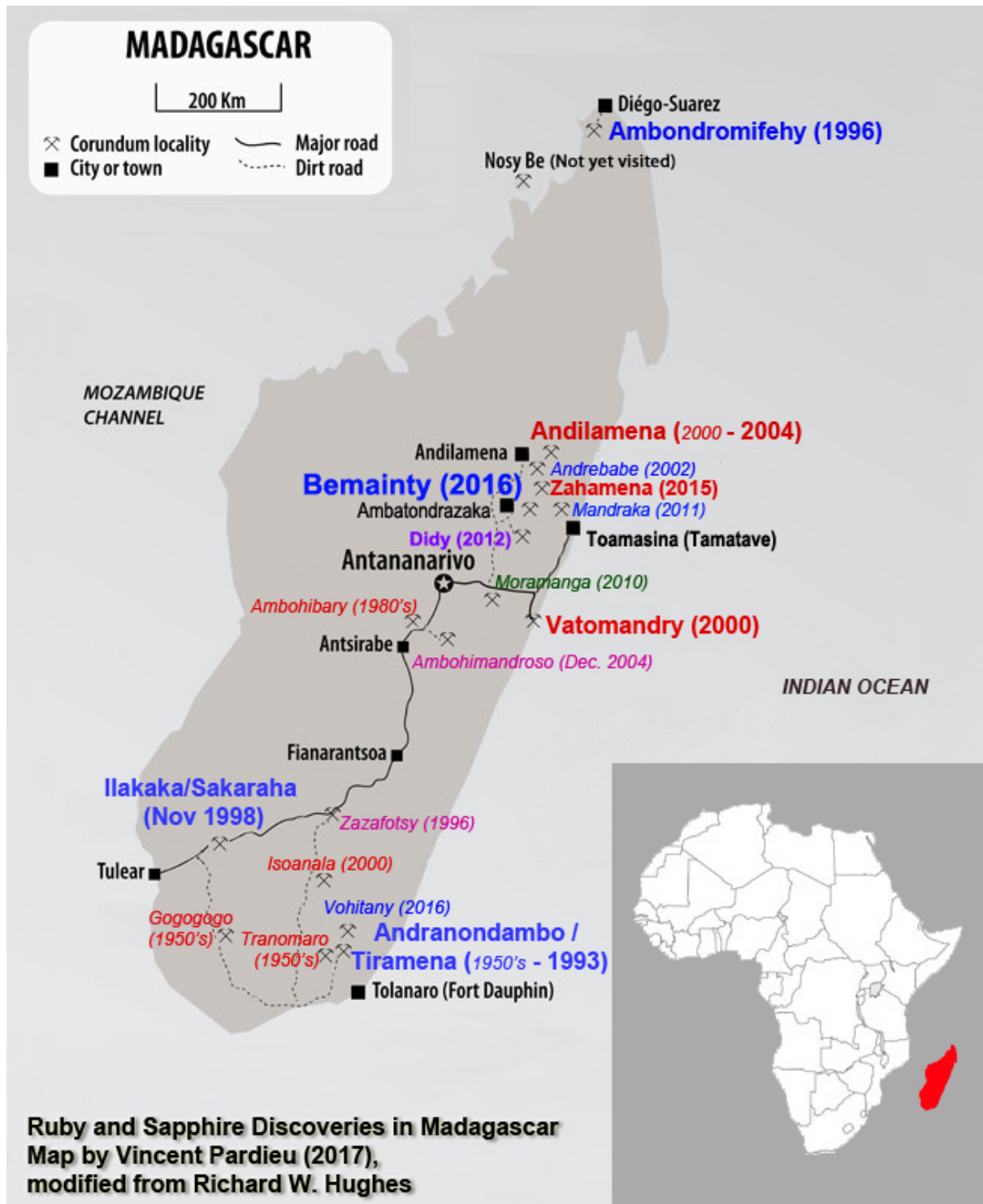


Figure 29: Map showing the main ruby and sapphire discoveries in Madagascar. Most of the recently discoveries are taking place in the jungle between Andilamena, Toamasina and Ambatondrazaka. Map courtesy: Richard W. Hughes (2006), modified and updated by Vincent Pardieu (2017).

## Geology of the new sapphire deposit near Bemainty:

### Global context:

Madagascar, sometimes known as the “Red island” due to its red soils, shares many geological features with other known gem mining areas like Sri Lanka and East Africa (Mozambique, Tanzania and Kenya). In fact, the islands’ rocks, like those of these other gem producing countries, show records of the East-African orogeny (i.e., mountain-building tectonic event) between ~900 My and ~550 My. This orogeny is the zone where two huge landmasses joined to form the Gondwana supercontinent. The western part of Gondwana consisted of present-day South America and most of Africa. Remnants of the eastern part of this supercontinent can be found in present-day India, Antarctica, Australia, Madagascar and Sri Lanka.

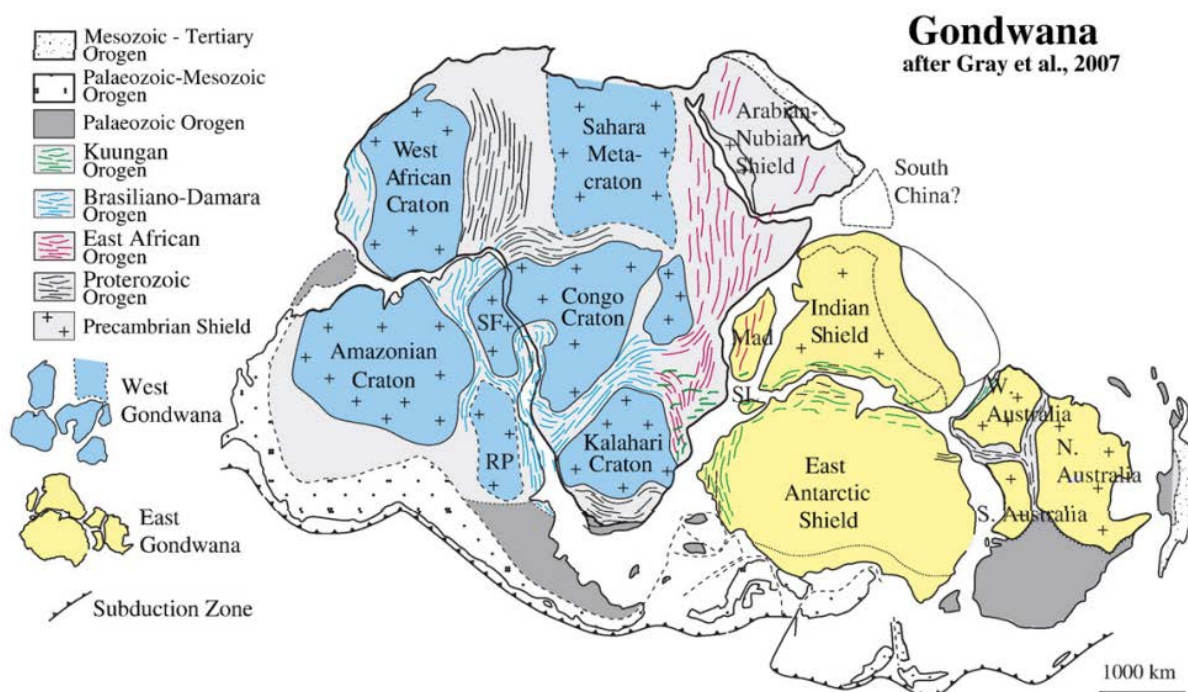


Figure 30: Map of the Gondwana supercontinent, after Gray et al.,2007

After the formation of the supercontinent, Madagascar remained in the center of Gondwana for a long time. 150 My ago, the eastern part of Gondwana started to separate, opening the ocean between the East-African mainland and Madagascar. The opening of the Indian ocean occurred even more recently, around 90 My. At this time India and Sri Lanka split from Madagascar and rapidly drifted towards the northeast. This period is associated with very intense volcanism in Madagascar (De Wit, 2003).

## Local context:

The Malagasy geology is dominated by a Precambrian, crystalline basement in the east and sedimentary basins in the west. The geology of Madagascar is a major study area of the BRGM. This is France's leading public institution in Earth science applications for the management of surface and subsurface resources and risks.

The most important units in the area that is studied are: Antananarivo, Tsaratanana and Betsimisaraka units (see Figure 31).

The Antananarivo unit is a vast ensemble of poorly differentiated (probably Archean) gneiss and migmatites with many granitic intrusions which are dated at 2500 My. Magmatic events at 800 and 630-500 My are well represented, suggesting an indisputably African affinity to this unit.

The Tsaratanana unit consists of gneiss and migmatites associated with many basic and ultrabasic rocks dated at 2500 My and 800 My. This unit could correspond to an Archean Greenstone Belt, affected by high-temperature metamorphism. In some places according to the BRGM, there are some evidences that this unit has been thrust over the Antananarivo Unit (Goncalves & Al, 2003)

The Betsimisaraka Unit is made of gneiss and mica schists with many intercalations of basic and ultrabasic rocks. Where the high pressure metamorphism is observed, a suture zone between the Indian Block (Antongil) and the African Block (Antananarivo) is proposed. This suture is interpreted as an indication of the 550-500 My collision which generated Eastern Gondwana, (Collins & Al, 2002)

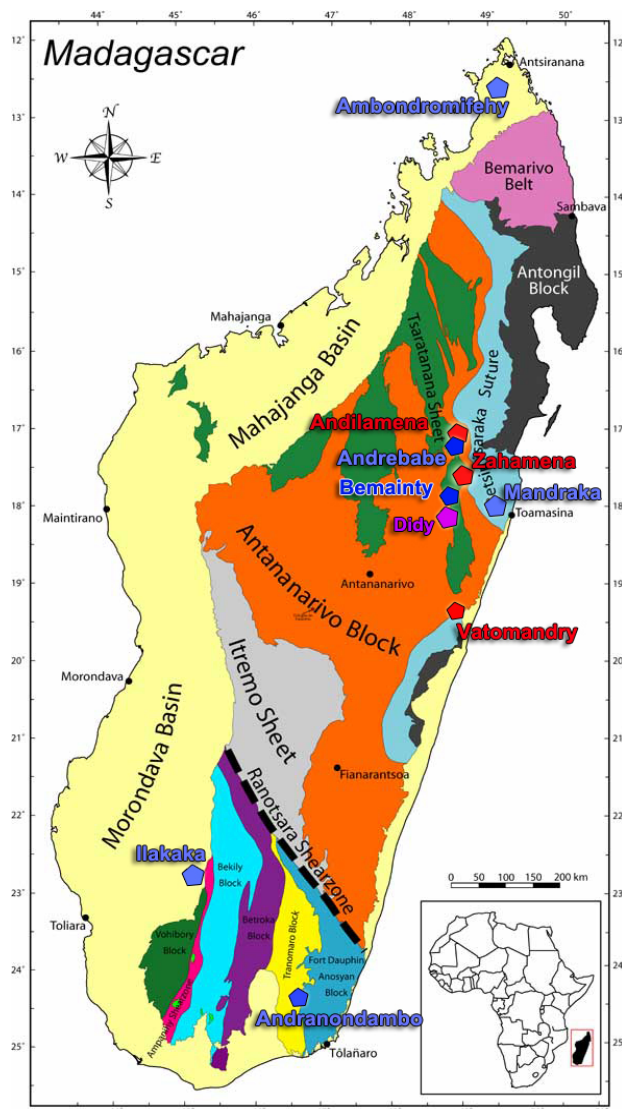


Figure 31: Simplified Geological Map of Madagascar presenting the main units with the localization of the main ruby and sapphire deposits (Map adapted from Windley & Al. 1984, Collins and Windley, 2002 and Jons et al., 2006).

## Gemstones in the geological context:

It is interesting to see that the known ruby and blue sapphire deposits of Andilamena, Andrebabe, Didy, Zahamena and Bemainty are all located along the junction between the Antananarivo and the Tsaratanana units. The only gem corundum deposit in northeastern Madagascar that is not located on this boundary is the Toamasina/Mandraka sapphire deposit. However this deposit is known to be a secondary deposit. It is very likely that the sapphires from this deposit originated in the same area as the other ruby and sapphires from this area. Sapphires from Mandraka and Bemainty share a lot of similarities and occur in the same drainage basin, with the Mandraka deposit located far downstream... This hypothesis is analyzed in more detail in (Rakotondrazafy et al., 2008)

## Part 1: Complete study of a blue sapphire reportedly from Bemainty area near Ambatondrazaka, Madagascar:

### Materials and Methods:

#### Samples Selection:

Thirty eight sapphire samples (see Figure 32) were collected at Ambatondrazaka by a trustable gem merchant from Nov 4<sup>th</sup> to 28<sup>th</sup> 2016. This parcel is believed to be representative for the production that was seen at that time in the area. These samples were catalogued as E1 type according to the GIA cataloguing system (see Annex A), this means they were collected from a trustable secondary source near the mining area. Therefore this study should be taken only as a preliminary study. The fact is that it is not really sure that all these samples were actually mined from that area as many miners and dealers came to Ambatondrazaka not only with money but also with stones. Some carry synthetics, unsold stones from other deposits in Madagascar or even treated stones from Thailand or Sri Lanka. The simple reason is that the stones are following the buyers and of course some unscrupulous people see a good opportunity to make some additional business in these gem rushes. Nevertheless we do believe that the samples presented in this study were mined at Bemainty.



Figure 32: Sapphires reportedly from the new mining site at Bemainty, near Ambatondrazaka, Madagascar. The stones are weighting from 0.2 to 6 carats. Photo: V. Raynaud © GIA

The samples were then seen by author VP in Bangkok. After acquiring these samples for his personal collection, he provided them to the GIA Laboratory in Bangkok for study and data collection. Most of

the sapphires from that parcel were blue but 4 pinkish orange stones and several blue stones with colorless or pink color zoning were also present.

### **Sample Fabrication:**

All the samples in this study were fabricated in the GIA Laboratory Bangkok by Victoria Raynaud. The samples were fabricated for 2 different purposes:

1 sample was found to be clean enough to be fabricated as “spectra quality sample”. To fit into this group the samples had to possess a clean area large enough to enable high quality reference spectra to be collected perpendicular to the c-axis.

10 other samples were too included to collect high quality optical data from, so they were fabricated in order to document their inclusions. In some cases one window was polished perpendicular to the c-axis, while in other cases, directions not specifically related to the c-axis were windowed in order to optimize the study of their internal features.

All these samples were subsequently polished with great care to enable good quality spectra to be collected. Optical path lengths of the wafers were measured with a Mitutoyo Series 395 spherical micrometer with an accuracy of 2 microns.

### **Instrumentation:**

#### *Sample photography:*

To document the color of our samples, we used a Canon EOS 5D camera with a Canon Macro MP-E 65mm lens adapted to a camera stand. In order to produce consistent results for each GIA reference sample the photographs were taken under exactly the same lighting conditions, with the reference samples being placed in a Logan Electric Tru-View 810 Color Corrected Light Box (5000K lamp). A neutral density filter was used to calibrate the camera light box combination to produce a neutral gray. High-resolution reference photographs were then collected using transmitted light. As the reference photos were taken of wafers cut perpendicular or parallel to the c-axis, the color of the samples in the photographs taken using transmitted light can be considered representative of the color, respectively, of a nearly pure o-ray or e-ray.

Photomicrographs of internal features were captured at up to 180x magnification with a Nikon SMZ 1500 system using darkfield, brightfield, diffused and oblique illumination, together with a fiber-optic light source when necessary. *Note:* The field of view information in the captions was calculated based on the magnification power of the microscope. On each photo a scale has been added showing 25% of the total field of view for the sake of consistency. The measurement on the scale was rounded up to the nearest whole number after the decimal place for better clarity.

### *UV-Vis-NIR spectroscopy:*

Ultraviolet-visible-near infrared (UV-Vis-NIR) spectra were collected using a Hitachi U-2910 spectrophotometer for polarized ordinary and extraordinary rays, integrating with a polarizer accessory controlled by ThorLabs APT. We used 1.5 mm as the slit width. The spectra obtained were corrected by calculating the reflection loss from the index of refraction data and the data was converted to absorption coefficients using  $\alpha = 2.303A/d$  where “d” is the depth in centimeters.

### *Infrared Absorption (FTIR) spectroscopy:*

Fourier-transform infrared (FTIR) spectroscopy was performed using a Thermo Nicolet 6700 FTIR spectrometer equipped with an XT-KBr beam splitter and a mercury-cadmium-telluride (MCT) detector operating with a 4x beam condenser accessory, and resolution was set at  $4\text{ cm}^{-1}$  with  $1.928\text{ cm}^{-1}$  data spacing. The spectra obtained were converted to absorption coefficients using  $\alpha = 2.303A/d$  where “d” is the depth in centimeters.

### *Raman spectroscopy:*

Raman spectra were used to identify inclusions using a Renishaw inVia Raman microscope fitted with a 514 nm argon-ion laser. The Raman spectra were collected in the range 100 and  $1500\text{ cm}^{-1}$ . The accumulation was set at 3 to 15 to improve the signal to noise ratio of the spectra. Spectra were calibrated using the  $520.5\text{ cm}^{-1}$  line of a silicon wafer. In all cases, we used the RRuff database as a reference in our attempts to identify inclusions. Spectra comparisons were performed using Renishaw Wire (version 3.4) and/or Thermo Galactic “Spectral ID” (version 3.02) software.

### *Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS):*

For chemical analysis, we used LA-ICP-MS technology with a Thermo Fisher Scientific iCAP Q Induced Coupled Plasma - Mass Spectrometer (ICP-MS) coupled with a Q-switched Nd:YAG Laser Ablation (LA) device operating at a wavelength of 213 nm. Laser conditions used  $55\text{ }\mu\text{m}$  diameter laser spots, a fluency of around  $10\text{ J/cm}^2$ , and a 15 Hz repetition rate. 12 spots were analyzed on each wafer. For the ICP-MS operations, the forward power was set at  $\sim 1350\text{ W}$  and the typical nebulizer gas flow was  $\sim 1.00\text{ L/min}$ . The carrier gas used in the laser ablation unit was He, set at  $\sim 0.60\text{ L/min}$ . The criteria for the alignment and tuning sequence were to maximize Be counts and keep the ThO/Th ratio below 2%. A special set of synthetic corundum reference standards were used for quantitative analysis. All elemental measurements were normalized on Al (internal element standard), this value approximates to the chemical composition of corundum.

## Preliminary study of blue sapphire 100322689865 reportedly from the Bemainty area, Ambatondrazaka, Madagascar:

GIA reference sample 100322689865 is a E1 type sample (See Annex A) believed to have been mined from the new mining site around Bemainty near Ambatondrazaka, Madagascar in November 2016. We selected it for this study as it is clean with an attractive blue color and thus it is seen as quite representative of most of the material from that new area that will not need heat treatment to reach the market.

The specimen weighed 0.583 carats before fabrication (see Figure 33). It had an attractive medium blue color with medium dichroism and was transparent. A few unhealed surface reaching fissures were filled with some yellow to brown foreign substance of natural looking origin. The stone was carefully fabricated into a thin optical wafer weighing 0.260 carats, with carefully polished windows parallel to the c-axis of the crystal. When viewed under long-wave and short-wave UV light no reaction was observed.

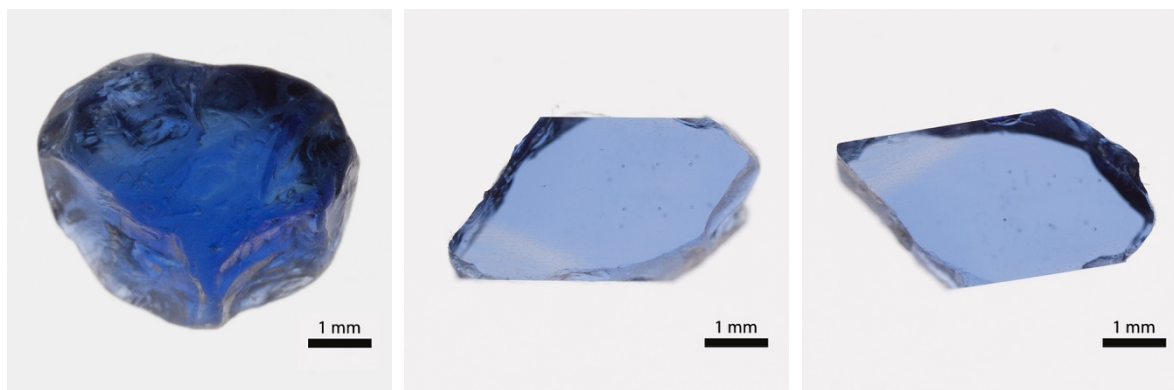


Figure 33: GIA reference sample 100322689865 before (left) and after (center and right) fabrication. The photos were color calibrated using transmitted light. The two photos after fabrication show the two sides of the wafer looking down perpendicular to the direction of the c-axis of the crystal. The color seen is a medium blue with some color banding. Photos: S. Engniwat © GIA.

## Microscopic examination:

GIA reference sample xx865 was mostly clean except a band of minute particles and needles (see Figure 34 and Figure 35). These inclusions could be seen arranged as low density band perpendicular to the c-axis (following the basal pinacoid) mainly on one side of the sample (Figure 33) associated with a colorless area. The area selected for spectroscopy contained almost no particles, thus light scattering resulting from the presence of inclusions is limited.

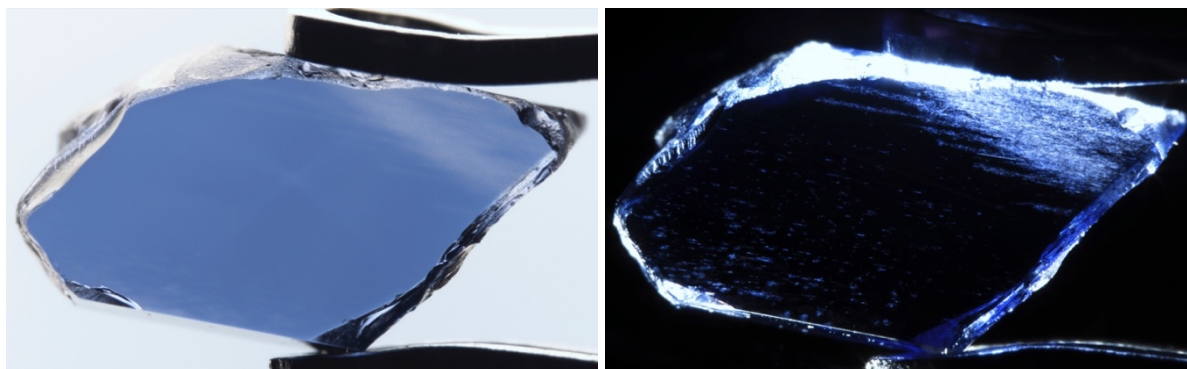


Figure 34: Detailed views of GIA reference sample xx865 using bright field illumination (left) and fiber optic light (right). We can clearly see that particles associated with colorless areas are present in the entire sample. The needles, seen in the lower part of the sample, are all aligned on the basal pinacoid, parallel to the window that was polished perpendicular to the c-axis. Field of view 5.16mm, photos: Victoria Raynaud © GIA.

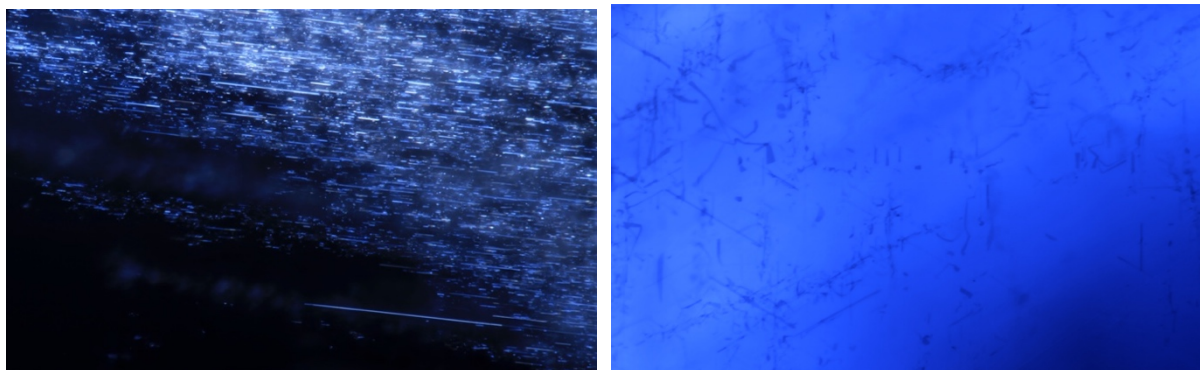
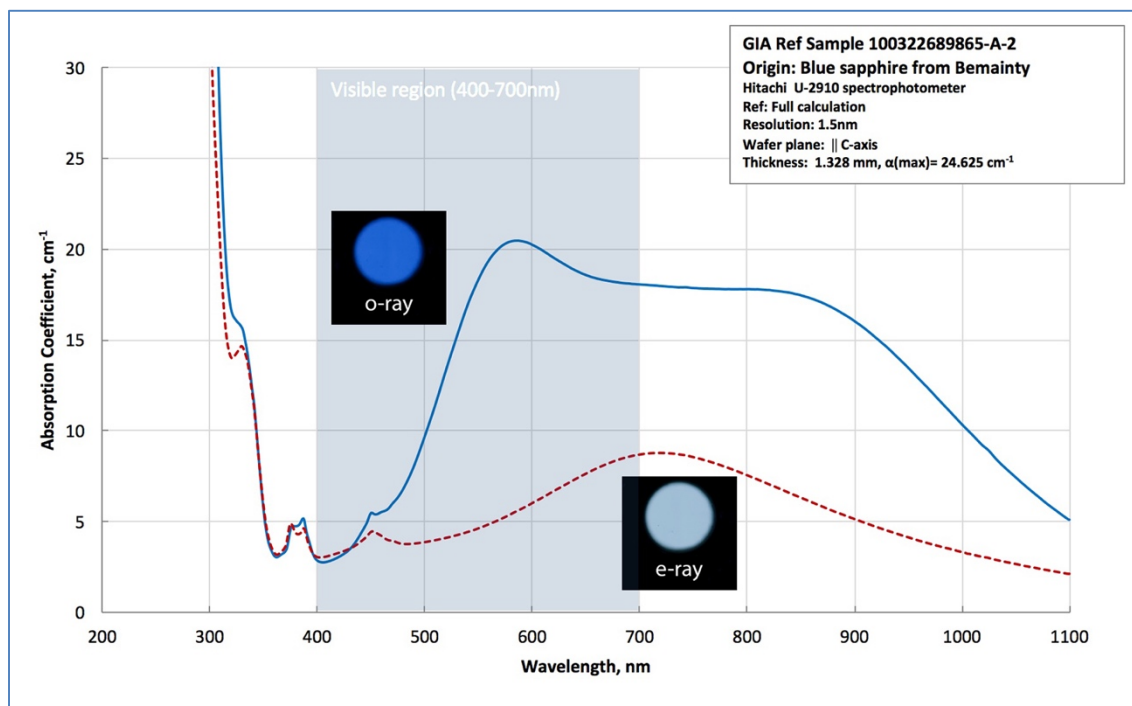


Figure 35: Detailed views of the needles and particles in GIA reference sample xx865. On the left, we see the needles in a direction perpendicular to the c-axis while on the right the needles are seen in the direction of the c-axis. Field of view 1.20mm (left), 0.94mm (right), photos: Victoria Raynaud © GIA.

## UV-Vis-NIR and FTIR Spectroscopy:

Polarized UV-Vis-NIR spectra (o-ray and e-ray) were collected from the specimen in an area that had only few needles and particles (see Figure 36). The ordinary ray (o-ray) spectrum shows not only a strong broad band absorption around 580 nm, but also around 850 nm in the near infrared region. This absorption feature at 850nm is usually found in basalt-related blue sapphires, but usually it is stronger than the band at 580nm. It could be due to an  $\text{Fe}^{2+}$ - $\text{Fe}^{3+}$  related broad band (Fritsch and Mercer 1993). The broad band visible around 500 to 600 nm in the o-ray is the main reason for the

blue coloration in the sapphire as it absorbs light in the green, yellow and red parts of the visible spectrum (indicated in medium blue on (Figure 36). It can be attributed to charge transfer absorption by  $\text{Fe}^{2+}\text{-Ti}^{4+}$ . The absorption at 330 nm commonly called “shoulder” is related to  $\text{Fe}^{3+}$  pairs. The 377 and 450 nm are associated with  $\text{Fe}^{3+}$  pairs while the 388 nm is associated with single  $\text{Fe}^{3+}$  ions (Ferguson 1971). The absorption edge referred at  $10 \text{ cm}^{-1}$  can be observed at 343 nm for both the e-ray and o-ray. It suggests some significant iron content. In this sample, it is interesting to note that the minimum absorption level is to the right of the 377 and 388 absorption peaks at 405 nm for the o- ray and 402 nm for the e-ray with the o-ray (2.72 abs coef.) being a little lower than that of the e-ray (3.05 abs. coef.).



**Figure 36: Polarized UV-Vis-NIR absorption spectra of GIA reference specimen xx865 with inset color calibrated polarized photos of the beam path area for the o- and e-rays. Optical path length: 1.328 mm. Weight: 0.260 carats. Color: medium blue.**

An infrared spectrum (see Figure 37) was collected through the same area as the UV-VIS spectrum. However, in this sample the FTIR spectrum wasn't oriented using a polarizer. An absorption feature was observed at  $3309 \text{ cm}^{-1}$ . This feature is commonly found in natural sapphires. It was described as an O-H related absorption feature in basalt-related sapphires (Smith G&G 1995) or heat treated rubies from Mong Hsu (Smith 1995).

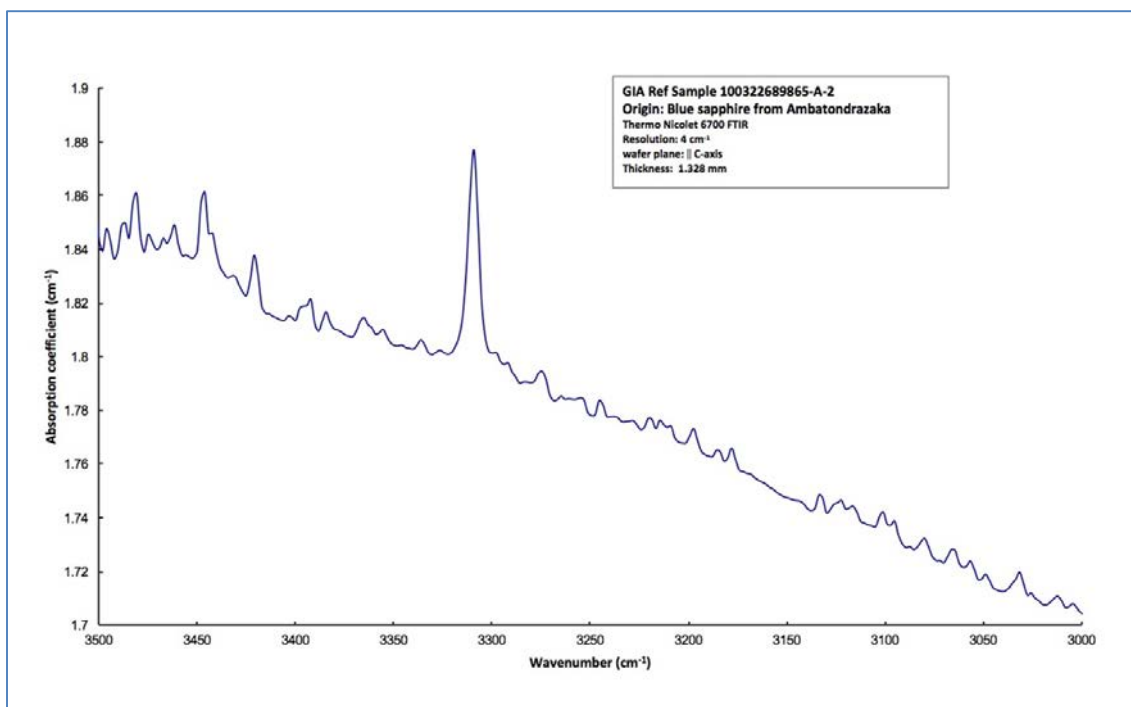


Figure 37: FTIR spectrum of GIA reference specimen xx865 in the 3000 to 3500  $\text{cm}^{-1}$  range. Optical path length: 1.328 mm. Weight: 0.260 carats. Color: medium blue.

## Chemistry:

LA-ICP-MS chemical data (Table 1) was collected on each side of GIA reference sample 1003226898652. Six spots were analyzed on each side of the wafer (see Figure 38), in the same area that was studied with FTIR and UV-Vis-NIR spectroscopy.

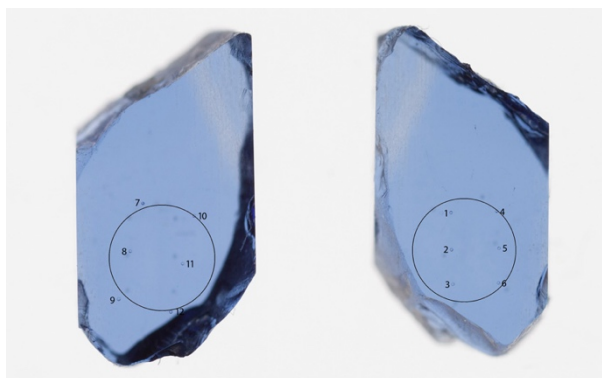


Figure 38: GIA reference sample xx865 showing the location of the 12 spots where LA-ICP-MS analysis was conducted on each side of the wafer. The circle represents the area studied with UV-Vis and FTIR. Photos: S. Engniwat © GIA.

The collected chemical data (see Table 1) showed a very limited amount of trace elements. Only significant amounts of iron (Fe), gallium (Ga), and titanium (Ti) were detected. Small amount of magnesium (Mg) and vanadium (V) were shown. Cr and all other trace elements were below the detection limit. The iron content was found to be in the medium / high range with 730 to 811 ppm.

The range of Ti content after subtracting the Mg content is about 14 to 18 ppma, giving a medium blue color.

**Table 1: LA-ICP-MS results in parts per million atomic (ppma) units for GIA reference sample 668918602-A. “BDL” stands for “Below Detection Limit”, “BQL” stands for “Below Quantification Limit”**

Specimen 100322689865 Spot number (color of the area)	<sup>9</sup> Be	<sup>24</sup> Mg	<sup>47</sup> Ti	<sup>51</sup> V	<sup>52</sup> Cr	<sup>56</sup> Fe	<sup>69</sup> Ga
SP1 (medium blue)	BDL	BQL	17	0.3	BDL	1307	33
SP2 (medium blue)	BDL	BDL	15	0.3	BQL	1603	35
SP3 (medium blue)	BDL	BQL	16	0.3	BDL	1442	41
SP4 (medium blue)	BDL	BQL	16	0.3	BDL	1369	36
SP5 (medium blue)	BQL	BQL	14	0.2	BDL	1336	36
SP6 (medium blue)	BDL	BQL	17	0.3	BDL	1482	36
SP7 (medium blue)	BDL	BQL	13	0.2	BDL	1438	35
SP8 (medium blue)	BDL	BQL	18	0.3	BDL	1468	39
SP9 (medium blue)	BDL	BQL	16	0.2	BQL	1314	34
SP10 (medium blue)	BDL	BQL	15	0.2	BDL	1468	35
SP11 (medium blue)	BDL	BDL	15	0.2	BQL	1325	34
SP12 (medium blue)	BDL	BQL	14	0.3	BDL	1434	35
<b>Average in ppma ± Standard Deviation</b>			15.6 ± 1.4	0.26 ± 0.06		1415 ± 88	35.7 ± 2.1
Detection Limit	0.1	0.2	0.8	0.1	0.4	3.1	0.02

### Discussion about the data collected from GIA reference sample 100322689865:

On the UV-Vis-NIR spectra (see Figure 36) the blue color for the sample can be explained by the presence of a broad absorption band for the o-ray starting around 450 nm. It relates to inter-valence charge transfer absorption by Fe<sup>2+</sup>-Ti<sup>4+</sup> pair. The blue color seen here seems to be produced by an average of 15 ppma of titanium content associated with iron.

The absorption band in the near-infrared centered at 850nm and the presence of the “shoulder like” spectral feature at 330nm in UV range are common features in basalt-related blue sapphires that have a much higher iron content compared to most metamorphic type blue sapphires. The presence of a significant iron content was confirmed by LA-ICP-MS as the iron content was found to be on average 1415 ppma, which is very high for metamorphic type blue sapphires.

Without Cr and a rather high Fe content, it is logic that no fluorescence reaction was seen under ultra-violet lighting.

All the spectroscopy results are compatible with the chemical data collected from the sample proving that this sapphire, besides some significant iron content and traces of gallium and titanium, is particularly pure.

## Part 2: The internal world and trace element chemistry of sapphires from Bemainty area near Ambatondrazaka, Madagascar:

A microscopic study of the internal features seen in 10 reference specimens reportedly from the new sapphire mining site at Bemainty near Ambatondrazaka was quite interesting particularly when compared with the trace element chemistry data collected from these stones:

Overall, the most common inclusions seen in these sapphires were bands of minute particles, flake-like inclusions, needles and also platelets. The stones studied were ranging from milky to silky with a wide range of particles and needles. We could see that, like in many other deposits, milky stones were usually rather low in iron while silky stones had a rather higher iron content. Interestingly we could find out that blue sapphires from Bemainty areas were covering a very wide iron content range from as low as 250 ppma to as high as 1700 ppma. The stones with low iron content were reminding those from Ilakaka (Madagascar) or Sri Lanka while the aspect of the silky ones with higher iron content were more reminding what was known from sapphires from Burma or Tanzania.

<b>Milky type (43 spots)</b> <b>xx845, 846, 855, 857, 861</b>	24Mg	47Ti	51V	53Cr	57Fe	69Ga
min	4	23	4	2	245	10
max	74	290	16	12	701	17
average	36	90	9	5	465	14

<b>Short needles type (9 spots)</b> <b>xx841, 854</b>	24Mg	47Ti	51V	53Cr	57Fe	69Ga
min	2	5	0	0	898	27
max	3	27	1	0	1398	53
average	8	18	3	0	1120	39

<b>Silky type (30 spots)</b> <b>xx852, 862, 866</b>	24Mg	47Ti	51V	53Cr	57Fe	69Ga
min	2	9	0	0	1398	18
max	47	70	16	31	1716	56
average	16	30	6	12	1515	38

The following milky type samples xx845, xx861, rich in minute particles had a low iron content with respectively 240 to 300 and 380 to 410 ppma of iron. Besides milky particles, they were found to have some flake-like inclusions and stringers reminding what is known in Kashmir-like samples from Ilakaka in Madagascar. Milky particles were also found in sample xx857 with 620 to 700ppma of iron:

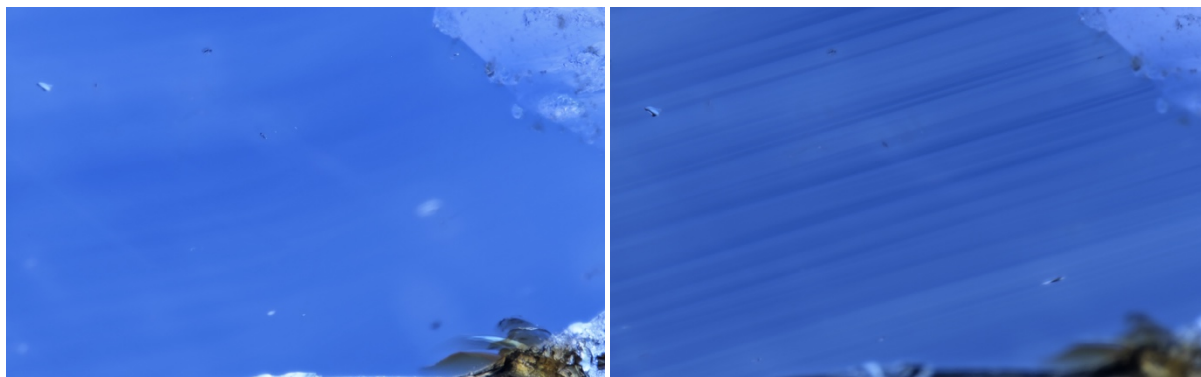


Figure 39: Left and right two different views of reference sample 100322689845 in diffused light conditions. On the left the sample looks milky but actually when it is tilted correctly bands of minute particles appear clearly. Field of view 4.32mm, photos: Victoria Raynaud ©GIA.

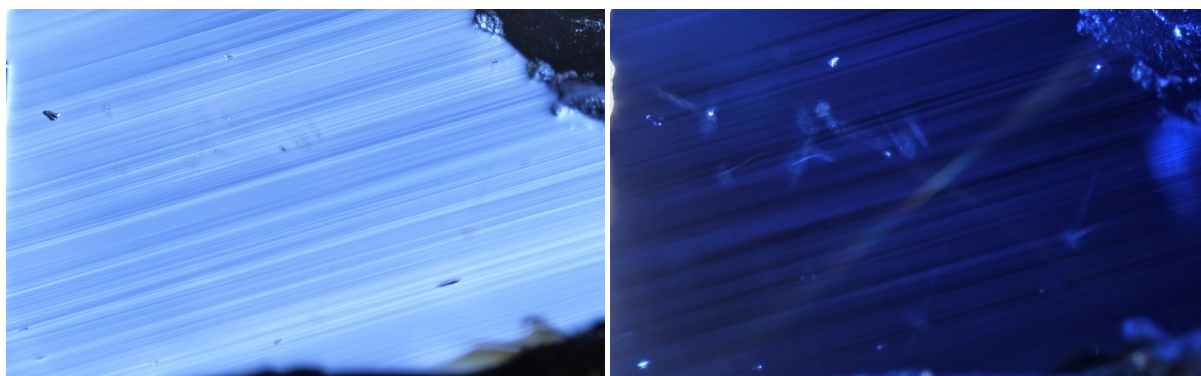


Figure 40: Left and right two other views of reference sample 100322689845 in the same position as over but this time using bright field on the left and fiber optics on the right. We can see that minute particles are associated with colorless areas, as it is normal in unheated blue sapphires. Interestingly delicate flake-like features become visible using fiber optic illumination. Field of view 4.32mm, photos: Victoria Raynaud © GIA.

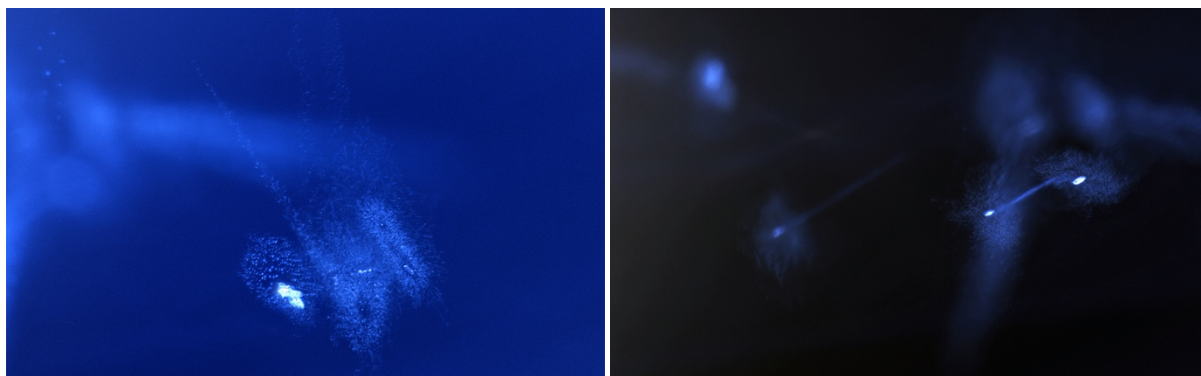


Figure 41: Left and right two different detailed views of delicate flake-like features associated with small unidentified crystals in reference sample 100322689845. Field of view 1.2mm(left), 1.08mm (right), photos: Victoria Raynaud © GIA.

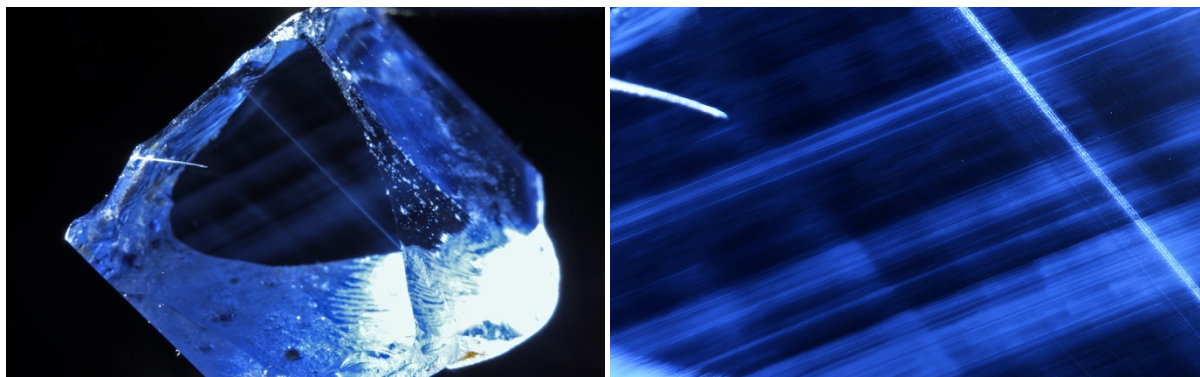


Figure 42: Left and right two different views of reference sample 100322689861 under fiber optic illumination, right being magnified. Left: we can see on the lower left part of the sample the window that was polished perpendicular to the c-axis. We can clearly see that one band of minute particle is parallel to that window, following the basal plane of the crystal while the others are following the hexagonal prisms of the sapphire crystal, see for details on the right side. Field of view 10.08mm(left), 3.60mm (right), photos: Victoria Raynaud © GIA.



Figure 43: Left and right two difference views of GIA reference sample 100322689857 under diffused light (left) and fiber optics (right). Left the sample looks simply milky but after tilting it we can see that the milkyness is actually due to bands of minute particles. Field of view 1.08mm (left), 3.84mm (right), photos: Victoria Raynaud © GIA.

In sample xx841 and xx864 the iron content was a bit higher reaching respectively 900 to 1100 and 1060 to 1150 ppma, in this case we could see some short mostly thin needles alongside few bands of particles appearing a bit coarser than in the previous samples with lower iron content.

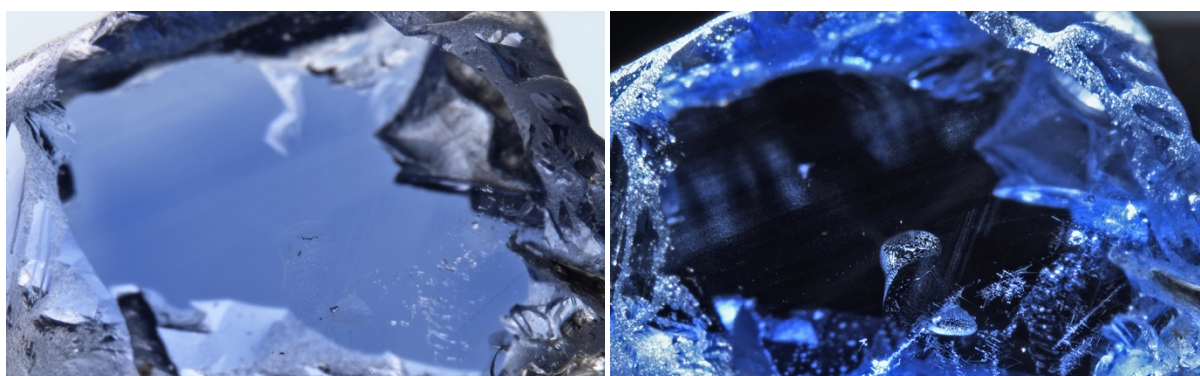


Figure 44: Left and right two different views of reference sample 100322689841: Left under bright field and right under fiber optic illumination. The sample looks milky in some areas and silky in others. In this case, the particles are coarser than in the previous samples. Field of view 4.32mm, photos: Victoria Raynaud © GIA.

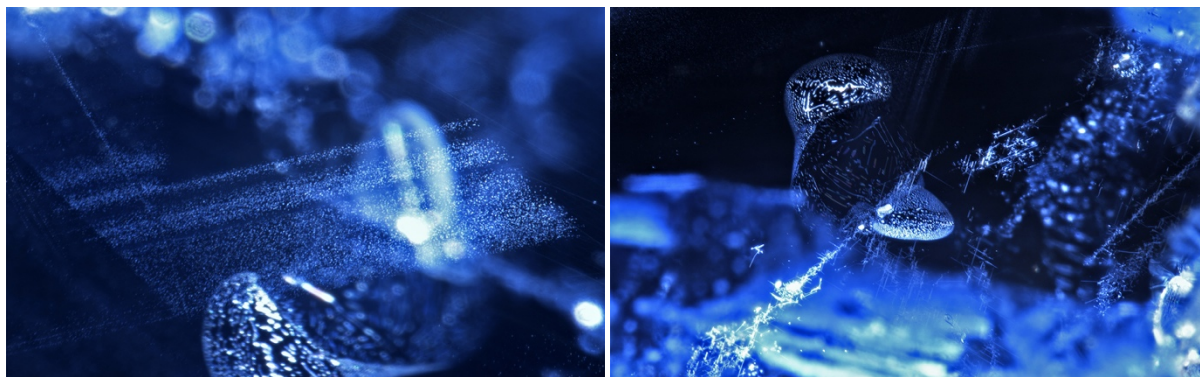


Figure 45: Detailed views on the particles (left) and short needles (right) in reference sample 100322689841 using fiber optic illumination. The particle seen left are coarser than those seen in the previous samples, besides that some groups of short arrow shaped needles are clearly seen forming nests in the right part of the sample. Field of view 1.80mm (left), 2.30mm (right), photos: Victoria Raynaud © GIA..

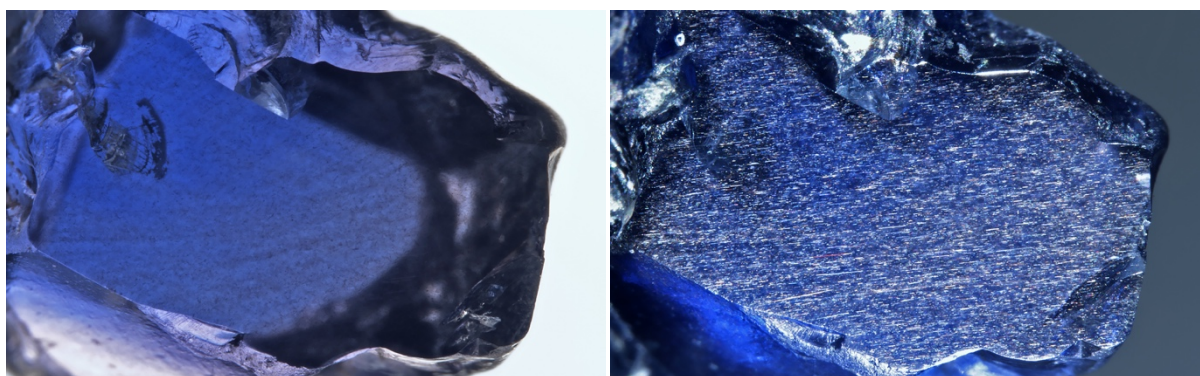


Figure 46: Left and right two different views of reference sample 100322689864: Left under bright field and right under fiber optic illumination. We can see that the stone is rich in short thin needles. Field of view 4.90mm, photos: Victoria Raynaud © GIA..

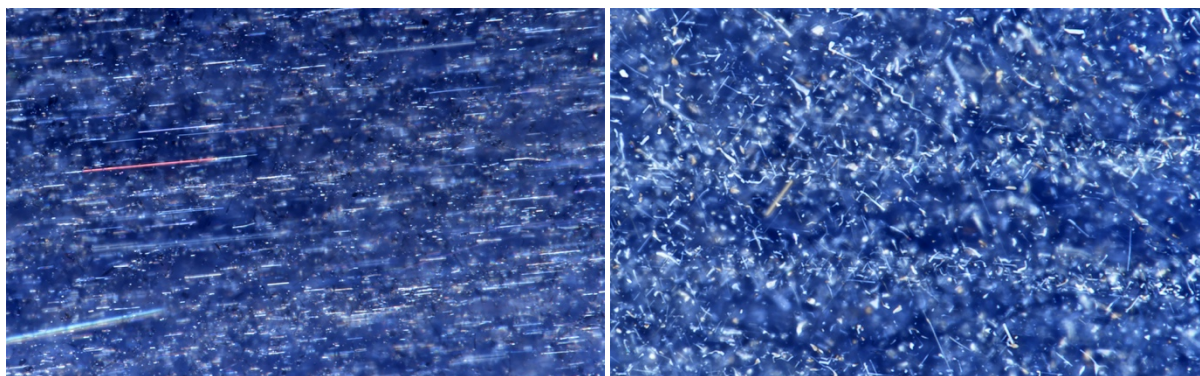


Figure 47: Left and right two different views of reference sample 100322689864 under fiber optic illumination, the short needles seen on the left look actually for some of them as irregular platelets while seen at very high magnification as on the right. Field of view 1.20mm (left), 1.07mm (right), photos: Victoria Raynaud © GIA..

The following samples xx862, xx866 xx852 were found to be rich in short brownish needles, whitish disk like flakes, and platelets presenting some irregular shapes. Most of them had a silky rather than milky aspect. Their iron content was found to be much higher than in the previous milky stones with respectively 1430 to 1600, 1500 to 1600, 1400 to 1720 and ppm of iron. The coarser particles were found, and this is not a surprise, in sample xx852 which is the sample with the higher iron content.



Figure 48: Left and right two different views of reference sample 100322689862: Left under bright field illumination and right using fiber optics. We can see that the blue areas are found in area without needles or particles as is expected for unheated stones. Field of view 10.08mm, photos: Victoria Raynaud © GIA.



Figure 49: Left and right two detailed views of the needles, particles and platelets found in reference sample 100322689862 using fiber optic illumination. Here, we see a combination of thin and arrow shaped needles intersecting at 60/ 120 degrees associated with coarser reflective platelets with irregular shapes. Field of view 1.45mm, photos: Victoria Raynaud © GIA.

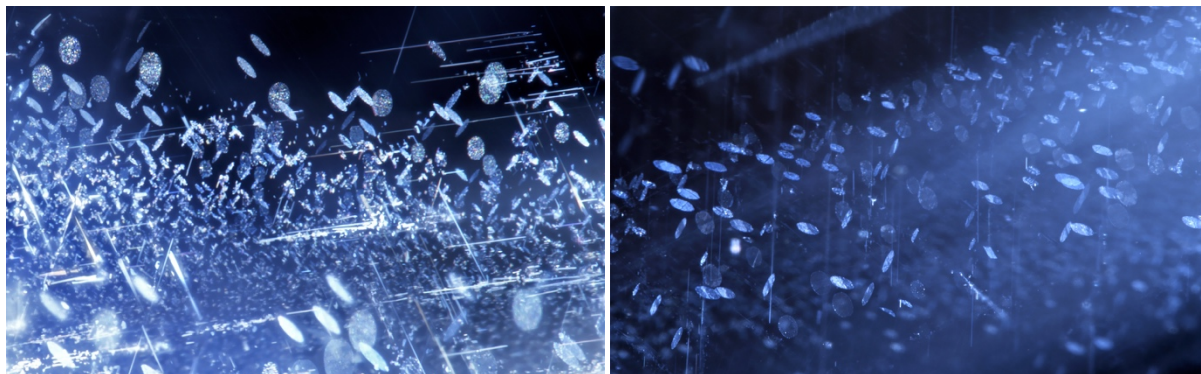


Figure 50: Left and right detailed view of needles associated with whitish reflective flake-like disks showing in most case a regular slightly oval regular shape seen in reference sample 100322689862 using fiber optic illumination. Field of view 1.58mm (left), 2.40mm (right), photos: Victoria Raynaud © GIA.

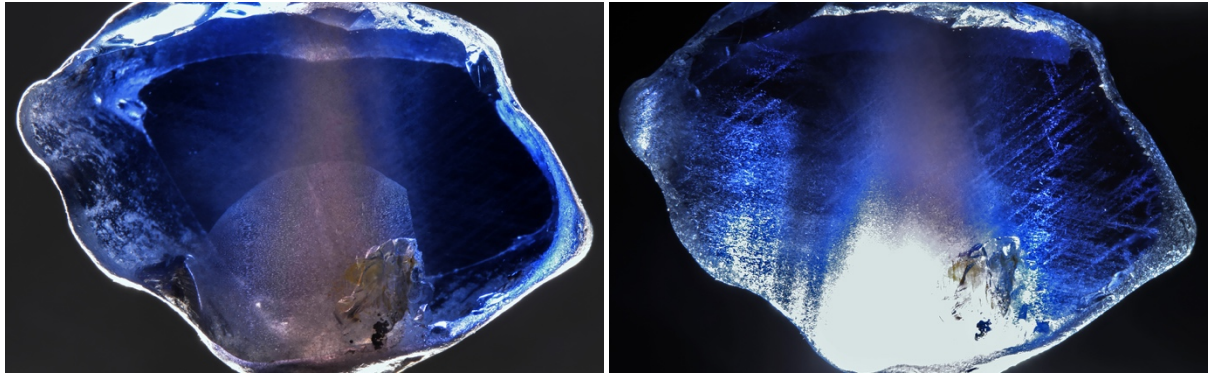


Figure 51: Left and right two different views of reference sample 100322689866, left under dark field illumination, right using fiber optic illumination. We can see that the sample is very silky and more particularly in the central brownish band. Most of the blue areas are actually mostly free of any particles or needles. Field of view 9.64mm, photos: Victoria Raynaud © GIA.



Figure 52: Detailed view of the needles and irregularly shaped platelets found in reference sample 100322689866 using fiber optic illumination. Field of view 1.20mm, photos: Victoria Raynaud © GIA.

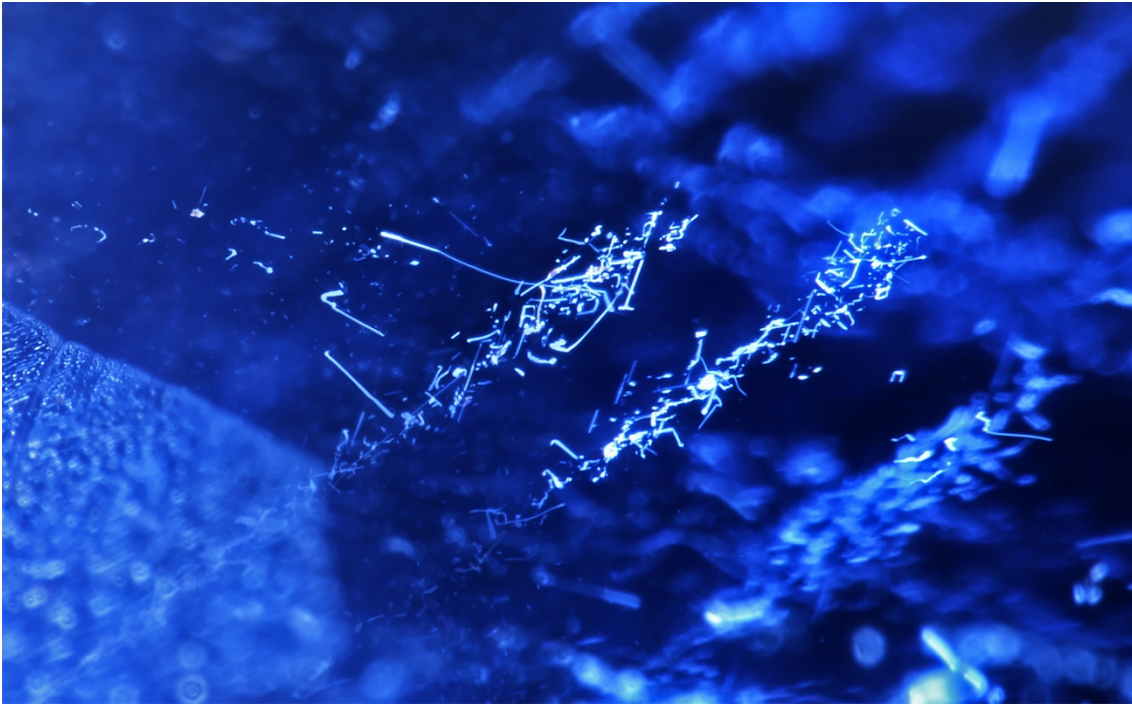


Figure 53: Another detailed view of the particles, needles and irregular platelets seen in reference sample 100322689866 using fiber optic illumination. Field of view 1.44mm, photos: Victoria Raynaud © GIA.

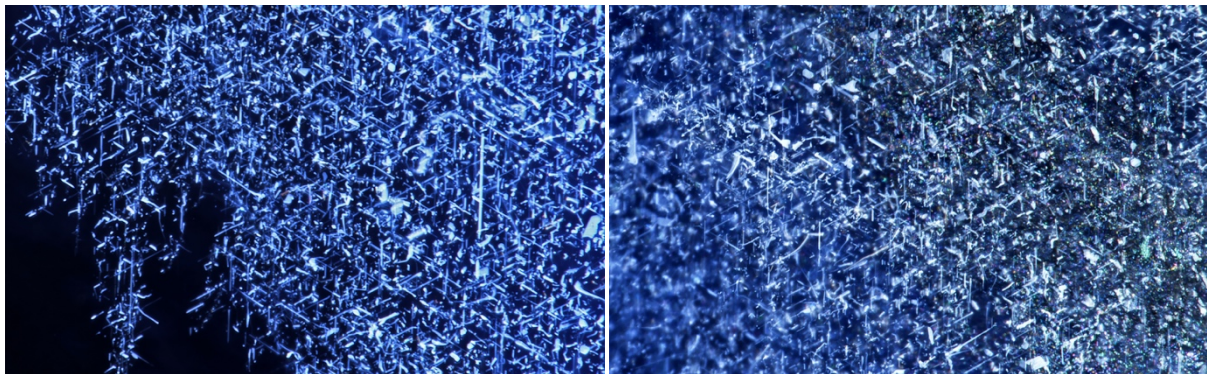


Figure 54: Left and right two different views of the particles and irregularly shaped platelets found in reference sample 100322689852 using fiber optic illumination. This sample has the highest iron content (nearly 1700 ppma) of all studied samples. Field of view 1.07mm (left), 1.44mm (right), photos: Victoria Raynaud © GIA..

Besides particles and needles, healed fissures were also commonly found in the samples examined. They were mainly composed of short isolated negative crystals, usually showing good iridescence.

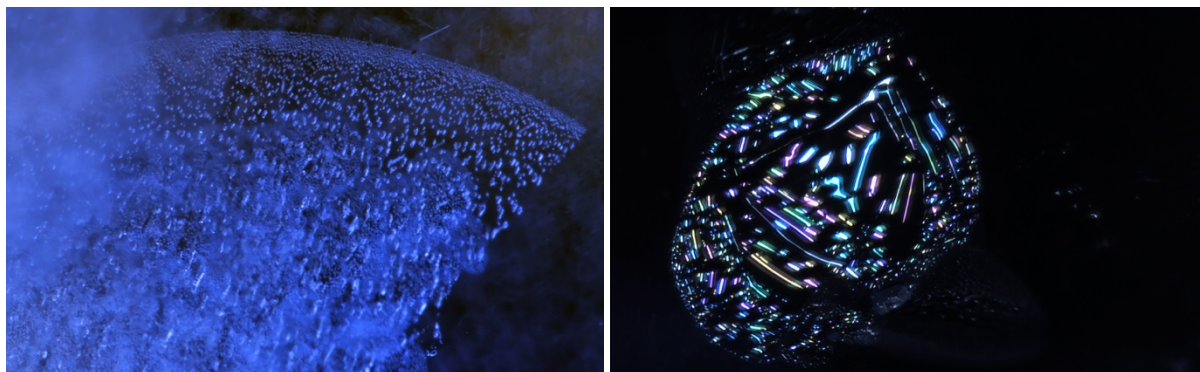


Figure 55: Detailed views on healed fissures found left in reference sample 100322689852 and right in reference sample 100322689841 using dark field illumination on the left and fiber optics on the right. Field of view 1.30mm (left), 1.00mm (right), photos: Victoria Raynaud © GIA.

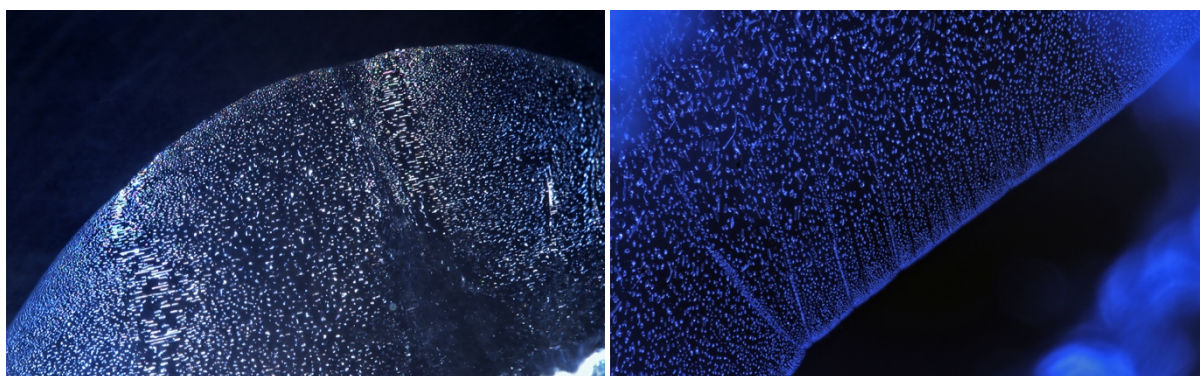


Figure 56: Detailed views on healed fissures found left in reference sample 100322689866 (using fiber optic illumination) and right in reference sample 100322689852 this time under dark field illumination. In both case the healed fissures are composed of short isolated negative crystals. Field of view 2.88mm (left), 1.44mm (right), photos: Victoria Raynaud © GIA..

Besides particles and needles, the crystal inclusions found in sapphires from Ambatondrazaka area are very similar to those usually seen in metamorphic blue sapphires from the Didy area (Pardieu, 2012) The main crystal inclusions seen in sapphires from the Ambatondrazaka area are feldspar, mica and zircon crystals.



Figure 57: Left and right two different views of the same area in reference sample 100322689841, left under fiber optic illumination, right under bright field. We can discover here a group of rounded transparent crystals identified using Raman as feldspar (Using the RUFF Database as reference) associated with short needles. Interestingly using bright field we can see that most of these feldspar crystals are associated with a tiny black spot of unknown nature. Field of view 1.20mm, photos: Victoria Raynaud © GIA.



Figure 58: View of GIA reference sample xx841 using dark field, we can discover some healed fissures associated with a group of rounded transparent feldspar crystals. Field of view 1.12mm, photos: Victoria Raynaud © GIA.



Figure 59: Left and right two different views on inclusions found in reference sample 100322689846 using bright field illumination. Left: Two tabular transparent crystals identified as mica with Raman and right: Few transparent crystals associated with unhealed tension fissures identified as zircon with Raman (using the RUFF database as reference). Field of view 1.20mm (left), 1.44mm (right), photos: Victoria Raynaud © GIA.



Figure 60: Two different views on zircon crystals (identified with Raman using the RUFF database as reference) associated with unhealed tension fissures using bright field illumination. Left in reference sample xx845 and right in reference sample xx855. Field of view 1.07mm (left), 3.60mm (right), photos: Victoria Raynaud © GIA.

## Summary:

Blue sapphires are one of the most popular colored stones in the trade, thus the discovery of a new deposit producing attractive large stones is getting a lot of attention from the gem trade. In this particular case, the discovery is nevertheless raising some important issues as it is located at Bemainty, deep inside a forest covered area dedicated to conservation.

Furthermore, the preliminary study of a parcel of blue sapphires reportedly from that new deposit shows that the identification of the origin of these stones will be very challenging as the material produced from that area seems to cover a wide range from milky “geuda” type stones with low iron content very similar to those produced in Ilakaka (Madagascar) and from Sri Lankan deposits and also it produces stones with higher iron content showing a more silky aspect reminding in this case blue sapphires produced from deposits in Mogok (Myanmar), Tunduru or Umba (Tanzania).

These stones will present some serious challenges for laboratories trying to identify the geographic origin of blue sapphires based on the inclusion scene and simple trace element chemistry. Some more in-depth study of these stones will be necessary in order to be able to find a way to identify their geographic provenance with confidence.

## About the Authors:

Vincent Pardieu (vince@fieldgemology.org) is a Bangkok based independent researcher.

Wim Vertrieest (wvertrie@gia.edu) is field gemologist at GIA in Bangkok.

Ungkhana Atikarnsakul (uatikarn@gia.edu), Vararut Weeramankhonlert (vweeramo@gia.edu), and Victoria Raynaud (vraynaud@gia.edu) are analysts at GIA in Thailand.

Rosey Perkins (rosey\_perkins@yahoo.co.uk) is an independent London based gemologist.

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## Annex A: GIA Field Gemology cataloguing System

This system was developed at the GIA Field Gemology department to precisely document the way in which a given research sample was collected.

### **A conditions: Mined/collected by the field-gemologist.**

- A1: Collected in-situ from a primary deposit by the field-gemologist.
- A2: Collected on the floor/mine waste at the mine (primary/secondary) by the field-gemologist.
- A3: Collected after digging in a secondary deposit by the field-gemologist.

### **B conditions: Field-gemologist witnessed the mining.**

- B1: Collected on site in jig/sieve from the mine in a secondary type deposit by field-gemologist.
- B2: Collected on site in miner's bottle from mine in a secondary type deposit by mines or by field-gemologist.

### **C conditions: Field-gemologist collected from miners at the mine but without witnessing the mining process.**

- C1: Collected at mine from mine owner (not mined that day in front of field-gemologist's eyes).
- C2: Collected at mine from miner on site (not mined that day in front of field-gemologist's eyes).

### **D conditions: Field-gemologist collected the stones from miner but not at the mines.**

- D1: Collected from mine owner (at HQ near the mines).
- D2: Collected from miner (near the mines).
- D3: Collected from person claiming to be a miner (mine not visited).
- D4: Collected from miner in regional/international market.

### **E conditions: Field-gemologist collected the stones from a secondary source close to the mines.**

- E1: Bought from trusted secondary source (gemologist/dealer/broker) at local market (close to source).
- E2: Bought from trusted secondary source (gemologist/dealer/broker) at regional market (close to source).
- E3: Bought from unknown secondary source at local gem market (close to source).
- E4: Bought from unknown secondary source at regional gem market (close to source).

### **F conditions: Field-gemologist collected the stones from a secondary source in international market.**

- F1: Bought from unknown dealer at international gem market (gem show...).
- F2: Bought from trusted source (gemologist/collector/dealer...) in an international market.
- F3: Bought from a lab client after the stone was submitted to the GIA Laboratory.

### **Z conditions: No information about how the stone was collected.**

- Z1: Lost information.
- Z2: No information.

## Bibliography:

Besairie, H. (1966). "Gîtes minéraux de Madagascar." *Annales Géologiques de Madagascar*, Vol. 1, No. 34, 437 pp.

Fritsch, E. and Mercer, M., (1993). "Blue color in sapphire caused by Fe<sup>2+</sup>/Fe<sup>3+</sup> intervalence charge transfer", *Gems & Gemology*, Vol. 29, No. 3, Fall 1993, Letters pp. 151 and 226.

Ferguson, J., and Fielding, P.E., (1971). "The origins of the colours of yellow, green, and blue sapphires", *Chem. Phys. Lett.*, Vol. 10, pp. 262-265.

Hughes, R. W., Pardieu, V., et al. (2006). "Sorcerers & sapphires: A visit to Madagascar." *The Guide*, Vol. 25 (Issue 1, Part 1, January–February): pp. 1, 4–6.

<http://www.lotusgemology.com/index.php/library/articles/161-sorcerers-sapphires-a-visit-to-madagascar>

Hughes, R.W., Manoratkul, W., Hughes, B., (2015). "Let it bleed - New rubies from Madagascar", <http://www.lotusgemology.com/index.php/library/articles/322-blood-red-rubies-from-madagascar-lotus-gemology>

Lacroix, A. (1922, 1923). *Minéralogie de Madagascar*. Paris, Société d'Éditions Géographiques, Maritimes et Coloniales.

Leuenberger, A., (2001). "The new ruby deposits in eastern Madagascar: Mining and production." *Gems & Gemology*, Vol. 37, No 2, Summer 2001, pp. 147-149.

Pardieu, V. (2005). "Lead glass filled/repared rubies.", [http://www.fieldgemology.org/Ruby\\_lead\\_glass\\_treatment.pdf](http://www.fieldgemology.org/Ruby_lead_glass_treatment.pdf)

Pardieu, V. and R. M. Wise (2005). *Ruby boom town*. Colored Stone.

Pardieu, V., (2007) "Discovering beryllium in Madagascar blue sapphires.", *InColor Magazine*.

Pardieu, V., Saewseaw, S., Thirangoon, K., Lomthong, P., (2011), "Beryllium- and Tungsten-Bearing Sapphires from Afghanistan.", *Gems & Gemology*, Vol. 47, Spring 2011, pp. 53-54.

Pardieu, V., Rakotosaona, N., (2012), "Ruby and sapphire rush near Didy, Madagascar (April - June 2012)", [http://www.giathai.net/pdf/Didy\\_Madagascar\\_US.pdf](http://www.giathai.net/pdf/Didy_Madagascar_US.pdf)

Pardieu, V., Sangsawong, S., Detroyat, S., (2015), "Rubies from a new deposit in Zahamena National Park, Madagascar", *Gems & Gemology*, Vol. 51, No 4, *Gems News International*, pp.454-456, <https://www.gia.edu/gems-gemology/winter-2015-gemnews-rubies-new-deposit-zahamena-national-park-madagascar>

Perkins, R., (2016) "Thoughts on a visit to a sapphire rush near Ambatondrazaka, Madagascar", [www.roseyperkins.com](http://www.roseyperkins.com), <http://roseyperkins.com/visit-sapphire-rush-near-ambatondrazaka-madagascar/>

Perkins, R., (2016) "Visit to sapphire rush East of Ambatondrazaka, Madagascar",  
www.roseyperkins.com, <http://roseyperkins.com/sapphire-rush-madagascars-rainforest/>

Perkins, R., (2016) "Sapphire rush East of Ambatondrazaka, October 2016", www.roseyperkins.com,  
<http://roseyperkins.com/sapphire-rush-east-ambatondrazaka-oct-2016/>

Rakotondrazafy, A. M. R., Giuliani, G., Ohnenstetter, D., Fallick, A.E., Rakotosamizanany, S.,  
Andriamamonjy, A., Ralantoarison, T., Razanatseheno, M., Offant, Y., Garnier, V., Maluski, H.,  
Dunaigre, C., Schwarz, D., Ratrimo, V., (2008). "Gem Corundum Deposits of Madagascar: A Review."  
Ore Geology Reviews (34): pp. 134-154.

Shen, A., Lu, R., (2011). "Unusually High Beryllium in Three Blue Sapphires.", Gems & Gemology, Vol.  
47, No.3, pp 232-233.

Smith, C.P., (1995). "A contribution to understanding the infrared spectra of rubies from Mong Hsu,  
Myanmar.", Journal of Gemmology, Vol. 24, No.5, pp. 321–335.

Smith, C.P., Kammerling, R.C., Keller, A.S., Peretti, A., Scarratt, K.V., Khoa, N.D., Repetto, S., (1995).  
"Sapphires from southern Vietnam." Gems & Gemology, Vol. 31, No. 3, Fall 1995, pp. 168–186.