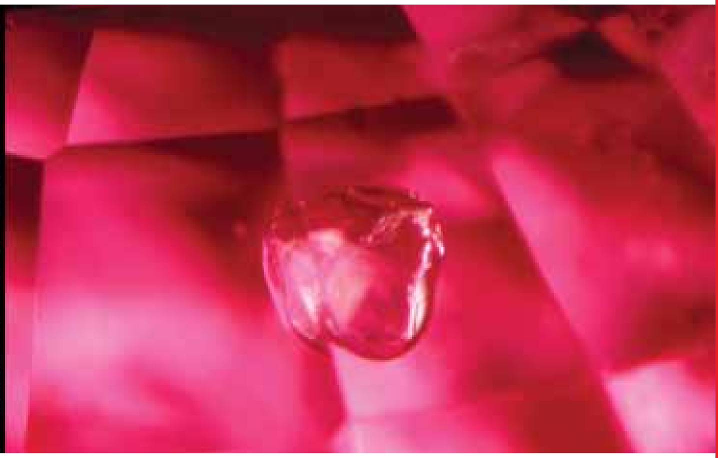
Contributions to Gemology

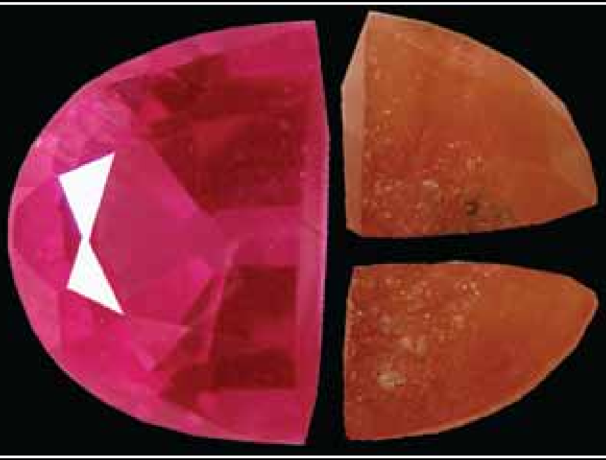
No.2 August 2003

Report on a Ruby and Spinel Mine in Namya (Northern Burma)



Identification of Spinel and Ruby from Namya

Rare Gemstone: Painite



Beryllium Treatment (Part B)

GRS GEMRESEARCH SWISSLAB

Message From The Editor's Desk

GRS is honored and proud to welcome you to our second issue of Contributions to Gemology. We are working and striving continuously to share knowledge, research, and detailed information concerning the exciting field of modern gemology. Our first issue has already earned the respect and praise of the scientific and gemological community.

The international response and recognition included the "Award of Excellence" from a recognized Jewelry Association, and reviews in major newspapers around the world, as well as from Universities and trade organizations. The details and responses are all available from our website at *www.gemresearch.ch/news/RFC.htm*

This issue is again our contribution to gemology and is our way of sharing news and exciting discoveries with the public, the trade and the scientific world.

While our first journal primarily focused on scientific analyses of a new treatment, this issue will also cover various gemmological as well as mineralogical topics.

Let us share with you the exciting moment an extremely important ruby and spinel mine was discovered in Burma, called "Namya" or "Nant Yah". In 2001, GRS made an expedition by elephant to a completely new locality in Burma, never before visited by a gemological laboratory. This inside story documents the continuous challenge the laboratory faced to constantly update its reference materials from new mines and new localities. This important research and the collection of reference samples is at the heart of a modern gemological laboratory.

Our first issue was published during the time of a hot international debate on a new corundum treatment. We focused on detailing and scientifically explaining what was happening.

The second Issue (Contributions to Gemology No. 2) will be divided into 4 sections:

1) The exciting expedition to the new ruby and spinel mine in Burma.
2) Gemological research and identification of the new rubies and spinel from Namya (pronounced Naya).
3) New and rare collector gemstones (such as "Painite").
4) GRS and Swiss Federal Institute of Technology (SFIT) new joint research and important information on Beryllium treated corundum (Part B).

At GRS we strive to be on the leading edge of modern gemological research. We are proud to present this second issue which also contains a VCD. We believe that information and knowledge is only important if it can be shared with the world.

Here is our Contributions to Gemology.

Thank you and let us now take you on an adventure to the origin of magnificent Burmese rubies and spinels.

July 2003, Lucerne, Switzerland.

Dr. Adolf Peretti FGG FGA
European Geologist

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Publisher

J.C.C. Printing Co., LTD. Bangkok, Thailand

Distributor

GRS (Thailand) Co., LTD.
388 Mahaesak Rd., Bangkok 10500, Thailand.

Direct orders by Internet

www.gemresearch.ch
keyword "GRS Pioneer Issue"

Price : 50.- US $

Abstract

The "Second Issue of Contributions to Gemology" focuses on the latest news from the world of gemological discoveries.

New mines producing "pigeon's blood" rubies and vibrant colored spinels have been found in a remote part of Northern Burma (Myanmar) called "Namya". An intriguing GRS expedition to Namya in 2001 is documented in a photo album and VCD movie report.

Gemological research and identification of the new rubies and spinels from Namya include the use of latest technology for chemical analyses (LA-ICP-MS).

Two more of the world's rarest collector gemstones - "Painite" - have been found which resulted in scientific research cooperation.

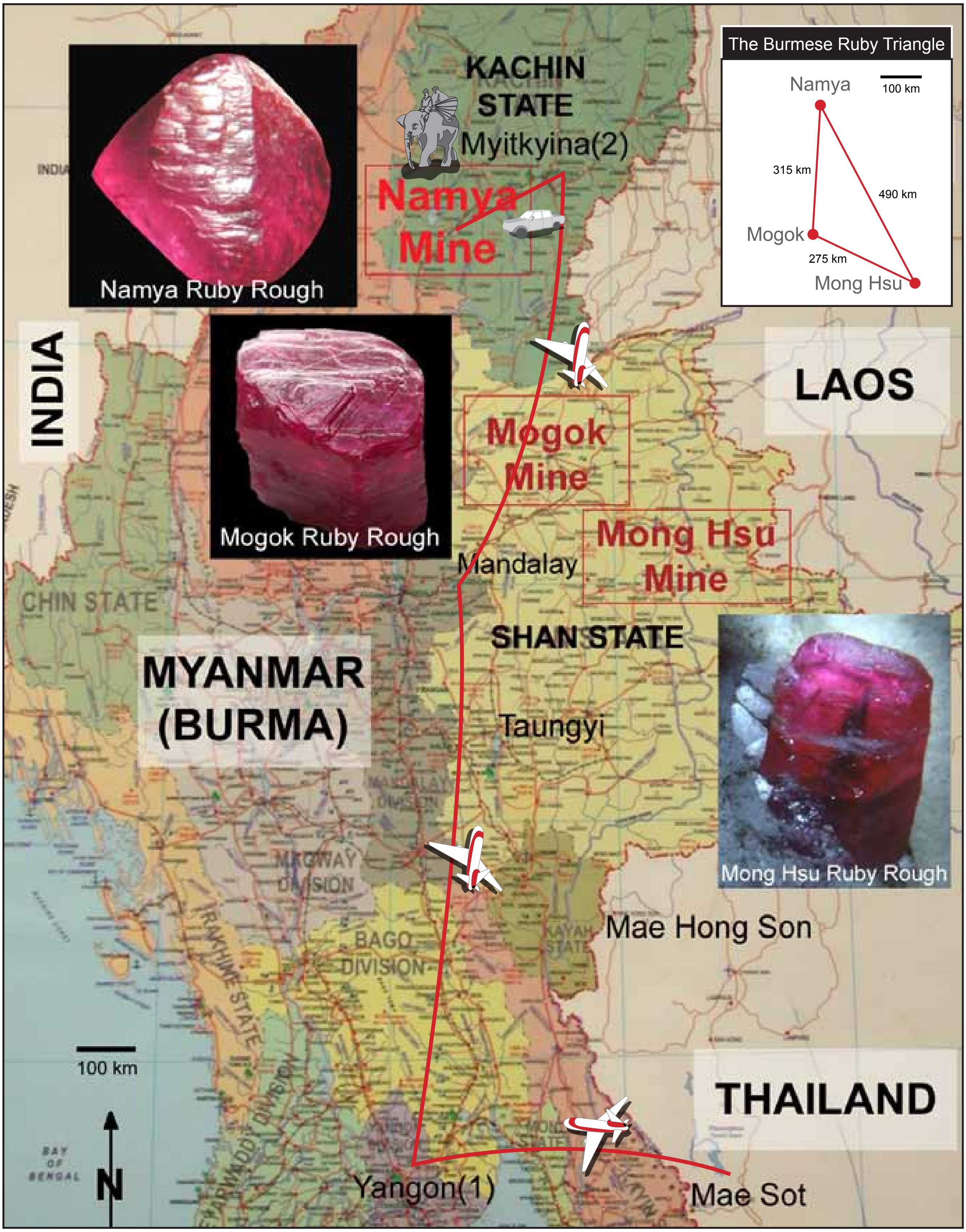
Part B of the contribution to the understanding of a new treatment for corundum is the research on Beryllium-treated pink sapphires and rubies.

What's inside?

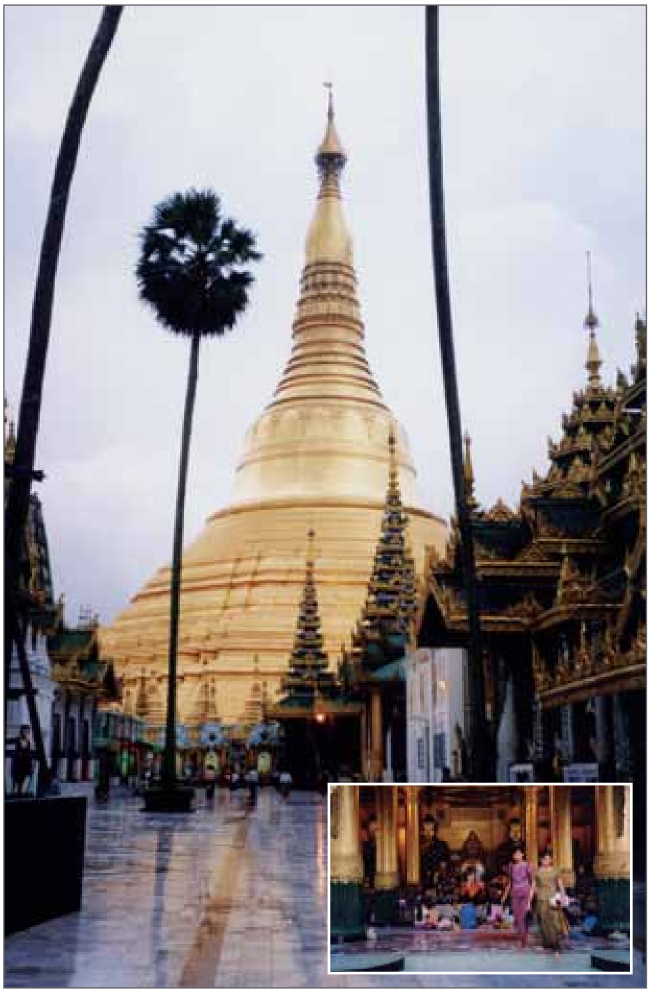
Expedition to the Namya Mines in Northern Burma

Adolf Peretti(*) and Anong Kanpraphai (**)

* GRS Gemresearch Swisslab LTD, Lucerne, Switzerland
** GRS (Thailand) Co., LTD, Bangkok, Thailand

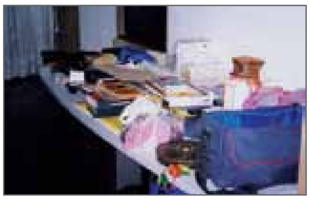


Shwedagon Pagoda, Yangoon (Myanmar)



The well-known Shwedagon Pagoda in Yangoon, Burma (Myanmar).

Preparation for expedition to the ruby mines in Northern Burma: From Myitkyina to Namya



A 4 wheel drive pick-up with high-wheels is an absolute necessity for the drive from Myitkyina to the Namya mining area. The expedition material list was extensive and included a digital camera, camera film (for backup) and video, a portable laboratory (including a microscope), GPS for satellite orientation, various Burmese language dictionaries, packing material for collection of reference samples (and labeling ruby samples), a portable kitchen with gasoline stove, a first aid kit, extensive preventive medicine (including anti Malarial, antibiotic and anti diarrhea drugs) and water cleansing chemicals.

Map of the Central and Northern Part of Burma (Myanmar) showing 3 major mining areas of commercial importance: Mong Hsu, Mogok and Namya. The mines are found in a distance of several hundred kilometers (see inserted "Ruby mine triangle"), and the 3 typical rough stones from these mines are shown: A rough ruby with bluish core (as formed in the marble-mother rock) from Mong Hsu; an over 50 ct rough ruby with well-established crystal growth faces from the Dattaw mine in Mogok; and a 2ct rough ruby with its own characteristic growth features from Namya. Both Mogok and Mong Hsu mines are found in the Shan States of Eastern Burma, which border Thailand, Laos and China (the so-called "Golden Triangle" region). The Namya mines are situated in the Kachin State in the Northern part of Burma, which borders China in the East, and India in the West. The expedition to the mines was separated into 5 different steps:

1.) a flight from Bangkok to Yangoon (Capital of Burma, Myanmar);

2.) a flight from Yangoon to Mandalay;

3.) a flight from Mandalay to Myitkyina;

4.) a cross-country car ride from Myitkyina to Namya, and

5.) a messy elephant ride (during the rainy season) to the mining area.

Myitkyina



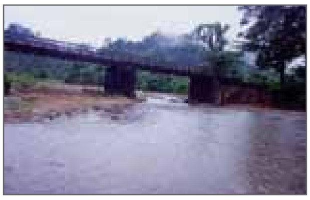



The scenery in Myitkyina (Kachin State). Impressions: Buddhist temples, kiosk with local journals, local housing, and some road infrastructure from WWII. Driving on unpaved country roads from Myitkyina to Namy: the landscape is dominated by rice fields, rivers and farming. Notably absent is any modern agricultural machinery.

Rainy season road conditions (July 2001) on the way to the Namya mine. This main road over a hilly pass connects the central part of Kachin state with the Namya ruby and Pagan Jade mines. Heavy traffic often delays public transportation by days, or renders any passage virtually impossible during heavy rain

On the way from Myitkyina to Namya (25° 18.42N/ 096° 56.31E)






Landscape on the way to Namya





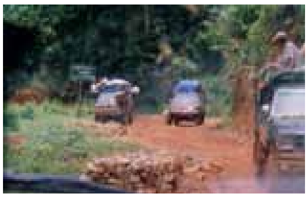



Road conditions on the way to Namya (25° 36.98N/ 096° 34.94E, 773Ft)









Namya village (25° 37.73N/ 096° 33.17E, 525 Ft)






We finally entered the village of Namya after days of delay caused by muddy roads and traffic jams. Hotels and good food were scarce in the village in July 2001, thus food quality needed to be constantly monitored. Basic fresh food, including rice, eggs and corn, was cooked in local kitchens.

Hiring Elephants at Namya







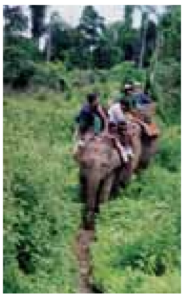
We switched transportation to elephants for the daily excursions into the jungle mining areas, making sure to prepare a day bag, including a camera, a change of clothing, a first-aid kit, bags for samples and labeling, gemological equipment (a portable laboratory), camera equipment, malaria and other insect bite prevention (long white trousers and spray), boots for working at the mines, extensive sun protection, sunglasses, and enough food and water for two days (2 liters of water per person per-day). All bags were placed in the baskets on either side of the elephants. A secondary elephant also followed carrying a government guide with stamps and permission from the government to enter the mines and wireless communication. The expedition route was monitored by a satellite positioning system (GPS).

By Elephant to Sabow Mining Camp (near Namya)











*Hiring an elephant is a must. Along the way we constantly came across foolhardy adventurers who were either too exhausted to continue, were suffering from the effects of the sun, or couldn't cross 1-2 meter deep rivers. Elephants also keep you away from natural predators such as snakes, ants, bugs, and mosquitoes, as well as any difficult vegetation. The terrain is also covered with dangerous mine shafts and tunnels, which should only be negotiated on elephant back.

Sabow Mining Camp near Namya (25° 30.74N/ 096° 32.87E, 524 Ft)

Entering the Sabow mining area (which maintains the characteristics of a gold rush town, except here the hunt is for rubies and spinel). Infrastructure - food, a barber's kiosk, entertainment and gambling activities - was in limited supply. Upon arrival we were dramatically received by local law enforcement personnel, who wrongly assumed we had arrived at the restricted area without permission. We soon discovered we were the first foreigners ever to do so.

Mining at Sabow Mining Camp (near Namya)

Our main purpose at the mine was to investigate the scale of mining activity, to study the occurrence of rubies, collect reference samples, and to film and document the mining activities. This would eventually lead to a guide on the commercial importance of the mine, while providing the lab with valuable reference samples. It became evident that the mining activities were relatively well mechanized with diesel motor driven high pressure hoses and several washing places prevalent. The mining was near surface in secondary sedimentary deposits, composed of fine grained clay soils and marble fragment sands. Mining activities were constantly on the move to new areas for near surface mining, gradually covering an increasing larger area and causing rapid deforestation.

Checking Gemstones at the Sabow Mining Camp

By Elephant to Manow (near Namya)

Sabow was also home to a makeshift hut incorporating a temporary restaurant, which was in extremely close proximity to the mine. The location gave us an ideal place to set up our laboratory, including a binocular microscope with fiberoptic illumination run on a battery supply. Through one of our local guides, we organized an inspection of currently and previously produced rubies. We bought the samples with characteristic inclusions, and proceeded to journey by elephant to another mining spot, yet were intercepted by a none-informed armed police patrol that placed us - and our elephants - under short arrest. It became evident that entering such areas without accreditation is near impossible, and of very high risk, as even with official papers we still had to enter into tough negotiation before we were allowed to continue our journey.

Manow Mining Camp (25° 37.34N/ 096° 32.51E, 560 Ft)

Our journey continued with visits to different mines in the area, covering around 5km. At Manow mining camp we discovered a completely different scene. This mine had already been active for several years, it extended over a larger area, and mining was individually organized and on a much more primitive basis than the previous camp. Mining involved primarily digging the rubies directly from under the trees, and washing and dumping places were widely unorganized and spread over a large area. Groups of miners constantly circled our group, badgering us to buy their stones until agents appeared, desperately trying control the situation. The mine was multi-ethnic and they appeared to have greater experience in dealing with foreign buyers.

Mining at the Manow Mining Camp (near Namya)

Acquisition of Rough Ruby and Spinel Reference Samples at the Manow Camp (Namya)

The trip concluded with an enjoyable elephant ride back to the Namya village, where we began preparing for the exhausting journey back to Myitkyina. However, there was a cloud hanging over us - we were all well aware that soon we would have to embark on the much-dreaded journey back to Yangoon, where we would no doubt encounter numerous official road blocks, each with an officer demanding to see and collect a set of official documents from our guide, each around 150 pages deep. This is the price gemologists must pay to be the first to visit a new mining area.

Appendix:

A VCD Movie (see cover) is attached to this publication showing the details of the expedition. Included are details on studied inclusions characteristic of Namya rubies and samples of commercially important ruby and spinel. Please note the user instructions below.

Reference:

Peretti A. (2003): Expedition to the new ruby and spinel mine in Burma (Namya). Contributions to Gemology, No. 2, EXTRA VCD Movie

How to play this movie on a computer?

This VCD can be played in a PC. A movie player is automatically started when the VCD is put in the CD-drive, unless the auto play feature is disabled. If it is disabled, double click on VIPLAY.EXE.

The VCD can also be played in VCD/DVD players. DVD quality can be ordered by contacting http://www.gemresearch.ch

Warning: Authentic VCDs are marked with a GRS hologram. No hologram identifies an unauthorized copy.

Fig. B1 *An 11ct rough Namya Ruby appeared at an auction for a reserve price of over US$100 000.*

Fig. B2 *This unheated 11ct rough Namya ruby yielded an over 5 ct faceted gemstone*

Namya Rubies

by Adolf Peretti

GRS Gemresearch Swisslab AG, Lucerne, Switzerland

Every time a new mine appears on the market, a new challenge is presented to gemologists in gem testing laboratories all over the world, with regard to the positive identification of the new material against natural and synthetic counterparts. A review of international auctions on gemstones, such as Christie's and Sotheby's, showed that the auction houses state the country of origin in their catalogues, alongside international recognized laboratory reports (Reviewed at www.gemresearch.ch /auctions). This study presents the first results of the identification of Namya rubies collected by the expedition (Peretti and Kanpraphai, 2003, this issue). A total of 1000 samples were tested, and then stored in the permanent GRS reference collection. From the 1000 samples, approx. 30 gem quality faceted gemstones in the range of 3ct to over 10cts were investigated. They were available for testing as rough, and after cutting as finished faceted rubies (e.g. Figs. B3, B4). Other high valuable rough and faceted rubies were also investigated (An example of a high valuable rough is shown in Fig. B1, also published as lot 513 in the Union of Myanmar Sixteenth Gems & Jade Sale (2003) catalogue of the Myanmar Gems & Jade Auction (in the catalogue, "Namya" is written as "Nant Yah") with a reserve price of over US$100, 000 - final auction price not known at time of printing). Other samples of high valuable gemstones are shown in the VCD Movie in the Appendix.

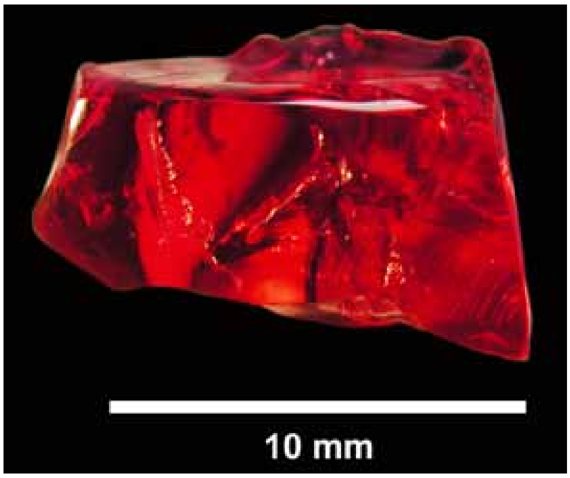


Fig. B3 *This preformed unheated vivid red Namya ruby exceeded 6 cts and was faceted to a magnificent ruby of over 3cts.*

Fig. B4 *Two examples of unheated vivid red "pigeon's blood" rubies from Namya (Burma/Myanmar) which were on the market in 2003. Courtesy C.H. Lapidaries LTD (Bangkok, Thailand)*

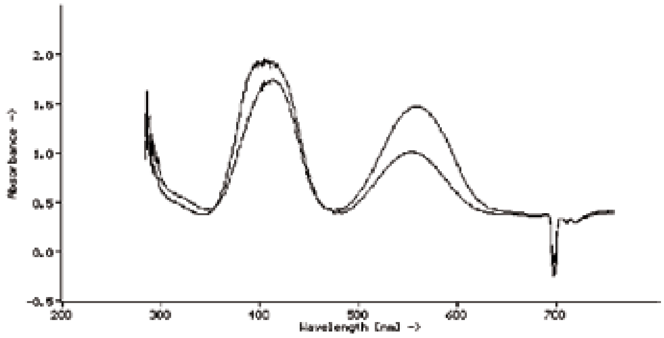


Fig. B5 Absorption spectra of Namya ruby characteristic of highly fluorescent rubies of low Fe and high Cr- concentrations, similarly known in Mogok rubies (including fluorescent lines produced by multi-channel spectroscopic measurements) .

Provided in this section is a photo album of inclusions in rubies authentically collected from the mines. The rubies are presently stored in the GRS collection for further research by Scanning Electron Microscopy and Raman spectroscopy. This project, however, is currently in preparation and is not the scope of this article. The purpose of the photo album is to help identification of these materials through microscopy. A

Namya pinkish-red Ruby		Li 7 ppm	Be 9 ppm	B 11 ppm	Na 23 ppm	Mg 25 ppm	Si 29 ppm	K 39 ppm	Ca 42 ppm	Ti 49 ppm	V 51 ppm	Cr 53 ppm	Mn 55 ppm	Fe 57 ppm	Co 59 ppm	Ni 61 ppm	Cu 65 ppm	Ga 69 ppm	Sn 120 ppm
ap09b09	Nr. 9	bd	bd	bd	8.06	152.0	762	12.1	bd	227.1	179.9	935	bd	224.3	bd	bd	bd	72.7	bd
ap09b10	Nr. 9	bd	bd	bd	0.92	168.0	654	bd	bd	217.2	173.1	758	bd	38.7	bd	bd	bd	72.8	2.15
ap09b11	Nr. 9	bd	bd	bd	5.93	165.0	bd	62.3	bd	220.6	238.1	1348	bd	183.5	bd	8.39	bd	79.2	1.13
	average	bd	bd	bd	(.97)	162.0	(521	(25)	bd	221.6	197.1	1014	bd	148.8	bd	bd	bd	74.9	(1.40
	stdev.	-	-	-	3.67	8.0	329	32.4	-	5.04	35.7	303	-	97.5	-	-	-	3.8	bd

Normalized to Al = 526604 (Detection limit - See Table)

Elements below detection:
Sc, As, Rb, Sr, Y, Nb, Mo, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Th, U, Bi, Pb, Zr

Origin	Namya	Namya	Namya	Namya	Namya	Namya	Namya	Namya	Namya	Namya
Sample	NAYA-0.343	NAYA-0.421	NAYA3-0.252	NAYA4-0.0343	NAYA5-0.256	NAYA6-0.269	NAYA7-0.182	NAYA-1.92	NAYA-0.77	NAYA-0.69
Color	colorless	pink	pink	pink	pinkish-red	vivid red	deep red	purple	purple-pink	vivid red
Cut	faceted	faceted	faceted	faceted	faceted	faceted	faceted	rough	rough	rough
TiO_2	0.028	0.022	bd	0.015	0.034	0.003	0.006	0.042	0.029	0.039
V_2O_5	0.059	0.013	0.076	0.062	0.115	0.156	0.13	0.058	0.238	0.56
Cr_2O_3	0.039	0.119	0.21	0.329	0.353	1.204	1.561	0.079	0.408	1.854
MnO	bd	bd	0.002	bd	bd	0.008	0.012	0.001	bd	0.006
Fe_2O_3	0.028	0.006	0.026	0.018	0.018	0.017	0.009	0.024	0.025	0.08
Ga_2O_3	0.02	0.004	0.013	0.005	0.024	0.014	bd	0.013	0.011	0.031

Origin	Pyen Pit	Pyen Pit	Mogok	Mogok	Mogok	Mogok	Mogok
Sample	12624-0.910	12625-1.226	12627-1.150	12613-4.932	12602-0.613	12603-0.632	BU-0.864
Color	pastel pink	pastel pink	pastel pink	pink	pink	pink	vivid red
Cut	faceted	faceted	faceted	faceted	faceted	faceted	faceted
TiO_2	0.005	0.008	0.011	0.009	0.071	0.005	0.032
V_2O_5	bd	bd	0.009	bd	0.11	0.033	0.197
Cr_2O_3	0.013	0.016	0.005	0.007	0.18	0.122	0.916
MnO	0.001	bd	bd	0.002	bd	bd	bd
Fe_2O_3	0.437	0.409	0.077	0.065	0.017	0.009	0.016
Ga_2O_3	0.014	0.017	0.014	0.017	0.021	0.013	0.008

***Tab.B1** Chemical analyses of rubies by ED-XRF in wt.-% (by Dr. A. Burkhardt, IFZAA, Switzerland) and LA-ICP-MS analyses (in ppm, on the top) by the Laboratory of Inorganic Chemistry, SFIT, Zurich.*

comparison is made between rubies from the classical mining area of Mogok (Myanmar) and rubies from Namya (Myanmar) on the basis of chemical and spectroscopic testing using ED-XRF and LA-ICP-MS and absorption spectroscopy.

Gemmological properties

Color

All different color varieties have been found, ranging from light pink to vivid pink (belonging to the group of natural pink sapphires), to deep red. A set of rubies from the expedition material has been sorted in terms of increasing color and subsequently been cut to sizes ranging from 0.3 to 0.6 ct. Most vivid red colors can be found, including those which can be characterized as "Pigeon's blood" (See Photo Album Fig. 1,2)

A large quantity of rough are available from the colors that are graded as pinkish-red, either belonging to pink sapphires or pinkish-red rubies, depending on subtle differences in the number of red reflections emerging from a faceted stone face-up. Lines of pinkish-red to red rubies, sized 2-3 cts, were assembled in a circle according to size, shape and color (similar to a necklace format) for evaluation purposes (see VCD Movie in Appendix). Sets with such excellent clarity and brilliant color reflections are rare. Faceted rubies are characterized by clarity and brilliancy. For pinkish-red colors, occasionally purple overtones were present, and a small percentage of the tested materials were deep to dark red.

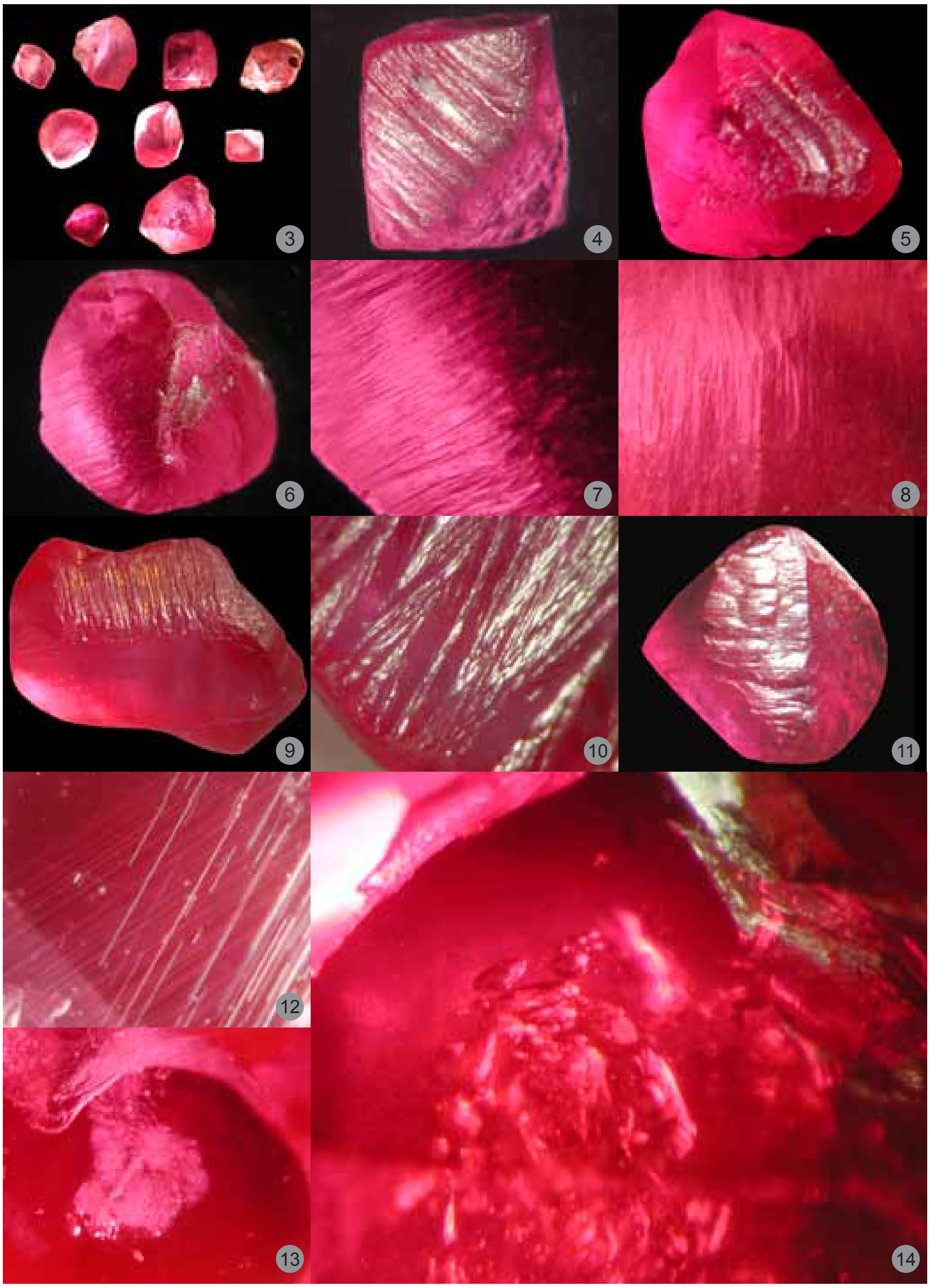
Commercial highly valuable fine red rough stones exceeding 10 ct were occasionally observed (see VCD Movie in Appendix). Large stones clean to the naked eye with fine color and excellent clarity do occur, but must be considered extremely rare (see VCD-Movie in Appendix). Rare single stones of "pigeon's blood" quality faceted in sizes of approx. 3 ct. do occur (see VCD Movie in Appendix), and should be classified as very rare.

The commercial importance of the Namya ruby mines

In general, the absence of cracks in the Namya rubies, the fluid feathers, the relative lack of inclusions, and the array of fine colors, will see the mine provide a new important source of unheated facetable goods of all color varieties. The rubies are of significant commercial size and value.

Before cutting: Rough rubies collected by the author at the Namya mines

After cutting: Faceted Namya rubies of pink to vivid red colors (below 1ct in size).



Rough crystals

The typical rough shape of Namya rubies is shown in Figs. 3, 4, 5, 6, 9, 11 and 24. A distorted triangle shape with irregular curved markings on the surface is clearly noticeable. A majority of the rubies tested were not water-worn and also did not exhibit typical pyramidal, rhombohedral, prismatic or pinacoid growth faces. Their formation was obviously related to interstitial growth in metamorphic rocks, such as marbles. Such triangular shapes are often observed in highly metamorphosed rocks.

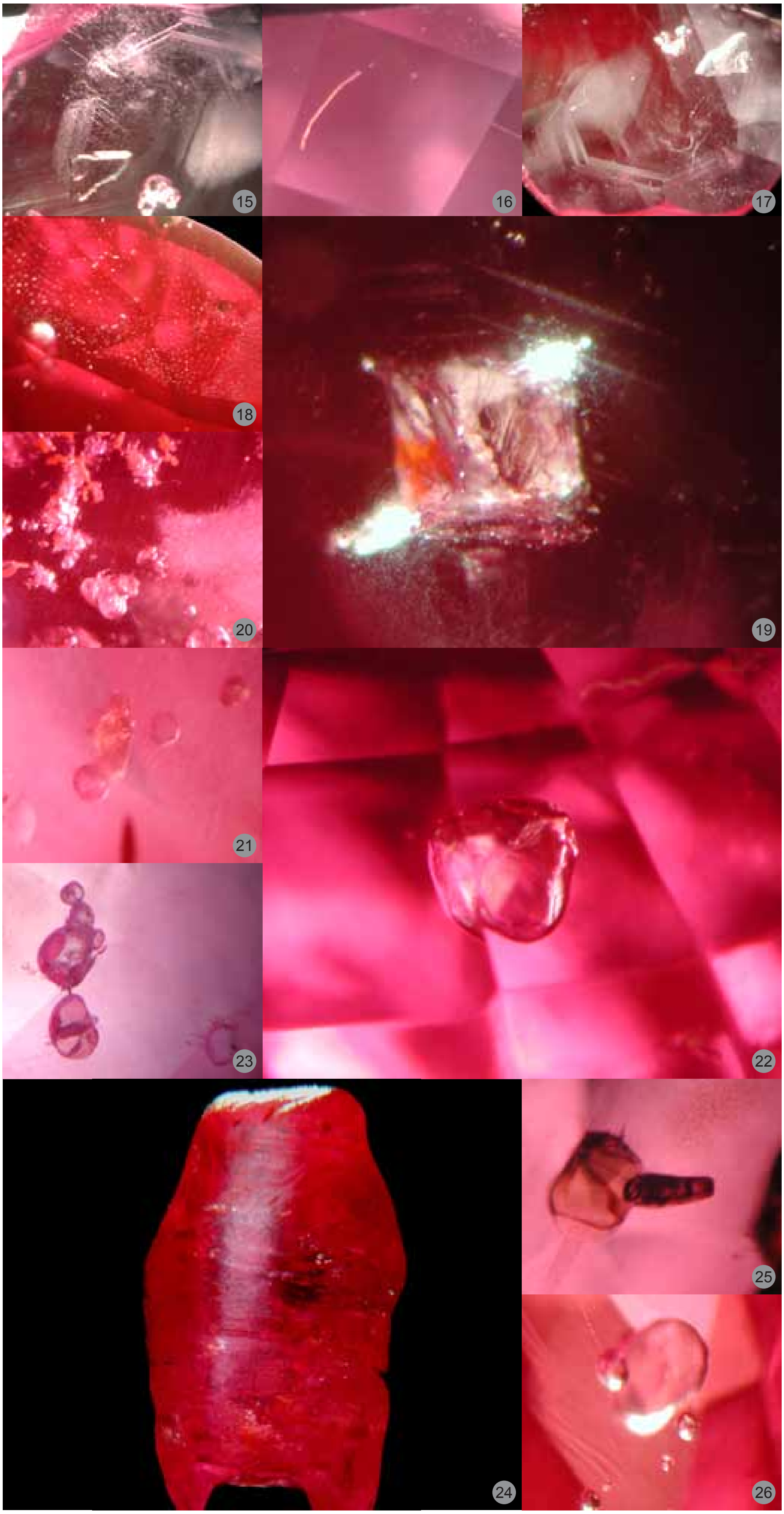
Inclusion description

3,4,5,6,9,11 = Rough Namya rubies.

7,8,10 = Typical surface markings on rough Namya rubies.

12 = Oriented rutile needle inclusions.

13 = "silk dust" and crystal inclusions in central part of the crystals.



Solid inclusions

- Concentrations of transparent inclusions in the center of the gemstones (Fig. 14).
- Irregular shaped crystal inclusions with rounded edges in different colors (Fig. 14, 21, 22, 26, 27, 29 and 36).
- Isometric round crystals with one prominent crystal face (Fig. 23).

Fluid feathers

Secondary healing feathers are remarkably rare (Fig. 18).
Irregularly shaped large negative crystals (Fig. 19).

Location Coordinates

25° 39.74N/ 096° 32.87E
Namya Mine (Sabow camp)
Fig. 3 - 23,37 - 38

25° 37.34N/ 096° 32.51E
Namya Mine (Manow camp)
Fig. 24 - 26, 28 - 29,
32 - 35

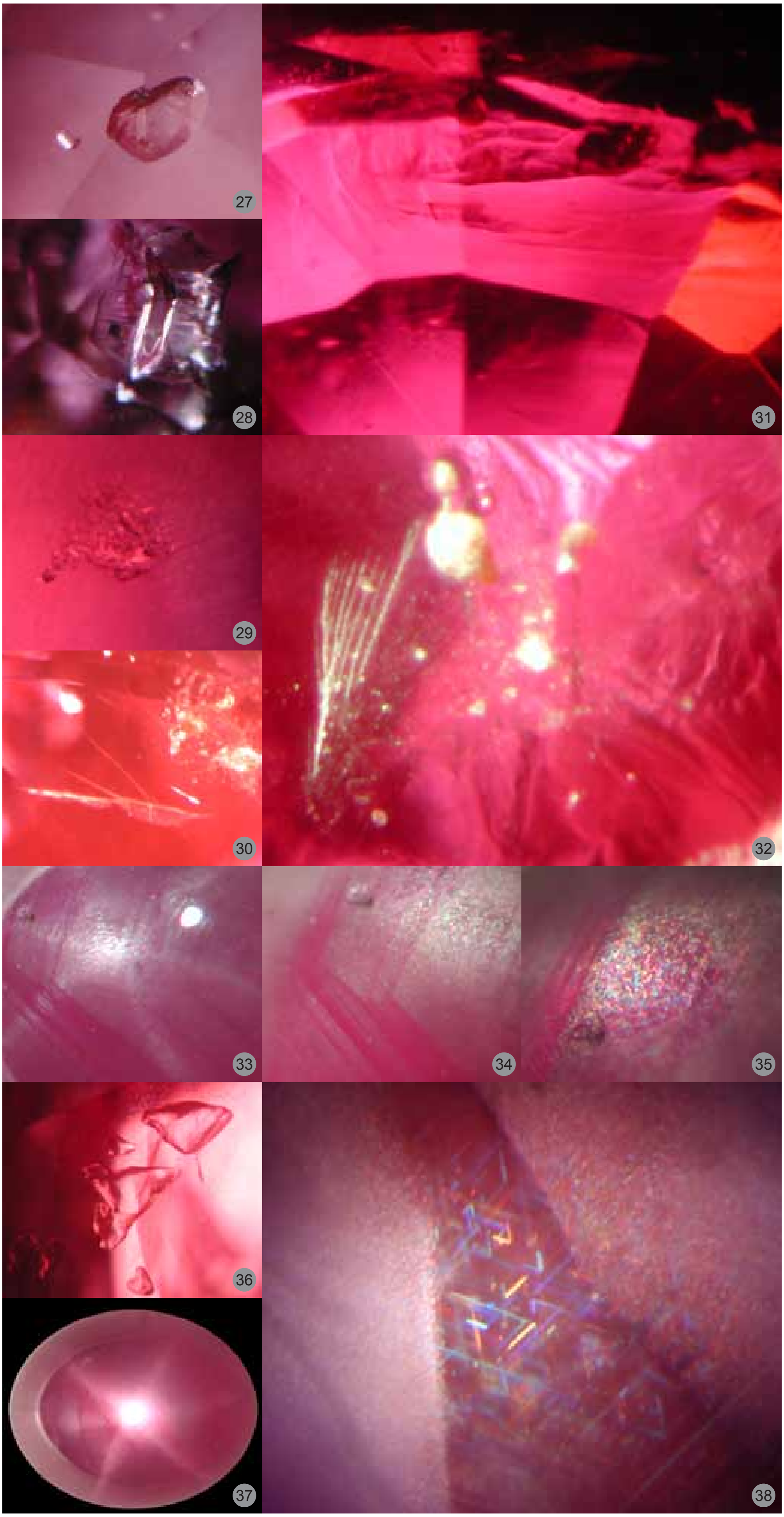
Inclusion description

15, 17 = Different arrangements of rutile in nests along internal growth features.

18 = Fluid feathers with isolated negative tubes.

19, 20, 21, 22, 23, 25, 26 = Inclusions of various shapes and arrangements.

24 Namya rough with rutile enrichments in central portions of the rubies.



Color zoning

Blue color zoning is largely absent. Swirled growth zones are found instead (Fig. 31 and Fig. 32).

Rutile needles

The most prominent type of inclusions are rutile inclusions of various arrangements:

- Short needles in dense networks (Fig. 34, 35, 38)

- Long loose needles of rutile (Fig. 12).

- Short needles concentrated along growth zones (Fig. 17).

- Oriented rutile needles emerging from concentrations of nests of short rutile needles (Fig. 15).

- Rutile needles may be dense and oriented causing a star effect (Fig. 37).

Inclusion Descriptions

27, 28, 29, 36 = solid inclusions of various shape, isolated, or clustered .

30 = Rarely observed non-rutile needles and twinning.

31, 32 = Swirled crystal growth and complicated irregular internal growth patterns.

33, 34, 35, 38 = oriented short rutile needles in arrangements producing star effect.

Gemological Properties

UV fluorescence: Very strong red in long UV, strong red in short UV.
Refractive indexes, densities were found in the normal range for corundum.

Chemical testing

ED-XRF analyses were performed on 10 rubies from Namya, and 7 samples from Mogok and Pyen Pit. Seven of the 10 Namya samples correspond to a master set ranging from near colorless, pink, and pinkish-red, to red, vivid red and deep red. Preliminary LA-ICP-MS analyses were performed on a typical pinkish-red Namya Ruby. For the details of the methods, see Peretti and Günther (2002).

Results

As shown in Tab. B1, the rubies from Namya are characterized by Cr-concentrations up to 1.5 wt-% (deep red overtones). The typical vivid red rubies ("pigeon's blood" color) have Cr-concentrations of approx. 1 wt-%.

Iron (Fe) -concentrations are below approx. 0.03 wt-%, titanium are also relatively low, vanadium concentrations show a high variability (up to relatively high values of over 0.2 wt.-%) and Ga - concentrations are relatively high (with some variations). Lighter elements, such as Lithium (Li), Beryllium (Be), and Boron (B) are below the detection limit. The relatively high V, Ga, Cr and low Fe values are typically found in rubies from Mogok and other rubies originating from marble deposits (see Muhlmeister et al. (1998).

Literature:

Muhlmeister S., Fritsch E., Shigley J.E, Devouard B., Laurs B.M. (1998): Separating Natural and Synthetic Rubies on the Basis of Trace-Element Chemistry. Gems & Gemology, Vol. 34, No.2, pp.80-101.

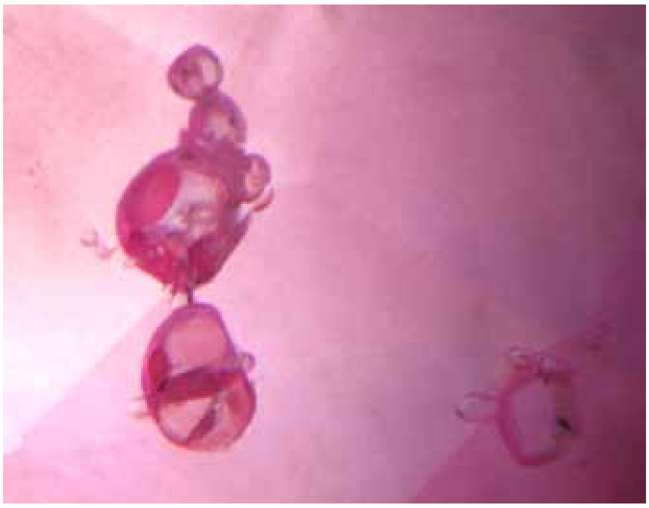


Photo Album Picture No.23 enlarged:
Solid inclusions in Namya rubies

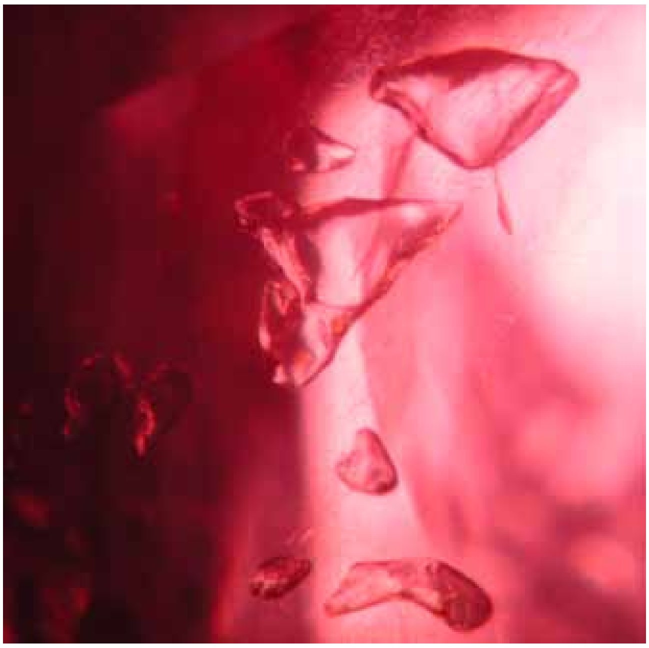


Photo Album Picture No.36 enlarged:
Typical solid inclusions in Namya rubies

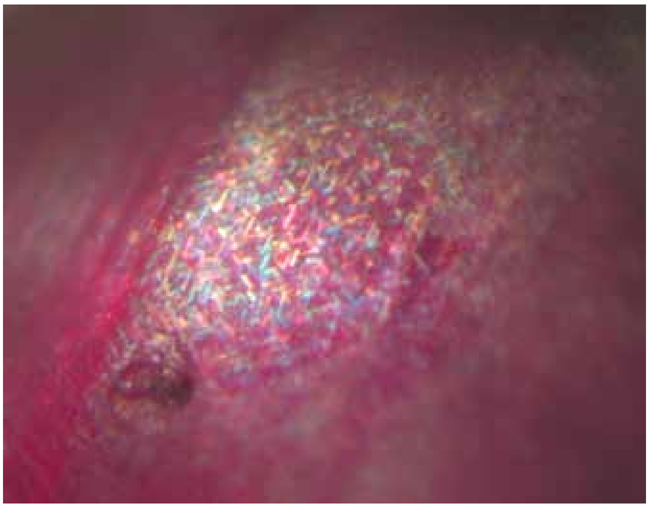


Photo Album Picture No.35 enlarged:
Rutile needles in Namya rubies

Spinel from Namya

By Adolf Peretti (*) and Detlef Günther (**)

(*) GRS Gemresearch Swisslab AG, Lucerne, Switzerland
(**) Institute of Chemistry, Swiss Federal Institute of Technology, Zurich, Switzerland.

During gemological testing at the Namya mines in 2001, spinel was discovered mixed in with the ruby lots. Further samples of these Namya spinel materials occurred later-on in the market in Bangkok at the end of 2002 and early 2003. The spinel soon gained market attention due to its unusually vibrant color (Fig. 1) (see VCD Movie in Appendix). Larger sizes over 10 cts were studied later on in the market as valuable specimens could not be acquired at the mining spots. In this report, we present chemical analyses for these spinels by LA-ICP-MS which were carried out in the Laboratory on Inorganic Chemistry of the Swiss Federal Institute of Technology in Zurich (Switzerland). In addition, absorption spectroscopy of different spinel from different origins were acquired. The focus of this analyses was on different spinel from Mogok and Namya, as well as two types of synthetic spinels.

For additional identification criteria, a photo album of spinel inclusions is attached.

Materials and Methods

Approx. 150 spinels were tested, the majority from the expedition to Namya, including a series of gem quality faceted Namya spinel from 1 to over 10cts originating from the market in Bangkok .

A representative set of samples was selected for testing by LA-ICP-MS (Tab. C1). From the synthetic material, approx 50 chemical analyses are presently available and are currently being expanded for further statistics. For details on methods see Guillong and Günther (2001) and Peretti and Günther (2002).

Comparison of Namya and Mogok Spinel

The color of the Burmese spinels (Mogok and Namya) stretches across the entire spectrum as shown in Fig. C4. Three different color groups can be distinguished:

Group A: Purple to green.

Color description: purple, violet, blue and bluish-green colors with variable color saturation from pastel to vivid, strong variation in tone, creating blackish overtones.

Absorption spectra: bands and lines in the range of

Fig. C1 *A series of commercially important faceted spinels are shown in the category of 2-3 carats in size. The first row shows 2 spinel from Mogok, the second and third row shows 4 spinels from Namya.*

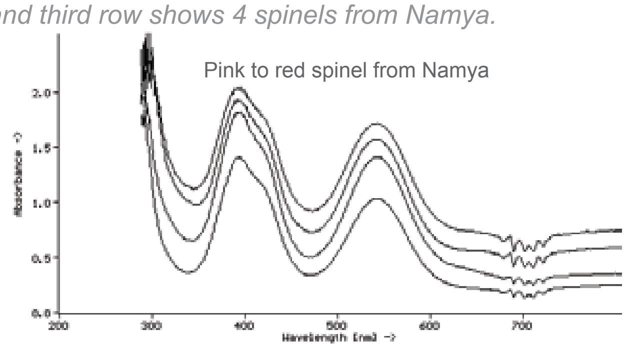


Fig. C2 *Absorption spectra of a series of pinkish-red to vivid red spinels from Namya.*

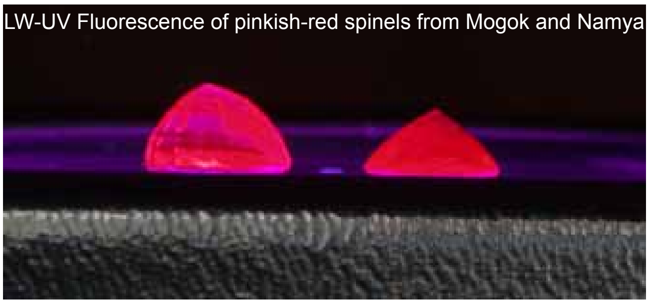
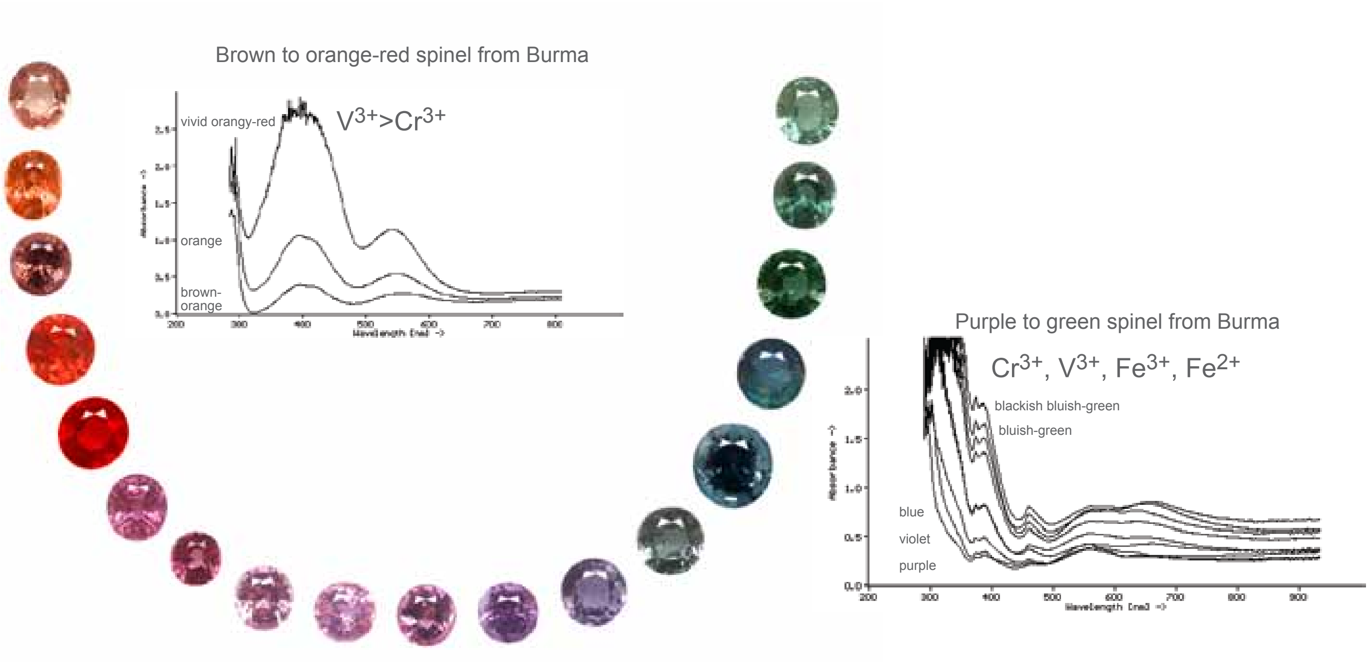


Fig. C3 *Two samples of the spinels with high fluorescence intensity are shown. Left side Mogok and right side Namya with subtle differences due to the variation in chemistry (see Tab. C1).*



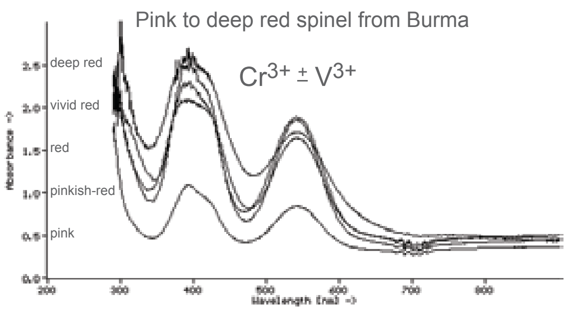


Fig. C4 *Different spinels from Namya and Mogok almost covering the entire color spectrum are shown (size 2-4 cts). The absorption curves of the different spinel colors were measured by UV-VIS-NIR spectroscopy (including fluorescent lines produced by multi-channel spectroscopic measurements). The origin of color is interpreted in terms of Fe2+, Fe3+, V3+, Cr3+ (Schmetzer et al. (1989)). For chemical compositions see Tab. C1 and Fig. C5*

630-650 nm, 550 to 565nm, 460nm, 387nm and 373nm. The absorption edge is typically found between 300nm to 350nm. Depending on the color (Fig. C4), the absorption spectra is variable with respect to the intensity of the 458 and 650nm bands, the 386nm and 374nm absorption bands and the 556nm band (Fig. C4). In greenish-colored samples, the 374nm line dominates the 386nm band. The UV absorption edge continuously shifts from 295nm (in purple colors) to 350nm in more greenish colored spinels (Fig. C4). The chemical composition of this group is characterized by trace elements Cr, Fe and Zn concentrations (Fig. C5 and Tab. C1).

Group B: Brown or orange-red colors

Color description: Red or pink color is modified by orange and/or brown.

Absorption spectra: Major bands at 550nm can be correlated with orange color components. The absorption minimum and edge in the UV is variable and can be correlated with the color. High Vanadium (V) concentrations were found in addition to Cr (Fig. C4, and C5).

Group C: Pink to vivid red Colors

Absorption spectra: Major absorption bands centered at 538nm and 391 nm as well as lines in the red region of the spectrum (Fig. C4). The absorption edge in the UV is found at 295 nm. The Namya spinel studied in this report belongs to this group as well as the Mogok spinels. These spinels have the highest UV transparency window (absorption band minimum at 342nm), the lowest total absorption edge towards the UV, and show fluorescent lines in the red region of the spectrum. Chemical composition is characterized by dominantly chromium and low iron concentrations. Additional light elements present were Lithium (Li) and Beryllium (Be), which were of special gemmological interest.

Other Gemological Data

The refractive index is lowest in pastel purple to green and orange to brown colors. It increases with color intensity and tone. The variation is, however, relatively small, covering a range between 1.715 to 1.719. The Namya and Mogok spinels of pinkish-red to vivid red colors are highest ranging from an RI of 1.719 to 1.720. Density of the spinels varies between 3.61 to 3.69.

UV fluorescence is found to be strongest in group C (Fig. C3). The highest level of fluorescence in this group is found in the Namya spinels
UV 254: Strong orangy-red
UV 365: Very strong orangy-red.

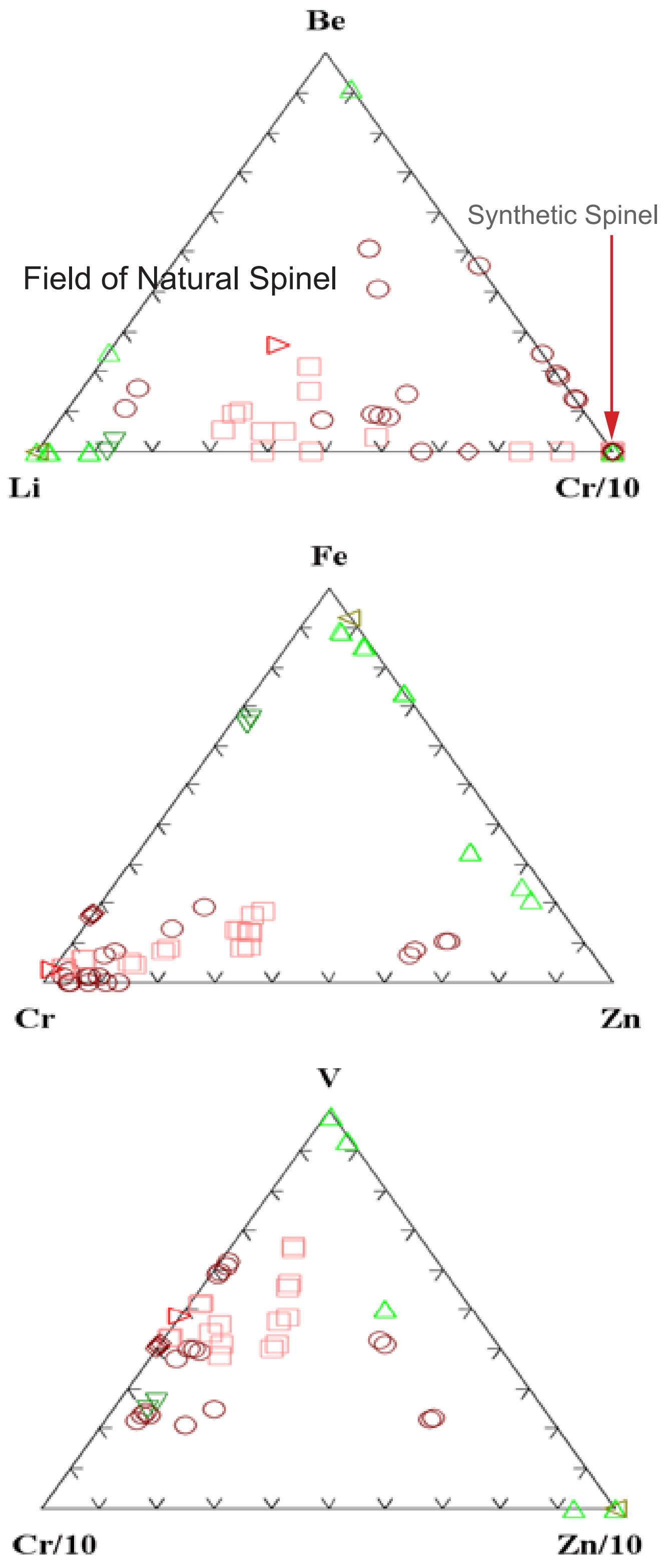


Fig. C5 Diagrams showing the different compositions for spinel. Chemical differences in Cr, V, and Fe can be correlated with the different color types (see Schmetzer et al. (1989)) but no correlation was found with respect to Cobalt (Co), see Tab. C1. Light element concentrations (Li and Be) provide a new test for identification of natural spinel against synthetic counterparts. Non-averaged values of Tab. C1 used (ppmw transformed into ppma)

Legend on the right.

Light Element Test for Identification of Spinel by LA-ICP-MS

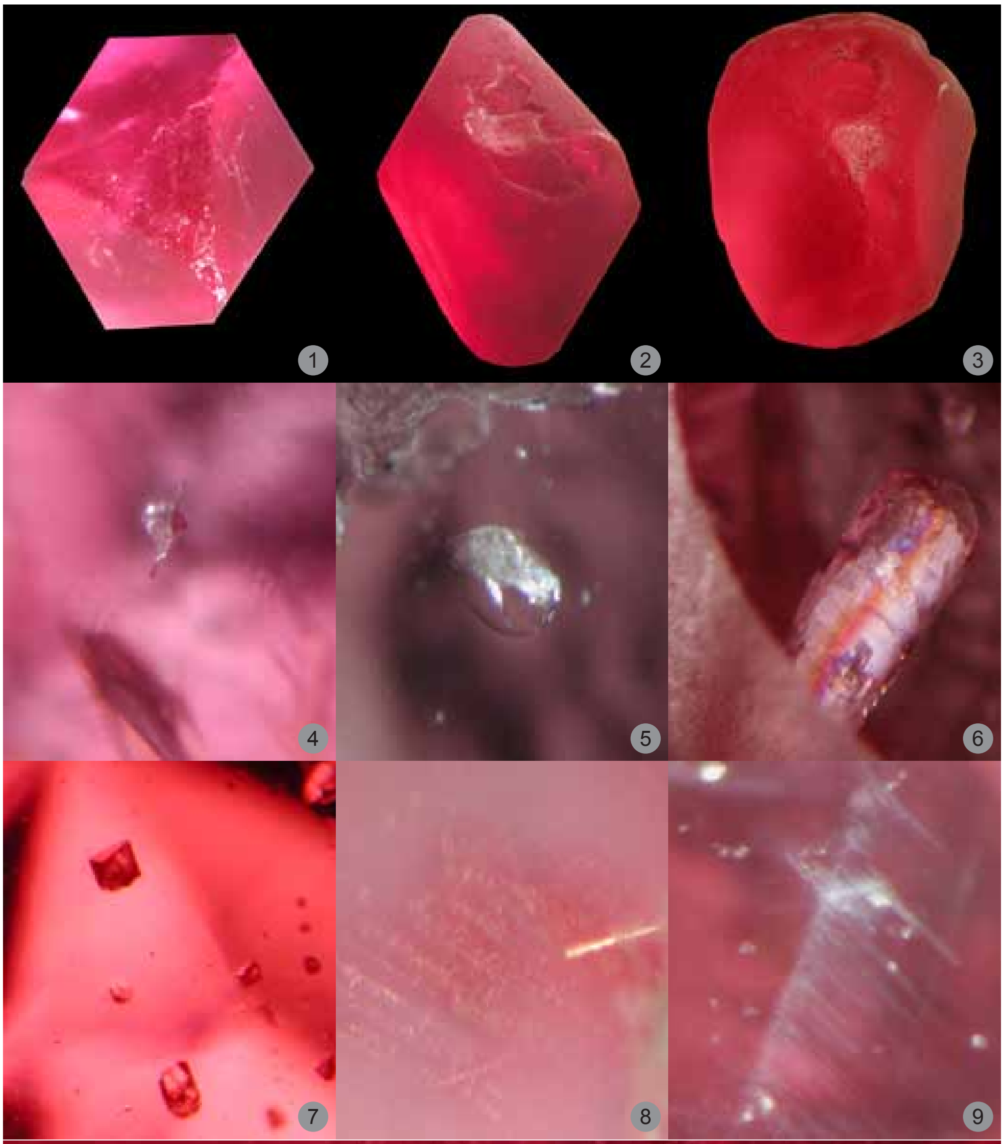
The chemical composition of the spinels is presented in Tab. C1 and graphically in Fig. C5. Different groups of natural and synthetic spinels are shown. From the different elements present in the spinels, our research has been focused on the presence of concentrations of light elements which have not yet been considered in the gemological literature. In natural spinel from different origins, trace elements of Lithium (Li) and Beryllium (Be) were determined in pink to vivid red colors such as spinels from Namya and other natural and synthetic counterparts. Si, Ti, V, Cr, Zn and Ga concentrations are highly variable and were detected in many spinel and in synthetic spinel from Russia with the exception of Zn. However, in more than 50 spot analyses of synthetic spinels none of the elements Be and Li were detected above the limits of detection (Tab. C1). Therefore, we propose that these elements can be used as a new separation test between synthetic and natural counterparts, which can be seen as an additional test using Zn and Ti - concentrations as proposed by Mühlmeister, et al (1993).

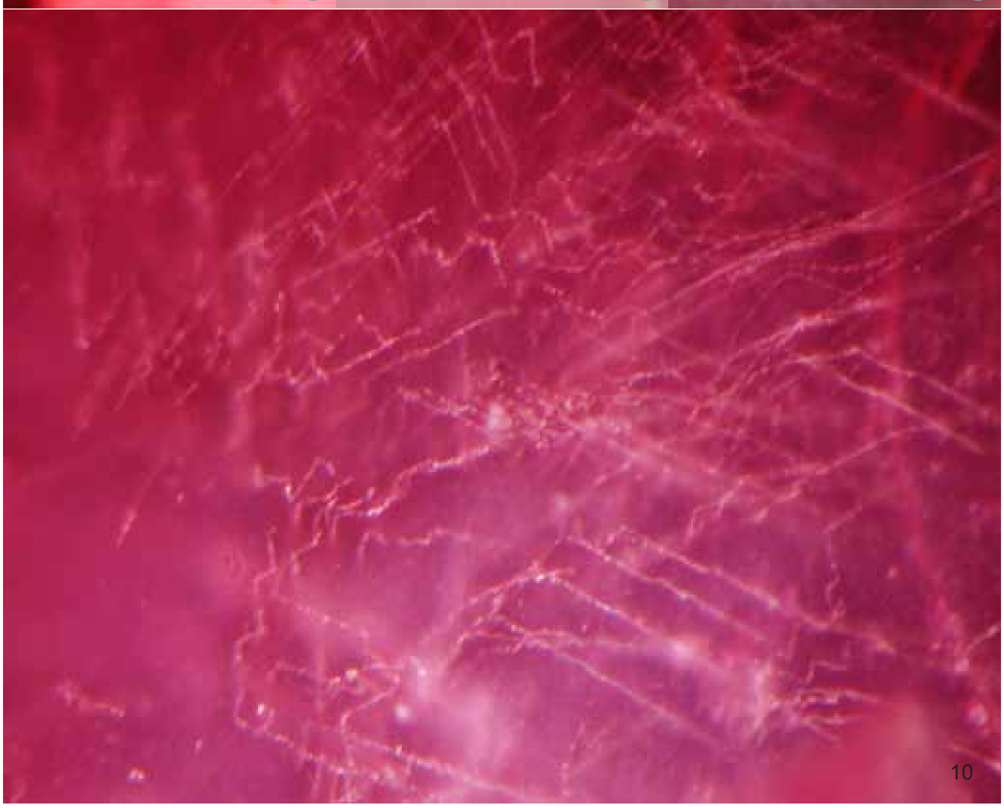
References:

Mühlmeister S., Koivula J.I., Kammerling R.C., Smith, C.P., Fritsch E. and Shigley J.E. (1993): Flux-grown Red and Blue Spinels from Russia, Gems&Gemology, Summer, VolXXIV.

Schmetzer K., Haxel C. and Amthauer G. (1989): Color of natural spinels, gahnospinels and gahnites. Neues Jahrbuch Miner. Abh., 160, 2, pp. 159-180.

Origin	Color	Symbol
Namya	pink	○
Namya	pink	
Namya	vivid pink	
Namya	pinkish-red	
Namya	pinkish-red	
Namya	pinkish-red	
Namya	pinkish-red	
Namya	red	
Namya	red	
Mogok, Pyen Pit	red	□
Mogok, Pyen Pit	red	
Mogok, Pyen Pit	red	
Mogok, Ohn Gaing	red	
Mogok, Ohn Gaing	red	
Mogok, In Gaung	red	
Mogok, Chaung Gyi	pinkish-red	
Mogok, Shwe Phy Aye	red	
Mogok	orange	△
Mogok	orange-red	
Mogok	purple	
Mogok	green	
Mogok	bluish-green	
Madagascar	blue	◁
Madagascar	pink	▷
Vietnam	pink	▽
Synthetic Russian	pinkish-red	◇
and Verneuil Spinel	near coloress	





Rough Crystal

1 Octahedral shaped rough spinel as identified and collected at the Namya mines (below 0.5 ct).

2,3 Larger sized Namya Spinel crystals (2-3 ct).

Inclusion description

Negative crystals of octagonal shape with (7), or without, associated tension cracks (4). Round transparent solid inclusions (5) are rarely seen along with elongated crystal inclusions (6). Geometrically arranged particles or needles (8,9) with whitish clouds and streamers are found. Particle concentrations are found along junctions and steps following the crystallographically determined directions in spinel.

1-3 Namya rough crystals. Perfect octahedral crystal (1), and irregular rounded shapes (3).

8,9 Oriented whitish reflecting particles.

4,7 Octahedral negative crystals with tension cracks (4), or without, and with secondary feathers (4)

5 Solid rounded inclusions (5), and elongated (6) inclusions.

New Findings of Painite

by Adolf Peretti (*)

(*) GRS Gemresearch Swisslab AG, Lucerne, Switzerland

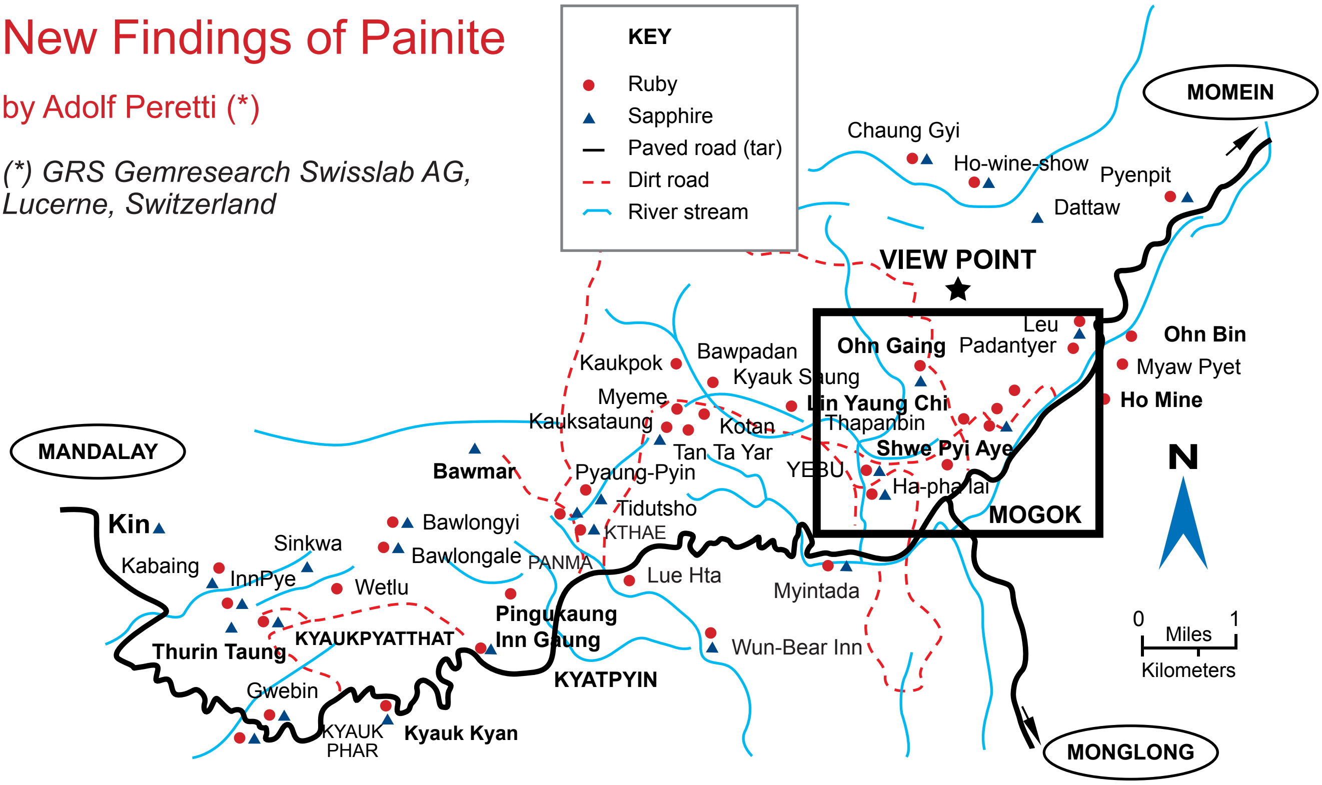


Fig. D1 Map of the Mogok and the Ohn-Gaing/ Sagaing mining area (outlined in the Map). Ruby and sapphire mines are indicated. The picture shows the mining area North of Mogok (Myanmar) as seen from the view point (Ohn-Gaing in the foreground and Mogok in the background). Picture taken by the author during the study of the Ohn-Gaing mine and the study of Painite No.6a in Mogok in the year 2002

Painite was first mentioned by Claringbull-Gordon et al. (1957) after being found in the Mogok Stone Tract and named after Arthur Charles Davy Pain - a well known mineralogist and gemologist of the Mogok area. Painite is so rare that worldwide available specimens are individually numbered. To the best knowledge of the author, crystals No.1 and No.2 are currently deposited in the collection of the Natural History Museum London (a small sample slice from No. 1 is at Caltec University), Crystal, No.3 is in the

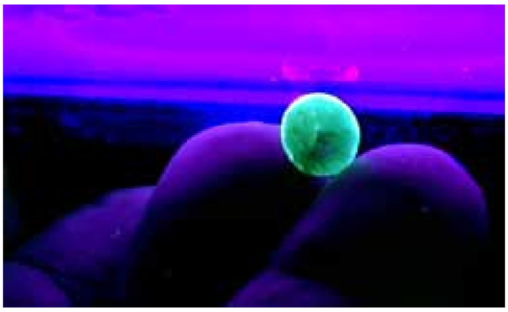


Fig.D2 *UV short wave fluorescence of Painite No. 5*

Fig.D3 *Painite is dichroitic and uniaxial as can be seen using a polariscope (parallel and crossed polarizers) and a projection sphere.*

Gemological Institute of America collection, while Crystal No. 4 is now in two pieces - both privately owned. Two more samples have recently been discovered by A. Peretti: A 2.54 ct faceted Painite, which was identified through testing in Bangkok (Thailand) and labeled as Painite No.5, Painite No. 6a, a large rough fragment of 54 cts (dimensions: 18.7x14.3x10.8 mm) - indirectly discovered from the miner's production, not directly from the mining spot - during an expedition in May 2002 to Mogok close to the private, government licensed Ohn-Gaing mine, Sagaing, Mogok district, Myanmar (Fig.D5). A small fragment (0.15 ct) of this rough Painite was obtained from 6a, and labeled Painite No. 6b. (Fig.D6), whereas the mother piece remained with its finder in Mogok. A research project on Painite No. 5 and 6b revealed that the crystal structure of Painite as presented by Moore and Araki (1976) needed to be revised. For details on the gemologial and special testing see Armbruster et al. (2003).

Painite No. 5

Fig.D4 *A faceted Painite of 2.54 ct which was identified in 2001 during testing in Bangkok (labeled as Painite No.5). Painite No.5 was used for detailed chemical analyses (see Armbruster et al., submitted) GRS collection.*

Painite No. 6a

Fig.D5 *Picture of the 54 ct Painite (labeled Painite No.6a) photographed with crystallographic faces present and in a direction where ruby overgrowth has been found. Studied in Mogok. This piece remains in the country of origin.*

Painite No.6b

Fig.D6 *Picture of the Painite No. 6b (Painite "No. 6b"). A 0.15 ct reference sample from Painite No. 6b was used for detailed chemical and structural analyses which guided to a revision of the crystal structure of Painite (Armbruster et.al (2003), submitted). GRS collection.*

Gemmological data

Optical character: Uniaxial, negative, e=1.789 and o=1.815, Pleochroism: very strong brownish-red to orange-yellow, Density: 4.00 +/- 0.01

A scientific study on Painite 5 and 6b will be published elsewhere and is submitted to:

Armbruster, Th. (1), Dobelin, N. (1), Peretti A. (2), Günther D. (3), Reusser E. (4) and Grobety, B (5) (2003):
The crystal structure of Painite $CaZrB[Al_9O_{18}]$, revisited, American Mineralogist, submitted.

(1) Laboratorium für chemische und mineralogische Kristallographie, University of Bern, Berne, Switzerland
(2) GRS Gemresearch Swisslab LTD., Hirschmattstr. 6, CH-6003 Luzern, Switzerland
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(4) Institute of Mineralogy and Petrography, Swiss Federal Institute of Technology, Zürich, Switzerland
(5) Department of Geosciences, University of Fribourg, Fribourg, Switzerland

Further references:

Caringbull G.F., Hey M.H., Payne C.J. (1957): Painite, a new mineral from Mogok, Burma. Mineralogical Magazine 31, 420-5.
Harlow, G.E. (2000) The Mogok Stone Tract, Myanmar: Minerals with complex parageneses. In: Proceedings of the 4th conference on "Minerals and Museums", Melbourne, Australia, 75.
Iyer, L.A.N. (1953).The geology and gemstones of the Mogok Stone Tract, Burma. Memoirs of the Geological Survey of India, 82, pp. 100.
Moore, P.B. and Araki, T. (1976) Painite, $CaZrB[Al_9O_{18}]$: Its crystal structure and relation to jeremejevite, $B_5[[\ ]_3Al_6(OH)_3O_{15}]$, and fluoborite, $B_3[Mg_9(F,OH)_9O_9]$. American Mineralogist, 61, 88-94.
Shigley, J. E., Kampf, A. R., and Rossman, G. R. (1986) New data on Painite. Mineralogical Magazine, 50, 267-270.
Webster, R. (1994) Gems, their sources, descriptions and identification, p.1027, Butterworths. Sevenoaks, UK.

The Beryllium Treatment of Fancy Sapphires with a New Heat-treatment Technique (Part B).

by Adolf Peretti (*), Detlef Günther(**) and Anne-Liese Graber (**)

(*) GRS Gemresearch Swisslab LTD, Switzerland
(**) Institute of Chemistry, Swiss Federal Institute of Technology, Zurich, Switzerland.

Introduction

The new heat treatment of corundum is a technique that involves extremely high temperatures, oxidation conditions and diffusion of Beryllium into the corundum's surface (Peretti and Günther, 2002, Hanni and Pettke, 2002, Emmet et al., 2003). Part A of this study (Peretti and Günther, 2002) concentrated on the interaction of Beryllium with the parent chemistry of natural fancy sapphires and other gemological aspects. It was noticed that only very minor concentrations of Beryllium were present in the treated sapphires. This data was confirmed later by Hanni and Pettke (2002). As mentioned earlier, the understanding of the direct contribution of Beryllium to the color of these treated natural sapphires needed additional research (see Peretti and Günther, Contributions to Gemology 2002, vol. 1, page 39). As pointed out in a recently published article on this new treatment (Emmett et al., 2003), the understanding of the new treatment needs more precise data on various trace elements that are not yet available in world literature. In part B of the characterization of the new treatment, we provide extended chemical analyses of natural and synthetic materials, including sapphires, and test the models proposed by Emmett et al. (2003).

Materials and Methods

The studied materials include synthetic materials from various manufacturers. Colorless synthetic sapphires were from watch glass producers in Switzerland, synthetic pink, orange and yellow Verneuil sapphires were obtained from Djevahirdijan SA (Monthey, Switzerland), and synthetic hydrothermal rubies were from Novosibirk (Russia). Further natural samples are listed in Tab. 6 of Peretti and Günther (2002) and additional samples of rubies and blue sapphires were collected in the market in Bangkok (see Tab. E2 and E3).

Samples were prepared with rough, as well as faceted materials, and cut in half. One piece was kept untreated for reference ("reference samples"), and one half piece sent for commercial Beryllium treatment with the new method to a specialized commercial factory in Chantaburi (Thailand). The heating experiments were reportedly carried out at very high temperature near the melting point of corundum under high oxidation conditions, including Beryllium diffusion. Details of the method remain the intellectual property of the factory. After the Be-treated samples came back from Chantaburi, untreated and treated samples were compared and color changes investigated (E1, E9 and E13). The treated samples were cut in half for further chemical and spectroscopic analyses (e.g. Fig. E5). Further samples of natural blue sapphires, fancy sapphires and rubies have also been Beryllium-treated by the same factory as well as by another factory in Bangkok. For comparison, additional natural orange sapphires were investigated which were heated by conventional methods (Tab. E3). The samples were measured for chemical composition by LA-ICP-MS (see Guillong and Günther (2001)), for origin of color by UV-VIS-NIR-Spectroscopy, and for structural/chemical analyses by Cathodoluminescence .

Cathodoluminescence Analyses (CL)

The analyses were carried out by Prof. K. Ramseyer at the University of Berne, Institute of Geological Sciences, Berne (Switzerland). The same methods were applied as described by Ramsayer K. (2002).

	Before Be - Treatment			After Be -Treatment			Color Change
	Sample	Color	Doped by	Sample	Color	Doped by	
Synthetic Corundum	GRS 2	**colorless**	Na, Mg, K, (Si, Fe, Ti, Cu)	GRS 1 *(from GRS 2)*	**light brown**	Be, Na, K, (Si, Fe, Ti)	**(x)**
	GRS 12	**light pink**	**Mg**, Ca, **Cr**, Si (Fe, Na, Ti)	GRS 13 *(from GRS 12)*	**orangy-pink****	**Be**, Na, **Mg**, Ca, **Cr**	**(x)**
	GRS 4	**pink**	Na, **Cr** (Mg, Si)	GRS 5 *(from GRS 4)*	**orange**	**Be, Cr** (Mg, Si)	**x**
	GRS 8	**vivid pink**	Na, **Cr** (Fe)	GRS 9 *(from GRS 8)*	**orange**	**Be, Cr** (Si)	**x**
	GRS 15	**vivid pink**	Mg, Si, Ti, **Cr**, Fe	GRS 16 *(from GRS 15)*	**vivid orange**	**Be**, Na, Mg, Si, K, Ti, **Cr**	**x**
	GRS 10	**light orange (*)**	K, **Cr**, Si	GRS 11 *(from GRS 10)*	**orange**	**Be, Cr**, Zr	**(x)**
	GRS 17	**orange**	Ti, **Mg**, Si, **Cr**	GRS 18 *(from GRS 17)*	**orange**	**Be**, Ti, **Mg**, Si, **Cr**	
	GRS 19	**yellow**	Mg, Si, Ni	GRS 20 *(from GRS 19)*	**yellow**	**Be**, **Mg**, Si, **Ni**	
Synthetic Ruby	GRS 25	**purplish pinkish red**	Na, **Ti, Cr, Fe**, Ni	GRS 26 *(from GRS 25)*	**orange**	**Be**, Ti, Si, **Cr, Fe**, Ni	**x**
	GRS 27	**red**	Mg,Ti, Si, **Cr, Fe**, Ni	GRS 28 *(from GRS 27)*	**orange-red**	**Be**, Mg, Si, Ti, **Cr, Fe,** Ni	**x**
	GRS 29	**dark red**	Na, Mg, Si, K, Ti, **Cr, Fe**, Ni	GRS 30 *(from GRS 29)*	**dark orangy-red**	**Be**, Mg, Si, Ti, **Cr, Fe**, Ni	**x**

(*) color change from pink to pinkish-orange induced by irradiation treatment

***Table E1:** Synthetic Rubies and synthetic Colored Sapphires before and after Beryllium treatment. Dominant trace elements are in bold. Note: Only Cr-rich samples were reacting to the Beryllium treatment. Be = Beryllium, Na = Sodium, Mg = Magnesium, Si = Silica, K= Potassium, Ti = Titanium, Cr = Chromium, Fe = Iron, Ni = Nickel.*

Fig. E1 *Pink sapphires and brownish pink sapphires were subjected to the new Beryllium-treatment. Note: Color change from pink to orangy-pink due to the new treatment.*

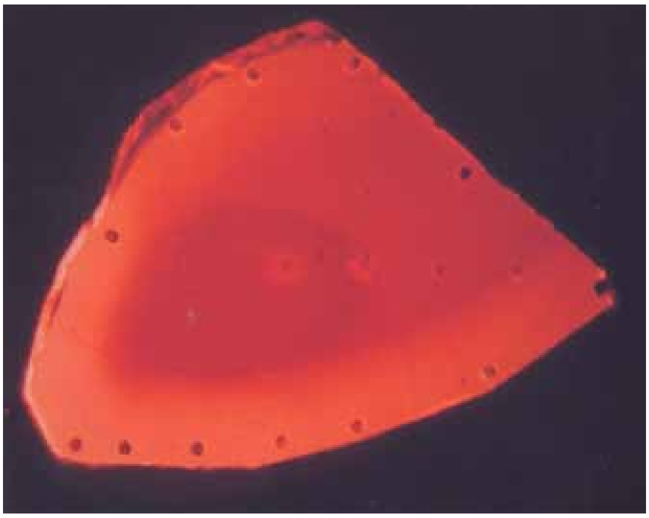


Fig. E2 *Cathodoluminescence microphotograph of a Beryllium-treated natural orangy-pink sapphire (by Prof. K. Ramseyer). The Beryllium treatment produces a zoning of chemical and/or structural defect contrasts showing an outer rim, inner rim and an inner core. Methods see Peretti and Günther (2002). Craters from LA-ICP-MS (80 micrometers in diameter).*

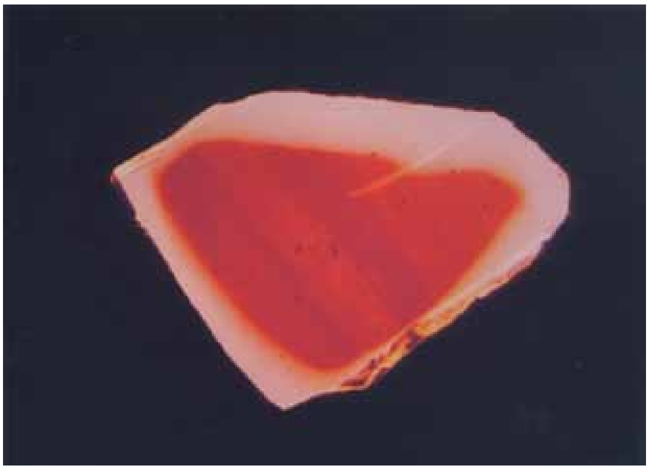


Fig. E3 *Cathodoluminescence microphotograph of a Beryllium-treated natural orangy-pink sapphire (by Prof. K. Ramseyer). The picture shows the chemical and/or structural defect contrasts of the natural growth in the centre of a faceted gemstone (diagonal growth lines). The Beryllium treatment resets this contrast in a rim perpendicular to the natural growth zones.*

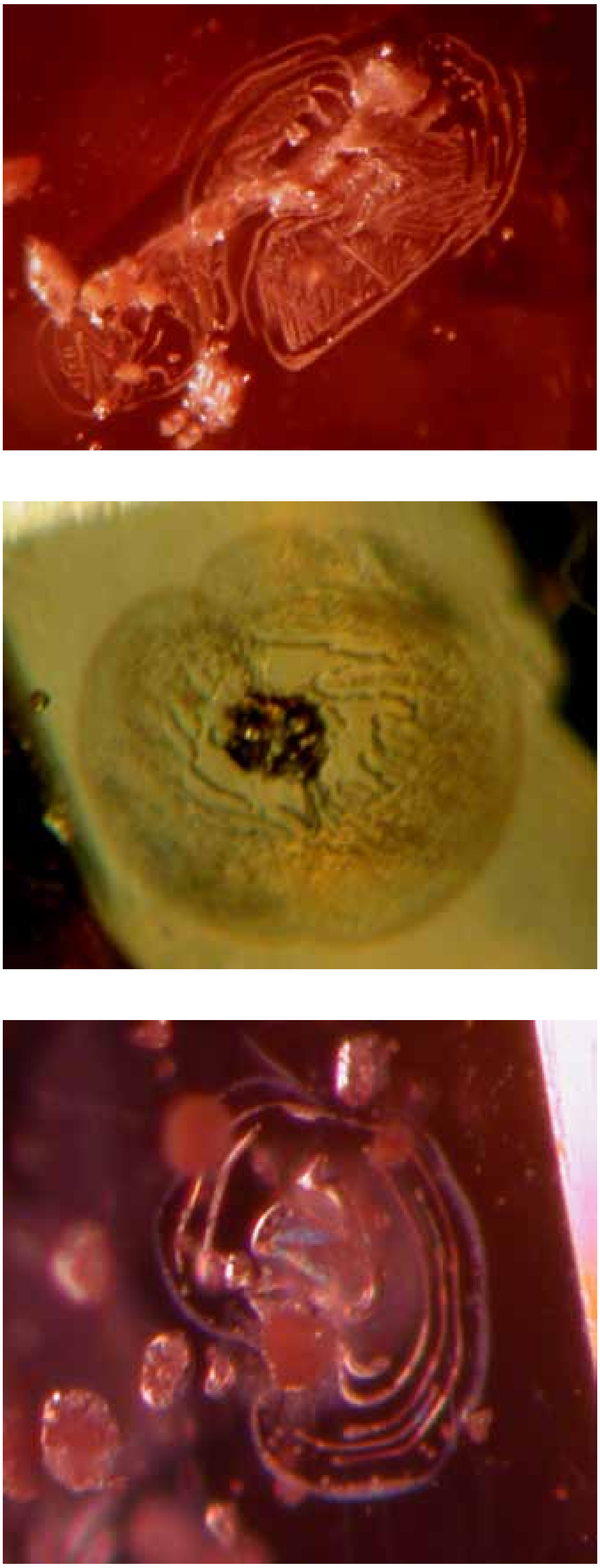


Fig. E4 *Microphotograph of inclusions in Beryllium-treated natural sapphires. Melted inclusions with feathers characteristic for high temperature treatment. More on http://www.gemresearch.ch/inclusions. Magnification in the microscope 60x-80x. Fibre optic illumination. Pictures by John de Jaegher. Copyright GRS.*

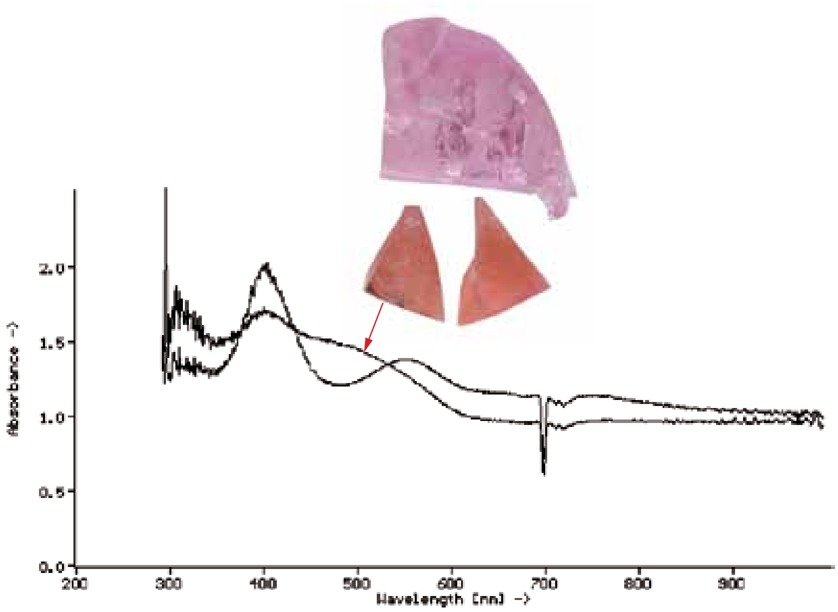


Fig. E5 *Polarized UV-VIS-NIR absorption spectra of synthetic pink sapphires (reference sample) and Beryllium-treated synthetic orange sapphires. Inserted picture shows the untreated reference (pink) and Beryllium-treated samples (orange) (including fluorescent lines produced by multi-channel spectroscopic measurements). Spectra are recorded in the same crystallographic direction. There is a shift in absorption due to a different sampling volume. Increase in absorption towards the blue region of the spectrum is interpreted as Beryllium (Be)-Chromium (Cr)-color centers superimposed to Cr^{3+} (Emmett et al., 2003).*

Results

The results of the CL investigation on two samples are shown in Fig. E2 and E3. More confirmation found that the trace element distribution is completely rearranged by the new treatment, particularly in the zones containing Beryllium. This was evident by extinction of chemical and structural patterns in the treated sapphires (Fig. E3). As shown in Fig. E2, an inner core was detected. This inner core is formed outside the zones enriched in Beryllium.

LA-ICP-MS chemical analyses

The LA-ICP-MS measurements were carried out by the Laboratory of Inorganic Chemistry at the Swiss Federal Institute of Technology, Honggerberg Zurich). The details on the methods, data calculation, normalization procedures and error margins can be found in Peretti and Günther (2002) or on the Internet under
www.gemresearch.ch/journal/E-IM.htm

An additional set of more than 40 samples has been analyzed including various categories of synthetic, unheated, conventional heated, as well as Beryllium treated samples (see Tab. E1, E2 and E3). Due to detailed series of spots in various profiles on the samples, a total of approx. 1000 chemical data points were collected. Each spot was analyzed for 40 elements. The data shown in Tab. E2 and E3.

Results: Beryllium-Treated Synthetic Pink and other Synthetic Colored Sapphires

The results of Beryllium-Treated Synthetic Sapphires are shown in Fig. E6 to E25 and in Tab. E1, E2 and E47a. The group of synthetic Pink Sapphires can be subdivided into two different categories depending on the reaction to the Beryllium treatment. One group of synthetic sapphires did not color-change after Beryllium treatment. The non color-changing category includes synthetic orange and yellow sapphires that contain various elements including Na, Mg, Ni, Sn and Zr (see Tab. E1 and E2). The second group of color-changing samples include synthetic pink sapphires that became more orange with Beryllium-treatment (Tab. E1 and E2). These samples were dominated by Cr traces. Another sample which was doped by Cr and Mg was only partially color-changed. All the Beryllium-treated samples contain traces of Beryllium, with enriched concentrations at the rim (e.g. Fig. E12). Increasing Cr and Beryllium concentrations are correlated with increasing intensity in orange color. Trace element concentrations of many of the elements were heterogeneous (Fig. E8, E12, E16, E22, E19, E25): This is interpreted as chemical zoning in the stones, which is not uncommon in the Verneuil materials.

Be-Treated Hydrothermal Synthetic Rubies (TAIRUS, Novosibirsk)

After Beryllium-treatment, synthetic rubies changed to more orange or less dark colors (Tab. E1). The results of the chemical analyses are shown in Fig. E26 to E45). This color change can be correlated with increasing Be-concentrations, independently of the concentrations of Fe (Fig. E47b). A series of other trace elements are present in these synthetic hydrothermal rubies, including Mg, Ti, Si, Cr, Mn, Fe, Ni and minor Sn. They did not prevent the treatment success (Fig. E29. E33, E37, E40 and E46).

Be-Treated Synthetic Colorless Sapphire

White corundum (without Cr-concentrations) slightly color-changed to light brown after the Beryllium treatment. Additional traces of Beryllium were detected in the samples (Tab. E1)

Before Beryllium Treatment	After Beryllium Treatment

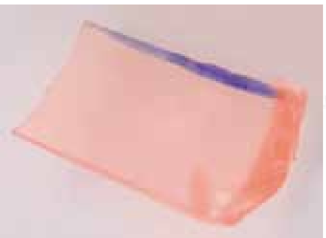


Fig. E6 *Microphotograph of GRS 8 (Synthetic light pink sapphire)*
Fig. E7 *Drawing of GRS 8. Analysis was performed with 61 spots along the broken line (crater diameter : 80 µm)*

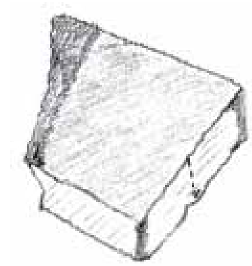


Fig. E10 *Microphotograph of GRS 9 (synthetic orange sapphire)*
Fig. E11 *Drawing of GRS 9. Analysis was performed with 12 spots along the broken line (crater diameter : 80 µm)*

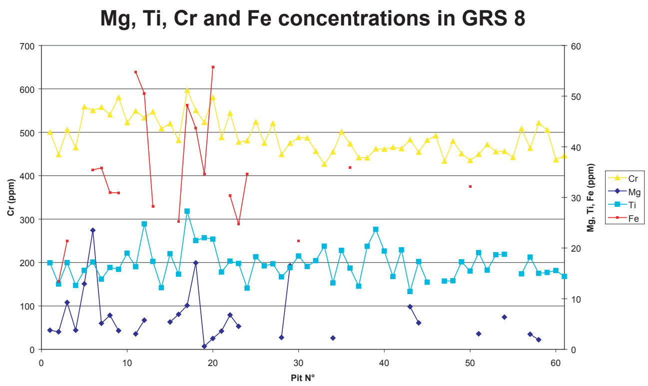


Fig. E8 *The chemical variations in a profile across a synthetic pink sapphire (GRS 8) are shown (in ppm). Complete data see Tab. E2*

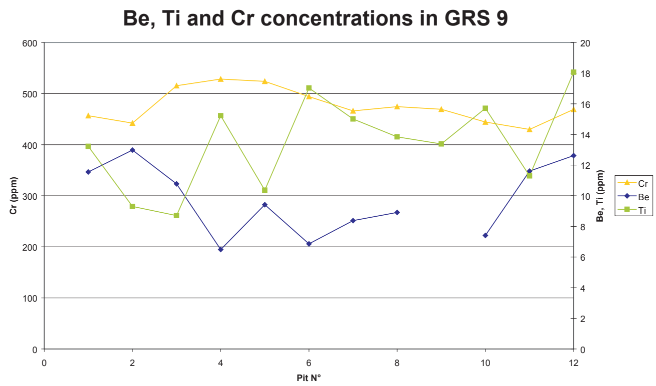


Fig. E12 *The chemical variations in a profile across a Beryllium-treated synthetic orange sapphire (GRS 9) are shown (in ppm). Untreated reference sample is GRS 8). For complete data, see Tab. E2.*

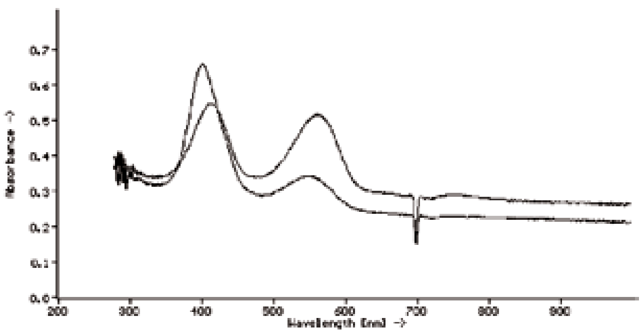


Fig. E9 *Polarized UV-VIS-NIR absorption spectra of synthetic pink sapphires (GRS 8) parallel and perpendicular to the c-axis. Absorption characteristics (including fluorescent lines produced by multi-channel spectroscopic measurements) due to* Cr^{3+}.

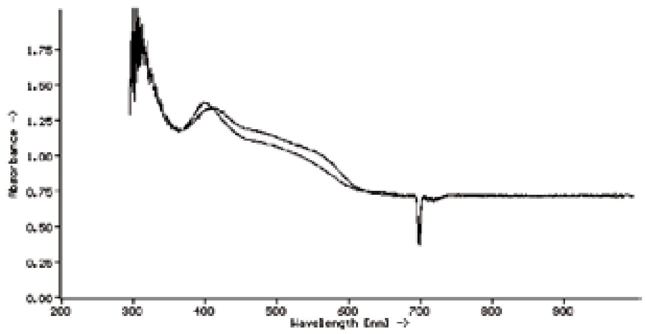


Fig. E13 *Polarized UV-VIS-NIR absorption spectra of Beryllium-treated synthetic orange sapphires parallel and perpendicular to the c-axis. Absorption characteristics (including fluorescent lines produced by multi-channel spectroscopic measurements) due to* Cr^{3+} *and Cr-Beryllium color centers. The untreated reference sample is GRS 8.*

Before Beryllium Treatment

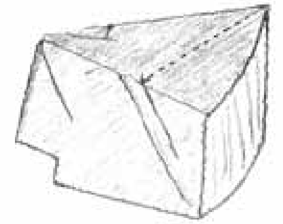


Fig. E14 *Microphotograph of GRS 12 (synthetic pink sapphire) Fig. E 15 Drawing of GRS 12. Analysis was performed with 40 spots along the broken line (crater diameter: 80 µm)*

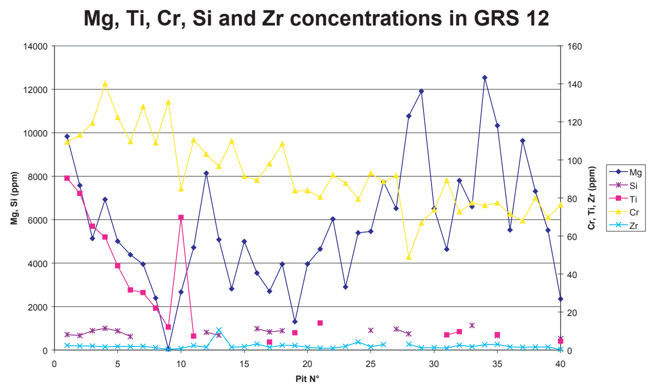


Fig. E16 *The chemical variations in a profile across a synthetic pink sapphire are shown (in ppm). Complete data see Tab. E2.*

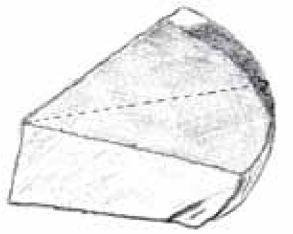


Fig. E17 *Microphotograph of GRS 17 (synthetic deep orange sapphire)*
Fig. E18 *Drawing of GRS 17. Analysis was performed with 80 spots along the broken line (crater diameter: 80 µm)*

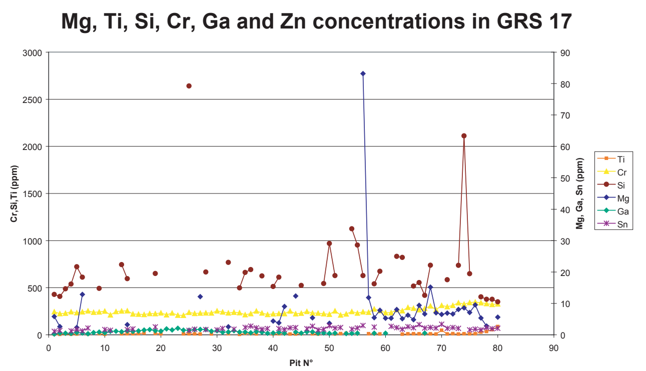
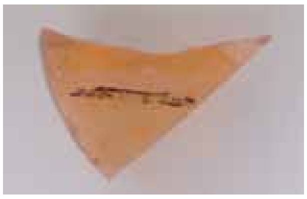


Fig. E19 *The chemical variations in a profile across a synthetic deep orange sapphire (GRS 17) are shown (in ppm). Complete data see Tab. E2*

After Beryllium Treatment



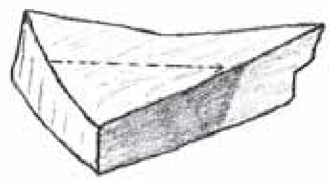


Fig. E20 *Microphotograph of GRS 13 (synthetic pink sapphire)* ***Fig. E21*** *Drawing of GRS 13. Analysis was performed with 33 spots along the broken line (crater diameter: 80 µm)*

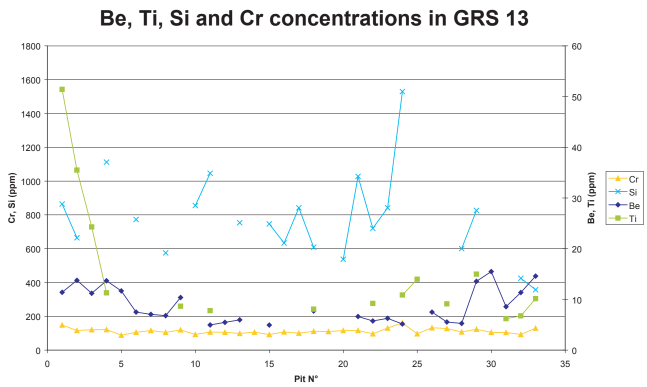


Fig. E22 *The chemical variations in a profile across a Beryllium-treated synthetic orange-pink sapphire (GRS 13) are shown (in ppm). The untreated corresponding sample is GRS 12. complete data see Tab. E2.*

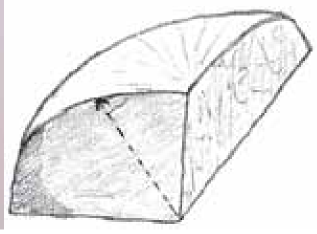


Fig. E23 *Microphotograph of GRS 18 (synthetic deep orange sapphire)*
Fig. E24 *Drawing of GRS 18. Analysis was performed with 35 spots along the broken line (crater diameter: 80 µm)*

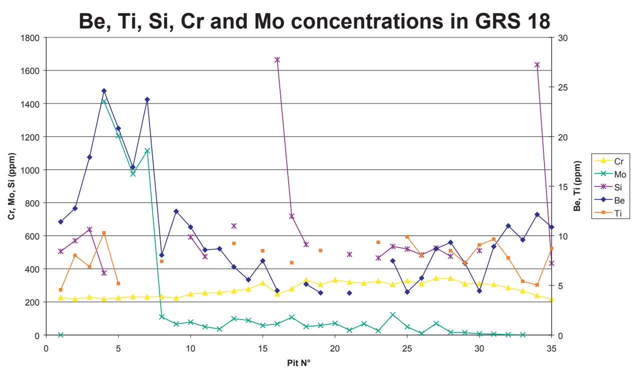


Fig. E25 *The chemical variations in a profile across a Beryllium-treated synthetic deep orange sapphire (GRS 18) (in ppm). Corresponding untreated sample is GRS 18. For complete data, see Tab. E2*

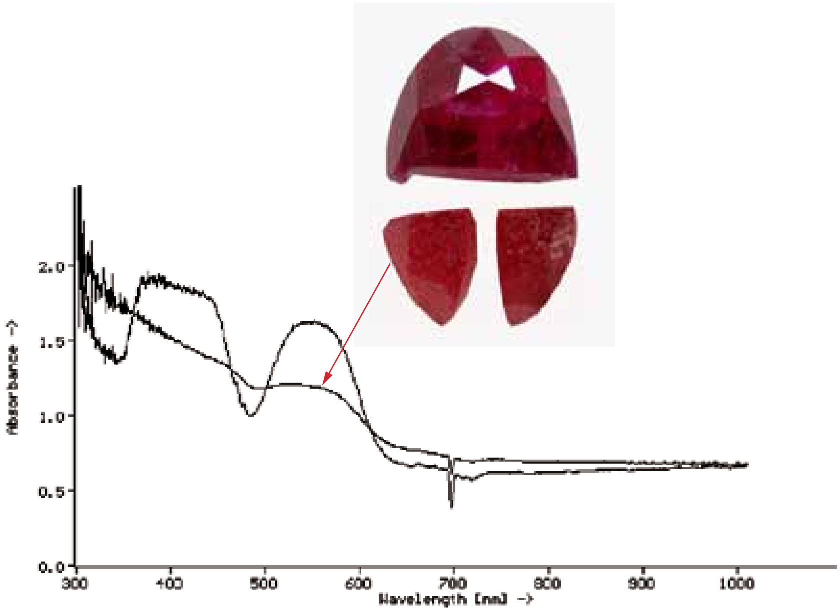


Fig. E26 *Polarized UV-VIS-NIR absorption spectra of synthetic hydrothermal rubies (reference sample) and Beryllium-treated synthetic deep orange sapphires (including fluorescent lines produced by multi-channel spectroscopic measurements). Inserted picture shows the untreated reference (red) and Beryllium-treated samples (orange). Spectra are recorded in the same crystallographic direction. A shift in absorption is due to a different sampling volume. Increase in absorption towards the blue region of the spectrum is interpreted as color centers involving Beryllium and other trace elements superimposed to Cr^{3+}-absorptions (see Emmett et al., 2003).*

Be-Treated Natural Rubies and Sapphires

The measured samples of natural rubies and sapphires are listed in Tab E3 and shown in Fig. E47c and Fig. E48. Reviewing the data of Tab. E3, it is evident that concentrations of Silica (Si) were found in all samples. Comparing the values with those presented by Emmett et al. (2003), it was found that much higher Si concentrations were measured in our investigation. They are approx 10 to 20 times higher than the values published by Emmett et al. (2003) on similar samples. The distribution of Si in the samples, however, was found to be heterogeneous, e.g. areas that had Si below the detection limit were found in a distance of 50 to 100 microns next to areas of significant Si concentrations. Only minor concentrations of Sn, Ni, Mn, Ca and Li were occasionally also detected in addition to the elements Mg, Ti, V, Cr, and Fe, both in samples before and after Beryllium-Treatment (Tab. E3). Beryllium was found in all Beryllium-treated samples. The concentration of Beryllium increased towards the rim as previously reported (Peretti and Günther, 2002).

Chemical Identification Charts for Beryllium-Treated Corundum

For further interpretation of the data, we selected 660 spot analyses from our data bank, which included various samples unheated, enhanced and Beryllium-treated sapphires. A further selection was made for the group of Beryllium-treated samples, from which we did not take into account the data that were obtained from measurements at or near the surface. In such a way, we eliminated contamination resulting from the treatment experiments which were found at the surface of the samples (high Be, Mg, Cr, Fe, Zr). The data were transformed from ppmw (w = weight) to ppma (a = atomic) and are graphically presented in Fig. E48 and E49.

UV-VIS-NIR Spectroscopic Origin of Color Analyses

UV-VIS-NIR Spectra was measured with a 1024 diode array multi-channel spectrometer (for further details see Peretti and Günther (2002)). Polarized spectra were measured on synthetic corundum, both for untreated and for Beryllium treated samples. The results are shown in Figs. E5, E9, E13, E26, E30 and E34. In comparison to the untreated reference samples, it was found that the absorption curves increased towards the blue region of the spectrum. These broad bands in the UV region of the spectrum can be interpreted as proof of the presence of color centers involving Beryllium and other elements (see Emmett et al., 2003).

Identification by Inclusions

In Part A of our study we elaborated on the melting of zircon and transformation into Zr-Oxide and glass using Scanning Electron Microscope analyses. This melting of minerals other than corundum has been related to the high temperature used for Beryllium treatment (Peretti and Gunther, 2002). This findings have been recently confirmed by the studies of Emmett et al. (2003) on studies on zircons included in sapphires, where they found that the Zr-Oxides can be identified as badelleyite. This mineral melting phenomena has become a help in identifying this new treatment (see Fig. E4). Further valid identification criteria in orange to orange-red sapphires from Songea (Tanzania) turned out to be the blue halos around mineral inclusions. For further information on inclusions we have provided extensive inclusion website under www.gemresearch.ch/inclusions.

Before Beryllium Treatment	After Beryllium Treatment

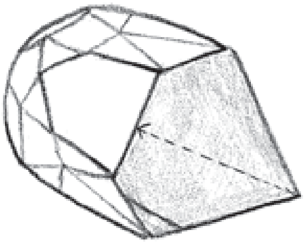


Fig. E27 *Microphotograph of GRS 25 (synthetic ruby)*
Fig. E28 *Drawing of GRS 25. Analysis was performed with 18 spots along the broken line (Crater diameter: 80 µm*

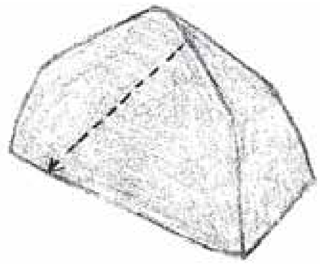


Fig. E31 *Microphotograph of GRS 26 (synthetic orange-red sapphire)*
Fig. E32 *Drawing of GRS 26. Analysis was performed with 16 spots along the broken line (crater diameter: 80 µm)*

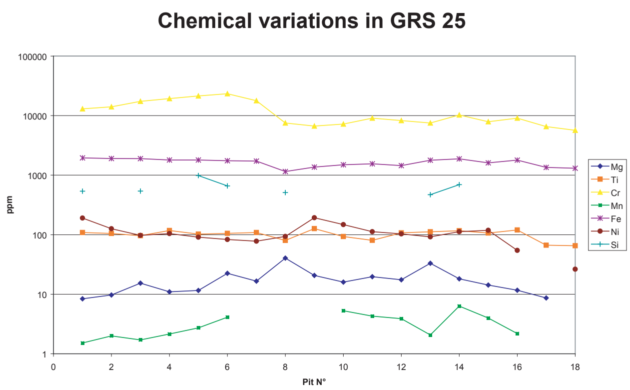


Fig. E29 *The chemical variations in a profile across a synthetic hydrothermal ruby are shown (in ppm). Sample No. GRS 25. complete data see Tab. E2.*

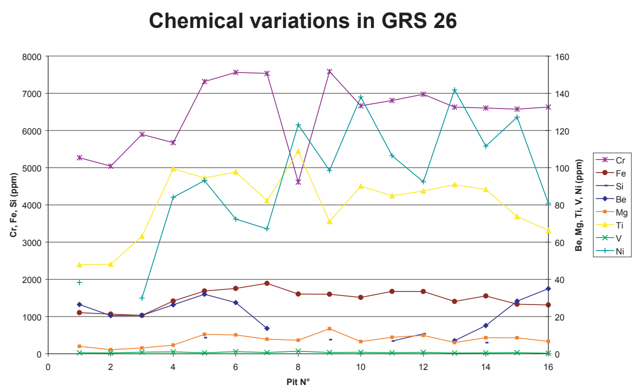


Fig. E33 *The chemical variations in a profile across a Beryllium-treated synthetic orange-red sapphire are shown (in ppm). Sample No. GRS 26 (untreated reference sample is GRS 25). Silica concentrations out of scale.*

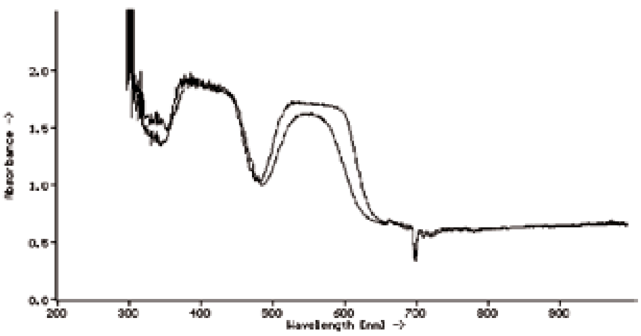


Fig. E30 *Polarized UV-VIS-NIR absorption spectra of a synthetic hydrothermal ruby in a direction parallel and perpendicular to the c-axis. Absorption characteristics (inclusive fluorescence lines) due to Cr^{3+}(including fluorescent lines produced by multi-channel spectroscopic measurements).*

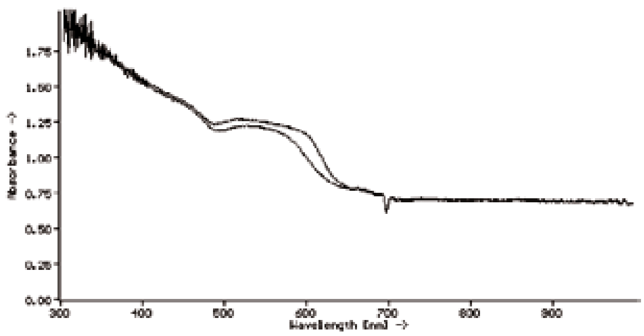


Fig. E34 *Polarized UV-VIS-NIR absorption spectra of a Beryllium-treated synthetic orange-red sapphire (GRS 26) in a direction parallel and perpendicular to the c-axis. Absorption characteristics (including fluorescent lines produced by multi-channel spectroscopic measurements) due to Cr^{3+} and color centers involving Beryllium and other trace elements (General increase in absorption in the blue region of the spectrum). Untreated reference sample is GRS 25.*

Before Beryllium Treatment	After Beryllium Treatment

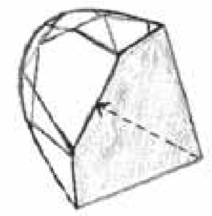


Fig. E35 *Microphotograph of GRS 27 (synthetic ruby)*
Fig. E36 *Drawing of GRS 27. Analysis was performed with 16 spots along the broken line (crater diameter: 80 µm)*

Chemical variations in GRS 27

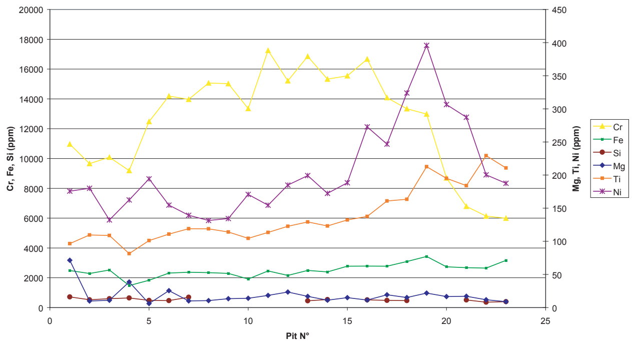


Fig. E37 *The chemical variations in a profile across a synthetic hydrothermal ruby (GRS 27) are shown (in ppm). Complete data see Tab. E2.*

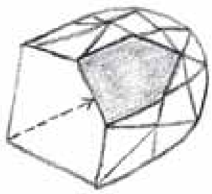


Fig. E38 *Microphotograph of GRS 29 (synthetic ruby)*
Fig. E39 *Drawing of GRS 29. Analysis was performed with 21 spots along the broken line (crater diameter: 80 µm)*

Chemical variations in GRS 29

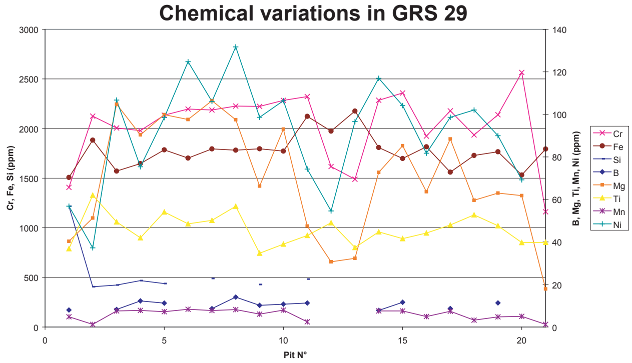


Fig. E40 The *chemical variations in a profile across a synthetic hydrothermal ruby (GRS 29) are shown (in ppm). Complete data see Tab. E2.*

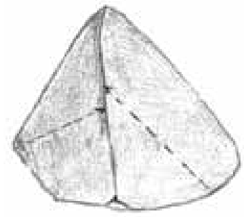


Fig. E41 *Microphotograph of GRS 28 (synthetic orange sapphire, Beryllium-treated sample GRS 27)*
Fig. E42 *Drawing of GRS 28. Analysis was performed along the two broken lines (crater diameter: 80 µm) Side 1: 23 pits; Side 2: 15 pits*

Chemical variations in GRS 28

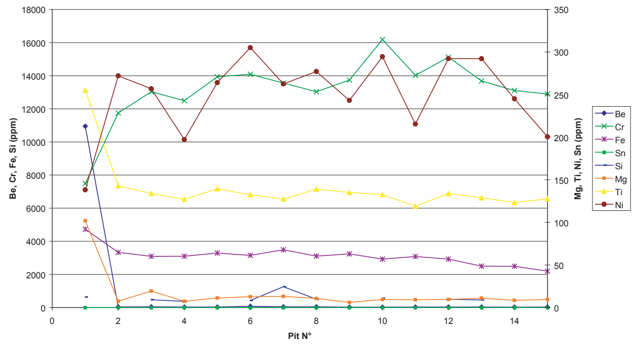


Fig. E43 *The chemical variations in a profile across a Beryllium-treated synthetic orange sapphire (GRS 28) are shown (in ppm). Untreated reference sample is GRS 27. complete data see Tab. E2.*

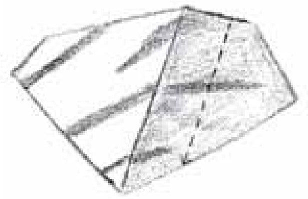


Fig. E44 *Microphotograph of GRS 30 (synthetic orange sapphire, Beryllium-treated sample GRS 29)*
Fig. E45 *Drawing of GRS 30. Analysis was performed with 20 spots along the broken line (crater diameter: 80 µm)*

Chemical variations in GRS 30

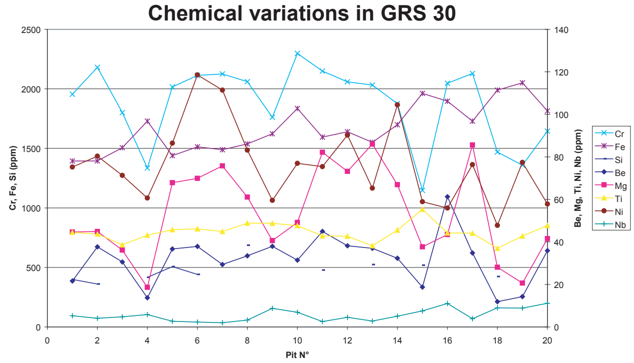


Fig. E46 *The chemical variations in a profile across a Beryllium-treated synthetic orange sapphire (GRS 30) are shown (in ppm). Untreated reference sample is GRS 29. complete data see Tab. E2.*

Fig. E47a

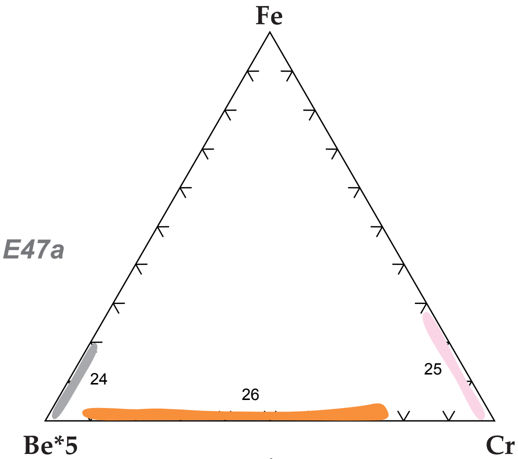


Fig. E47b

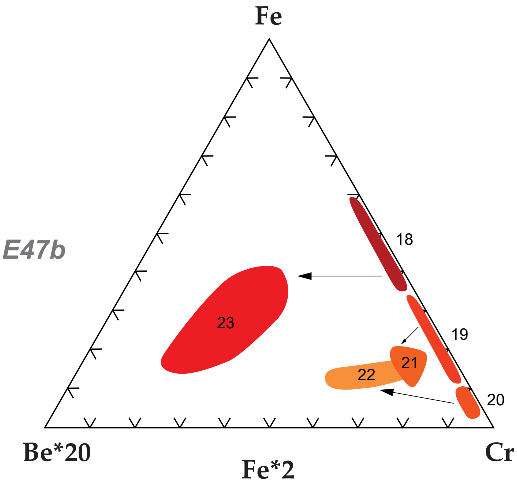


Fig. E47c

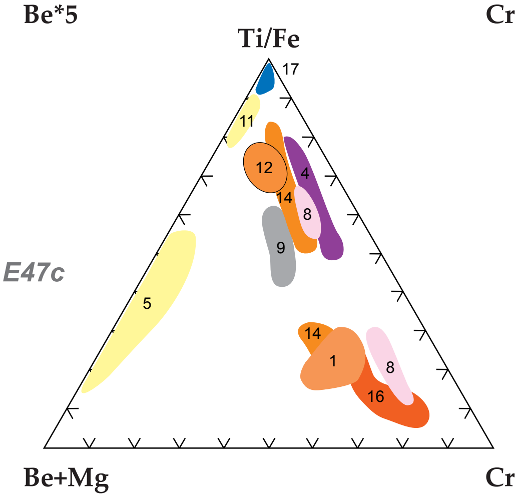


Fig. E47d

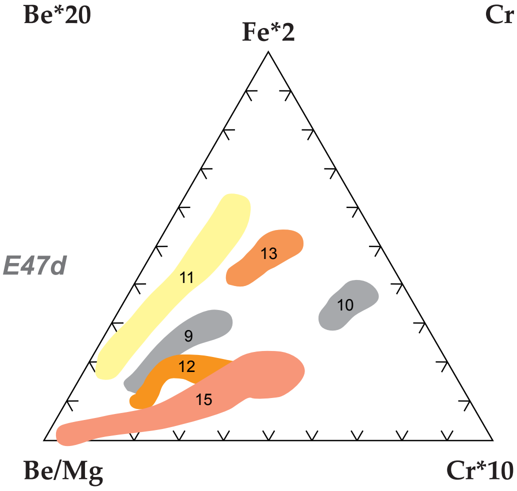


***Fig. E47** Chemical comparison of Beryllium-treated and untreated samples (see Legend below). Data from Peretti and Günther (2002), Tab. E2 and E3 (non-averaged complete data set used, see text).*
***Fig. E47a** Beryllium treatment produces orange in synthetic pink sapphires caused by an increase in Beryllium (Be) in presence of Chromium (Cr).*
***Fig. E47b** Beryllium treatment of synthetic rubies shifts the color to orange, due to an increase in Beryllium in presence of Cr, independent of Iron (Fe)-concentrations.*
***Fig. E47c** Beryllium treatment of natural fancy sapphires produces orange with increasing (Mg+Be)-concentration at variable Ti/Fe-ratios and variable Cr-concentrations (Mg = Magnesium, Ti = Titanium)*
***Fig. E47d** Padparadscha color is produced at variable Be/Mg-concentrations with increasing concentrations of Cr*

Legend

1. *Natural Padparadscha (N)*
2. *Natural Violet Sapphire (N)*
3. *Natural Purple Sapphire (N)*
4. *Natural Purple to Violet Sapphire (N)*
5. *Natural Yellow Sapphire (E)*
6. *Natural Orange Sapphire (E)*
7. *Natural Padparadscha (E)*
8. *Natural Pink Sapphire (E)*
9. *Natural Colorless Sapphire (Be-treated)*
10. *Natural White Sapphire (Be-treated)*
11. *Natural Yellow Sapphire (Be-treated)*
12. *Natural Orange Sapphire (Be-treated)*
13. *Natural Padparadscha Pinkish-orange (Be-treated)*
14. *Natural Padparadscha (Be-treated)*
15. *Natural Padparadscha (Orangy-pink) (Be-treated)*
16. *Natural Orangy-red Sapphire (Be-treated)*
17. *Natural Sapphire (Be-treated)*
18. *Synthetic hydrothermal Ruby GRS 29*
19. *Synthetic hydrothermal Ruby GRS 27*
20. *Synthetic hydrothermal Ruby GRS 25*
21. *Synthetic hydrothermal Ruby (Be-treated) GRS 28*
22. *Synthetic hydrothermal Ruby (Be-treated) GRS 26*
23. *Synthetic hydrothermal Ruby (Be-treated) GRS 30*
24. *Light cream Colorless Synthetic Sapphire (Be-treated)*
25. *Synthetic Pink Sapphire*
26. *Synthetic Orangy-Pink Sapphire (Be-treated)*

Discussion

The new treatment is characterized by the formation of an additional yellow to orange color in Corundum. Chemical and spectroscopic measurements show that the color change can be explained by color centers involving various trace elements including Beryllium (Peretti and Günther (2002), Emmett et al. (2003) and references therein). From detailed LA-ICP-MS chemical analyses, it is evident that a large variety of trace elements are present in the Beryllium treated samples (Fig. E12, E22, E25, E33, E43 and E46). As shown by our experiments with synthetic pink sapphires, Cr and Be alone, at the absence of other trace elements, are sufficient for the formation of orange color centers. From the Beryllium treatment of synthetic materials, it is concluded that corundum without Ti and Cr is not changing the color. Other trace element combinations without the presence of Ti, Mg and Be can also form yellow to orange coloration (e.g. Ni see Tab. E1). Synthetic materials, lacking V but with Cr, Ti, Mg, Fe did color change after treatment with Beryllium. This indicates that V does not have to be present for a color change. In more chemically complex natural corundum, increasing relatively lower Ti-concentrations in the presence of other trace elements (such as Beryllium) are favorable for the formation of the orange color. Special attention, however, needs to be paid to the additional presence of detectable concentrations of Si in the treated samples. A model for the explanation of the formation of orange color centers was proposed by Emmett et al. (2003) based on the (Ti+Si/Mg+Be)-ratio. As shown by our investigation (Fig. E48a and Fig.E48b), a better correlation is found using the Ti/(Mg+Be)-ratio, without taking into account the Si concentrations. The orange color is formed by the new treatment in samples with Ti/(Mg+Be)<1 (Fig. E48b). From the distribution of Si in our samples, it seems that Si is hetrogeneously distributed in the Be-treated corundum and may not take part in the reaction with Beryllium. For other trace elements that can theoretically be important to the origin of color in corundum, we found that the concentrations of Co, Cu, Zr, Ba and Pb were present at, or below, the detection limits. Therefore, their role in the treatment is limited as well as unlikely (Tab. E3). Other areas of additional research are necessary to understand the complex re-crystallization process that occurs in connection with this new treatment (see Fig. E2 and E3). Furthermore, it seems to us that modern multi-element cluster analyses (see Moon A.R. and Philips M.R. (1994) are unavoidable in understanding the new treatment.

Literature

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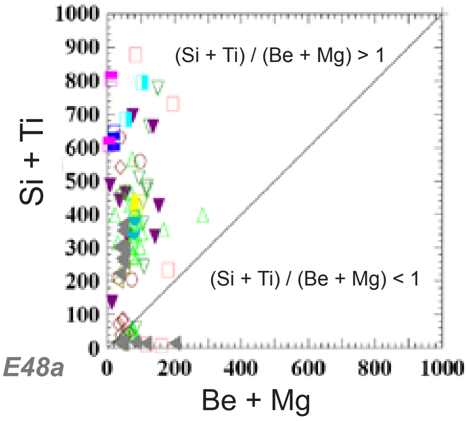

Fig. E48a

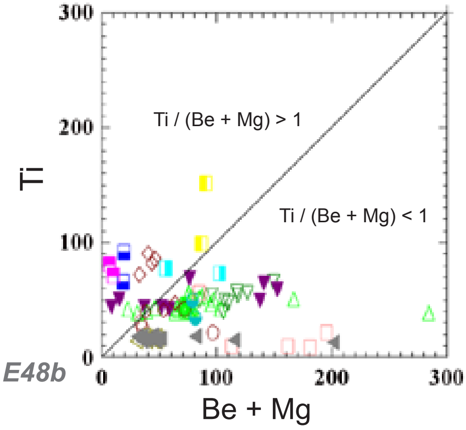

Fig. E48b

***Fig. E48** Chemical composition of Si, Ti, Be and Mg in natural corundum heat-treated with conventional methods, and with Beryllium treatment. The additional orange color is formed in the field of Ti/(Be + Mg) <1 (Fig. E48b and Legend) and not in the field (Ti + Si)/(Be + Mg) <1. See Emmett et al. (2003) for further discussion on Si in corundum. Symbols, see Legend below.*

Legend

Orange Sapphire, Madagascar Conventional heating	**GRS 35 S1**
Orange Sapphire, Madagascar Conventional heating	**GRS 35 S2**
Padparadscha, Madagascar Conventional heating	**Rosa 3.59**
Slightly orangy-pink Sapphire Madagascar, New Treatment	**GRS 33**
Padparadscha, Madagascar New Treatment	**GRS 34**
Padparadscha, Madagascar New Treatment (zoned)	**12916**
Padparadscha, Madagascar New Treatment (zoned)	**12916 S2**
Ruby, vivid red, Madagascar New Treatment	**Rot 10.69**
Natural Sapphire, blue Conventional heating	**12132**
Natural Sapphire, dark blue Conventional heating	**12344 S1**
Natural Sapphire, dark blue Conventional heating	**5.019ct S1**
Natural Sapphire, vivid blue New Treatment	**12133**
Natural Sapphire, deep blue New Treatment	**12134**

Tab. E2 (continued) LA-ICP-MS Analyses (in ppm) of Beryllium Treated Synthetic and Natural Corundum

Pit N°	Sample N°	Li 7 ppm	Be 9 ppm	B 11 ppm	Na 23 ppm	Mg 25 ppm	Si 29 ppm	K 39 ppm	Ca 42 ppm	Ti 49 ppm	V 51 ppm	Cr 53 ppm	Mn 55 ppm	Fe 57 ppm	Co 59 ppm	Ni 61 ppm	Cu 65 ppm	Ga 69 ppm	Y 89 ppm	Zr 90 ppm	Nb 93 ppm	Mo 95 ppm	Sn 120 ppm	Pb 208 ppm
GRS 25	min.	bd		bd	bd	bd	bd	6.1	bd	65.3	bd	5664	bd	1152	bd	bd	bd	bd	bd	bd	bd		0.93	0.10
Synthetic Ruby	max.	0.39		7.5	121	40.4	986	30.1	474	127	1.4	23353	6.3	1951	0.35	193	1.7	0.46	0.11	0.95	0.51		3.3	0.88
red	Average	(0.39)	bd	(6.7)	(15.6)	(17.4)	(628)	14.2	(253)	101	(0.67)	11782	(3.2)	1642	(0.20)	(107)	(1.2)	(0.41)	(0.08)	(0.30)	(0.23)	bd	1.8	0.50
GRS 26	min.	-	bd	-	bd	2.2	bd	bd	-	47.9	0.30	4615	bd	1031	bd	bd		bd		bd	0.09		1.1	bd
Synthetic Ruby	max.	-	35.0	-	4.5	13.5	538	4.2	-	109	1.4	7587	4.6	1892	0.26	142		0.42		0.27	0.50		2.5	0.16
red Be-treated Profile	Average	-	(22.96)	-	(3.8)	7.4	(397)	(2.4)	-	80.9	0.70	6461	(2.2)	1477	(0.20)	(93.7)	bd	(0.32)	bd	(0.19)	0.24	bd	1.7	(0.11)
GRS 27	min.		-	bd	bd	6.0	bd	bd	bd	81.5	bd	5998	bd	1477	bd	131	bd	bd	bd	bd	bd		bd	bd
Synthetic Ruby	max.		-	5.6	16.5	71.4	717	14.5	494	229	0.70	17249	3.3	3429	0.30	396	3.5	0.68	0.16	0.80	0.53		7.3	18.4
dark red	Average	bd	-	(5.5)	(9.8)	18.2	(525)	(9.3)	(354)	138	(0.55)	12559	(2.3)	2497	(0.25)	204	(1.6)	(0.51)	(0.11)	(0.42)	(0.31)	bd	(3.0)	(1.4)
GRS 28	min.	bd	bd	bd	bd	5.3	bd	bd	-	86.0	bd	7087		1740	bd	112		bd	bd	bd	bd		1.4	bd
Synthetic Ruby	max.	0.64	35.6	9.4	5.2	273	608	8.3	-	183	0.83	18300		3292	0.25	474		0.62	0.27	1.0	0.41		7.3	0.41
dark red Be-treated Profile	Average	(0.38)	(17.95)	(6.8)	(3.5)	20.3	(503)	(4.7)	-	134	(0.61)	14174	bd	2322	(0.17)	243	bd	(0.39)	(0.12)	(0.47)	(0.25)	bd	2.5	(0.15)
GRS 29	min.	-	-	bd	2.4	17.9	406	3.1	bd	34.7	bd	1161	bd	1508	bd	bd	bd	bd	bd	bd	2.4		1.1	bd
Synthetic Ruby	max.	-	-	14.0	55.6	106	1216	55.5	224	62.0	2.7	2565	8.4	2177	1.6	132	1.9	0.61	0.35	0.19	12.4		3.1	1.1
pinkish-red	Average	-	-	(10.3)	22.4	70.0	544	21.7	(172)	45.8	(1.3)	2036	(5.9)	1773	(1.0)	(91.5)	(1.3)	(0.45)	(0.20)	(0.09)	5.4	bd	1.9	(0.45)
GRS 30	min.		11.9	bd	-	18.7	bd	bd	-	37.0	bd	1147	bd	1393	bd	47.8	bd	bd	bd	bd	2.0	bd	1.2	bd
Synthetic Ruby	max.		61.2	14.1	-	86.0	686	7.4	-	55.3	3.4	2298	18.3	2051	1.6	119	5.9	0.76	0.31	0.15	11.1	1.7	2.9	0.15
pinkish-red Be-treated Profile	Average	bd	32.0	(10.3)	-	53.7	(475)	(4.0)	-	44.6	(1.6)	1878	(6.5)	1669	(0.93)	76.7	(3.3)	(0.46)	(0.20)	(0.11)	5.6	(0.67)	2.0	(0.10)
GRS 35	min.			bd		40.1	bd		-	32.3	9.2	217	-	5207			bd	63.1		bd	-		1.2	bd
Natural orange Sapphire	max.			6.1		59.1	622		-	45.6	10.9	308	-	5659			0.95	71.5		0.14	-		1.8	0.22
heated (no Be treatment) Surface analysis	Average	bd	bd	(5.9)	bd	48.4	(370)	bd	-	38.8	9.9	280	-	5429	bd	bd	(0.95)	66.7	bd	(0.07)	-	bd	1.5	(0.14)
GRS 35.2	min.			bd		35.6	bd	-	-	32.0	8.8	256	bd	5635		-		64.3			bd		bd	bd
Natural orange Sapphire	max.			5.8		57.4	491	-	-	50.3	11.3	312	3.3	6697		-		75.6			0.08		1.8	0.15
heated (no Be treatment) Surface analysis	Average	bd	bd	(5.3)	bd	47.7	(375)	-	-	39.6	10.0	279	(3.3)	6191	bd	-	bd	70.0	bd	bd	(0.04)	bd	(1.4)	(0.11)
GRS 35.3	min.			bd		35.6	bd	-	-	32.0	8.8	256	bd	5635		-		64.3			bd		bd	bd
Natural orange Sapphire	max.			5.8		57.4	491	-	-	50.3	11.3	312	3.3	6697		-		75.6			0.08		1.8	0.15
heated (no Be treatment) Surface analysis	Average	bd	bd	(5.3)	bd	47.7	(375)	-	-	39.6	10.0	279	(3.3)	6191	bd	-	bd	70.0	bd	bd	(0.04)	bd	(1.4)	(0.11)
GRS 21	min.	-	bd	bd	bd	bd	bd	bd	-	72.5	23.6	bd		201	-	-	bd	bd		bd	bd		bd	bd
Natural blue Sapphire	max.	-	3.7	5.4	23.9	3.5	1290	18.9	-	281	46.6	14.5		635	-	-	28.4	0.60		1.4	0.04		2.1	0.18
Be-Treated Profile	Average	-	(2.1)	(4.3)	(11.2)	(2.3)	(620)	(13.3)	-	137	33.3	(9.2)	bd	401	-	-	(9.5)	(0.44)	bd	(0.58)	(0.04)	bd	(1.5)	(0.15)
GRS 23	min.		bd	bd	bd	bd	bd	bd	bd	70.4	24.5	bd	-	510	bd		bd	0.95	-		-	bd	bd	bd
Natural blue Sapphire	max.		11.2	7.1	115	3.2	2713	7.6	8137	128	45.4	14.8	-	910	5.8		1.3	2.2	-		-	1.6	2.5	0.26
Be-Treated Profile	Average	bd	(6.55)	(6.4)	(20.8)	(2.0)	(760)	(5.9)	(8137)	93.1	35.9	(11.0)	-	712	(2.2)	bd	(0.91)	1.4	-	bd	-	(1.2)	(1.7)	(0.22)
GRS 24	min.	bd	32.6	bd	bd	6.2	bd	bd	bd	80.9	16.9	bd	bd	396	bd	bd	bd	3.7		3.3	bd	bd	bd	bd
Natural blue Sapphire	max.	0.38	51.0	6.5	7.5	51.9	5608	15.9	800	158	29.4	24.3	2.1	791	0.32	35.1	3.8	19.1		5.9	0.16	0.95	3.6	0.71
Be-Treated Surface analysis	Average	(0.38)	41.4	(4.7)	(2.6)	22.3	(701)	(7.1)	(331)	103	22.3	(14.6)	(1.8)	568	(0.16)	(17.1)	(1.2)	11.8	bd	4.9	(0.08)	(0.42)	(1.5)	(0.36)
	LOD Be (ppm)	0.35	2.3	3.5	2.3	2.1	334	3.7	124	4.8	0.37	10	1.6	17	0.22	28	0.86	0.24	0.08	0.12		0.72	1.3	0.1

Tab. E2 (continued) LA-ICP-MS Analyses (in ppm) of Beryllium Treated Synthetic Corundum

		Li	Be	B	Na	Mg	Si	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Ga	Y	Zr	Mo	Sn	Pb
GRS 2	min.	-		bd	bd	bd	bd	bd	-	bd	bd	bd	bd	bd	bd	bd	bd	bd				bd	bd
Synthetic White	max.	-		4.0	39.9	22.7	1268	31.7	-	54.8	0.52	13.7	537	101	4.9	97.7	63.6	0.78				2.3	0.61
Sapphire	Average	-	bd	(4.0)	(16.7)	(8.3)	(489)	(15.4)	-	(9.8)	(0.45)	(13.7)	(537)	(41.6)	(1.7)	(60.1)	(12.1)	(0.33)	bd	bd	bd	(1.6)	(0.28)
GRS 1	min.	bd	bd	bd	17.5	bd	370	9.8		1.0	bd	bd		bd			bd	bd	-	0.03			0.09
White Synthetic	max.	0.49	6.3	3.5	174	128	851	41.9		85.8	0.52	143		42.3			0.91	8.1	-	3.1			0.65
Sapphire Be-treated Profile	Average	(0.21)	(2.7)	(1.8)	75.6	(29.3)	609	25.1	bd	22.3	(0.20)	(45.1)	bd	(9.5)	bd	bd	(0.34)	(1.8)	-	0.98	bd	bd	0.25
GRS 10	min.	bd	bd	bd	bd	bd	bd	bd	-	bd	bd	68.0	-	bd	bd		bd	bd	bd	bd		bd	bd
Irradiated Orange	max.	0.37	3.1	4.2	16.2	14.2	717	62.1	-	41.1	1.6	150	-	17.2	0.30		24.1	1.6	0.20	0.22		2.5	0.58
Synthetic sapph.	Average	(0.37)	(2.3)	(3.9)	(5.1)	(6.9)	(676)	(10.0)	-	(13.7)	(1.6)	90.5	-	(17.3)	(0.22)	bd	(5.4)	(0.93)	(0.05)	(0.08)	bd	(1.5)	(0.26)
GRS 11	min.	-	8.6	-	bd	bd	bd	bd	bd	bd	bd	76.9	bd	bd	-		bd	bd	bd	bd	bd	bd	bd
Synthetic Orange Sapphire irradiated	max.	-	2572	-	568	149	1441	226	1145	100	0.61	173	5.0	1220	-		1.6	38.3	11.5	980	0.87	2.5	0.45
and Be-treated	Average	-	212	-	(124)	(34.7)	(595)	(62.4)	(1145)	(18.4)	(0.61)	97.5	(5.0)	(1220)	-	bd	(1.5)	(5.8)	(11.5)	(245)	(0.62)	(1.7)	(0.18)
GRS 12	min.	bd	bd	bd	bd	bd	bd	bd	bd	bd	-	48.9	bd	bd	bd		bd	bd	bd	bd	bd	bd	bd
Synthetic	max.	0.90	3.3	6.2	678.8	12536	1134	13.7	4719	90.4	-	140	2.8	77.8	3.2		6.4	0.72	0.12	10.6	1.2	4.6	3.97
pink Sapphire	Average	(0.77)	(3.3)	(4.9)	(33.2)	(5732)	(818)	(8.1)	(1515)	(31.8)	-	92.5	(2.6)	(38.8)	(0.85)	bd	(2.5)	(0.48)	(0.06)	(2.1)	(0.71)	(2.4)	(0.54)
GRS 13	min.	bd	bd	bd	bd	2065	bd	bd	bd	bd	-	88.0	-	bd	bd	-	bd	bd		0.37	bd	bd	bd
Synthetic Pink Sapphire	max.	1.4	15.5	30.6	364	35158	1529	385	8024	51.4	-	161	-	28.7	17.1	-	3.1	1.6		5.4	1.5	3.3	2.0
Be-treated Profile	Average	(1.4)	(8.8)	(9.6)	(27.4)	14485	(778)	(42.6)	(1944)	(15.2)	-	112	-	(21.9)	(7.4)	-	(1.5)	(0.99)	bd	2.3	(0.47)	(2.0)	(0.39)
GRS 4	min.	bd	bd	bd	bd	bd	bd	bd	-	bd	bd	bd	bd	bd	bd		bd	bd	bd	bd	bd	bd	bd
Synthetic	max.	0.49	3.6	18.8	71.2	159	1341	61.4	-	73.8	0.38	335	3.5	117	0.40		41.5	1.2	0.12	0.69	0.80	2.9	0.90
Pink Sapphire	Average	(0.42)	(3.3)	(10.9)	(13.5)	(14.6)	(605)	(15.5)	-	(13.4)	(0.32)	(261)	(2.6)	(31.8)	(0.24)	bd	(4.5)	(0.68)	(0.08)	(0.22)	(0.39)	(2.0)	(0.29)
GRS 5	min.	-	bd	bd	bd	bd	bd	bd	-	bd		238	-	bd		-		bd		-		bd	bd
Synthetic Pink	max.	-	12.4	7.3	14.6	15.8	1000	159	-	9.9		336	-	18.1		-		0.36		-		2.3	0.45
Sapphire Be-treated	Average	-	(7.8)	(4.8)	(5.7)	(6.8)	(529)	(23.0)	-	(6.6)	bd	282	-	(17.2)	bd	-	bd	(0.27)	bd	-	bd	(1.9)	(0.17)
GRS 8	min.		bd	bd	bd	bd	bd	bd		bd	bd	427	bd	bd	bd		bd	1.2	bd	bd		bd	bd
Synthetic	max.		2.1	4.5	143	23.5	749	18.2		27.3	0.44	597	3.3	55.8	0.29		4.2	2.3	1.1	1.0		2.7	2.0
Pink Sapphire	Average	bd	(1.7)	(4.5)	(11.4)	(6.41)	(489)	(6.4)	bd	(16.9)	(0.35)	491	(3.3)	(34.4)	(0.26)	bd	(2.1)	1.6	(0.16)	(0.26)	bd	(2.1)	(0.61)
GRS 9	min.	-	bd	-	bd	-	bd	bd	-	8.7		430	-	-		-		0.30				bd	-
Synthetic	max.	-	13.0	-	4.1	-	512	6.3	-	18.1		528	-	-		-		0.79				2.0	-
Pink Sapphire Be-treated Profile	Average	-	(9.7)	-	(3.2)	-	(411)	(5.5)	-	13.4	bd	476	-	-	bd	-	bd	0.55	bd	bd	bd	(1.8)	-
GRS 15	min.	-	bd	bd	bd	bd	bd	bd	-	8.8	-	459	-	bd		-	bd	bd		bd		bd	bd
Synthetic	max.	-	3.0	5.5	63.2	50.2	542	153	-	148	-	740	-	48.7		-	5.3	0.96		0.12		3.1	4.2
pink Sapphire	Average	-	(2.4)	(5.5)	(19.4)	(9.1)	(504)	(29.2)	-	30.3	-	565	-	(27.2)	bd	-	(2.2)	(0.59)	bd	(0.06)	bd	(1.8)	(0.50)
GRS 16	min.	bd	0.65	bd	2.6	bd	165	bd	bd	7.3	bd	273	bd	bd				0.08	-	bd		0.37	bd
Synthetic Orange	max.	0.38	15029	7.7	81.1	61.9	1127	28.7	237	260	2.4	805	3.5	1881				142	-	170		1.7	0.30
Sapphire Be-treated	Average	-	2949	-	22.5	-	479	-	-	87.7	-	508	-	-	bd	bd	bd	24.9	-	24.9	bd	1.1	-
GRS 17	min.	bd	bd	bd	bd	bd	bd	bd	-	bd	bd	207	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd
Synthetic	max.	0.48	3.2	4.9	63.4	83.2	2641	21.5	-	87.6	0.88	347	2.3	216	0.45	45.9	6.0	2.1	0.09	0.16	0.86	3.4	2.8
Orange Sapphire	Average	(0.38)	(1.4)	(4.4)	(9.5)	(8.9)	(700)	(9.5)	-	(13.6)	(0.88)	250	(2.2)	(49.7)	(0.27)	(37.1)	(2.0)	(0.92)	(0.03)	(0.08)	(0.55)	(2.1)	(0.39)
GRS 18	min.	bd	bd	bd	bd	bd	bd	bd	bd	bd	bd	217	-	bd				bd	bd	bd	bd	bd	bd
Synthetic Orange	max.	0.44	24.6	5.0	28.6	10.7	1664	6.2	559	10.3	1.5	343	-	104				0.77	0.10	2.2	1413	3.3	0.14
Sapphire Be-treated	Average	(0.44)	(10.2)	(5.0)	(8.2)	(3.5)	(641)	(4.2)	(371)	(7.8)	(1.0)	276	-	(38.5)	bd	bd	bd	(0.48)	(0.08)	(1.2)	(196)	(1.8)	(0.09)
GRS 19	min.	-	bd	bd	bd	bd	bd	bd	-	bd	bd	-	bd	bd		bd	bd	bd	bd	bd	bd	bd	bd
Synthetic Yellow	max.	-	2.7	5.8	6.0	57.5	1173	9.8	-	9.1	1.9	-	46.9	193		62.4	2.0	1.5	0.10	0.19	0.96	3.1	0.88
Sapphire	Average	-	(1.1)	(3.9)	(4.2)	(7.6)	(681)	(6.0)	-	(9.1)	(1.9)	-	(46.9)	(105)	bd	(39.4)	(1.5)	(0.95)	(0.03)	(0.08)	(0.39)	(1.7)	(0.34)
GRS 20	min.	bd	bd	-	bd	bd	bd	bd	-	-				bd		bd		bd	bd	bd	bd	bd	bd
Synthetic Yellow	max.	0.71	23.1	-	7.1	14.5	694	7.8	-	-				60.8		55.8		0.75	0.12	0.29	0.73	2.6	0.25
Sapphire Be-treated	Average	(0.54)	(11.1)	-	(3.9)	(5.3)	(476)	(7.8)	-	-	bd	bd	bd	(29.4)	bd	(36.3)	bd	(0.48)	(0.06)	(0.19)	(0.70)	(1.9)	(0.14)
	LOD (ppm)	**0.35**	**2.3**	**3.5**	**2.3**	**2.1**	**334**	**3.7**	**124**	**4.8**	**0.37**	**10**	**1.6**	**17**	**0.22**	**28**	**0.86**	**0.24**	**0.08**	**0.12**	**0.72**	**1.3**	**0.1**

Tab. E3 LA-ICP-MS Analyses (in ppm) of Beryllium Treated and Conventional Heated Natural Corundum

Sample	ID		Li	Be	B	Na	Mg	Si	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Ga	Zr	Sn	Ba	Pb
			7	9	11	23	25	29	39	42	49	51	53	55	57	59	61	65	69	90	120	138	208
			ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Orange Sapphire, Madagascar	**GRS 35 S1**	Average	bd	bd	bd	bd	48.45	370.4	bd	bd	38.76	9.94	279.8	bd	5429	bd	bd	bd	66.74	bd	bd	bd	bd
Conventional heating		*St. Dev.*					*5.6*	*122.2*			*4.0*	*0.4*	*23.7*		*149.5*				*2.6*				
Orange Sapphire, Madagascar	**GRS 35 S2**	Average	bd	bd	bd	bd	47.67	374.7	bd	bd	39.63	10.00	279.0	3.32	6191	bd	bd	bd	70.04	bd	bd	bd	bd
Conventional heating		*St. Dev.*					*6.5*	*63.1*			*4.5*	*0.7*	*15.0*		*324.6*				*2.9*				
Padparadscha, Madagascar	**Rosa 3.59**	Average	bd	bd	bd	bd	73.09	(847)	bd	bd	69.41	10.96	47.91	bd	145.3	bd	bd	bd	104.7	bd	bd	bd	bd
Conventional heating		*St. Dev.*					*9.4*	*799.8*			*18.0*	*1.5*	*15.1*		*29.0*				*6.8*				
Slightly orangy-pink Sapphire	**GRS 33**	Average	bd	6.40	bd	bd	96.89	448.6	bd	bd	105.4	28.36	656	bd	1031	bd	bd	bd	95.89	(1.38)	bd	bd	bd
Madagascar, New Treatment		*St. Dev.*		*1.6*			*21.1*	*104.3*			*11.3*	*2.3*	*51.9*		*62.9*				*5.3*	*2.8*			
Pink Sapphire, Madagascar	**GRS 34**	Average	3.95	bd	10.92	(78.44)	(403.0)	(1272)	(73.60)	321.9	(225.3)	45.64	384.5	5.04	(116.3)	0.83	bd	(50.97)	107.5	bd	bd	(4.86)	(3.36)
Beryllium Treatment		*St. Dev.*			*3.5*	*128.8*	*1005.2*	*1143.0*	*133.4*		*211.2*	*4.5*	*81.0*		*236.2*			*86.9*	*4.6*			*6.5*	*4.2*
Padparadscha, Madagascar	**12916**	Average	bd	12.67	bd	(8.66)	98.78	(543)	(9.48)	bd	123.6	25.70	331.2	bd	333.3	bd	bd	bd	98.79	(2.21)	bd	bd	bd
Beryllium Treatment (zoned)		*St. Dev.*		*3.4*		*15.3*	*20.1*	*286.4*	*9.7*		*16.7*	*2.2*	*23.4*		*46.2*				*6.0*	*3.1*			
Padparadscha, Madagascar	**12916 S2**	Average	bd	(21.01)	bd	bd	96.56	538	(16.74)	bd	122.1	22.22	289.2	bd	515	bd	bd	bd	101.9	(22.44)	2.29	bd	bd
Beryllium Treatment (zoned)		*St. Dev.*		*12.3*			*17.4*	*232.0*	*20.0*		*23.3*	*2.9*	*19.7*		*157.2*				*5.6*	*15.2*	*1.0*		
Ruby, vivid red, Madagascar	**Rot 10.69**	Average	bd	(26.78)	bd	bd	46.49	(484.1)	bd	214.2	(50.12)	53.99	2059	bd	716	bd	(51.95)	bd	132.96	(1.03)	bd	bd	bd
Beryllium Treatment		*St. Dev.*		*19.9*			*22.5*	*539.0*		*243.5*	*47.9*	*5.6*	*98.2*		*84.1*		*51.6*		*3.1*	*1.3*			
Natural Sapphire, blue	**12132**	Average	bd	bd	bd	(5.28)	87.89	759	bd	bd	183.8	8.35	bd	bd	947	bd	bd	bd	74.80	bd	(7.61)	bd	bd
Conventional heating		*St. Dev.*				*6.1*	*12.8*	*8.4*			*43.1*	*0.9*			*30.5*				*1.5*		*4.6*		
Natural Sapphire, dark blue	**12344 S1**	Average	bd	bd	bd	bd	22.34	914	bd	bd	176.7	4.20	bd	bd	8187	bd	bd	bd	238.4	bd	bd	bd	bd
Conventional heating		*St. Dev.*					*1.3*	*112.5*			*7.4*	*0.2*			*79.1*				*1.7*				
Natural Sapphire, dark blue	**5.019ct S1**	Average	bd	bd	bd	bd	bd	451.1	bd	bd	98.16	2.89	bd	bd	6559	bd	bd	bd	242.6	bd	5.68	bd	bd
Conventional heating		*St. Dev.*						*58.9*			*24.6*	*0.2*			*44.6*				*4.0*		*1.6*		
Natural Sapphire, vivid blue	**12133**	Average	bd	3.42	bd	bd	48.63	871	bd	bd	177.8	17.91	bd	bd	499.0	bd	bd	bd	66.34	bd	3.22	bd	0.55
Beryllium Treatment		*St. Dev.*		*1.5*			*17.2*	*202.0*			*15.4*	*0.3*			*33.0*				*1.2*		*0.1*		
Natural Sapphire, deep blue	**12134**	Average	bd	bd	bd	bd	188.3	417.3	bd	bd	293.8	17.57	(17.47)	bd	916	bd	bd	bd	44.93	bd	bd	bd	0.28
Beryllium Treatment		*St. Dev.*					*73.1*	*32.2*			*87.0*	*1.1*	*22.6*		*36.1*				*0.1*				*0.3*

Al normalized to 526600

LOD (ppm)	Li	Be	B	Na	Mg	Si	K	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Ga	Zr	Sn	Ba	Pb
LOD (ppm)	0.85	2.6	10.7	4.5	5.8	290	9.3	174	8.5	0.51	14	2.73	29	0.44	40	1.99	0.61	0.4	2.21	0.26	0.24

Tab. C1 LA-ICP-MS Analyses (in ppm) of Natural and Synthetic Spinel

Origin	Color	Sample No		Li ppm	Be ppm	B ppm	Na ppm	Si ppm	K ppm	Ca ppm	Ti ppm	V ppm	Cr ppm	Mn ppm	Fe ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	Ga ppm
Namya	pink	Nr. 6_2	average	59.0	19.3	bd	3.39	538	7.98	(360)	29.1	271	7329	157	68.3	bd	bd	1.14	762	79.2
			stdev.	0.1	4		0.6	14	1.1	555	4	2	649	3	23			0.3	13	2
Namya	pink	Nr. 7_2	average	225	46.7	bd	bd	673	bd	bd	15.5	208.0	2196	61.4	1021	0.90	4.25	bd	7408	315
			stdev.	9	7			196			0.6	0.1	8	1	34	0.1	0.4		61	3
Namya	vivid pink	Nr. 8_2	average	10.2	53.4	bd	bd	597	bd	bd	bd	393	2216	10.93	560	1.51	8.09	bd	5302	836
			stdev.	2.3	11			218				1.8	30	0.5	6	0.03	1.5		263	15
Namya	pinkish-red	Nr. 1_2	average	bd	27.5	bd	bd	571	bd	bd	222	101	3203	154	868	0.21	bd	bd	1038	280
			stdev.		8			105			13	9	696	7	111	0.1			68	13
Namya	pinkish-red	Nr. 3_2	average	83.0	24.3	bd	2.41	469	bd	bd	47	255	7129	121	78.1	bd	bd	1.19	761	64
			stdev.	21	2		0.5	126			3	19	207	1	1			0.3	111	1
Namya	pinkish-red	Nr. 4_2	average	bd	19.4	bd	1.45	593	bd	bd	567	788	4930	57.4	34.2	bd	bd	bd	305	47.6
			stdev.		8			204			3	3	176	5	13				8	1
Namya	pinkish-red	Nr. 5_2	average	33.1	9.09	bd	2.13	663	bd	bd	138	336	4823	169	55.0	bd	bd	1.42	824	51.4
			stdev.	6.2	2		0.4	42			2	12	42	3	11			0.8	33	4
Namya	red	Nr. 9_2	average	bd	bd	bd	(4.54)	570	bd	bd	169	1124	17182	6.96	1613	1.00	17.7	(1.65)	1988	133
			stdev.				5.7	65			5	25	1732	0.7	128	0.2	1.3	1.1	12	2
Namya	red	Nr. 10_2	average	bd	11.4	bd	(15.6)	1095	(24.4)	bd	1800	1142	8042	67.8	177	bd	bd	(14.5)	296	82.6
			stdev.		1.6		17	357	26		87	9	122	1	55			13.3	11	3
Mogok, Pyen Pit	red	Nr. 2_1	average	159	(14.0)	bd	bd	631	bd	bd	45.0	1211	6645	20.3	1621	4.11	102	1.04	4372	264
			stdev.	33	9			82			3.9	6	316	0.6	94.0	0.2	13	0.5	164	11
Mogok, Pyen Pit	red	Nr.10_1	average	22.0	bd	bd	bd	650	bd	bd	47.5	969	12569	21.7	1470	4.29	104	bd	3649	293
			stdev.	6				154			2	12	69	0.6	81	0.2	1		71	8
Mogok, Pyen Pit	red	Nr. 17_2	average	213	10.5	bd	bd	616	bd	bd	64.6	1760	18538	16.2	1088	4.52	112	0.85	3784	299
			stdev.	63	4			19			12	183	534	0.6	3	0.6	5	0.2	411	27
Mogok, Ohn Gaing	red	Nr. 4_1	average	bd	bd	bd	bd	595	bd	bd	386	611	5858	31.9	906	1.06	7.09	0.70	3739	101
			stdev.					240			23	13	238	1.0	40	0.2	0.5	0.3	39	6
Mogok, Ohn Gaing	red	Nr. 6_1	average	bd	5.16	bd	bd	554	bd	bd	369	765	7368	48.2	463	0.71	23.7	bd	474	64.8
			stdev.		0.3			87			5	4	97	0.5	14	0.01	5		12	0.1
Mogok, In Gaung	red	Nr. 7_1	average	185	12.1	bd	bd	702	bd	bd	246	1215	9321	9.7	3289	0.78	bd	0.74	6194	216
			stdev.	11	2			47			5	26	430	0.7	103	0.03		0.2	130	17
Mogok, Chaung Gyi	pinkish-red	Nr. 19_2	average	189	32.2	bd	(1.73)	520	bd	bd	170	1923	7175	19.8	1744	6.40	112	(3.58)	4191	303
			stdev.	14	1.3		1.9	172			4	93	211	2	11	0.2	9.6	3.8	71	7
Mogok, Shwe Phy Aye	red	Nr. 8_1	average	91.2	52.7	bd	(2.40)	667	bd	bd	589	423	6153	53.3	217	bd	bd	(0.74)	159	1
			stdev.	0.05	5		2.4	291			8	3	78	1.5	15			0.6	10	0.2
Mogok	orange	Nr. 16_2	average	bd	(15.4)	bd	8.75	474	14.4	bd	59.2	2558	67.7	9.0	680	bd	bd	1.17	2620	242
			stdev.		12		0.0	96	0.3		21	115	5	0.1	12			0.3	19	10
Mogok	orange-red	Nr. 15_2	average	bd	bd	bd	20.1	553	36.4	(175)	155	6198	126	9.21	466	bd	8.18	4.85	1023	154
			stdev.				3	9	14.5	234	25	149	31	0.1	19		2.4	0.9	53	6
Mogok	purple	Nr. 14_2	average	221	bd	bd	(33.8)	469	8.91	bd	57.3	75.2	317	378	10005	3.47	(3.72)	bd	956	171
			stdev.	8			28	49	3.1		3	1	13.4	4	413	0.3	3.4		17	0.1
Mogok	green	Nr. 12_2	average	37.9	8.50	bd	7.67	644	5.43	bd	8.20	29.1	24	268	7677	2.38	bd	1.16	3239	126
			stdev.	10	2.7		1.3	101	0.1		2.0	0.5	2	6	326	0.1		0.4	152	6
Mogok	bluish-green	Nr.11_2	average	18.7	bd	bd	6.22	681	(13.3)	bd	30.6	35.5	95	176	9999	0.42	5.48	(0.94)	1865	62.4
			stdev.	0.9			2.5	9	12		6	0.4	3	3	147	0.1	1.3	0.7	1	0.2
Madagascar	blue	Nr. 13_2	average	30.4	bd	bd	bd	557	bd	bd	40.0	26.2	bd	199	16985	10.11	40.4	0.84	1548	134
			stdev.	1.8				3			0.2	0.8		3	0.1	0.2	0.7	0.3	11	3
Madagascar	pink	Nr. 18_2	average	73.8	55.6	bd	bd	582	bd	bd	549	374	3693	35.8	114	bd	bd	(0.73)	60.8	1.02
			stdev.	1.4	5.4			95			23	18	38	2	11			0.7	7	0.1
Vietnam	pink	Nr. 5_1	average	578	11.5	bd	bd	548	bd	bd	68.3	263	6182	65.5	14331	32.4	86.9	1.26	726	129
			stdev.	58	4.8			145			1	2	482	1.4	410	1	13	0.4	53	0.9
Synthetic Russia	pinkish-red	Nr. 1_1	average	bd	bd	bd	bd	534	bd	bd	bd	200	3421	185.8	723	0.76	124	1.20	41	58.7
			stdev.					9.9				7	46	6.1	21	0.03	25	0.2	1	0.8
Synthetic, Russia	pinkish-red	Nr. 3_1	average	bd	bd	bd	bd	605	bd	bd	(18.0)	172	3295	183	735	0.87	165	bd	42.6	54.9
			stdev.					76			22	4	44	1	9	0.1	9		1	0.2
		LOD (ppm)		7.4	4.6	18.2	1.2	314	4.3	167	4.1	0.49	6.6	0.97	14.8	0.14	3.2	0.62	1.3	0.23

Normalized to Al+Mg = 100 wt.-% by difference

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(Contributions to Gemology (2002), No.1 On-line)

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(Photo Album of inclusions, e.g. inclusions in Beryllium treated gemstones)

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(GRS discoveries of new minerals and application details)

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Acknowledgements

We would like to thank all the persons and institutions who helped for this report.
Dr. A. Burkhardt for ED-XRF analysis, Prof. K. Ramseyer (University of Berne) and Dr. J. Mullis for cathodoluminescene analysis, Mrs Kathrin Hametner and Mr. B. Hattendorf (co-worker in the group of trace elements and micro analytic of LAC laboratory at ETH, Zurich. Mrs Anong Kanpraphai, GRS (Thailand) Co. LTD for digital artwork, Anong Imaging (Bangkok) for picture artwork, IMAGIMAX Animation & Design Studio (Bangkok, Thailand) for graphic and artwork, Mr. Sumet Tanthadilok for designing, Mr. Saleem Michael for scientific graphics and preparing this report for the Internet, Mr. John deJaegher (G.G.) for assistance and Marcus Brogden for English corrections and Lewis Allen for some editorial work. Without the support of the trade including various wholesale companies in Bangkok and mining companies world-wide, it would not have been possible to receive enough reference materials. Thanks also to the companies in Bangkok and Chantaburi (Thailand) for heat treating our reference samples with the new method in their factories. Thanks to all people of Burma(Myanmar) for support during the expedition in 2001. This issue was supported by C.H. Lapidaries LTD. (Bangkok, Thailand), Crown Color, Geneva (Siwtzerland), GRS (Thailand) Co., LTD., Bangkok and by GRS Gemresearch Swisslab AG (Switzerland) and the family of Adolf Peretti.

Important Information

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