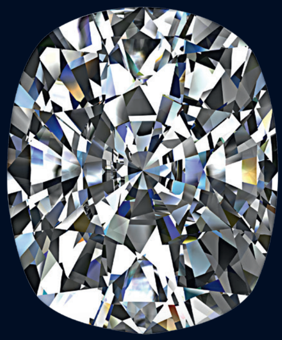

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Gemmological Features of Pink and Purple Diamonds from Siberia and Arkhangelsk Region
西伯利亞和阿爾漢格爾斯克地區的粉紅色和紫色鑽石的寶石學特徵


Yuri Shelemetiev


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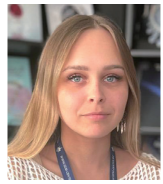
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所有寶石中，彩鑽代表了很小但非常有趣的一部分。最近，優質粉紅鑽石的世界拍賣價格已達到每克拉500萬美元。粉紅色鑽石在自然界中很少出現，因此市場上也有實驗室培育和顏色處理的粉紅色鑽石。天然粉紅鑽石特性的表徵有助於將天然粉紅鑽石與其合成和處理過的模擬石區分開來。此外，文獻中有一些理論認為，粉紅色鑽石具有可以判斷其地理來源的特徵。在許多礦床中都發現了粉紅鑽石，包括阿蓋爾（澳洲）、印度南部（戈爾康達地區）、巴西（米納斯吉拉斯州）、坦尚尼亞（威廉森礦場）、印尼（婆羅洲）、委內瑞拉和南非（Premier/Cullinan礦）（Gaillou等人）等，2010）。除此之外，在西伯利亞（Internationalnaya Pipe，請參閱Yuryeva等人，2020年）、Anabar地盾以及阿爾漢格爾斯克地區的Lomonosov礦床還發現了粉紅色鑽石。

莫斯科國立大學寶石學中心對這組刻面天然粉紅色和紫色鑽石進行了研究。這些鑽石是在西伯利亞和阿爾漢格爾斯克地區開採的，並備來源記錄。西伯利亞和阿爾漢格爾斯克地區的鑽石礦區屬於不同的地質結構：西伯利亞克拉通和波羅的海地盾（圖1）。我們將在此報告我們研究中揭示的特性，並與現有文獻中報告的其他粉紅色鑽石特徵進行比較，討論這些特性。

Introduction

Among all precious stones fancy coloured diamonds represent a small but very interesting part. Recent international auction prices for top quality fancy pink diamonds have reached USD5 million per carat. Pink diamonds rarely occur in nature so there are also lab grown and colour treated pink diamonds on the market. Characterisation of natural pink diamond properties is helpful for separating natural pink diamonds from their synthetic and treated analogues. Also, there are theories in literature that pink diamonds have features that can tell their geographic origin. Pink diamonds were found in many deposits including Argyle (Australia), Southern India (Golconda area), Brazil (Minas Gerais), Tanzania (Williamson mine), Indonesia (Borneo), Venezuela and South Africa (Premier/Cullinan mine) (Gaillou et al., 2010). Apart from that there are findings of pink diamonds in Siberia (Internationalnaya pipe, see for example Yuryeva et al., 2020), at the Anabar shield, and at the Lomonosov deposit in Arkhangelsk region.

The set of faceted natural pink and purple diamonds was studied at MSU Gemmological Center. These diamonds were mined in Siberia and Arkhangelsk region and have documented origin. Diamond bearing fields in Siberia and Arkhangelsk region belong to different geological structures: Siberian craton and Baltic shield (Fig. 1). We will report here properties revealed under our study and discuss these properties in comparison to other pink diamond features reported in the existing literatures.

Materials and Methods

In this study we examined 33 natural faceted pink diamonds that were submitted to the MSU Gemmological Center. Regarding geographic origin, most pink diamonds are related to

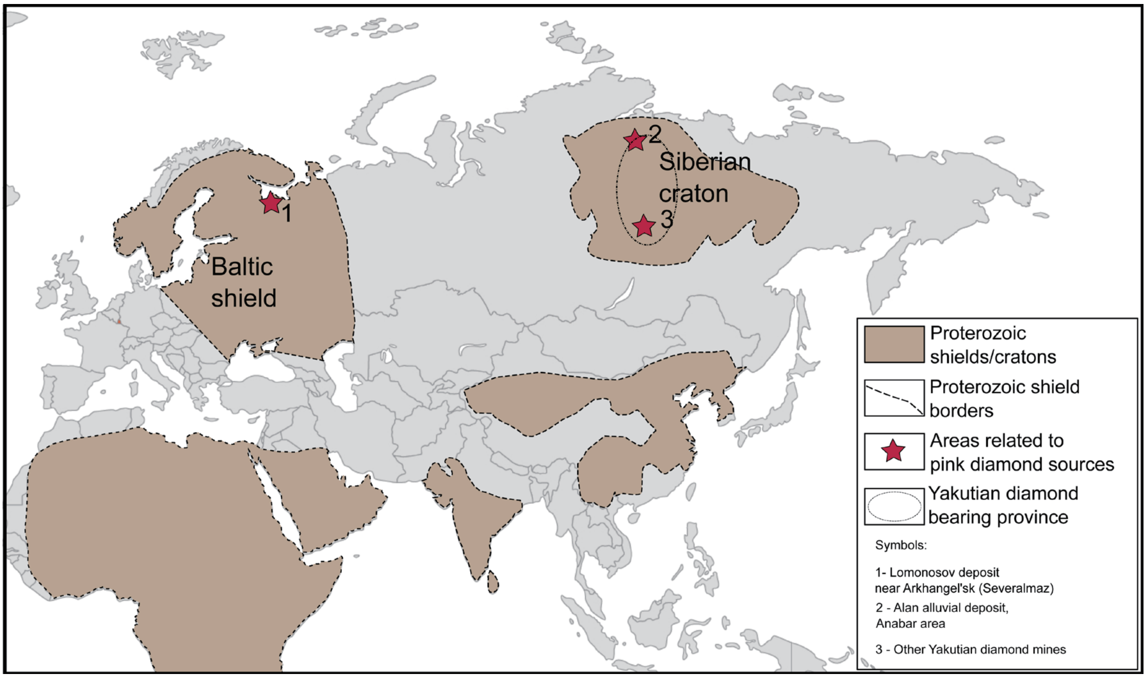

Fig. 1 Simplified scheme of pink diamond sources that are located in two different geological structures: Baltic shield and Siberian craton. *Modified after Marshak, 2005.*
位於兩個不同地質結構的粉紅色鑽石來源的簡化方案：波羅的海地盾和西伯利亞克拉通。

Yakutian diamond bearing province (22 of 33 pink diamonds), the rest of them come from the Lomonosov deposit of Arkhangelsk region (6 of 33 pink diamonds) and the Alan alluvial deposit in the Anabar area (5 of 33 pink diamonds). The mass of these samples vary from 0.16 to 0.50 ct, their shape ranges from cushion (21 pcs), oval (7 pcs), or pear (4 pcs), to round (1 pc). Gemmological properties of all samples are shown in Table 1. Our laboratory has graded the colour of all these diamonds and performed measurements of UV-Vis-NIR absorption, IR transmission, PL (photoluminescence) spectra, and Raman scattering of the inclusions.

Colour grades are varied from Faint Pink to Fancy Deep Purplish Pink, most of these diamonds have a purple body colour and in some cases pink. The pink diamonds examined have brown, pink, purple colour modifiers. Modifying colours such as orange, purple, and brown are common in pinks. Grey is also seen as a colour modifier, but rarely. The saturation varies from Faint Pink to Fancy Vivid Pinkish Purple. Fig. 2 illustrates the variety of colours seen in pink diamonds from different locations examined in this study: ranging from pink through purplish pink and with some bearing brownish tint. Most of our samples have "none" fluorescence grade, and only two are graded as "faint".

Table 1 Gemmological properties of samples under study. Yak – Yakutia; Alan – Alan, Anabar; Lom – Lomonosov mine, Severalmaz.
研究樣品的寶石學特性

Ref	Mass (ct)	Shape	Colour	Clarity	Fluor
Yak 01	0.21	RD	Deep Purplish Pink	I1	NONE
Yak 02	0.21	PS	Fancy Purplish Pink	SI1	NONE
Yak 03	0.31	OV	Fancy Purple	SI1	NONE
Yak 04	0.16	CUSH	Vivid Pinkish Purple	I1	NONE
Yak 05	0.21	CUSH	Fancy Purplish Pink	SI1	NONE
Yak 06	0.22	CUSH	Fancy Purplish Pink	SI2	NONE
Yak 07	0.22	CUSH	Intense Purple	SI2	NONE
Yak 08	0.22	CUSH	Intense Purplish Pink	SI2	NONE
Yak 09	0.22	CUSH	Intense Purple	I1	NONE
Yak 10	0.20	CUSH	Intense Pinkish Purple	I1	NONE
Yak 11	0.21	CUSH	Intense Purple	I2	NONE
Yak 12	0.28	CUSH	Fancy Pink Purple	VS1	NONE

to be con't next page

continue to previous page

Ref	Mass (ct)	Shape	Colour	Clarity	Fluor
Yak 13	0.28	CUSH	Intense Purplish Pink	SI1	NONE
Yak 14	0.23	CUSH	Deep Purplish Pink	SI1	NONE
Yak 15	0.31	CUSH	Fancy Purple	SI1	NONE
Yak 16	0.30	CUSH	Fancy Pinkish Purple	I1	NONE
Yak 17	0.35	CUSH	Fancy Pinkish Purple	SI2	NONE
Yak 18	0.30	CUSH	Intense Purple	I1	NONE
Yak 19	0.31	CUSH	Intense Purple	I1	NONE
Yak 20	0.31	CUSH	Faint Pink	I1	NONE
Yak 21	0.33	CUSH	Fancy Purple	I1	NONE
Yak 22	0.31	CUSH	Fancy Pinkish Purple	I1	NONE
Lom 01	0.23	PS	Fancy Brownish Pink	SI2	NONE

Ref	Mass (ct)	Shape	Colour	Clarity	Fluor
Lom 02	0.31	PS	Fancy Purplish Pink	VS1	NONE
Lom 03	0.24	OV	Fancy Brownish Pink	SI1	NONE
Lom 04	0.39	OV	Faint Pink	VVS2	FNT
Lom 05	0.50	OV	Fancy Brownish Pink	SI2	NONE
Lom 06	0.32	CUSH	Fancy Brownish Pink	VVS2	NONE
Alan 01	0.40	PS	Fancy Purple	VS2	NONE
Alan 02	0.23	OV	Fancy Light Purple	VS2	NONE
Alan 03	0.31	OV	Intense Brownish Pink	VVS1	NONE
Alan 04	0.35	OV	Fancy Brownish Pink	VVS2	FNT
Alan 05	0.28	CUSH	Fancy Brownish Pink	SI1	NONE

Fig. 2 Pink and purple diamond samples used for this study: Lomonosov mine, Severalmaz (upper row), Alan, Anabar (middle row), and Yakutia (bottom row). Size range is from 0.16 ct to 0.50 ct. Colour grades: from Faint Pink to Fancy Vivid Pinkish Purple. FOV 45 mm. *Photo by Ioanna Kirillina.*
本研究使用的粉紅色和紫色鑽石樣本：羅蒙諾索夫礦場、Severalmaz（上排）、Alan、Anabar（中排）和Yakutia（下排）。尺寸範圍為0.16克拉至0.50克拉。顏色等級：從淡粉紅色到艷彩粉紫色。視場45毫米。

UV-Vis-NIR spectra were recorded at room temperature with an Ocean Optics QE65000 spectrometer with FOIS-1 integral sphere and HL-2000-HP light source, with 400-1000 nm spectral range, using a 50 μm slit, 1 second exposure and averaging the results over 50 scans.

FTIR transmission spectra were collected from 8000 to 500 cm^{-1} range using a Bruker ALPHA spectrometer using 2 cm^{-1} resolution, 32 scans, at room temperature.

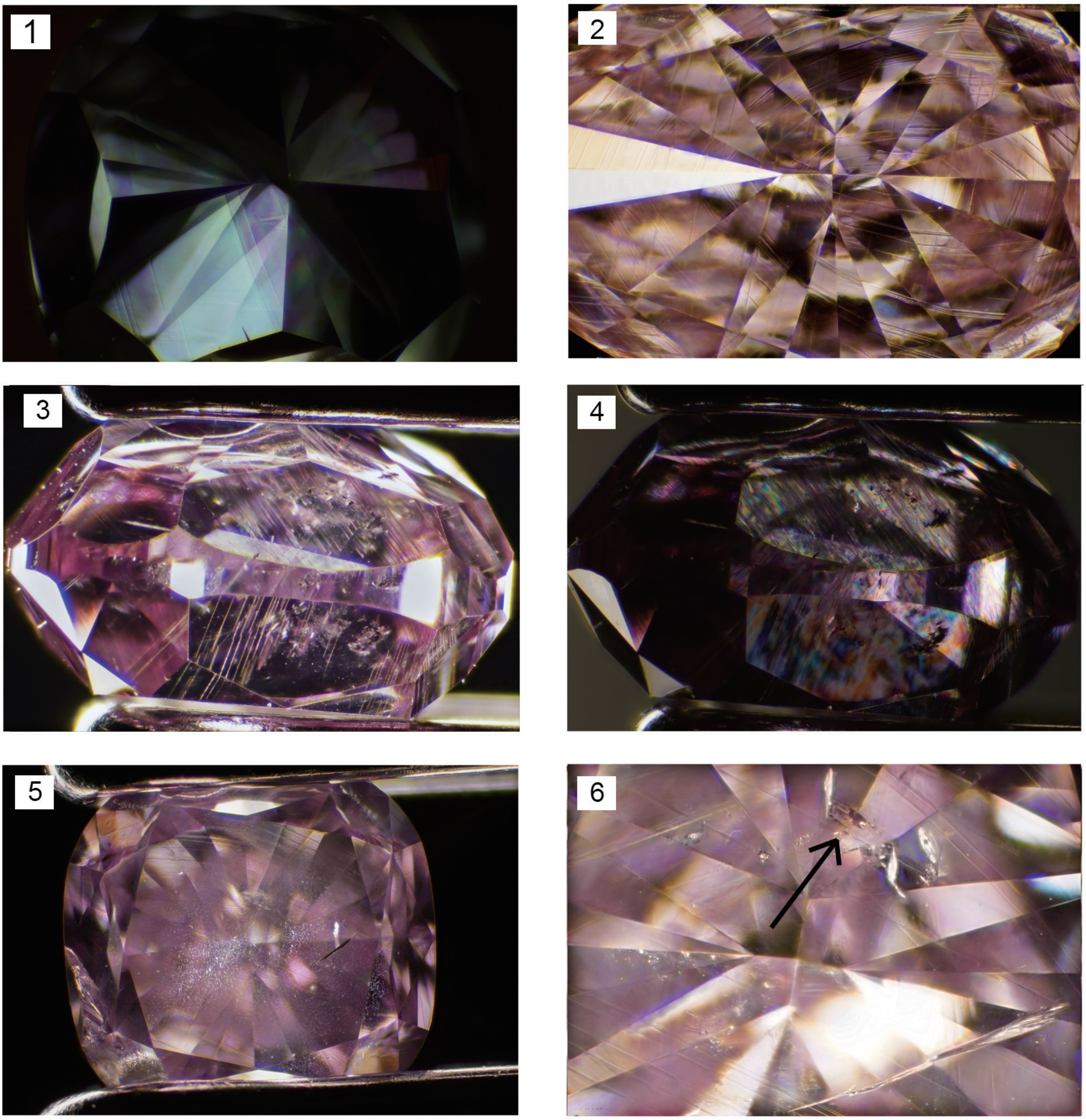

Fig. 3 The most common microscopic features of pink diamonds from this study as elaborated in next page: 1 - colour zoning and internal graining (Yak 17), FOV 2 mm; 2 - external graining lines at the crown and pavilion facets (Lom 02), FOV 4 mm; 3 and 4 - this diamond shows anomalous birefringence that is viewed through crossed polarizers (right), indicating that the lattice has been distorted due to plastic deformation (Yak 19), FOV 7 mm; 5 - a cloud under the table (Yak 11), FOV 8 mm; 6 - several inclusions with cracked halos (identified with micro-Raman as a mineral from pyroxene-omphacite group) (Yak 06), FOV 2 mm. *Photo by Olga Yarapova.*

後頁描述的本研究中粉紅鑽石最常見的微觀特徵：1 - 色域和內部紋理(Yak 17)，FOV 2 mm；2 - 冠部和亭部刻面的外部紋理線(Lom 02)，FOV 4 mm；3和4 - 透過正交偏振片（右）觀察，這顆鑽石顯示出異常雙折射，顯示晶格因塑性變形而扭曲(Yak 19)，FOV 7 mm；5 - 桌面下的雲狀物(Yak 11)，FOV 8 mm；6 - 數個帶有裂紋暈圈的包裹體（經微拉曼鑑定為輝石綠輝石族礦物）(Yak 06)，FOV 2 mm。

PL spectra were collected from Aurora Diamond Inspector S1 at liquid nitrogen temperature (~77 K) using excitation wavelength of 365 nm, 390 nm and 520 nm at 365-1000 nm, 390-1000 nm and 520-1000 nm ranges respectively. Also, for 18 samples PL spectra were recorded at liquid nitrogen temperature (~77 K) on an EnSpectr R532 Raman spectrometer with excitation laser wavelength of 532 nm, laser power 30 mW over the 365-900 nm range. PL images were collected from Aurora Diamond Inspector V1 at room temperature using UV lamps with excitation wavelengths of 365 nm (long-wave UV), 254 nm (short-wave UV) and 220 nm (Deep UV).

Raman spectra of inclusions and some photomicrographs were collected using EnSpectr R532 Raman spectrometer with excitation laser wavelength of 532 nm, laser power 30 mW over the 400-4000 nm range with Olympus BX-53 optical attachment and digital camera.

Microscopic Features

Most of the examined pink and purple diamonds have microscopic features that are typical for natural pink diamonds. They are shown on Fig. 3 of the previous page. Almost every pink or purple diamond has classical features which are consequences of stress and plastic deformation: internal and external graining, anomalous birefringence under crossed polarisers, colour zoning. Some of our samples have fissures (cracks) and inclusions with cracked halos. The clarity of these samples was graded within VVS1 to I1 range. More details about mineral inclusions identified using Micro-Raman spectroscopy can be found below in the part of “Inclusions and Micro-Raman Spectroscopy”.

UV-Vis-NIR Absorption Spectra

The optical absorption spectra were recorded for all 33 samples. All the diamonds examined showed common N3 absorption with 415 nm zero phonon line and broad absorption band with a maximum near 550 nm that contributes to the pink colouration. Considering similarities and differences of data obtained it was logical to divide all spectra into 3 types (examples are represented on Fig. 4): 1) 415 nm and 550 nm absorption bands are relatively similar to each other by intensity of absorption and clearly displayed on the spectrum; 2) 415 nm is more intensive than 550 nm absorption band or 550 nm line is weak; 3) 415 nm is more intensive than 550 nm absorption band and in between them we can see a broad absorption band at 480 nm that usually attributed to brown modifier in pink and purple diamonds. The more intensive absorption bands are on an optical spectrum, the brighter purple colour is observed in a diamond (Fig. 5). As it was

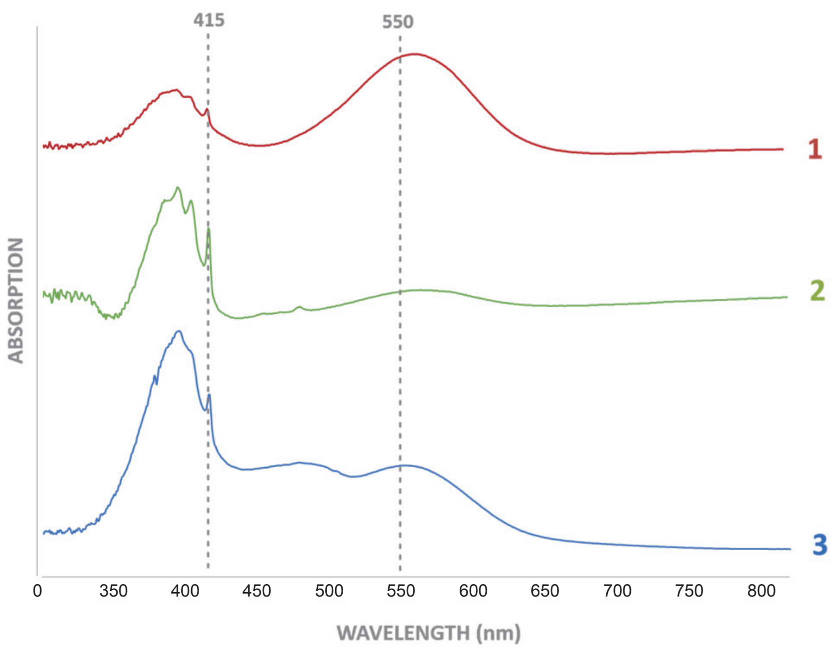

Fig. 4 UV-Vis-NIR spectra of 3 types of pink and purple diamonds: 1 - Fancy Pink Purple (Yak 12); 2 - Faint Pink (Lom 04); 3 - Fancy Brownish Pink (Alan 04).
3種粉紅色和紫色鑽石的紫外線-可見光-近紅外光譜：1 - 彩粉紅紫色(Yak 12)；2 - 淡粉紅色(Lom 04)；3 - 彩棕粉紅色(Alan 04)

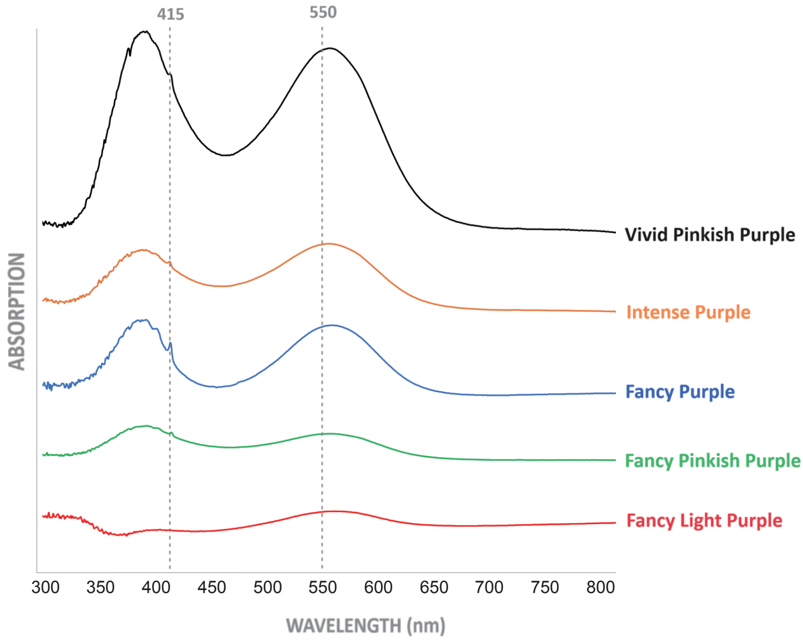

Fig. 5 Correlation of UV-Vis-NIR absorption spectra and colour intensity of pink and purple diamonds. Colour grades and locations: Fancy Light Purple (Alan 02); Fancy Pinkish Purple (Yak 16); Fancy Purple (Alan 01); Intense Purple (Yak 18); Vivid Pinkish Purple (Yak 04).
粉紅色和紫色鑽石的紫外線-可見-近紅外線吸收光譜與顏色強度的相關性。顏色等級與位置：彩淺紫色(Alan 02)；彩粉紅紫色(Yak 16)；彩紫色(Alan 01)；強烈紫色(Yak 18)；豔彩粉紅紫色(Yak 04)。

described and proved before, the colouration of pink and purple diamonds strongly correlates with intensity of 550 nm absorption band *(Hofer, 1985)*. Regarding nitrogen centres, a 415 nm absorption band is related to the presence of N3 defects. There are absorption windows in most of samples between N3 and 550 nm absorption. The visible colours are results of superposition of absorption bands and absorption windows. These superpositions are quite individual for each sample and this explains broad varieties of visible colours for all diamonds under study. There is not any spectral feature that can explain why pink hue dominates in one part of diamonds and purple hue in another part. According to prior reports purple diamonds has 550 nm band shifted slightly towards longer wavelengths (see *Eaton-Magaña et al, 2020*) although our results do not support that statement.

IR Spectra

Total content of nitrogen N_{tot} calculated on the base of IR spectra is 600 - 800 ppm, reaching 1200 ppm for a few samples. Hydrogen related peak 3107 cm^{-1} was found in 19 samples. This peak is attributed in literature to the N3VH centre. According to IR spectra all samples can be divided into two groups: with and without 3107 cm^{-1} peak (see sample spectra at Fig. 6 in next page). This peak is not correlated with other centres visible in IR spectra and does not influence on colour. But the total percentage of diamonds with hydrogen related 3107 cm^{-1} peak in much higher than for colourless diamonds.

All diamonds are found to be IaA type with prevalence of A centres. Fig. 7 in next page shows the degree of nitrogen aggregation from A centre (two nitrogen atoms) to more complex aggregates including B centres (four nitrogen atoms plus vacancy) and other aggregates such as H3 or N3, that are not detectable with IR. Nitrogen aggregation degree is 0 - 21%. At the same time samples have relatively high (for this % B) platelets absorption 8 - 12 cm^{-1}, that suggests active transformation of nitrogen defects. Usually, platelets are formed due to A to B centres transformation.

The plots for A centres versus B centres concentration are used in previous studies of pink and purple diamonds *(Eaton-Magaña at al, 2020)*. Some researchers discussed that such data can be helpful for distinguishing diamonds from specific deposits. But we cannot say that our samples are fitted at one small area at the N aggregation plot. Also there is no correlation between the presence of hydrogen related 3107 cm^{-1} peak and nitrogen aggregation degree.

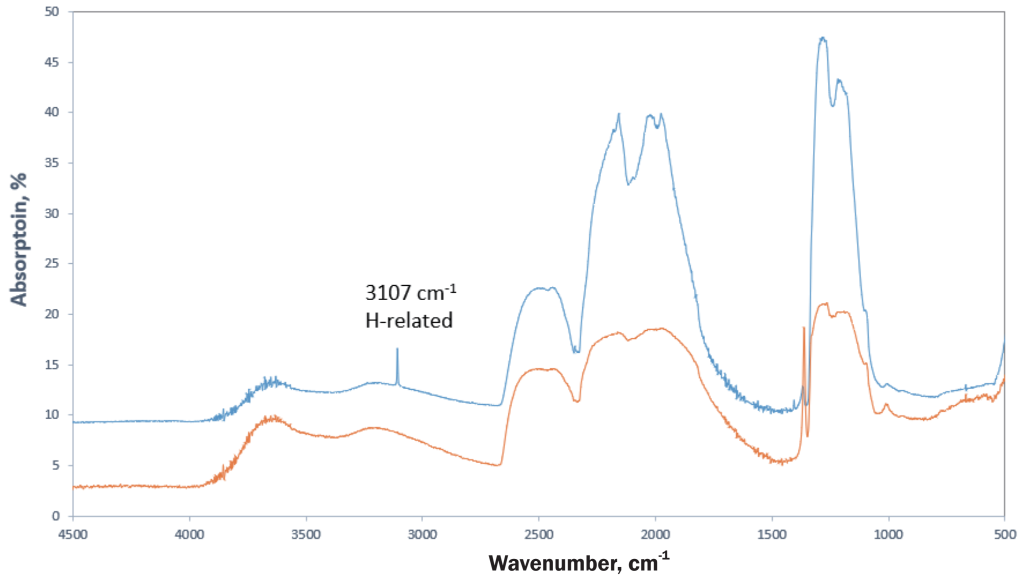

Fig. 6 Comparison of absorption spectra in the IR region with and without hydrogen related peak (3107 cm^{-1}). Sample with H-related peak - Fancy Pink Purple (Yak 12); sample without H-related peak - Fancy Purplish Pink (Lom 02).
比較具有和不具有氫相關峰值(3107 cm^{-1})的紅外線區域吸收光譜。具有H相關峰的樣品 - 彩粉紅紫色(Yak 12)；沒有H相關峰的樣品 - 彩紫粉紅色(Lom 02)

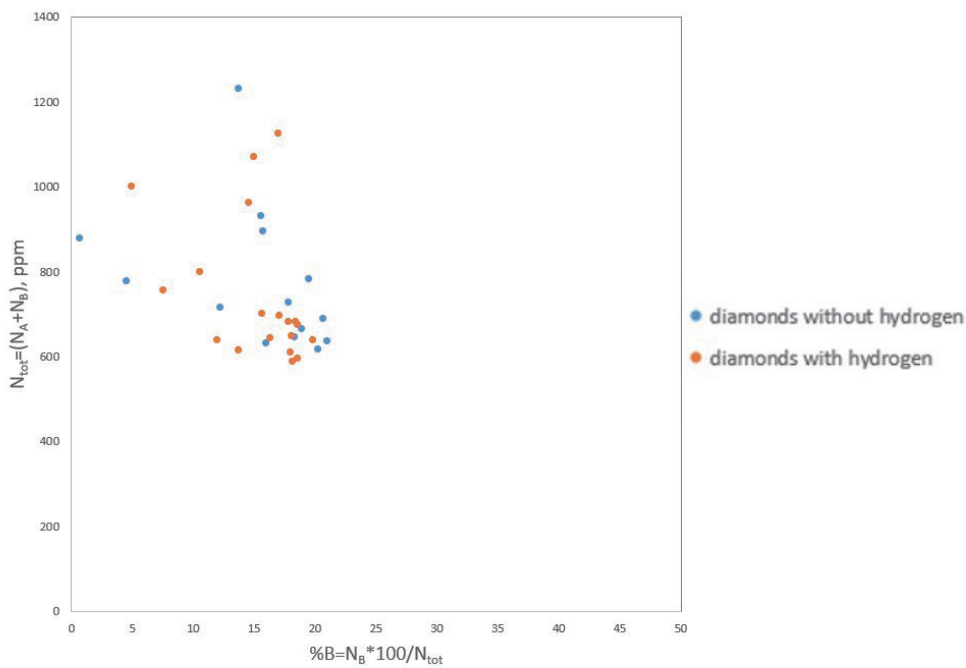

Fig. 7 Total N concentration ($N_{tot}= N_A+N_B$) versus percentage of B aggregates (%B) for samples with hydrogen related centres (orange dots) and without hydrogen (blue dots).
具有氫相關中心（橙色點）和不含氫（藍色點）的樣品的總N濃度($N_{tot} = N_A+N_B$)與B聚集體百分比(% **B**)。

PL (photoluminescence) Spectra and Images

All samples show fluorescence on PL images and emissions in their PL spectra. The N3 centre with zero phonon line 415 nm was detected in the PL spectra of all samples. The stronger presence of N3 in PL spectra, the brighter blue PL colour.

Also, most PL spectra show an H3 centre with zero phonon line at 503 nm. The relative intensity of the 415 and 503 nm peaks influences the luminescence colour of the diamonds. In some samples yellowish-green PL colour prevails because of high concentration of H3 centre (Fig. 8 – 2) in next page.

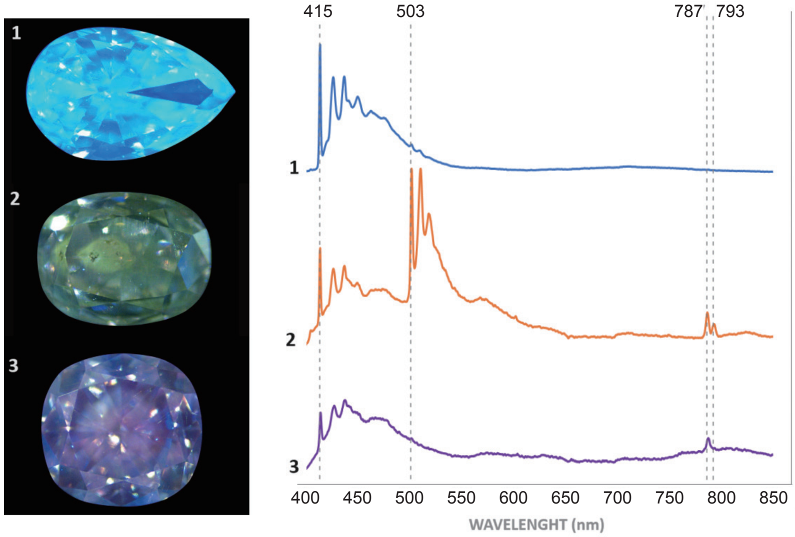

Fig. 8 PL spectra (365 nm excitation) of pink and purple diamonds with blue (1), yellow (2) and violet (3) luminescence.
1 – Fancy Purplish Pink (Lom 02), 2 – Intense Purple (Yak 03), 3 – Fancy Pinkish Purple (Yak 17).
帶有藍色(1)、黃色(2)和紫色(3)發光的粉紅色和紫色鑽石的PL 光譜（365 nm激發）。
1 – 彩紫粉紅色(Lom 02)、2 – 強烈紫色(Yak 03)、3 – 彩粉紅紫色(Yak 17)

A weak H4 centre (peak at 496 nm) is observed in several PL spectra. The H4 centre is detected in 4 samples with strong H3 absorption and yellow luminescence, and H4 intensity is always weaker than H3. Sometimes a 612 nm peak was detected in the PL spectra. This 612 or 613 nm PL centre has been reported in untreated brown and pink diamond crystals from various deposits *(Smith et al., 2000; Gaillou et al., 2010; Titkov et al., 2008)*. Other PL spectral features are 787 nm and 793 nm peaks. They are attributed in literature as associated with hydrogen and/or nickel impurities. A single peak at 787 nm is less common. It is worth noting that samples in which an infrared band at 3107 cm^{-1} (hydrogen related band) usually show two PL peaks, 787 and 792 nm together.

Inclusions and Micro-Raman Spectroscopy

12 samples were examined for inclusions using Raman spectroscopy. These samples were selected for testing after visual inspection of all samples under the microscope with crossed polarisers. In 2 of 12 samples solid mineral phases were identified. The first sample (Yak 08) contained multiple inclusions identified as clinopyroxene group mineral after comparing the obtained spectra with the RRUFF database spectrum (Fig. 9). In the second sample (Yak 21) a

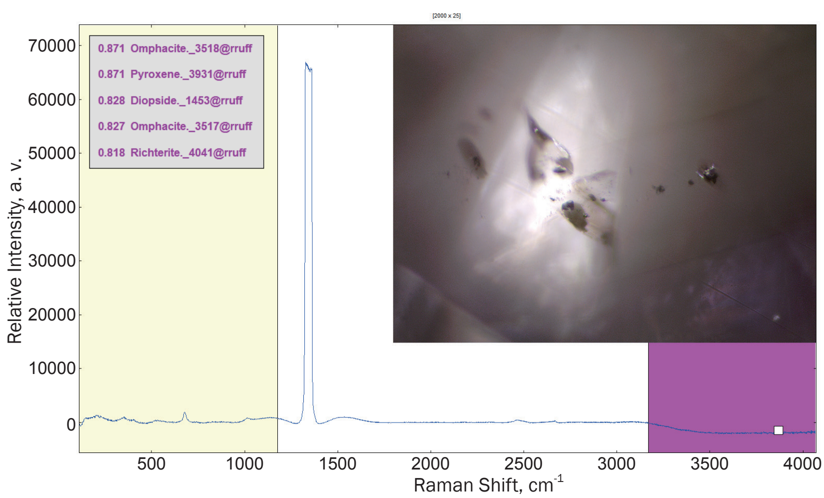

Fig. 9 Clinopyroxene inclusions in diamond (Yak 08). All solid inclusions were identified as a clinopyroxene in this sample, each of them is surrounded by a cracked halo.
鑽石中的單斜輝石包裹體(Yak 08)。此樣品中的所有固體包裹體均被鑑定為單斜輝石，每個包裹體均被破裂的光環包圍。

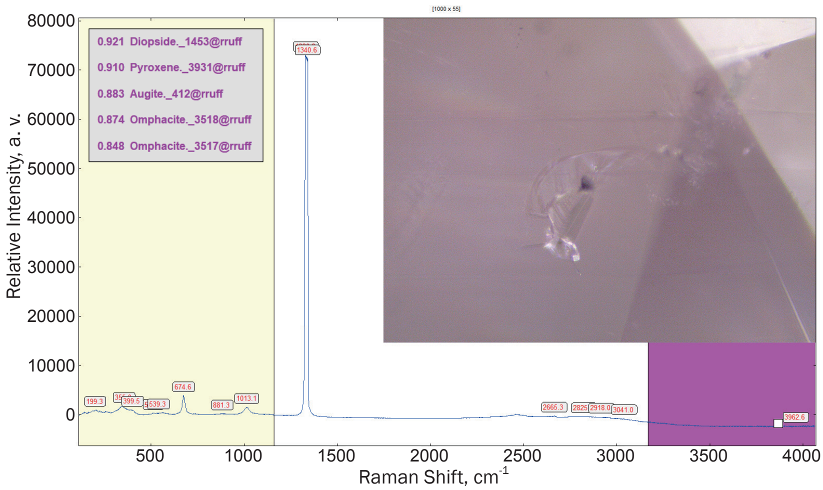

Fig. 10 Diopside inclusion in diamond (Yak 21).
鑽石中的透輝石內含物(Yak 21)

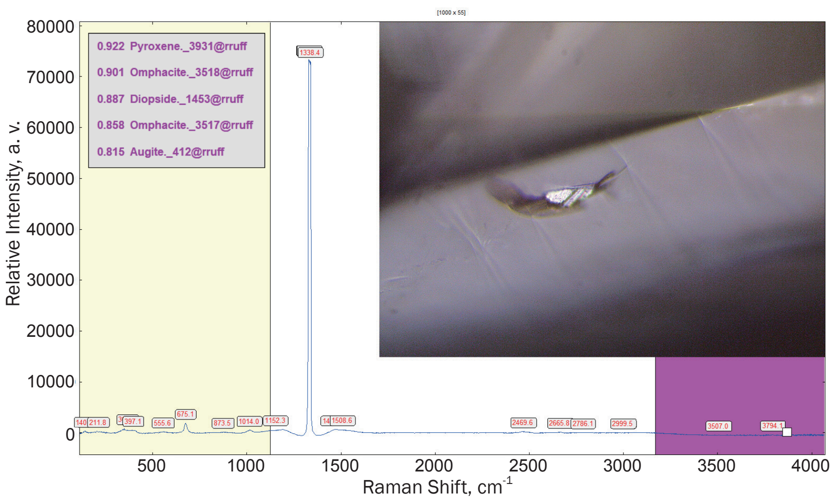

Fig. 11 Diopside inclusion in diamond (Yak 21).
鑽石中的透輝石內含物(Yak 21)

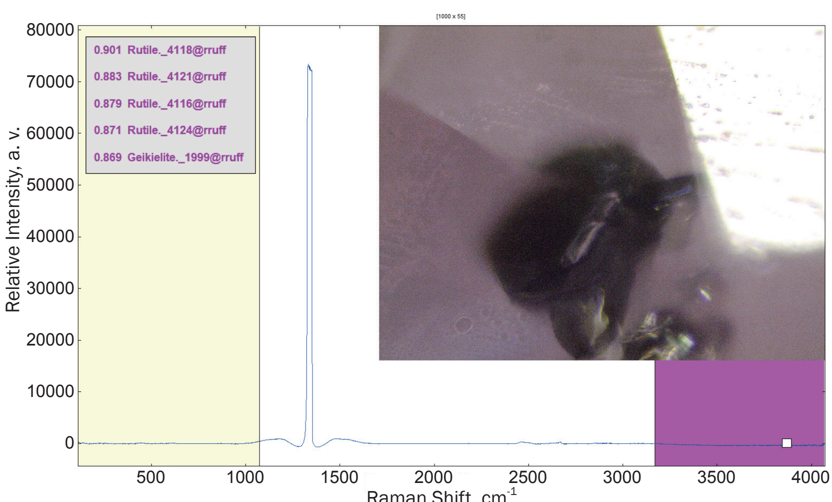

Fig. 12 Rutile inclusion in diamond (Yak 21).
鑽石中的金紅石內含物(Yak 21)

mineral of the pyroxene group, diopside, was also found (Fig. 10 and 11). Both samples were cut from diamonds mined in the Yakutian diamond-bearing province. There are several diopside grains in this pink diamond. Rutile was found unexpectly. This has been rarely described in the literature as inclusion in diamond (Fig. 12, Yak 21). Today it is known that inclusions of clinopyroxene and rutile are typical for eclogitic diamonds *(Stachel et al., 2022)*.

Results of the investigation are shown in Table 2. They include total nitrogen, percentage of A and B aggregates, platelets and hydrogen related peak average mean and modal deviations. Diamonds from all three locations are similar in total concentration of nitrogen.

Diamonds from Lomonosov deposit are characterised by absence of hydrogen related centres (this centre was found only in one sample) and higher presence of platelets estimated to absorption coefficient in IR spectra.

Samples from Alan, Anabar have lower concentration of hydrogen related N3VH centres (absorption coefficient 0-1 cm^{-1}; in one sample 5 cm^{-1}), and relatively less platelets compared with samples from Lomonosov. According to IR data properties of Lomonosov and Alan diamonds are quite similar.

Samples from Yakutian mines repeal a broader range of nitrogen related centres but same average values. Hydrogen related peak 3107 cm^{-1} is detected in most samples with relatively higher concentration: from 0 to 7 with average 3. Also, platelets concentration is less in these samples.

Table 2 Summary of obtained data 數據摘要

Parameter	Lomonosov	Alan	Yakutia
No of samples	6	5	22
Colour bands	Observed	Observed	Observed
Pink graining	Observed	Observed	Observed
Absorption peaks, nm	415 peak and 550 band, in 4 samples 480 band	415 peak and 550 band, in 2 samples 480 band	415 peak and 550 band
N total, ppm*	710±90	750±90	590±120
A and B centres	A > B	A > B	A > B
%B*	18±2	18±2	15±3
P, cm^{-1}*	9±3	7±3	6±2
Hydrogen, cm^{-1}*	1±1	1.5±1	3±3
Hydrogen	In 1 sample	In 2 samples	In 15 samples
PL colours, 365 nm (long-wave UV), 254 nm (short-wave UV) and 220 nm (Deep UV) lamps	Blue (5 samples) and yellow+pink (1 sample)	Blue (all samples)	Blue (11 samples) yellow (6 samples) purple (3 samples) yellow+blue (2 samples)
PL spectra peaks, 365 nm, 390 nm and 520 nm lasers	Typically 415 and 503 nm	Typically 415 and 503 nm, Rarely 787 nm	Typically 415 and 503 nm, Rarely 496, 612, 787 and 793 nm
Inclusions	Not identified	Not identified	3 (pyroxene group, diopside, rutile)
Colour grades	Faint Pink Fancy Purplish Pink Fancy Brownish Pink	Fancy Light Purple Fancy Brownish Pink Fancy Purple Intense Brownish Pink	Fancy Purplish Pink Fancy Pink Purple Fancy Pinkish Purple Fancy Purple Fancy Intense Purplish Pink Fancy Intense Pinkish Purple Fancy Intense Purple Fancy Vivid Pinkish Purple Fancy Deep Purplish Pink

Result of our study grouped by deposits.
*Average mean and modal deviation
我們的研究結果按礦區分組
*平均值和模態偏差

Discussions

Natural diamonds have a long geological history. They are subjected to post-growth processes such as nitrogen aggregation, the formation of new centres, plastic deformation, partial dissolution, etching, crack formation, epigenetic changes of inclusions, and others. We can observe evidence of these processes using non-destructive research methods.

In particular, plastic deformations in diamonds can create brown, or more rarely pink or purple colours. The nature of the pink colour of diamonds was unclear for a long period of time, but then more and more researchers began to associate it with plastic deformation, which was confirmed microscopically and appears as 550 nm band in absorption spectra.

More detailed studies of the pink colour by Titkov et al., 2008 using the EPR method made it possible to associate the pink colour with the M2 centre. The centre is formed by two non-equivalent nitrogen atoms separated by three carbon atoms, with the nitrogen atoms located along the [001] direction, forming opposite vertices of a polyhedron, similar in configuration to an octahedron with reduced symmetry *(Titkov et al., 2012)*. The model of M2 centre is shown at Fig. 13. It is likely that the M2 centre appears in the visible range as a colour centre and is responsible for the emergence of the 550 nm absorption band *(Titkov et al., 2008)*. In our study, we can see a broad absorption band with a maximum of 550 nm in all optical spectra of examined samples, which is combined with a wide photoluminescence band in the range of 600 – 730 nm, relatively low intensity. This is consistent with the Eaton-Magaña et al., 2020 and other publications where authors show co-existence of 550 nm band in absorption with 600 – 730 band in Pl spectra for pink diamonds.

Another important property is the presence of an N3 centre in almost all analysed pink diamonds, which is shown in absorption and luminescence spectra with zero line 415 nm.

Pink diamonds of type IIa are also described in the literature, but we did not find such diamonds in our studies. According to past observations, nitrogen-free diamonds from the Anabar placers are characterised by a pink colour (without additional colour components) and weak blue PL colour.

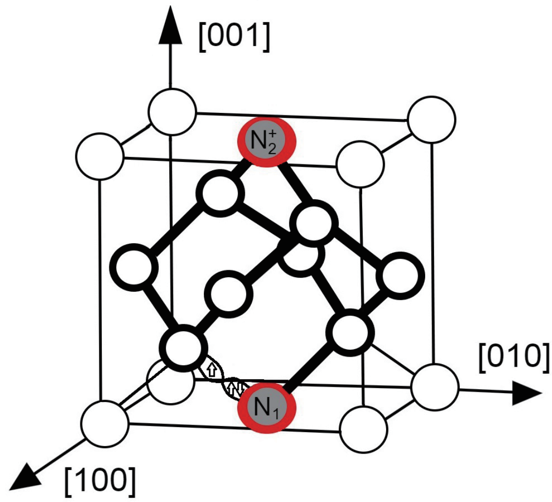

Fig. 13 The structural model of M2 optical centre according to Titkov et al., 2012. Red circles – nitrogen atoms, black circles – carbon atoms.
根據Titkov等人，2012的M2光學中心的結構模型

The presence of inclusions (clinopyroxenes) that were determined using the Micro-Raman spectroscopy testifies to the diamond formation in ultramafic or eclogitic rocks. Unlike type IIa pink diamonds, which are supposed to form at sub-lithospheric depths, the stones we examined show a typical lithospheric origin. But it should be noted that it was not possible to determine most of the inclusions that we saw due to their small size and other limitations reliably.

Considering sources of the studied stones, the Lomonosov deposit is a primary mine. Diamonds are mined from kimberlite bodies. The age of the pipes is estimated by geologists as 340 - 390 Ma (*Smit and Shor, 2017*). The Alan mine is a placer deposit, which, along with other placers, is located in the Anabar shield area. Pink diamonds are also found in other placer deposits in the area. The primary sources of these placers have not been found yet. The rest of the stones studied were mined in deposits of Yakutia; where we do not have data from which exact mines. But it is known that mostly pink diamonds are mined in the International pipe, Mirny region, which is the primary mine. Kimberlites of Yakutia have different geological ages. In particular, kimberlites of the Mirny region are dated back to 344 - 370 Ma. Diamonds are older than kimberlites, and we do not have non-destructive methods to determine the age of pink diamonds. The similarity of all groups of diamonds indicates the similarity of the processes occurring in nature, which led to the formation of plastic deformations in diamonds, including those associated with pink colouration. Similar geological processes take place in other diamond bearing regions. Thus most of the pink diamond properties are quite similar from one region to another.

The question on the possibility of determining the geographic origin of diamonds is complex today. The groups of diamond deposits from which we studied are located in different regions at a considerable distance from each other. However we have not established any differences in the properties of diamonds of one group from another. The properties of pink and purple diamonds from different deposits are similar, and the concentrations of impurities are overlapping. Low aggregation state of nitrogen was found in all studied samples. That was also mentioned by *(Kriulina et al, 2023)* for other pink samples from Lomonosov mine. Pink diamonds from the Argyle deposit (Australia, now closed) have statistical differences in the ratio of A and B centres, but pink diamonds from all other deposits, including those studied by us, are similar in properties.

Summary

Considering all results received by gemmological and instrumental methods we can conclude that all 33 pink and purple diamonds belong to Ia physical type with A aggregates prevail on B aggregates. Pink and purple colours are due to 550 nm band recorded in visible part of their absorption spectra. Pl images of diamonds under study show different PL colours, sometimes with PL colour zoning, under different Pl wavelength. PL spectra obtained with excitation wavelength of 365 nm, 390 nm and 520 nm show presence of various Pl centres and, most notable, broad 600 – 730 band, which may be weak in intensity but correlates with 550 nm absorption band. Such optical centres as N3 (415 nm) and H3 (503 nm) are often seen in our samples, together with other less common centres. Pink and purple colours have uneven distribution and linked to plastic deformation bands inside diamonds.

Generally, the properties of pink and purple diamonds that we examined agree with the data of earlier publications and with studies of other natural pink and purple diamonds in our laboratory. From a gemmological point of view, it is interesting to study samples linked to various deposits and mining regions. The rare pink and purple diamond colouration is associated with structural deformations that occur during the post-growth history of diamond crystals. Revealed properties are enough to identify these stones as natural, untreated confidently. For the possibility of determining the origin of generic diamonds that come to laboratories from unknown sources, this seems problematic at the moment, at least at the current stage of analytical methods.

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