The Aurora Collection: **An Excursion into the World of Fancy Color Diamonds**

By Thomas Hainschwang and Franck Notari

Until the late 1980s, fancy color diamonds were only of limited interest for the gem market: demand was not very high and so their prices were comparatively low. In 1987, for example, the 0.95 carat fancy red I1 clarity Hancock red diamond sold for a price equivalent to $926,315 per carat in 1987.

In the jewelry trade, fancy color diamonds are not extremely widespread even today, and most jewelry stores only rarely show colored diamonds in their showcases. The vast majority of diamonds that are traded are D-Z colorless to yellowish diamonds. As a result, the public is generally still unaware that there are diamonds in almost all colors of the rainbow.

This article is based on the first ever complete analysis of one of the most important fancy color diamond collections – the Aurora Collection (Figure 1) – in the Natural History Museum (NHM) in London by GGTL Laboratories in spring 2015.

Background Information

The Aurora Collection project was created in 1983 by Harry Rodman (who died in 2008) and Alan Bronstein; it took 25 years to complete the collection. With the Aurora Collection (today also called the Aurora Pyramid of Hope) they brought into life what has become the most renowned collection of fancy color diamonds, together with the Aurora Butterfly of Peace. An illustrated study of the Aurora Collection was published in 1998 by Stephen Hofer – a very detailed description of the collection that at the time consisted of 260 diamonds of all colors. The main topic is the color description and grading of these fascinating diamonds.

Figure 1: The display of the Aurora Collection at the Natural History Museum in London. (Photo: T. Hainschwang)

Top to Bottom

Figure 2:
The Natural History Museum in London. (Photo: T. Hainschwang)
One of the authors (TH) after the arrival at the museum – with the car filled up to the roof by high-tech analytical instruments. (Photo: F. Notari)

Figure 3:
One of the authors (FN) at the office at the Natural History Museum in London just after transporting all the material and (below) after installation of the equipment. (Photos: T. Hainschwang)

Today, the Aurora Collection consists of 295 fancy color diamonds and is on permanent display in The Vault at the Natural History Museum (NHM) in London. As part of our green diamond research project, we contacted Alan Hart of the NHM for permission to analyze their natural green color diamonds and - thanks to the kind permission of Alan Bronstein - in the course of organizing our visit to the museum the project of also analyzing the entire Aurora Collection was born. It took more than two years until this research project was finally realized, and for which all the analytical equipment had to be transported to London. In order to be able to test the entire collection, it was decided that the two authors, plus Candice Caplan, would travel to London and work on it for a week.

The preparation for this challenging project started with the packing and transporting of the UV-Vis-NIR, infrared and Raman/Photoluminescence spectrometers of the GGTL Liechtenstein laboratory to Geneva. There, the Leica Trinocular Microscope and the DFI fluorescence imaging and spectroscopy microscope plus all other necessary tools were added and all the papers for the customs procedures were prepared. Finally Franck's car was filled up with all the boxed instruments (which included five desktop computers plus five screens) and all these were transported to London in a marathon drive of more than 12 hours (with more than two hours spent at Customs) by Franck Notari and Candice Caplan. This included transporting analytical instruments, with a total value of over $600,000, by car from Liechtenstein and Geneva to London (Figure 2).

More than half a day was needed to install all the instruments at the offices of the NHM (Figure 3) and from then on more than 300 diamonds were tested by a range of analytical instruments for six days. All the equipment was then packed and loaded into the car again and taken back to Geneva and then to Liechtenstein where all the equipment had to be reinstalled in the two laboratories. This project therefore involved 3,000 km of car travel and an enormous effort to get the proper equipment to the NHM and back.

The diamonds were tested by microscopy (Leica M205C with Leica DFC450C camera), infrared spectroscopy (Perkin Elmer Spectrum 100S FTIR with cooled DTGS detector), low temperature UV-Vis-NIR spectroscopy (GGTL D-C 3 UV-Vis-NIR spectrometer), low temperature photoluminescence spectroscopy using 405, 473 and 532 nm laser excitations (GGTL PL-7 system, high resolution echelle spectrograph by Catalina Scientific with an Andor Neo sCMOS camera) and fluorescence imaging (GGTL DFI Laser+ luminescence imaging and spectroscopy system). In order to be able to properly analyze the stones, they had to be removed from the display where they were attached by a silicone-type

The "Aurora Collection"

Diamonds of all Colors of the Rainbow

Yellow Diamonds

After (near) colorless diamonds, the best known diamond color is yellow. Yellow diamonds can exhibit a large range of modifying colors, such as orange, brown, green or gray. The Aurora Collection contains a wide range of yellow diamonds, with or without modifying colors. The most desirable and valuable color is a pure vivid yellow (Figure 4). The yellow color in such diamonds is caused by nitrogen impurities, the N3 and N2 nitrogen aggregates are responsible for the lighter yellow colors (type Ia diamonds) and the colors of highest saturation are due to single substitutional nitrogen (type Ib diamond). Natural yellow diamonds are relatively common, but the purest and brightest yellow diamonds are rare in sizes above 0.5 carat, especially when cut as round brilliants.

Figure 4. Left: Aurora #197, a vivid yellow diamond of 1.07 ct. Right: Aurora #135, brownish orangish yellow diamond.

Orange Diamonds

Pure orange diamonds are very rare, indeed among the rarest of all diamonds. Most orange diamonds show mixed colors of orange modified by yellow and/or brown. Besides pure orange color diamonds, orange diamonds which show a pink modifying color are very rare. The Aurora Collection contains a large variety of orange-hued diamonds of which two fine stones can be seen in Figure 5. Orange diamonds are either type Ib or of a typically undefined type that exhibits a strong 480 nm absorption in the UV-Vis-NIR

Figure 5. Left: Aurora 240, 1.70 ct. Right: A splendid 2.48 ct pinkish orange diamond added to the collection after 1998.

absorption spectrum. The orange hue of type Ib diamonds is mostly the result of a relatively high single nitrogen content combined with some plastic deformation. The other cause of orange color, the 480 nm absorption band, seems to be caused by an oxygen-related defect. The purest and most attractive orange diamonds are generally these 480 nm band diamonds.

Brown Diamonds

Brown color diamonds which are often less appreciated are well represented in the Aurora Collection (Figure 6), and since these diamonds can show many hues, tones and saturations, they are the most common ones in this collection, together with yellow diamonds. The vast majority of brown diamonds owe their color to defects that consist of large quantities of vacancies, or so-called vacancy clusters. These defects are the result of post-growth plastic deformation. The color of such plastically deformed brown diamonds is concentrated in very narrow bands that follow the octahedral crystal directions, so-called colored graining. Brown diamonds can be of any type, hence type Ia, Ib, IIa and even IIb.

Figure 6. Left: Aurora #259, a brown diamond of 2.83 ct. Right: Aurora #11, a reddish orangish brown diamond of 0.35 ct.

Pink to Purple Diamonds

Pink to purple (to red) diamonds are the rarest of all diamonds, especially in larger sizes. The Aurora Collection, which contains many such colored diamonds in a large variety of hues, tones and saturations, is only missing a truly red diamond (Figure 7). Since the cause of this color variety is very similar to the cause of color of many brown diamonds – a defect related to post-growth plastic deformation – pink to purple diamonds can exhibit brown color modifiers.

The color of such diamonds is generally not homogenously distributed, but is concentrated in very narrow bands that follow the octahedral crystal directions. Pink to red diamonds can be either type IaAB (hence containing aggregated nitrogen) or type IIa (practically nitrogen-free), while purple diamonds are almost always nearly pure type IaA. The purple color is the result of a broad 550 nm absorption band alone, while pink to purplish pink in type Ia diamonds is the result of this 550 nm absorption band combined with the absorption of N3 and N2 centers.

Figure 7. Left: Aurora AA31, a pinkish purple diamond; right: A 1.52 ct intense purplish pink diamond added to the collection after 1998.

Type IIb Gray to Blue Diamonds

The most attractive gray to blue diamonds are of type IIb, which means that some boron atoms replace carbon atoms in the lattice of these stones and that practically no nitrogen is present. The boron causes the diamonds to be electrically conductive and induces the gray to blue color: extremely low boron contents cause gray color while a higher boron content causes a blue color. Type IIb diamonds are very rare, and attractively colored type IIb blue diamonds are very highly valued. In the Aurora Collection an impressive range and variety of gray to blue type IIb diamonds can be found (Figure 8).

Figure 8. Left: Aurora #79, an intense blue diamond of 0.61 ct. Right: Aurora #251, a bluish gray diamond of 2.12 ct.

Hydrogen-Rich Type Ia Gray to Violet Diamonds

Only four diamonds in the Aurora Collection belong to this group (Figure 9). These diamonds are only found in the Argyle mine in Australia, and stones larger than a few points are extremely rare. Even rarer are stones that appear violet and not mainly gray: most of these diamonds have a very low saturation and hence look gray rather than violet. To the inexperienced observer these stones look like type IIb blue gray diamonds, but they are always violet and not blue. In contrast to type IIb gray to blue diamonds these stones are type Ia and always unusually rich in hydrogen.

Figure 9. Aurora 188: A rare hydrogen-rich violet gray diamond of 1.02 ct.

Olive Diamonds

A vast variety of olive colored diamonds is part of the Aurora Collection. The color olive is a mixture of yellow, green, brown and/or gray, or blue and brown. Olive diamonds are nearly as common as brown diamonds, but there are some rare ones. Common are plastically deformed type Ib diamonds (Figure 10, left), and hydrogen- and nitrogen-rich type Ia diamonds. Relatively rare are chameleon diamonds (Figure 10, center), while very rare are plastically deformed type IIb diamonds (Figure 10, right). Chameleon diamonds are thermochromic and photochromic and show typically olive to green color under ambient conditions but change their color temporarily to yellow or orange when heated to 140°C or after storage in the dark for several days. Chameleon diamonds with a strong color change are rare, especially in larger sizes.

Figure 10. Left: Aurora #97, a type Ib "olive" diamond of 0.65 ct. Center: Aurora #255, a chameleon diamond of 2.50 ct. Right: Aurora #134, a type IIb olive gray diamond of 0.75 ct.

The rarest olive diamonds are the ones that are type IIb; their olive color is the result of deformation-related brown color overlaying a boron-related blue hue. Such rare type IIb olive diamonds can be HPHT treated to eliminate the brown color and in consequence obtain a gray to blue color. In the Aurora Collection, four such type IIb olive diamonds can be found.

Inclusion-Related White to Gray Diamonds

Only a few of these rather uncommon diamonds can be found in this collection (Figure 11). They generally exhibit no intrinsic body color, except faint yellow or olive hues, and their white to gray opalescent appearance is only caused by the presence of large quantities of tiny particles or voids. These clouds cause the light to scatter and hence the white to gray appearance. When the particles/voids are small enough, or when the blue luminescence is strong enough, then the color may appear bluish. These diamonds are typically type IaB and relatively rich in hydrogen.

Figure 11. Left: Aurora #257, a fancy bluish white diamond of 2.53 ct. Right: Aurora #126, a fancy grayish white diamond of 0.74 ct.

Green Emitter Diamonds

These diamonds can also be found well represented in the collection (Figure 12). Green emitter diamonds are stones that are colored yellow by the H3 center, usually combined with the N3/N2 centers. They appear green because the H3 center does not only induce yellow color but also strong yellowish green fluorescence. This strong green fluorescence is triggered by any light that contains wavelengths below 503 nm, and hence by daylight and any type of commercial light source.

Green emitter diamonds typically show signs of strong post-growth plastic deformation and natural irradiation plus annealing.

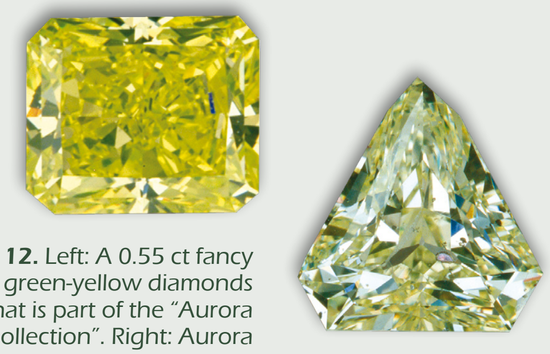

Figure 12. Left: A 0.55 ct fancy vivid green-yellow diamonds that is part of the "Aurora Collection". Right: Aurora # 244, a light green yellow diamond of 1.84 ct.

Irradiation-Related Green to Greenish Blue Diamonds

The Aurora Collection shows a surprisingly large quantity of diamonds with irradiation-related green to greenish blue colors (Figure 13). Such colors are caused by natural – and artificial – high energy irradiation. This irradiation can be either particles, such as electrons and neutrons or gamma waves. Gamma irradiation is thought to be the main reason for natural green to greenish blue color, while it is practically impossible to induce such colors artificially due to the inefficiency of defect creation by gamma rays. Even after years of irradiation in a Co^{60}, source diamonds do not exhibit any noticeable green or greenish blue color.

The origin of color determination of diamonds with irradiation-related green to greenish blue color is very challenging and can be impossible. Hence it is not rare to see origin of color currently undeterminable for such diamonds.

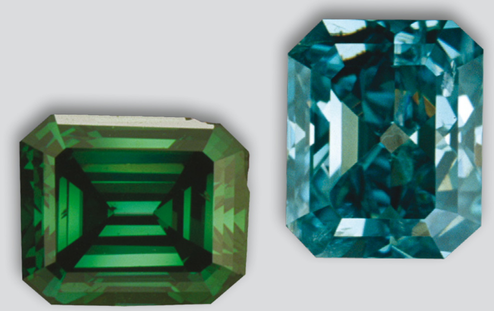

Figure 13. Left: A 0.62 ct fancy deep bluish green diamonds that is part of the "Aurora Collection". Right: Aurora # 29, a deep greenish blue diamond of 0.43 ct.

Discussion and Concluding Remarks

The world of fancy color diamonds is a very complex one and enormous amounts of reference data need to be collected in order to have a complete insight into the defects characteristic of diamonds with natural coloration. Without testing as many diamonds of as many colors as possible, one will never be able to reliably distinguish natural and synthetic diamonds and to identify the origin of the color of fancy color diamonds.

This paper shows the difficulties involved in testing fancy color diamonds, when they cannot be transported to the laboratory but when they need to be analyzed on-site. This is typically the case when stones are tested in museums. GGTL Laboratories has been testing historical fancy color diamonds in museums for several years now in order to build more reliable databases, particularly for irradiation-related green to greenish blue diamonds, and in order to finally develop reliable criteria for the identification of such irradiation-related colors. While typically only a few diamonds are tested at a time, the project of testing the approximately 300 diamonds of the Aurora Collection within a week was very challenging: it was difficult and stressful to collect the large amount of spectra for these diamonds and to perform all the necessary tests, such as luminescence imaging and immersion microscopy.

The Aurora Collection is a fascinating collection of fancy color diamonds. It includes a range of colors unmatched by any other fancy color diamond collection. The collection includes practically all the different types and categories of diamonds seen in nature, including curiosities and rarities. The very detailed analysis of all the diamonds in this collection has permitted us to give a rather condensed overview of the world of fancy color diamonds. Obviously, this paper does not give an insight into all aspects of fancy color diamonds but only a very superficial look at what one can expect. Nonetheless, some basic aspects of natural fancy color diamonds can be shown based on this unique fancy color diamond collection.

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ACKNOWLEDGEMENTS:

The authors are grateful to Alan Bronstein for his kind permission to test the Aurora Collection and for supplying the original documents and photos of the diamonds; and to Alan Hart of the NHM in London for all his support to make this research project possible.