CHARACTERIZATION AND GRADING OF NATURAL-COLOR PINK DIAMONDS

By John M. King, James E. Shigley, Scott S. Guhin, Thomas H. Gelb, and Matthew Hall

The GIA Gem Trade Laboratory (GTL) collected gemological data on 1,490 natural-color pink gem diamonds—both types I and II. While there was some overlap in gemological properties between the two diamond types, they did show differences in their color ranges, ultraviolet fluorescence, absorption spectra, and microscopic features. The color description terminology used for pink diamonds on GIA GTL grading reports is discussed and illustrated, with a separate commentary on red diamonds.

Known for their great beauty and rarity, pink diamonds have long been sought after by jewelers, collectors, and consumers (figure 1). Notable pink diamonds such as the Darya-i-Nur (reported to weigh more than 175 ct), the Agra (known historically to weigh 32.24 ct and recently recut to 28.15 ct), and the 20.53 ct Hortensia (figure 2) add to and sustain interest in these gems (Balfour, 2000). Table 1 lists a number of larger "named" faceted pink diamonds that have contributed to our fascination with them over the years. As with blue diamonds, however, the infrequency with which pink diamonds were encountered in the trade (prior to the discovery of the Argyle mine in Australia) or were documented by gemological laboratories resulted in a scarcity of published information on them.

This article presents data for an extensive population of nearly 1,500 pink diamonds examined in the GIA Gem Trade Laboratory (GTL) over a specific period during the last few years. To the best of our knowledge, this report is the first gemological study of a large sample of pink diamonds that are representative of what currently exists in the marketplace. Following some comments on the history of pink diamonds and their geographic sources, this article will focus on expanding the database of information on this important group of colored diamonds by documenting and reporting on their range of color and other gemological properties. In particular, we looked for correlations of characteristics or properties with the two type classifications in which pink diamonds occur: those with a relatively high nitrogen content (type I), and those with virtually no nitrogen (type II). Note that, throughout this article, the term *pink* is used generically, when appropriate, to refer to the entire color range of pink diamonds. This includes those having brown, purple, or orange modifying components. In all these instances, however, the predominant color appearance is pink; thus, *pink* is the last term in the diamond's color description. For a discussion of "red" diamonds, see box A.

BACKGROUND

Historical and Geographic Origin. Over the centuries, pink gem diamonds have been recovered from several localities. Some historic diamonds, such as the Agra, originated in India (Balfour, 2000);

See end of article for About the Authors and Acknowledgments.

*Note that this article contains a number of photos illustrating subtle distinctions in color. Because of the inherent difficulties of controlling color in printing (as well as the instability of inks over time), the color in an illustration may differ from the actual color of the diamond.

GEMS & GEMOLOGY, Vol. 38, No. 2, pp. 128–147.

Figure 1. The fascination with pink diamonds dates back centuries. For the contemporary diamantaire, the range of colors—such as those shown here—offers many possibilities for different tastes. The diamonds in the two rings are a Fancy Intense purplish pink (left, 5.04 ct) and Fancy Intense pink (right, 3.75 ct); the round and triangular loose diamonds (0.38 and 0.54 ct) are Fancy Intense purplish pink, and the 1.12 ct oval is Fancy Deep orangy pink. The rings are courtesy of Rima Investors Corp. (left) and Mona Nesseth, Custom & Estate Jewels (property of a private collector). Photo © GIA and Harold & Erica Van Pelt.

their exact geographic sources in that country remain uncertain, although the Golconda region is one likely area. A number of pink diamonds—some quite large—have been found sporadically in alluvial workings along the interior rivers of Brazil, particularly in the region called Triangulo Mineiro ("Mining Triangle"; also known as Alto Paranaiba, near the city of Uberlandia; see Svisero et al., 1984; Cassedanne, 1989) in the state of Minas Gerais. A 78 ct pink diamond crystal was found at an undisclosed location in Minas Gerais in 1999 (Hart, 2000). Beginning in the 1940s, the Williamson mine in Tanzania produced a small number of pink diamonds, the most famous of which was a 54.5 ct crystal section that was fashioned into a 23.6 ct round brilliant (the "Williamson Pink") and presented to then-Princess Elizabeth on the occasion of her wedding ("Pink diamond gift ...," 1948; Balfour, 1982). Another occasional source is Kalimantan, Indonesia, on the island of Borneo (Ball, 1934; reported to be along the Kapuas River—see Fritsch, 1998), although no large or deeply colored pink diamonds are known from there. On occasion, the Premier mine near Johannesburg in South Africa has produced pink diamonds (L. Wolf, pers. comm., 2002).

From the late 1980s on, however, the supply coming from the Argyle mine in Australia greatly increased the availability of pink and, on rare occasions, red diamonds (Hofer, 1985; Shigley et al., 2001). Even with this production, from April 2000 to April 2001 pink diamonds represented fewer than 10,000 carats of the 25 to 30 million carats of rough production from this one mine. Of these, fewer than 10% weighed more than 0.20 ct (Michelle, 2001). The most important of the pink Argyle diamonds are offered at special auctions ("Argyle Diamond's Pink Diamond Tender, 1985–1996," 1997; Roskin, 2001a).

Figure 2. The 20.53 ct Hortensia was included in the 1791 inventory of the crown jewels of France, but was one of several pieces stolen from the Grande Meuble palace in 1792. It was recovered shortly thereafter, and later became associated with the family of Napoleon. It is currently displayed in the Galerie d'Apollon at the Louvre Museum in Paris. Photo courtesy of Art Resource.

Noted Auction Sales. In recent history, pink diamonds have been important components of high-profile sales by auction houses. In November 1994, Christie's (Geneva) sold a 19.66 ct Fancy pink diamond for $377,483 per carat; a year later, in November 1995, Sotheby's (Geneva) sold a 7.37 ct Fancy Intense purplish pink diamond for $818,863 per carat. More recently, in May 1999, Christie's (Geneva) auctioned a 20.83 ct Faint pink for $474,000 per carat, and a 5.74 ct Fancy pink for $665,000 per carat (Blauer, 2000).

TABLE 1. Notable named faceted pink diamonds, weighing more than 9 ct.[a]

Weight (ct)	Shape	Color[b]	Name
242.31[c]	Flat oblong	"Light pink"	Great Table
175 to 195[d]	Rectangular step	"Light pink"	Darya-i-Nur
140.50	Cushion brilliant	"Pink"	Regent
72	Cushion brilliant	"Rose pink"	Nepal Pink
70.39[e]	Pear brilliant	Fancy Light pink	Empress Rose
60.75	(Not stated)	"Light rose"	Cuiaba
60[f]	Oval brilliant	"Rose pink"	Nur-ul-Ain
56.71	Table	"Light pink"	Shah Jahan
40.30[g]	Pear brilliant	Fancy Light pink	Carlotta
34.64	Cushion brilliant	Fancy pink	Princie
29.78	Pear brilliant	"Pink"	Pink Sun Rise
28.15[h]	Rectangular modified brilliant	Fancy Intense pink	Agra
24.78	Pear brilliant	"Light pink"	Peach Blossom
24.44	Emerald-cut	"Pink"	Mouawad Lilac Pink
23.60	Round brilliant	"Light pink"	Williamson Pink
22.84[i]	Marquise brilliant	Fancy pink	Winston Pink
21.06[j]	Rectangular modified brilliant	Fancy pink	Mouawad Pink
21.00	Square	"Rose"	Mazarin no. 7
20.53	Shield	"Pink"	Hortensia
17.00	Square	"Reddish pink"	Mazarin no. 12
15	Pear brilliant	"Pink"	Kirti-Nur
13.35	Cushion brilliant	"Pink"	Paul I
9.93	Rectangular step	"Pink"	Orchid
9.01	Pear brilliant	"Light pink"	Grande Conde

[a] *Sources of information: GIA Gem Trade Laboratory grading reports, as well as Henry (1979),* GIA Diamond Dictionary *(1993), Hofer (1998), and Balfour (2000).*
[b] *Color descriptions in quotation marks are taken from the literature. GIA GTL fancy grade descriptions represent the terminology in use at the time of the report (modifications to this terminology were introduced in 1995; see King et al., 1994).*
[c] *Weight in old carats.*
[d] *Estimated weight range.*
[e] *Examined by GIA in 2001.*
[f] *Estimated weight.*
[g] *Examined by GIA in 1978.*
[h] *Examined by GIA in 1998. The Agra was known historically to weigh 32.24 ct but was subsequently recut.*
[i] *Examined by GIA in 1974.*
[j] *Examined by GIA in 1989.*

Past Studies. Except for occasional discussions of famous examples and/or historical geographic sources, there have been few published studies of the gemological properties of pink diamonds as a group. Some information on them can be found in Orlov (1977), Liddicoat (1987), Harris (1994), Webster (1994), and Hofer (1998). Most recent discussions have been on the type I pink diamonds found at the Argyle mine (see, e.g., Chapman et al., 1996; Shigley et al., 2001). Less information has been documented on type II pink diamonds, although two exceptions are Anderson (1960) and Scarratt (1987).

There have also been some shorter reports on "pink" diamonds:

- General information (Henry, 1979; Kane, 1987; Shigley and Fritsch, 1993; Fritsch, 1998; Balfour, 2000; Roskin, 2001b), and absorption spectra and fluorescence reactions (Scarratt, 1987; Fritsch, 1998)
- Descriptions of particular diamonds in the GIA Gem Trade Lab Notes section of *Gems & Gemology* (e.g., Crowningshield, 1959, 1960)
- Reports on the photochromic behavior of some pink diamonds, in which they change color under different conditions (Van Royen, 1995; Liu et al., 1998; Van Bockstael, 1998; Koivula and Tannous, 2001)
- Treated "pink" diamonds and their identification (Crowningshield and Reinitz, 1995; Kammerling et al., 1995; King et al., 1996; Reinitz and Moses, 1998)
- Treated synthetic red diamonds and their identification (Moses et al., 1993)
- Information on auction sales (Blauer, 2000)

Color and Color Origin. The cause of color in type I and type II pink diamonds (figure 3) is still the subject of scientific investigations (see Collins, 1982; Chapman and Humble, 1991; Fritsch, 1998; Chapman and Noble, 1999). There is no evidence that this coloration is due to any trace element (such as nitrogen or boron) in the crystal structure of the diamond (although early work erroneously suggested that manganese was responsible for the pink color; see Raal, 1958). The cause appears to be similar to that which produces brown coloration in diamond,

that is, a *color center* (or centers)—an atomic-level lattice defect that can selectively absorb light in the visible region of the spectrum (Collins, 1982; Jackson, 1997). In type I and some type II diamonds, this color center is often concentrated along parallel slip planes, so that pink or brown planes (i.e., colored graining) are seen in an otherwise near-colorless diamond (figure 4). This similarity of color origin is supported by observations that diamonds can vary from pink through brown-pink to brown, and that all of these hues have some similar features (i.e., banded internal colored graining and a visible spectrum dominated by a broad 550 nm absorption band of varying intensity; Collins, 1982).

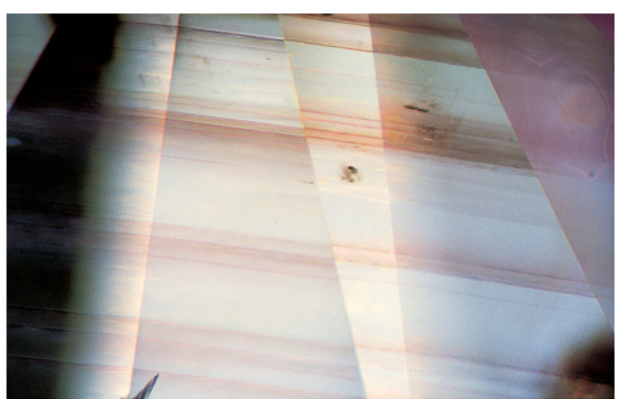
When the coloration is planar, it is thought to have been the result of plastic deformation of the diamond while it was in the earth (Collins, 1982). During this deformation, layers of carbon atoms that are parallel to the orientation of the applied stress are displaced slightly with respect to one another along parallel gliding or slip planes. As mentioned above, this situation gives rise to the creation of a color center of unknown structure along these slip planes that can in turn produce the spectral feature responsible for the pink or brown color.

Figure 3. Pink diamonds may be either type I or type II. In this photo, two type I pink diamonds, the smaller 0.41 ct Fancy Deep pink pear shape on the left and the 1.53 ct Fancy Deep pink square on the right, are juxtaposed with four type II pinks. The type II pink diamonds range in size from the 1.03 ct Fancy Intense orangy pink heart shape on the lower right to the 8.01 ct Fancy Vivid pink pear shape in the center. Photo by Elizabeth Schrader.

GIA Color Description Nomenclature for "Pink" Diamonds. Colors appear different in a given hue range depending on their tone and saturation. The color description GIA gives for colored diamonds on grading reports is based on the hue designation on the color wheel (figure 5) or on the tone and saturation of that hue (see, e.g., King et al., 1994). At certain saturations and tones, the term *pink* is used to describe diamonds in the hue range from reddish purple to orange. Although at higher saturations the hue is clearly reddish purple to orange (as indicated by the solid circle next to the hue name in figure 6), at lower saturations and lighter tones the overall color appearance is predominantly pink (i.e., *pink* is the only or final word in the color description, such as *purple-pink*, *purplish pink* or *orangy pink*—or any of these color terms with a "brownish" modifier, as well as *brown-pink*). Even at some relatively higher saturations and darker tones, diamonds in the purple-red, purplish red, red, and orangy red hue ranges also appear predominantly pink.

Because the GIA Gem Trade Laboratory uses the term *pink* to refer to certain combinations of tone/saturation attributes for a range of color hues, it is always applied independently of the term *red*. This means that our terminology system for colored diamonds does not use the descriptions "reddish pink" and "pinkish red" (this would be similar to the use of color names such as "strong bluish blue" or "pale yellowish yellow," which are not part of

Figure 4. In many "pink" diamonds, especially those that are type I, the pink color is distributed unevenly, and is concentrated along parallel bands. These bands are oriented along the octahedral {111} planes; they probably are the result of plastic deformation of the diamond during its geologic history in the earth. Photomicrograph by John I. Koivula; magnified 15×.



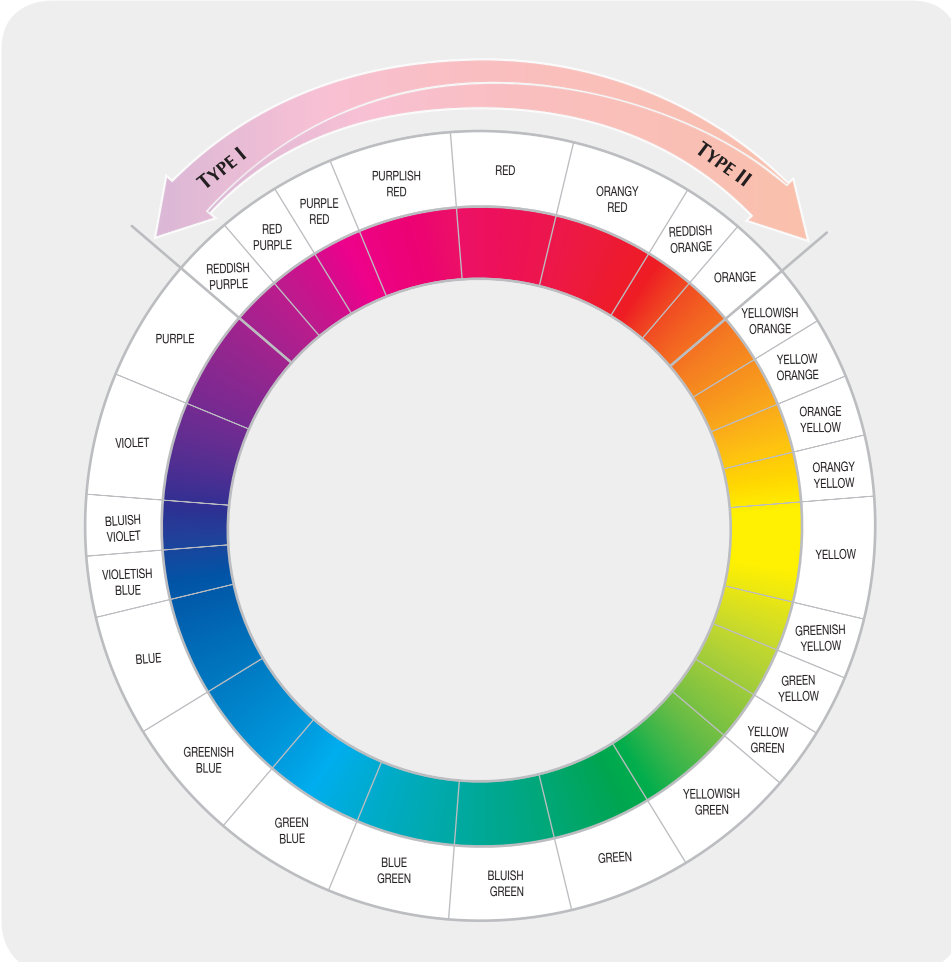


Figure 5. This diagram illustrates the relatively wide range of hues in diamonds (indicated by the arrows) that GIA GTL associates with the term pink. *Because* pink *is used to indicate a color appearance for diamonds, and is not a true hue term, this range also includes orange, where pale colors can appear pink. The arrows used here to note the range of occurrence of pink diamonds also indicate the distribution of the two types in our sample. While there is overlap throughout the hues, a larger quantity (shown by the wider size of the arrow) of type I pinks are often "cooler" in appearance than type II. The opposite was noted for type II diamonds, which tend to be "warmer" in appearance.*

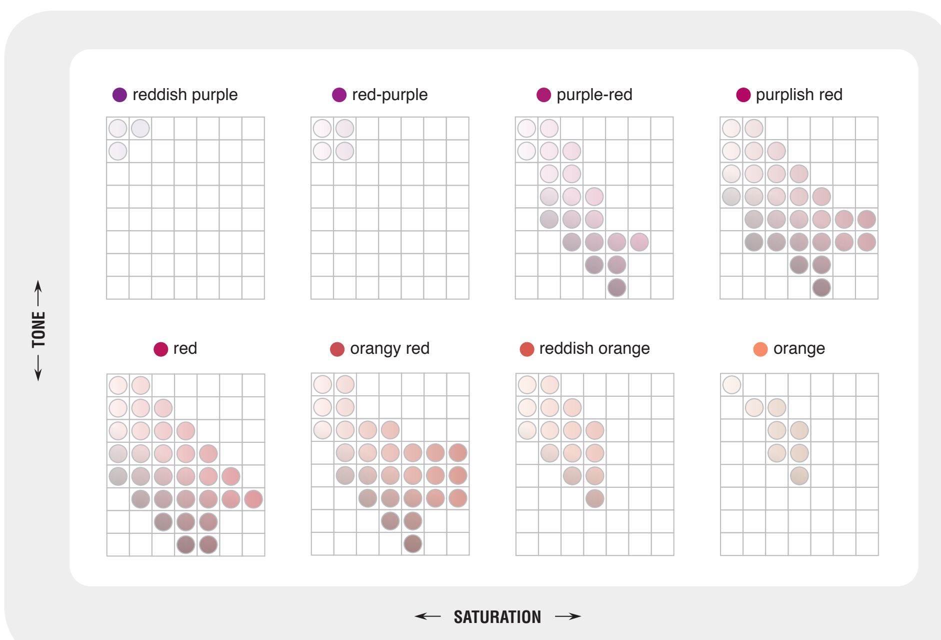


Figure 6. Each of the eight tone/saturation grids shown here relates to one of the hues in figure 5 with color appearances described as pink in the GIA GTL system. Each square in a grid (which is actually a three-dimensional box in color space) represents a range of appearances associated with a color term. The shaded areas in each hue indicate boxes that would be associated with a description that is predominantly pink. It is important to remember that these boxes include pink descriptions modified by orangy, purplish, purple, brown, *and* brownish, *as well as simply* pink.

TABLE 2. Distribution of the sample pink diamonds by fancy grade and diamond type.

Grade	Overall		Type I		Type II	
	No.	%	No.	%	No.	%
Faint	114	8	64	5	50	15
Very Light	78	5	49	5	29	9
Light	170	11	99	8	71	22
Fancy Light	156	10	104	9	52	16
Fancy	488	33	402	34	86	26
Fancy Intense	282	19	257	22	25	8
Fancy Deep	147	10	142	12	5	2
Fancy Vivid	55	4	49	5	6	2
Total	1,490	100%	1,166	100%	324	100%

our grading terminology either).

It is also important to note that color nomenclature systems are not universal, so the visual appearances associated with terms such as *pink* and *red* in diamonds are not necessarily the same as for color naming systems for other materials, such as fabrics, paints, or other gemstones.

MATERIALS AND METHODS

Samples. Since the 1950s, many thousands of colored diamonds have been submitted annually to the GIA Gem Trade Laboratory for identification and/or grading reports. For the present study, we gathered data on a group of 1,490 diamonds (see table 2; for specific data within each group, please see the *Gems & Gemology* data depository on the Internet [www.gia.edu/gandg/ggDataDepository.cfm]), the total number submitted to GIA GTL during a specific period within the past few years. Each of these diamonds was described on our laboratory reports as being predominantly pink in color appearance (i.e., *pink* was the final term in the color description; table 3 indicates the color breakdown for the four stronger grade ranges, which represent the largest number of samples). The diamonds in the overall group ranged from 0.06 to more than 50 ct (92 weighed more than 5 ct, and 30 of these weighed more than 9 ct). Some gemological observations could not be made on all the diamonds in this group because of time constraints in the grading service or the type of service (e.g., a less comprehensive "identification and origin" report) requested by the client.

Grading and Testing Methods. We used the GIA Gem Trade Laboratory methodology for color grading colored diamonds to describe all of these study samples (see King et al., 1994). Trained laboratory staff evaluated each of the diamonds using a standardized D65 "daylight" lighting environment (as provided by the Macbeth Judge II illumination box). Typically from three to six staff members independently compared the overall face-up characteristic color of each diamond to GIA colored diamond color references within this viewing box.

Equipment used for the gemological examinations included a standard gemological microscope, a GIA Gem Instruments ultraviolet unit with long-wave (365 nm) and short-wave (254 nm) lamps, and a desk-model prism spectroscope. For a representative group of stones, we recorded visible absorption spectra with a Hitachi U4001 spectrophotometer (350–750 nm) at cryogenic (liquid nitrogen) temperatures, and infrared spectra with a Nicolet 510 FTIR

TABLE 3. "Pink" color descriptions in the sample diamonds for the four stronger grade ranges.

	Fancy		Fancy Intense		Fancy Deep		Fancy Vivid		Total no.
	No.	%	No.	%	No.	%	No.	%	
Purple-pink	33	7	10	3	2	1	5	10	50
Purplish pink	70	14	140	50	35	24	38	69	283
Pink	115	24	112	40	54	37	9	16	290
Orangy pink	81	17	20	7	19	13	3	5	123
Brownish purple-pink	7	1	0	0	1	1	0	0	8
Brownish purplish pink	11	2	0	0	0	0	0	0	11
Brownish pink	64	13	0	0	2	1	0	0	66
Brownish orangy pink	47	10	0	0	19	13	0	0	66
Brown-pink	60	12	0	0	15	10	0	0	75
Total	488	100%	282	100%	147	100%	55	100%	972

Box A: Understanding the Relationship of Pink and "Red" Diamonds in GIA's Color Grading System

Diamonds described as predominantly red are among the most intriguing and highly valued gems in the world, both because of the richness of their color and their extreme rarity (figure A-1). Trade and public recognition of red diamonds expanded greatly following the record $926,316-per-carat price paid for a 0.95 ct purplish red diamond (known as the Hancock Red) at a Christie's auction in New York in 1987 (Kane, 1987; Federman, 1992). A decade later, in 1997, Christie's Geneva offered a 1.75 ct diamond crystal that was described by GIA GTL as purplish red (figure A-2). Typically, rough diamonds are not offered at auction, because the outcome of their color appearance after cutting would still be in question. Nonetheless, diamonds described as being predominantly red are so rare that it was feasible in this instance. At auction, this 1.75 ct crystal sold for $805,000 (we do not know if it was subsequently faceted). The staff of the GIA Gem Trade Laboratory first examined this diamond crystal 20 years earlier, when they confirmed its natural color. As recently as December 2001, Phillips (New York) sold a 1.92 ct Fancy red diamond for approximately $860,000 per carat, the second highest per-carat price paid at auction for a gemstone.

Although occasional reports have been published, very few red diamonds have been documented in detail (see, e.g., Kane, 1987). Table A-1, which lists diamonds in the public domain that have been given a "red" color description by GIA GTL since the sale of the Hancock Red in 1987, gives some perspective on the rarity of predominantly red diamonds (as we have done throughout this article, we refer here to diamonds for which the predominant color appears red: orangy red, red, purplish red, purple-red, brownish red, and brown-red).

There are two aspects of the GIA Gem Trade Laboratory's colored diamond color grading system that, when combined, describe a diamond's color appearance. One is the fancy grade, which represents regions of the combined effect of tone and saturation on the face-up appearance of a colored diamond. The other is the color description, which locates the hue range and, at times, more specific areas within the fancy grade. For example, within the grade range of Fancy Deep (which describes diamonds that are moderate to dark in tone and moderate to strong in saturation) are areas described as pink, brownish pink,

Figure A-1. This 5.11 ct Fancy red shield shape is an example of this rare color in diamonds. In the experience of the GIA Gem Trade Laboratory, and as seen in table A-1, most of the diamonds described as predominantly red are "cooler" in appearance and termed purplish red. *This diamond, which is "red" without any modifier, is quite unusual. Courtesy of William Goldberg Diamond Corp.; photo by Elizabeth Schrader.*

TABLE A-1. "Red" diamonds in the public domain documented by GIA.[a]

Weight (ct)	Shape	Color grade	Featured by[b]	Year last examined by GIA GTL
5.11	Shield	Fancy red	William Goldberg	1997
1.92	Rectangle	Fancy red	Phillip's New York	2001
1.78	Oval	Fancy purplish red	Argyle Tender	1997
1.75	Rough	Purplish red[c]	Christie's Geneva	1997
1.12	Square	Fancy purplish red	Christie's Geneva	2001
1.06	Oval	Fancy purplish red	Argyle Tender	1998
1.00	Pear	Fancy purplish red	Christie's New York	1997
0.95	Round	Fancy purplish red	Christie's New York	1987
0.75	Rectangle	Fancy purplish red	Christie's Geneva	1998
0.73	Rectangle	Fancy red	Christie's Hong Kong	2001
0.59	Oval	Fancy purplish red	Christie's Hong Kong	2000
0.54	Emerald	Fancy purplish red	Argyle Tender	1998
0.42	Emerald	Fancy purplish red	Argyle Tender	1997
0.41	Round	Fancy purplish red	Christie's New York	2001
0.25	Oval	Fancy red	Christie's New York	1996

[a] *While many people in the industry may describe a diamond as red, the lack of a systematic approach to that determination makes such statements difficult to substantiate. Because of this, the table presents only GIA-documented red diamonds in the public domain. Not all diamonds graded red by GIA are included in this table because of client confidentiality.*

[b] *Company that has promoted or otherwise placed the information in the public domain.*

[c] *Rough diamonds are not given "Fancy grades"; rather they are only given a color description.*

Figure A-2. "Red" diamonds are so rare that this 1.75 ct purplish red crystal sold at the Christie's Geneva November 1997 auction for $805,000. Courtesy of Christie's.

brown-pink, and pink-brown. A Fancy Deep pink diamond is located in the moderate to lighter toned, more saturated portion of the Fancy Deep range, whereas Fancy Deep pink-brown diamonds are in the darker, weaker portion of the range.

This relationship of fancy grade and color descriptions in GIA's system is also consistent with the term *red*. In our experience to date, diamonds described as *red* or *reddish* occur in a limited range of tone and saturation. Consequently, we have applied only one fancy grade thus far: "Fancy." Since the range of color depth in which red diamonds are known is not wide, additional fancy grades have not been required.

As with the transition from one grade to the next for pink diamonds, the transition in appearance between pink and red is smooth (figure A-3). The majority of diamonds described as red to date tend to cluster near the pink/red description boundary (in the GIA GTL system, the typical transition is between either Fancy Deep or Fancy Vivid "pink" and Fancy "red"). As is the case throughout the system, diamonds near a boundary may have a similar appearance yet be described differently. While the appearance difference between pink and red may be subtle at times, the tone and saturation of color that results in the face-up appearance associated with red is seldom encountered.

A special problem with red diamonds is that few people in the trade ever have the opportunity to see significant quantities of them. Just as for pink diamonds, a red "determination" requires the use of consistent methodology and comparison to known references. Without examples readily available in the market, opinions can vary greatly regarding what a "red" diamond should look like. Dealers impassioned about the prospect of having a diamond of this color often believe that moderately dark, moderately strong pinks are red because they lack points of reference. Alternatively, some dealers feel diamonds that are described as red are too pale because they don't look like rubies; although "red" diamonds represent the strongest, darkest color appearances in their hue range, they may not look like other "red" gemstones. Or, only having seen a purplish red diamond, a dealer may incorrectly feel that a warmer red is "brownish" (similar situations also have been encountered with warmer pink diamonds). In the GIA GTL system, the appearance associated with the description "red" should be and is related to diamond, not other gems, so the color appearance of red in diamond may be very different from red in garnet, ruby, or spinel.

From the limited number of predominantly red diamonds seen by GIA, it appears their cause of color is the same broad 550 nm absorption band, with an associated band at 390 nm, that is found in the spectra of pink diamonds, except that in red diamonds it is considerably stronger. Our observations over the last several years have not revealed any distinctive gemological features associated with diamonds described as red as compared to their pink counterparts.

Figure A-3. This illustration reproduces the darker, most saturated (lower right) area of the pink grid in the fold-out chart accompanying this article. The transition in color appearance between diamonds described as "pink" and "red" is smooth, if often subtle. Nevertheless, the tone and saturation necessary to yield a face-up color appearance described as predominantly red is rarely encountered.

spectrometer (6000–400 cm^{-1}) at room temperature. Diamond type was determined by one or more methods, including absorption spectra (by use of the prism spectroscope or an infrared spectrometer), short-wave UV transparency, and photoluminescence (PL) spectroscopy using a Renishaw laser Raman spectrometer. It should be mentioned that these two type categories (I and II) are not completely distinct (i.e., there is no strict boundary between them). As the nitrogen content decreases, the two types become less easy to distinguish. Historically, the type II category was defined simply by the lack of nitrogen-related features in the infrared spectrum of a diamond (Robertson et al., 1934). With the increased sensitivity of newer infrared spectrometers, weak nitrogen-related spectral features can be detected more easily. Consequently, the number of diamonds considered type II has tended to decline (for a discussion of diamond type, see Fritsch and Scarratt, 1992).

Figure 7. These two pie charts illustrate the distribution of the 1,166 type I and 324 type II pink diamonds in the sample by several weight categories. Note that type II pink diamonds tend to be larger than their type I counterparts.

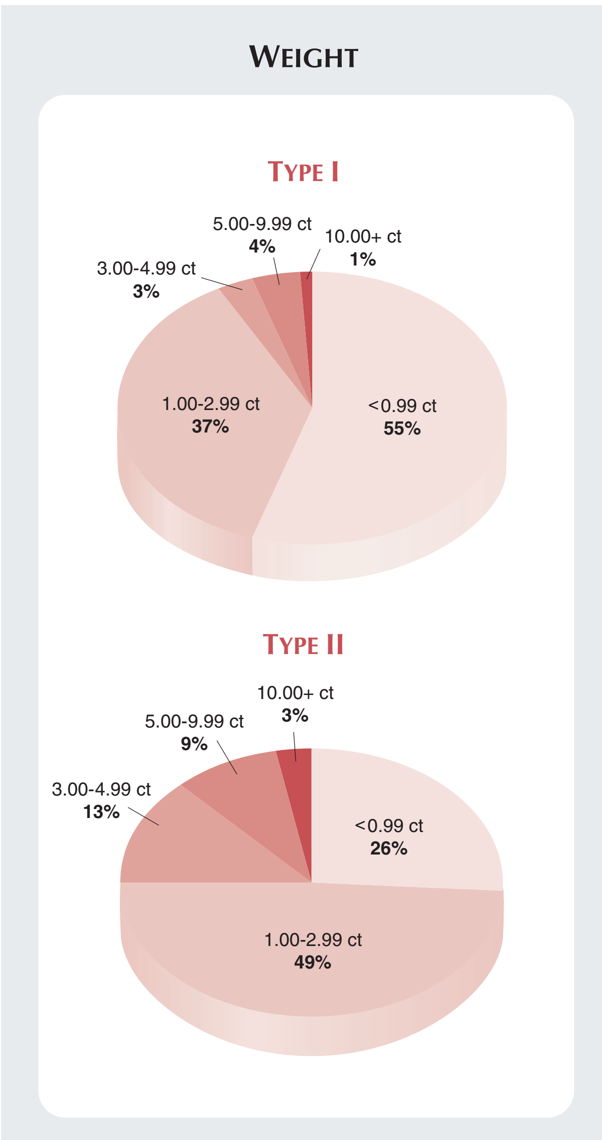


Figure 8. As indicated in figure 7, type II pink diamonds tend to be larger than type I pinks. This unusually large (50.08 ct) Fancy orangy pink diamond is a type II. Courtesy of Julius Klein Diamonds, Inc.; photo by Elizabeth Schrader.

DATA ANALYSIS AND RESULTS

Diamond Type. Of the 1,490 diamonds examined for this study, 1,166 were type I and 324 were type II.

Weight. Twelve percent of our type II samples were 5 ct or larger, whereas only 5% of our type I diamonds were in this category (see figure 7). This is consistent with observations made over the years that large diamonds (in colors other than yellow) frequently are type II (see figure 8).

Color Appearance. The three diagrams in the foldout chart illustrate the wide range of color appearances associated with pink diamonds at three positions on the hue circle (i.e., purplish red, red, and orangy red). Each diagram shows the lighter, less-saturated colors in the upper left, and the darker,

Figure 10. The colors of pink diamonds transition smoothly from one hue to the next. The diamonds shown here illustrate four of the more typical hue appearances encountered in this study. The 0.28 ct marquise on the left is Fancy Intense purple-pink, the 0.41 ct round brilliant is Fancy Intense purplish pink, the 0.48 ct emerald cut next to it is Fancy Intense pink, and the 0.33 ct rectangular diamond on the far right is Fancy Intense orangy pink. Photo by Jennifer Vaccaro and Elizabeth Schrader.

more-saturated colors toward the lower right. The transitions among hue, tone, and saturation for pink diamonds are relatively smooth, with subtle differences in appearance typically encountered between neighboring colors. Understanding the appearances of pink diamonds is challenging because they occur in such a wide range of hues (again, see figure 5). This is very different from the situation of, for example, blue diamonds (King et al., 1998), where the hue range is very limited.

GIA GTL Fancy Grade Terminology. The 1,490 study samples covered all of the GIA GTL fancy grades except Fancy Dark. For pink diamonds, this color grade usually is dominated by brown (and therefore typically results in descriptions of pink-brown, pinkish brown, or brown). Figure 9 shows how the 1,490 diamonds fell into the remaining eight grade categories used by GIA GTL.

Hue. There is a smooth gradation from one hue to the next in pink diamonds (figure 10). While there was complete overlap of the color ranges for both types I and II in the study samples, type I pink dia-

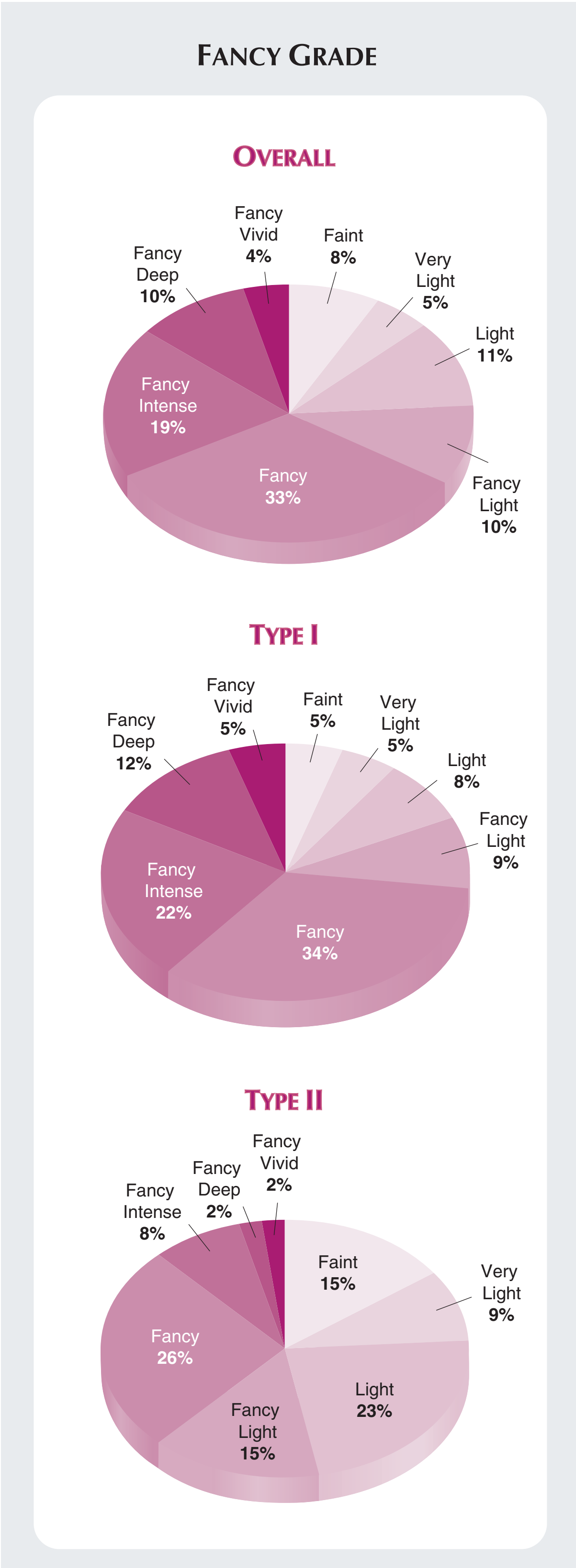
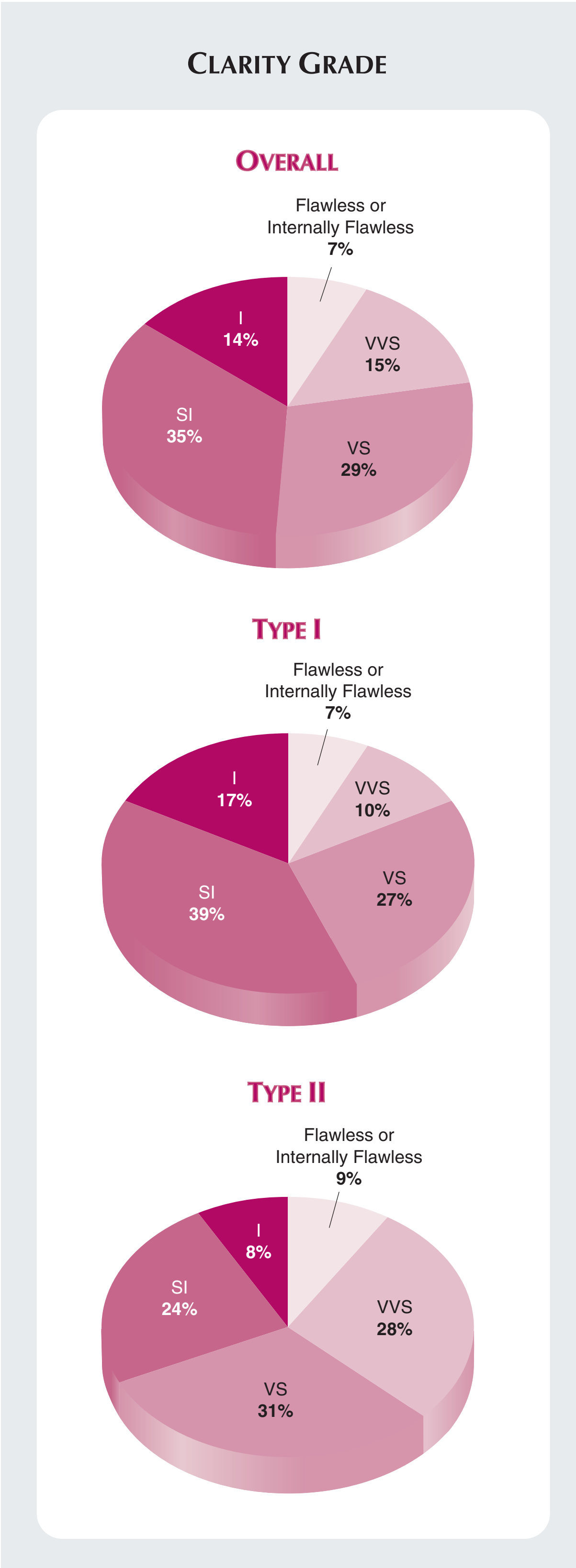


Figure 9. These pie charts illustrate the percentages of the 1,490 pink diamonds studied in each of the GIA GTL fancy grade categories. Note that a higher percentage of type I pink diamonds (1,166 samples) were found in the more saturated grade ranges of Fancy Deep, Fancy Intense, and Fancy Vivid.



monds more commonly exhibit "cooler" hues (i.e., toward purple), whereas type II pink diamonds more commonly occur in the "warmer" hue ranges (i.e., toward orange). Of the 324 type II diamonds, 42% were in the warmer hues (with descriptions such as brownish orangy pink, brown-pink, and orangy pink), whereas of the 1,166 type I diamonds, only 29% were in that range.

Tone and Saturation. The tone and saturation ranges of pink diamonds can vary greatly depending on their hue (again, see figure 6). As illustrated in figure 9, 66% of the 1,490 diamonds fell into the four stronger-saturation and darker-tone categories (Fancy, Fancy Intense, Fancy Deep, and Fancy Vivid). It was interesting to note that this group encompassed 73% of the 1,166 type I diamonds but only 38% of the 324 type II diamonds. Based on the samples in our study (and our experience in general), type I pink diamonds are almost twice as likely as their type II counterparts to be stronger and darker in color. Type II pink diamonds are generally lighter in tone, although they vary in saturation from very weak to moderately strong.

Microscopic Examination. *Clarity.* Pink diamonds tend to be included, as is reflected in their clarity grades (figure 11). Of the 691 diamonds examined for clarity, only 7% were in the Flawless or Internally Flawless (FL/IF) grades, whereas almost half (49%) were in the Slightly Included (SI) or Included (I) grades. Overall, the most common clarity grade range was SI (35%). However, 56% of the 488 type I diamonds in this group had the lower clarity grades (SI and I), compared to only 32% of the 203 type II diamonds. Thus, on average, type II pink diamonds receive higher clarity grades (FL/IF, VVS, and VS) than type I pink diamonds.

Inclusions. Pink diamonds may exhibit fractures or cleavages as well as mineral inclusions. The internal features observed in our study samples were typical of those generally seen in other included diamonds. Dark, opaque graphite spots (figure 12, left) or pinpoint inclusions were more common in the type II

Figure 11. These pie charts illustrate the breakdown by clarity grade for the 691 pink diamonds examined for this characteristic, overall and by type. Note that the (203) type II samples were generally higher in clarity than the (488) type I samples.

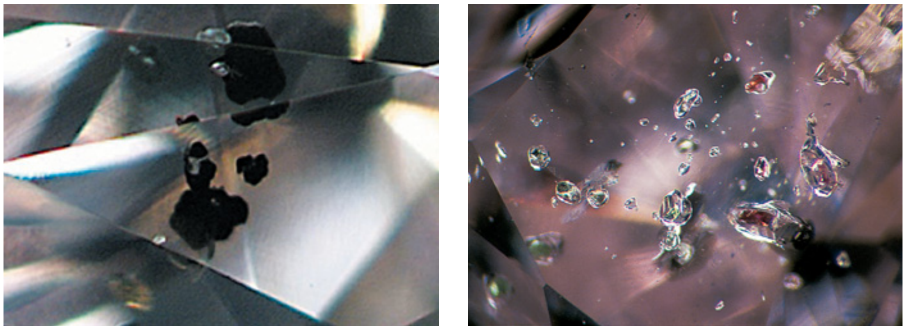


Figure 12. The mineral inclusions in the pink diamonds studied were typical of those generally seen in other diamonds. Left: Type II pinks were more likely to have dark, opaque graphite spots. Right: This type I diamond contains inclusions of garnet and pyroxene. Photomicrographs by Thomas H. Gelb and John I. Koivula; magnified 50× and 15×, respectively).

pink diamonds than in the type I pinks (similar-appearing inclusions have been observed in blue diamonds; see King et al., 1998). In our study sample, the type I pink diamonds more often contained mineral inclusions such as garnet and pyroxene (figure 12, right), or anhedral crystals of diamond.

Graining. Both internal and surface graining are frequently seen in pink diamonds. The photomicrographs in figure 13 illustrate some common forms of this graining. Surface graining typically appears as linear patterns that cross facet junctions (figure 13A). If the linear pattern is extensive and reflects

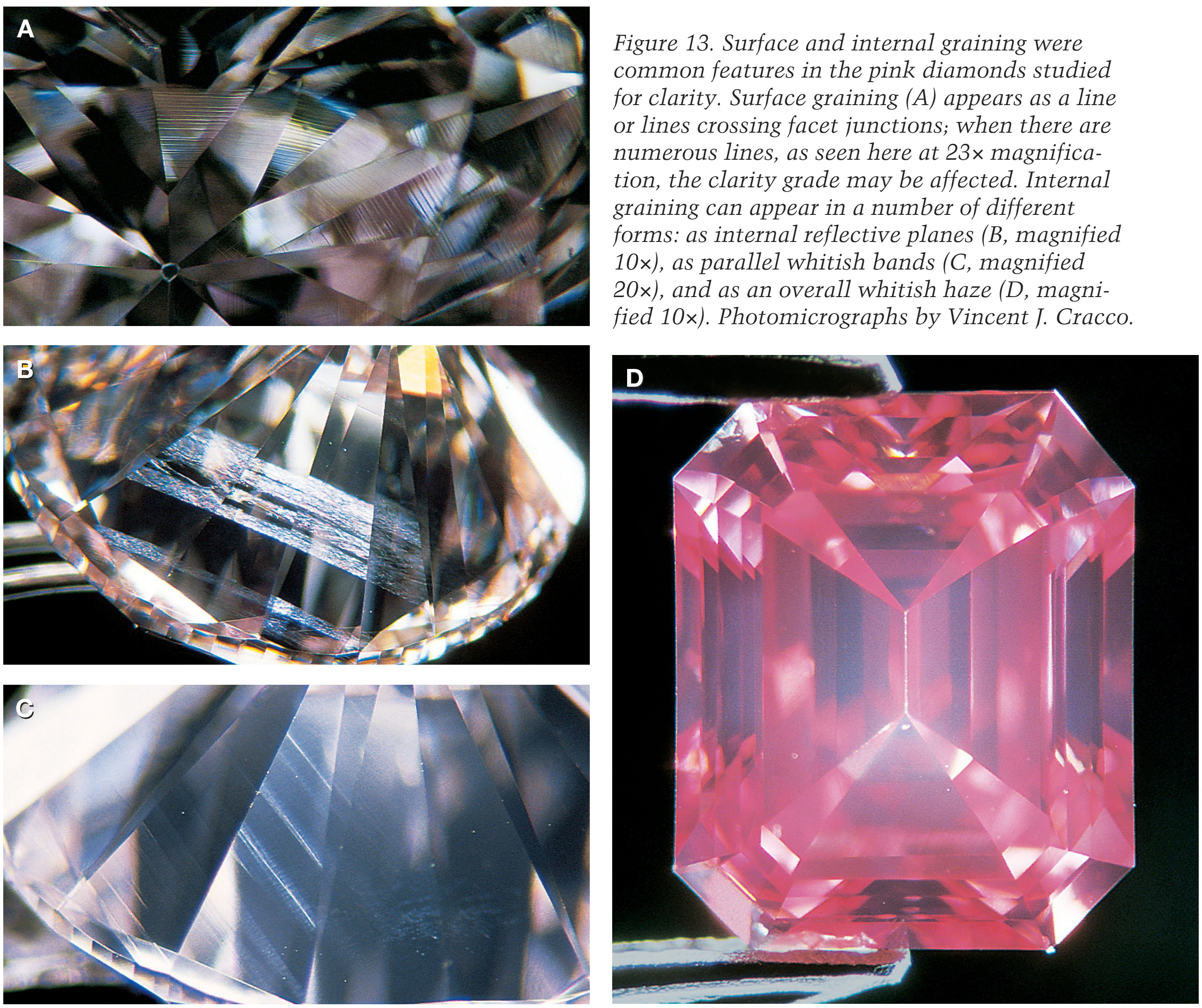


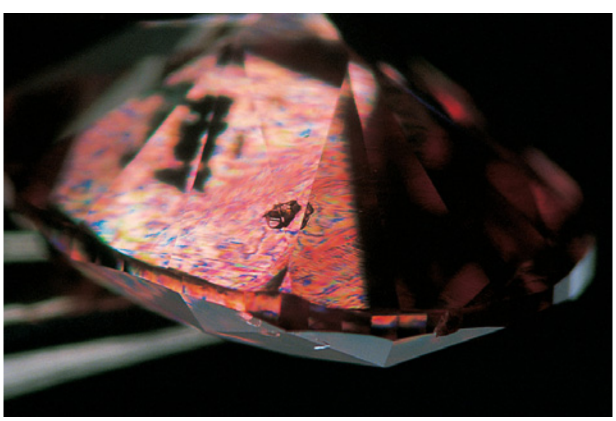
Figure 13. Surface and internal graining were common features in the pink diamonds studied for clarity. Surface graining (A) appears as a line or lines crossing facet junctions; when there are numerous lines, as seen here at 23× magnification, the clarity grade may be affected. Internal graining can appear in a number of different forms: as internal reflective planes (B, magnified 10×), as parallel whitish bands (C, magnified 20×), and as an overall whitish haze (D, magnified 10×). Photomicrographs by Vincent J. Cracco.

Figure 14. Color zoning may appear as thin, discrete, parallel bands. In this 2.12 ct oval brilliant, very narrow color zones are visible in the girdle, paralleling the table facet. The orientation of such bands may affect the face-up color appearance. Photomicrograph by Vincent J. Cracco; magnified 20×.

around the diamond when it is viewed in the face-up position, it can lower the clarity grade. Even if there are only a few surface lines, they are noted in the "Comments" section of the grading report for identification purposes.

Internal planar graining that reaches the surface is sometimes seen as reflective sheets that may appear colorless, pink, or brown (figure 13B); such graining may impact both the clarity grade and the color description. The presence of both pink and brown colors of graining in the same diamond is uncommon, but we have observed it on several occasions. This graining can occur in one or more planes oriented along octahedral {111} directions.

Figure 15. This pink diamond displays bright interference colors in a mosaic pattern when it is observed with magnification between crossed polarizing filters. This anomalous birefringence is evidence that the diamond was subjected to plastic deformation while it was in the earth. Photomicrograph by Vincent J. Cracco; magnified 23×.



In addition to surface lines and reflective planes, internal graining also can appear as whitish bands (figure 13C), or as an overall hazy appearance (figure 13D). When observed with magnification, this haziness may appear cottony, wispy, or silky, and can impart a shimmer- or rain-like quality that may affect the transparency and clarity grade of the diamond.

Among our study samples, the type I pink diamonds were more likely to have surface grain lines and reflective internal planes. In contrast, graining in the type II samples was more likely to appear as an overall haze with varying degrees of transparency rather than as distinct bands.

Color Zoning. Color zoning was noted in 46% of the diamonds examined. This zoning most often appeared as discrete, parallel bands of darker pink color or alternating pink and colorless areas (again, see figure 4). Less commonly, color zoning was seen as an indistinct distribution of color. Zoning was noted more often in those pink diamonds that displayed a greater depth of color; it is likely the darker color contributed to making the distinction between colored and colorless, or differently colored, areas more visible. As mentioned previously, the type I pink diamonds in our study were more likely to display stronger, darker colors. Therefore, it was not surprising to find color zoning observed in 65% of our type I samples, but in only 12% of the type II diamonds examined. In the more intensely colored type I diamonds, we observed the pink coloration as broad bands oriented parallel to the internal graining. In some samples, the color zoning occurred as thin, discrete bands (figure 14) that appeared either pink or brown depending on the direction of the illumination. In type II diamonds, banding may be present but is much less obvious.

Anomalous Birefringence (Strain). As noted above, pink diamonds may be subject to plastic deformation in the earth. The resulting strain pattern can be seen when crossed polarizing filters are used (figure 15). These patterns may parallel the orientation of the pink color zoning, but more typically they are seen as a mosaic arrangement of bright interference colors that change as the diamond is tilted during observation.

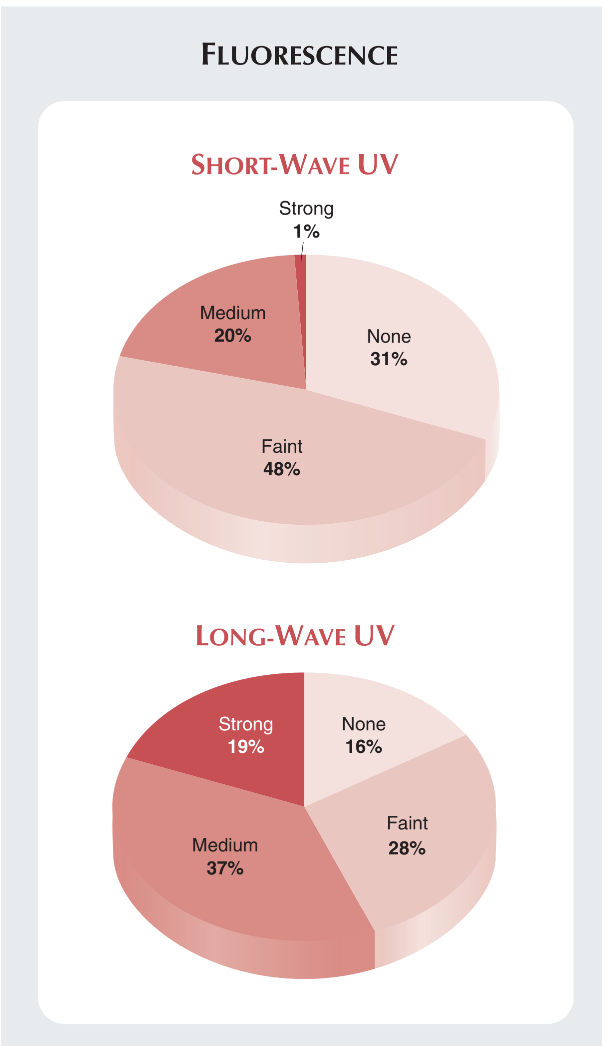
Ultraviolet Fluorescence. In our sample, 1,363 pink diamonds of both types were examined for fluorescence to short- and long-wave UV radiation. We found that 79% showed either no reaction or a faint reaction to short-wave UV (SWUV), whereas approximately 20% exhibited medium fluorescence, and only 1% exhibited strong fluorescence (figure 16). When exposed to long-wave UV (LWUV), 44% exhibited no or a faint reaction and 56% displayed medium to strong fluorescence.

More than half of the type I pink diamonds exhibited a medium to strong reaction to LWUV, most commonly blue in color. The same samples exhibited no or only a faint reaction to SWUV, usually blue or yellow.

Most of the type II pink diamonds exhibited faint to medium fluorescence to LWUV, usually blue; 84% showed only a faint (usually blue) or no reaction to SWUV. It has been our experience that increasing the duration of SWUV exposure by a number of seconds tends to strengthen the intensity of the fluorescence reaction (to a level similar to the LWUV reaction). On occasion, type II pink diamonds display medium-to-strong orange fluorescence to both kinds of UV radiation (Anderson, 1960; Scarratt, 1987; and our own observations). These diamonds commonly exhibited a 575 nm absorption line at room temperature (seen with a desk-model spectroscope) and an adjacent emission line on the low energy side.

In some diamonds, the fluorescence reaction appeared "transparent," whereas in others it appeared cloudy, turbid, or chalky. The type I pink diamonds more frequently appeared chalky to both LWUV and SWUV, whereas their type II counterparts usually did not exhibit a chalky appearance.

Figure 16. In general, the pink diamonds examined for fluorescence (1,363 samples) showed a stronger reaction to long-wave UV radiation than to short-wave UV. This same pattern was consistent for both the type I and type II diamonds, although type I pink diamonds tended to have a stronger reaction (medium to strong) to long-wave UV than their type II counterparts (faint to medium).



Infrared/Visible Spectra. Figures 17A and 17B depict typical infrared spectra of a type I and type II pink diamond, respectively. These are consistent with the spectra observed for diamonds in this study. Absorption features in the one-phonon region (between 1000 and 1400 cm^{-1}) indicate the presence of nitrogen in a diamond (Fritsch and Scarratt, 1992). As mentioned above, as the nitrogen concentration decreases, the one-phonon absorption decreases. When this absorption is not detectable, the diamond is by definition type II.

The dominant feature in the visible spectra of pink diamonds is a broad absorption band centered around 550 nm (figures 17C and 17D) that, as mentioned above, is responsible for the color in most pink diamonds (Collins, 1982). Typically, the 550 nm absorption band occurs together with a band at 390 nm (Collins, 1982). This applies to both type II and type I diamonds, although in the case of type I diamonds (figure 17C), the 390 nm band is superimposed on the N3 center. Further evidence that the 550 and 390 nm bands are linked is that they increase or decrease together in response to thermochromic or photochromic (heat- or light-related)

effects (C. Welbourn, pers. comm., 2002).

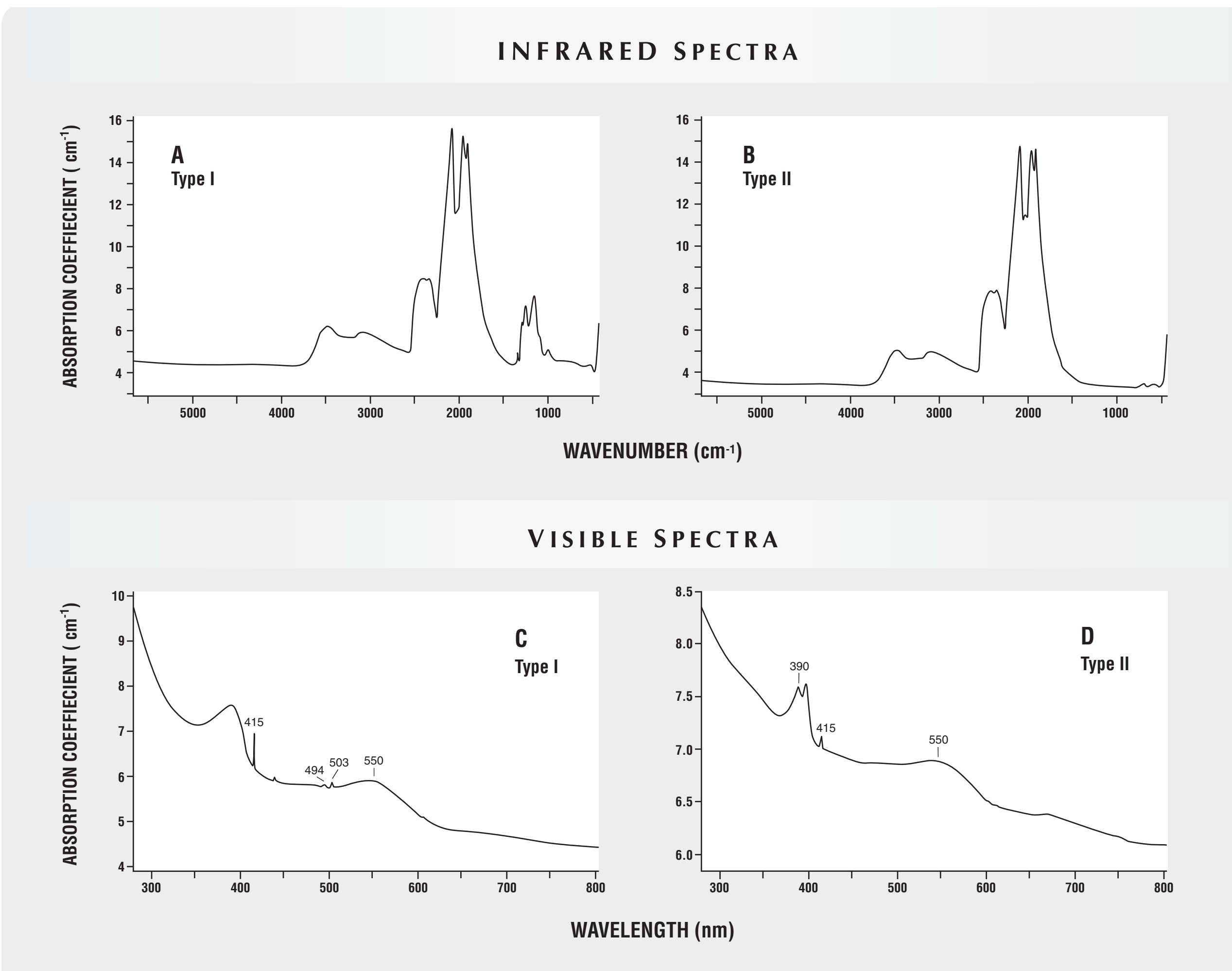
In addition to absorptions at 550 and 390 nm, the visible spectra of many pink diamonds contain an absorption line at 415 nm. This feature is due to the N3 center (Collins, 1982). In type I pink diamonds, the N3 center overlaps the 390 nm absorption band, and is typically accompanied by an increase in absorption toward the ultraviolet. The N3 center in type II diamonds is generally very weak to nonexistent due to the low nitrogen content; consequently, the 390 nm absorption may be clearly observed in the spectrum (figure 17D).

In type I diamonds, in addition to the 415 nm line, we occasionally noted absorption bands at 494 and 503 nm (associated with the H3 color center [Collins, 1982]).

DISCUSSION

Color Relationships. GIA GTL color descriptions for pink diamonds depend on variations in hue, tone, and/or saturation. The subtle differences that can occur in these three color attributes, independently or in combination, add to the complexity of consistently determining the fancy color grade or description of pink diamonds. For example:

Figure 17. Spectra A and B depict typical infrared spectra of type I and type II pink diamonds. Absorption between 1000 cm^{-1} and 1400 cm^{-1} approximates the concentration of nitrogen in a diamond, and in turn determines the diamond type. Spectra C and D represent typical visible spectra of type I and type II pink diamonds. Both these spectra exhibit broad absorption at 550 nm; however, type I diamonds show strong absorption at 415 nm, whereas in type II diamonds the 415 nm absorption is absent or very weak.



- "Warmer" (i.e., orangy) pink diamonds may be confused with brownish pink if color is not compared to color references using consistent observation methodology (figure 18). It is not uncommon for observers who see a "warmer" color appearance to associate it with low saturation (i.e., with the terms *brownish* or *brown*) instead of with a certain hue. Relatively strong warmer color appearances, such as orangy pink, can be incorrectly valued if their color is not analyzed properly.
- "Cooler" (i.e., purplish) pink diamonds often appear weaker than warmer pinks of similar tone and saturation (figure 19), as has been noted in color studies for other materials (Albers, 1975). Again, if such diamonds are not analyzed using consistent methodology and comparison to known references, such colors may be graded lower for strength.

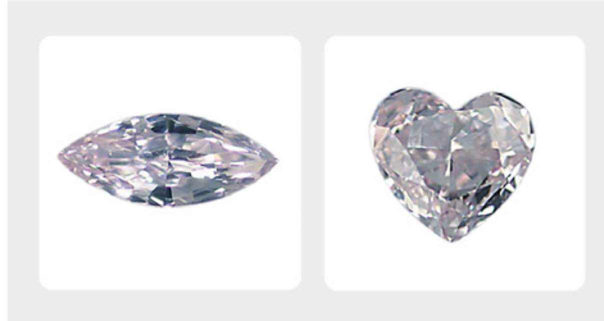
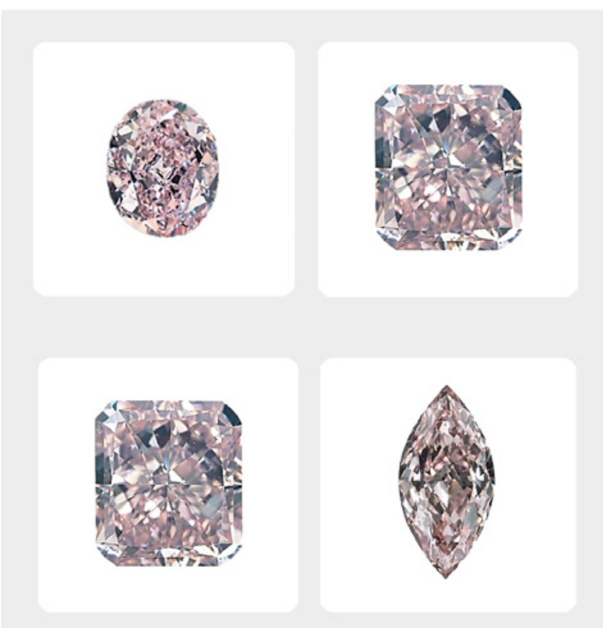


Figure 19. Pink diamonds with a noticeable purple component to their color may appear less saturated if compared to a pink diamond of warmer color. For example, the two diamonds seen here are considered to be of similar saturation in the GIA grading system. To the inexperienced observer, however, the cooler pink of the marquise on the left might appear weaker than the warmer pink of the heart shape on the right. Photos by Elizabeth Schrader.

Figure 18. When evaluating the appearance of a colored diamond, it is necessary to compare the stone in question to known color references. If this is not done, it is difficult to judge correctly what attribute(s) are affecting appearance. "Warm"-color pink diamonds are often considered weaker (i.e., browner) unless they are compared to graded-brownish/brown diamonds. On the top, a pink diamond (left) is shown next to an orangy pink diamond. In this comparison, it is easy to misinterpret the orangy pink color appearance as brownish. On the bottom, the same orangy pink diamond (now on the left) is placed next to a brownish pink marquise—and the difference in color appearance is apparent. Photos by Elizabeth Schrader and Don Mengason.



It is important to remember that all of these factors (hue, tone, and saturation) are a continuum in color space. The GIA grading system has established boundaries for groups of diamonds representing a range of tones and saturations of color within this continuum. For different hues, the tone and saturation boundaries will differ because of the natural range in which that color occurs (e.g., just as blue occurs in a narrower range of saturation than yellow [see again, King et al., 1998], pink occurs in a slightly narrower range than orangy pink). The fancy grade and color description boundaries gradate subtly around the hue circle (King et al., 1994). As a result, for each hue (e.g., red [pink] or orangy red [orangy pink], the range of tones and saturation may differ from one fancy grade to another. That is, as illustrated in figure 20, a pink diamond that falls within the Fancy Intense grade range may be similar in tone and saturation to an orangy pink diamond in the Fancy range.

Clarity. The primary importance of color in the valuation of colored diamonds is clearly supported with pink diamonds. As shown in figure 11, over half (56%) of the sample diamonds were of SI or I clarity grades, yet dealers indicate that this grading

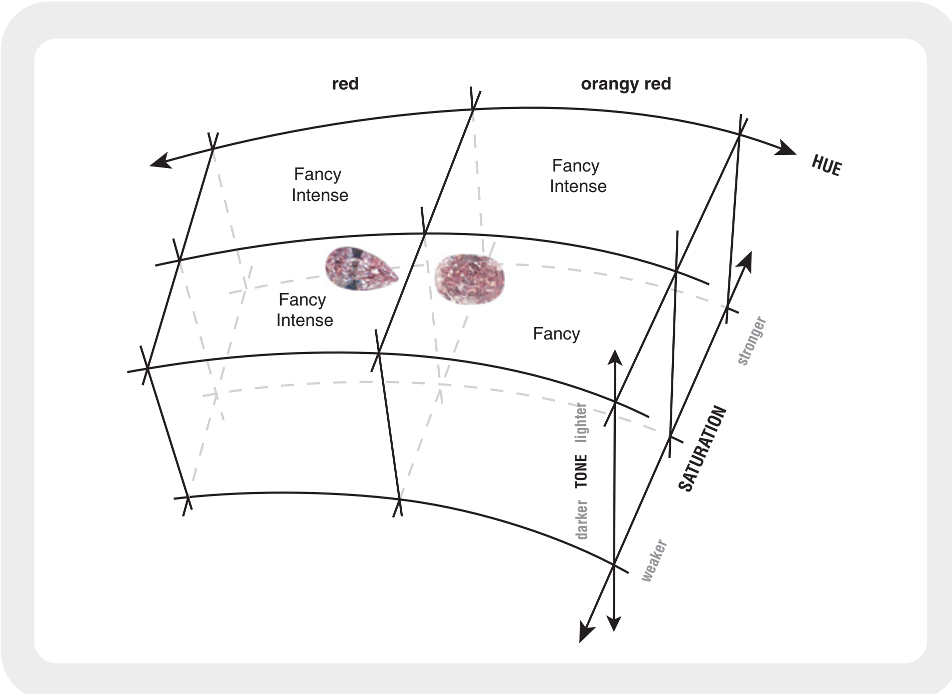


Figure 20. Because different hues encompass different ranges of tone and saturation, it is not uncommon to encounter two diamonds of similar tone and saturation but different fancy grades, as seen here for these two—Fancy Intense pink and Fancy orangy pink—diamonds. The chart shows a section in color space, with different fancy grades for the red (pink) and orangy red (orangy pink) hues denoted by three-dimensional "boxes." Photos by Elizabeth Schrader.

aspect is of secondary importance to that of color in determining the value of a pink diamond (M. Kirschenbaum, pers. comm., 2002).

Type II diamonds have been noted to be of higher clarity than type I diamonds (Scarratt, 1987). This observation was supported by our study, as 68% of the type II pink diamonds in our sample group were FL/IF, VVS, or VS.

Graining and Color Zoning. As mentioned previously, the graining and color zoning in type I pink diamonds often occurs in discrete bands. The number of planes and their intensity of color affect the overall depth (i.e., the combination of tone and saturation) of color in a pink diamond (which is the basis for judging face-up color appearance; see King et al., 1994). In our sample, we found a direct correlation between more intense or more numerous banded colored graining (that is appropriately oriented) and a stronger face-up color appearance.

Manufacturing. Many of the concerns manufacturers have when working with pink diamonds are similar to those discussed previously for blue diamonds (King et al., 1998). To achieve the best face-up color appearance, diamond cutters often use French culets and half-moon facets on the pavilion around the girdle (Watermeyer, 1991). These tech-

Figure 21. When pink diamonds are manufactured, the potential difference in color appearance between the rough and the faceted gem can be dramatic. This series show the original cleaved rough (left), the gem being cut from this rough at an interim stage in the faceting process (17.39 ct; middle), and the final 12.74 ct Fancy Vivid orangy pink diamond (right). Courtesy of Jacques Mouw; photos by Elizabeth Schrader.

niques help cutters achieve the strongest face-up color with an even distribution.

As mentioned above, color zoning in pink diamonds can affect the intensity of color. When such zones are present, their orientation relative to the table during cutting is critical to obtaining the best face-up appearance for a given facet arrangement.

One important distinction in the manufacture of pink diamonds is the change in color appearance that can occur during the cutting process. Manufacturers have reported observing a range of changes during the polishing process. When hot from the polishing wheel, some pink diamonds may appear weaker (closer to colorless) than their stable color. Immediately on cooling, the same diamonds may appear stronger than their stable color. This color change is temporary, and the diamonds do not retain the stronger pink color. Input energy (from heat due to the friction created by the rotating polishing wheel) produces these changes (M. Witriol, pers. comm., 2002).

As is often the case with colored diamond rough, the change in color appearance from the original rough to the faceted diamond can be significant. Figure 21 shows the transition in appearance of a diamond that when finished was graded Fancy Vivid orangy pink.

Spectroscopy. The broad region of absorption centered at about 550 nm is due to a color center of unknown structure along slip planes in a pink diamond (Raal, 1958; Collins, 1982; Fritsch, 1998). The broad band at 550 nm is always accompanied by a band at about 390 nm (again, see figure 17C and D). Shigley and Fritsch (1993) presented a comparison of the visible spectra of three diamonds (red-brown, purplish red, and purplish pink) to illustrate the presence of the same 550 nm absorption band in differing intensity in each spectrum. In our sample, we also noted the increasing strength of the 550 nm absorption band with greater depth of the pink-to-red color.

Figure 22. With the discovery of the Argyle mine in Western Australia, pink diamonds have become more available and gained broader commercial importance. As illustrated here, pink diamond melee and even larger single stones have established a special niche in the gem and jewelry industry. The Fancy orangy pink diamond in the ring weighs 1.15 ct; whereas the cross, dangle earrings, and brooch are set with a total weight in pink diamonds of 0.33 ct, 1.14 ct, and 1.43 ct, respectively. Courtesy of Alan Friedman Co., Beverly Hills, California; photo © Harold & Erica Van Pelt.

SUMMARY AND CONCLUSIONS

The beauty and relative rarity of pink diamonds have made them highly valued and desired through the centuries. Although they have been recovered from a number of localities around the world, historically their production has been quite sporadic. Only in the past 20 years has one source, the Argyle mine in Australia, produced a consistent supply of pink diamonds, which has given these special gemstones broader commercial importance in the jewelry marketplace (figure 22).

This report is based on the largest sample of pink diamonds published to date. With regard to the two types in which pink diamonds occur, I and II, this study confirmed that while the gemological characteristics associated with pink diamonds in these two categories may overlap, in the majority of cases there are some general differences in color appearance, clarity, and graining.

A key goal of this study was to illustrate aspects of the color grading of pink diamonds, which span a wide range of color hues, tones, and saturations. Again, this large sample confirmed the broader range of tones and saturations in some hue categories, and the importance of using consistent observation methodology and established color references in the color grading of colored diamonds.

ABOUT THE AUTHORS

Mr. King is laboratory projects officer, Mr. Gelb is staff gemologist, and Mr. Hall is analytical equipment supervisor at the GIA Gem Trade Laboratory (GTL) in New York. Dr. Shigley is director of GIA Research, and Mr. Guhin is grading lab manager at GIA GTL, in Carlsbad, California.

ACKNOWLEDGMENTS: The authors thank Thomas M. Moses, vice-president of Identification Services at GIA GTL in New York, for his comments and suggestions. Akira Hyatt, staff gemologist at GIA GTL in New York, assisted in the selection of images and determining their color relationship. Kim Cino, administrative director of GIA GTL in Carlsbad, assisted with the Horizon computer management system retrieval of data on pink diamonds. Kim Rockwell, staff gemologist in GIA GTL Identification in Carlsbad, and David Kondo, staff gemologist in GIA GTL Identification in New York, collected visible spectra on a selection of pink diamonds. Wuyi Wang, research scientist in GIA GTL Identification in New York, offered comments on the spectra. Elizabeth Schrader, digital imaging operator at GIA GTL in New York, photographed and created composite illustrations of many of the diamonds in this article. Martin Kirschenbaum of M. Kirschenbaum Trading, Lewis Wolf of Lewis Wolf Trading, Mates Witriol, and Christopher M. Welbourn of De Beers DTC Research Centre provided insights and helpful information.

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