

# Diplôme Universitaire de Gemmologie

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by

Franck NOTARI

## THE PADPARADSCHA SAPPHIRE

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at the Geology Department  
in front of the following board of examiners:

Mr B. LASNIER	Professor	Chairman
Mr E. FRITSCH	Professor	Vice-Chairman
Mr S. LEFRANT	Professor	Examiner
Mr J. GIRARDEAU	Professor	Examiner
Mr J.-P. GAUTHIER	Professor	Examiner
Mr M. SPIESSER	Lecturer	Examiner
Mr J.-P. POIROT	Former Manager of the CCIP's Diamonds Checking Duties	Examiner
Mr H.A. HÄNNI	Manager of the Swiss Institute of Gemmology	Guest
Mr P. ENTREMONT	President of the French Gemmological Society	Guest

# 0. Introduction

*Au carrefour de la science et de la poésie,  
cette gemme exceptionnelle illustre remarquablement bien la richesse d'interprétation  
et la sensibilité de la gemmologie d'hier et d'aujourd'hui.  
Son nom et l'appréciation de sa couleur sont nés de la perception subtile,  
historique et affective que les hommes ont de leur monde.  
Elle est une part de la mémoire d'une culture universelle,  
celle qui fait que notre regard s'attarde sur le beau,  
que notre esprit s'émeut d'un scintillement aux subtiles teintes,  
qui fait que enfin nos pas ralentissent,  
laissant un instant le doute et la poésie nous rattraper.*



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We make a point of thanking the following people for their help:

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Michael Krzemnicki, mineralogist; Mr Roland Maestrati, gemmologist; Mr Walter Meili; Mrs  
Mathilde Morand; Mr Marc Noverraz, lapidary; Mr Louis Picard; Mr Leslie Punchihewa,  
gemmologist in Colombo; Mr Christophe Zen-Ruffinen, lapidary.

## Foreword

This work represents a long inquiry – on the ground (Sri Lanka) as well as in books - during which I have had fruitful discussions with Sri Lankan gemmologists, tradesmen, collectors and scholars.

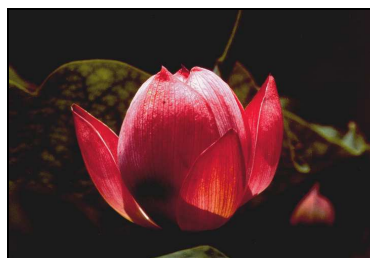
Padparadscha does not belong to us. It is a notion. Besides the fact that its identity is essentially related to a particular culture, it happens that this notion can also be characterized by a scientific approach.

As we will see, this notion has been corrupted several times throughout its history, by different mechanisms such as simple particular commercial constraint, individual behaviour depending on lucre or human difficulty in understanding and describing with objectivity the colours that they perceive.

It can also be added that this notion has been transmitted orally over the centuries without being precisely characterized.

Everybody knows that game in which each child in a group alternately whispers a sentence in their neighbour's ear. At the end, the sentence does not have much in common with what it sounded like at the beginning.

Given that, the padparadscha notion was born about twenty centuries ago, whereas the generalisation of written culture in most people only dates back to two centuries or so, it is obvious that over a period of about eighteen centuries men have built an idea of the padparadscha that has varied considerably according to interests, periods and places.



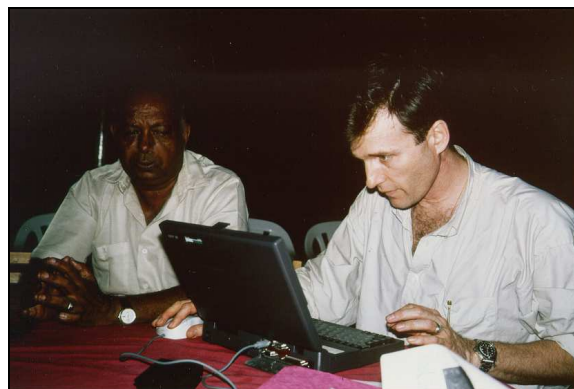
Moreover some criteria are no longer precisely identifiable. For instance, because of the great number of Lotus (*Nelumbo nucifera* [*Nelumbium Speciosum indica*]) varieties and consequently of Lotus colours known today, the original hue on which the padparadscha notion was based cannot be defined any more.

The considerable and patient work to which Christine Jomard (D.U.G. dissertation, 1996) has devoted herself served as a starting point for this study. Beginning from the "archaeo-padparadscha" of ancient texts, the "available" bibliography pictures an evolution of the chromatic concept, and leads to define the concept of two distinct "habits".

The notion of Padparadscha, having only been applied to gems originating from Sri Lanka so far, has a whole chapter dedicated to the characterization of this origin.

Distinction criteria enabling to recognize pink-orangey brownish sapphires coming from East Africa and improperly called padparadschas are suggested.

A charter is proposed by way of conclusion. It explains in details the characteristics that constitute the diagnosis of padparadscha.



Interview

Cliché C. Jomard

# 1. Habit and Dimensions

## 1.0 Habit

Following the observation of a great number of padparadschas, we have noticed the existence of four distinct groups possessing manifestly different internal and depositary characteristics. Therefore we suggest to use the notion of habit for a better understanding of this very peculiar population of sapphires. This tool helps us to understand some deviations from the standard colour and enables us to better recognize the "boundary" stones deserving even so the designation of "padparadscha". The names of the habits derive from the terminologies used by Sri Lankan tradesmen.

*The habit, loan word from the study of the human body, is a notion commonly used in mineralogy where it categorizes individuals of the same species into homogeneous groups on the basis of criteria of colour, morphology or internal structures.*

*In crystallography, this word designates more precisely groups presenting redundant characteristics of crystalline developments or flaws within a species.*

*The aim of this study is to describe cut gems, therefore the crystalline habit "sensu stricto" cannot be applicable. We will then use this word to define the general aspect of a cut gem, considering the inclusions, the colour(s) and their latent or revealed potentialities, the transparency / clarity, the effects produced by the cut and any other notable feature.*

*This approach is applicable to the padparadschas' available on the market, among which can be distinguish four habits. The first two correspond to the notion of real padparadscha, the third corresponds to the notion of created or induced padparadscha, and the fourth cannot be designated by the name padparadscha.*

## 1.1 Description of the "Habits"

### 1.1.1 "Native" Habit

We will call "native" ("original" in French) the habit that is generally considered as the oldest and most representative of the concept by Western laboratories as well as by Sri Lankan tradesmen:

The material is generally very pure, not presenting many veils, only rarely containing xenospecific or multiphase inclusions, and giving very sparkling faceted stones with a high "dispersion". The colour, orangey pink, homogeneous to the eye, is always pastel, with a low to medium saturation and light tone, well-balanced in the norm in most cases (see conclusion charter). It strives a bit towards the orange pole sometimes, but rarely, and only weakly towards the pink pole. In the great majority of cases, this habit shows a blue colour zoning that is often visible to the naked eye and always visible during an examination in immersion. This colour zoning, that lapidaries attempt to place as parallel as possible to the table, but at best parallel to the angle of the pavilion for this habit, can be considered as one of the elements characterizing the Sri Lankan\* origin (see 2.4.2).

\* Only in the case of orangey pink pastel sapphires, since this colour zoning can be found in corundums of diverse colours and origins.

### 1.1.2 "Antique Colour" Habit

The definition of the "Antique Colour" habit ("antique" in French) refers to the colour that is closest to the ancient Indian chromatic concept (see 2.0):

Stones moderately included to pure, containing the habitual range of inclusions found in Sri Lankan sapphires, except for rutile crystals that only rarely appear. The colour ranges from much paler to much stronger than in the first habit, and strives towards the pink pole, very rarely towards the orange pole. The acceptance of this tendency towards pink, makes that Sri Lankan merchants often offer padparadschas which are hard to differentiate from pink sapphires. This drift (see 2.0) emphasizes the validity of the use of a colour charter (see conclusion) clearly defining the chromatic limits of the appellation. The stones of this habit are sometimes badly oriented (table parallel to axis c), and show an apparent dichroism. In this case, the blue colour zoning (rare for this habit) obviously tends to be nearly parallel to the table.

### 1.1.3 "Market Quality" (or "Induced") Habit

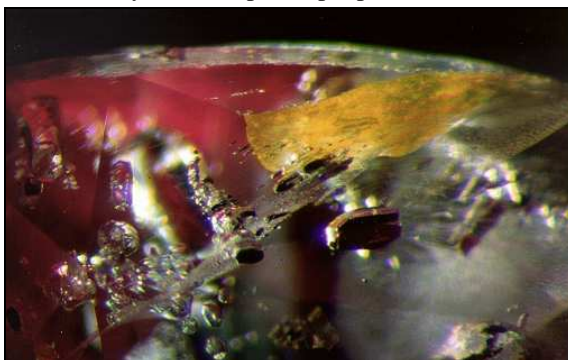
The "Market quality" or "Induced" habit ("induit" in French) depends directly on the lapidary's skill. This habit is characterized by a non-homogeneous colour, at least laterally, in wide pink and yellow colour zonings usually visible to the naked eye and positioned more or less parallel to the table, which gives an illusion of padparadscha colour, through mixing, when the gem is examined in apical view. The populations of inclusions found in this habit are those of the "Antique Colour" habit, but they are usually smaller, which gives a less glittering aspect to the gems of this category. This habit is generally the result of a thermal or irradiation treatment on medium quality pink sapphires.

### 1.1.4 "Deceptive" Habit

This habit does not deserve the designation of padparadscha:

It comprises pink sapphires of light to medium saturation with iron oxide intrusions in the cracks. These gems have a colour that is very close to the padparadschas because of reflection effects.

The intimacy of a deceptive "padparadscha" ...



Cliché F. Notari



Cliché F. Notari



### 1.1.5 Summary

Habit	Colours	Internal Characteristics
"Native"	Pastel orangey pink, occasional incursion towards the orange pole, very rarely towards the pink pole.	No or few inclusions, high apparent reflection, blue colour zoning generally parallel to the angle of the pavilion.
"Antique colour"	Pink pole of the tone, rarely towards orange, apparent dichroism often marked.	Usual inclusions of Sri Lankan sapphires, but rarely rutile. Blue colour zoning rare, often nearly parallel to the table.
"Market quality" or "Induced"	"Native" or "Antique" colour in apical view. Yellow and pink colour zonings easily observable laterally. Generally no blue colour zoning.	Usual inclusions of Sri Lankan sapphires, indications of thermal treatment.
"Deceptive"	Colour similar to "Native" or "Antique", but usually more yellowish and duller.	Iron oxide intrusions.

### Photograph 1

Padparadschas



Cliché C. Imbard

## 1.2 Dimensions

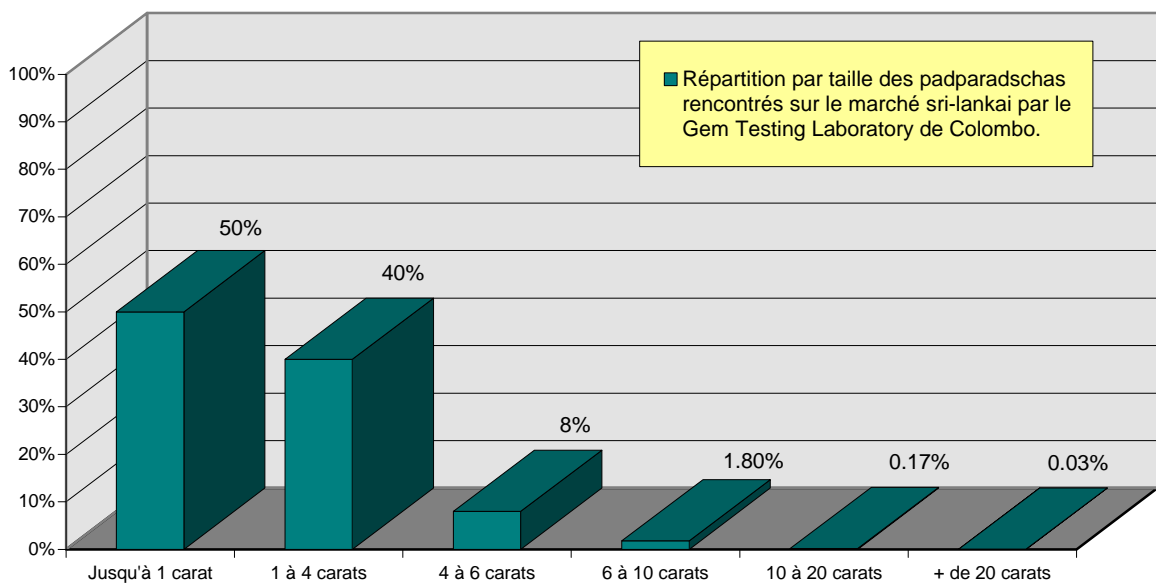
Padparadschas are usually not very big. The delicate balance of conditions (precisely at the level of chromogenic elements) required for the genesis of this sapphire has not yet been found in any other deposit in the world at a comparable scale to the one of Sri Lanka. It can easily be assumed that the specificity of the environment and the delicacy of the mechanisms generating the padparadscha's colour could hardly have been maintained over the necessary period of time for the development of large-sized crystals.

Actually, if gems of ten to twenty carats are overabundant among blue sapphires, their percentage is nevertheless not significantly superior to padparadschas in comparison with the enormous total production.

On the other hand, gems of more than twenty carats are extremely rare among padparadschas whereas blue sapphires of thirty, fifty or a hundred carats are quite regularly found.

Diagram 1

Size Distribution



Statistic data, focusing on a period of 26 years (1969 - 1995), provided by Mr Leslie J. Punchihewa, manager of the First Gem Testing Laboratory in Colombo. The 1'126 carats rough stone extracted in 1982 does not appear on the diagram.

Photograph 2



*The Original*  
Certificate of Gem Identification  
*From the First*  
Gem Testing Laboratory

Prepared by  
*Sri Lanka's most experienced and renowned gemmologist*  
**Leslie Joseph Punchihewa**  
B.A. (Cey.); F.G.A. (Gt. Britain) Diploma in Gemmology (G.A.G.T.L.)  
Certificates in Colouredstones & Diamonds (G.I.A.)  
Author: Gem Buying Hints & G.T.L. Quality Grading System for Gemstones

Procedure

General Data *Weight 5.79c. Dimensions: 10.88 x 8.88 x 7.22mm.*  
*Rough. Colour: Slightly Orangish Pink.*

Diagnostic Data *R. 9.1.762 - 1.770 D.R. 008 U-*  
*Healter; Silk; Crystallites.*

Comments *This particular rough specimen is*  
*to dominantly pink. As it contains*  
*some orange it may be called*  
*Pathiparaji.*

Conclusion

*The Gemstone of which the description and analysis are recorded above is certified to be a:*  
*Natural (Genuine) Pathiparaji rough specimen.*

Reference

Date. *14.3.95*

Certificate No. *13656*

Laboratory Fees. *250/-*

Test requested by Address.



*Leslie J. Punchihewa*

Director, Gem Testing Laboratory



## 2. Colour and Chemistry

### 2.0 – General Points

The colour of Padparadscha is an ancient subject of controversy.

There are two historical concepts: the Indian and the Sri-Lankan (or Singhalese).

Christine Jomard's thorough investigations in ancient books have shown that the colour of padparadscha has been defined in India from the fifth century onwards as "red with a very unobtrusive orangey underhue", and as "strong orangey pink, almost red, with a touch of magenta" in the oral tradition. These definitions of colour, confirmed by all the scholars that we have met, explain the fact that padparadscha was quoted under the name of "ruby" in the Ratnaparîskâ (India, before the 6<sup>th</sup> century A.D.). This old Indian concept corresponds to the chromatic characteristics of the present "Antique Colour" habit, although the latter is a bit stronger.



Cliché: H.A. Hänni

Nowadays it is the "Native" concept that tends to be the reference in the West. Sri-Lankan consider both the "Native" and "Antique" colours as valid criteria, but they tolerate a substantial drift towards pink for the "Antique Colour" habit.

It seems that, in the past, padparadschas of a strong colour, which were more appreciated and negotiated on a higher basis, were exported to India. On the point of view of commercial practice, the notion of preciousness is more perceptible if the gem's colour is vivid. Therefore such a gem is easier to negotiate. Gems of a less strong colour were put on sale on the places of production, so they became the hue criterion in Ceylon. The West, which stocked up on the places of production, adopted this criterion.

It is not possible to situate chronologically the exact beginning of the divergence between the two concepts, but it is anterior to the fifth century. The Indian concept, which tended at the time to link padparadschas with rubies, resulted in their absorption in the ruby category. The similarity of colour as well as the numerical superiority of rubies finally got the better of a concept that was not differentiated enough, whereas the Sri-Lankan concept remained.

This kind of drift is frequent, and commercial necessities have a great influence on the instability of a chromatic concept. It is still a topical subject as it can be seen in M.M.M. Mahroof's article (1992), where the discussion focuses on the status of Sri-Lankan rubies. Most of these rubies show a weak colour saturation, which differs substantially from the criteria in use. Besides, in the West, these stones are generally sold under the name of "pink sapphires". The article recounts a debate that took place during the reunion of an important association of precious stones tradesmen. The conclusion suggested at the end of the reunion is interesting because it considerably widens the concept of ruby and puts forward the designation "very pale pink rubies" (sic) instead of the current designation "pink sapphire". Obviously this procedure is a way to take over a highly rated appellation (ruby) for a less rated gem. Rubies corresponding to the expected colour have actually always been found in Sri Lanka [Bella Sidney Woolf, (1914), Louis Finot, (1896)] but they are rare. But is it not this rarity precisely that gives them their value?

The undoubted legitimacy of economical constraints often confronts gemmological and historical realities. Nevertheless, working on the assumption that commercial considerations develop from gemmological definitions, it seems hardly acceptable that the former would control the latter. The Indian concept example of a padparadscha of a very saturated colour shows that, in such a case, this principle is doomed to failure.

## 2.1 – About the Specific Colour of Padparadscha

We have seen that in the past the two chromatic concepts of padparadscha were centered on pink, with the addition of a more or less orangey, yellow touch. Therefore the clear definition of the typical colour, whatever its tendency towards one pole or the other, is orangey pink. This implies that it is a pink pole more or less tinted with orangey yellow.

The definition "pinkish orange" often found in the literature does not correspond to reality since it defines an orange pole with pink added. Orange is an inappropriate definition of colour but it is frequently found. It does not correspond to the notion passed on by Sri-Lankan tradition nor to the colours permitted by the physical and chemical nature of the padparadschas analyzed in this work (see 2.4.2).

Moreover, the only major drift in the past (whose mainspring was the intensification of colour with total freedom for the choice of the pole, see 2.0) was towards pink.

Thus we can say that the typical colour of padparadscha ranges from a pink where the orange touch can hardly be perceived to equality between pink and orange. Beyond this equality, towards orange, a sapphire does not deserve the designation padparadscha. The pink component must always be clearly perceived. Obviously this declension must be situated in a light to medium saturation, otherwise pink would be red.

This range can be subdivided into two categories:

The first half, from pink onwards, corresponds to the "antique colour" habit (see 1.1.2);

The second half, towards the point of equality between pink and orange, will be representative of the "native" habit (see 1.1.1).

These two subdivisions are not arbitrary choices, but correspond, firstly, to the two chromatic poles of padparadscha shown by history (see 2.0), and secondly to the two groups that can be separated upon chemical (quantification of chromogenic agents), and depositary (inclusions and cutting parameters ensuing

from the habit *sensu stricto* of rough stones) criteria. This second category is not easy to perceive because it is quite hard to gather enough padparadschas to have a representative selection of samples.

Diagram 2

Random colours, see conclusion charter

Type colour of padparadscha		
Antique Colour Habit	Native Habit	Treated Sapphires, Umba, Malawi, etc.

Photograph 2

Choice of a padparadscha



Cliché C. Jomard

## 2.2.0 – Methodology and Vision

Defining the colour of a gem is not easy and automated colorimetry systems are not satisfyingly efficient in routine.

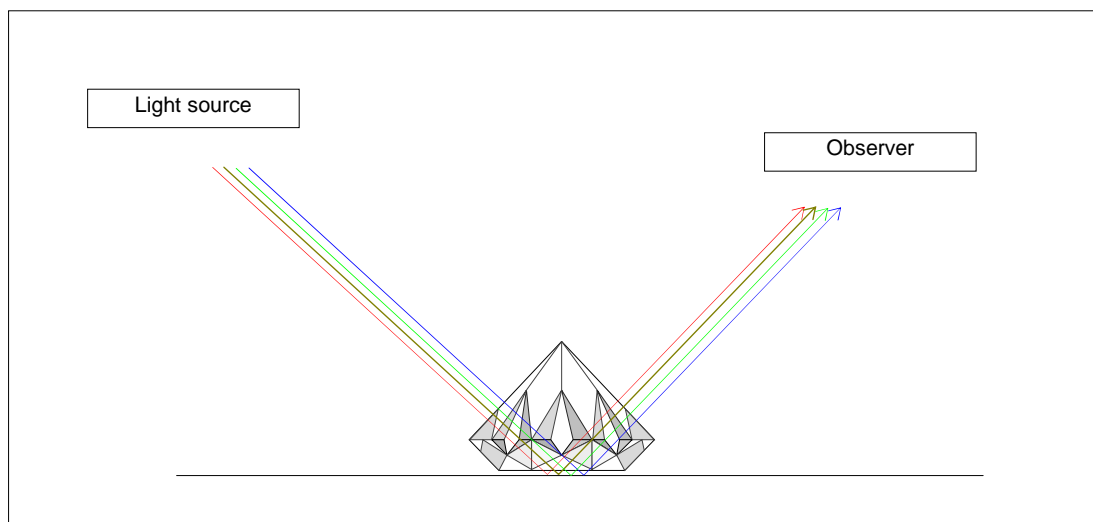
In gemmology there are tools of definition by comparison which have the advantage of being simple and of giving precise enough indications.

### Angle of observation of a gem:

In apical view (from the table), colour varies according to several factors such as the position of the light source, the position of the observer, the reflection of surrounding coloured elements etc.

It is possible to obtain constancy of the conditions of observation by turning the gem upside down (fig. 2) and placing it on a perfectly white surface. However it should be noticed that its colour will then seem more saturated (see 2.2.2). When the colour reemitted by the white background is observed through the stone, what is perceived is the "body" colour (or mass colour). In the case of gems with strong saturation, it is advisable to make sure that the power of the light source is not too strong in order to not generate simultaneous contrast. This has the effect of accentuating the difference of colour between the white background and the gem, making the latter's colour more difficult to perceive. This method enables to represent the colour of a gem in a uniform manner, which makes it easier to compare with a paper standards. Then it is possible to swivel the stone round in order to perceive possible differences of colour linked to the optic angle's orientation.

Diagram 3

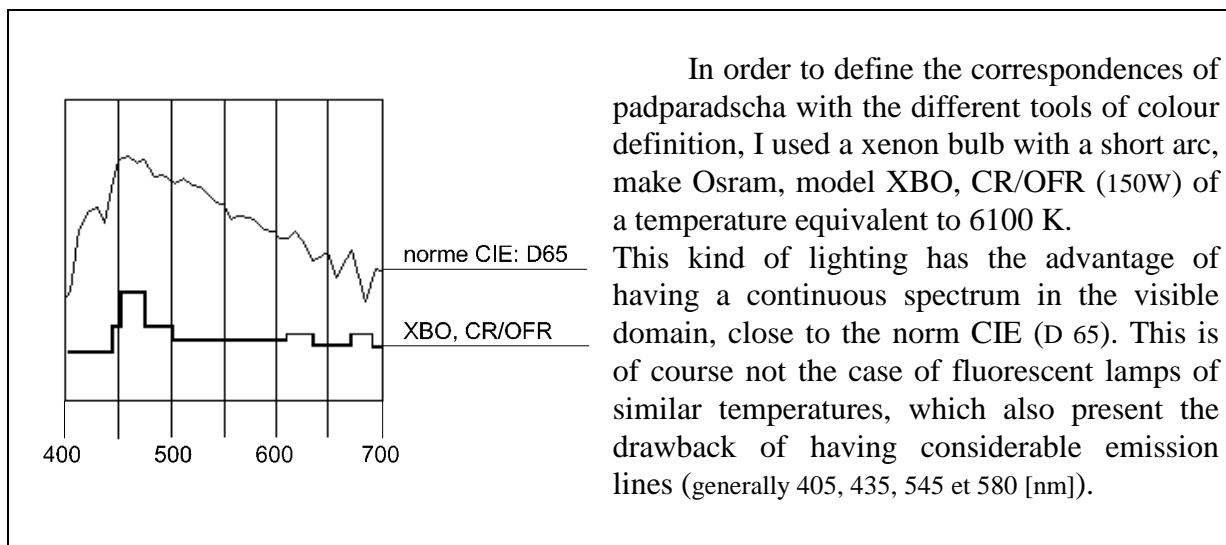


### 2.2.1 - Lighting:

Lighting plays a great part in the estimation of colour. Usual lightings (halogens, fluorescent lamps) are unsuitable because they are coloured. A coloured lighting generates an adaptation to this colour in the observer's eye (consecutive contrast) and makes them perceive the complementary colour of the light in question. This will reduce their capacity to perceive colours close to that of the lighting. This adaptation becomes more pronounced with the time of exposure.

Diagram 4

#### Light source



D'après J. Sersen, 1990 (modifié)

### 2.2.2 - Variations in the Appearance of Colours:

Numerous factors may modify the perception of colours in general. There can be several factors having an effect at the same time.

#### Differential sensitivity:

The capacity of differentiating colours varies along the spectrum. It is bad at both ends, and particularly in the red beyond 680 [nm]. On the other hand we are capable of a differentiation of about 1 [nm] from +- 490 to +-590 [nm].

#### Bezold-Brucke phenomenon:

A change in the appearance of colours occurs in conditions of very strong luminance (quantity of light emitted by a surface): the aspect of greens and reds becomes close to yellows, and the aspect of purples and blue-greens becomes close to blues.

#### Purkinje phenomenon (does not apply to transparent gems):

The perception of a colour's luminosity is modified by differences of luminance. In photopic vision (vision in full light), the wavelength of 555 [nm] will have the most luminous appearance, whereas in scotopic vision (vision in weak luminosity) this maximum will be situated around 510 [nm].

#### Abney effect:



The information picked up by the eye's photoreceptors is sometimes subjected to a modification of the perception of colour during its transfer to the optic centre. This modification is proportional to the decreasing of saturation.

Other factors:

Sociocultural level, sex and especially age also play a part in the estimation of colours. A progressive degradation of the capacities of perception of colour starts around the age of 25 or 30.

The personal sensitivity of each individual may also be mentioned. As for people regularly confronted with gems, they develop a "gemmological culture" which makes that, unless pathological state, a consensus emerges as regards the estimation of colours.

Thus the estimation of a colour is difficult and subjected to considerable variations. Given the complexity of the optical properties of gems, it is obviously almost impossible to grade a colour with precision and in a repetitive way only using our optical capacities. As there is still no reliable automated system, it is imperative to follow an extremely strict methodology while using the existing tools (Gemset, Gem Dialogue, Pantone Palette etc.), since it is primarily the differences in observation conditions which lead to the greatest variations of interpretation (by the way, the methodology should always be mentioned with graduation results).

### 2.3.0 - Colour

The perception of colour can be defined according to three criteria:

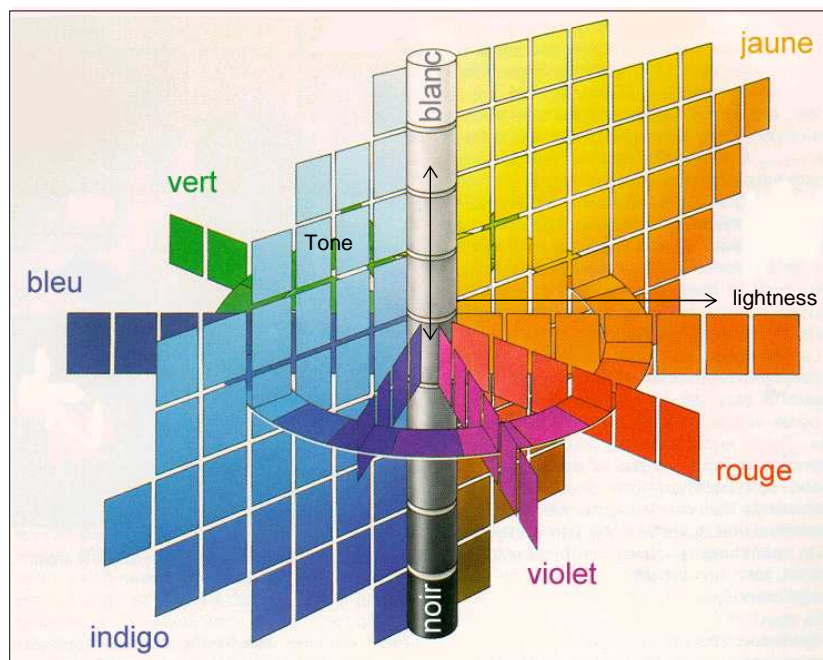
- Hue: It is the basis itself of coloured vision, linked to the spectrum's wavelengths. The spectrum is arbitrarily divided into seven "colours": purple, indigo, blue, green, yellow, orange and red.

- Lightness (or Chroma or Intensity): It depends on the quantity of white added to a colour (a pure spectral colour is of maximum lightness). Nevertheless, the lightnesses of the different colours are variable. Those at the spectrum's ends are very intense whereas yellow is not very much. Thus only a small quantity of red would be sufficient to colour white light, whereas a greater quantity of yellow would be necessary.

- Tone (or Value): It is not a chromatic factor because it is proportional to the radiation's energy level. In conditions of very high or very weak tone, all colours have a tendency to desaturate.

#### Diagram 5

Munsell's Colours' Solid



D'après Bariand P., Poirot J.-P., 1985

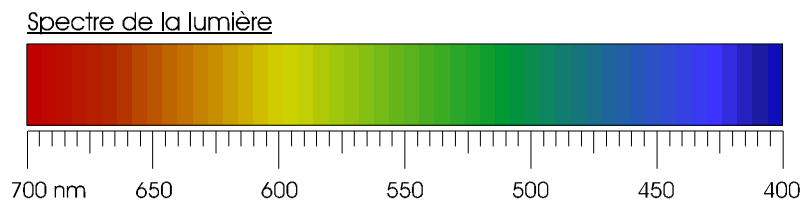
Munsell's colours' solid is an example of method used to define colour. The sample's colour is compared to the chromatic units forming the solid. The chosen unit is defined by three coordinates, hue, lightness and tone. Despite its level of perfecting, this system does not represent a real advantage over those used in gemmology at the moment (see 2.3), because it does not get rid of the problems stemming from the comparison of gems with complex optical properties to plane and opaque standard surfaces.

## Diagram 6

### Spectrum Colours:

Colours	Wavelength in [nm]	Complementary Colours
extreme purple	400	
medium purple	420	yellowish green
purple-blue	440	
medium blue	470	yellow
blue-green	500	
medium green	530	crimson
yellowish green	560	
medium yellow	580	blue
orangey yellow	590	
medium orangey	600	greenish blue
orangey-red	610	
medium red	650	green-blue
extreme red	780	

## Figure 1



*The english speaking people use the spectrum the other way around compared to this one, purple on the left and red on the right.*

### 2.3.1 – The Colour of Padparadscha (Correspondences):

#### Tools

Gem Set

Gem Dialogue, (basis)

Methuen Handbook of Color

Code des Couleurs (Séguy, 1936)

Pantone, (basis)

Atlas chromatique DIN 6164 (Biesalsky 1957)

modèles directs:

<u>hue</u>	<u>lightness</u>	<u>tone</u>
5:	2 / 4	1
6:	2 / 4	1

#### References

oR 3/4, rO 3/4, rO 2/3,  
RO/OR 3/4, RO/OR 2/3,  
RO/OR 2/2, yo 3/3, yo 2/3,  
o 3/3, O 5/4, O 4/3, O3/4,  
O 2/2

R 20 / 10, 20, 30, 40, 50,  
O 2R / 10, 20, 30, 40, 50  
R / 10

8-A-2, 3  
9-A-2, 3, 4, 5, 6  
10-A- 2, 3, 4, 5, 6  
11-A- 2, 3

165, 169, 170, 175, 178,  
182, 183, 184, 185, 188, 189,  
190, 194, 195,  
197, 198, 199, 200.

1625 c - 1635 c  
169 c - 170 c  
162 c

These mentions are indicators rather than definitive definitions of the colour of padparadscha, because of the multiple variations of a gem's colour depending on its purity, its cut, the orientation of its optical axis etc.

### 2.3.2 - Quotations

Terminology Considerations Regarding Padparadscha and African Orange Sapphire

Dr H.A. Hänni, Swiss Gemmological Institute SSEF, Basel

*The term Padparadscha (english spelling after CIBJO) has been used for pinkish orange or orangey pinkish corundum with pastels colours /... .../producing a pinkish-orange colour of weak saturation. /... .../of the described pastel colour./...*

Communication of June 1995

Considérations terminologiques sur le Padparadscha et les saphirs oranges africains

Dr H.A. Hänni, Institut suisse de Gemmologie SSEF, Bâle

*Le terme Padparadscha (selon l'orthographe anglaise de la CIBJO), a été utilisé pour les corindons orange-rosés ou rose-orangés de teinte pastel/... .../produisant une couleur orange rosé de saturation légère/... .../de la couleur pastel décrite/...*

Communication de juin 1995

Shida Junko, Jewellery News Asia, (1992):

*.../Sapphires from Africa are not certified as padparadscha because colour is not orangy-pink but is more brownish-pink or brownish-red./...*

Kamil Ismail, Jewellery News Asia, (1992):

*.../Colour in padparadscha is a narrow range between red and orange/...*

Koivula John I., Kammerling Robert G., Gems & Gemology, (1989):

*("Padparadscha" sapphire) .../ a pleasing "classic" pinkish orange oval mixed-cut sapphire/...*

Liddicoat Richard T., Gems & Gemology, (1972):

*.../ Traditionally, the term "padparadscha" was limited to the light reddish-orange stones that are typical of the Ceylon source. In the Umba River Mines, producers have been finding many orangy-brown stones that are much darker and much less appealing to the average person than the lovely Singhalese stones./...*

## 2.4.0 – Origin of the Colour

Padparadscha is a chromatic variety (orangey pink) of corundum ( $\alpha\text{Al}_2\text{O}_3$ ) *aluminium oxide*, which is an allochromatic (colourless) material in its pure form. Its colour comes from elements which are not part of its structural formula:

$\text{Cr}^{3+}$  : Trivalent chromium of ( $\text{Cr}_2\text{O}_3$ ) , for the pink component.

$\text{Fe}^{3+}$  : Trivalent iron of ( $\text{Fe}_2\text{O}_3$ ), for the yellow component.

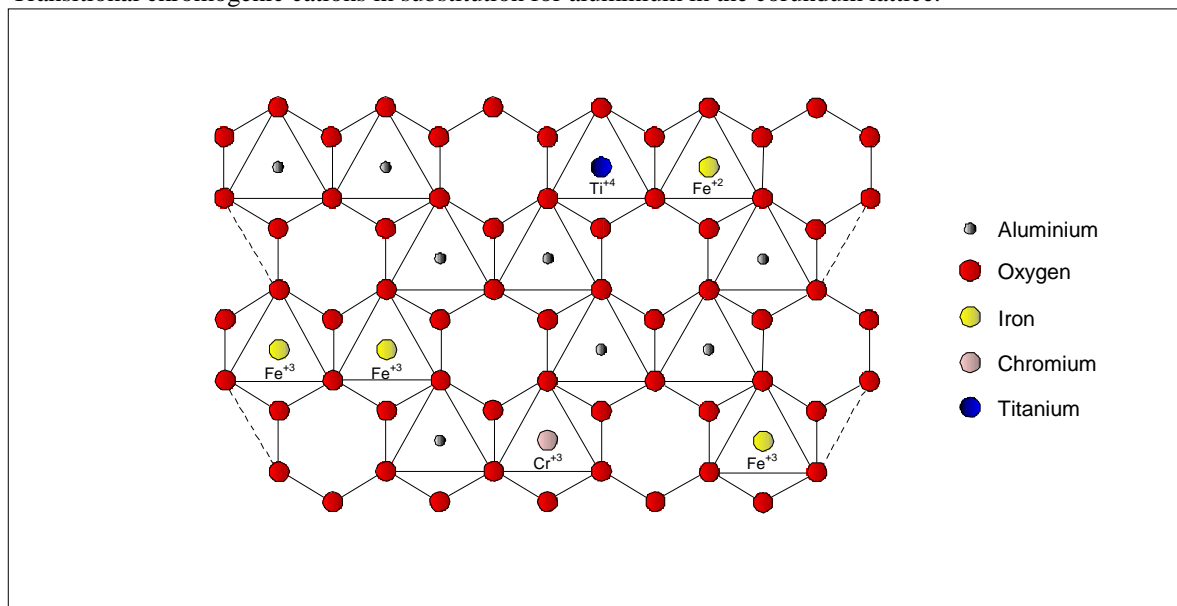
These elements (chromophores) are present in proportions of  $\approx 0,04$  to  $0,8\%$  replacing a few  $\text{Al}^{3+}$  ions<sup>1</sup> in the crystal lattice, (*for information, the concentration of  $\text{Cr}^{3+}$  found in Sri-Lankan rubies of medium saturation/lightness amounts to  $\approx 1\%$* ).

Non defined coloured centres also take part in the colour of padparadschas<sup>(a)</sup> of the native habit exclusively<sup>(b)</sup>. (<sup>(a)</sup> Prof. Hans Bill personal communication 1996, <sup>(b)</sup> F. Notari)

As in other corundums, the colour induced by impurities is modified more or less intensely by several factors such as interactions between chromogenic ions and oxygen atoms according to their pressure, the distance separating them from those atoms, the values of electrostatic repulsion of surrounding ions, variations of concentration of these ions in some parts of the host crystal lattice, and the type of bond defined by their position in the atomic structure.

### Diagram 7

Transitional chromogenic cations in substitution for aluminium in the corundum lattice.



<sup>1</sup> Ions are atoms which have won or lost electrons. Then they either have a negative (anions) or a positive charge (cations).

## 2.4.1 - Role of the Chromophores:

Trivalent chromium ( $\text{Cr}^{3+}$ ) intervenes as a simple transitional element. It is positioned in the ligands field in octahedric coordination (six neighbouring oxygens). Its role and the quantities in which it is present are fundamental because trivalent chromium generates the pink touch on which the concept is based.

"Dispersed" or "isolated" trivalent iron ( $\text{Fe}^{3+}$ ) intervenes in an intervalent charge transfer with oxygen ( $\text{O}^{2-}$ ). It participates in the yellow touch through the absorption of a part of the wavelengths in the purple.

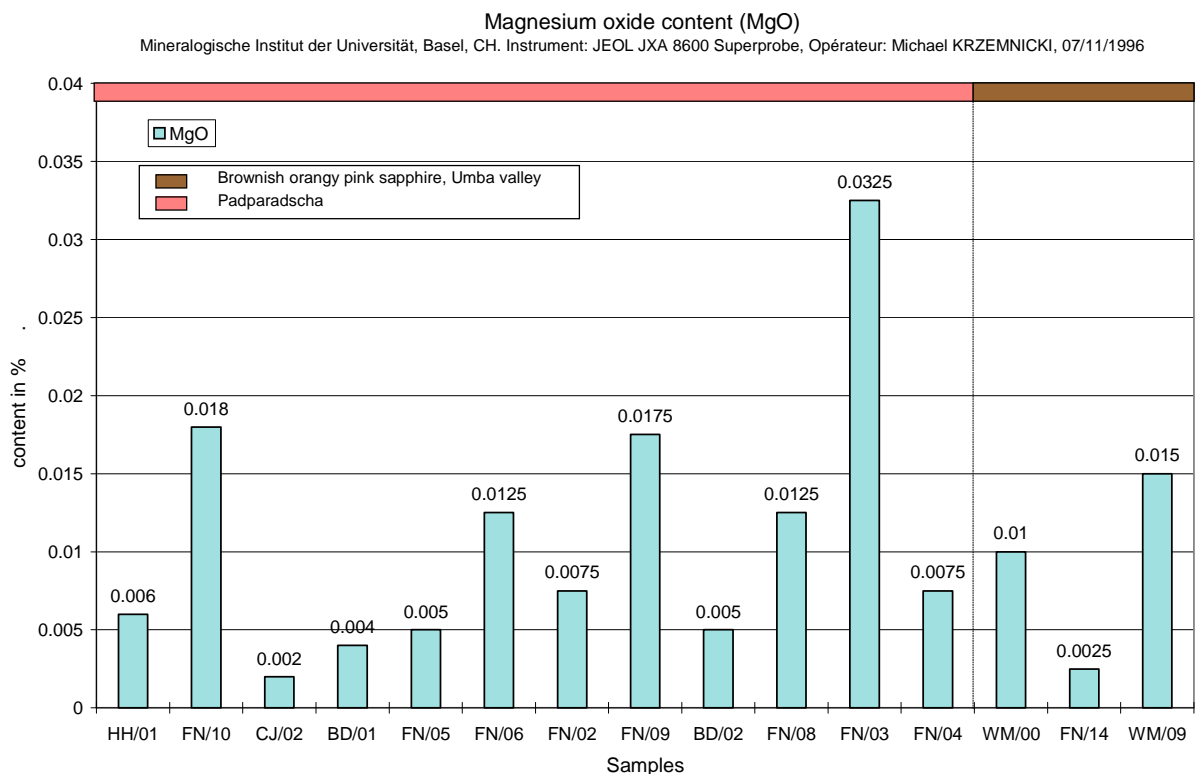
To a lesser extent, trivalent iron in pair ( $\text{Fe}^{3+} / \text{Fe}^{3+}$ ) intervening in a pair transition via an oxygen (O) completes the action of dispersed  $\text{Fe}^{3+}$ . Although its absorption covers a larger part of the spectrum than  $\text{Fe}^{3+}$ , for reasons of quantities and/or interaction with its surroundings, it is more discreet (voir tableau 11).

Coloured centres participate in the yellow touch of padparadschas of the native habit only. Their nature is still unknown today (Prof. H. Bill, personal communication, 1996).

## Magnesium

Contrary to what has been written (Nassau, 1983), magnesium does not seem to intervene in the colour of padparadscha. Indeed, if it is possible to see a certain correlation between the intensity of the colour and the iron and chromium content, there is obviously none with magnesium contents (histogram No 1), knowing that the colours of samples CJ/02, BD/01 and BD/02 are on average more saturated than those of samples FN/10, FN/09 and FN/03.

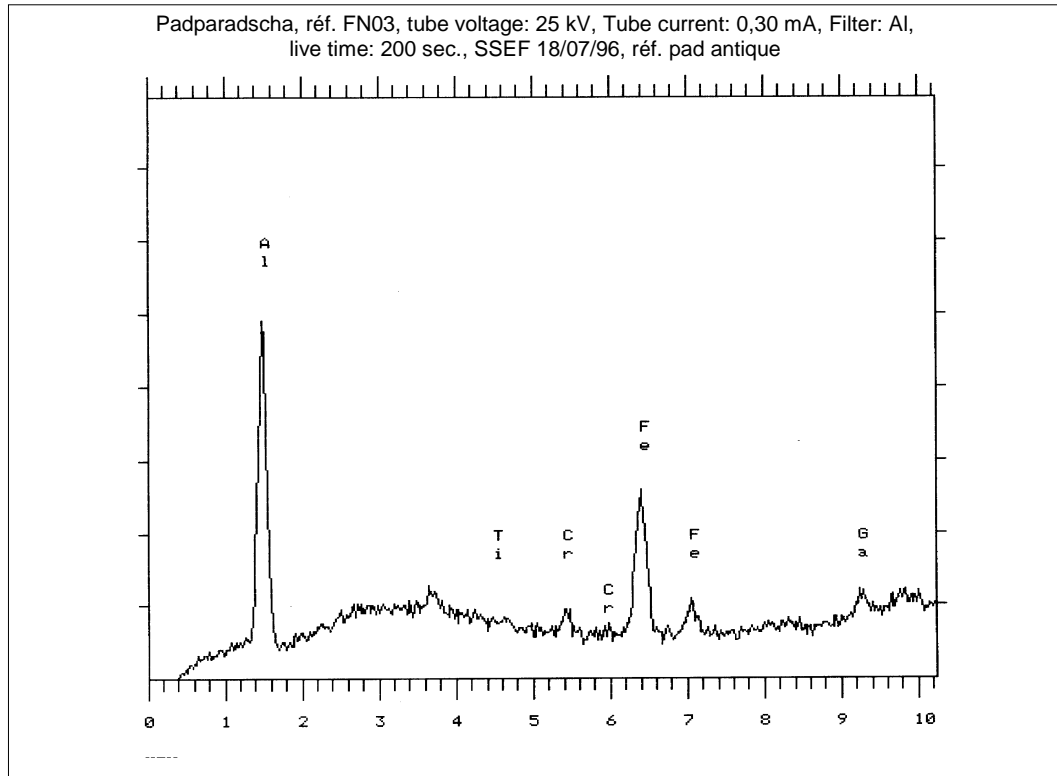
## Histogram 1



In the following spectrum, the identity of the chromogenic elements of padparadscha (Cr, Fe) is revealed in energy dispersion X ray fluorescence:

Spectrum 1

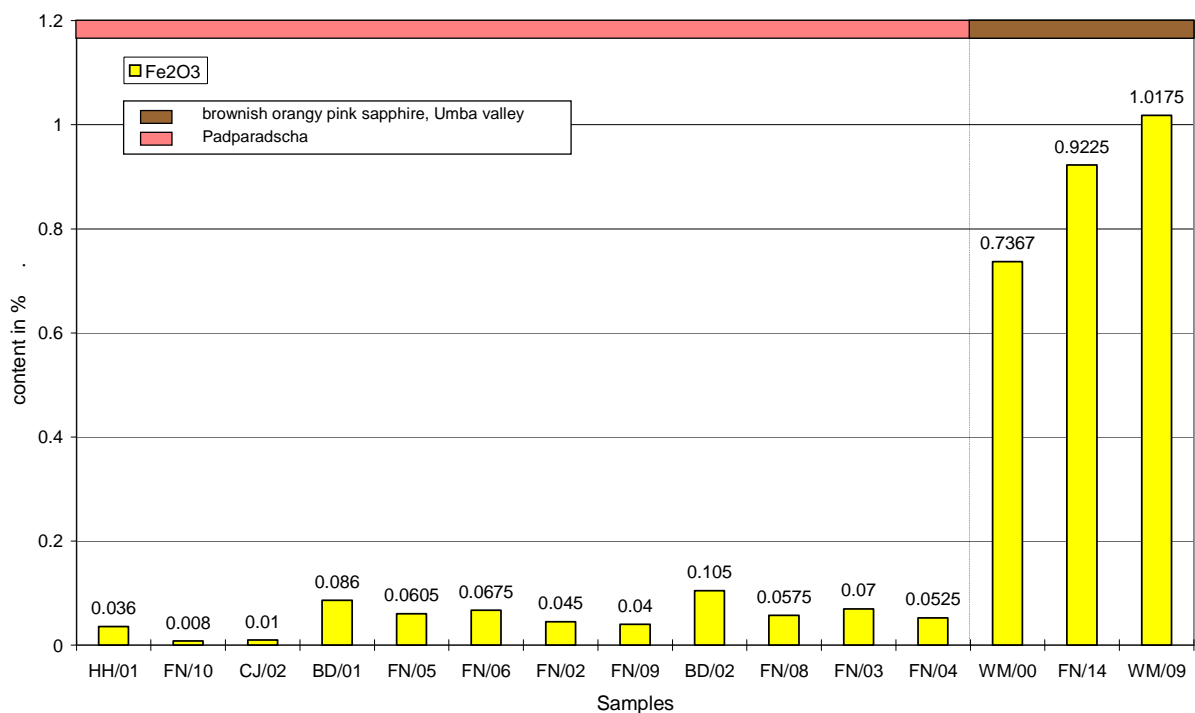
Spectrum in energy dispersion X ray fluorescence:



Histogram 2

Iron oxide content (Fe<sub>2</sub>O<sub>3</sub>)

Mineralogische Institut der Universität, Basel, CH. Instrument: JEOL JXA 8600 Superprobe, Opérateur: Michael KRZEMNICKI, 07/11/1996





## 2.4.2 – Blue Colour Zonings:

As blue colour zonings oriented in  $(11\bar{2}1)$  are one of the characteristics of padparadscha (see 2.4.2), they deserve to be mentioned as regards to their global colour. Indeed, although they are very discreet, they participate in the gem's global colour through the addition of a cold touch. In such a case, they can be perceived in spectroscopy by a broadening towards red from the absorption of chromium at 554 [nm] by addition to the absorption of the IVCT  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  at 565 [nm] (see diagram 11).

### The role of the blue component's chromophores:

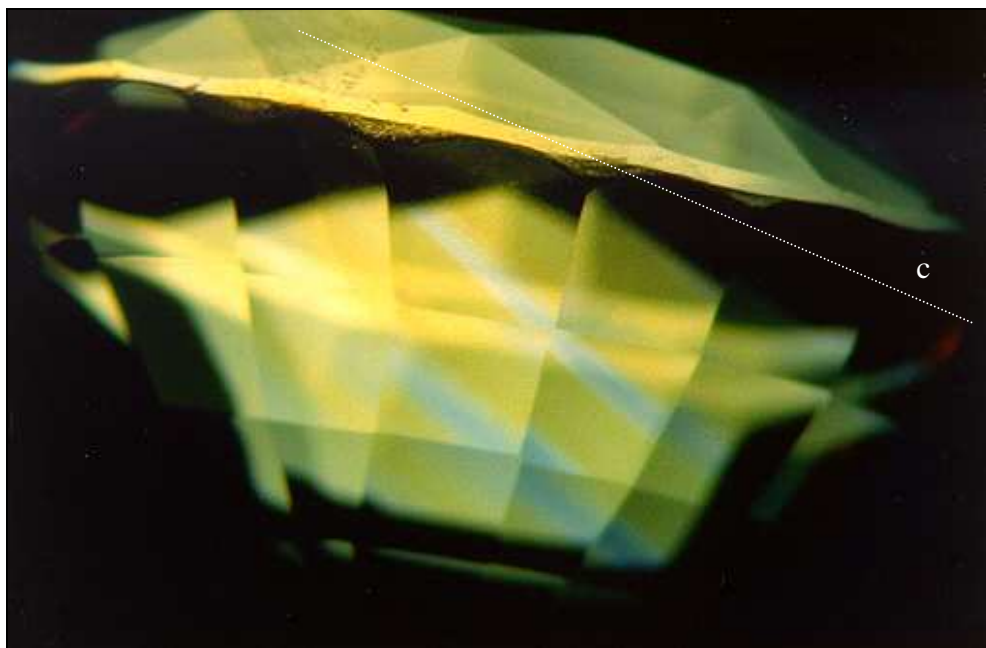
Divalent iron ( $\text{Fe}^{2+}$ ) and tetravalent titanium ( $\text{Ti}^{4+}$ ) intervene in an intervalent charge transfer via one oxygen (O).

Dispersed trivalent iron ( $\text{Fe}^{3+}$ ) intervenes in an intervalent charge transfer with oxygen ( $\text{O}^{2-}$ ).

Bivalent iron ( $\text{Fe}^{2+}$ ) associated with trivalent iron ( $\text{Fe}^{3+}$ ) intervene in a pair transition involving one oxygen ( $\text{O}^{2-}$ ) (usually only for sapphires of basaltic origin).

### Photograph 3

Blue colour zonings of padparadschas. The dotted line represents axis "c".



### 2.4.3 - UV- Visible Spectra

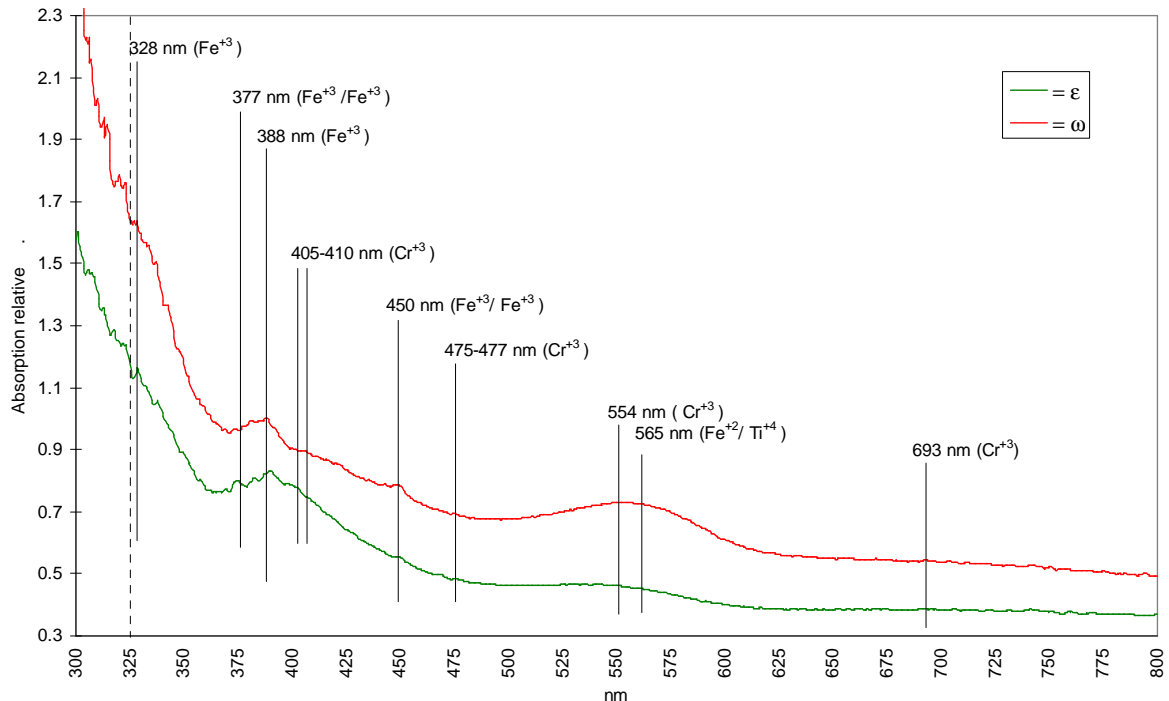
In spectrum no 1, the peaks at 693, 554, and 405-410 [nm] correspond to trivalent chromium ( $\text{Cr}^{3+}$ ) in simple transition, the peaks at 450 and 377 [nm] to trivalent iron in pair transition [note the discretion of the absorption compared to the Umba sapphires, (spectrum 4)], and the peaks at 388 and 328 [nm] to trivalent iron in simple transition. This spectrum can be considered as characteristic of padparadscha.

The broadening of the absorption of chromium at 554 [nm] through superposing of the absorption of transfer Iron  $\rightarrow$  Titanium (see detail, spectrum 3) can be seen.

Indexings of absorption on spectra in this work are common to padparadschas and Umba Valley sapphires. These are the last drift of the chromatic concept of padparadscha. Thus some of the absorptions marked are not very representative or even non-existent (for example  $\text{Fe}^{3+}/\text{Fe}^{3+}$  at 377 [nm]).

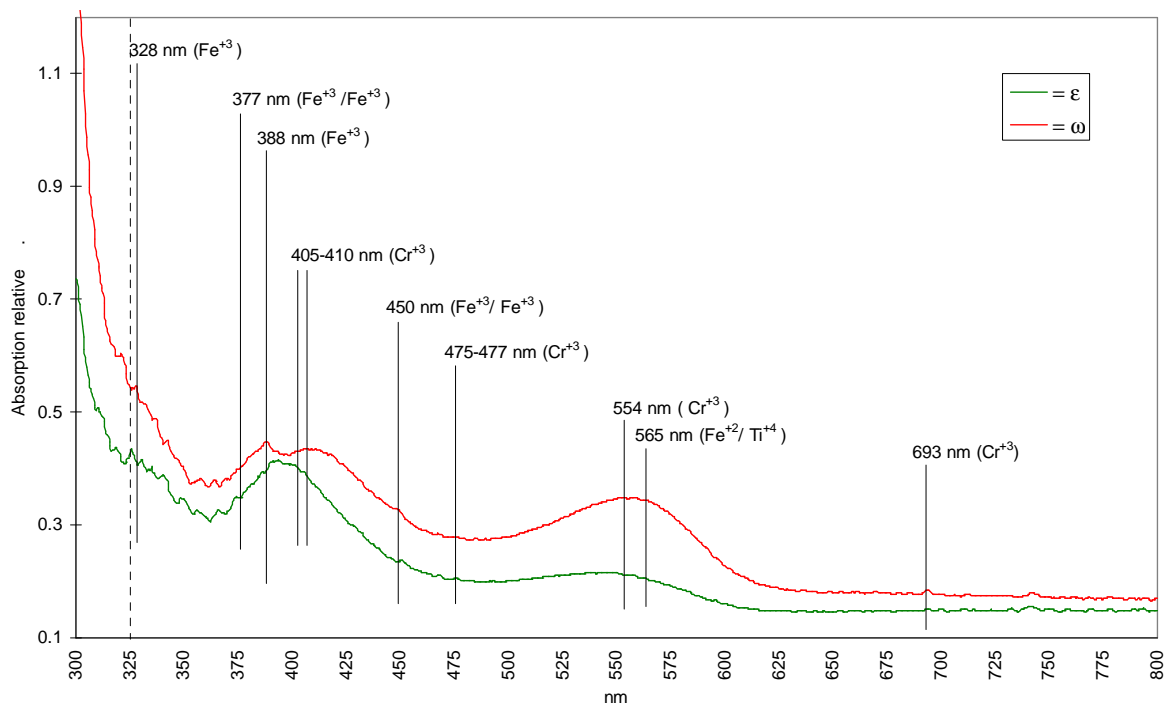
#### Spectrum 2

Padparadscha, habitus original, Sri-lanka, 5.756 ct., ( $E \perp c$ , polarisé), réf. PE/01  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 10/09/96



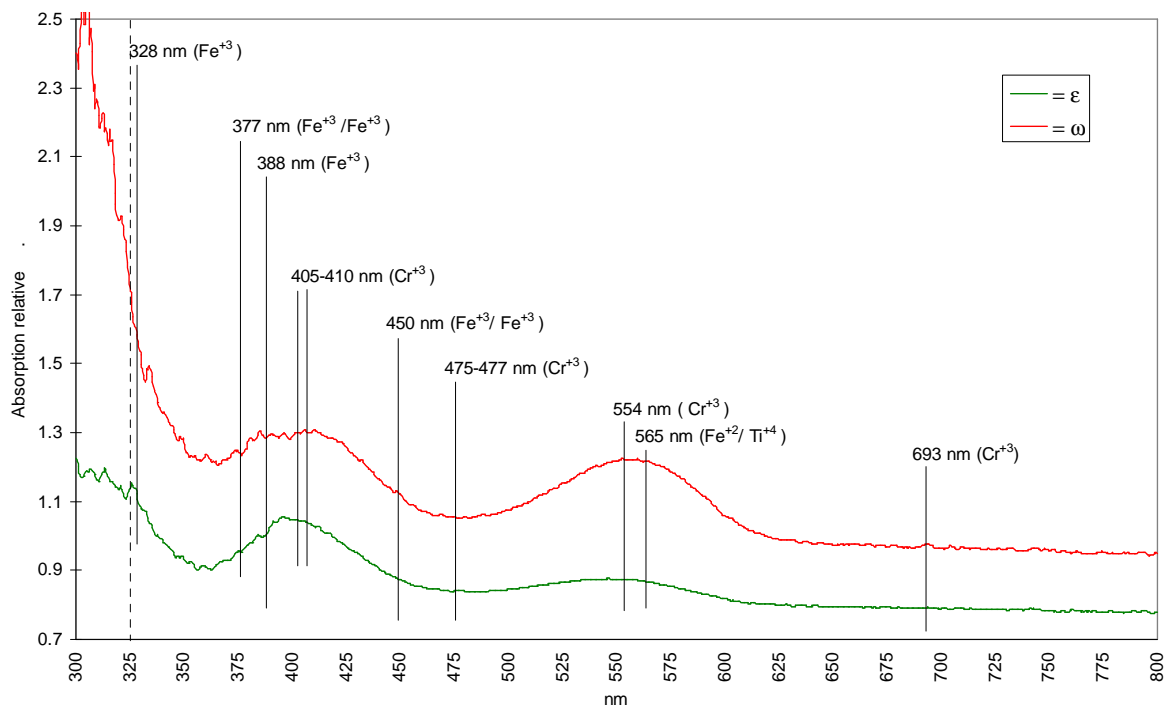
#### Spectrum 3

Padparadscha, habitus antique, Sri-lanka, 2.422 ct., (E ⊥ c, polarisé), réf. FN/03  
 300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 10/09/96



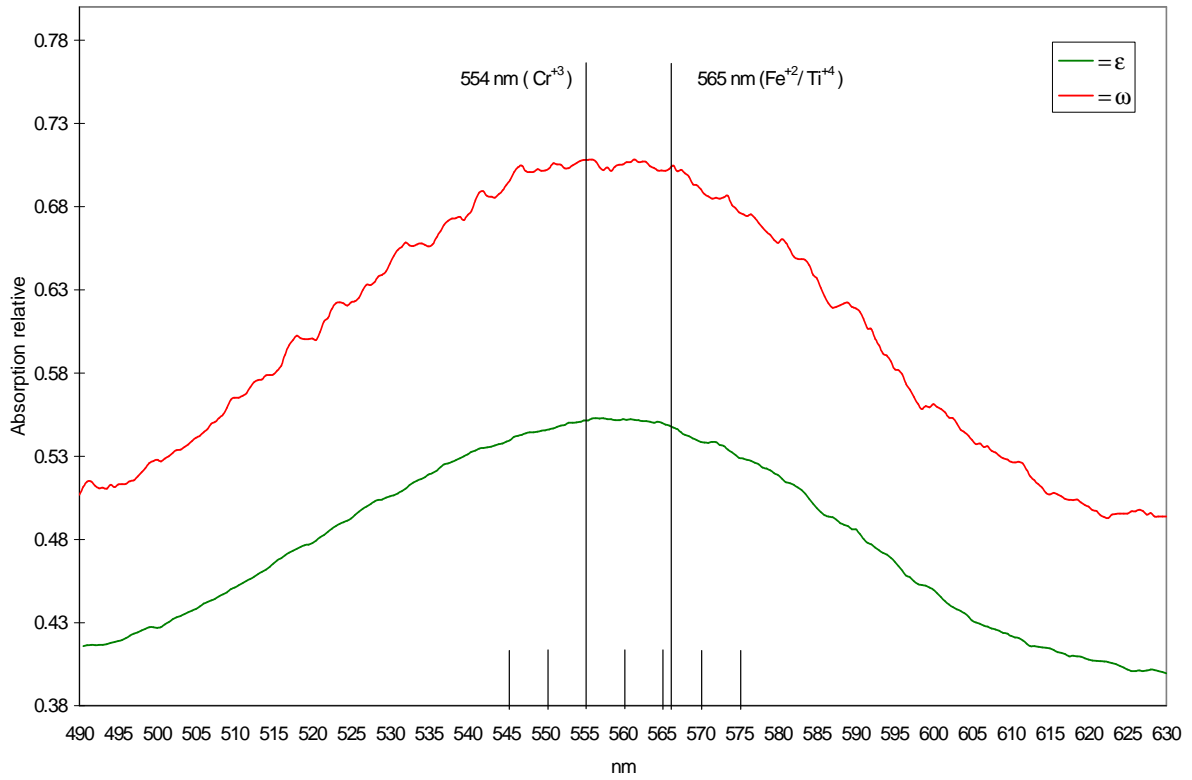
Spectrum 4

Padparadscha, habitus antique, Sri-lanka, 2.469 ct., (E ⊥ c, polarisé), réf. PE/12  
 300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 10/09/96



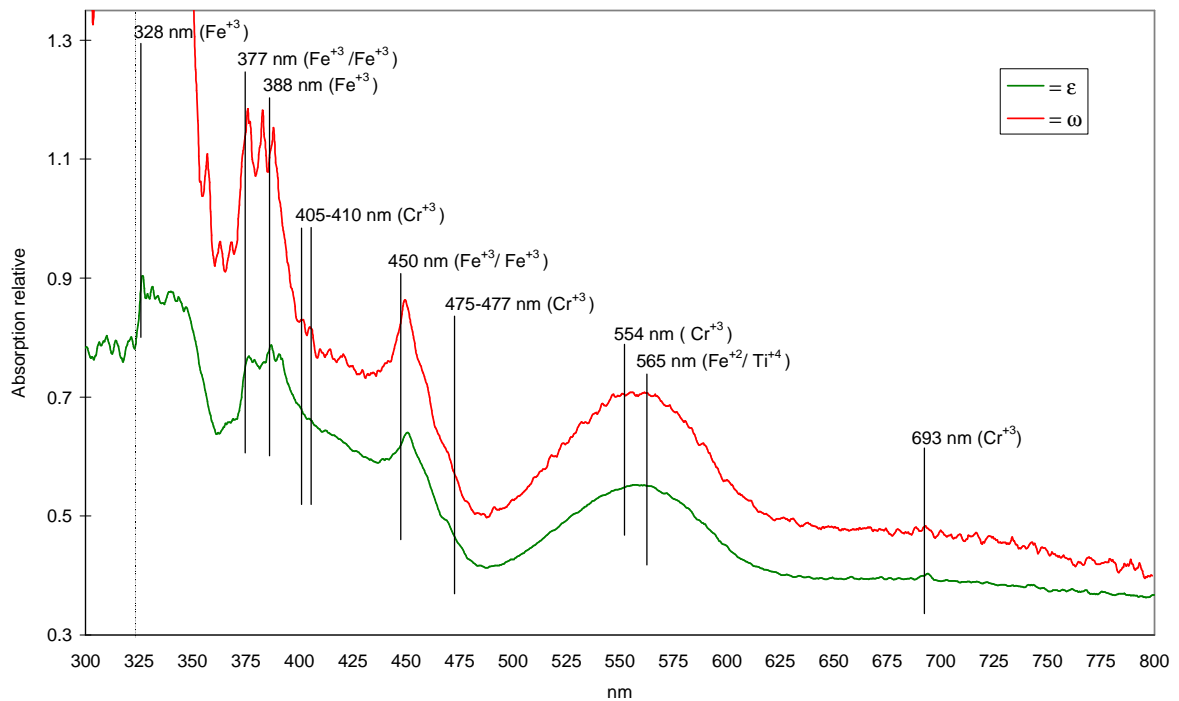
Spectrum 5

Absorptions jointes de la transition du  $\text{Cr}^{3+}$  (554 nm) et de l'IVCT  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  (565 nm) ( $E \perp c$ , polarisé)  
 300 nm/min., slit 1.0 nm, integrating sphere, polarizing filter type HNPB, 19/10/96



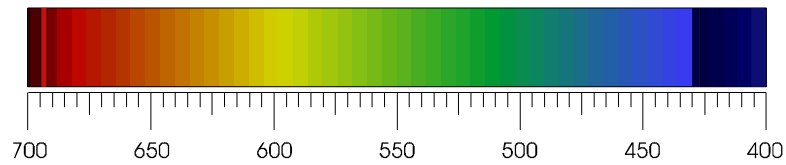
### Spectrum 6

Brownish orangy pink sapphire, Umba valley, Tanzania, 0.801 ct., ( $E \perp c$ , polarised), réf. FN/38  
 300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNPB, 20/10/96



## 2.4.4 - Hand Spectra (network spectroscope, model "DGX" (first version))

### Spectrum 7

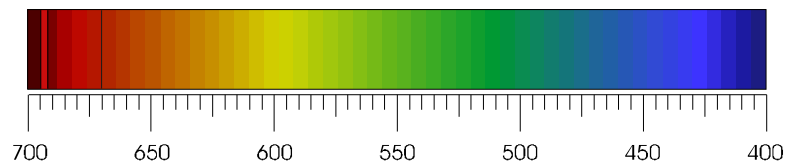


Padparadscha, native habit, orangey pole, Sri Lanka  
Reference FN/03.

Visible absorptions:

692, 694, 700 [nm]

### Spectrum 8

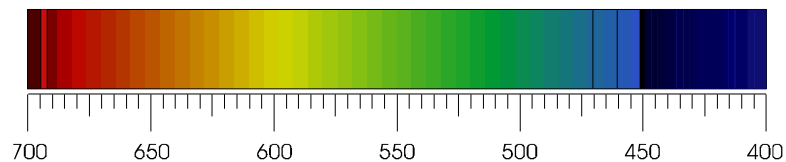


Padparadscha, antique colour habit, pink pole, Sri Lanka.  
Reference PE/12.

Visible absorptions:

668, **692**, **694** [nm]

### Spectrum 9



Orangey brownish pink sapphire, Umba Valley, Tanzania.  
Reference WM/09.

Visible absorptions:

**450**, 460, 471 [nm]

**692**, **694** [nm]

## 2.5 – Transitional Elements

### Theory:

A transitional element is a chemical element which has, in its fundamental state, for one of its oxidization numbers, an incomplete electronic underlayer  $d$  or  $f$  (except for elements Zn, Cd and Hg).

If an atom receives energy when it is in its state called *fundamental* (fundamental state of energy  $E_1$ ), it becomes *excited* (excited state of energy  $E_n > E_1$ ). Energies  $E_n$  do not have any value. They are a discontinuous succession of energy levels.

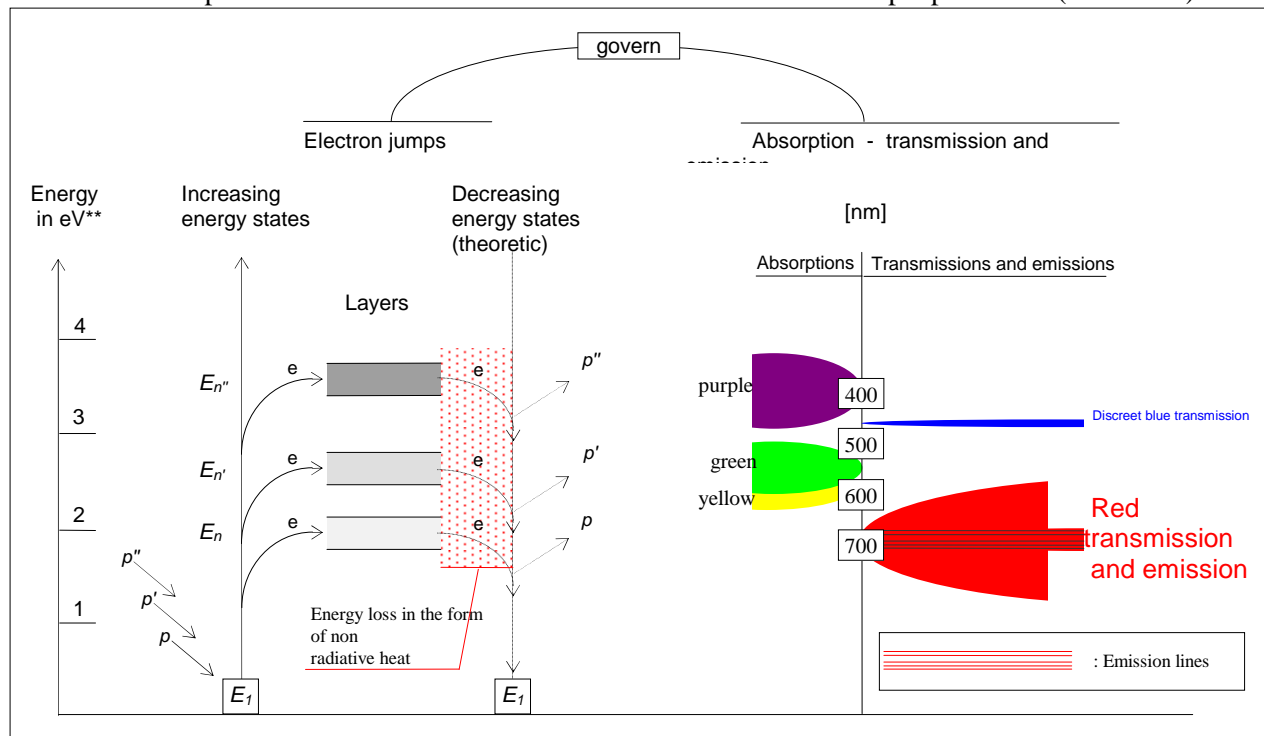
The excited atom will have a tendency to go back to its fundamental state by a *transition* during which it will emit an energy photon  $h\nu_{n1} = E_n - E_1$ .

Globally, the transition of a level  $n$  to a level  $p$  ( $E_n > E_p$ ) is accompanied by the emission of a photon whose frequency  $\nu_{np}$  is determined by  $h\nu_{np} = E_n - E_p$ . Conversely, the absorption of a photon of frequency  $\nu_{np}$  causes a transition from level  $E_p$  to level  $E_n$ .

D'après J.-P. Sarmant, 1988

### Diagram 9

Cr<sup>3+</sup> simple transition mechanisms in octahedric coordination in a padparadscha (corundum)



Where:  $e$  = electron -  $p$  = photon -  $E_1$  = fundamental state and  $E_n$  = excited state (where:  $E = h\nu$ )

F. Notari, 1996

### Chromium simple transition mechanisms in padparadschas:

Each electron layer has its own energy level, which increases from the internal layer to the external layer.

Thus, the transfer of an electron to an external layer requires an additional energy supply. This energy is taken from visible light by photon absorption. Then the atom is said to be in an *excited* state ( $E_n$ ).

\*\* eV: *electron-volt*: energy acquired by an electron accelerated by a potential difference of 1 volt. (1 eV =  $1,602 \cdot 10^{-19}$ J)

Transferred electrons only temporarily occupy the upper layers, and they go back to their initial layers by restoring an energy equivalent to the one originally absorbed, either in the form of photons or of other types of radiations (as well as non radiative heat). Then the atom is in a state called *fundamental* ( $E_1$ ).

The energy of photons is proportional to the frequency of the wave to which they are associated ( $E = h\nu$ )\*. For a given jump length, and according to the electrostatic repulsion values to which the electron is subjected, the taking will occur at a precise wavelength, whose energy level satisfies the needs. The further the electron will have to move away from the nucleus, the greater its energy need will be, and the absorption will then occur at high frequencies.

The sum of the wavelengths in which no absorption has taken place will form the *residual* or *transmitted* light that generates the pink touch of padparadscha.

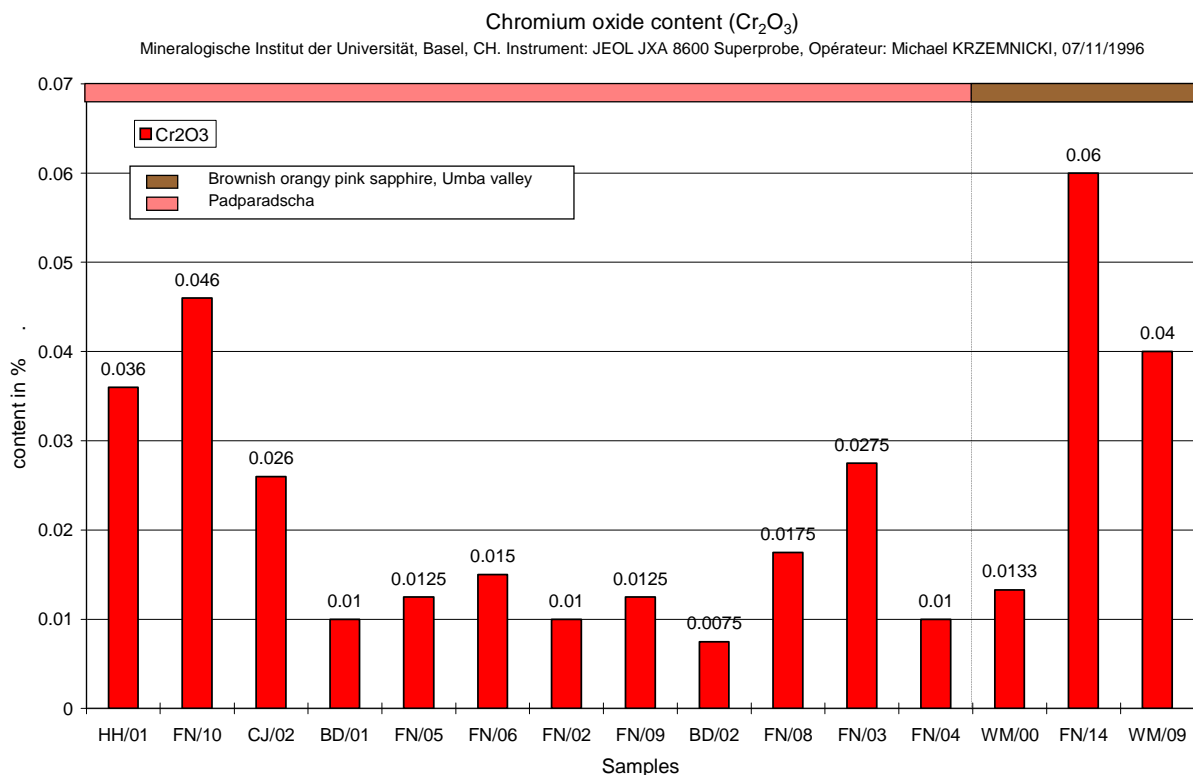
The intensity of pink will be proportional to the quantity of chromium atoms contained in the gem (0,01 to 0,4%).

To complete this model, it should be specified that when a chromium atom goes back to its fundamental state ( $E_1$ ), the electrons restore the energy particularly in the form of fluorescence, which participates to some extent in the gem's colour. This fluorescence mainly appears in very thin emission lines at the following wavelengths: 694.2 [nm] and 692.8 [nm] for isolated chromium atoms, 702.4 [nm], 705,7 [nm], 698.5 [nm] and 700.3 [nm] for atoms associated or in pair.

Because they are very thin and superposed on absorption lines, these emission lines are not always easily detectable with spectrophotometers. Microspectrofluorescence seems to be a good way to reveal them (J. Dubois-Fournier, B. Lenain, D. Le Maguer, 1989).

\*  $E = h\nu$  (Planck-Einstein relation) where  $h = 6,626176 \cdot 10^{-34}$  joule-second<sup>-1</sup>, at  $5 \cdot 10^{-6}$  (Planck constant) and  $\nu$  = wave frequency.

### Histogram 3



## 2.6 - IVCT of the Blue Colour Zonings

Padparadschas often show blue colour zonings whose medium thicknesses generally range from 0,1 to 1 [mm], and are orientated according to the bipyramid's  $(11\bar{2}1)$  sides, at  $20,1^\circ$  of axis "c".

In sapphires of similar colour, only populations from Sri Lanka quite regularly show a colour zoning in this orientation. This colour zoning can be considered as a characteristic feature of padparadscha.

The blue colour zonings are essentially due to the presence of iron and titanium in the form of  $(\text{Ti}^{4+})$  tetravalent titanium of  $(\text{TiO}_2)$ , of  $(\text{Fe}^{3+})$  trivalent iron and of  $(\text{Fe}^{2+})$  bivalent iron of  $(\text{Fe}_2\text{O}_3)$ , in quantities of 0,005 to 0,05 %. These transitional cations generate the colour through mechanisms of Intervalence Charge Transfer (IVCT), and through a transition of pair  $(\text{Fe}^{3+} / \text{Fe}^{3+})$  which absorbs in the UV.

When tetravalent titanium and trivalent iron are close enough to each other and subjected to white light excitation, receiving an amount of energy of at least 2eV (Angenault Jacques, 1995), an electron (*valency electron*) of the superficial layer (*valency layer*) of  $\text{Fe}^{2+}$  will also occupy the valency layer of  $\text{Ti}^{4+}$  and that of the involved oxygen. According to the literature, the protagonists's valencies are modified then, but this is not exactly true as it is a molecular orbital ( $\text{Fe}^{2+} \leftrightarrow \text{Ti}^{4+} \leftrightarrow 3 \text{O}^{2-}$ ) (cf diagram 11).

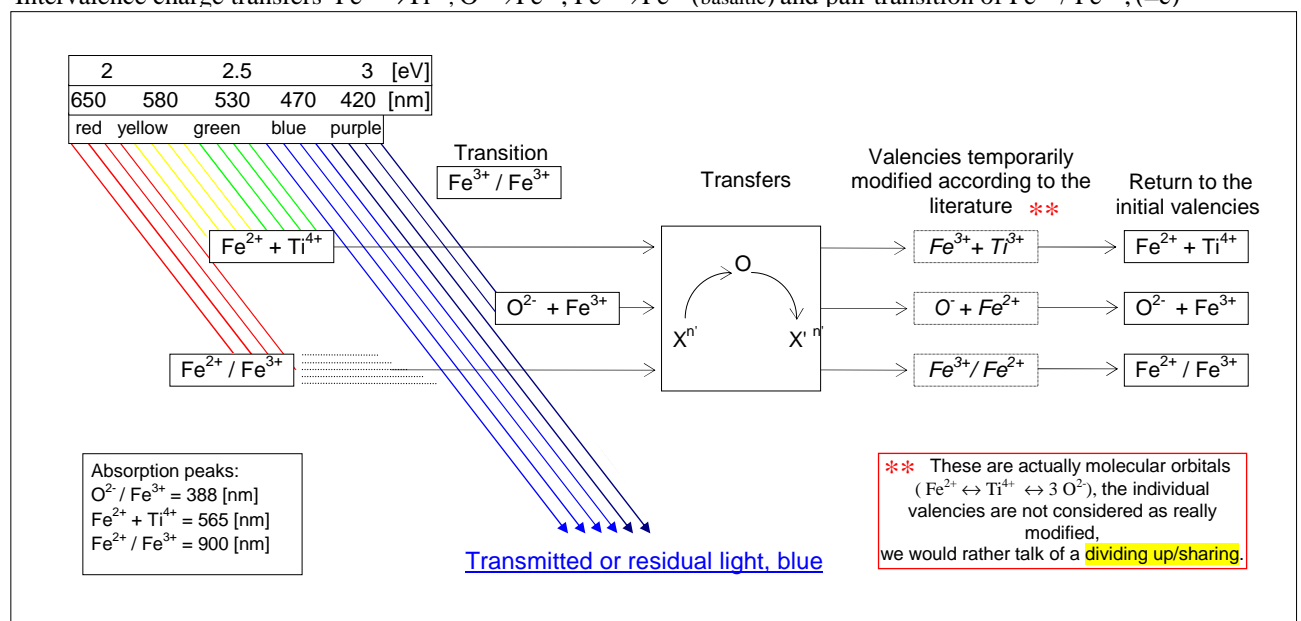
The taking of the energy necessary for the mechanism is revealed through an absorption of visible light at about 565 nanometres.

There is also an IVCT  $\text{O}^{2-} \rightarrow \text{Fe}^{3+}$ : *absorption at 388[nm]*. This transfer shows itself in the very near ultraviolet and spreads to the threshold of purple. Furthermore there is an IVCT  $\text{Fe}^{2+} / \text{Fe}^{3+}$ : *absorption in the infrared spreading to the visible,  $\pm 500$  [nm]* in basaltic sapphires.

**Diagram 11**

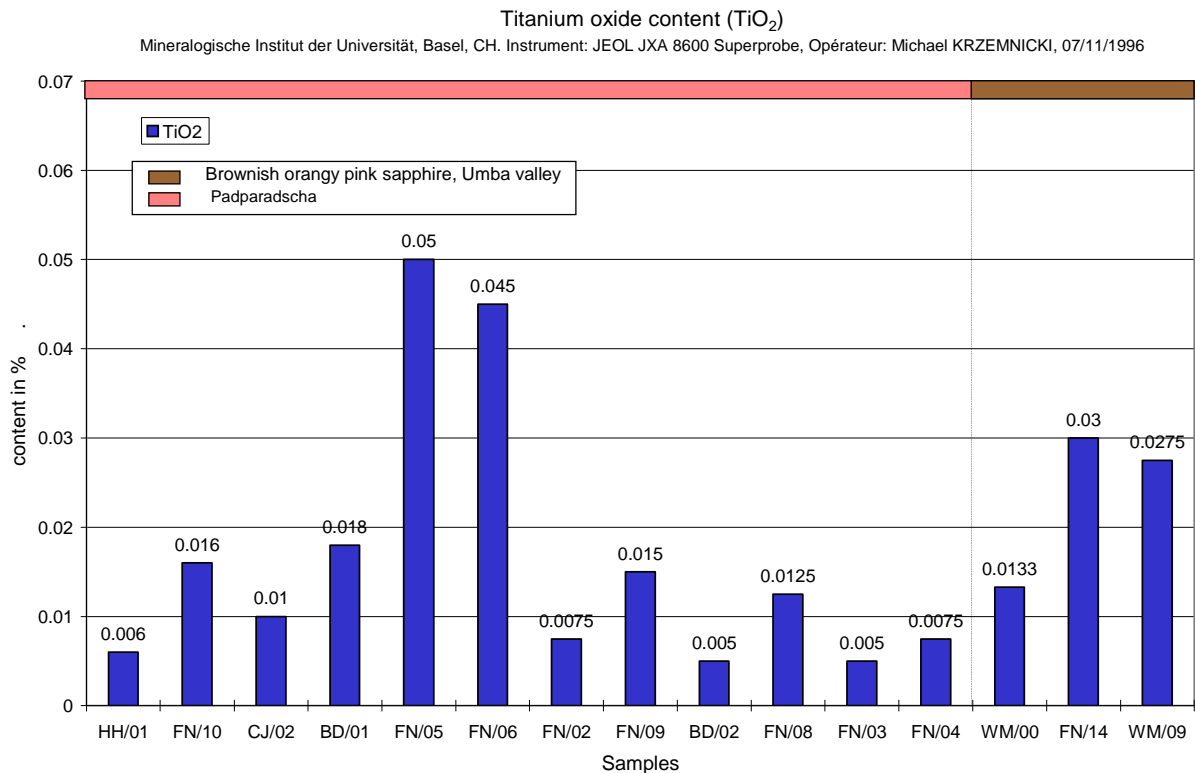
**Causes of the colour of blue sapphires (metamorphic):**

Intervalence charge transfers  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$ ,  $\text{O}^{2-} \rightarrow \text{Fe}^{3+}$ ,  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$  (basaltic) and pair transition of  $\text{Fe}^{3+} / \text{Fe}^{3+}$ , (=c)





## Histogram 4



## 2.7 Coloured Centres

### Theory:

Coloured centres are punctual flaws of the crystal lattice. They are atoms, ions, molecules, in which an electron is in an abnormal situation. There are three types of coloured centres:

Centre **F**: made of an electron occupying the place of an anion.

Centre **V**: made of a hole occupying the place of a cation.

Centre **U**: made of an interstitial or substitution hydrogen atom.

J.-P. Mathieu, A. Kastler, P. Fleury, 1991

Natural coloured centres are generally atoms in which an electron has been ejected from its orbital by a high energy radiation. When it is combined with a neighbouring element, they form a whole that can generate an absorption through a charge transfer mechanism (ex. amethysts, where Fe<sup>3+</sup> impurities have been transformed into Fe<sup>4+</sup> under the effect of a natural irradiation). A charge transfer will form between tetravalent iron and one oxygen (O<sup>2-</sup> → Fe<sup>4+</sup>), and as a result there will be a considerable absorption in the region of yellow-green.

More complex coloured centres exist, where two different elements, after irradiation, combine with one oxygen, and provoke an absorption that none of them could have provoked individually (ex. yellow tourmalines called Tsilaisites: Mn<sup>2+</sup> → O → Ti<sup>4+</sup> (Fritsch E., 1987)).

These coloured centres can also be gaps (i.e. atoms absent from their sites), caused either by a high energy radiation or by a deficiency during the gem's growth. In order to retain a neutral charge, a gap can be occupied by an electron if it is an anion gap, or by a particle of positive charge (proton) if it is a cation gap.

In corundums, and thus in padparadschas, the exact nature of coloured centres is not well-known at the moment. Nevertheless, we know that they are stable and that they are formed during the gem's growth (E. Fritsch, personal communication, 1996).

Authentication methods in laboratories are confronted with two categories of coloured centres: stable and unstable. Stable centres are flaws which generally appeared during the gem's growth. Unstable centres are due to exposure to an ionizing radiation, natural or not. In the case of padparadscha, these unstable centres have always been considered as due to the action of man. In reality, solarization phenomena observed in padparadschas should put us on our guard: the usual decoloration test (Nassau, 1983) which is the practice in some laboratories should not be used any more as we still do not understand that mechanism. Besides, it would be judicious to reconsider the nature of this test, which is debatable from a deontological point of view.

## 2.8 The "Problem" of the Umba Valley (Tanzania)

The Umba Valley region (Tanzania) has been producing great quantities of sapphires of all colours for a long time. A certain percentage of orangey-pink sapphires with a brown underhue can be found in this production. Each of these three colours are always present, in variable proportion. Most of the time these sapphires are proposed on the market under the name of "padparadscha" or, at best, "African padparadscha".

It should be noted that the Sri-Lankan standard (orangey pink, more or less pastel) is globally admitted in gemmological circles, with slight deviations, whereas the "African" standard (orange or orangey pink with a brown underhue) is put forward as correct by commercial circles.

We are forced to recognize that if laboratories and gemmologists have no advantage in choosing one or the other standard, commercial networks established in Africa or distributors of this production are well advised to make their goods benefit from the appeal of the renowned appellation. Obviously, here commercial's interests are in contrast with the gemmological reality. This is probably a miscalculation regarding these African sapphires. It would actually have been good to promote the appellation "Umba", because these sapphires are often very beautiful, although very different from padparadschas. Their intrinsic characteristics would have been sufficient to make them appreciated for themselves.

It is important to notice that in all cases (ancient texts, oral tradition, modern Sri-Lankan and Western uses), the colour of Padparadscha is centered on orangey pink, with an incursion towards the pink pole in certain periods or places, as we have seen already, but never towards the orange pole.

As for the brown colour, the only existing allusion is by Mahinda Gunawardene (1985), (*./Pinkish-orange to pinkish-yellow with areas of orange-brown and pinkish-orange/.*). This mention is unique. The observation could have been done on a variant specimen, not representative of the population, or on a thermally treated specimen (those orangey-yellow or brownish-orangey colour zonings are precisely indications of this kind of treatment, see photograph 4 below).

In a strictly chromatic approach, the orangey or brownish-orangey pole to which sapphires from the Umba Valley and from Malawi belong excludes them from the Padparadscha designation.
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### Photograph 4

Yellow-brown colour zonings caused by a thermal treatment, Sri Lanka sapphire

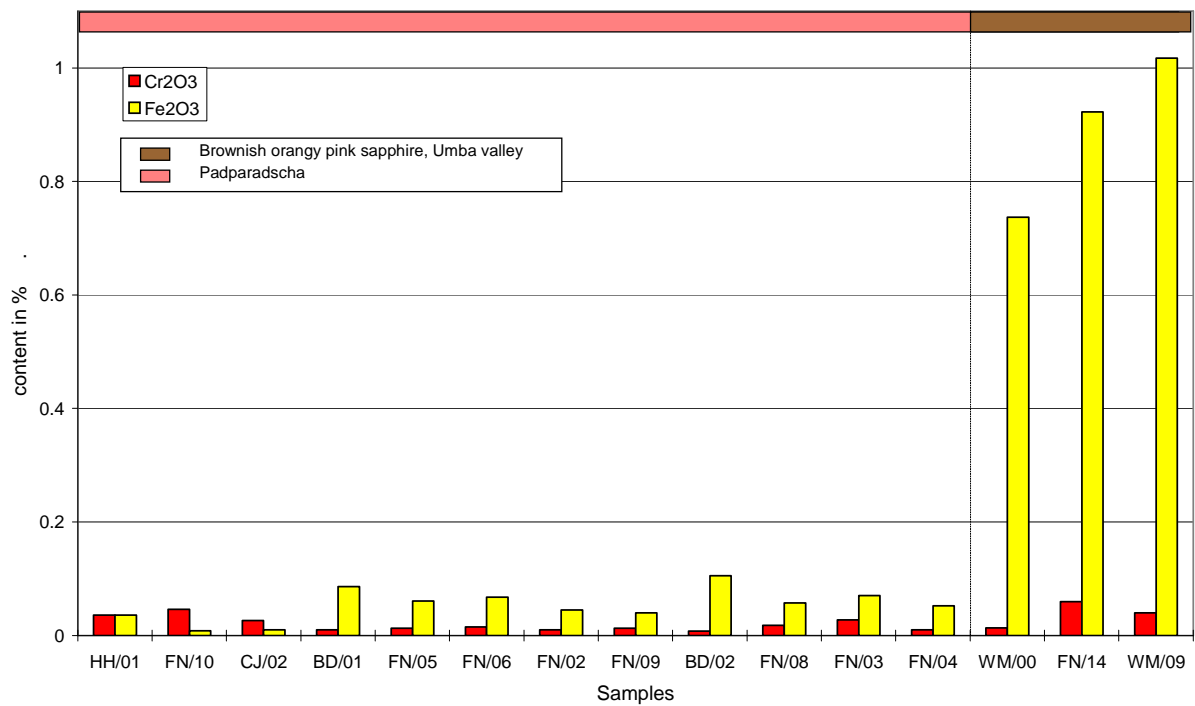


Cliché F. Notari

### Histogram 5

Chromium oxide content ( $\text{Cr}_2\text{O}_3$ ) and Iron oxide content ( $\text{Fe}_2\text{O}_3$ )

Mineralogische Institut der Universität, Basel, CH. Instrument: JEOL JXA 8600 Superprobe, Opérateur: Michael KRZEMNICKI, 07/11/1996



# 3. Syntheses

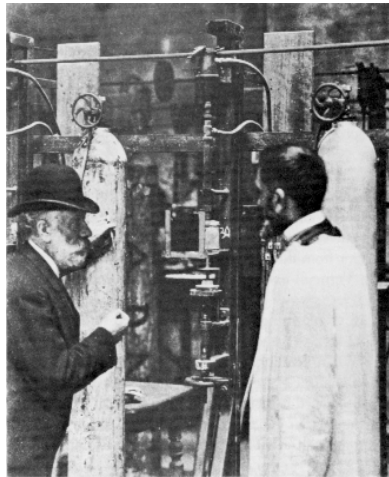
## 3.0 – General Points

Several thousands of years before Jesus Christ, men started imitating mineral matter by heating steatite with addition of different salts, in order to obtain substitutes for turquoise, malachite and lapis lazuli.

They have made great progress since then...

### Brief review :

The first corundum synthesis (ruby) was made by M. A. Gaudin around 1837. Then, at the end of the 19<sup>th</sup> century, Edmond Frémy produced some syntheses by accident during an experimentation at the factory of Sèvres. In 1886, the first industrial production arrived on the market under the name of "Geneva Ruby". Auguste Verneuil, who was Frémy's student, took interest in this new technique and gave it the development that we know.

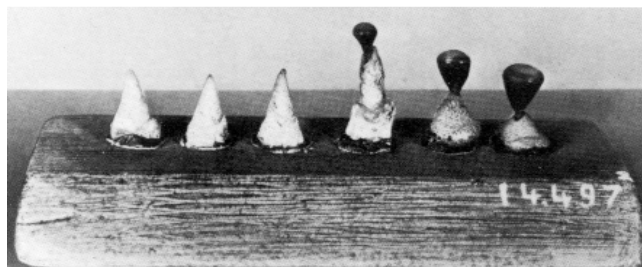


Auguste Verneuil in 1910

Syntheses of all manufacturing processes have enjoyed great success since then, at the beginning for simple economic reasons, and then for scientific applications (ex. laser), and this was definitely the main reason for their "explosion".

Synthetic padparadschas only represent a tiny part of the considerable world production.

Criteria to identify the most common syntheses are proposed below.



Synthetic ruby balls, Museum des Arts et des Sciences, Paris

### 3.1 - Discussion

The syntheses of padparadscha most commonly found on the market are, in frequency order, fusion syntheses (Verneuil), anhydrous dissolution syntheses (flux) and pulling syntheses (Czochralsky).

Apart from the Chatham production, all syntheses have orange as a dominant colour, which does not correspond to the standard. This is probably due to the fact that at the time when the first productions of orange sapphires appeared (at the beginning of the century), the colour of padparadscha was not very well understood. Indeed, the first quotation of the term in Western literature only dates back to 1909 (Bauer Max). This exotic name of a gem which contained the word "orange" in its colour description was considered as perfectly convenient for the new variety of synthetic corundum.

In the forties, for most people, "padparadscha" only meant a synthetic orange gem. In an advertising book of the Ruppenthal firm of Idar-Oberstein, there is a sales catalogue dating back to August 18<sup>th</sup> 1938 where the word padparadscha only designates an orange synthetic sapphire.

This was probably one of the reasons for the current use of this name to describe orange or similarly coloured sapphires from East Africa (Tanzania, Malawi).

Nowadays, apart from those produced by Chatham, the syntheses proposed under this name, even though sophisticated, can very easily be differentiated from padparadschas because of their orange colour. But if a simple look at these corundum enables to distinguish them as a chromatic variety, it is definitely not sufficient to determine their synthetic nature.

A. Synthetische Edelsteine			
1. Edelsteine			
Größe	Spinelle	Safir blau, Safir violett, Zambucit, Padparadscha, Rubin dunkel	Alle anderen Korunde
über 1/4 bis 1/2	6,4	11	8,3
1/4 bis 1/4	5,5	9,7	6,4
1/4 bis 1	4,6	7,4	5
1 bis 2	3	5,5	3,7
2 bis 3	2,1	3,7	2,5
3	1,4	2,6	1,9

Ruppenthal Paul, (1985), *Edelsteine, Handel und Industrie in Raum Idar-Oberstein von 1923 bis 1985*, A. Ruppenthal, Idar-Oberstein, D.

### 3.2 - Distinction

Beyond classic distinction methods, syntheses can effectively be identified through spectroscopy in the visible domain, as can be seen from spectra 1, 3, 4, 6-9. Producers are incapable of "doping" their corundum with iron and this remarkably characterizes the spectra. Trivalent chromium (Cr<sup>3+</sup>) does appear, but iron is generally replaced by trivalent nickel (Ni<sup>3+</sup>), one of whose absorptions shows itself around 400 - 420 nm and is superposed to the chromium's absorption at 405-410 nm.

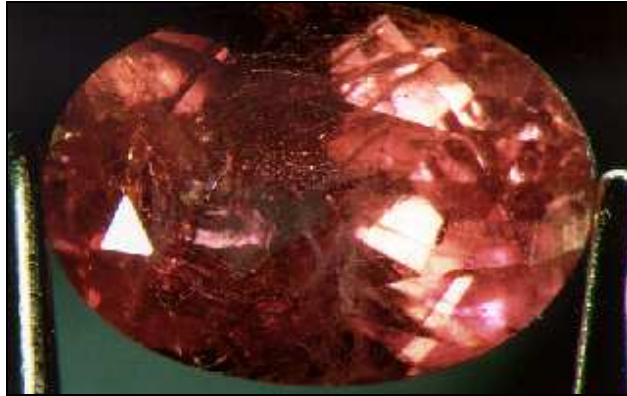
Another approach resorts to X fluorescence spectrometry, in order to reveal traces of gallium (spectra 1, 2). This method is often used to help to recognize synthetic gems (ex. alexandrite, emerald etc.). Theory says that gallium should always be present in natural gems, and absent or present in very small quantities in syntheses. This must be interpreted with caution, because it can be below the threshold of detection in a natural gem according to the type of analysis carried out, as can be

seen from diagram 1, or present in a synthetic gem (up to 100 ppm, E. Fritsch, personal communication, 1996). Chemical analysis with a microprobe is very punctual, and sometimes considers an area of the stone in which there is no gallium (compare histogram 6 with spectrum 10, two methods of analysis on the same sample). Only fluorescence X-ray spectrometry correctly reports the absence or presence of gallium, because it considers a volume of sample convenient for this kind of procedure (spectra 1, 1<sup>bis</sup> and 2).



Moreover, in the case of corundum, this method has the disadvantage of a blurred area linked to the contents ranging from 18 to 22 ppm, because these are contents common to some natural corundums (Tanzania) and to some syntheses (Chatham) (H.W. Schrader, U. Henn, 1985).

Chatham synthetic sapphire



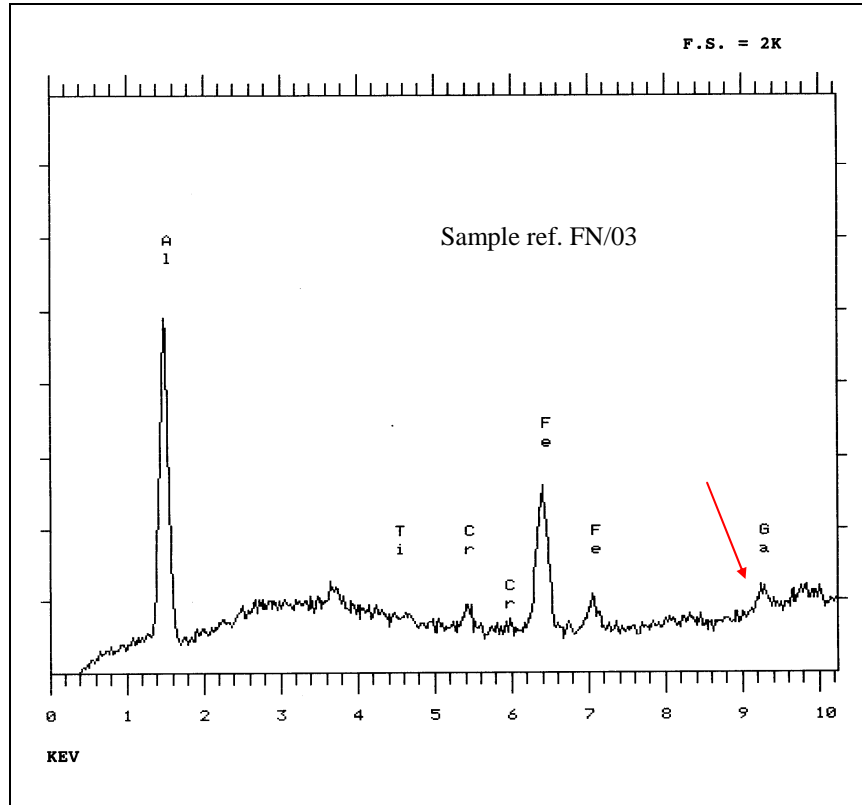
Cliché F. Notari

Chatham, detail

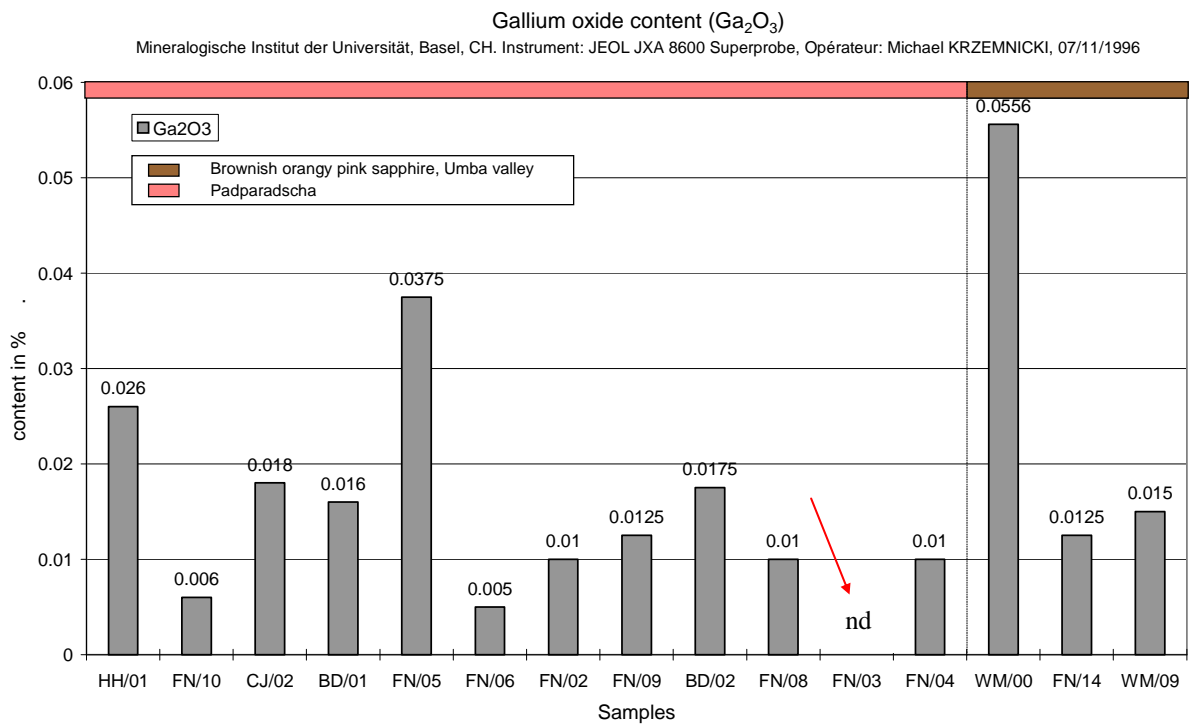


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# Spectrum 10



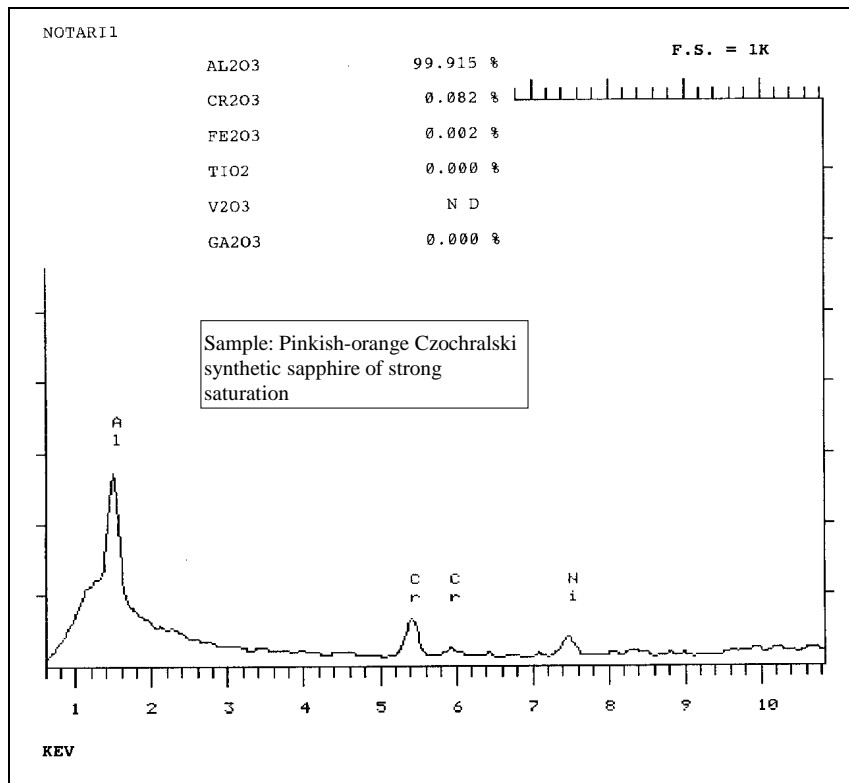
Histogram 6



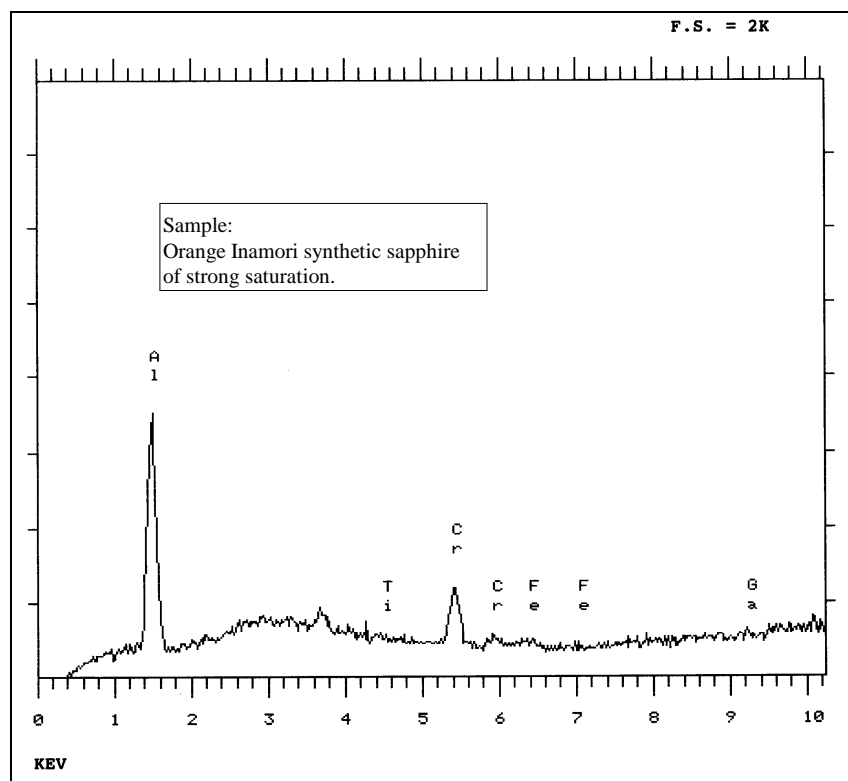


# Spectrum 1

## Revelation of the absence of gallium through X fluorescence spectrometry

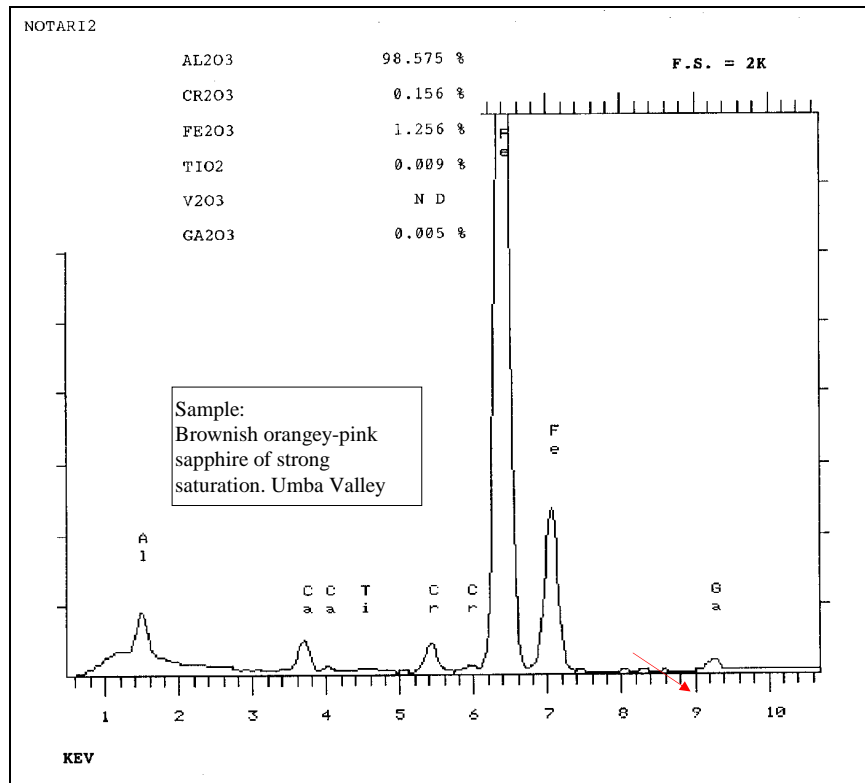


# Spectrum 1<sup>bis</sup>



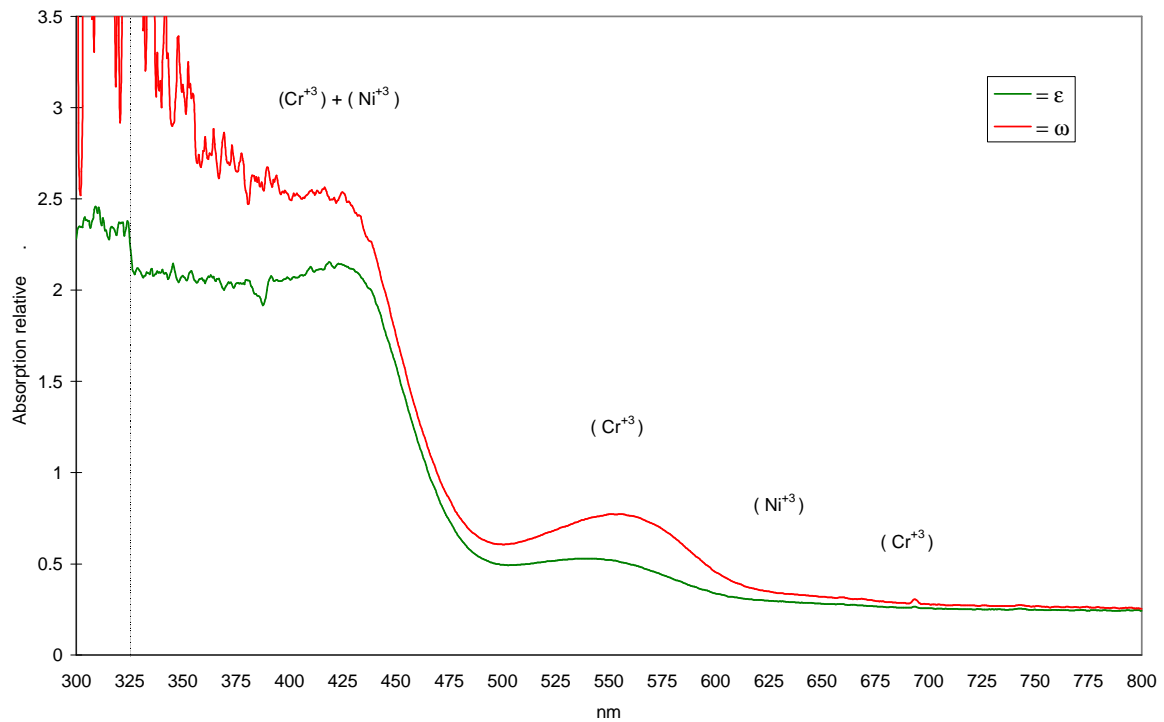
## Spectrum 2

### Revelation of gallium through X fluorescence spectrometry



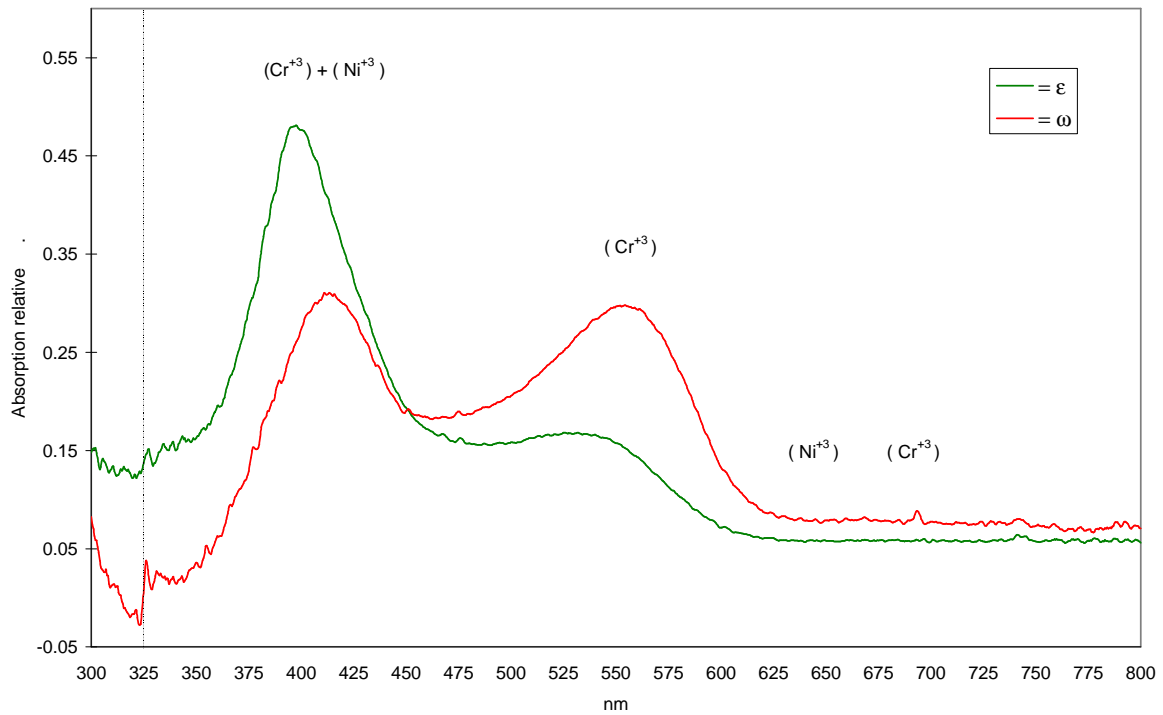
## Spectrum 3

Padparadscha synthetic Verneuil, 3.616 ct., (E ⊥ c, polarised), réf. FN/65  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 12/08/96



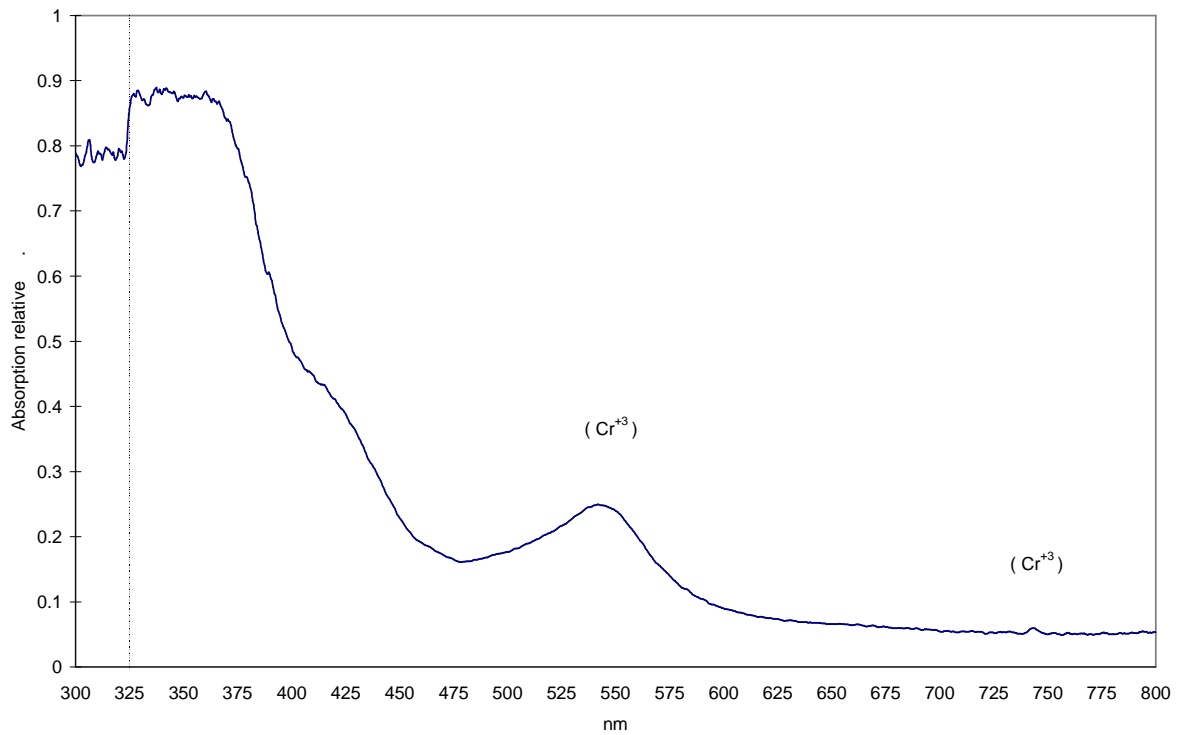
## Spectrum 4

Padparadscha synthetic verneuil, reference of Dina Level, 2.978 ct., (E  $\perp$  c, polarisé), réf. PE/11  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 20/10/96



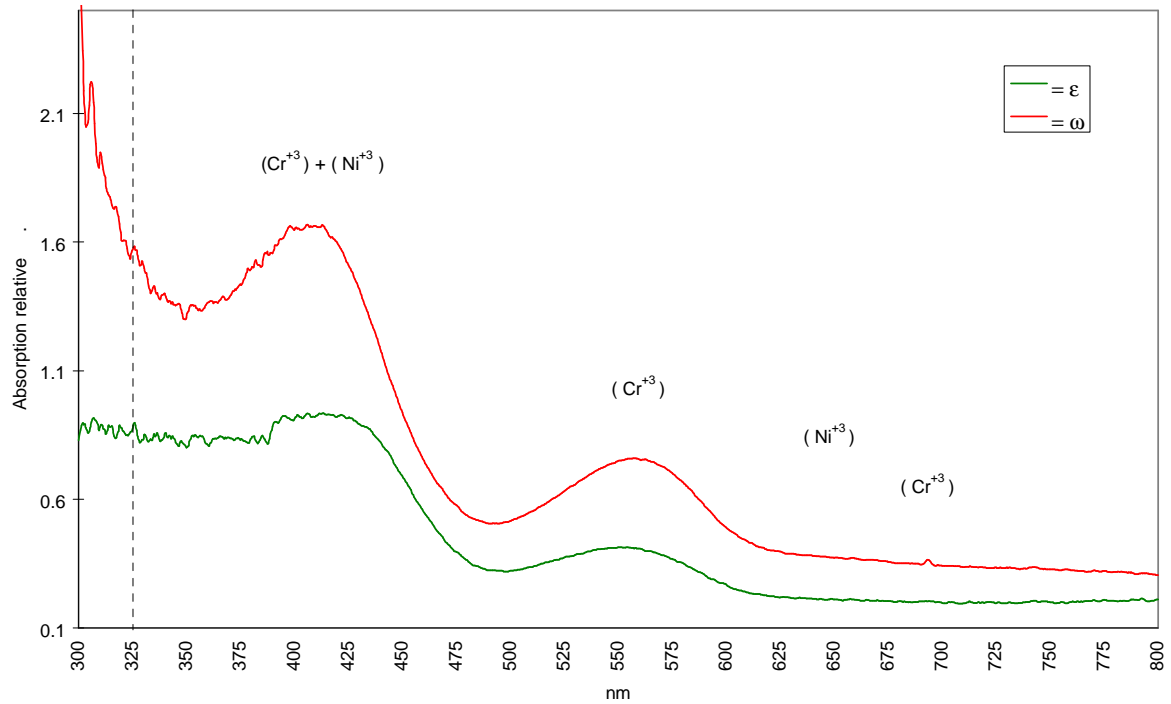
## Spectrum 5 (for pleasure)

orangy pink pastel glass, Padparadscha's reference from Dina Level, 1.750 ct., réf. PE/10  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 20/10/96



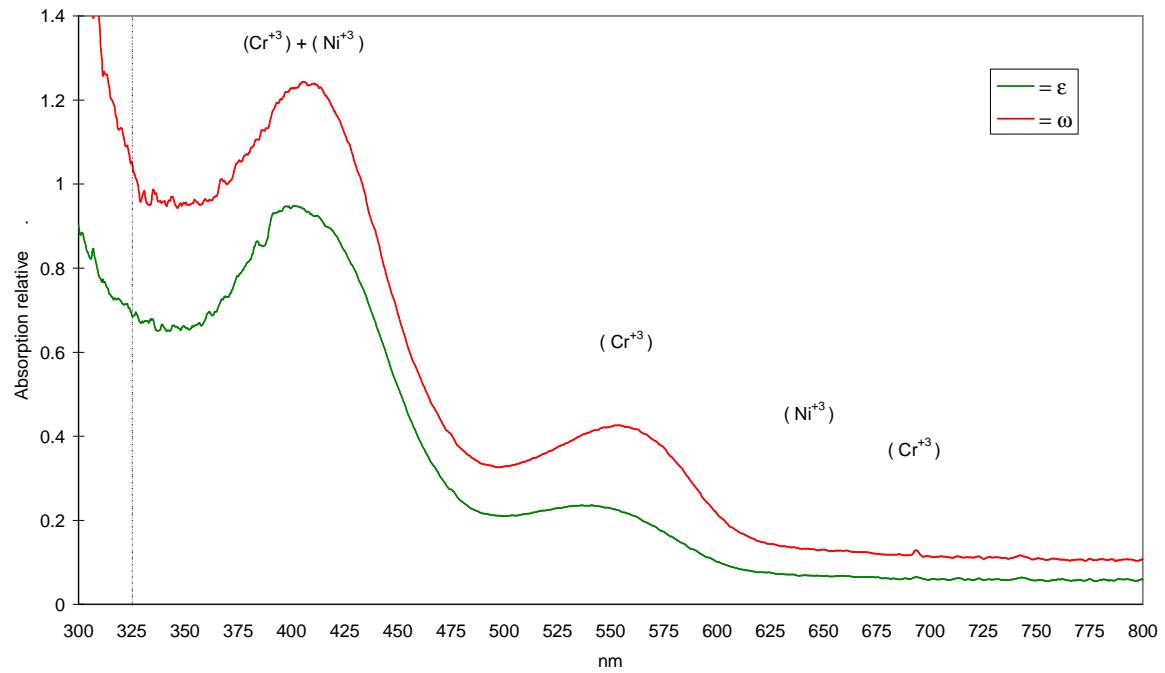
## Spectrum 6

Czochralsky "Padparadscha", 3.448 ct., (E ⊥ c, polarisé), réf. FN/65  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 15/09/96



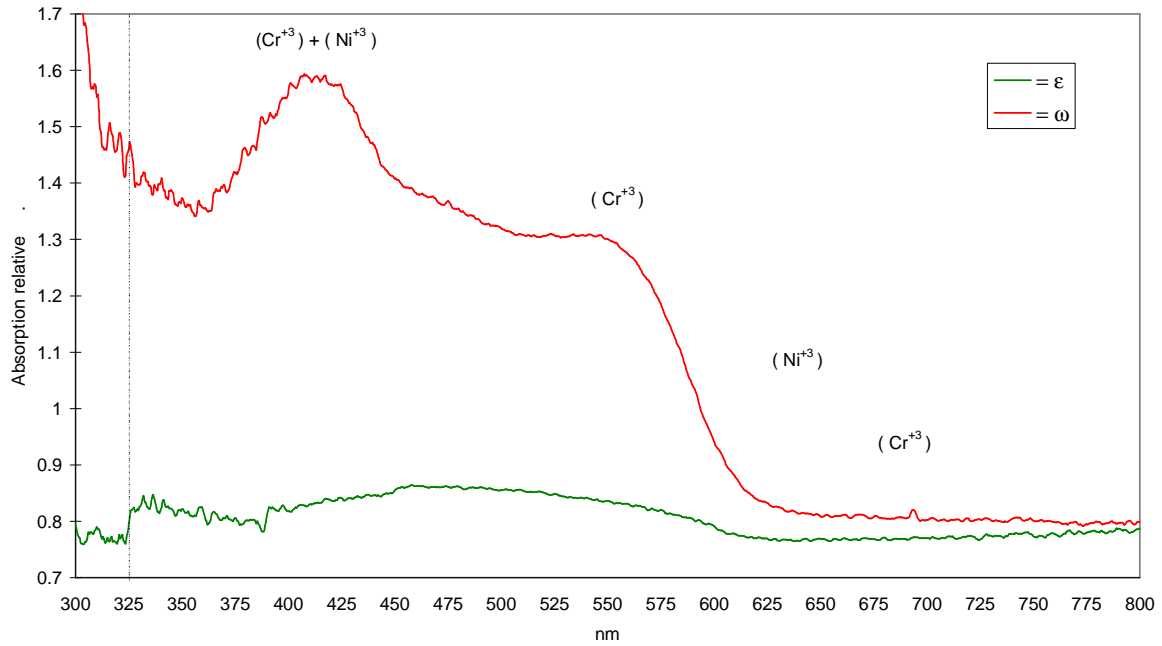
## Spectrum 7

Padparadscha synthetic, Kimberley, 1.487 ct., (E ⊥ c, polarisé), réf. FN/20  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 17/09/96



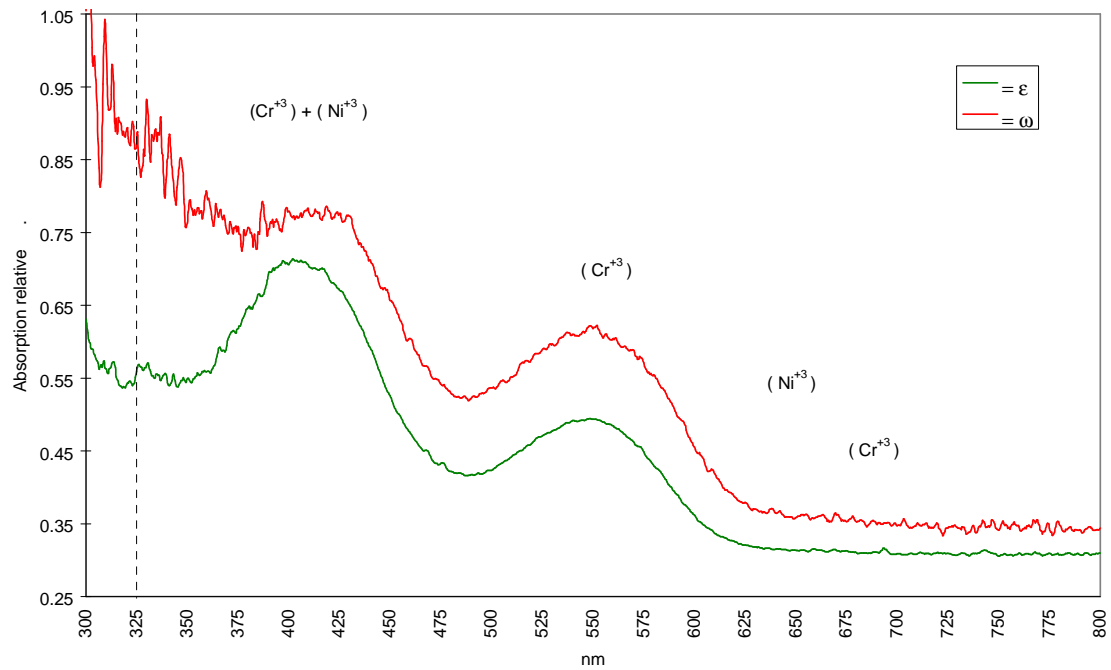
## Spectrum 8

Padparadscha synthetic Inamori, 1.115 ct., ( $E \perp c$ , polarisé), réf. FN/19  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 12/09/96



## Spectrum 9

Padparadscha synthétique Chatam, 1.100 ct., ( $E \perp c$ , polarisé), réf. FN/18  
300 nm/min., slit 1.0 nm, wavelenght change 325 nm, integrating sphere, polarizing filter type HNP'B, 20/09/96



## 4. Treatments

### 4.0 - General Points

More and more treated padparadschas can be found in Sri Lanka. They are either simply thermally treated or irradiated. The majority is thermally treated, at "best" through the ancestral technique of "*Batâ-Kubalâ*" or Blow Pipe. The forced air heating technique with bellows (more recently with a hair-dryer...) enabling to reach  $\approx 1600^{\circ}\text{C}$  (air and lignite) is rather reserved for other colours of corundum. Different combustible ingredients and methods are used to obtain good conditions of temperature and oxidation, according to the expected goals.

#### Blow Pipe:

The officiant pokes the embers with a pipe. The poked area is precise, so that the heat to which the gem is subjected can be measured. This work necessitates much regularity that is why the man has a watch in his hand enabling him to control the heating time without useless movements. The gem in treatment is a star ruby. After two hours of treatment, the colour of this ruby will have gained in purity after softening of a blue note that gave the gem a purplish shade.



In the past some stones were sent to Thailand to be treated in modern furnaces, and then they were sent back to Sri Lanka where they were negotiated. Around 1980, traditional furnaces Cliché F. Notari began to be modified with pure oxygen supply systems. Since around 1985, high-performance furnaces have been manufactured in Sri Lanka.

The amount of irradiated padparadschas is also in progress because it is very easy to have access to medical X-ray installations, which are sufficient to obtain the expected effect. Indeed, radiography equipment commonly develop a tension of 100 [kV] and yellow coloured centres can be provoked in corundum from 15 to 20 [kV] (Prof. H. Bill, personal communication).

## 4.1 – The Blow Pipe "Low Temperature" Thermal Treatment

This treatment has been in use for a long time. There is already a reference to it at the beginning of our millennium: (*AL-BIRUNI, ABU RAYHAN MUHAMMED IBN AHMED, (≈ 1000), Kitab al-jamahir fi ma'rifat al-jawahir (Book of knowledge of precious stones)*). It was practised with very simple equipment consisting mainly in a small hearth made of baked clay, open, containing charcoal poked by an officiant blowing into a bamboo (nowadays a metal pipe). It is definitely the first technique used by man in order to modify the colour of gems.

Originally this treatment was used to soften the blue areas giving a purple tonality to rubies and pink sapphires ( $\approx 1000^{\circ}\text{C}$  in oxidizing environment,  $\{\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$ , which hides the charge transfer  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}\}$ , if the quantities of  $\text{Fe}^{3+}$  released are not too considerable, they will not have any significant influence on the colour).

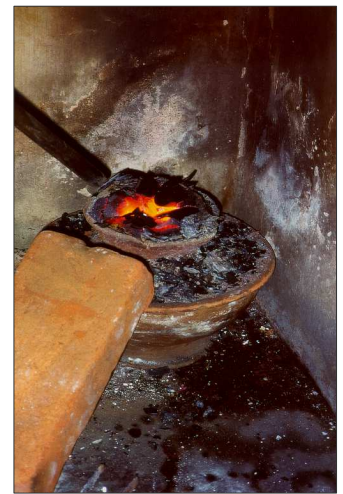
Nowadays, the softening of blue areas is still topical as regards to padparadschas, furthermore with the possibility of reinforcing a yellow touch sometimes almost invisible at the start ( $\pm 1600^{\circ}\text{C}$  in oxidizing environment (it is necessary to use lignite as fuel to be able to obtain such a high temperature with a blow pipe; this technique is rarely employed for padparadschas)), which gives the aspect of a padparadscha to a pink sapphire. It should be noticed that the presence of a blue area in a padparadscha is no guarantee of the absence of a treatment because in the great majority of cases, that area has only been softened.

The temperatures obtained with the Blow Pipe method can exceed  $1'000^{\circ}\text{C}$ . The heating time of corundum can vary from 2 to 48 hours! (When several officiants take turns) according to the type of sapphire and the intensity of the blue area that has to be treated. More precisely, padparadschas are generally treated over periods of 2 to 4-5 hours.

At the moment, this heating technique for corundum at relatively low temperatures and sometimes over a long period of time is quite difficult to reveal clearly, whatever the means used (infrared imagery (Fjordgreen, 1986), UV-visible spectroscopy, observation with ultraviolet, macroscopic and microscopic etc.).

Most classic solid inclusions of Sri Lankan sapphires have a melting point superior to  $1'100^{\circ}\text{C}$  (the inclusion with the lowest melting point is pyrites:  $1'170^{\circ}\text{C}$ ), which is above the temperatures generally reached by this method. Detection of Blow Pipe treatment through microscopic examination can only be convincing in the presence of inclusions sufficiently big and/or having such a coefficient of expansion that they will generate the characteristic fractures (ex: liquid  $\text{CO}_2$ , of quite large dimensions, because it seems that the expansion of very small-sized diphases cannot break the stone's plating). This case is rare among padparadschas treated in this way.

Photo 2



Cliché F. Notari

The numerous variations in the physical and chemical nature of corundum, and the diverse methods available to treat them thermally, make it very complicated to understand the mechanisms generated by these treatments.

Moreover, for these reasons and for protection of "know how", the information published so far is incomplete and does not enable to clearly deduce the heating methods used.

The "mild" ( $\approx 1000^\circ\text{C}$ ) heating technique is still favoured today. Sapphires corresponding to padparadschas of good quality in the eyes of Sri-Lankans are treated on the spot with blow pipes, never in powerful furnaces.

On the other hand, great quantities of pink sapphires of poor to medium quality are heated more vigorously in modern furnaces. Before 1980, these stones were sent to Thailand for this purpose. Between 1980 and 1985, modified furnaces and modern equipment have permitted to heat these sapphires intensely on the island and this had the effect of spreading them on the local market.

Nowadays the trade of padparadschas of good and high quality resolutely turns to foreign countries (in decreasing order Japan, Switzerland and the United States), where the vigilance of laboratories encourages Sri-Lankan merchants to send untreated stones only, insofar as they are in a position to know if they are treated or not.

The great majority of those important gems is sold abroad. As a result it is very difficult to find good padparadschas on the local market. If one wants to buy a beautiful untreated padparadscha in Sri Lanka, they will have to go to an important merchant and try to negotiate a gem just before it is sent abroad.

#### 4.1.1 – How to Reveal Low Temperature Thermal Treatment

The various analyses carried out during this work show that it is still impossible to reveal the blow pipe thermal treatment of padparadschas in a quantifiable and well definite way today.

It is useful to recall that this heating technique is only intended to improve a gem that already has all the physical and chemical characteristics of a padparadscha, whereas high temperature heating creates a padparadscha from another sapphire (for instance a pink sapphire). Blow pipe treatment usually only generates minor quantitative modifications of the absorptions.

The blue colour zonings, which are the main aim of this treatment, are generally only softened. The release of  $\text{Fe}^{3+}$  is weak and only slightly increases the absorptions of the charge transfer  $\text{Fe}^{3+}/\text{O}^{2-}$  at 388 [nm] and of the pair transition  $\text{Fe}^{3+}/\text{Fe}^{3+}$  at 377 and 450 [nm], which are already present in unheated padparadschas.

At these temperatures small inclusions usually remain intact, and so do small diphases  $\text{CO}_2$  gas/liquid.

Only the stress of big inclusions or big diphases are convincing, but low-quality padparadschas are not treated with blow pipes but at high temperatures in modern furnaces.

The coloured centres of the original habit will definitely be revealing. One day...

#### 4.1.2 - How to Reveal High Temperature Thermal Treatment

Spectroscopy should be a tool.

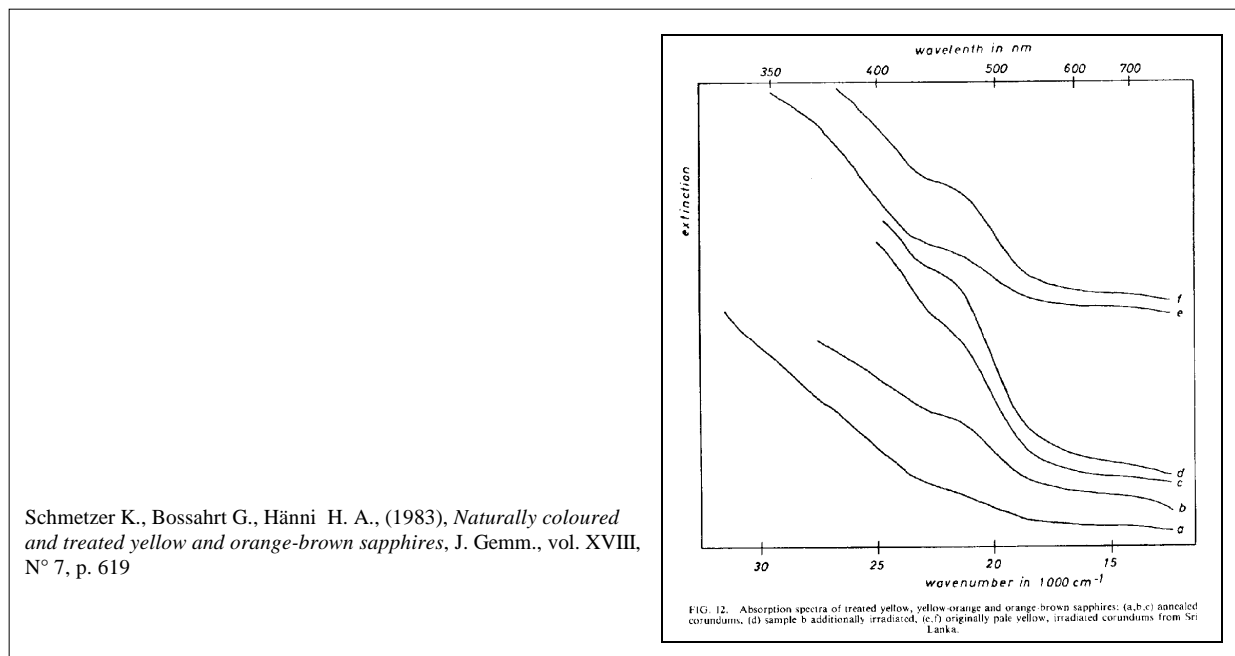
It is sometimes possible to detect the heating of blue sapphires from Sri Lanka coming from "Geudas" in spectroscopy, working on the assumption that thermal treatment, because of the presence of titanium in rutile ( $\text{TiO}_2$ ), generates a certain quantity of  $\text{Fe}^{2+}$  according to the principle:



$\text{TiO}_2 + (\text{Al}^{3+}, \text{Fe}^{3+})_2\text{O}_3 \rightarrow (\text{Al}^{3+}, \text{Ti}^{4+}, \text{Fe}^{2+})_2\text{O}_3$ , favouring the transfer of charge  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$ , and drastically decreasing the absorptions of transfer  $\text{Fe}^{2+}/\text{Fe}^{3+}$  at 870 [nm], as well as the absorptions of the transfer of charges of  $\text{Fe}^{3+}/\text{O}^{2-}$  at 388 [nm] and of the transition of pair  $\text{Fe}^{3+}/\text{Fe}^{3+}$  at 377 and 450 [nm]. (Schmetzer Karl, Kiefert Lore, (1990), *Spectroscopic Evidence for Heat Treatment of Blue Sapphire from Sri-Lanka - Additional Data*, J. Gemm., Vol. XXII, N° 2, pp 80-82).

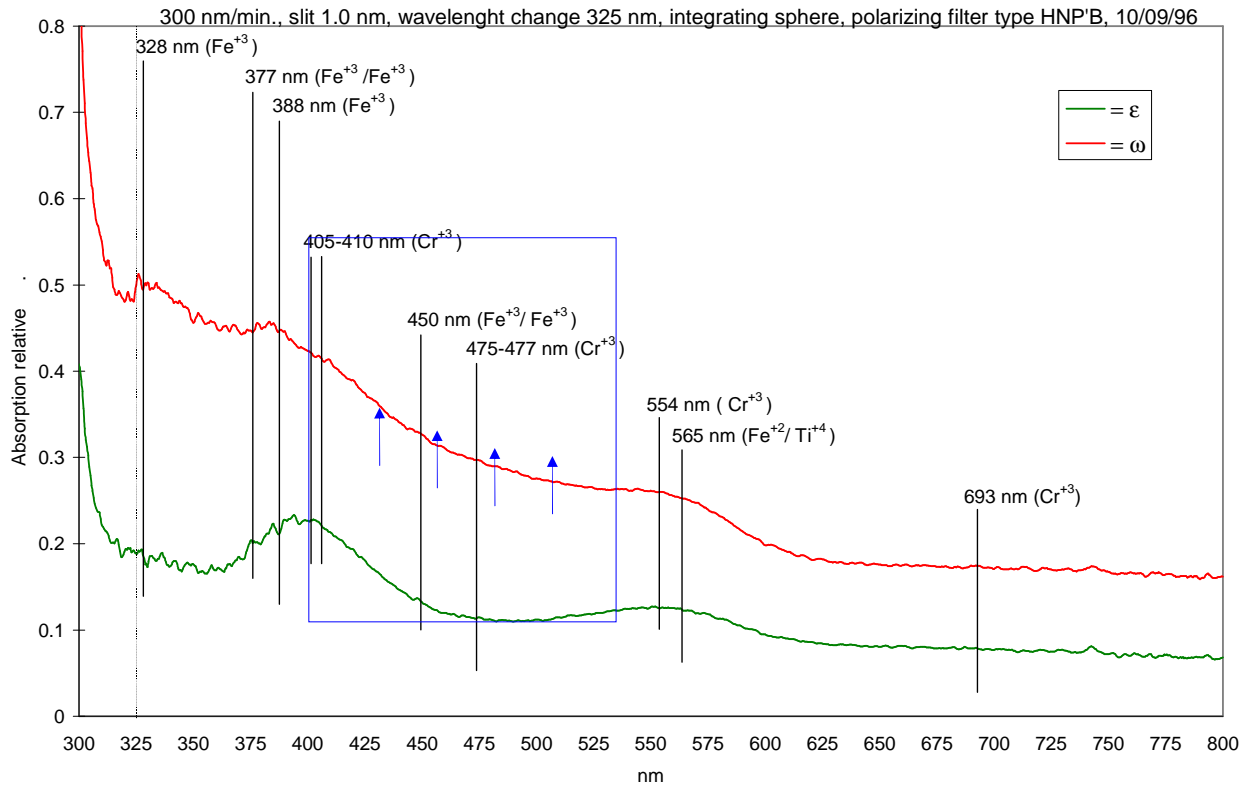
"Padparadschas" heated at high temperatures are generally detectable. Indeed, the transformation of  $\text{Fe}^{2+}$  (coming from interstitial  $\text{Fe}^{2+}$ , from the resorption of inclusions (hematite  $\alpha \text{Fe}_2\text{O}_3$ ), and released during transfer  $\text{Fe}^{2+}/\text{Ti}^{4+}$ ) into  $\text{Fe}^{3+}$  significantly increases absorptions of the transfer of charges of  $\text{Fe}^{3+}/\text{O}^{2-}$  at 388 [nm] and of the pair transition  $\text{Fe}^{3+}/\text{Fe}^{3+}$  at 377 and 450 [nm]). The spectrum of sapphires treated in this way shows a filling of the valley standing between the two absorptions of the simple transition of  $\text{Cr}^{3+}$  at 405-410 and at 554 [nm], and the discreet natural peak of absorption  $\text{Fe}^{3+}/\text{Fe}^{3+}$  at 450 [nm] disappears, leaving space for a wide and considerable absorption (see diagrams 1 and 2). Schmetzer, Bossahrt and Hänni already noticed that in 1983, and centred this wide absorption band, which they also attributed to  $\text{Fe}^{3+}$ , at 465 [nm]. This intensification is very spectacular on their spectra of yellow sapphires (see picture 2, below). As regards padparadscha, (465 [nm]) the two absorptions of  $\text{Cr}^{3+}$  at 405-410 and at 554 [nm] are on either side of that area. Therefore, this modification of the absorption of iron can be less easily perceptible in specimens where the pink touch is relatively saturated. But in some cases (specimens originally containing much  $\text{Fe}^{2+}$ ), the absorption of  $\text{Cr}^{3+}$  at 554 [nm] can nearly be hidden by the increase of the trivalent iron absorption (see diagrams 1 and 3).

### Diagram 1



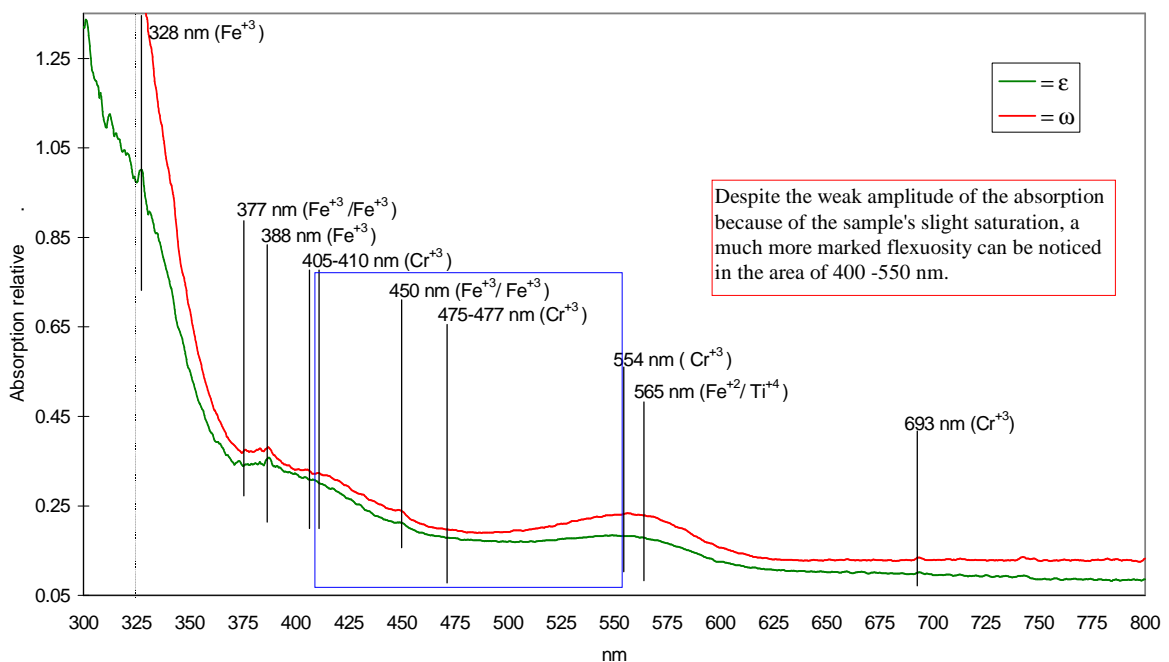
## Spectrum 1

Induced light saturation on a Padparadscha, cheat treated in Thaïlande, 1.360 ct., ( $E \perp c$ , polarisé), réf. FN/11



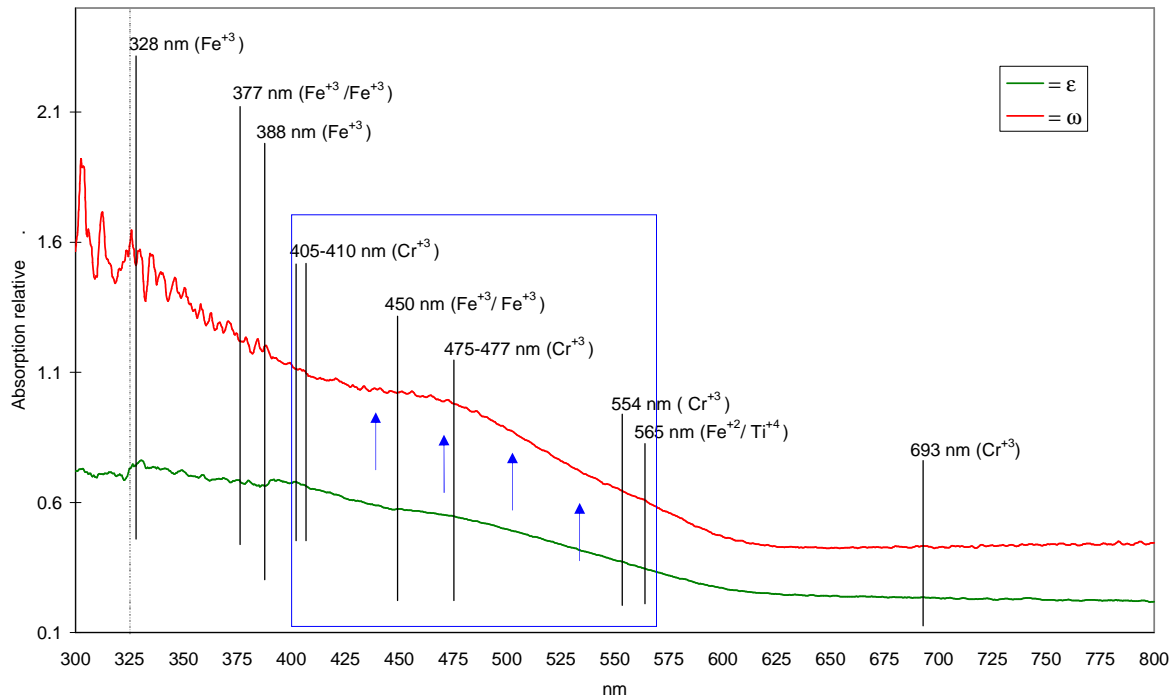
## Spectrum 2

Padparadscha "original", very light saturation, Sri-lanka, 2.125 ct., ( $E \perp c$ , polarisé), réf. PE/08  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 19/10/96



## Spectrum 3

orange sapphire, heat treated, Sri-lanka, 1.480 ct., (E ⊥ c, polarisé), réf. PE/15  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 10/09/96



## 4.2 - Irradiation

There have been installations used to "improve" yellow sapphires through irradiation in Sri Lanka since 1975. In 1978, people started to use them to turn pink sapphires into Padparadschas. The treatments' rate (thermal and irradiation, sometimes both at the same time) has increased over the last decade and put eight times as much as the initial production on the market! On the other hand, the quantity of untreated Padparadschas on the local market has singularly fallen for two reasons:

- Big untreated gems are negotiated abroad where tests in laboratories encourage merchants to "play the game".

- Small and medium gems which are too pink, although already of a correct colour, are treated in the hope of improving them even so.

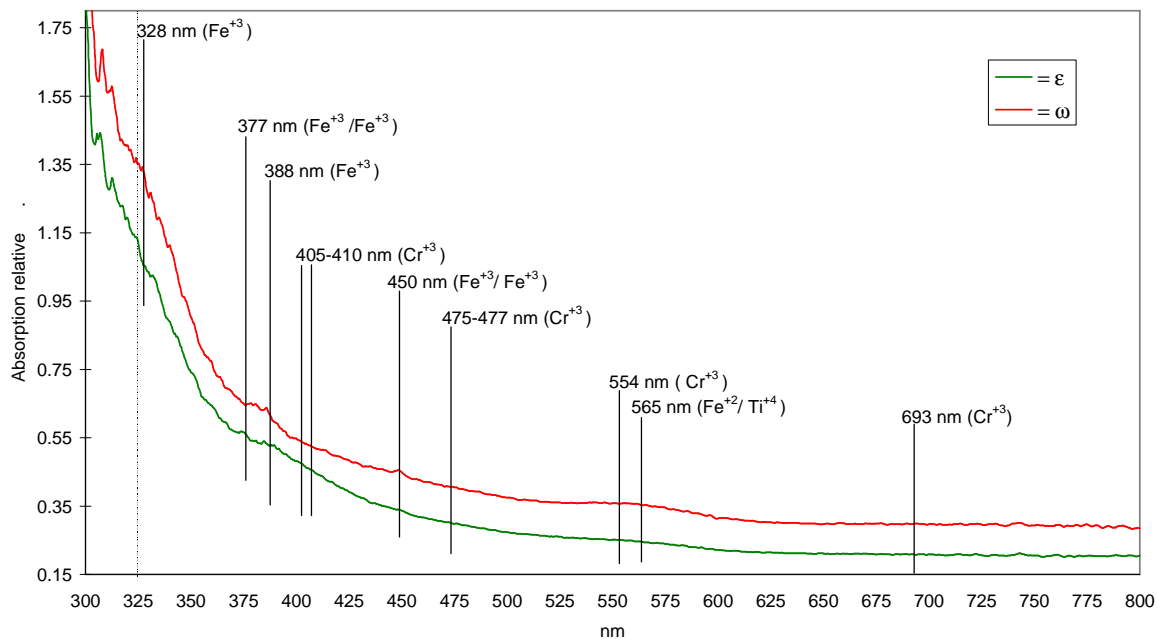
### 4.2.1 – How to Reveal Irradiation

The irradiation of sapphires in order to obtain "padparadschas" is clearly revealed in spectroscopy, as can be seen from diagrams 4 and 5. The modification of the absorption curve is similar to the one found in specimens heated at high temperatures.

After decolouration through UV or Nassau's "fading test", the absorption decreases, but there is still a "flattening" of the spectrum (see spectrum 3). Non decoloured stones show a spectacular increase of absorption of the pair transition  $\text{Fe}^{3+} / \text{Fe}^{3+}$  at 450 nm (spectrum 5).

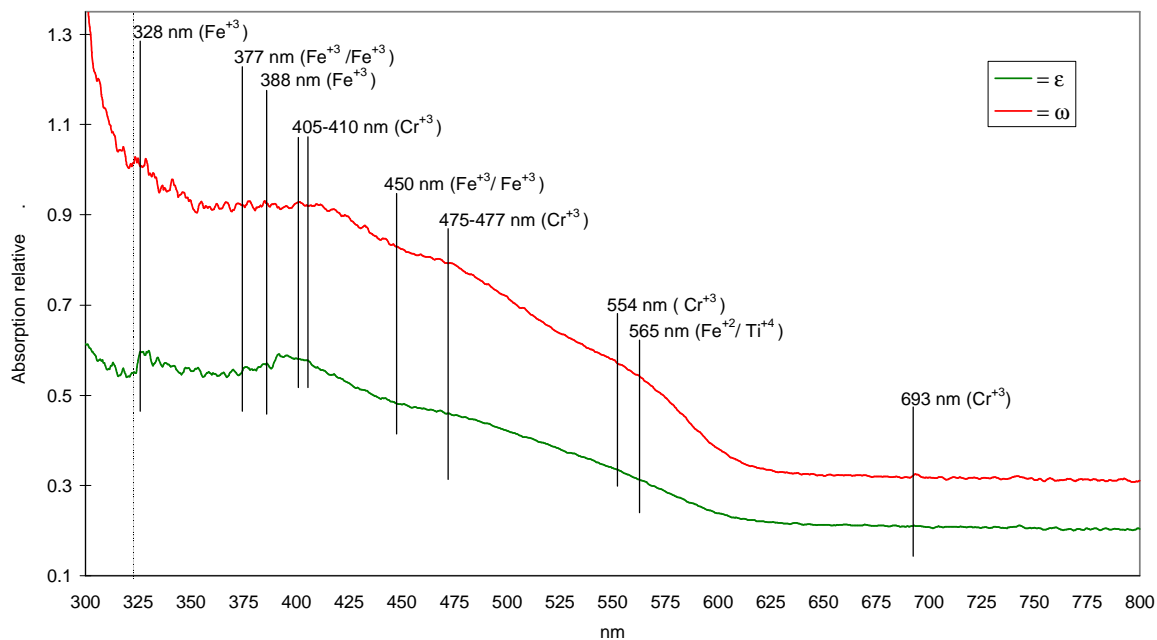
## Spectrum 4

"Padparadscha" irradiated, bleached, 3.411 ct., ( $E \perp c$ , polarisé), réf. PE/09  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 20/09/96



## Spectrum 5

"Padparadscha" irradiated, vivid orange, 0.937 ct., ( $E \perp c$ , polarisé), réf. PE/03  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 20/10/96



## 4.3 - Solarisation

### Report of a solarisation mechanism in a padparadscha:

While we were visiting Sri Lanka merchants told us that some gems sent to Japan were returned decoloured and marked "treated". To hear them talk it was sufficient then to expose these stones to sunlight on a mirror to see them take their initial colour back after a few hours...

Back to Europe, Mr Pascal Entremont had the possibility of repeating this "operation" on a 5,7 carats "antique colour" padparadscha (ref. PE/01) which had considerably lightened over a dozen years storage in the dark. After a one afternoon exposure to sunlight it had taken its original colour back. So there is a solarisation mechanism in padparadscha. Unfortunately the modification has not been quantified, because the operator was incredulous and conducted this experiment without really believing it would work. This being said, his incredulity and the fact that Pascal Entremont is a very experienced gemmologist leave no doubt about the phenomenon's reality.

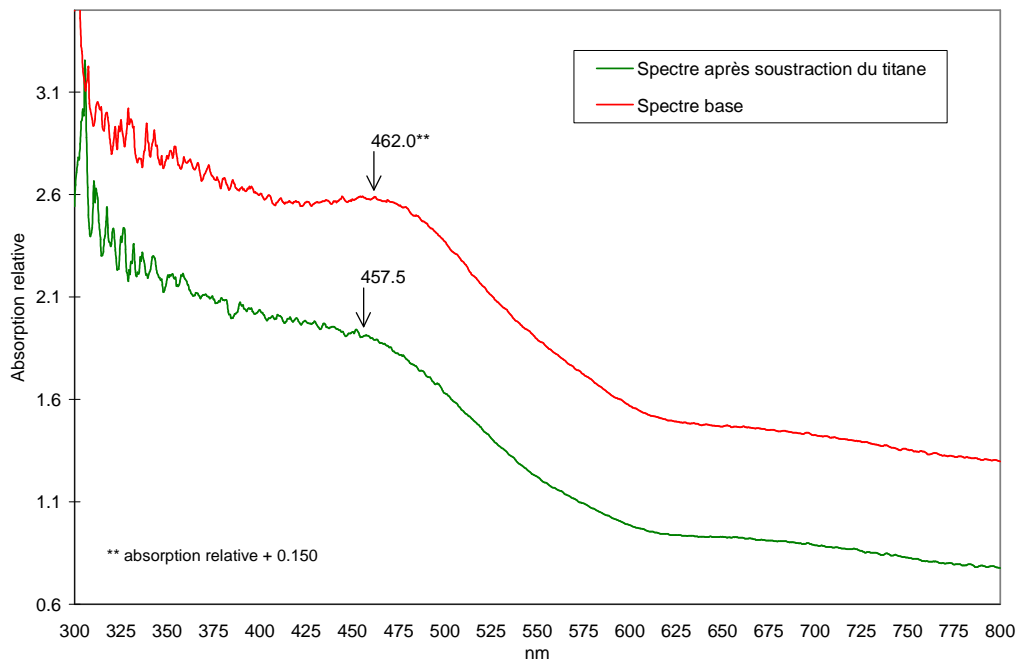
We have supposed that an irradiation treatment could have modified the gem's  $Ti^{+4}$  into  $Ti^{3+}$ . It is known that  $Ti^{3+}$ , in corundum, from a concentration of 20 ppm, can generate a pink touch when it is subjected to soft X rays or even UV.

This phenomenon has been noticed on watch glasses made of synthetic sapphire polluted by titanium. During the process of making (very reducing),  $Ti^{4+}$  can transform into  $Ti^{3+}$ . The mentioned glasses turned slightly pink with time (Hans Bill, 1992, personal communication).

Although this padparadscha (PE/01) did not have the characteristic spectrum of an irradiated stone (spectrum 7), we have made a spectrum subtracting a  $Ti^{3+}$  signal (example spectrum 6) established from a sample kindly provided by the Djevahirdjian firm in Monthey, Switzerland. The result was not really convincing. So far we do not have any acceptable explanation to describe this mechanism.

### Spectrum 6

Padparadscha irradiated, réf. PE/03, = c, Spectres comparatifs après soustraction de l'absorption de  $Ti^{+3}$  (échantillon réf. FN48-a). (Baseline system) 300 nm/min., slit 1.0 nm, Wavelength change 325 nm, integrating sphere, 14/10/96



## Spectrum 7

Padparadscha, habitus original, Sri-lanka, 5.756 ct., ( $E \perp c$ , polarisé), réf. PE/01  
300 nm/min., slit 1.0 nm, wavelength change 325 nm, integrating sphere, polarizing filter type HNP'B, 10/09/96

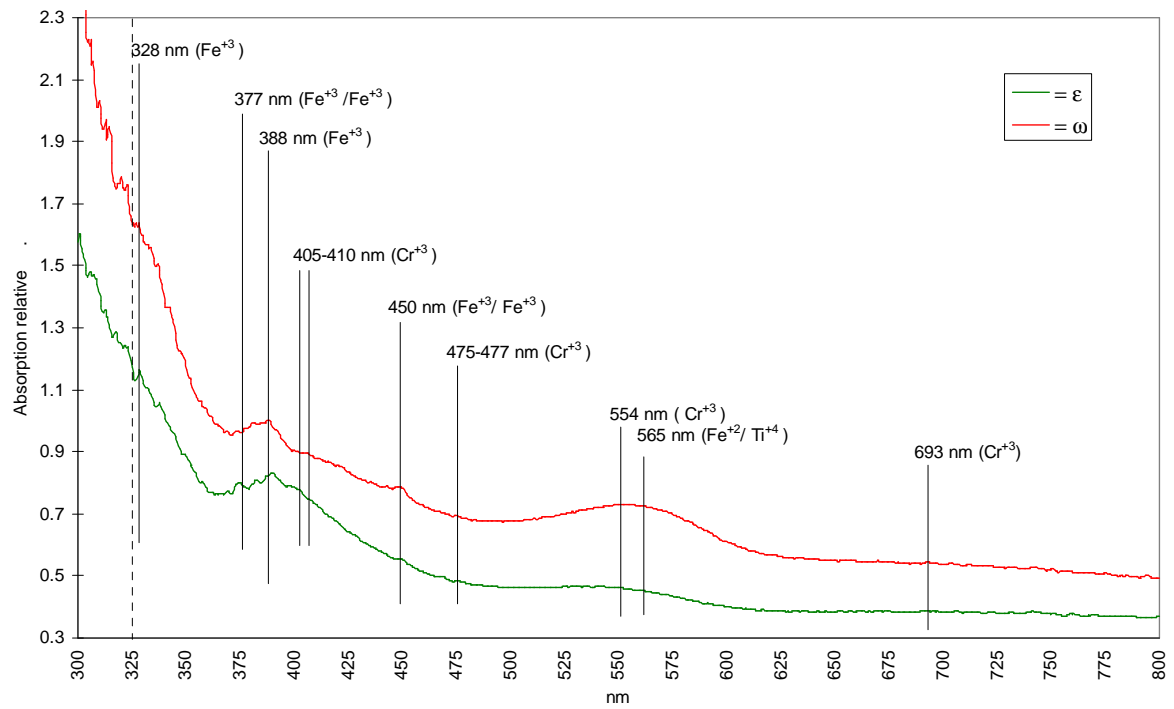
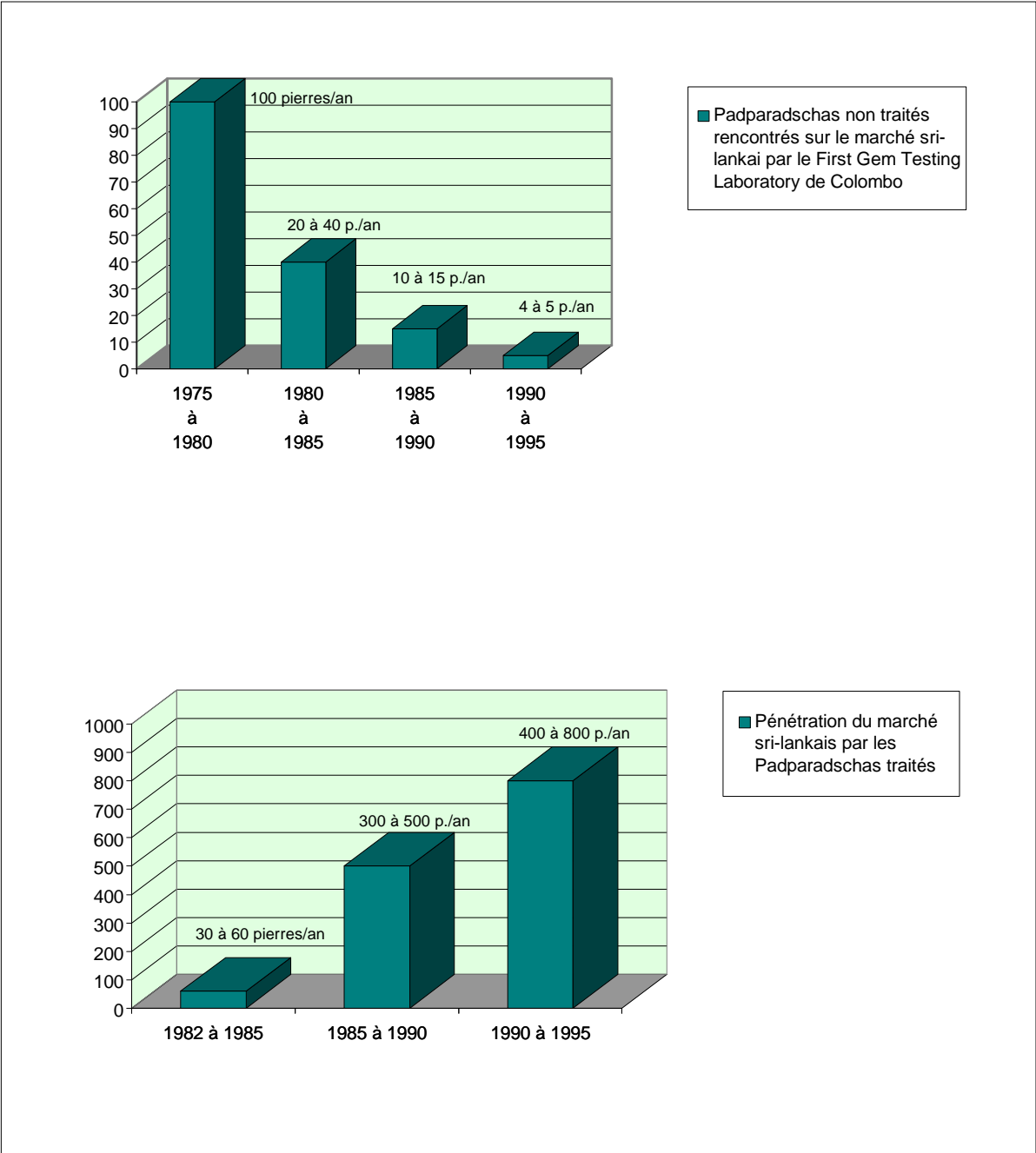


Diagram 3

Proportion statistic of treated stones:



Information: Mr Leslie J. Punchihewa, manager of the First Gem Testing Laboratory of Colombo.

# 5. Origin

Two thousand years ago, on the island of Ceylon, men separated, from the thousands of sapphires that they extracted from the ground, a variety whose colour had an exceptional quality in their eyes. At the time, spectral analyses, X-ray fluorescence and the Raman microprobe did not exist. Only the way people looked at the world made them perceive the difference. They projected their poetry and their sense of beauty in this gem. They integrated it into the



Sri Lanka: monsoon

aesthetics of their culture and passed it on and taught it to us. According to me, this gives them a kind of moral property on Padparadscha, because it is not certain that we would have been able to invent it without them.

## 5.0 - General Points

It is generally admitted in gemmological circles today that padparadschas are native to Sri Lanka and that this origin is one of the concept's components. But taking into account the origin in the definition of padparadscha implies that it can be determined with reliability. As a matter of fact, several deposits produce sapphires of similar colours.

Laboratories base their selves on inclusions study and use spectroscopy and chemical analysis in order to define the depositary characteristics of a corundum and give a verdict on its origin. We will try to propose some additional markers. (Hughes Richard W. et al., 1988).

As there is no deposit producing sapphires combining all the characteristics of padparadscha (absorption spectrum, chemical composition, inclusions, habit, blue colour zoning characteristics, crystalline habit sensu stricto, traditional gemmological analysis and especially colour) to our knowledge, the parameters defining the identity of a padparadscha also characterize the Sri-Lankan origin.

Deposits where sapphires of colours close to that of padparadscha have been found:

SOUTH AFRICA, Namaqualand; MYANMAR, Mogok; COLOMBIA, Mercaderes; INDIA, Orissa; KENYA, Chania River, Mangari Swamp; MADAGASCAR, unknown deposit; MALAWI, Chimwadzulu Hill; TANZANIA, Uмба Valley; VIET NAM; USA, Yogo, Rock Creek, Granite Co, etc.



## 5.1 - Deposits (Sri Lanka)

The deposits from where Padparadschas are extracted are situated in a granulitic facies area encompassing the central and southern part of the Highlands group and the south-west group. They are in a geostructural domain determined by a collision context.

The strong general metamorphism (catazonal) is 1'150 to 3'000 million years old.

### 5.1.1 – Secondary Deposits

These deposits (see map) are made up of eluvial (products stemming from a soil's leaching) and alluvial (rivers' and lakes' sediments) residue and residual<sup>2</sup> deposits divided into three main poles: the regions of Ratnapura, Elahera and Buttala. The gems, because of their density, are collected in the basic layers, at the bed-rock level (rocky bed covered with alluvium). This gravel containing gemstones is called "*illam*".

- The Ratnapura region comprises mainly eluvial deposits, made up of residual sediments and gravel, containing uneroded rock fragments. This residue is inserted between layers of sand, clay and lateritic beds.

- North of the massif, in the Elahera region, the exploited deposits are as much alluvial as eluvial.

- South-west of the massif, the Buttala region comprises essentially alluvial deposits.

These detrital deposits formed in fluvial and lakes environment through erosion processes more active than those of biorhexistasia (alteration and destruction of soils in relation with the variations of the vegetable cover). They stemmed from cordierite gneiss, which apparently come from pelites (very thin-grained sedimentary detrital rock) rich in alumina (T. Munasinghe & C.B. Dissanayake, 1981).

### 5.1.2 – Primary Deposits

Primary deposits in which Padparadschas can be found are made up of granulites, orthogneiss (garnet gneiss, garnet-sillimanite-biotite gneiss) and charnockites in decreasing order of corundum content.

Charnockites<sup>3</sup> and granulites were apparently produced through metamorphism of volcanic rocks, assuming that charnockites are of magmatic origin.

These deposits are hardly exploitable, their production is almost non-existent as regards padparadschas and it is excessively rare to find "fresh" rough stones.

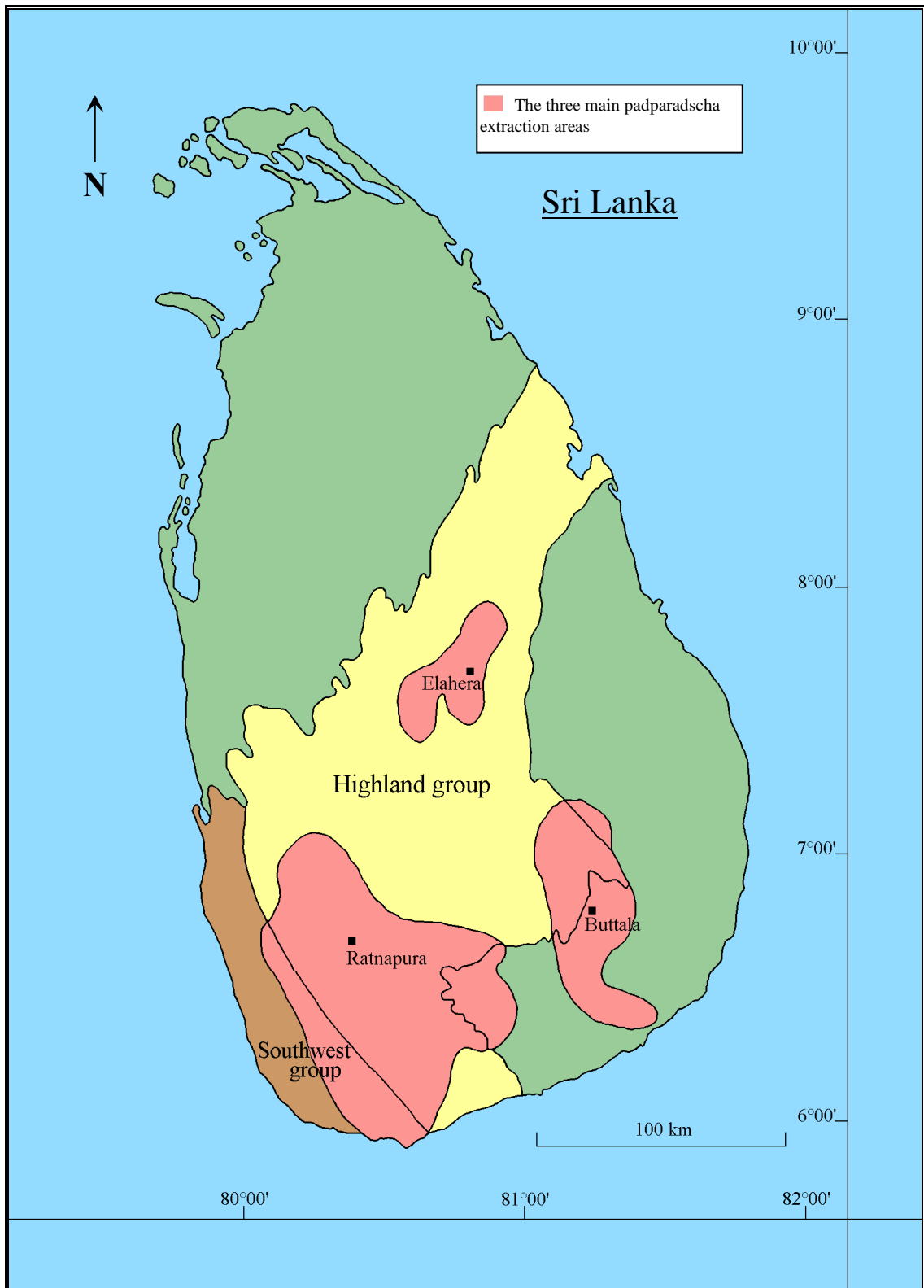
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<sup>2</sup> Formations whose materials which have remained to the spot proceed from the alteration of preexisting rocks having lost a great part of their constituents through dissolution

<sup>3</sup> (dedicated to Charnock, founder of Calcutta): Magmatic rock with a granite or gneissic granite facies. The origin of charnockites is subject to discussions, for some people they are magmatic (hypersthene granites), for others they stem from catazonal metamorphism with the same paragenesis as granulites (from which they differ in structure).

Diagram 1

Main padparadscha extraction areas



F. Notari, d'après C.B. Dissanayake & M.S. Rupasinghe

## 5.2.0 - Distinction between the Origins Sri Lanka / East Africa

The great quantity of sapphires from East Africa (Umba Valley) put on the market under the name "Padparadscha" or "African Padparadscha" justifies the existence of this table.

Less numerous, but also incorrectly called padparadschas, orange sapphires from Malawi have similar features to sapphires from Umba.

Table 2

Criteria	Sri Lanka	Umba Valley
Colour	Pastel orangey pink (see 2,2), often with an extension towards pink.	Orangey pink, always with a brownish under-hue, which is inversely proportional to the intensity of red and can disappear completely in rubies. Tendency to extend towards brownish orange or orangey brownish red-pink.
Chemistry	See 2.3.1	Globally much higher Fe <sub>2</sub> O <sub>3</sub> content. In spectroscopy, a considerable absorption due to a pair transition Fe <sup>3+</sup> /Fe <sup>3+</sup> appears at 450 [nm] (see spectra chapter 2 and diagram 5 below)
Inclusions	Depending on the habit, usual inclusions of Sri-Lankan corundum. (see 4.1) Very few polysynthetic twin planes, the rare exceptions are generally turned only to one of the three directions. Blue colour zonings oriented along the bipyramid's sides (11 $\bar{2}$ 1) (at 20,1° of axis "c") (see diagram 4).	The high iron content (diagram 5) is often revealed through the presence of groups of lepidocrocite crystals ( $\gamma$ -Fe <sup>3+</sup> O(OH) in thin elongated hexagonal plaques, orange in diascopy (photographs 4"). Presence of polycrystalline böhmite in sticks (AlOOH) positioned according to the twin planes intersections (photographs 5"). During heating, fractures develop from these sticks. (These two inclusions are unknown in padparadschas). Generally few rutile bristles, or of very small granulometry. Frequent corroded zircon crystals, often in groups. Polysynthetic twin planes turned to two, sometimes three directions of the rhombohedron r, r' et r'' (10 $\bar{1}$ 1) very frequent (photographs 7" and diagram 4 below). Blue colour zonings never observed by the author in specimens of similar colour of Padparadschas.
Aspect of rough stones	Most rough stones come from secondary deposits and are "eroded / tumbled". When they are full of their shape, they are hexagonal bipyramids.	Trade rough stones generally have no visible crystalline habit (they are broken). Crystals are usually prismatic tabular, with the rhombohedron's twin planes lines well visible on the basal pinacoid's sides. A less coloured core, "prismatic" hexagonal, parallel to axis "c", is often visible.
Coloured centres	Coloured centres participating in the yellow touch of the native habit.	No coloured centres participating in the yellow touch.
Refractive index	( $\epsilon$ ) generally comprised between 1.760 and 1.761 and ( $\omega$ ) between 1.768 and 1.769 (almost 90% at 1.769) (diagram 2 <sup>bis</sup> ). In most cases birefringence is of 0.008. (diagram 2 <sup>ter</sup> ).	( $\epsilon$ ) from 1.760 to 1.768, (the majority is situated between 1.764 and 1.766), and ( $\omega$ ) from 1.768 to 1.769. (see diagram 2 <sup>bis</sup> ). In most cases birefringence is of 0.009. (diagram 2 <sup>ter</sup> ).
Fluorescence	Native habit: 365nm: marked to medium, apricot, pinkish apricot. 253.7nm: medium to slight, ochrous apricot, pinkish apricot. Other habits: 365nm: marked to medium, red, pinkish red, orangey red. 253.7nm: medium to slight, same colours.	365nm: very slightly red, sometimes inert. 253.7nm: inert, exceptionally very slightly red.

## Refractive Index and Birefringence:

These measurements have been taken by two operators, with a ROS Gem Optic refractometer fitted out with a polarizer, and monochromatic sodium lighting. Three series of sapphires have been considered: one series of fifteen padparadschas, one series of thirteen sapphires from the Umba Valley, and one series of seven synthetic padparadschas of different origins. The gems had been chosen at random, before their measurements were taken.

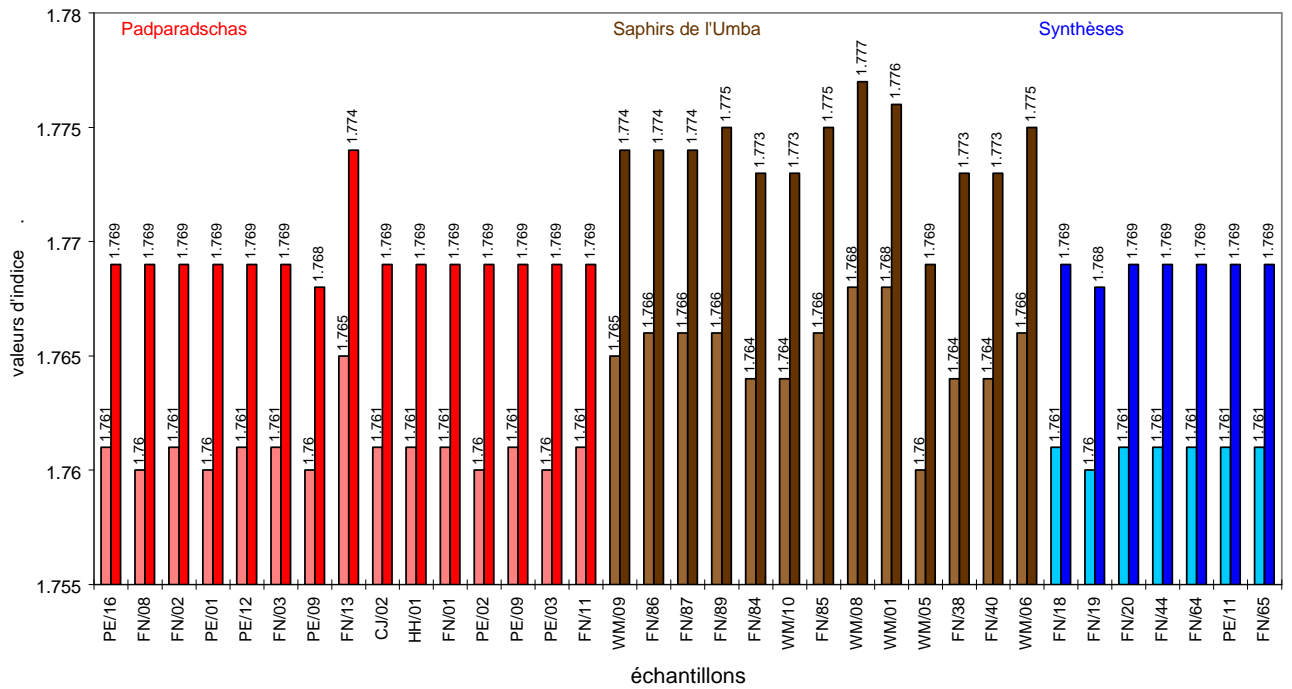
The refractive index is globally higher in sapphires from the Umba Valley than in padparadschas. It will be noticed that the index of padparadschas' ordinary ray is very constant (1.769), only two specimens out of fifteen vary (one below (1.768), one above (1.774)), whereas in Umba sapphires, the ordinary index is variable and presents six different values for a number of samples inferior to padparadschas'.

On average the birefringence of padparadschas tends to be lower than Umba's sapphires, but this feature is not determining.

Sample	$\epsilon$	$\omega$	Birefringence	Material
PE/16	1.761	1.769	0.008	Native Padparadscha
FN/08	1.760	1.769	0.009	Native Padparadscha
FN/02	1.761	1.769	0.008	Native Padparadscha
PE/01	1.760	1.769	0.008	Native Padparadscha
PE/12	1.761	1.769	0.008	Antique Colour Padparadscha
FN/03	1.761	1.769	0.008	Antique Colour Padparadscha
PE/09	1.760	1.768	0.008	Native Padparadscha
FN/13	1.765	1.774	0.009	Native Padparadscha
CJ/02	1.761	1.769	0.008	Native Padparadscha
HH/01	1.761	1.769	0.008	Antique Colour Padparadscha
FN/01	1.761	1.769	0.008	Native Padparadscha
PE/02	1.760	1.769	0.009	Antique Colour Padparadscha
PE/09	1.761	1.769	0.008	Irradiated decoloured Padparadscha
PE/03	1.760	1.769	0.009	Irradiated orange Padparadscha
FN/11	1.761	1.769	0.009	Induced Padparadscha (high-temperature heating)
WM/09	1.765	1.774	0.009	Orange-brown Umba Sapphire
FN/86	1.766	1.774	0.008	Strong brownish orangey red Umba Sapphire
FN/87	1.766	1.774	0.008	Strong brownish orangey red Umba Sapphire
FN/89	1.766	1.775	0.009	Strong brownish orangey red Umba Sapphire
FN/84	1.764	1.773	0.009	Strong pinkish red Umba Sapphire, slightly orangey
WM/10	1.764	1.773	0.009	Brownish orangey red Umba Sapphire
FN/85	1.766	1.775	0.009	Strong purplish red Umba Sapphire
WM/08	1.768	1.777	0.009	Strong orangey pink Umba Sapphire
WM/01	1.768	1.776	0.008	Pinkish orange Umba Sapphire, slightly brownish
WM/05	1.760	1.769	0.008	Medium orangey pink Umba Sapphire
FN/38	1.764	1.773	0.009	Light pink Umba Sapphire, with a light brown underhue
FN/40	1.764	1.773	0.009	Brownish orangey pink Umba Sapphire
WM/06	1.766	1.775	0.009	Orangey pink Umba Sapphire, very slightly brownish
FN/18	1.761	1.769	0.008	Orangey pink Chatam synthetic
FN/19	1.760	1.768	0.008	Orange Inamori synthetic, 1990
FN/20	1.761	1.769	0.008	Orange Kimberley synthetic
FN/44	1.761	1.769	0.008	Orange Inamori synthetic, 1996
FN/64	1.761	1.769	0.008	Brownish orange Czochralski synthetic
PE/11	1.761	1.769	0.008	Orangey pink Verneuil synthetic
FN/65	1.761	1.769	0.008	Orange Verneuil synthetic

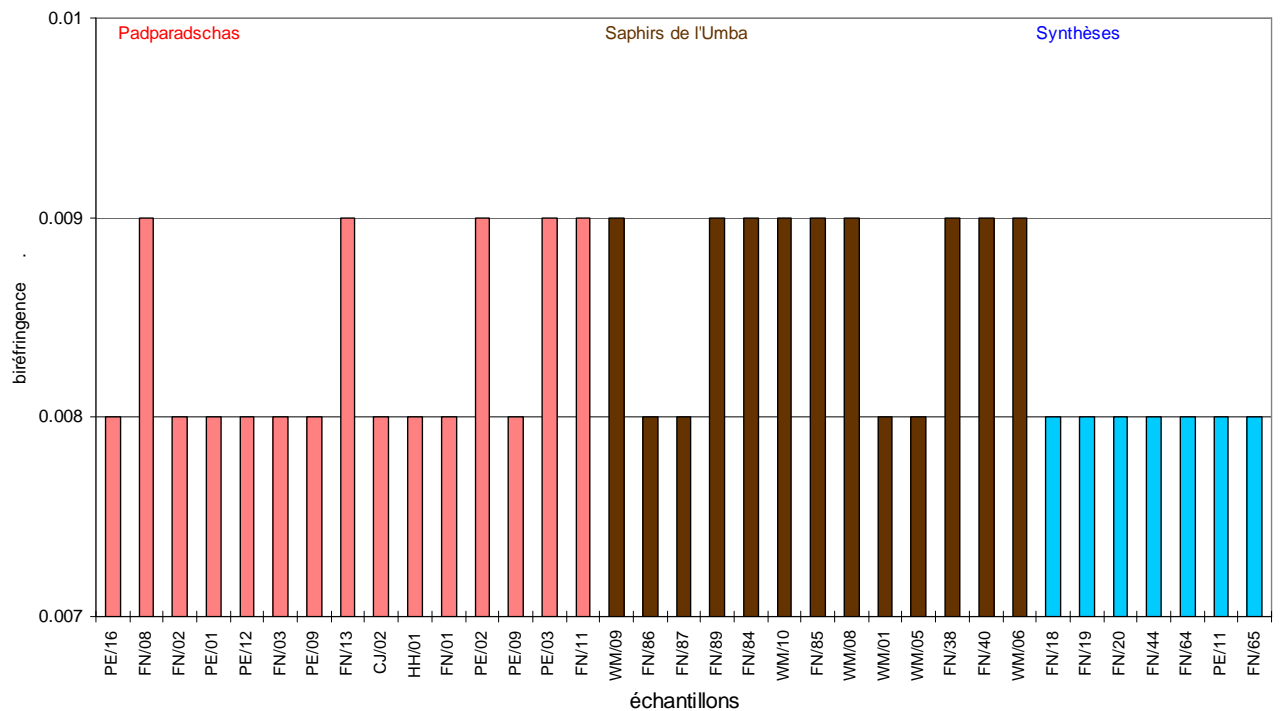
## Diagram 2<sup>bis</sup>

Indices de réfraction comparés entre trois populations de saphirs:  
Padparadschas: de PE/16 à FN/11; Saphirs de l'Umba: de WM/09 à WM/06; Synthétiques variés: de FN/18 à FN/65



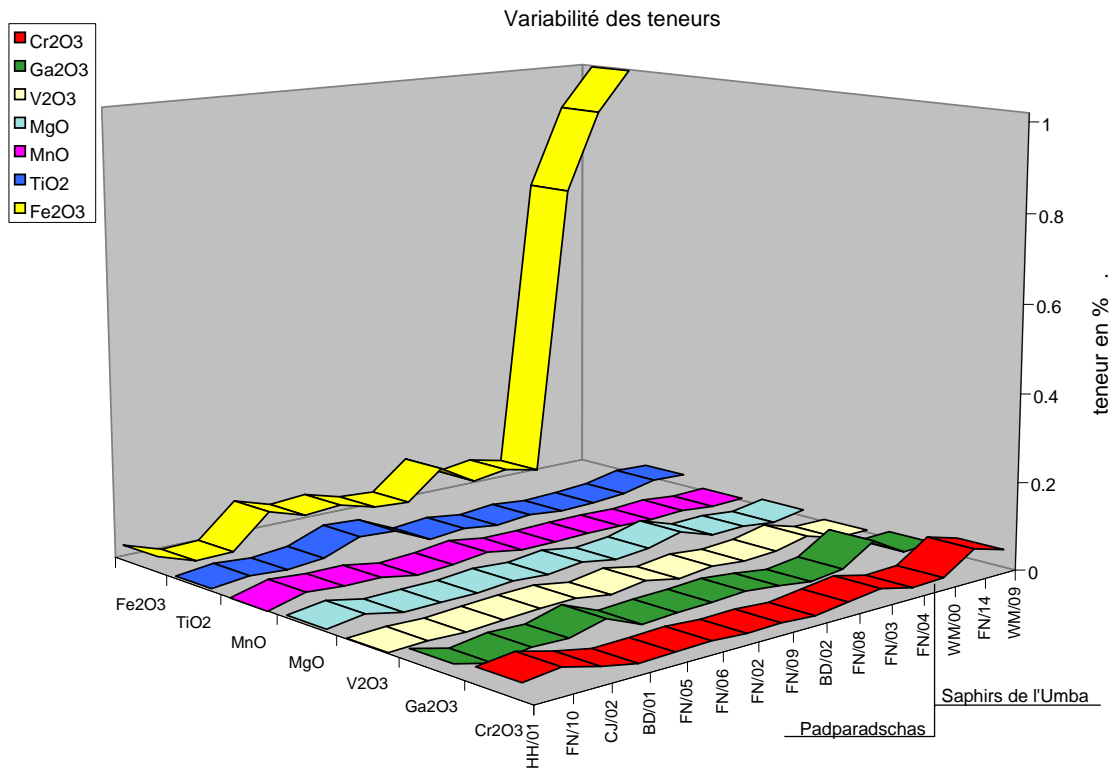
## Diagram 2<sup>ter</sup>

Biréfringences comparées entre trois populations de saphirs  
Padparadschas: de PE/16 à FN/11; Saphirs de l'Umba: de WM/09 à WM/06; Synthétiques variés: de FN/18 à FN/65

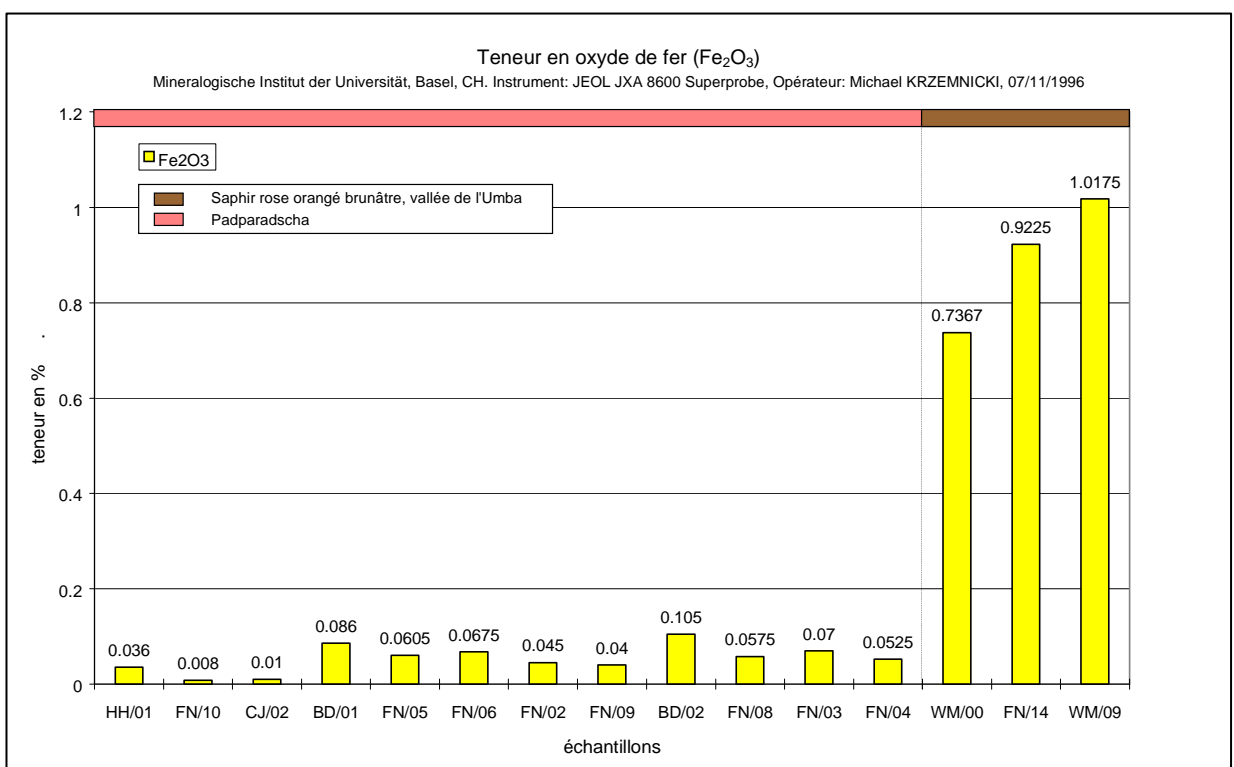


## Iron Content:

In sapphires from the Umba Valley, the iron content can be up to ten times superior to padparadschas'. It can be seen on this graph that there is no relation between the values of the iron contents and those of the other elements considered.



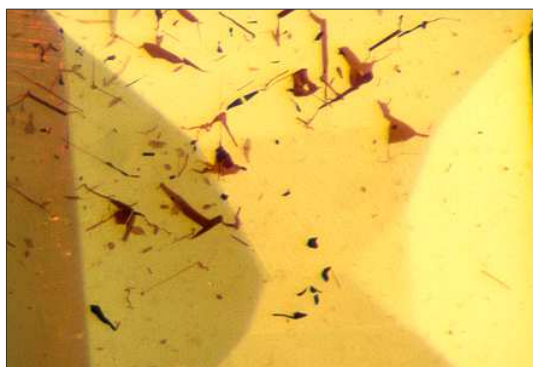
Graph 2  
Histogram 5



The high iron content found in Umba sapphires explains the frequent presence of "lepidocrocite" inclusions ( $\gamma\text{-Fe}^{3+}\text{O(OH)}$ ), which are never found in padparadschas.

Photograph 4

Lepidocrocite crystals, Umba sapphire



Photograph 4<sup>bis</sup>

Lepidocrocite crystals, Umba sapphire

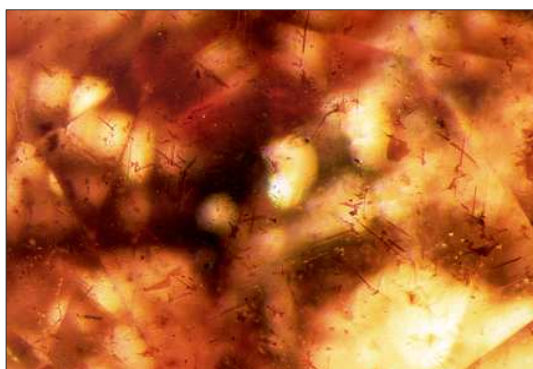


Diagram 6

Published chemical analyses of trace elements in Tanzanian corundums, oxides, in % of weight.

Sample	Mn	Ti	Fe	Cr	V
pale brown <sup>a</sup>	0.51	0.0046	<0.001	<0.0001	<0.001
pale brown <sup>a</sup>	0.08	0.0360	<0.001	<0.0001	<0.001
yellow <sup>a</sup>	0.09	0.0050	1.80	0.0006	0.009
dark pink <sup>a</sup>	0.33	0.0060	0.250	0.0170	0.008
dark pink <sup>a</sup>	0.19	0.0110	0.060	0.0090	0.006
dark pink <sup>a</sup>	0.02	0.0030	0.190	0.0006	0.030
dark pink <sup>a</sup>	0.12	0.0070	0.050	0.0004	0.011
dark pink <sup>a</sup>	0.11	0.0080	0.270	0.0070	0.008
dark pink <sup>a</sup>	0.15	0.0070	0.530	0.0011	0.009
reddish brown <sup>b</sup>	--	n.d.	1.10	0.12	n.d.
reddish brown <sup>b</sup>	--	0.36	1.10	0.13	n.d.
reddish brown <sup>b</sup>	--	0.03	1.53	0.09	n.d.
reddish brown <sup>b</sup>	--	0.03	1.62	n.d.	n.d.
red	--	0.006	0.05	0.03	n.d.
purple <sup>c</sup>	--	0.009	0.1	0.04	0.002
bluish <sup>c</sup>	--	0.006	0.6	0.014	n.d.
yellow-green <sup>c</sup>	--	0.006	0.5	0.007	n.d.
greenish <sup>c</sup>	--	0.009	0.4	0.002	n.d.

<sup>a</sup> Garcia-Gimenez R. & Leguey S., 1990, (atomic absorption spectroscopy).

<sup>b</sup> Gunawardene Mahinda, 1984, (microprobe, Basel).

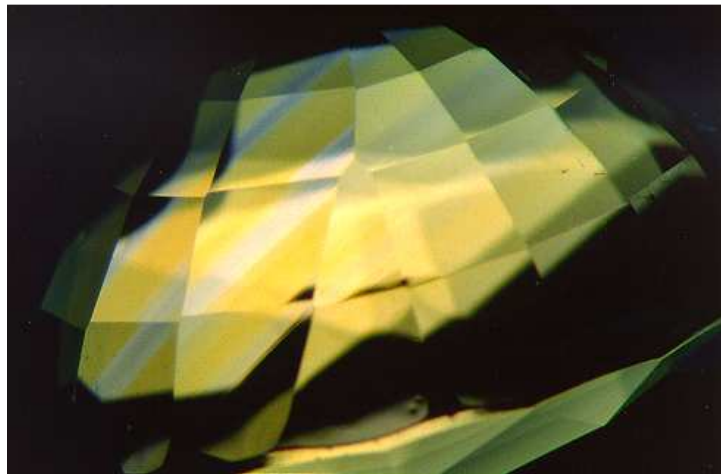
<sup>c</sup> Harder H., 1969, (Fluorescence X).

### 5.2.1 Colour Zonings: Umba / Sri Lanka

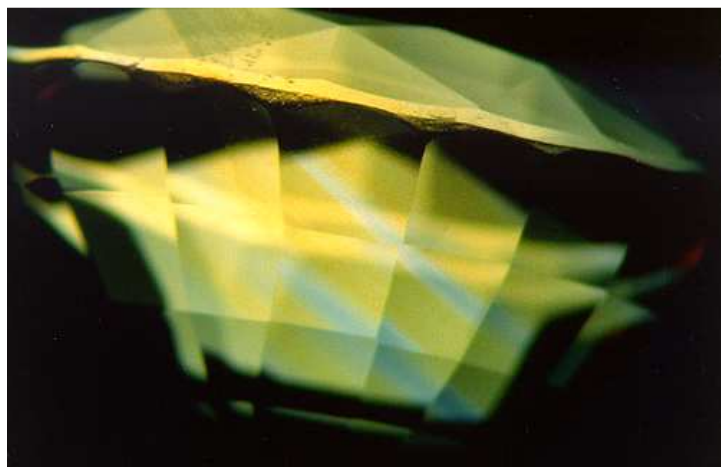
The crystalline habit (*sensu stricto*) of sapphires from the Umba Valley is prismatic hexagonal or tabular hexagonal. The rare colour zonings that can be found in them (colour zonings sometimes including blue or colour zonings composed of xenospecific inclusions of small granulometry) are positioned parallel to the prism's sides ( $11\bar{2}0$ ). During microscopic examination of cut gems, the angle of these colour zonings in relation to axis "c" or to polysynthetic twin planes is revealing. They will be parallel to axis "c", and form an angle of  $32,4^\circ$  with the twin planes. There are no colour zonings parallel to the basal pinacoid (0001) as in Madagascar (see photograph 8).

#### Blue colour zonings in padparadscha

Photograph 1



Photograph 2





## 5.2.2 Nature of the Blue Colour Zonings in Padparadschas:

The blue colour zonings of padparadschas are always positioned at  $20,1^\circ$  of axis "c" or  $12,3^\circ$  of the eventual twin planes. Indeed, padparadschas only come from one type of crystal which is a hexagonal bipyramid with its sides orientated in  $(11\bar{2}1)$  when completed, whereas one can find as many crystals completed in bipyramids with their sides orientated in  $(11\bar{2}1)$  as in  $(22\bar{4}1)$  in Sri Lanka. Nevertheless we have noticed that in some samples colour zonings showed both orientations in relation to axis "c". In these cases it appears that the crystal's "core" is formed of a bipyramid with its sides in  $(22\bar{4}1)$ , and that the crystal becomes a bipyramid with its sides orientated in  $(11\bar{2}1)$  simultaneously with the appearance of blue colour zonings. The stage where the sides are orientated in  $(22\bar{4}1)$  sometimes shows an alternation of numerous and "closely woven" very thin pink and yellow zonings that the stage in  $(11\bar{2}1)$  does not possess. This state of the colour zonings either represents rapid alternations in the supply of chromogenic components (Fe, Cr) or alternations in the crystal's capacity to fix such or such element, because of the crystal's own capacities or because of variations in the environment conditions. This change of nature of the chromogenic elements, which corresponds to the blue colour zonings (Cr  $\rightarrow$  Ti), does not seem to justify such a modification of the crystalline structure.

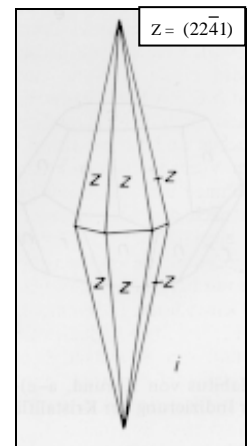
Two hypotheses remain:

- This change of crystalline habit may correspond to a modification of the global or partial environment conditions (pressure, temperature, growth speed, etc.), which would be directly (cause or effect) or indirectly linked to the Ti supply. These modifications may have a direct influence on the crystalline growth.
- There may exist, for a given environment, a "critical" size from which the crystal would change habit. The stage  $(11\bar{2}1)$  would then correspond to a "seed" state. This hypothesis could be supported by the fact that we do not remember seeing any big bipyramidal crystals with sides orientated in  $(22\bar{4}1)$  in Sri Lanka. On the contrary big crystals always had faces in  $(11\bar{2}1)$ .

The FN/04 sample is the most representative of this change of habit. It was technically impossible to take a picture of the orientation in  $(11\bar{2}1)$  because the "core" colour zonings, which were of a very light saturation, could not be seen on the film. The copy is kept in the author's archives.

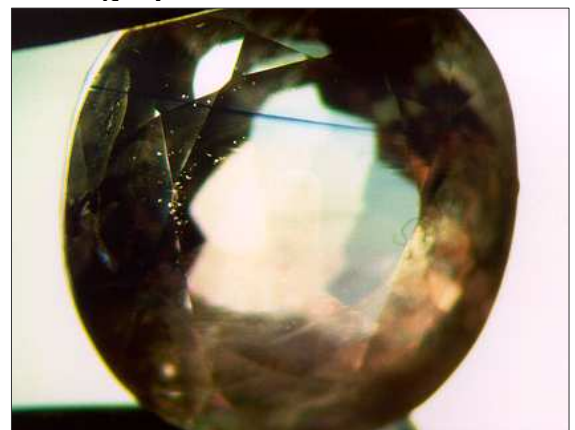
These differences of orientations have been revealed, thank to a Wild M9 (Wild = Leica today) binocular, light source (100[w]) Nossigem with a Sortoscope SC-W-200 base and a SC-P-70 diffusing plate. Wild polarizer on the microscope's body and Nossigem polarizer on the base. Gems placed in vertical immersion, in isopropylene.

Diagram 3



D'après K. Schmetzer

Photograph 18



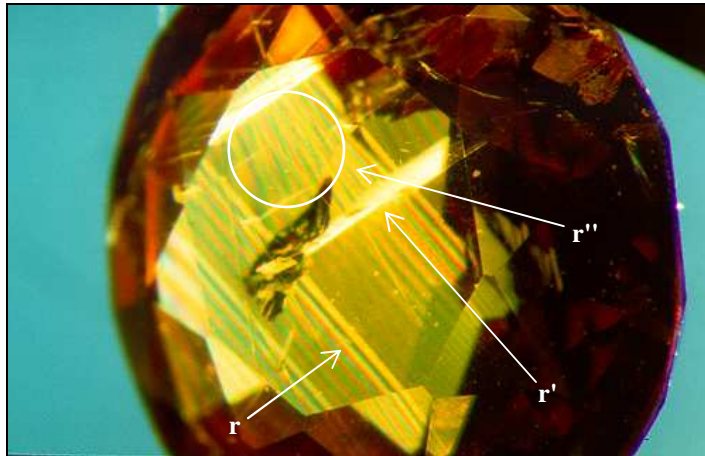
Cliché F. Notari



Polycrystalline Twin Planes:

Photograph 6<sup>bis</sup>

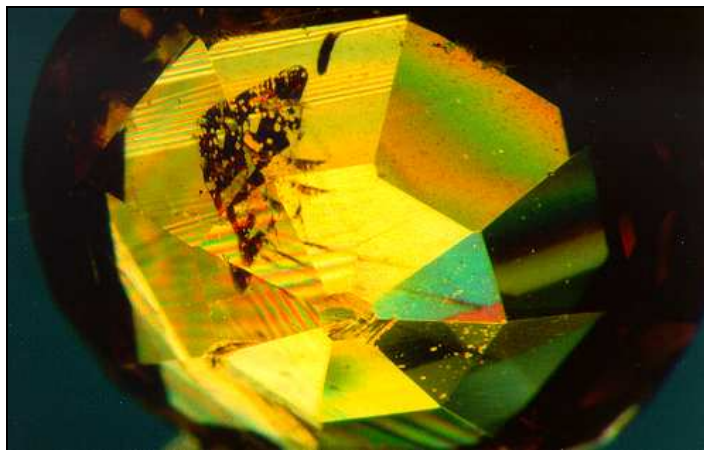
Polysynthetic twins planes, Umba sapphire



Clichés F. Notari

Photograph 6<sup>ter</sup>

Polysynthetic twins planes, Umba sapphire



Clichés F. Notari

Photograph 6<sup>quart</sup>

Polysynthetic twins planes, Umba ruby

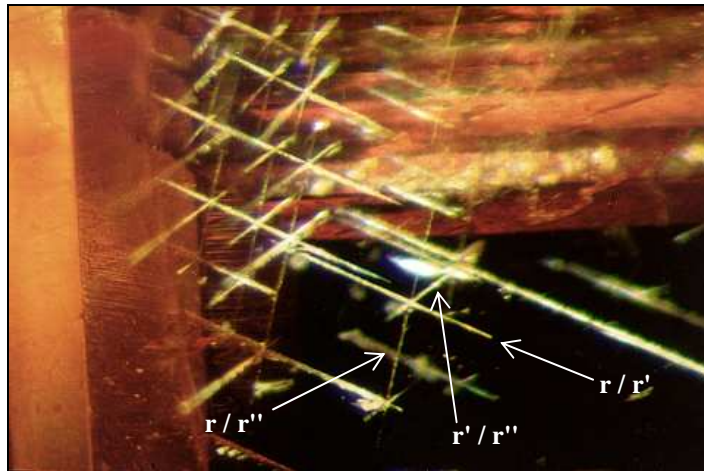


Clichés F. Notari

Böhmite:

Photograph 5<sup>bis</sup>

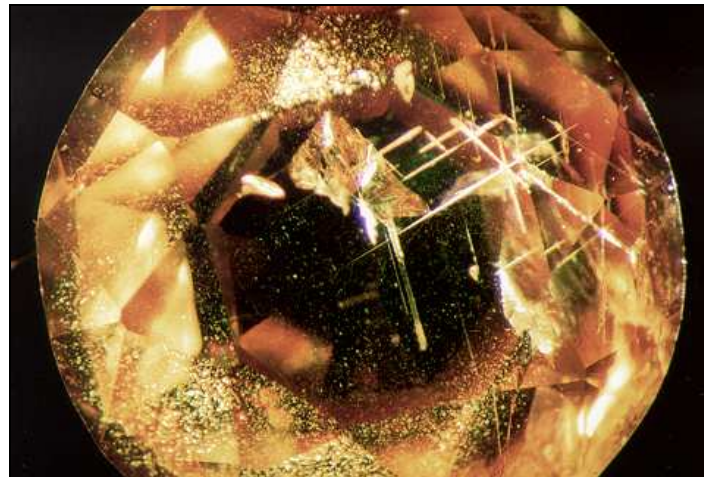
Polycrystalline böhmite, Umba sapphire



Clichés F. Notari

Photograph 5

Polycrystalline böhmite, Umba sapphire



Clichés F. Notari

Photograph 5<sup>ter</sup>

Polycrystalline böhmite, Umba sapphire



Clichés F. Notari

Blue Colour

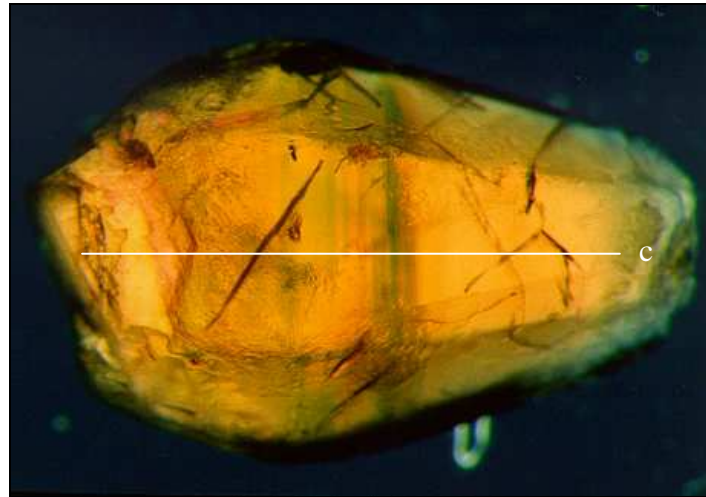
Zoning, variant:



In Madagascar there are sapphires with a colour close to padparadschas' and showing a blue colour zoning. However, in these sapphires, the colour zoning is parallel to the basal pinacoid, i.e. perpendicular to axis "c". This orientation is unknown in padparadschas.

Photograph 8

Madagascar sapphire showing blue colour zonings parallel to the basal pinacoid.



Clichés F. Notari

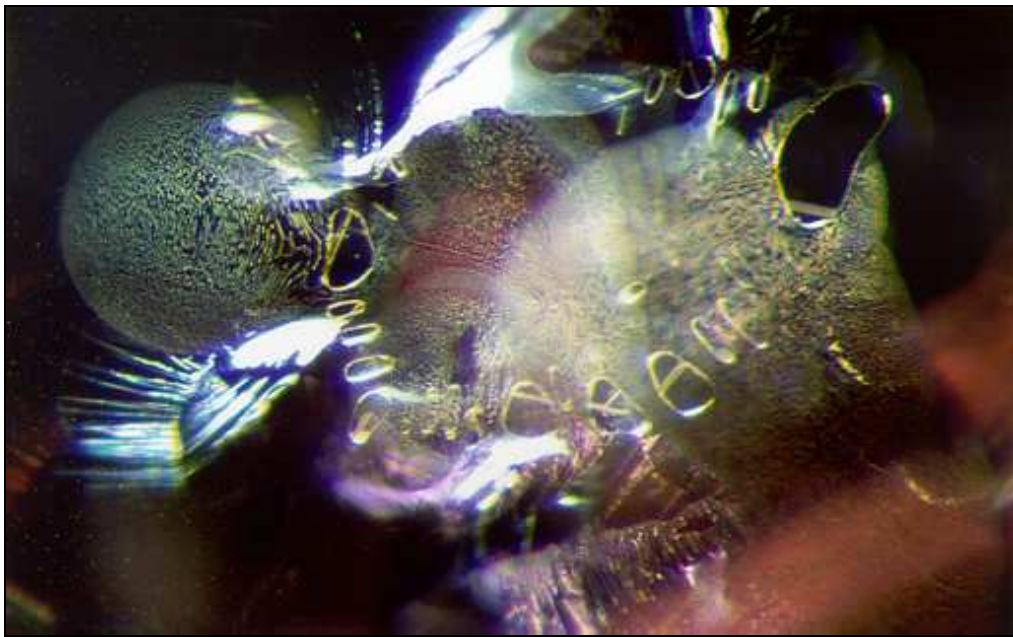
# 6. Inclusions

## 6.0 – General Points

The inclusions found in padparadschas are the same as in all Sri-Lankan corundum. Sri Lanka probably presents one of the greatest varieties of corundum inclusions among the deposits known.

Following the usual gemmological approach, they can be classified into three categories: protogenetic, syngenetic and epigenetic. This classification, which is very useful in some cases, must be relativized. Indeed, individual cases can be observed in petrogenesis mechanisms, which quite often make that such or such inclusion does not belong to the category to which it is supposed to belong.

### Photograph 1



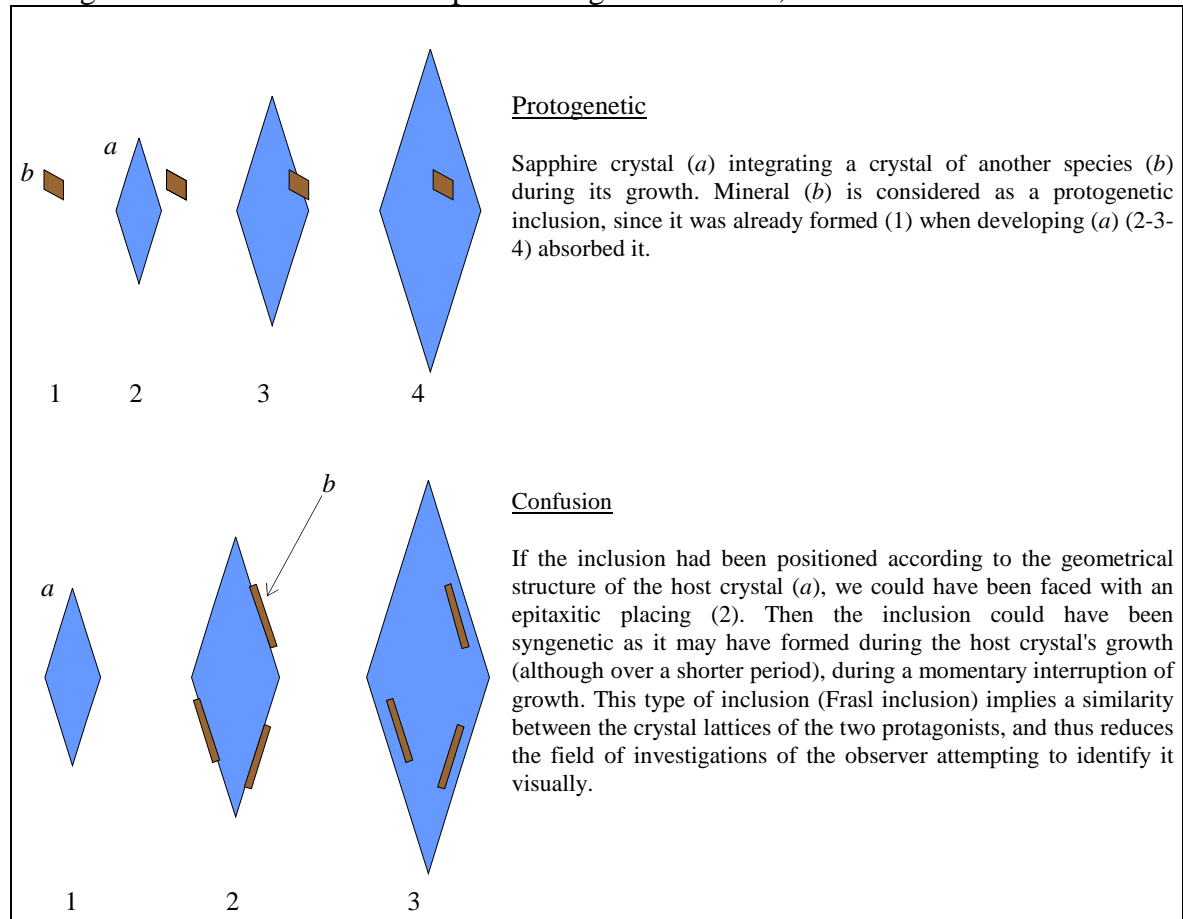
Healing crystallizations, recent fractures, gaps containing mother solution and a non-identified mineral in beige sticks.

## 6.1 - Protogenetic Inclusions

Solid inclusions which were formed before the host gem and were imprisoned in it during its growth.

Diagram 1

Protogenetic inclusion in metamorphic or magmatic context, confusions:



F. Notari, 1996

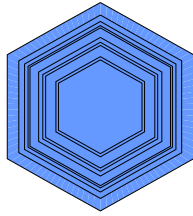
## 6.2 – Syngenetic Inclusions:

Inclusions which were formed at the same time as the host gem: all remarkable characteristics due to growth effects. Fluid and gaseous inclusions also belong to this category and are divided into two sub-categories:

- Primary inclusions, contained in negative crystals, are liquids and gas imprisoned during the gem's formation.
- Secondary inclusions are fractures filled with growth solution and partly healed. According to some authors, they are comparable to epigenetic inclusions.

## Diagram 2

### Syngenetic Inclusion



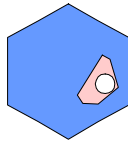
Colour zonings positioned according to the bipyramids' sides, in  $(11\bar{2}1)$ ,  $(22\bar{4}1)$  and  $(22\bar{4}3)$ , (for the crystalline habits sensu stricto found in Sri Lanka). These colour zonings are due to a concentration of chromogenic agents or xenospecific inclusions, of fine granulometry.

F. Notari, 1996

## 6.2.1 – Primary Syngenetic Inclusions

### Diagram 2<sup>bis</sup>

#### Primary Syngenetic Inclusions:

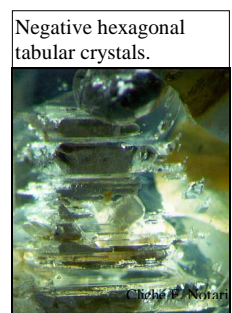


Negative crystal containing CO<sub>2</sub> in liquid (pink) and gaseous (white) phase.

F. Notari, 1996

### Example: diphase CO<sub>2</sub>:

Diphase liquid/gaseous CO<sub>2</sub> inclusions are frequently found in padparadschas, as in all Sri-Lankan corundums. They can be found in negative crystals of two types: hexagonal tabular and in hexagonal bipyramids. They can be used during microscopic examination to give a verdict on the possibility of a thermal treatment, as theory has it that the presence of such a diphase is a reliable indication proving the absence of heating (see 3.1).



CO<sub>2</sub> is a gas with a vigorous behaviour. Its critical thermal points are - 56,6°C for the change from the liquid to the solid state, and +31,1°C for the change from the gaseous to the liquid state. Its coefficient of expansion is about thirty times superior to that of water. This last point is particularly important for gemmologists. Indeed, the observation of two-phases with powerful lightings entails making sure that the gem is not overheated so that the two-phases does not disappear under the effect of the liquid phase's expansion. Thus it is advisable to rapidly carry out the observations. By the way it should be noted that Sri-Lankan summery thermal conditions are often sufficient to make CO<sub>2</sub> two-phases disappear.

Beside CO<sub>2</sub>, this negative crystal also contains a graphite crystal visible on the left, diaspore crystals, one or more sulphur crystals invisible on the pictures at the bottom and a rutile crystal in



thin stick. The nature of the fluid and solids was identified thank to Raman spectroscopy at the Swiss Gemmological Institute's laboratory in Basel (see Raman spectrum No 1).

Photograph 2

2-phase Inclusion



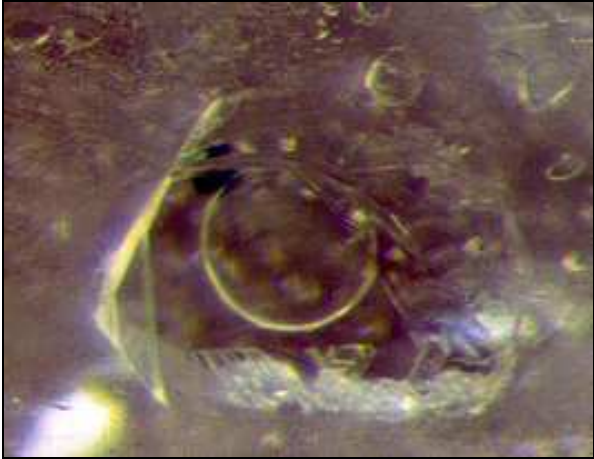
Cliché F. Notari

A vehement two-phases:

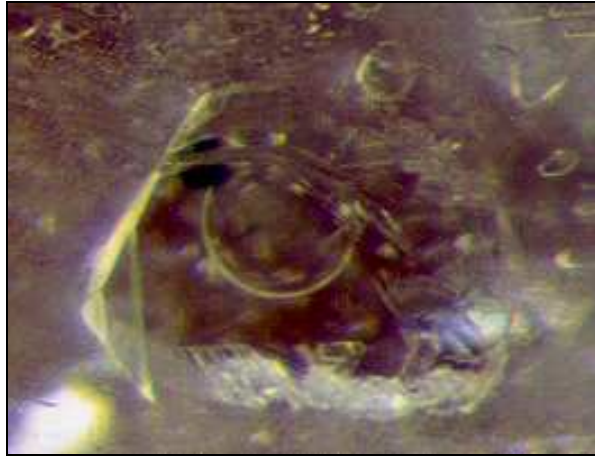
The following series of photographs illustrates the quick retraction of the two-phases of a CO<sup>2</sup> liquid/gaseous diphas, until it disappears completely. It is a negative crystal of hexagonal tabular type oriented in the basal plane.

Photographs 3

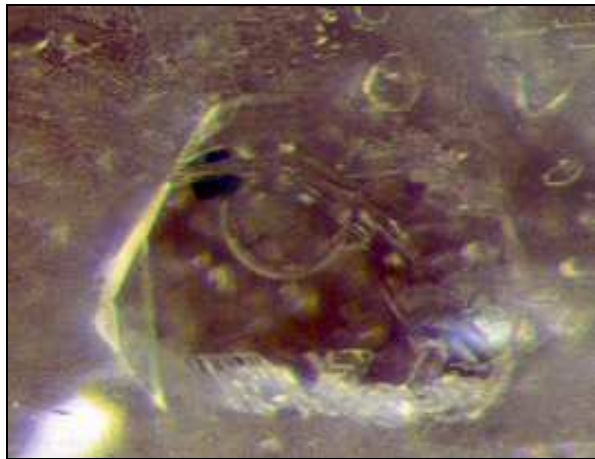
1



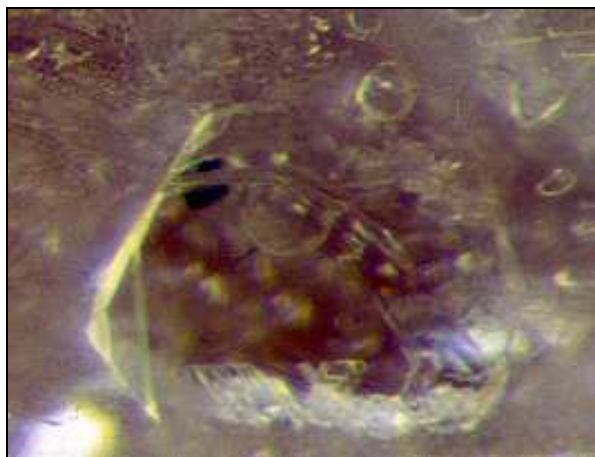
2



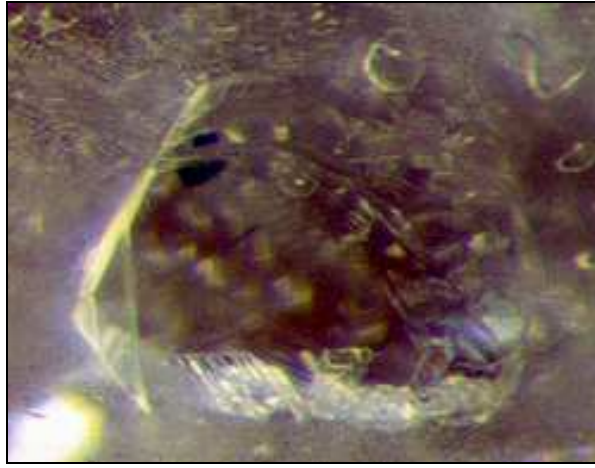
3



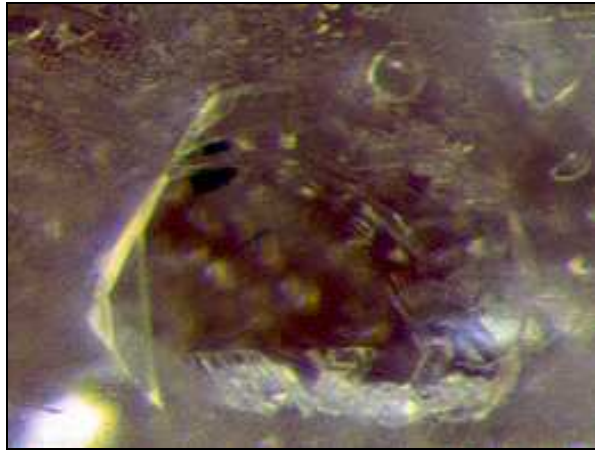
4



5



6



## 6.2.2 – Secondary Syngenetic Inclusions

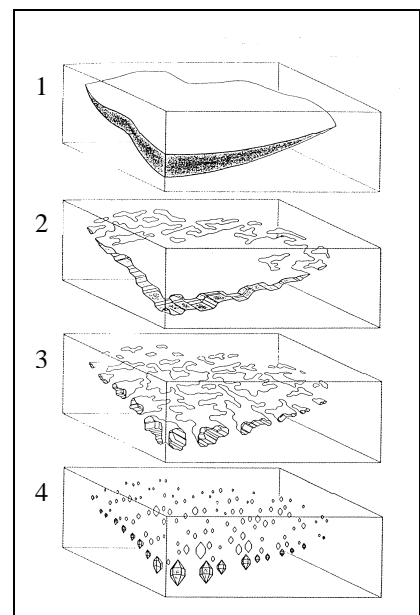
Diagram 3:

1 - A fissure in the crystal traps the mother-solution.

2 - Healing starts, thanks to the constituent materials provided by the mother-solution. In the fissure's narrowest areas, the process of reconstruction begins and creates lagoon or dendritic structures which have a tendency to form compartments.

3 - The fissure is clearly partitioned and imprisons the solution. A still shapeless canvas of gaps is outlined.

4 - Gaps finish filling in reproducing the host crystal's structure. Some will form negative (i.e.empty) crystals, others will form positive (i.e.full) crystals, according to the quantity of constituent materials provided by the mother-solution and to the dimension of the gaps to fill.



in J.-P. Chalain 1992, d'après Roedder, 1962

This type of inclusion (veil, butterfly wing) makes it possible to efficiently differentiate natural corundum from synthetic ones (anhydrous dissolution).

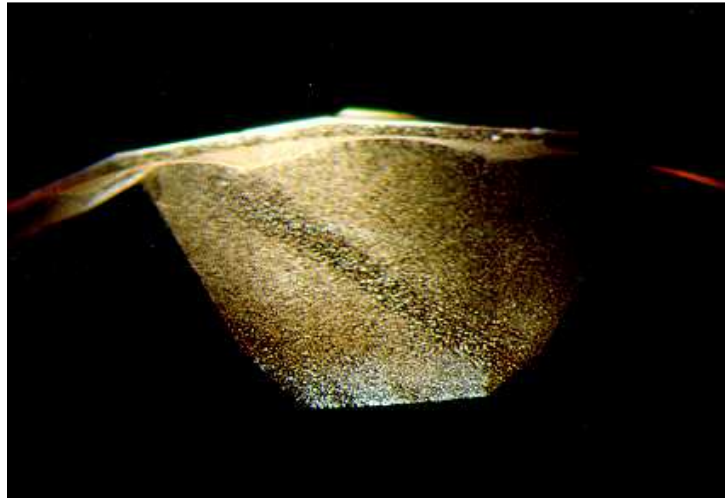
### Veils

The veils of Padparadschas and other sapphires are formed of a considerable number of crystalline gaps or negative crystals grouped together and forming plane or flexuous structures. Their dimension is variable, and ranges from a punctuation of elements sometimes measuring less than  $1^{/10}$  of a millimetre to elongated gaps that can be several millimetres long and are called "fingerprints" ("treillis" or "maillage" in French).

In the case of padparadschas, we have seen that these veils sometimes cross the plan of a blue colour zoning. It can then be observed (photograph 6) that at the intersection veil/blue colour zoning, the population of cavities forming the veil is almost reduced by half. The explanation is probably that in this area the chemical composition of the middle is more favourable to healing.

## Photograph 6

Less punctuated area of the veil, corresponding to the passage of the blue colour zoning



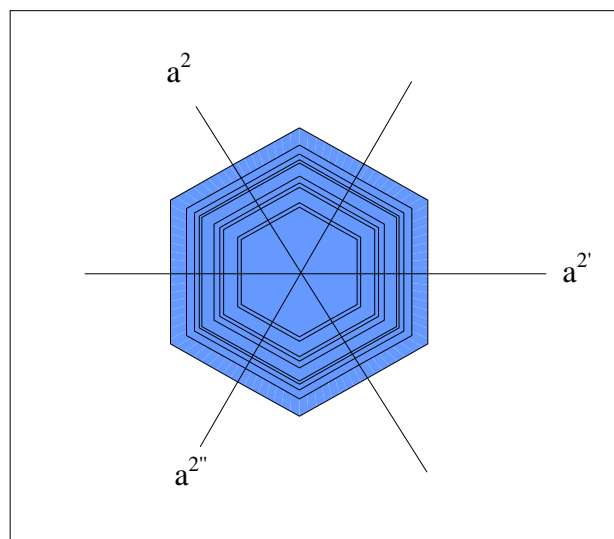
Working on the assumption that blue colour zonings can be found in many corundum, notably in rubies, this observation is interesting in the detection of treatments aiming at making the said colour zonings disappear. Indeed, if such a veil is observed, possessing a rectilinear band with a clearly diminished density of negative crystals, however without there being a visible blue colour zoning in the gem, it will be reasonable to think that the stone has been thermally treated.

## 6.3 - Epigenetic Inclusions

Inclusions that were formed after the host gem stopped growing.

They are several types of epigenetic inclusions. In corundum, the most remarkable example is rutile (and hematite with a different orientation). Through a mechanism of exsolution of the titanium contained in the gem, rutile crystallizes parallel to the sides of the prism (or of the bipyramid). Through an effect of light diffusion in the rutile capillaries (and only if the gem is cut in cabochon, axis "c" crossing its apex), a six-branched star will appear, whose three lines will be parallel to the three axes of order 2 represented:  $a^2$ ,  $a^{2'}$  et  $a^{2''}$ .

## Diagram 3'



## 6.4 - Xenospecific Inclusions

Xenospecific inclusions (from Greek. *xenos*, foreign; and low Latin *specificus*; from *species*, species: of another species to that of the host crystal) are good origin markers. They are closely linked to petrogenesis conditions, which considerably vary from a deposit to another. Their identification (species and morphologic characteristics) makes it possible to determine the origin of a large number of corundum. In the case of padparadscha, xenospecific inclusions enable us to clearly distinguish them from East African sapphires (see diagram 1 in 5.1.2).

### 6.4.1 – Survey of the Xenospecific Inclusions of Sri-Lankan Corundums

Diagram No 4

T.Themelis (1992)	R.Hughes (1990)	R.Newmann (1991)
Apatite	Apatite	Apatite
Calcite	Calcite	Calcite
Chalcopyrite		
Diaspore		
Feldspath		
Garnet	Garnet	Garnet
Hematite	Hematite	
Hornblende		
<i>Mica</i>	<i>Mica</i>	Mica
Biotite	Biotite	
Muscovite		
Phlogopite	Phlogopite	Calcite
Pyrite	Pyrite	Pyrite
Pyrrhotite	Pyrrhotite	
Rutile	Rutile	
Spinel	Spinel	Spinel
Tourmaline	Tourmaline	Tourmaline
Uraninite		
Zircon	Zircon	Zircon

We can add sulphur to this list of inclusions found in Sri Lanka as we identified it with a Raman microprobe while preparing this work. We can also confirm the existence of diaspore quoted by Ted Themelis (1992).

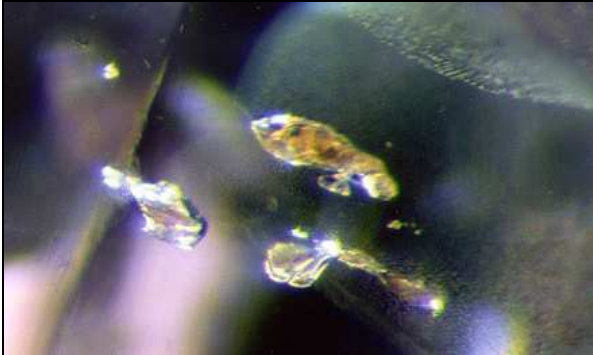
Some Xenospecific Inclusions:

Apatite



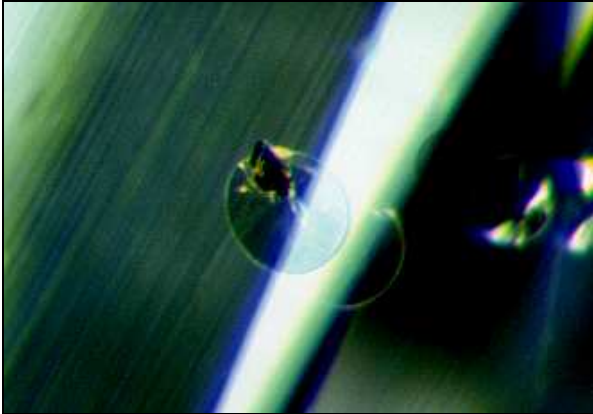
Cliché F. Notari

Micas



Cliché F. Notari

Graphite



Cliché F. Notari



## 6.5 - Identification of Inclusions with a Raman Microprobe

Identification of inclusions in padparadschas thanks to Raman laser spectrometry.

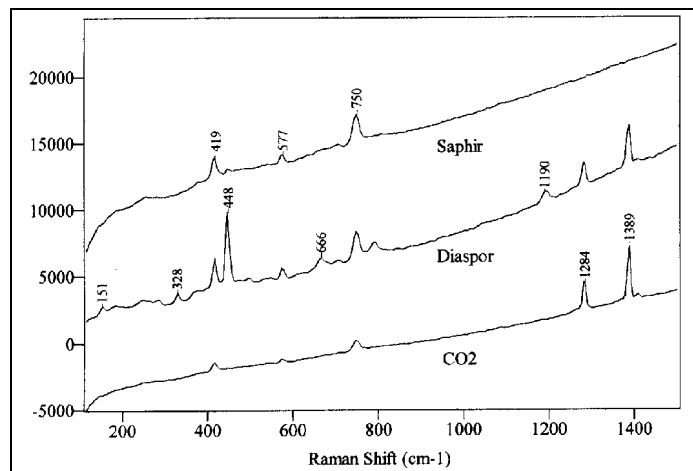


Sir Chandrasekhara Venkata Raman, Nobel Prize in Physics in 1930

The Raman microprobe reports the nature of materials by revealing the vibratory modes of their molecules' chemical bonds. It is an effective tool for the identification of inclusions, even capable of differentiating polymorphous substances such as Aragonite / Calcite.

Nevertheless, the identification of inclusions is not always easy, and spectra are not necessarily clear (see spectrum No 11). A lot of patience is needed to obtain a spectrum like the one opposite.

The signal of inclusions is sometimes hidden by the one of the host gem; an apparently unique inclusion can be double; their orientation has an influence on the position of peaks, etc.



The following spectra are not representative of the sum of inclusions found in padparadschas.

During this research we revealed the presence of sulphur in a padparadscha. This sulphur was identified in a negative crystal that also contained diaspor, rutile, a graphite crystal in hexagonal plaque and CO<sub>2</sub> in liquid and gaseous phases (see photograph 2).

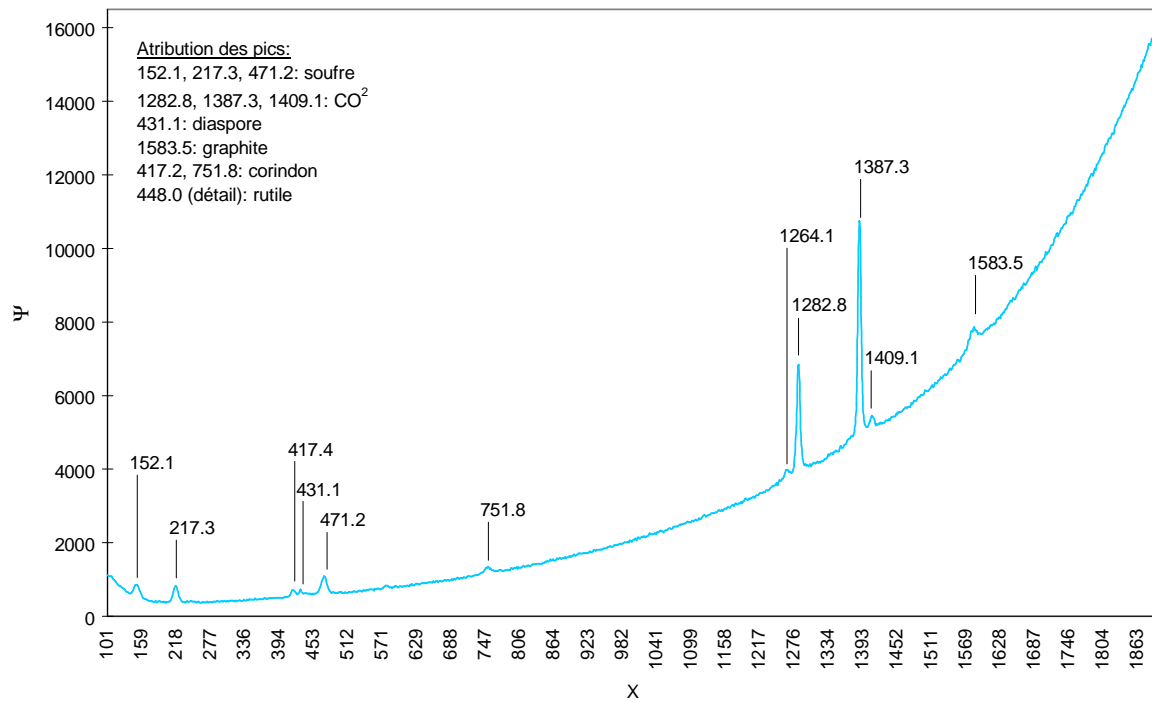


## Spectrum No 1

### 2-phase Inclusion in a Padparadscha

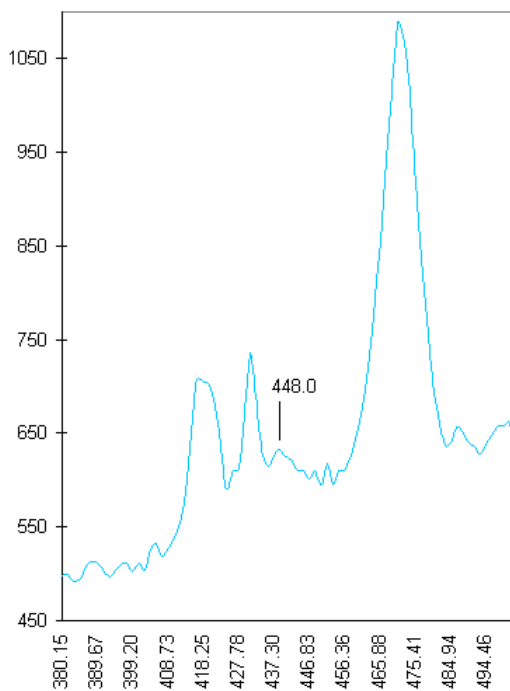
Spectre général d'une inclusion multiphase d'un padparadscha, Sri-lanka, réf. FN/01

File: FN/FN01\$1, Ex. time: 10.000 secs, Light source 19436  $\text{cm}^{-1}$ , 1'134 points, operator F. Notari, SSEF Basel, 15/11/96



## Spectrum No 2

### Rutile (Detail)

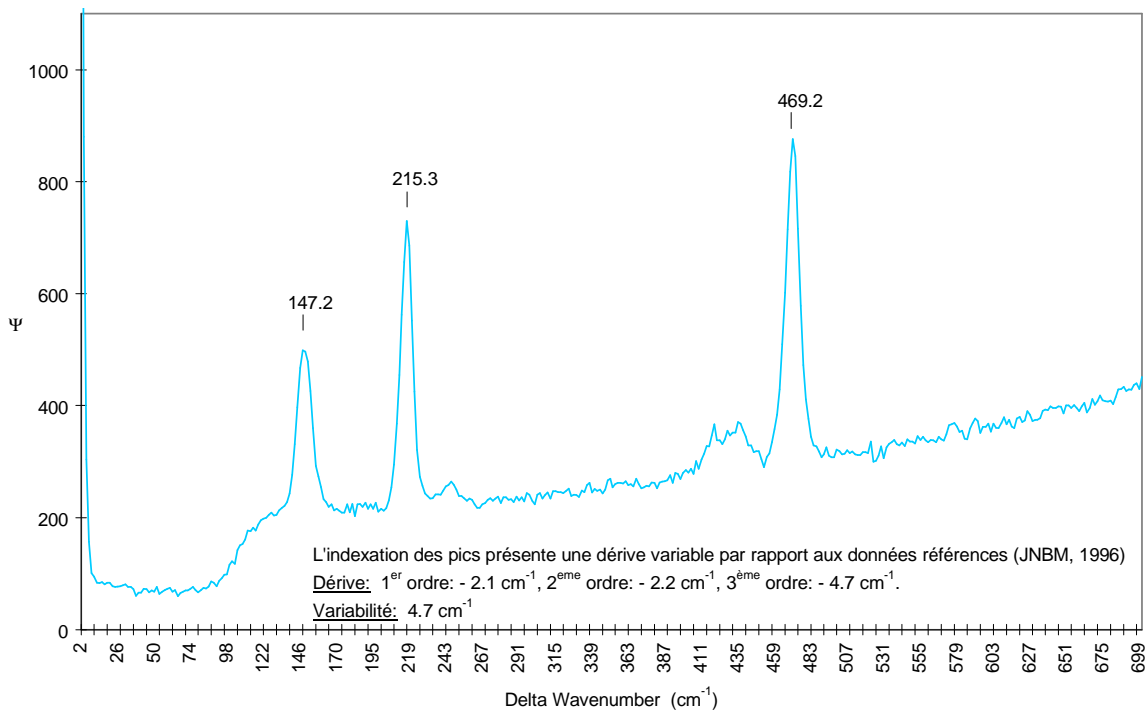


Detail of spectrum 1 showing the first order peak of rutile (+ 3  $\text{cm}^{-1}$ ) compared to the reference data, SSEF 1996). The rutile inclusion is very small and only discreetly shows itself on the general spectrum's scale. Second and third order peaks (237.0 et 603  $\text{cm}^{-1}$ ) are invisible.

### Spectrum No 3

### Sulphur

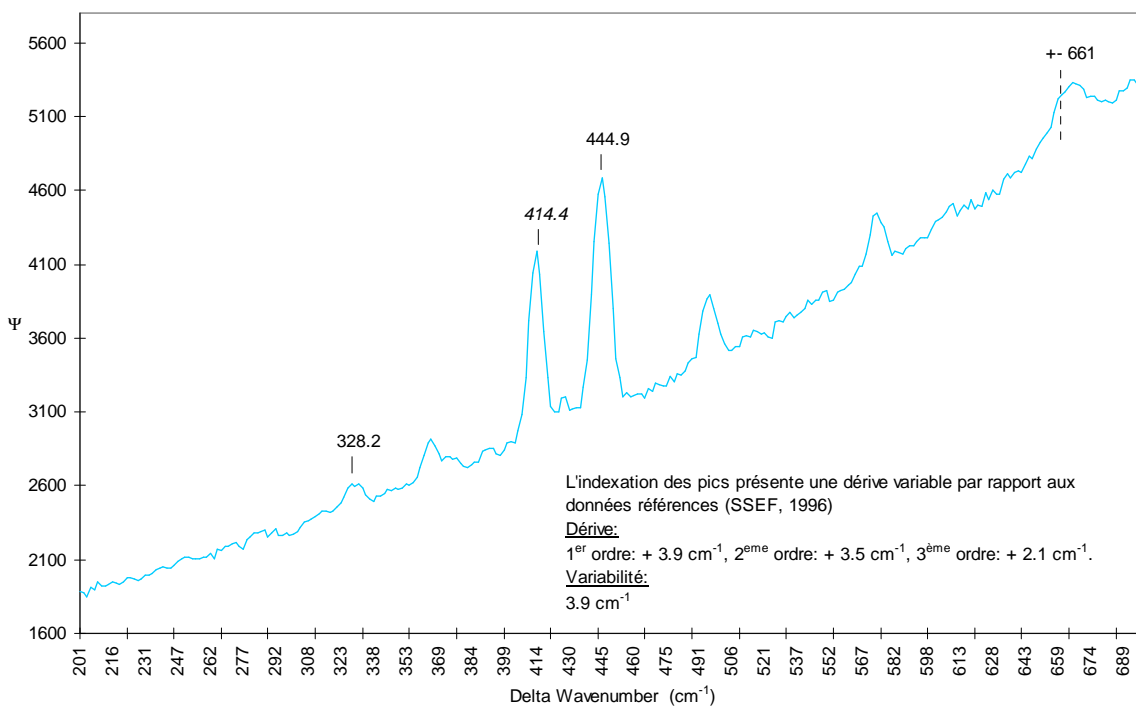
Inclusion de soufre dans un cristal négatif tabulaire d'un padparadscha brut, Sri-lanka, réf. FN/01  
File: NOTARI4, Ex. time: 79.768 secs, Light source 19436  $\text{cm}^{-1}$ , 408 points, operator F. Notari, SSEF Basel, 08/11/95



### Spectrum No 4

### Diaspore

Inclusion de diaspore dans un cristal négatif tabulaire d'un padparadscha brut, Sri-lanka, réf. FN/01  
File: NOTARI2, Ex. time: 319.104 secs, Light source 19436  $\text{cm}^{-1}$ , 295 points, operator F. Notari, SSEF Basel, 08/11/95

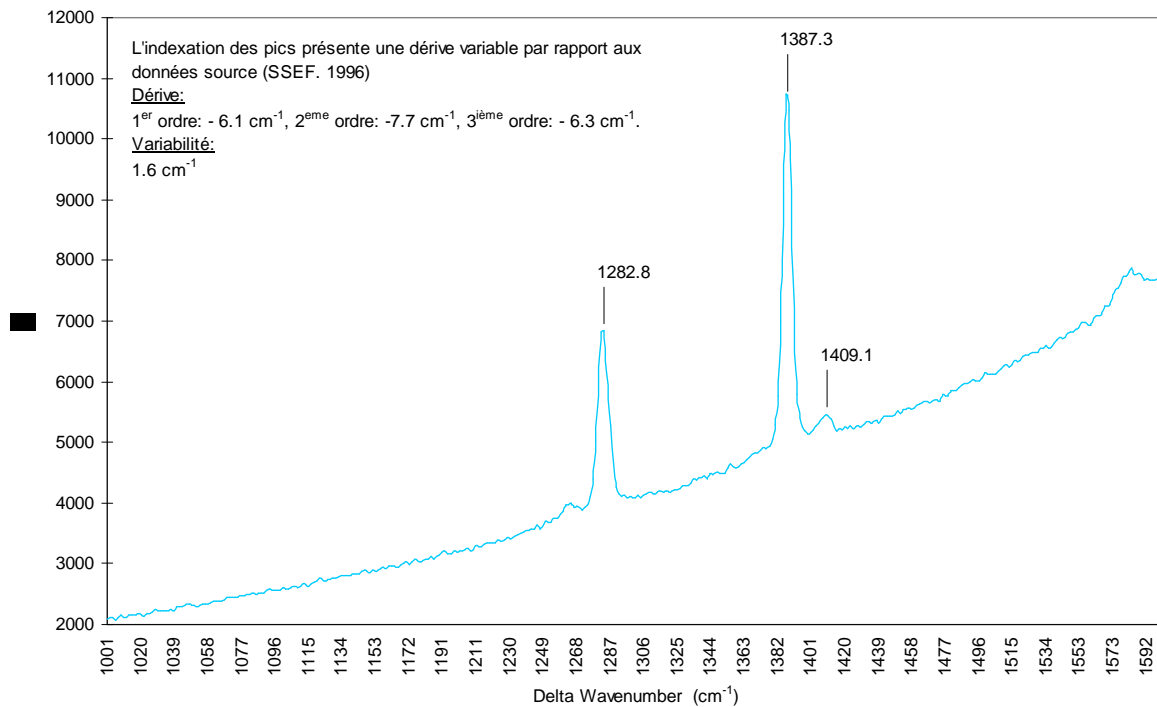


## Spectrum No 5

### Liquid CO<sub>2</sub>

Inclusion de CO<sub>2</sub> dans padparadscha, Sri-lanka, réf. FN/01

File: FN/FN01\$1, Ex. time: 10.000 secs, Light source 19436 cm<sup>-1</sup>, 378 points, operator F. Notari, SSEF Basel, 15/11/96

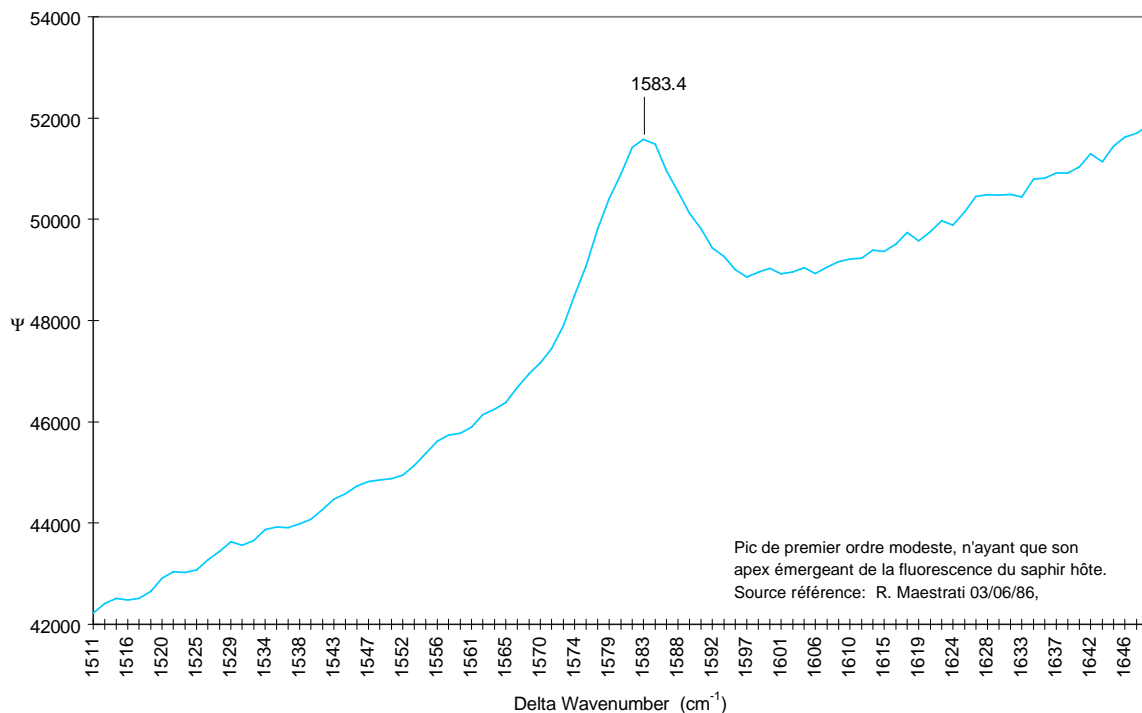


## Spectrum No 6

### Graphite

Inclusion de graphite (plaquette hexagonale) dans saphir incolore du Sri-lanka, réf. FN/57

File: ALO\_C\_SR2, Ex. time: 89.739 secs, Light source 19436 cm<sup>-1</sup>, 400 points, operator Lore Kiefert, SSEF Basel, 25/10/96

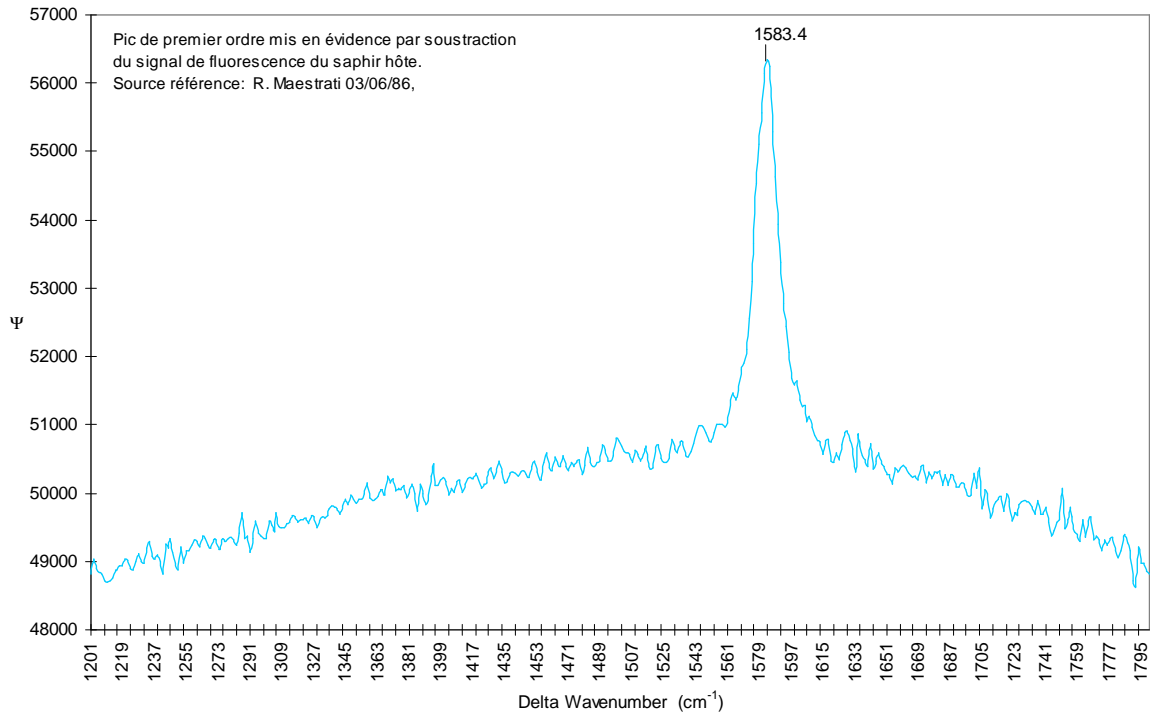


## Spectrum No 7

### Graphite

Inclusion de graphite (plaquette hexagonale) dans saphir incolore du Sri-lanka, réf. FN/57

File: ALO\_SR2, Ex. time: 89.739 secs, Light source 19436  $\text{cm}^{-1}$ , 400 points, operator Lore Kiefert, SSEF Basel, 25/10/96

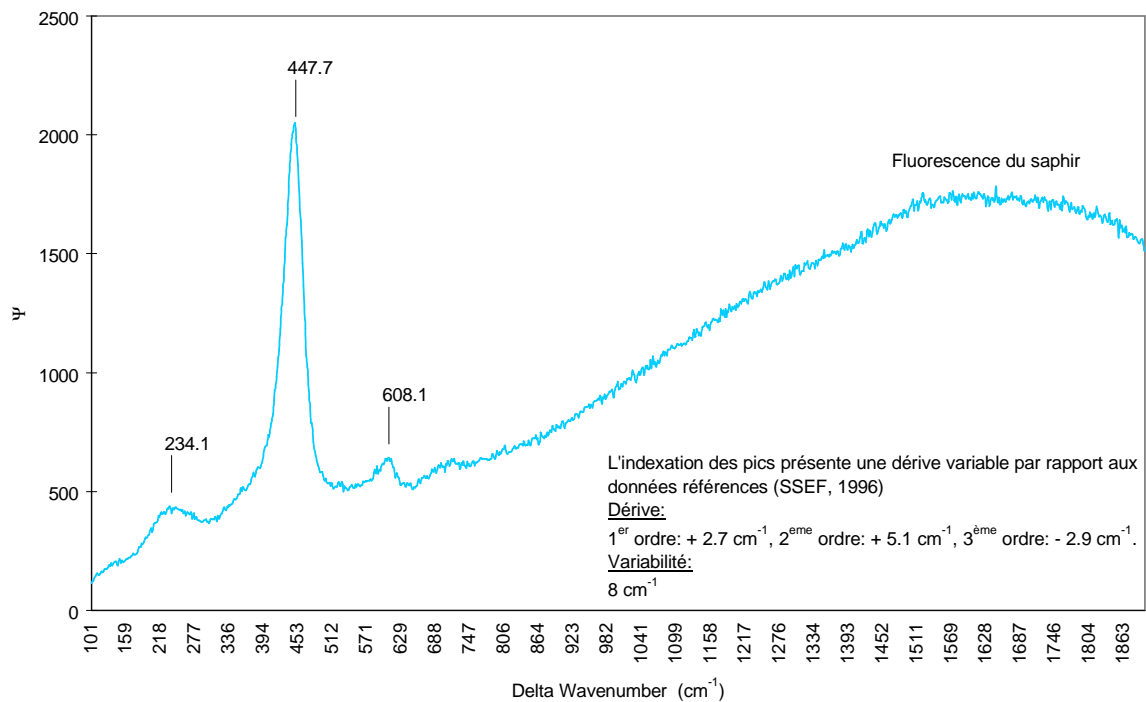


## Spectrum No 8

### Rutile

Inclusion de rutile dans saphir rose-violet du Sri-lanka, réf. FN/78

File: FN/78, Ex. time: 10.000 secs, Light source 19436  $\text{cm}^{-1}$ , 1'134 points, operator F. Notari, SSEF Basel, 15/11/96

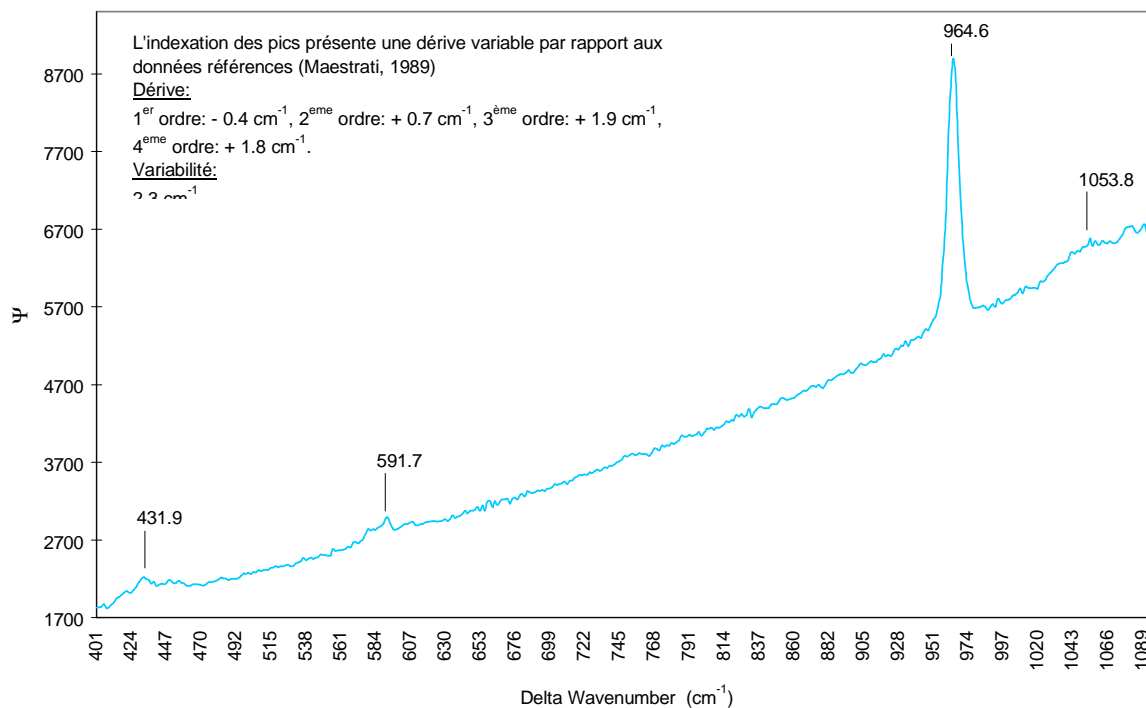


## Spectrum No 9

### Apatite

Inclusion d'apatite dans un padparadscha, Sri-lanka, réf. FN/80

File: Notari X1, Ex. time: 10.000 secs, Light source 19436  $\text{cm}^{-1}$ , 427 points, operator F. Notari, SSEF Basel, 15/11/96

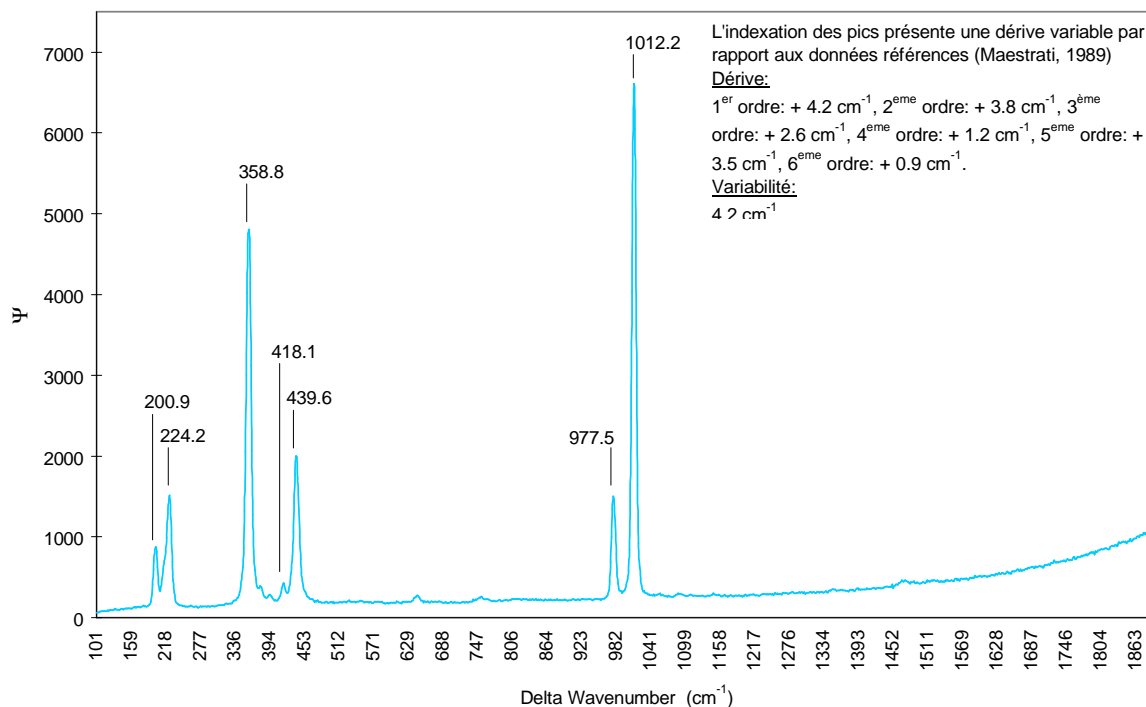


## Spectrum No 10

### Zircon

Inclusion de zircon dans saphir rose-orangé brunâtre de l'Umba, Tanzanie, réf. WM/09

File: WM/09, Ex. time: 10.000 secs, Light source 19436  $\text{cm}^{-1}$ , 1'134 points, operator F. Notari, SSEF Basel, 15/11/96

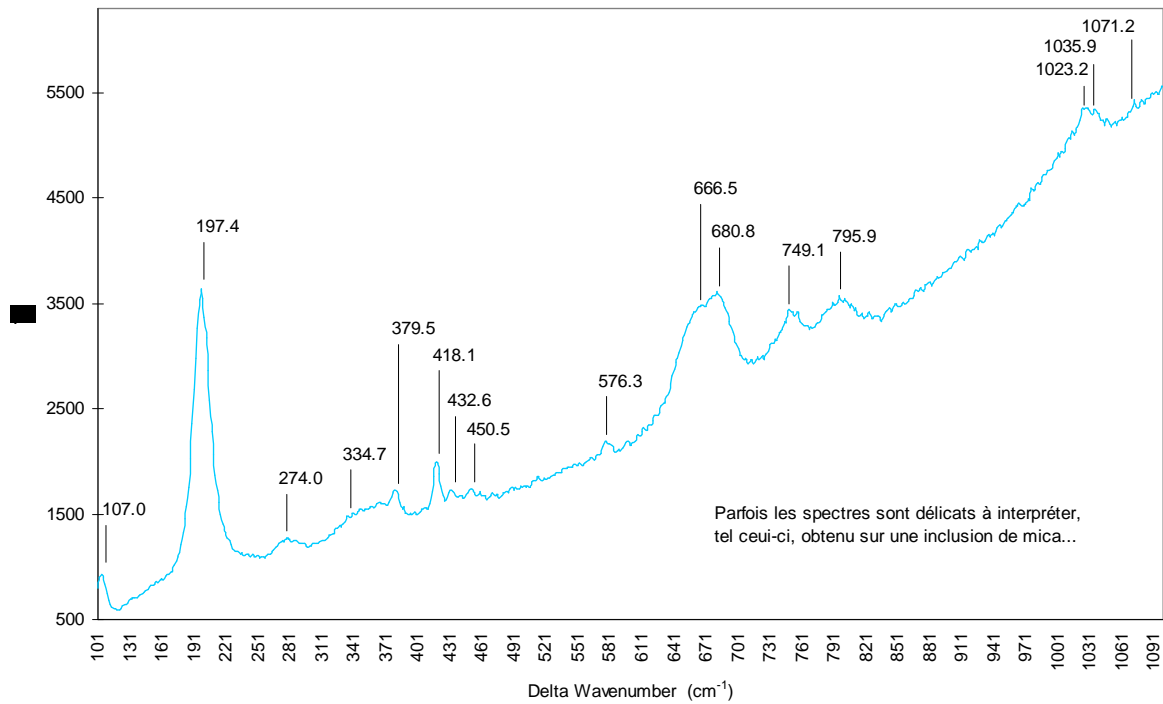


## Spectrum No 11

### Unidentified Mica

Inclusion de mica dans saphir rose-violet du Sri-lanka, réf. FN/81

File: X2\$1 Ex. time: 10.000 secs, Light source 19436 cm<sup>-1</sup>, 600 points, operator F. Notari, SSEF Basel, 15/11/96



## 7. Reference Samples

The samples on which this study is based are listed and specified as follows:

### Padparadschas:

Reference	Shape	Weight/ ct	L	l	e	Type	Chromatic pole	Analytical deeds (glossary at the end of the chapter)
FN/01	½ crystal	5.792	10.96	9.14	7.39	antique colour	pink	pol/us/phot/Ram (FN01\$1, NOT4, 2,) /UV-Vis./ inv incl
CJ/02	oval faceted	0.530	5.43	3.67	3.12	native	centred	UV-Vis. <i>cj02 (=c)02-2,02-p2(+c) / Ms</i>
HH/01	trilliant	0.741	5.83	5.30	2.91	antique colour	centred	us/Ms
PE/01	ov. fac.	5.756	10.01	9.17	6.54	native	pinkish yellow	UV-Vis. <i>Pad-01 (=c)</i>
FN/02	round fac.	7.858	11.24	--	7.47	native	centred	us/phot./fX UV-Vis. <i>fn2, fn2-p</i>
FN/03	ov. fac.	2.422	8.74	7.01	4.21	antique colour	pink	us/phot./fX/UV-Vis. <i>fn3, fn3-p</i>
FN/04	ov. fac.	2.837	6.77	5.89	6.61	antique colour	pink	us/phot
FN/05	ov. fac.	2.039	7.15	6.40	4.78	antique colour	pink	us/phot
FN/06	ov. fac.	1.020	6.14	4.78	3.82	antique colour	centred	us
FN/07	pear fac.	0.688	6.19	4.41	2.92	antique colour	extreme pink	us/phot
FN/08	ov. fac.	0.783	5.49	4.42	2.92	native	extreme yellow	us
FN/09	ov. fac.	0.586	5.36	3.79	3.34	antique colour	pink	us
FN/10	trilliant	0.413	6.15	3.69	2.35	antique colour	pink	us/Ms
FN/11	ov. fac.	1.360	8.27	6.19	2.45	market quality	pink	us/phot
FN/12	cabochon ov.	1.102	6.11	5.54	3.27	market quality	pink	us
FN/13 SAP.1.L / JN 01	cushion fac.	2.526	9.04	7.10	3.46	native	yellow	us/fX
PE/02 SAP.2.L / JN02	ov. fac.	3.001	9.51	6.80	5.40	antique colour	pink	us/ UV-Vis. <i>pe02(=c)02-2 (+c)</i>
PE/03 SAP.3.L / JN03	cush. fac.	0.937	6.54	4.75	3.01	native	orange, irradiated	us/fX/ UV-Vis. <i>pe03(=c)03-2 (+c)</i>
PE/04 SAP.4.L / JN04	round fac.	0.795	5.60	--	2.75	native	centred	us
PE/05 SAP.5.L / JN05	cush. fac.	1.781	8.54	5.74	3.48	native	orange, irradiated	us/fX/ UV-Vis. <i>pe05 (=c) pe05-2 (+c)/phot</i>
PE/06 SAP.6.L / JN06	cush. fac.	1.348	6.73	5.63	3.82	antique colour	pink	us
PE/07 SAP.7.L / JN07	ov. fac.	2.339	8.86	7.04	3.78	antique colour	centred-pink	us/ UV-Vis. <i>pe07 (=c)07-2 (+c)</i>
PE/08 SAP.8.L / JN08	cush. fac.	2.125	8.34	6.45	4.14	native	centred	us
PE/09 SAP.9.L / JN09	cush. fac.	3.411	8.73	7.56	4.55	native	slightly pinkish yellow, irradiated	us
FN/45	oval	0.620	5.59	4.20	3.15	market quality	x-light pink	us

PE/12	ov. fac.	2.469	7.80	6.89	5.26	antique colour	very slightly orangey pink	us/phot/UV-Vis. <i>pe12 (=c)12-2,12-2b(+c) pe12-p,12-pb(=c), 12-p2,12-p2b(+c)</i>
PE/13	ov. fac.	0.990	6.88	4.53	3.24	antique colour	med.+ orangey pink	us
PE/14	ov. fac.	2.050	8.39	7.21	3.92	antique colour	Very slightly pink + orange	us
PE/15	ov. fac.	1.480	7.53	5.12	4.93		orange, irradiated	UV-Vis. <i>pe15 (=c)15-2(+c) 15-p2(+c)/phot</i>
PE/16	cush. fac.	1.940	7.74	7.08	3.64	native	pastel orangey pink	us
PE/17	ov. fac.	0.778	6.45	4.54	3.01	antique colour	very slightly orangey strong pink	us/phot
BDR/01	ov. fac.	5.238	9.87	8.92	6.64	native	pastel orangey pink	us / Ms
BDR/02	ov. fac.	2.38	7.91	4.20	299	antique colour	orangey pink of medium saturation	us / Ms
FN/80	ov. fac.	0.544	5.62	3.90	2.72	antique colour	orangey pink of very light saturation	us/Ram (X1)/phot

### Various sapphires:

Reference	Shape	Weight/ct	L	l	e	Origin	Colour	Analytical deeds
FN/35	ov. fac.	0.929	6.87	4.94	2.72	Sri-lanka	pink of light saturation	UV-Vis. <i>fn0035(=c)</i>
FN/36	ov. fac.	0.458	5.20	4.11	2.38	Sri-lanka	pink of light saturation	UV-Vis. <i>fn0036(=c)</i>
FN/52	ov. fac.	2.962	9.24	6.90	5.01	Sri-lanka	slightly yellowish pink, x-light	UV-Vis. <i>fn52-1(=c)-2(+c)</i>
FN/53	round fac.	0.878	5.2	--	2.87	Sri-lanka	strong purplish pink	us/phot
FN/54	ov. fac.	0.754	5.07	4.83	3.19	Sri-lanka	yellow of light saturation	us
FN/55	ov. fac.	0.454	5.35	4.47	1.95	Sri-lanka	pink of medium saturation	us
FN/56	ov. fac.	1.136	5.99	5.81	3.06	Sri-lanka	yellow of light saturation	us
FN/57	round fac.	0.601	4.95	--	2.95	Sri-lanka	colourless	us/Ram (ALO_C_SR2)/phot
FN/58	fancy triangle	0.340	4.88	5.04	2.17	Sri-lanka	orangey pink light+	us
FN/59	fancy triangle	2.562	10.57	7.67	4.15	Sri-lanka	light blue and x-light pink	us
FN/63	ov. fac.	0.280	4.31	3.29	2.46	Sri-lanka	x-light pink	us
FN/69	ov. fac.	1.996				Sri-lanka	straw-coloured	UV-Vis. <i>fn69 (=c)-2(+c)</i>
FN/70	ov. fac.	1.062				Sri-lanka	straw-coloured	UV-Vis. <i>fn70 (=c)-2(+c)</i>
FN/71	ov. cab.	1.280	6.36	5.42	3.54	Sri-lanka	med. Blue and pink	us
FN/72	round fac.	0.184	3.51	--	2.22	Sri-lanka	pastel blue	us/phot
FN/73	round fac.	0.336	3.92	--	2.23	Sri-lanka	med. purple-pink	us
FN/74	round fac.	0.673	5.28	--	3.01	Sri-lanka	pastel blue	us/phot
FN/75	round fac.	1.395	6.27	--	4.14	Sri-lanka	pastel blue	us
FN/76	ov. fac.	0.421	4.75	4.14	2.27	Sri-lanka	pastel blue	us
FN/77	round fac.	0.252	3.59	--	2.41	Sri-lanka	pastel blue	us/phot
FN/78	round fac.	0.385	4.01	--	2.75	Sri-lanka	med. purple pink	us/Ram
FN/79	ov. fac.	0.520	4.51	4.24	3.17	Sri-lanka	pastel blue	us
FN/81	ov. fac.	0.397	4.96	3.35	2.68	Sri-lanka	x-light purple pink	us/Ram (X2\$1)/phot
FN/82	ov. fac.			5.91	3.79	Sri-lanka	colourless	us/phot/Ram



Various:

Reference	Name	Shape	Weight/ct	L	l	e	Origin	Colour	Analytical deeds
FN/46	Spinel	oval	1.50	8.72	6.25	3.57	Myanmar	medium orangey old rose	us
FN/51	Sapphire	Crystal	0.445	5.08	3.22	2.81	Madagascar	pinkish brown + blue colour zoning =c	us/phot

Various rough corundums from Sri-lanka:

Reference	Weight /ct	L	l	e	Analytical deeds
CJ/01	21.398	32.56	10.78	7.19	pol/us/phot/inv incl
FN/20	17.470	17.50	10.40	9.50	pol/us
FN/21	13.416	12.80	10.90	9.20	pol/us/phot

Syntheses:

Reference	Manufacturer	Shape	Weight/ct	L	l	e	Comments	Analytical deeds
FN/18	Chatam <sup>1985</sup>	ov. fac.	1.100	7.08	5.01	3.64		us, UV-Vis. <i>fn18 (=c)</i> <i>fn18-2 (+c)/phot</i>
FN/19	Inamori <sup>1990</sup>	ov. fac.	1.115	7.03	5.04	4.18		us/fX/UV-Vis. <i>fn19 (=c)</i> <i>fn19-2 (+c)</i>
FN/20	Kimberley	trilliant	1.487	7.08	6.99	4.28		UV-Vis. <i>fn20 (=c)</i> <i>fn20-2 (+c)</i>
FN/44	Inamori <sup>1996</sup>	marquise	1.375	10.16	5.15	3.89		réf.In. ps-m-
FN/47-x	Flame fusion Djevahirdjian	rough					Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.1%	UV-Vis. <i>fn0037/38(=/+c)</i>
FN/47-a	Flame fusion Djevahirdjian	½ rough	5.299	9.62	7.96	4.54	Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.1% (poids)	UV-Vis. <i>fn/47a-1(=/c)</i>
FN/47-b	Flame fusion Djevahirdjian	½ rough	5.498	9.83	7.96	4.64	Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.1% (poids)	UV-Vis. <i>fn/47b-1(=/c)</i>
FN/48-x	Flame fusion Djevahirdjian	rough					Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.15%	UV-Vis. <i>fn0039/40(=/+c)</i>
FN/48-a	Flame fusion Djevahirdjian	½ rough	10.560	10.05	12.11	5.33	Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.15% (poids)	us
FN/48-b	Flame fusion Djevahirdjian	½ rough	7.296	10.10	11.80	4.56	Al <sub>2</sub> O <sub>3</sub> + TiO <sub>2</sub> 0.15% (poids)	us
FN/49	Flame fusion Djevahirdjian	rough ½ bout.	143.021	46.3	21.6	11.4	Ref. DJEV. 50 sp	us
FN/50	Flame fusion Djevahirdjian	rough ½ bout.	107.414	41.3	20.2	10.5	Ref. DJEV. 55 sp	us
PE/10	Glass	round fac.	1.750	6.54	--	4.80	Ref. Padparadscha Dina LEVEL	UV-Vis. <i>pe10</i>
PE/11	Flame fusion	ov. fac.	2.978	10.03	8.02	4.57	Ref. Padparadscha Dina LEVEL	UV-Vis. <i>pe11 (=c)</i> <i>pe11-2 (+c)</i>
FN/64	Czochralski	emer. fac.	3.448	9.28	7.17	4.65	Bought by a tourist in Ouro Preto (Brazil) in 1984, rough-hewn, as an imperial topaz.	UV-Vis. <i>fn64 (=c)</i> <i>fn64-2 (+c)</i>
FN/65	Flame fusion	pear fac.	3.616	2.86	8.19	4.60		UV-Vis. <i>fn65 (=c)</i> <i>fn65-2 (+c)</i>
FN/66	Flame fusion	emer. fac.	3.834	10.09	8.10	4.38		us
FN/67	Flame fusion	emer. fac.	3.921	10.25	8.24	4.34		UV-Vis. <i>fn67(=c)</i> <i>fn67-2(+c)</i>
FN/68	Flame fusion	ov. fac.	3.337	10.02	8.14	4.51		UV-Vis. <i>fn68(=c)</i> <i>fn68-2(+c)</i>
FN/83	Flame fusion	rough	42.066				colourless	us

## Umba sapphires:

The studies of distinction between padparadschas and orangey sapphires from East Africa have been carried out on 532 cut samples, of a unitary weight of 0.2 to 6 carats, coming from the Umba region. Only 30 of these stones are listed below. They are the ones whose photographs and analytical deeds are quoted in this work and they are kept by the author.

Reference	Shape	Weight /ct	L	l	e	Analytical deeds	Colour
FN/13	ov. fac.	1.515	7.13	6.03	3.98	us/phot UV-Vis. <i>fn13, fn13-p</i>	
FN/14	ov. fac.	0.551	5.63	4.27	3.64	us/phot	
FN/15	round fac.	0.347	3.89	--	2.75	us/phot	
FN/16	ov. fac.	0.325	4.94	3.01	2.33	us/phot	
FN/17	round cab.	0.446	3.99	--	2.64	us	
WM/01	round. fac.	0.859	5.9	--	2.87	UV-Vis. <i>wm01(=c)</i> <i>wm01-2(+c)</i> /phot	pinkish orangey, slightly brown
WM/02	round fac.	0.211	3.51	--	2.44	phot	medium orangey pink
WM/03	ov. fac.	1.093	8.30	5.52	2.47	UV-Vis. <i>wm03(=c)</i> <i>wm03-2(+c)</i> /phot	medium orangey red
WM/04	ov. fac.	1.501	7.53	6.05	3.68	UV-Vis. <i>wm04(+c)</i> <i>wm04-2(=c)</i> /phot	medium orangey red
WM/05	rect. step fac.	0.669	5.59	4.57	2.38	UV-Vis. <i>wm05(=c)</i> <i>wm05-2(+c)</i> /phot	medium orangey pink
WM/06	rect. step fac	0.327	4.52	3.00	2.04	UV-Vis. <i>wm06(=c)</i> <i>wm06-2(+c)</i> /phot	medium orangey pink
WM/07	square princess	0.540	4.50	4.46	2.24	UV-Vis. <i>wm07(=c)</i> <i>wm07-2(+c)</i> /phot	strong orangey pink
WM/08	square princess	0.513	4.47	4.44	2.34	UV-Vis. <i>wm08(=c)</i> <i>wm08-2(+c)</i> /phot	strong orangey pink
WM/09	square princess	0.692	4.78	4.81	3.05	UV-Vis. <i>fn0011/0012</i> , Ram (WM09)/phot/us	brown orangey pink
WM/10	emer. fac.	7.140	14.60	8.85		UV-Vis. <i>wm10(=c)</i> <i>wm10-2(+c)</i> /phot/us	brown orangey
HOH/FN/37	square princess	0.229	3.28	3.27	2.28	phot	brownish orangey pink
HOH/FN/38	round	0.801	5.38	--	3.36	phot	light pink, brown underhue
HOH/FN/39	round	0.113	2.61	--	1.81	phot	slightly pinkish red + brown
HOH/FN/40	marquise	0.412	6.95	3.49	2.32	phot	brown orangey pink
HOH/FN/41	rond	0.424	4.33	--	2.96	phot	brown orangey pink
HOH/FN/42	marquise	0.196	5.41	2.65	1.52	us/phot	brown orangey pink
HOH/FN/43	square princess	0.519	4.43	4.47	2.72	UV-Vis. <i>fn0023/24/25(+c)</i>	brown orangey pink
FN/60	rect. cush.	1.146	8.09	4.74	3.03	us	strong orangey pink
FN/61	round fac.	0.393	4.40	--	2.16	us	strong orangey pink
FN/62	coussin rect.	0.843	5.60	4.94	3.21	us	strong orangey pink
FN/84,LWM	ov. fac.					us/phot	medium orangey pink
FN/85,LWM	ov. fac.					us/phot	brownish red
FN/86,LWM	ov. fac.					us/fX	brownish orangey pink
FN/87,LWM	ov. fac.					us/fX	brownish red
FN/89,LWM	ov. fac.					us/fX	orangey red

Key to the analytical deeds and interventions:

inv incl	Identification of the inclusions
phot	Photograph
Ram	Raman microprobe spectrum
UV-Vis.	Ultra-violet-visible spectrophotometry
us	Usual analyses, R.I., p.s., spectrum man., opt charac., UV, etc.
fX	X Fluorescence
Ms	Microprobe
<i>pol</i>	<i>Sample polishing</i>

# 8. Chemical Analysis Data

## Chemical Analysis

Mineralogische Institut der Universität, Basel, CH

Instrument: JEOL JXA 8600 Superprobe, Operator: Michael KRZEMNICKI, 07/11/1996

acc.current 20 kV	beam 10 nA	beam t 1 µm	mode spot	correction ZAF
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Element	Setup	Time	Peak pos.	Bg +	Bg -
Al	Al_Ka1_spec1_TAP_5Ko.20	10	90.755	2.0	2.0
Ca	Ca_Ka1_spec2_PET_5Wo.20	30	107.388	1.5	2.5
Ti	Ti_Ka1_spec4_TAP_5Ti.30	30	87.505	2.0	2.5
Mg	Mg_Ka1_spec1_TAP_5OL.20	30	107.615	1.0	1.5
Mn	Mn_Ka1_spec2_PET_5Gr.20	30	67.076	2.0	2.0
Na	Na_Ka1_spec1_TAP_5Ab.20	30	129.575	1.0	1.5
Fe	Fe_Ka+_spec3_LIF_5Hm.20	30	134.872	2.0	2.5
K	K_Ka1_spec4_PET_5Or.20	30	119.382	2.0	2.0
V	V_Ka1_spec2_PET_5V.20	30	80.002	2.0	2.0
Cr	Cr_Ka1_spec4_PET_5Cr.20	30	72.727	2.0	2.0
Ga	Ga_La1_spec1_TAP_R05.20	30	122.830	2.0	2.0

Sample: HH/01

Oxides	N° 1	N° 2	N° 3	N° 4	N° 5	Average
Na <sub>2</sub> O	0.00	0.00	0.00	0.01	0.00	0.002
MgO	0.00	0.01	0.01	0.00	0.01	0.006
Al <sub>2</sub> O <sub>3</sub>	100.67	100.05	99.75	99.2	99.16	99.766
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.01	0.00	0.02
TiO <sub>2</sub>	0.00	0.00	0.01	0.01	0.01	0.006
Cr <sub>2</sub> O <sub>3</sub>	0.02	0.03	0.04	0.05	0.04	0.036
MnO	0.00	0.00	0.00	0.00	0.00	0.00
Fe <sub>2</sub> O <sub>3</sub>	0.02	0.03	0.04	0.05	0.04	0.036
Ga <sub>2</sub> O <sub>3</sub>	0.06	0.01	0.02	0.00	0.04	0.026
V <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.01	0.00	0.00	0.002
<b>Total</b>	<b>100.77</b>	<b>100.13</b>	<b>99.88</b>	<b>99.33</b>	<b>99.30</b>	<b>99.882</b>

Sample: FN/10

Oxides	N° 1	N° 2	N° 3	N° 4	N° 5	Average
Na <sub>2</sub> O	0.03	0.01	0.00	0.00	0.02	0.012
MgO	0.00	0.04	0.02	0.02	0.01	0.018
Al <sub>2</sub> O <sub>3</sub>	98.87	98.89	99.20	99.57	100.22	99.35
K <sub>2</sub> O	0.00	0.01	0.00	0.00	0.00	0.02
CaO	0.00	0.01	0.00	0.00	0.00	0.02
TiO <sub>2</sub>	0.00	0.02	0.03	0.03	0.00	0.016
Cr <sub>2</sub> O <sub>3</sub>	0.04	0.02	0.07	0.07	0.03	0.046
MnO	0.00	0.00	0.03	0.03	0.05	0.022
Fe <sub>2</sub> O <sub>3</sub>	0.01	0.02	0.00	0.00	0.01	0.008
Ga <sub>2</sub> O <sub>3</sub>	0.02	0.01	0.00	0.00	0.00	0.006
V <sub>2</sub> O <sub>3</sub>	0.01	0.02	0.00	0.00	0.00	0.006
<b>Total</b>	<b>98.98</b>	<b>99.05</b>	<b>99.35</b>	<b>99.72</b>	<b>100.34</b>	<b>99.488</b>

Sample: CJ/02

Oxides	N° 1	N° 2	N° 3	N° 4	N° 5	Average
Na <sub>2</sub> O	0.02	0.00	0.02	0.02	0.00	0.012
MgO	0.00	0.00	0.00	0.01	0.00	0.002
Al <sub>2</sub> O <sub>3</sub>	99.26	99.40	99.95	99.92	99.28	99.562
K <sub>2</sub> O	0.01	0.01	0.00	0.00	0.00	0.004
CaO	0.00	0.01	0.03	0.02	0.00	0.012
TiO <sub>2</sub>	0.02	0.00	0.00	0.02	0.01	0.01
Cr <sub>2</sub> O <sub>3</sub>	0.04	0.04	0.03	0.01	0.01	0.026
MnO	0.05	0.00	0.03	0.00	0.00	0.016
Fe <sub>2</sub> O <sub>3</sub>	0.01	0.01	0.03	0.00	0.00	0.01
Ga <sub>2</sub> O <sub>3</sub>	0.01	0.02	0.06	0.00	0.00	0.018
V <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.01	0.01	0.004
<b>Total</b>	<b>99.42</b>	<b>99.49</b>	<b>100.15</b>	<b>100.01</b>	<b>99.31</b>	<b>99.676</b>

Sample: BDRR/01

Oxides	N° 1	N° 2	N° 3	N° 4	N° 5	Average
Na <sub>2</sub> O	0.00	0.01	0.00	0.01	0.02	0.008
MgO	0.01	0.00	0.01	0.00	0.00	0.004
Al <sub>2</sub> O <sub>3</sub>	100.26	99.87	99.12	99.01	99.69	99.59
K <sub>2</sub> O	0.00	0.00	0.00	0.02	0.01	0.006
CaO	0.00	0.00	0.00	0.00	0.01	0.002
TiO <sub>2</sub>	0.00	0.02	0.05	0.00	0.02	0.018
Cr <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.05	0.00	0.01
MnO	0.00	0.03	0.00	0.05	0.00	0.016
Fe <sub>2</sub> O <sub>3</sub>	0.02	0.12	0.09	0.05	0.15	0.086
Ga <sub>2</sub> O <sub>3</sub>	0.01	0.01	0.00	0.03	0.03	0.016
V <sub>2</sub> O <sub>3</sub>	0.00	0.01	0.01	0.00	0.03	0.01
<b>Total</b>	<b>100.30</b>	<b>100.07</b>	<b>99.28</b>	<b>99.96</b>	<b>99.766</b>	<b>99.766</b>

Sample: FN/14

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.00	0.00	0.04	0.01
MgO	0.01	0.00	0.00	0.00	0.0025
Al <sub>2</sub> O <sub>3</sub>	98.20	98.15	98.98	98.21	98.385
K <sub>2</sub> O	0.01	0.00	0.00	0.01	0.005
CaO	0.00	0.01	0.00	0.02	0.0075
TiO <sub>2</sub>	0.03	0.00	0.02	0.07	0.03
Cr <sub>2</sub> O <sub>3</sub>	0.04	0.07	0.06	0.07	0.06
MnO	0.01	0.00	0.00	0.00	0.0025
Fe <sub>2</sub> O <sub>3</sub>	0.91	0.89	0.95	0.94	0.9225
Ga <sub>2</sub> O <sub>3</sub>	0.02	0.00	0.00	0.03	0.0125
V <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.00	00.00	0.005
<b>Total</b>	<b>99.23</b>	<b>99.14</b>	<b>100.01</b>	<b>99.39</b>	<b>99.4425</b>

Sample: FN/05

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.01	0.02	0.01	0.01
MgO	0.00	0.01	0.01	0.00	0.005
Al <sub>2</sub> O <sub>3</sub>	99.77	98.88	99.26	99.93	99.46
K <sub>2</sub> O	0.01	0.00	0.01	0.01	0.0075
CaO	0.00	0.00	0.00	0.00	0.00
TiO <sub>2</sub>	0.04	0.08	0.03	0.05	0.05
Cr <sub>2</sub> O <sub>3</sub>	0.02	0.02	0.00	0.01	0.0125
MnO	0.00	0.01	0.00	0.00	0.0025
Fe <sub>2</sub> O <sub>3</sub>	0.07	0.012	0.07	0.09	0.0605
Ga <sub>2</sub> O <sub>3</sub>	0.01	0.04	0.07	0.03	0.0375
V <sub>2</sub> O <sub>3</sub>	0.02	0.00	0.02	0.02	0.015
<b>Total</b>	<b>99.94</b>	<b>99.062</b>	<b>99.49</b>	<b>100.15</b>	<b>99.66</b>

Sample: FN/06

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.01	0.03	0.02	0.015
MgO	0.02	0.00	0.01	0.02	0.0125
Al <sub>2</sub> O <sub>3</sub>	99.05	99.34	99.94	99.68	99.5025
K <sub>2</sub> O	0.01	0.01	0.01	0.00	0.0075
CaO	0.00	0.01	0.00	0.00	0.0025
TiO <sub>2</sub>	0.05	0.05	0.02	0.06	0.045
Cr <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.02	0.04	0.015
MnO	0.01	0.00	0.00	0.02	0.0075
Fe <sub>2</sub> O <sub>3</sub>	0.07	0.06	0.09	0.05	0.0675
Ga <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.02	0.005
V <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.00	0.05	0.0175
<b>Total</b>	<b>99.21</b>	<b>99.50</b>	<b>100.12</b>	<b>99.96</b>	<b>99.6975</b>

Sample: FN/02

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.03	0.01	0.01	0.00	0.0125
MgO	0.00	0.00	0.02	0.01	0.0075
Al <sub>2</sub> O <sub>3</sub>	99.01	100.02	100.38	99.82	99.8075
K <sub>2</sub> O	0.00	0.00	0.00	0.01	0.0025
CaO	0.01	0.00	0.01	0.01	0.0075
TiO <sub>2</sub>	0.02	0.00	0.01	0.00	0.0075
Cr <sub>2</sub> O <sub>3</sub>	0.02	0.02	0.00	0.00	0.01
MnO	0.00	0.03	0.03	0.01	0.0175
Fe <sub>2</sub> O <sub>3</sub>	0.04	0.02	0.07	0.05	0.045
Ga <sub>2</sub> O <sub>3</sub>	0.01	0.00	0.02	0.01	0.01
V <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.00	0.00	0.005
<b>Total</b>	<b>99.14</b>	<b>100.12</b>	<b>100.55</b>	<b>99.92</b>	<b>99.9325</b>

Sample: FN/09

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.02	0.03	0.01	0.015
MgO	0.02	0.02	0.01	0.02	0.0175
Al <sub>2</sub> O <sub>3</sub>	99.48	99.10	99.65	100.27	99.625
K <sub>2</sub> O	0.00	0.00	0.01	0.01	0.005
CaO	0.00	0.00	0.00	0.00	0.00
TiO <sub>2</sub>	0.01	0.04	0.01	0.00	0.015
Cr <sub>2</sub> O <sub>3</sub>	0.03	0.00	0.02	0.00	0.0125
MnO	0.00	0.00	0.02	0.00	0.005
Fe <sub>2</sub> O <sub>3</sub>	0.05	0.03	0.02	0.06	0.04
Ga <sub>2</sub> O <sub>3</sub>	0.00	0.03	0.00	0.02	0.0125
V <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.02	0.03	0.0175
<b>Total</b>	<b>99.59</b>	<b>99.26</b>	<b>99.79</b>	<b>100.42</b>	<b>99.765</b>

Sample: BDRR/02

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.02	0.00	0.01	0.0075
MgO	0.00	0.00	0.01	0.01	0.005
Al <sub>2</sub> O <sub>3</sub>	99.6	100.66	99.41	99.23	99.725
K <sub>2</sub> O	0.01	0.00	0.01	0.00	0.005
CaO	0.01	0.00	0.00	0.00	0.0025
TiO <sub>2</sub>	0.02	0.00	0.00	0.00	0.005
Cr <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.00	0.01	0.0075
MnO	0.00	0.00	0.02	0.00	0.005
Fe <sub>2</sub> O <sub>3</sub>	0.10	0.11	0.11	0.10	0.105
Ga <sub>2</sub> O <sub>3</sub>	0.02	0.00	0.05	0.00	0.0175
V <sub>2</sub> O <sub>3</sub>	0.00	0.01	0.00	0.00	0.0025
<b>Total</b>	<b>99.76</b>	<b>100.82</b>	<b>99.61</b>	<b>99.36</b>	<b>99.8875</b>

Sample: WM/09

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.02	0.02	0.01	0.01	0.015
MgO	0.04	0.00	0.01	0.01	0.015
Al <sub>2</sub> O <sub>3</sub>	99.13	99.37	99.71	99.69	99.475
K <sub>2</sub> O	0.01	0.00	0.00	0.00	0.0025
CaO	0.00	0.00	0.00	0.00	0.00
TiO <sub>2</sub>	0.03	0.04	0.04	0.00	0.0275
Cr <sub>2</sub> O <sub>3</sub>	0.03	0.04	0.03	0.06	0.04
MnO	0.02	0.00	0.00	0.00	0.005
Fe <sub>2</sub> O <sub>3</sub>	1.00	1.01	1.02	1.04	1.0175
Ga <sub>2</sub> O <sub>3</sub>	0.06	0.00	0.00	0.00	0.015
V <sub>2</sub> O <sub>3</sub>	0.01	0.01	0.00	0.00	0.005
<b>Total</b>	<b>100.35</b>	<b>100.49</b>	<b>100.82</b>	<b>100.81</b>	<b>100.6175</b>

Sample: FN/08

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.03	0.03	0.02	0.02
MgO	0.02	0.01	0.01	0.01	0.0125
Al <sub>2</sub> O <sub>3</sub>	99.71	99.89	99.45	99.59	99.66
K <sub>2</sub> O	0.01	0.00	0.00	0.00	0.0025
CaO	0.00	0.00	0.00	0.01	0.0025
TiO <sub>2</sub>	0.00	0.02	0.02	0.01	0.0125
Cr <sub>2</sub> O <sub>3</sub>	0.00	0.05	0.02	0.00	0.0175
MnO	0.03	0.00	0.00	0.00	0.0075
Fe <sub>2</sub> O <sub>3</sub>	0.05	0.06	0.05	0.07	0.0575
Ga <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.01	0.01	0.01
V <sub>2</sub> O <sub>3</sub>	0.03	0.00	0.01	0.01	0.0125
<b>Total</b>	<b>99.85</b>	<b>100.08</b>	<b>99.60</b>	<b>99.73</b>	<b>99.815</b>

Sample: FN/03

Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.01	0.02	0.00	0.01	0.01
MgO	0.02	0.08	0.02	0.01	0.0325
Al <sub>2</sub> O <sub>3</sub>	99.68	100.10	99.34	99.08	99.55
K <sub>2</sub> O	0.00	0.00	0.00	0.01	0.0025
CaO	0.00	0.01	0.00	0.01	0.005
TiO <sub>2</sub>	0.01	0.01	0.00	0.00	0.005
Cr <sub>2</sub> O <sub>3</sub>	0.01	0.03	0.03	0.04	0.0275
MnO	0.01	0.00	0.02	0.00	0.0075
Fe <sub>2</sub> O <sub>3</sub>	0.07	0.09	0.04	0.08	0.07
Ga <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.00	0.00	0.00
V <sub>2</sub> O <sub>3</sub>	0.01	0.00	0.01	0.00	0.005
<b>Total</b>	<b>99.82</b>	<b>100.34</b>	<b>99.46</b>	<b>99.24</b>	<b>99.715</b>



Sample: FN/04

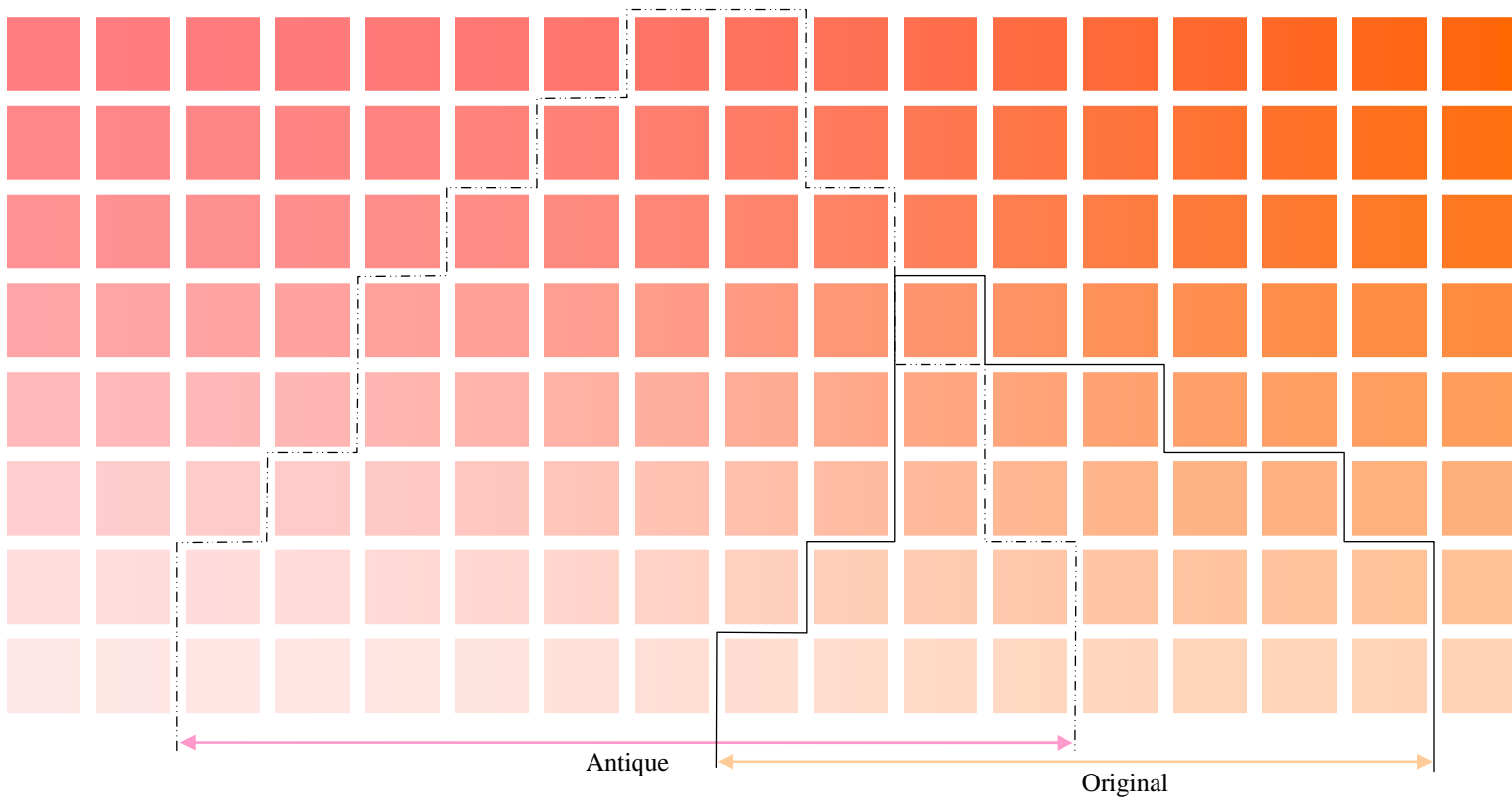
Oxides	N° 1	N° 2	N° 3	N° 4	Average
Na <sub>2</sub> O	0.00	0.01	0.02	0.02	0.0125
MgO	0.01	0.01	0.00	0.01	0.0075
Al <sub>2</sub> O <sub>3</sub>	99.42	99.74	99.21	99.31	99.42
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.02	0.00	0.005
TiO <sub>2</sub>	0.01	0.00	0.01	0.01	0.0075
Cr <sub>2</sub> O <sub>3</sub>	0.02	0.00	0.01	0.01	0.01
MnO	0.00	0.00	0.01	0.01	0.005
Fe <sub>2</sub> O <sub>3</sub>	0.04	0.04	0.07	0.06	0.0525
Ga <sub>2</sub> O <sub>3</sub>	0.00	0.02	0.01	0.01	0.01
V <sub>2</sub> O <sub>3</sub>	0.03	0.00	0.00	0.01	0.01
<b>Total</b>	<b>99.53</b>	<b>99.74</b>	<b>99.21</b>	<b>99.31</b>	<b>99.540</b>

Sample: WM/00 (WM/04)

Oxides	N° 1	N° 2	N° 3	Average
Na <sub>2</sub> O	0.00	0.00	0.02	0.0067
MgO	0.01	0.01	0.01	0.01
Al <sub>2</sub> O <sub>3</sub>	99.75	99.84	99.81	99.80
K <sub>2</sub> O	0.00	0.01	0.01	0.0067
CaO	0.02	0.01	0.01	0.0133
TiO <sub>2</sub>	0.03	0.01	0.00	0.0133
Cr <sub>2</sub> O <sub>3</sub>	0.01	0.01	0.02	0.0133
MnO	0.00	0.03	0.00	0.01
Fe <sub>2</sub> O <sub>3</sub>	0.70	0.72	0.79	0.7367
Ga <sub>2</sub> O <sub>3</sub>	0.08	0.03	0.06	0.0556
V <sub>2</sub> O <sub>3</sub>	0.04	0.03	0.01	0.0267
<b>Total</b>	<b>100.64</b>	<b>100.70</b>	<b>100.74</b>	<b>100.693</b>

## 9. Conclusion

### Padparadscha Charter



Pour comparer la couleur d'un Padparadscha à la charte, placer celui-ci à l'envers (sur la table) sur un carré de bristol (aux dimensions de la pierre). Utiliser un éclairage à la norme CIE: D55 ou D60 (5000 ou 6000K), ou procéder en lumière naturelle diffuse (celle-ci étant la plus adaptée). Déplacer l'ensemble pierre/bristol sur la charte et contrôler en observation apicale, que la gemme s'inscrive bien dans un des deux habitus du Padparadscha. L'examen aux UV courts et longs peut permettre de confirmer l'habitus. Conserver cette charte à l'abri de la lumière.

## Charter of Padparadscha (Corundum)

Native Habit	Antique Habit
<b>Colour</b> due to: Cr <sup>3+</sup> , Fe <sup>3+</sup> , coloured centres.	<b>Colour</b> due to: Cr <sup>3+</sup> , Fe <sup>3+</sup> , no centres.
One or more blue colour zonings, oriented in (11 $\bar{1}$ 1), are visible most of the time. No yellow colour zonings should be seen as they are generally due to thermal treatment.	
<b>Refractive index</b> : (W) between 1.768 et 1.769; (E) between 1.760 et 1.761. Birefringence: generally 0.008 ( $\pm$ 30% 0.009)	
<b>Fluorescence</b> : UVL (365 nm): medium to marked, from apricot to pinkish apricot colour. UVC (253.7 nm): light to medium, from slightly ochred apricot to pinkish apricot colour.	<b>Fluorescence</b> : UVL (365 nm): medium to marked, from red colour to pinkish red or orangey red. UVC (253.7 nm): light to medium, same colours.
A milky bluish or greenish fluorescence, sometimes in spots, reveals a high temperature thermal treatment (higher than 1100°C). Batā Kubāla heating can only be detected for the moment by examination of the inclusions.	
<b>Internal characteristics</b> : Usual inclusions in sapphires from Sri Lanka, no polycrystalline boehmite (AlOOH), no lepidocrocite ( $\gamma$ -Fe <sup>3+</sup> O(OH)). Polysynthetic macle plans are rare and never in two or three different directions at the same time (r, r' et r'' (10 $\bar{1}$ 1)). This is a particular characteristic of Tanzanian sapphires.	
Until now all padparadschas come from Sri Lanka.	
<p style="text-align: center;">UV-visible spectrum</p>	<p style="text-align: center;">UV-visible spectrum</p>
Absorptions: 700, 694, 692 nm.	Absorptions: 694, 692, 668 nm.
<p style="text-align: center;">Spectrum made by means of a network spectroscope</p>	<p style="text-align: center;">Spectrum made by means of a network spectroscope</p>



## Bibliography

This bibliography is divided into two parts. The first one (journals) is more technical and groups together articles from periodical publications and unpublished documents. The second one (books) is more general-interest and comprises proper books, but also dissertations and comparable works. It covers all the information referred by the author, it can be specific to padparadscha or associated (treatments, deposits producing sapphires of similar colour, physical and chemical principles etc.), i.e. every reference that he considered judicious to include for a correct understanding of the subject.

### Journals:

- **Ashbaugh III** Charles E., (1988), *Gemstone Irradiation and Radioactivity*, Gems & Gemology, Vol XXIV, N° 4, pp 196-213, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Bank H.**, (1979), *Orange-("Padparadscha") und andersfarbige Granate aus Ostafrika*, Z. Dt. Gemmol. Ges., Jahrgang 28, Heft 3, pp 146-147, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Bank H., Lind Th.**, (1988), *Rubine aus Malawi*, Z. Dt. Gemmol. Ges., Jahrgang 37, Heft 3/4, pp 113-119, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Bank H.**, (1989), *Malawi*, Neue Edelsteinvorkommen, Gemmologie aktuell, 1/89, p. 3, Deutsche Gemmologische Gesellschaft, Idar-Oberstein, Deutschland
- **Biesalski Ernst, Maatsch Richard, Benary Friedrich**, (1957), *Pflanzenfarben Atlas*, Musterschmidt-verlag, Frankfurt, Deutschland
- **Chevaleraud J.P.**, (1980), *Perception des couleurs*, Encycl. Méd. Chir., Ophtalmologie, Paris, France
- **Clark A. M.**, (1975), *Hey's Mineral Index*, third edition, Natural History Museum Publications, pp 157-158, ed. Chapman & Hall, London, England
- **Bosshart G.**, (1984), *Distinction entre rubis naturels et synthétiques par spectrophotométrie ultraviolette*, Revue de gemmologie a.f.g., N° 79, pp14-19, édité par l'Associacion française de gemmologie
- **Copeland L.L.**, (1973), *The Derivation of Gem Names*, Gems & Gemology, vol. XIV, N°5, pp 154-160, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Criddle A. J., Stanley C. J.**, (1993), *Quantitative Data File for ORE Minerals*, third edition, pp xxv, 114, Chapman & Hall, London, England
- **Crowningshield Robert**, (1979), *Some Sapphire Problems*, Developments and Highlights at GIA's Lab in New York, Gems & Gemology, Vol XVI, N° 7, pp 194-196, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Crowningshield Robert**, (1981), *The Heat and Diffusion Treatment of Natural and Synthetic Sapphires*, J. Gemm., Vol. XVII, N° 8, pp 528-541, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Crowningshield Robert**, (1983), *Padparadscha: What's in a Name*, Gems & Gemology, Vol XIX, N° 1, pp 30-36, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Dawidowicz Thierry**, (1989), *L'influence des inclusions sur la structure cristalline*, Revue de gemmologie a.f.g., N° 100, pp 23,24, édité par l'Associacion française de gemmologie
- **Delé-Dubois M.-L., Poirot J.-P., Schubnel H.-J.**, (1986), *Identification de micro-inclusions dans des rubis et émeraudes de synthèse par spectroscopie Raman*, Revue de gemmologie a.f.g., N° 88, pp 15-17, édité par l'Associacion française de gemmologie
- **Delé-Dubois M.-L., Dhameincourt P., Poirot J.-P., Schubnel H.-J.**, (1986), *Différenciation entre les gemmes naturelles et les matériaux synthétiques par microspectométrie Raman à laser*, Revue de gemmologie a.f.g., N° 88, pp 13, 14, édité par l'Associacion française de gemmologie
- **Dissanayake C.B., Rupasinghe M.S.**, (1993), *A Prospectors' Guide Map to the Gem Deposits of Sri Lanka*, Gems & Gemology, vol. XXIX, N°3, Fall 1993, pp. 173-181, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Dissanayake C.B., Rupasinghe M.S.**, (1992), *Application of Geochemistry to Exploration for Gem Deposits, Sri-lanka*, J. Gemm., Vol. XXIII, N° 3, pp 165-175, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Dubois-Fournier Josiane, Lenain Bruno, Le Maguer Didier**, (1989), *La microspectrofluorescence et ses applications en gemmologie*, Revue de gemmologie a.f.g., N° 100, pp 15-18, édité par l'Associacion française de gemmologie
- **Ediriweera R. N., Perera S. I.**, (1989), *Heat Treatment of Geuda Stones - Spectral Investigation*, J. Gemm., Vol. XXI, N° 7, pp 403-404, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Emmet John L., Douthit Troy R.**, (1993), *Heat Treating the Sapphires of Rock Creek, Montana*, Gems & Gemology, vol. XXIX, N° 4, Fall 1993, pp. 173-181, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Entremont Pascal**, (1987), *Padparadscha*, (Gem Echos), Monde & Minéraux, N° 81, pp 40, éd. Lithops, Paris, France
- **Fjordgreen O.**, (1986), *Infrared Detective*, Lapidary Journal, 39, N° 12, pp 39.41
- **Fritsch Emmanuel**, (1985), *La couleur des minéraux et des gemmes*, Monde & Minéraux, N° 67, pp 20-24, éd. Lithops, Paris, France
- **Fritsch Emmanuel**, (1985), *La couleur des minéraux et des gemmes*, Monde & Minéraux, N° 69, pp 12-17, éd. Lithops, Paris, France
- **Fritsch Emmanuel**, (1985), *La couleur des minéraux et des gemmes*, Monde & Minéraux, N° 70, pp 12-22, éd. Lithops, Paris, France
- **Fritsch Emmanuel, Rossman Georges R.**, (1987), *An Update on Color in Gems. Part 1: Introduction and Colors Caused by Dispersed Metal Ions*, Gems & Gemology, vol. XXIII, N°3, pp 126-139, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Fritsch Emmanuel, Rossman Georges R.**, (1988), *An Update on Color in Gems. Part 2: Introduction and Colors Caused by Dispersed Metal Ions*, Gems & Gemology, vol. XXIV, N°1, pp 3-15, edited by The Gemological Institute of America, Santa Monica, CA, USA

- **Fritsch** Emmanuel, **Rossmann** Georges R., (1988), *An Update on Color in Gems. Part 3: Introduction and Colors Caused by Dispersed Metal Ions*, Gems & Gemology, vol. XXIV, N°2, pp 81-102, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Galvier** Jacques, (1995), *La couleur des minéraux*, Le Règne minéral, N° 2, pp 4-25, éditions du Piat, Monistrol-sur-Loire
- **García Giménez R., Leguey S.**, *Saphirs et rubis de Tanzanie*, Revue de gemmologie a.f.g., N° 102, pp 5-7, édité par l'Associacion française de gemmologie
- **Grubessi** Odino, **Marcon** Renata, (1986), *A Peculiar Inclusion in a Yellow Corundum from Malawi*, J. Gemm., Vol. XX, N° 3, pp 163- 165, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Gübelin** Eduard, (1985), *Identification des nouveaux saphirs synthétiques et des saphirs traités*, Revue de gemmologie a.f.g., N° 82, pp 9-14, édité par l'Associacion française de gemmologie
- **Gübelin** Eduard, (1985), *Identification des nouveaux saphirs synthétiques et des saphirs traités*, Revue de gemmologie a.f.g., N° 83, pp 11-13, édité par l'Associacion française de gemmologie
- **Gunawardene** Mahinda, (1983), *Über die syntetischen blauen und orange-farbenen Saphire von Chatam*, Z. Dt. Gemmol. Ges., Jahrgang 32, Heft 4, pp 196-203, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Gunawardene** Mahinda, (1984), *Reddish-brown Sapphires from Umba Valley, Tanzania*, J. Gemm., Vol. XIX, N° 2, pp 139-144, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Gunawardene** Mahinda, (1984), *Contribution Toward the Identification of Treated Corundums: Heat and Diffusion Treated Rubies*, J. Gemm., Vol. XIX, N° 4, pp 298-310, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Gunawardene** Mahinda, (1985), *Identification Characteristics of Flux Grown Synthetic Orange Sapphires*, J. Gemm., Vol. XIX, N°5, pp 389-403, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Gunawardene** Mahinda, **Rupasinghe** Mahinda S., (1986), *The Elahera Gem Field in Central Sri-Lanka*, Gems & Gemology, vol. XXII, N°2, pp 80-95, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Hänni** Henry A., (1982), *Zur Erkennung diffusionsbehandelter Korunde*, Z. Dt. Gemmol. Ges., Jahrgang 31, Heft 1/2, pp 49-57, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Hänni** Henry A., **Stern** W. B., (1982), *Über die gemmologische Bedeutung des Gallium-Nachweises in Korunden*, Z. Dt. Gemmol. Ges., Jahrgang 31, Heft 4, pp 255-259, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Hänni** Henry A., (1987), *L'expertise d'authenticité de corindons: les méthodes et leurs limites*, Monde & Minéraux, N° 80, pp 26-30, 35-36, éd. Lithops, Paris, France
- **Hänni** Henry A., (1987), *Caractéristiques des corindons chauffés et traités par diffusion*, Monde & Minéraux, N° 81, pp 22-25, éd. Lithops, Paris, France
- **Hänni** Henry A., (1987), *On Corundums from Umba Valley, Tanzania*, J. Gemm., Vol. XX, N° 5, pp 278-284, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Hänni** Henry A., (1994), *How to Identify Douros Synthetic Rubies*, J. New Asia, september, N° 121, pp 156, 160, 164, 168. Published by Asian Business Press, HK
- **Hänni** Henry A., (1994), *Terminology Considerations Regarding Padparadscha and African Orange Sapphire*, non édité
- **Hänni** Henry A., **Kiefert** Lore, **Chalain** Jean-Pierre, **Wilcock** I.C., (1996), *Ein Renishaw Raman Mikroskop im gemmologischen Labor: Erste Erfahrungen bei der Anwendung*, Z. Dt. Gemmol. Ges., Jahrgang 45, Heft2, pp 55-70, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Harder** H., (1992), *Moonstone Mining in Sri-lanka: New Aspects*, J. Gemm., Vol XXIII, N°1, pp 27-35, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Henn** U., **Bank** H., (1989), *Orange-farbene Korunde aus Malawi*, Z. Dt. Gemmol. Ges., Jahrgang 38, Heft 4, pp 164-165, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Henn** U., **Bank** H., **Bank** F. H., (1990), *Red and Orange Corundum (Ruby and Padparadscha) from Malawi*, J. Gemm., Vol XXII, N° 2, pp 83-89, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Hughes** Richard W., (1987), *Fading Test for Heat-treated Yellow Sapphires from Sri-lanka*, Response, Lab Alert, ICA
- **Hughes** Richard W., (1988), *Pleochroism and Colored Stone Grading*, Gemological Digest, Vol. 2, N° 3, pp 16-24, edited by the Asian Institute of Gemological sciences, Bangkok, Thailand
- **Hughes** Richard W., (1988), *Identifying Yellow Sapphires - Two Important Techniques*, J. Gemm., Vol. XXI, N° 1, pp 23-25, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Hughes** Richard W., **Roedder** Edwin, **Koivula** John, **Brown** Graham, **Schiffmann** Charles A., **Gübelin** Eduard, **Hänni** Henry A., (1988), *A Question of Origin*, Gemological Digest, Vol. 3, N° 1, pp 16-32, edited by the Asian Institute of Gemological sciences, Bangkok, Thailand
- **Hurwit** Karin, (1987), *Heat-treated Yellow Sapphire*, (Gem Trade Lab Notes), Gems & Gemology, vol. XXIII, N°3, p.167, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Jewellery News Asia**, (1992), *Padparadscha Problem in Japan*, J. New Asia, october, N° 98, pp 102,104, Published by Asian Business Press, HK
- **Johnson** Mary L., **Mercer** Meredith E., **Fritsch** Emmanuel, **Maddison** Patricia, **Shigley** James E., (1995), *"Ti-Sapphire": Czochralsky-pulled Synthetic Pink Sapphire from Union Carbide*, Gems & Gemology, vol. XXXI, N°3, pp. 188 - 195, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Kammerling** Robert C., **Koivula** John I., **Kane** Robert E., (1990), *Gemstone Enhancement and its Detection in the 1980s*, Gems & Gemology., Vol. XXVI, N° 1, pp 32-49, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Kammerling**, Robert C., (1994), *How to Identify Red Diffusion-treated Corundum*, J. New Asia, August, N° 120, pp 78-88 pages paires seulement, Published by Asian Business Press, HK
- **Kammerling** Robert C., **Koivula** John I., **Fritsch** Emmanuel, (1995), *Sapphires and Other Gems from Tanzania*, (Gem News), Gems & Gemology, vol. XXXI, N°2, pp 133-134, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Kane** Robert E., (1986), *Sapphire, Pinkish Orange ("Padparadscha")*, (Gem Trade Lab Notes), Gems & Gemology, vol. XXII, N°1, pp 52-53, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Kiefert** Lore, (1987), *Mineralogie von Korund*, Thesis
- **King** John M., **Moses** Thomas M., **Shigley** James E., **Liu** Yan, (1994), *Color Grading of Colored Diamond in the GIA Gem Trade Laboratory*, Gems & Gemology, vol. XXX, N°4, pp 220-242, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Koivula** John I., **Kammerling** Robert G., (1989), *"Padparadscha" Sapphire*, (Gem News), Gems & Gemology., Vol. XXV, N° 2, pp 114-115, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Koivula** John I., (1986), *Carbon Dioxide Fluid Inclusions as Proof of Natural-colored Corundum*, Gems & Gemology, vol. XXII, N°3, pp 152-155, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Kyocera Corp.**, (1993), *Properties of Inamori Stones*, Kyoreca Corp., Gemstones division, Kyoto, Japan
- **Lasnier** Bernard, (1985), *Gemmes de synthèses et traitement des pierres naturelles*, (compte-rendu), Réunion de la section des Sciences de la Terre, U.F.R. des Sciences et Techniques de Nantes, France
- **Lasnier** B., **Fritsch** E., **Lefrant** S., (1996), *Mise en évidence d'un traitement à haute température d'un saphir par détermination des produits de fusion incongruente d'un zircon affleurant*, Abstracts, GeoRaman-96

- **Liddicoat** Richard T., (1977), *Comment on the Hixon Collection*, Gems & Gemology, vol. XV, N° 9, pp 1, back flyleaf, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Liddicoat** Richard T., (1972), *Color Nomenclature, Umba River again?*, (Developments and Highlights at GIA's Lab in L.A.), Gems & Gemology, vol. XIV, N°4, pp. 102-108, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Loughlin** Donald G., (1994), *Sri-lanka - a Gemstone Buyer's Dream*, Gemm. Can., N° 38-39, pp 8 -17, ed. J.W. Kuehn, Vancouver
- **Mahroof** M.M.M., (1989), *The Muslim Lapidary, Some Aspects of the Gem Folkway in Sri Lanka*, J. Gemm., Vol. XXI, N° 7, pp 405-410, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Mahroof** M.M.M., (1992), *The Sri Lankan Ruby: Fact or Fable?*, J. Gemm., Vol. XXIII, N°1, pp 20-24, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **McClure** Shane E., **Kammerling** Robert C., (1992), *Sapphire: Color-zoned Sapphire*, (Gem Trade Lab Notes), Gems & Gemology., Vol. XXVIII, N°4, pp 265-266, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **McClure** Shane E., **Kammerling** Robert C., **Fritsch** Emmanuel, (1993), *Update on Diffusion Treated Corundum: Red and Other Colors*, Gems & Gemology., Vol. XXIX, N°12, pp 17-28, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1974), *The Origins of Color in Gems and Minerals, Part 1*", Gems & Gemology., Vol. XIV, N° 12, pp 354-361, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1975), *The Origins of Color in Gems and Minerals, Part 2*", Gems & Gemology., Vol. XV, N° 1, pp 2-11, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1975), *The Origins of Color in Gems and Minerals, Part 3*", Gems & Gemology., Vol. XV, N° 2, pp 35-43, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1980), *Irradiation Induced Colors in Gemstones*, Gems & Gemology., Vol. XVI, N° 11, pp 343-355, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1981), *Heat Treating Ruby and Sapphire: Technical Aspect*, Gems & Gemology., Vol. XVII, N° 3, pp 121-131, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, **Valente** G. Kaye, (1987), *The Seven Types of Yellow Sapphire and Their Stability to Light*, Gems & Gemology., Vol. XXIII, N° 4, pp 222-231, edited by The Gemological Institute of America, Santa Monica, CA, USA
- **Nassau** Kurt, (1987), *On the Colour of Gemstones and Nelson's "Body Colour"*, J. Gemm., Vol. XX, N° 6, pp 350-351, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Nelson** James B., (1987), *The Body Colour of Gemstones*, J. Gemm., Vol. XX, N° 7/8, pp 460-466, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Nelson** James, (1986), *The Colour Bar in the Gemstones Industry*, J. Gemm., Vol. XX, N° 4, pp 217-237, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Nicolini** Pierre, (1990), *Gîtologie et exploitation minière*, Collection Technique et Documentation, pp. 271-283, Lavoisier, Paris, France
- **Notari** F., (1994), *"Catharsis" du Livre des Gemmes CIBJO, édition 1991*, pp 5, 12, édité par Franck Notari, Genève, Suisse
- **Pardon** Daniel, (1996), *Dans les mines de saphir du Queensland*, Minéraux & Fossiles, N° 244, p. 10, Ed. CEDIM, Paris, France
- **Perera** S. I., **Pannila** A. S., **Gunasekera** H. P. N. J., **Ediriweera** R. N., (1991), *Anomalous Behaviour of Certain Geuda Corundums During Heat Treatment*, J. Gemm., Vol. XXII, N° 7, pp 405-407, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain.
- **Peretti** A., **Mullis** J., **Mouawad** F., (1996), *The Role of Fluorine in the Formation of Colour Zoning in Rubies from Mong Hsu, Myanmar (Burma)*, J. Gemm., Vol. XXV, N° 1, pp 3-19, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Platen** H. V., *Zur Genese von Korund in metamorphen Bauxiten und Tonen*, Z. Dt. Gemmol. Ges., Jahrgang 37, Heft 3/4, pp 129-137, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Ponahlo** Johan, (1984), *A New Lamp Using Standard Illuminant A, C and D 65 for Colour-grading of Gemstones*, J. Gemm., Vol. XIX, N° 2, pp 163-173, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Ponahlo** Johann, **Koroschetz** Thomas, (1986) *Quantitative Cathodoluminescence of Gemstones*, (20<sup>th</sup> international Gemmological Conference), Austr. Gemm., may 1986
- **Ponahlo** J., (1989), *Quantitative Kathodolumineszenz von Rubinen aus Malawi*, Z. Dt. Gemmol. Ges., Jahrgang 38, Heft 1, pp 37-40, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Ponahlo** Johann, (1989), *Mikrospectralphotometrie der Edelstein-Kathodolumineszenz*, Z. Dt. Gemmol. Ges., Jahrgang 38, Heft 2/3, pp 63-84, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Ponahlo** Johann, (1993), *Kathodolumineszenz (KL) und KL-Spektren von Edelsteinen*, Teil 1, Z. Dt. Gemmol. Ges., Jahrgang 42, Heft 2/3, pp 101-113, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Ponahlo** Johann, (1993), *Kathodolumineszenz und Absorptionsspektren gelber Sapphire*, Teil 1, Z. Dt. Gemmol. Ges., Jahrgang 39, Heft 4, pp 225-228, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Ponahlo** Johann, (1993), *Kathodolumineszenz (KL) und KL-Spektren von Edelsteinen*, Teil 2, Z. Dt. Gemmol. Ges., Jahrgang 42, Heft 4, pp 149-162, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Robert** Dominique, (1988), *Padparadschas traités par irradiation*, Revue de gemmologie a.f.g., N° 96, p 4, édité par l'Association française de gemmologie
- **Rupasinghe** M.S., **Rupasinghe** R.A.P., **Dissanayake** C.B., **Ileperuma** K. & O.A., Peradeniya, (1993), *A Tentative Classification of Heat-treatable Corundum (Geuda) Stones*, Z. Dt. Gemmol. Ges., Jahrgang 42, Heft 2/3, pp 115-121, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Rutland** E. H., (1969), *Corundum from Malawi*, J. Gemm., Vol. XI, N° 8, pp 320-323, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Schiffmann** C.A., (1981), *Unstable Colour in a Yellow Sapphire from Sri-Lanka*, J. Gemmol., vol. XVII, N°8, pp 615-618, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Schmetzer** Karl, (1977), *Chrom, Eisen & Titan*, Lapis, Jahrgang 2, N° 8, pp 8-9, Verlag Christian Weise, München, Deutschland
- **Schmetzer** Karl, **Bank** H., (1981), *Die Farbensachen und Farben der Mineralart Korund*, Z. Dt. Gemmol. Ges., Jahrgang 30, Heft 3/4, pp 152-156, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Schmetzer** K., **Bossahrt** G., **Hänni** H. A., (1982), *Naturfarbene und behandelte gelbe und orange-braune Sapphire*, Z. Dt. Gemmol. Ges., Jahrgang 31, Heft 4, pp 265-279, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Schmetzer** K., **Bossahrt** G., **Hänni** H. A., (1983), *Naturally Coloured and Treated Yellow and Orange-brown Sapphires*, J. Gemm., vol. XVIII, N° 7, pp 607-622, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Schmetzer** Karl, (1985), *Distinction of Natural and Synthetic Rubies by Ultraviolet Absorption Spectroscopy - Possibilities and Limitations of the Method*, Z. Dt. Gemmol. Ges., Jahrgang 34, Heft 3/4, pp 101-129, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Schmetzer** Karl, (1987), *On Twinning in Natural and Synthetic Flux-grown Ruby*, J. Gemm., Vol. XX, N° 5, pp 294-305, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Schmetzer** Karl, (1988), *Examination of Three-phase Inclusion in Colorless, Yellow, and Blue Sapphires from Sri-Lanka*, Gems & Gemology., Vol. XXIV, N° 4, pp 107-111, edited by The Gemological Institute of America, Santa Monica, CA, USA

- **Schmetzer Karl, Kiefert Lore**, (1990), *Spectroscopic Evidence for Heat Treatment of Blue Sapphire from Sri-Lanka - Additional Data*, J. Gemm., Vol. XXII, N° 2, pp 80-82, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Schrader H.-W., Henn U.**, (1985), *Über die Problematik der Galliumgehalte als Hilfsmittel zur Unterscheidung von natürlichen Edelsteinen und synthetischen Steinen*, Z. Dt. Gemmol. Ges., Jahrgang 34, Heft 3/4, pp 152-159, Deutsche Gesellschaft für Edelsteinkunde, Idar-Oberstein, Deutschland
- **Sersen, William J.**, (1988), *Colored Stone Grading and the Question of Nomenclature*, Gemological Digest, Vol. 2, N° 3, pp 29-34, edited by the Asian Institute of Gemological sciences, Bangkok, Thaïlande
- **Sersen, William J.**, (1988), *Buying and Selling Gems, What Light is Best*, Gemological Digest, Vol. 2, N° 3, pp 45-56, edited by the Asian Institute of Gemological sciences, Bangkok, Thaïlande
- **Shida Junko**, (1992), *Color limitation of Padparadsha Sapphire*, JewelSiam, nov.-dec., pp 104 -106
- **Solomonov Vladimir I., Mikhailov Sergei G., Osipov Vladimir V.**, (1993), *Spectral-luminescent Technique for Gemmology*, The Electrophysic Institute of the Ural Division of the Russian Academy of Sciences, Ekaterinburg, Russie
- **Spießner M.**, (1994), *Bref rappel sur l'histoire des gemmes et de leur synthèses*, ICPM, Nantes, non publié
- **Temple, Sir Richard C.**, (1923), *Colour Symbolism, As a Subject for Indian Research*, Indian Antiquary, Vol. LII, pp 61-65, The British India Press, Mazgaon, India
- **Troup G. J., Hutton D. R., Pilbrow J. R.**, (1985), *Electron Spin Resonance Spectra of Natural and Synthetic Sapphires at S-band (2-4 GHz)*, J. Gemm., Vol. XIX, N°5, pp 431-436, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain
- **Troup G. J., Hutton D. R., Turner B.**, (1992), *Magnetic Resonance Distinction Between Synthetic and Natural "Padparadscha" Sapphire*, J. Gemm., Vol. XXIII, N° 2, pp 97-103, edited by The Gemmological Association and Gem Testing Laboratory of Great Britain

### Books:

- **Aballain M., Chambolle P., Derec-Poussier F., Guillemin C., Mignon R., Pierrot R., Sarcia J.A.**, (1968), *Index Alphabétique de Nomenclature Minéralogique*, Bureau de Recherches Géologiques et Minières, Imprimerie C.N.R.S., France
- **Adams Frank D., Graham R.P.D.**, (1926), *On Some Minerals from the Ruby Mining District of Mogok, Upper Burma*, trans. Roy. Soc. Of Canada, Thrd Ser., Vol. XX, Sect. IV, pp. 113-136, Ottawa, Canada
- **Anderson B.W.**, (1947), *Gem Testing*, Fourth edition, Heywood & Company, Ltd., London
- **Anderson B.W.**, (1990), *Gem Testing*, revised by E.A. Jobbins, tenth ed., Butterworth, London
- **Anderson B.W.**, (1971), *Identification des Pierres précieuses*, traduction C.A. Schiffmann, Ed. Hugo Buchser, Genève, Suisse
- **Angenault Jacques**, (1995), *La Chimie, Dictionnaire encyclopédique*, 2ème édition, Dunod, Paris, France
- **Arem J.E.**, (1987), *Color Encyclopedia of Gemstones* 2nd edition, Van Nostrand Reinhold, N.Y., USA
- **Arnaud Paul**, (1993), *Cours de Chimie Physique*, 3ème édition, Dunod, Paris, France
- **Ariyaratna D.H.**, (1993), *Gems of Shri Lanka*, fifth edition, D.H. Ariyaratna, London, England
- **Bank Hermann**, (1966), *Edelsteine und Mineralien*, zweite Auflage 1967, Alles + Brillant Fachverlag und Industrieservice, Taunus, Deutschland
- **Bank Hermann**, (1981), *Aus der Welt der Edelsteine*, 3ème édition, Pinguin-Verlag AG, Innsbruck, Autriche
- **Bariand P., Cesbron F., Geffroy J.**, (1984), *Les Minéraux, leurs gisements, leurs associations*, 3 volumes, Editions du B.R.G.M., Orléans, France
- **Bariand P., Poirot J.P.**, (1985), *Larousse des Pierres Précieuses*, Libr. Larousse, Paris, France
- **Barlow Alfred, Ernest**, (1915), *Corundum, its Occurrence, Distribution, Exploitation, and Uses*, Geological Survey, department of Mines, Ottawa, Canada
- **Bauer Max**, (1896), *Edelsteinkunde*, 1st edition, C. Hermann Tauchnitz Ed., Leipzig, DDR
- **Bauer Max**, (1909), *Edelsteinkunde*, 2nd edition, C. Hermann Tauchnitz Ed., Leipzig, DDR
- **Bauer Jaroslav, Tvrz F.**, (1972), *Der Kosmos-Mineralienführer*, Kosmos Gesellschaft der Naturfreunde Franckh'sche Verlagshandlung, Stuttgart, Deutschland
- **Baumgärtel Rolf, Quellmalz Werner, Schneider Werner**, (1988), *Schmuck und Edelsteine*, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, DDR
- **Bernard Maurice**, (1994), *Cours de chimie minérale*, 2ème édition, Dunod, Paris, France
- **Bétektine A.**, (1968), *Manuel de Minéralogie Descriptive*, 3ème édition, Éd. Mir, Moscou, URSS
- **Bolman J.**, (1942), *Welcher Edel- oder Schmuckstein*, E.J. Brill, Leiden, Holland
- **Bowersox Gary W., Chamberlin Bonita E.**, (1995), *Gemstones of Afghanistan*, Geoscience Press Inc., Tucson, Arizona, USA
- **Burkhardt Max**, (1918), *Die Grundgesetze der Farbenharmonie*, Verlag M. Malz Optische Werkstätte, St Gall, Schweiz
- **Calas G.**, (1986), *Méthodes Spectroscopiques appliquées aux Minéraux*, Société française de Minéralogie et Cristallographie, Paris, France
- **Cambridge University**, (1981), *The Cambridge Encyclopedia of Earth Sciences*, Cambridge University Press, Cambridge London, England
- **Castellani Augusto**, (1871), *Gems, Notes and Extracts*, Bell & Daldy, London, England
- **Chalain Jean-Pierre**, (1992), *Vers une gemmologie de laboratoire*, Faculté des Sciences et des Techniques, Mémoire de D.U.G., Université de Nantes, France
- **Chudoba, Gübelin E.**, (1953), *Schmuck und edelsteinkundliches Tachenbuch*, Verlag Bonner Universitäts-Buchdruckerei Gebr. Scheur G.m.b.H., Bonn, Deutschland
- **Chudoba, Gübelin E.**, (1956), *Echt oder Synthetisch*, Rühle Diebener Verlag KG, Stuttgart, Deutschland
- **Church A.H.**, (1887), *Colour*, Cassel & Company Ltd, London, England
- **CIBJO**, (1970), *Edelsteine, Perlen, Definitionen Anwendungsbestimmungen Übersicht*, Vereinigung Schweizerischer Juwelen und Edelmetallbranchen, Berne, Schweiz
- **CIBJO**, (1982), *Gemstones / Pearls*, Allemand anglais espagnol et français, International Confederation of Jewellery, Silverware, Diamonds, Pearls and Precious Stones, London, England
- **Clabaugh Stephen E.**, (1952), *Corundum Deposits of Montana*, Geological Survey, Bulletin N°983, United States Department of the Interior, Washington, USA
- **Cloos Walther**, (1965), *Kleine Edelsteinkunde*, 2eme éd., Verlag freies Geistesleben GmbH, Stuttgart, Deutschland
- **Cosandey René**, (1956), *Etude sur la préparation du corindon*, Thèse de Doctorat ès Sciences, Université de Lausanne, Faculté des Sciences
- **Deer W.A., Howie R.A., Zussman J.**, (1993 reprint), *An Introduction to the Rock Forming Minerals*, 2nd edition, Longman Sci.&Tech., Essex, England
- **Desautels Paul E.**, (1971), *The Gem Kingdom*, Macdonald and Co Ltd, London, England

- **Desautels** Paul E., (1973), *L'Univers de Pierres précieuses*, trad. Raymond Albeck, Arthaud, Paris, France
- **Deicha** G., (1955), *Les lacunes des cristaux et leur inclusions fluides*, Masson et Cie, Paris
- **Dragsted** Ove, (1972), *Edelsteine in Farben*, Trad. Dagmar-Renate Jehnich, Universitas Verlag, Berlin, Deutschland
- **Eiseman** Leatrice, **Herbert** Lawrence, (1990), *The Pantone Book of Color*, Harry N. Abrams Inc, New York, USA
- **Entremont** Pascal, (1992), *Chasseur de Pierres*, éditions Robert Laffont, Paris, France
- **Finot** Louis, (1896), *Les lapidaires indiens*, Bibliothèque de l'école des hautes études, Emile Bouillon éditeur, Paris, France
- **Fleischer** M., **Mandarino** J.A. (1995), *Glossary of Mineral Species*, The Mineralogical Record, Inc., Tucson, Arizona, USA
- **Font-Alba** M., (1960), *L'Encyclopédie en couleur de la Minéralogie*, Trad. R. Van Tassel, Marabout Université, Verviers, Belgique
- **Fontana** M., (1995), *Guide des Pierres Précieuses*, Editions de Vecchi, Paris, France
- **Foucault** A., **Raoult** J.F., (1995), *Dictionnaire de géologie*, 4ème édition, Masson, Paris, France
- **Friol** Marie-Françoise, (1994), *Transparence scientifique en gemmologie, Codification internationale des traitements*, Mémoire de D.U.G., Université de Nantes, France
- **GIA**, (1993), *Gem Reference Guide*, Gemological Institute of America, Santa Monica, California, USA
- **Girault** J., (1980), *Caractères optiques des minéraux transparents*, éd. Masson, Paris, France
- **Gravender** Milton F., (1952), *Fascinating Facts About Gems*, opusculé, tenth ed., The Gemological Institute of America, Los Angeles, CA, USA
- **Grether** P.A., (sans date), *Connaissance des Pierres précieuses*, à compte d'auteur, La-Chaux-de-fonds, Suisse
- **Gübelin** Eduard, (1942), *Saphire und Rubine*, opusculé édité par Eduard Gübelin, Lucerne, Schweiz (2 ex.)
- **Gübelin** Eduard, (1952), *Edelsteine*, N° 59, Hallwag AG, Bern, Schweiz
- **Gübelin** Eduard, (1968), *Die Edelsteine des insel Ceylon*, Gübelin, Lucerne, Schweiz
- **Gübelin** Eduard, (1969), *Pierres précieuses*, Editions Silva, Zürich, Schweiz
- **Gübelin** Eduard, (1974), *Internal World of Gemstones*, 1st ed., ABC Edition, Zurich, Schweiz
- **Gübelin** Eduard, **Koivula** John I., (1986), *Photoatlas of Inclusions in Gemstones*, ABC Editions, Zürich, Switzerland
- **Girault** J., (1980), *Caractères optiques des minéraux transparents*, éd. Masson, Paris, France
- **Grossmann** H., **Neuburger** A., (1918), *Die Synthetischen Edelsteine*, Verlag von M. Krayn, Berlin, Deutschland
- **Guhr** Andreas, **Nagler** Jörg, (1986), *Mythos der Steine*, Eller & Richter Verlag, Hamburg, Deutschland
- **Hahn** M., **Bank** H., (1986), *Edelsteinkunde*, Industrie und Handelskammer zu Koblenz Bezirksstelle Idar-oberstein, Deutschland
- **Hitzké** J.-C., (1988), *Dictionnaire de la Chimie et du Génie chimique*, J.-C. Hitzké, I.U.T., Illkirch Graffenstaden, France
- **Hodgkinson** Alan, (1995), *Visual Optics*, Gemworld international, Inc, Northbrook, Illinois, USA
- **Hughes** Richard W., (1990), *Corundum*, Butterworth-Heinemann Ltd, London, England
- **Hurlbut** Cornelius S. Jr., **Switzer** Georges S., (1979), *Gemmology*, Ed. John Wiley & Sons, New-York, USA
- **Institut Suisse de Gemmologie**, - (1995), *Identification of a Raman spectrum*, Laboratoire SSEF, Basel, Suisse
- **Keller** Peter C., (1990), *Gemstones and their Origins*, Van Nostrand Reinhold, New York, USA
- **Keller** Peter C., (1992), *Gemstones of East Africa*, Geoscience Press Inc., Phoenix, Arizona USA
- **Klein** Cornelis, **Hurlbut** Cornelius S.Jr., (1993), *Manual of Mineralogy*, 21st edition, John Wiley & Sons Inc, New York, USA
- **Kornerup** A., **Wanscher** J.H., (1984), *Methuen Handbook of Colour*, third edition, Introduced and revised by Don Pavey, Methuen, London, England
- **Krauss** Ferdinand, (1929), *Syntetische Edelsteine*, Verlag von Georg Stilke, Berlin, Deutschland
- **Lasnier** Bernard, (1993), *Minéralogie*, DEUG B2, Module G5, Université de Nantes, Nantes, France
- **Liddicoat** Richard T., (1993), *Handbook of Gem Identification*, 12th edition, G.I.A., Santa Monica, USA
- **Lüschen** Hans, (1968), *Die Namen der Steine*, Ott Verlag, Thun, Schweiz
- **Maestrati** Roland, (1989), *Catalogue Raman des Gemmes*, D.U.G., Univerité de Nantes, Nantes, France
- **Mathieu** J.P., **Kastler** A., **Fleury** P., (1991), *Dictionnaire de physique*, 3ème éd., Masson et Eyrolles, Paris, France
- **Michel** Hermann, (1914), *Künstliche Edelsteine*, Schriften des Vereins zur Verbreitungnatur Wiss. Kenntnisse, Wien, Autriche
- **Mottana** Annibale, **Burrigato** Francesco, (1990), *Absorbition Spectroscopy in Mineralogy*, Elsevier, Amsterdam, Hollande
- **Mumme** I.A., (1988), *The World of Sapphires*, Mumme Publications, Port Hacking, NSW, Australie
- **Nassau** Kurt, (1980), *Gems Made by Man*, Chilton Books Co, Radnor, Pennsylvania, USA
- **Nassau** Kurt, (1983), *The Physics and Chemistry of Color*, Wiley-Interscience Publ., New York, USA
- **Nassau** Kurt, (1984), *Gemstone Enhancement*, Butterworths, London, England
- **Notari** F., (1994), *Nomenclature des pierres précieuses fines et ornementales couramment utilisées en bijouterie-joaillerie*, édité par Franck Notari pour la Section suisse du Centre de Recherche Gemmologique, Genève, Suisse
- **Nekrassov** B., (1964), *Chimie minérale*, Éd. Mir, Moscou, URSS
- **Newman** Harold, (1981), *An Illustrated Dictionary of Jewellery*, Thames and Hudson, London, GB
- **Newman** Renée, (1991), *The Ruby & Sapphire Buying Guide*, International Jewelry Publications, Los Angeles, USA
- **O'Donoghue** M., (1983), *Identifying Man-made Gems*, NAG Press Ltd, London, England
- **O'Neil** Paul, (1984), *Der Planet erde Edelsteine*, trad. Hans-Heinrich Wellmann, Time-Life Bücher, Amsterdam, Holland
- **Payette** Francine, (1994), *La Gemmologie, Notions, Principes, Concepts*, 2eme édition, Fischer Press, Sillery, Canada
- **Pinet** Michèle, **Smith** David C., **Lasnier** Bernard, (1992), *La Microsonde Raman en Gemmologie, "Utilité de la Microsonde Raman pour l'identification non destructive des gemmes"*, Hors-série, Revue de Gemmologie A.F.G., Paris, France
- **Pratt** Joseph Hyde, (1901), *The Occurrence and Distribution of Corundum in the United States*, Bull. Of the United States Geological Survey, Serie A, Economic, Geology, 11, N° 180, , Washington, USA
- **Punchihewa** Leslie J., (1983), *Gem Buying Hints*, Leslie J. Punchihewa, Colombo, Sri Lanka
- **Read** P.G., (1991), *Gemmology*, Butterworth-Heinemann Ltd, London, England
- **Reuck** A.V.S. de, **Knight** Julie, (1965), *Colour Vision*, J. & A. Churchill, Ltd, London, England
- **Robbins** Manuel, (1994), *Fluorescence, Gems and Minerals under ultraviolet light*, Geoscience Press Inc., Phoenix, Arizona, USA
- **Roberts** W. L., **Rapp** G.R. Jr., **Weber** J., (1994), *Encyclopedia of Minerals*, 2nd edition, Van Nostrand Reinhold co, New York, USA
- **Rueder** Edwin, (1984), *Fluid Inclusions*, M.S.A. Rev. Min. vol. 12, Paul H. Ribbe Ed., Blacksburg Virginia, USA - (T.O<sup>FN</sup>)
- **Rosival** August, (1914), *Über Edle Steine*, Schriften des Vereins zur Verbreitungnatur Wiss. Kenntnisse, Wien, Autriche
- **Rösler** Hans Jürgen, (1988), *Lehrbuch der Mineralogie*, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, DDR
- **Ruppenthal** Paul, (1985), *Edelsteine, Handel und Industrie in Raum Idar-Oberstein von 1923 bis 1985*, A. Ruppenthal, Idar-Oberstein, Deutschland
- **Rys** Paul, **Zollinger** Heinrich, (1982), *Farbstoffchemie*, 3<sup>ème</sup> ed., Verlag Chemie GmbH, Weinheim Deutschland
- **Sarmant** Jean-Pierre, (1988), *Dictionnaire de Physique*, 2ème édition, Hachette, Paris, France  
Verlagsbuchhandlung. (Nägele u. Obermiller). Stuttgart, Deutschland
- **Séguy** E., (1936), *Code universel des couleurs*, Editions Lechevalier, Paris, France
- **Shepherd** T., **Rankin** A.H., **Alderton** D.H.M., (1985), *A Practical Guide to Fluid Inclusion Studies*, Blackie, Glasgow, England
- **Schlossmacher** Karl, (1969), *Edelsteine und Perlen*, 5<sup>ème</sup> ed., E.Schweizerbart'sche Verlagsbuchhandlung.  
(Nägele u. Obermiller). Stuttgart, Deutschland



- **Schmetzer** K., (1986), *Natürliche und synthetische Rubine, Eigenschaften und Bestimmung*, E.Schweizerbart'sche
- **Schöndorff** Erica, (1955), *Schmuck und Edelsteine*, Droemersch Verlag, München, Deutschland
- **Schubnel** H.-J., (1972), *Pierres Précieuses dans le Monde*, Horizons de France, Paris, France
- **Schubnel** H.-J., (1992), *La Microsonde Raman en Gemmologie, "Une méthode moderne d'identification et d'authentification des gemmes"*, Hors-série, Revue de Gemmologie A.F.G., Paris, France
- **Schumann** Walter, (1979), *Guide des pierres précieuses, pierres fines, pierres ornementales*, traduction Frances Georges-Catroux, Delachaux & Niestlé, Neuchâtel, Suisse
- **Sinkankas** John, (1988), *Gemstone & Mineral data Book*, Geoscience Press, Prescott Arizona, USA
- **Sinkankas** John, (1993), *Gemology an Annotated Bibliography*, The Scarecrow Press, Inc., London, England
- **Smith** G.F. Herbert, (1950), *Gemstones*, eleventh edition, Methuen & Co. LTD., London, England
- **Tacconi** Rosita, Rosignoli Maria Pia, (1968), *Gioielli e Pietre Preciose*, Mondadori, Verone, Italie
- **Tardy** (Lengellé Henri), (1965), *Les pierres précieuses, les pierres dures, les perles, l'ambre, l'écaïlle, l'ivoire et la répression des fraudes*, Tardy, Paris, France
- **Tardy** (Lengellé Henri et Maurice) et Dina **Level**, (1980), *Les Pierres précieuses*, 5<sup>ème</sup> édition revue et corrigée, édité par Maurice Lengellé-Tardy, Paris, France
- **Temple**, Sir Richard C., (1923), *Colour Symbolism, As a Subject for Indian Research*, The British India Press, Mazgaon, India (TAP)
- **Themelis** Ted, (1992), *The Heat Treatment of Ruby and Sapphire*, Gemlab Inc, USA
- **Vanlandingham** Sam L., (1985), *Geology of World Gem Deposit*, Van Nostrand Reinhold Company, New York, USA
- **Virginio** Albi, (1990), *Le cristal orange*, Editions Orionis, Cournon d'Auvergne, France
- **Wolf** Bella Sidney, (1929), *How to See Ceylon*, 4<sup>ème</sup> édition, The Time of Ceylon, Colombo, Ceylon
- **Vollstädt** Heiner, Baumgärtel Rolf, (1980), *Edelsteine*, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, Deutschland
- **Wahlstrom** Ernest E., (1966), *Optical Cristallography*, Third ed., Fth printing, John Wiley & Sons, New York, USA
- **Webster** Robert, (1994), *Gems, Their Sources, Description and Identification* 5th Ed. Rev. by B.W. Anderson, Butterworth-Heinemann Ltd, London, England
- **Whelan** Bride M., (1994), *Color Harmony*, Rockport Publishers, Massachusetts USA
- **Weibel** Max, (1985), *Edelsteine*, ABC Verlag, Zürich, Schweiz

#### Internet:

<http://www.gemlink.de/GEMLINK/G.Edelstein>, *Der Deutsche Server für Schmuck und Uhren*.

<http://www.gemstone.org/fancy.html>, *Sapphires: More than the Blues*.