Encyclopedia of Gemstones

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Gemstone

A selection of gemstone pebbles made by tumbling rough rock with abrasive grit, in a rotating drum. The biggest pebble here is 40 mm long (1.6 inches).

A **gemstone** or **gem** (also called a **precious** or **semi-precious stone**, or **jewel**) is a piece of mineral, which, in cut and polished form, is used to make jewelry or other adornments. However certain rocks, (such as lapis lazuli) and organic materials (such as amber or jet) are not minerals, but are still used for jewelry, and are therefore often considered to be gemstones as well. Most gemstones are hard, but some soft minerals are used in jewelry because of their lustre or other physical properties that have aesthetic value. Rarity is another characteristic that lends value to a gemstone. Apart from jewelry, from earliest antiquity until the 19th century engraved gems and hardstone carvings such as cups were major luxury art forms; the carvings of Carl Fabergé were the last significant works in this tradition.

Characteristics and classification

Spanish emerald and gold pendant at Victoria and Albert Museum.

The traditional classification in the West, which goes back to the Ancient Greeks, begins with a distinction between **precious** and **semi-precious stones**; similar distinctions are made in other cultures. In modern usage the precious stones are diamond, ruby, sapphire and emerald, with all other gemstones being semi-precious. This distinction is unscientific and reflects the rarity of the respective stones in ancient times, as well as their quality: all are translucent with fine color in their purest forms, except for the colorless diamond, and very hard, with hardnesses of 8-10 on the Mohs scale. Other stones are classified by their color, translucency and hardness. The traditional distinction does not necessarily reflect modern values, for example, while garnets are relatively inexpensive, a green garnet called Tsavorite, can be far more valuable than a mid-quality emerald. Another unscientific term for semi-precious gemstones used in art history and archaeology is hardstone. Use of the terms 'precious' and 'semi-precious' in a commercial context is, arguably, misleading in that it deceptively implies certain stones are intrinsically more valuable than others, which is not the case.

In modern times gemstones are identified by gemologists, who describe gems and their characteristics using technical terminology specific to the field of gemology. The first characteristic a gemologist uses to identify a gemstone is its chemical composition. For example, diamonds are made of carbon (C) and rubies of aluminium oxide (Al_2O_3). Next, many gems are crystals which are classified by their crystal system such as cubic or trigonal or monoclinic. Another term used is habit, the form the gem is usually found in. For example diamonds, which have a cubic crystal system, are often found as octahedrons.

Gemstones are classified into different *groups*, *species*, and *varieties*. For example, ruby is the red variety of the species corundum, while any other color of corundum is considered sapphire. Emerald (green), aquamarine (blue), red beryl (red), goshenite (colorless), heliodor (yellow), and morganite (pink) are all varieties of the mineral species beryl.

Gems are characterized in terms of refractive index, dispersion, specific gravity, hardness, cleavage, fracture, and luster. They may exhibit pleochroism or double refraction. They may have luminescence and a distinctive absorption spectrum.

Material or flaws within a stone may be present as inclusions.

Gemstones may also be classified in terms of their "water". This is a recognized grading of the gem's luster and/or transparency and/or "brilliance". Very transparent gems are considered "first water", while "second" or "third water" gems are those of a lesser transparency.

Value of gemstones

Jewelry made with amber.

There is no universally accepted grading system for gemstones. Diamonds are graded using a system developed by the Gemological Institute of America (GIA) in the early 1950s. Historically, all gemstones were graded using the naked eye. The GIA system included a major innovation: the introduction of 10x magnification as the standard for grading clarity. Other gemstones are still graded using the naked eye (assuming 20/20 vision).

A mnemonic device, the "four Cs" (color, cut, clarity and carat), has been introduced to help the consumer understand the factors used to grade a diamond. With modification, these categories can be useful in understanding the grading of all gemstones. The four criteria carry different weight depending upon whether they are applied to colored gemstones or to colorless diamond. In diamonds, cut is the primary determinant of value, followed by clarity and color. Diamonds are meant to sparkle, to break down light into its constituent rainbow colors (dispersion), chop it up into bright little pieces (scintillation), and deliver it to the eye (brilliance). In its rough crystalline form, a diamond will do none of these things; it requires proper fashioning and this is called "cut". In gemstones that have color, including colored diamonds, it is the purity and beauty of that color that is the primary determinant of quality.

Physical characteristics that make a colored stone valuable are color, clarity to a lesser extent (emeralds will always have a number of inclusions), cut, unusual optical phenomena within the stone such as color zoning, and asteria (star effects). The Greeks, for example, greatly valued asteria in gemstones, which were regarded as a powerful love charm, and Helen of Troy was known to have worn star-corundum.

Historically, gemstones were classified into **precious stones** and **semi-precious stones**. Because such a definition can change over time and vary with culture, it has always been a difficult matter to determine what constitutes *precious stones*.

Aside from the diamond, the ruby, sapphire, emerald, pearl (strictly speaking not a gemstone) and opal have also been considered to be precious. Up to the discoveries of bulk amethyst in Brazil in the 19th century, amethyst was considered a *precious stone* as well, going back to ancient Greece. Even in the last century certain stones such as aquamarine, peridot and cat's eye have been popular and hence been regarded as precious.

Nowadays such a distinction is no longer made by the trade. Many gemstones are used in even the most expensive jewelry, depending on the brand name of the designer, fashion trends, market supply, treatments etc. Nevertheless, diamonds, rubies, sapphires and emeralds still have a reputation that exceeds those of other gemstones.

Rare or unusual gemstones, generally meant to include those gemstones which occur so infrequently in gem quality that they are scarcely known except to connoisseurs, include andalusite, axinite, cassiterite, clinohumite and red beryl.

Gem prices can fluctuate heavily (such as those of tanzanite over the years) or can be quite stable (such as those of diamonds). In general per carat prices of larger stones are higher than those of smaller stones, but popularity of certain sizes of stone can affect prices. Typically prices can range from 1USD/carat for a normal amethyst to 20,000-50,000USD for a collector's three carat pigeon-blood almost "perfect" ruby.

Grading

Enamelled gold, amethyst and pearl pendant, about 1880, Pasquale Novissimo (1844–1914), V&A Museum number M.36-1928.

In the last two decades there has been a proliferation of certification for gemstones. There are a number of laboratories which grade and provide reports on diamonds.

- International Gemological Institute (IGI), independent laboratory for grading and evaluation of diamonds, jewellery and colored stones.
- Gemological Institute of America (GIA), the main provider of education services and diamond grading reports
- Hoge Raad voor Diamant (HRD Antwerp), The Diamond High Council, Belgium is one of Europe's oldest laboratories. Its main stakeholder is the Antwerp World Diamond Centre.
- American Gemological Society (AGS) is not as widely recognized nor as old as the GIA.
- American Gem Trade Laboratory which is part of the American Gem Trade Association (AGTA), a trade organization of jewelers and dealers of colored stones.
- American Gemological Laboratories (AGL), which was sold by "Collector's Universe" a NASDAQ listed company which specializes in certification of collectibles such as coins and stamps. It is now owned by Christopher P. Smith, who was awarded the Antonio C. Bonanno Award for Excellence in Gemology in 2009
- European Gemological Laboratory (EGL), founded in 1974 by Guy Margel in Belgium.

- Gemmological Association of All Japan (GAAJ-ZENHOKYO), Zenhokyo, Japan, active in gemological research
- Gemmological Institute of Thailand (GIT) is closely related to Chulalongkorn University
- Gemmology Institute of Southern Africa, Africa's premium gem laboratory.
- Asian Institute of Gemmological Sciences (AIGS), the oldest gemological institute in South East Asia, involved in gemological education and gem testing
- Swiss Gemmological Institute (SSEF), founded by Prof. Henry Hänni, focusing on colored gemstones and the identification of natural pearls
- Gübelin Gem Lab, the traditional Swiss lab founded by Dr. Eduard Gübelin. Their reports are widely considered as the ultimate judgement on high-end pearls, colored gemstones and diamonds.

Each laboratory has its own methodology to evaluate gemstones. Consequently a stone can be called "pink" by one lab while another lab calls it "Padparadscha". One lab can conclude a stone is untreated, while another lab concludes that it is heat treated. To minimise such differences, seven of the most respected labs, i.e. AGTA-GTL (New York), CISGEM (Milano), GAAJ-ZENHOKYO (Tokyo), GIA (Carlsbad), GIT (Bangkok), Gübelin (Lucerne) and SSEF (Basel), have established the Laboratory Manual Harmonisation Committee (LMHC), aiming at the standardization of wording on reports and certain analytical methods and interpretation of results. Country of origin has sometimes been difficult to find agreement on due to the constant discovery of new locations. Moreover determining a "country of origin" is much more difficult than determining other aspects of a gem (such as cut, clarity etc.).

Gem dealers are aware of the differences between gem laboratories and will make use of the discrepancies to obtain the best possible certificate.

Cutting and polishing

Raw gemstones.

A rural Thai gem cutter.

A few gemstones are used as gems in the crystal or other form in which they are found. Most however, are cut and polished for usage as jewelry. The picture to the left is of a rural, commercial cutting operation in Thailand. This small factory cuts thousands of carats of sapphire annually. The two main classifications are stones cut as smooth, dome shaped stones called cabochons, and stones which are cut with a faceting machine by polishing small flat windows called facets at regular intervals at exact angles.

Stones which are opaque such as opal, turquoise, variscite, etc. are commonly cut as cabochons. These gems are designed to show the stone's color or surface properties as in opal and star sapphires. Grinding wheels and polishing agents are used to grind, shape and polish the smooth dome shape of the stones.

Gems which are transparent are normally faceted, a method which shows the optical properties of the stone’s interior to its best advantage by maximizing reflected light which is perceived by the viewer as sparkle. There are many commonly used shapes for faceted stones. The facets must be cut at the proper angles, which varies depending on the optical properties of the gem. If the angles are too steep or too shallow, the light will pass through and not be reflected back toward the viewer. The faceting machine is used to hold the stone onto a flat lap for cutting and polishing the flat facets. Rarely, some cutters use special curved laps to cut and polish curved facets.

Gemstone color

Color is the most obvious and attractive feature of gemstones. The color of any material is due to the nature of light itself. Daylight, often called white light, is actually a mixture of different colors of light. When light passes through a material, some of the light may be absorbed, while the rest passes through. The part that is not absorbed reaches the eye as white light minus the absorbed colors. A ruby appears red because it absorbs all the other colors of white light (blue, yellow, green, etc.) except red.

The same material can exhibit different colors. For example ruby and sapphire have the same chemical composition (both are corundum) but exhibit different colors. Even the same gemstone can occur in many different colors: sapphires show different shades of blue and pink and "fancy sapphires" exhibit a whole range of other colors from yellow to orange-pink, the latter called "Padparadscha sapphire".

This difference in color is based on the atomic structure of the stone. Although the different stones formally have the same chemical composition, they are not exactly the same. Every now and then an atom is replaced by a completely different atom (and this could be as few as one in a million atoms). These so called impurities are sufficient to absorb certain colors and leave the other colors unaffected.

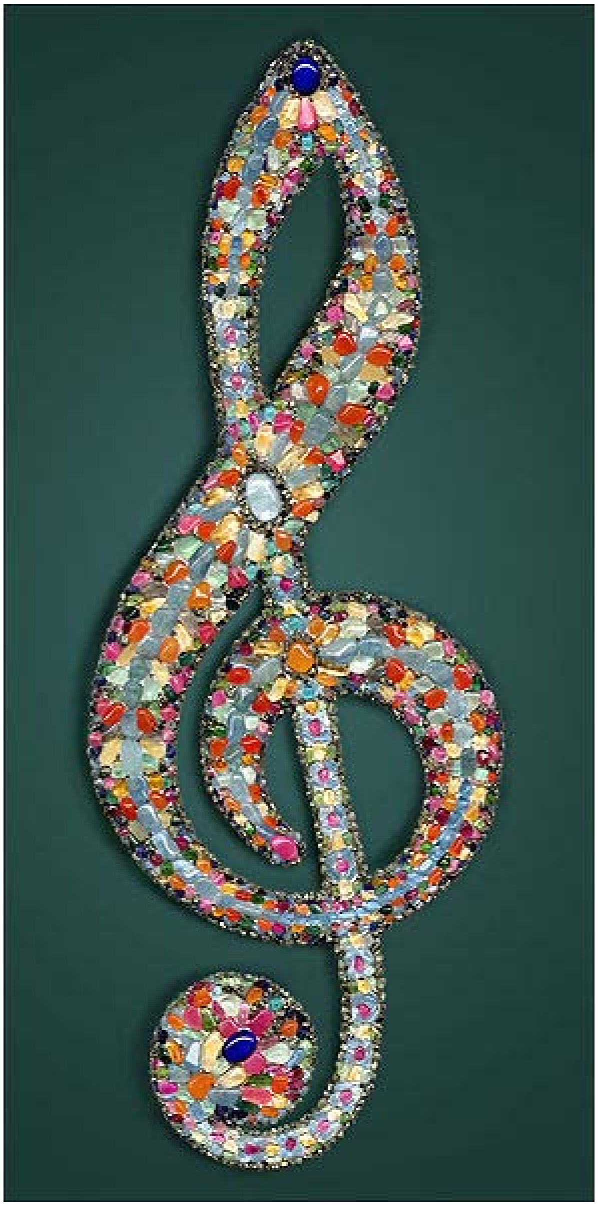
For example, beryl, which is colorless in its pure mineral form, becomes emerald with chromium impurities. If you add manganese instead of chromium, beryl becomes pink morganite. With iron, it becomes aquamarine.

Some gemstone treatments make use of the fact that these impurities can be "manipulated", thus changing the color of the gem.

Treatments applied to gemstones

Gemstones are often treated to enhance the color or clarity of the stone. Depending on the type and extent of treatment, they can affect the value of the stone. Some treatments are used widely because the resulting gem is stable, while others are not accepted most commonly because the gem color is unstable and may revert to the original tone.

Heat



A treble clef with gemstones.

Heat can improve gemstone color or clarity. The heating process has been well known to gem miners and cutters for centuries, and in many stone types heating is a common practice. Most citrine is made by heating amethyst, and partial heating with a strong gradient results in ametrine—a stone partly amethyst and partly citrine. Much aquamarine is heated to remove yellow tones and change the green color into the more desirable blue or enhance its existing blue color to a purer blue.

Nearly all tanzanite is heated at low temperatures to remove brown undertones and give a more desirable blue/purple color. A considerable portion of all sapphire and ruby is treated with a variety of heat treatments to improve both color and clarity.

When jewelry containing diamonds is heated (for repairs) the diamond should be protected with boracic acid; otherwise the diamond (which is pure carbon) could be burned on the surface or even burned completely up. When jewelry containing sapphires or rubies is heated, it should not be coated with boracic acid or any other substance, as this can etch the surface; they do not have to be "protected" like a diamond.

Radiation

Virtually all blue topaz, both the lighter and the darker blue shades such as "London" blue, has been irradiated to change the color from white to blue. Most greened quartz (Oro Verde) is also irradiated to achieve the yellow-green color.

Waxing/oiling

Emeralds containing natural fissures are sometimes filled with wax or oil to disguise them. This wax or oil is also colored to make the emerald appear of better color as well as clarity. Turquoise is also commonly treated in a similar manner.

Fracture filling

Fracture filling has been in use with different gemstones such as diamonds, emeralds and sapphires. In 2006 "glass filled rubies" received publicity. Rubies over 10 carat (2 g) with large fractures were filled with lead glass, thus dramatically improving the appearance (of larger rubies in particular). Such treatments are fairly easy to detect.

Synthetic and artificial gemstones

Some gemstones are manufactured to imitate other gemstones. For example, cubic zirconia is a synthetic diamond simulant composed of zirconium oxide. Moissanite is another example, although it is a gemstone in its own right. The imitations copy the look and color of the real stone but possess neither their chemical nor physical characteristics. Moissanite actually has a higher refractive index than diamond and when presented beside an equivalently sized and cut diamond will have more "fire" than the diamond.

However, lab created gemstones are not imitations. For example, diamonds, ruby, sapphires and emeralds have been manufactured in labs to possess identical chemical and physical characteristics to the naturally occurring variety. Synthetic (lab created) corundums, including ruby and sapphire, are very common and they cost only a fraction of the natural stones. Smaller synthetic diamonds have been manufactured in large quantities as industrial abrasives, although larger gem-quality synthetic diamonds are becoming available in multiple carats.

Whether a gemstone is a natural stone or a lab-created (synthetic) stone, the characteristics of each are the same. Lab-created stones tend to have a more vivid color to them, as impurities are not present in a lab and do not modify the clarity or color of the stone.

Hybrid gemstones

The terms synthetic, natural, artificial, and imitation are well-understood by gemologists. However, gemologists have had to continually explain these terms, as applied in gemology, both to those within and outside of the industry, as synthetic in particular has different definitions when applied to different fields.

It is precisely because certain new gem treatments overlap more than one gem category that the term hybrid has been suggested. These materials consist of an original natural material that has been significantly added to – to the extent that the term natural no longer applies. Hybrid gems consist of natural material along with artificial material – either synthetic growth or polymers or glasses.

Hybrid is defined as those gem materials where there is no easy means of separating the natural from the artificial components. This is key, in that with a doublet or a triplet, the natural material can be isolated, identified – and theoretically retrieved from the whole. Hybrid will not be confused with assembled, but it will encompass reconstructed materials as well as B-jades.

Hybrid will not apply to traditional oiling of emerald and (comparatively minor) fracture healing as seen in many Mong Hsu rubies; these treatments are insignificant in comparison and additives would account for less than 5% of the total mass in most cases, but there remains the possibility that some heavily treated stones in these categories may qualify as hybrids.

Major industry educators, dealers, and trade organizations have seen the need for this new upper-level category. In some ways it is a dramatic addition to the gemological terms, but is merely a natural evolution due to modern treatment methods.

Chapter- 2

Ruby

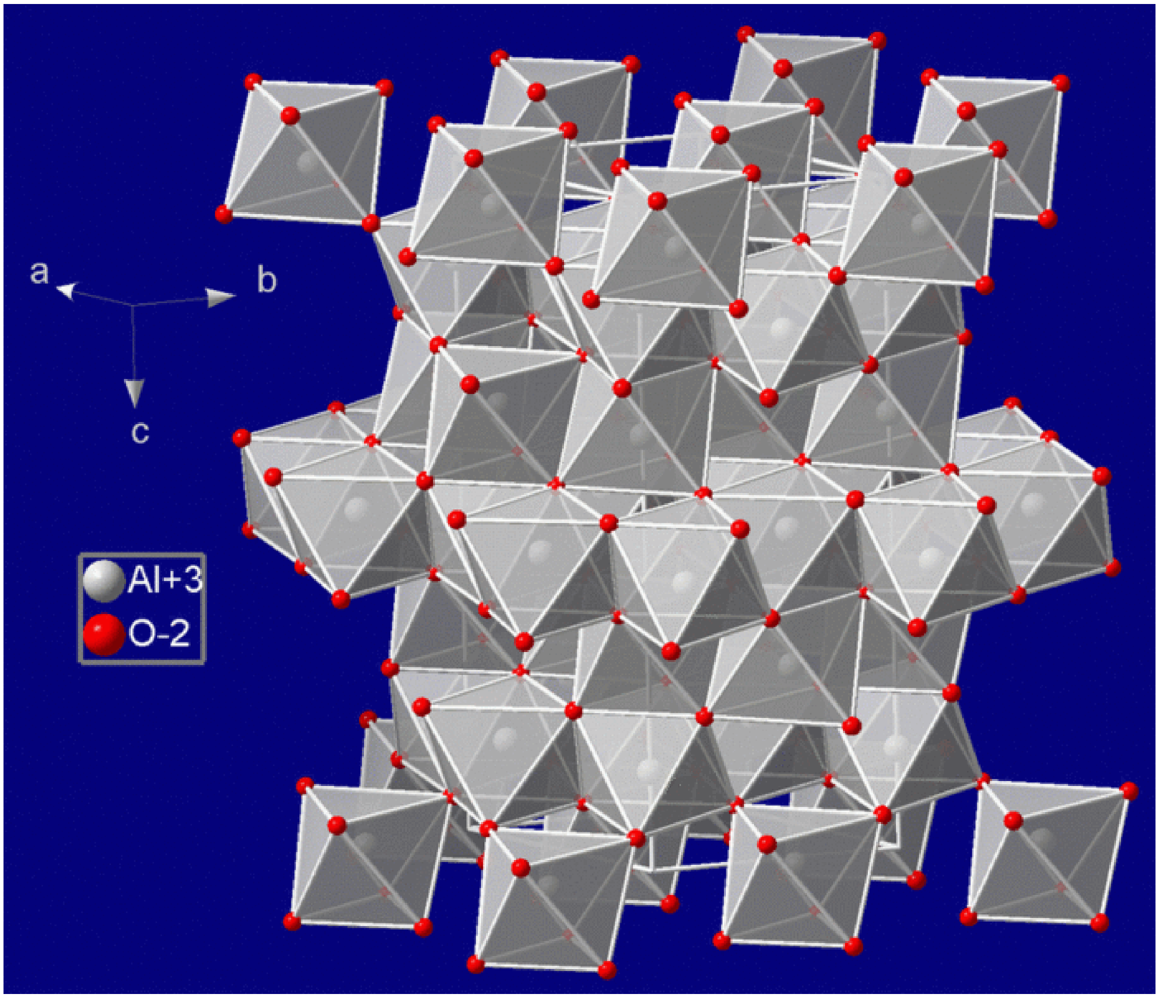
Ruby	

Natural ruby crystals from Winza, Tanzania

General	
Category	Mineral variety
Chemical formula	aluminium oxide with chromium, Al_2O_3:Cr

Identification	
Color	Red, may be brownish, purplish or pinkish
Crystal habit	Varies with locality. Terminated tabular hexagonal prisms.
Crystal system	Trigonal (Hexagonal Scalenohedral)

	Symbol (-3 2/m) Space Group: R-3c
Cleavage	No true cleavage
Fracture	Uneven or conchoidal
Mohs scale hardness	9.0
Luster	Vitreous
Streak	white
Diaphaneity	transparent
Specific gravity	4.0
Refractive index	n_ω=1.768 - 1.772 n_ε=1.760 - 1.763, Birefringence 0.008
Pleochroism	Orangey red, purplish red
Ultraviolet fluorescence	red under longwave
Melting point	2044 °C
Solubility	none
Major varieties	
Sapphire	Any color except red
Corundum	various colors
Emery	Granular



Crystal structure of ruby

The **ruby** is a pink to blood-red colored gemstone, a variety of the mineral corundum (aluminium oxide). The red color is caused mainly by the presence of the element chromium. Its name comes from *ruber*, Latin for red. Other varieties of gem-quality corundum are called sapphires. The ruby is considered one of the four precious stones, together with the sapphire, the emerald, and the diamond.

Prices of rubies are primarily determined by color. The brightest and most valuable "red" called pigeon blood-red, commands a huge premium over other rubies of similar quality. After color follows clarity: similar to diamonds, a clear stone will command a premium, but a ruby without any needle-like rutile inclusions may indicate that the stone has been treated. Cut and carat (weight) also determine the price.

Physical properties

Rubies have a hardness of 9.0 on the Mohs scale of mineral hardness. Among the natural gems only moissanite and diamond are harder, with diamond having a Mohs hardness of

10.0 and moissonite falling somewhere in between corundum (ruby) and diamond in hardness. Ruby is α-alumina (the most stable form of Al_2O_3) in which a small fraction of the aluminum^{3+} ions are replaced by chromium^{3+} ions. Each Cr^{3+} is surrounded octahedrally by six O^{2-} ions. This crystallographic arrangement strongly affects each Cr^{3+}, resulting in light absorption in the yellow-green region of the spectrum and thus in the red color of the gem. When yellow-green light is absorbed by Cr^{3+}, it is re-emitted as red luminescence. This red emission adds to the red colour perceived by the subtraction of green and violet light from white light, and adds luster to the gem's appearance. When the optical arrangement is such that the emission is stimulated by 694-nanometer photons reflecting back and forth between two mirrors, the emission grows strongly in intensity. This effect was used by Theodore Maiman in 1960 to make the first successful laser, based on ruby.

All natural rubies have imperfections in them, including color impurities and inclusions of rutile needles known as "silk". Gemologists use these needle inclusions found in natural rubies to distinguish them from synthetics, simulants, or substitutes. Usually the rough stone is heated before cutting. Almost all rubies today are treated in some form, with heat treatment being the most common practice. However, rubies that are completely untreated but still of excellent quality command a large premium.

Some rubies show a 3-point or 6-point asterism or "star". These rubies are cut into cabochons to display the effect properly. Asterisms are best visible with a single-light source, and move across the stone as the light moves or the stone is rotated. Such effects occur when light is reflected off the "silk" (the structurally oriented rutile needle inclusions) in a certain way. This is one example where inclusions increase the value of a gemstone. Furthermore, rubies can show color changes — though this occurs very rarely — as well as chatoyancy or the "cat's eye" effect.

Natural occurrence

The Mogok Valley in Upper Myanmar (Burma) was for centuries the world's main source for rubies. That region has produced some of the finest rubies ever mined, but in recent years very few good rubies have been found there. The very best color in Myanmar rubies is sometimes described as "pigeon's blood." In central Myanmar, the area of Mong Hsu began producing rubies during the 1990s and rapidly became the world's main ruby mining area. The most recently found ruby deposit in Myanmar is in Namya (Namyazeik) located in the northern state of Kachin.

Rubies have historically been mined in Thailand, the Pailin and Samlout District of Cambodia, Afghanistan and in Pakistan. Rubies have rarely been found in Sri Lanka, where pink sapphires are more common. After the Second World War ruby deposits were found in Tanzania, Madagascar, Vietnam, Nepal, Tajikistan, and Pakistan. A few rubies have been found in the U.S. states of Montana, North Carolina, and South Carolina. More recently, large ruby deposits have been found under the receding ice shelf of Greenland. In 2002 rubies were found in the Waseges River area of Kenya.

There are reports of a large deposit of rubies found in 2009 in Mozambique, in Nanhumbir in the Cabo Delgado district of Montepuez.

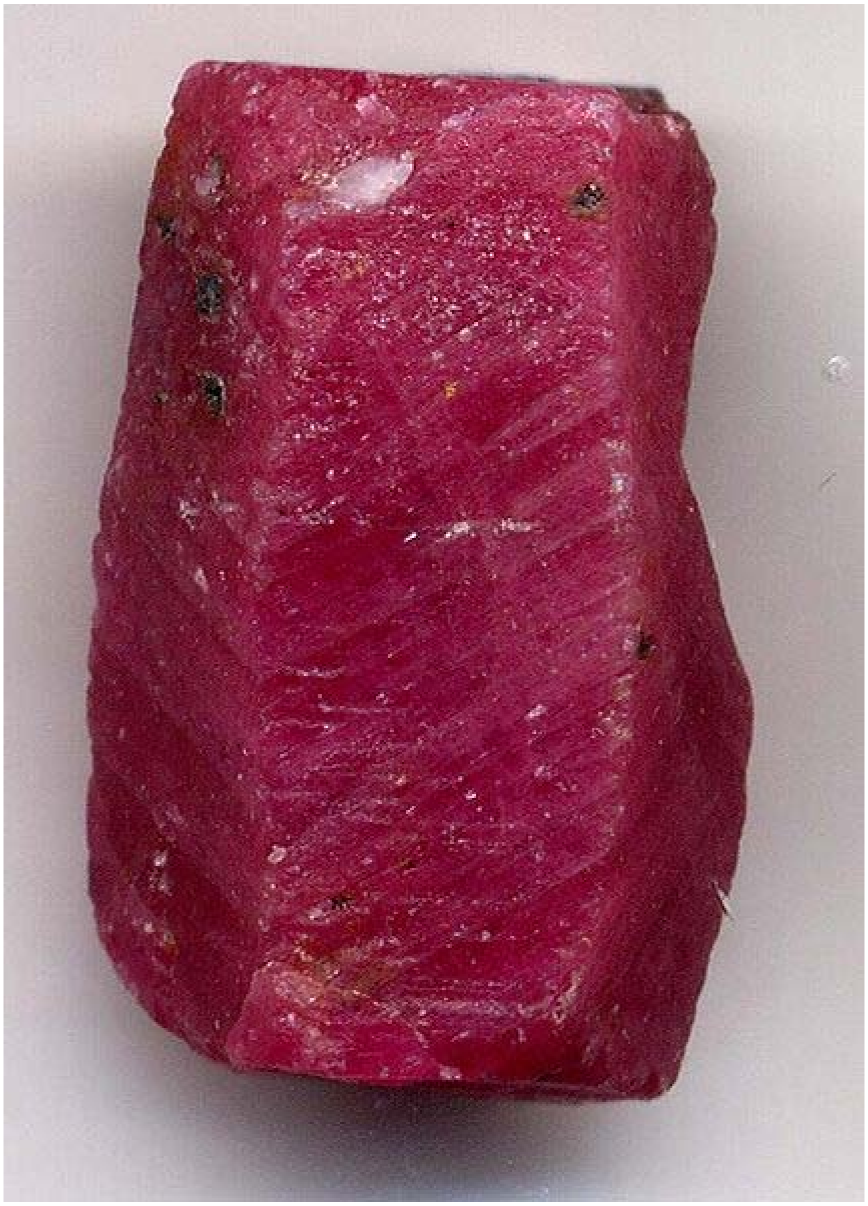
Spinel, another red gemstone, is sometimes found along with rubies in the same gem gravel or marble. Red spinel may be mistaken for ruby by those lacking experience with gems. However, the finest red spinels can have a value approaching that of the average ruby.

A cut ruby.

Factors affecting value

Diamonds are graded using criteria that have become known as the four Cs, namely color, cut, clarity and carat weight. Similarly natural rubies can be evaluated using the four Cs together with their size and geographic origin.

Color: In the evaluation of colored gemstones, color is the single most important factor. Color divides into three components; *hue*, *saturation* and *tone*. Hue refers to "color" as we normally use the term. Transparent gemstones occur in the following hues: red, orange, yellow, green, blue, violet, purple and pink. The first six are known as spectral hues; the last two are modified spectral hues. Purple is a hue that falls halfway between red and blue. Pink is a paler shade of red. In nature there are rarely pure hues so when speaking of the hue of a gemstone we speak of primary and secondary and sometimes tertiary hues. In ruby the primary hue must be red. All other hues of the gem species corundum are called sapphire. Ruby may exhibit a range of secondary hues. Orange, purple, violet and pink are possible.



A naturally occurring ruby crystal

Natural ruby with inclusions

Rubies set in jewellery

The finest ruby is best described as being a vivid medium-dark toned red. Secondary hues add an additional complication. Pink, orange, and purple are the normal secondary hues in ruby. Of the three, purple is preferred because, firstly, the purple reinforces the red making it appear richer. Secondly, purple occupies a position on the color wheel halfway between red and blue. In Burma where the term pigeon blood originated, rubies are set in pure gold. Pure gold is itself a highly saturated yellow. Set a purplish-red ruby in yellow and the yellow neutralizes its complement blue leaving the stone appearing to be pure red in the setting.

Treatments and enhancements

Improving the quality of gemstones by treating them is common practice. Some treatments are used in almost all cases and are therefore considered acceptable. During the late 1990s, a large supply of low-cost materials caused a sudden surge in supply of heat-treated rubies, leading to a downward pressure on ruby prices.

Improvements used include color alteration, improving transparency by dissolving rutile inclusions, healing of fractures (cracks) or even completely filling them.

The most common treatment is the application of heat. Most, if not all, rubies at the lower end of the market are heat treated on the rough stones to improve color, remove *purple tinge*, blue patches and silk. These heat treatments typically occur around temperatures of 1800 °C (3300 °F). Some rubies undergo a process of low tube heat, when the stone is heated over charcoal of a temperature of about 1300 °C (2400 °F) for 20 to 30 minutes. The silk is only partially broken as the color is improved.

A less acceptable treatment, which has gained notoriety in recent years, is lead glass filling. Filling the fractures inside the ruby with lead glass dramatically improves the transparency of the stone, making previously unsuitable rubies fit for applications in jewelry. The process is done in four steps:

1. The rough stones are pre-polished to eradicate all surface impurities that may affect the process
2. The rough is cleaned with hydrogen fluoride
3. The first heating process during which no fillers are added. The heating process eradicates impurities inside the fractures. Although this can be done at temperatures up to 1400 °C (2500 °F) it most likely occurs at a temperature of around 900 °C (1600 °F) since the rutile silk is still intact
4. The second heating process in an electrical oven with different chemical additives. Different solutions and mixes have shown to be successful, however mostly lead-containing glass-powder is used at present. The ruby is dipped into oils, then covered with powder, embedded on a tile and placed in the oven where it is heated at around 900 °C (1600 °F) for one hour in an oxidizing atmosphere. The orange colored powder transforms upon heating into a transparent to yellow-colored paste, which fills all fractures. After cooling the color of the paste is fully transparent and dramatically improves the overall transparency of the ruby.

If a color needs to be added, the glass powder can be "enhanced" with copper or other metal oxides as well as elements such as sodium, calcium, potassium etc.

The second heating process can be repeated three to four times, even applying different mixtures. When jewelry containing rubies is heated (for repairs) it should not be coated with boracic acid or any other substance, as this can etch the surface; it does not have to be "protected" like a diamond.

Synthetic and imitation rubies

In 1837 Gaudin made the first synthetic rubies by fusing potash alum at a high temperature with a little chromium as a pigment. In 1847 Ebelmen made white sapphire by fusing alumina in boric acid. In 1877 Frenic and Freil made crystal corundum from which small stones could be cut. Frimy and Auguste Verneuil manufactured artificial ruby by fusing BaF_2 and Al_2O_3 with a little Chromium at red heat. In 1903 Verneuil announced he could produce synthetic rubies on a commercial scale using this flame fusion process. By 1910, Verneuil's laboratory had expanded into a 30 furnace production facility, with annual gemstone production having reached 1,000 kg (2,205 lb) in 1907.

Other processes in which synthetic rubies can be produced are through the Czochralski's Pulling process, flux process, and the hydrothermal process. Most synthetic rubies originate from flame fusion, due to the low costs involved. Synthetic rubies may have no imperfections visible to the naked eye but magnification may reveal curves, striae and gas bubbles. The fewer the number and the less obvious the imperfections, the more valuable the ruby is; unless there are no imperfections (i.e., a "perfect" ruby), in which case it will be suspected of being artificial. Dopants are added to some manufactured rubies so they can be identified as synthetic, but most need gemological testing to determine their origin.

Synthetic rubies have technological uses as well as gemological ones. Rods of synthetic ruby are used to make ruby lasers and masers. The first working laser was made by Theodore H. Maiman in 1960 at Hughes Research Laboratories in Malibu, California, beating several research teams including those of Charles H. Townes at Columbia University, Arthur Schawlow at Bell Labs, and Gould at a company called TRG (Technical Research Group). Maiman used a solid-state light-pumped synthetic ruby to produce red laser light at a wavelength of 694 nanometers (nm). Ruby lasers are still in use. Rubies are also used in applications where high hardness is required such as at wear exposed locations in modern mechanical clockworks, or as scanning probe tips in a coordinate measuring machine.

Imitation rubies are also marketed. Red spinels, red garnets, and colored glass have been falsely claimed to be rubies. Imitations go back to Roman times and already in the 17th century techniques were developed to color foil red—by burning scarlet wool in the bottom part of the furnace—which was then placed under the imitation stone. Trade terms such as balas ruby for red spinel and rubellite for red tourmaline can mislead unsuspecting buyers. Such terms are therefore discouraged from use by many gemological associations such as the Laboratory Manual Harmonisation Committee (LMHC).

Records

Rubies at the National Museum of Natural History, Washington DC, USA

- The Smithsonian's National Museum of Natural History in Washington DC, has received one of the world's largest and finest ruby gemstones. The 23.1 carats (4.6 g) Burmese ruby, set in a platinum ring with diamonds, was donated by businessman and philanthropist Peter Buck in memory of his late wife Carmen Lúcia. This gemstone displays a richly saturated red color combined with an exceptional transparency. The finely proportioned cut provides vivid red reflections. The stone was mined from the Mogok region of Burma (now Myanmar) in the 1930s.
- In 2007 the London jeweler Garrard & Co featured on their website a heart-shaped 40.63-carat ruby.

Historical and cultural references

- An early recorded note of the transport and trading of rubies arises in the literature on the North Silk Road of China, wherein about 200 BC rubies were carried along this ancient trackway moving westward from China.
- Rubies have always been held in high esteem in Asian countries. They were used to ornament armor, scabbards, and harnesses of noblemen in India and China. Rubies were laid beneath the foundation of buildings to secure good fortune to the structure.

Chapter- 3

Sapphire

Sapphire	
	
The Hall Sapphire Necklace, the Bismarck Sapphire, and the Logan Sapphire on display at the Smithsonian Institution.	
General	
Category	Oxide mineral
Chemical formula	aluminium oxide, Al_2O_3
Identification	
Color	Every color except for red – which is called a ruby – or pinkish-orange (the padparadscha)
Crystal habit	massive and granular
Crystal system	Trigonal Symbol (32/m) Space Group: R3c
Cleavage	none

Fracture	conchoidal, splintery
Mohs scale hardness	9.0
Luster	vitreous
Streak	white
Specific gravity	3.95–4.03
Optical properties	Abbe number 72.2
Refractive index	n_ω=1.768–1.772 n_ε=1.760–1.763, Birefringence 0.008
Pleochroism	Strong
Melting point	2030–2050 °C
Fusibility	infusible
Solubility	Insoluble
Other characteristics	coefficient of thermal expansion (5.0–6.6)$\times10^{-6}$/K

Sapphire ("blue stone") is a gemstone variety of the mineral corundum, an aluminium oxide (α-Al_2O_3), when it is a color other than red or dark pink, in which case the gem would instead be called a ruby, considered to be a different gemstone. Trace amounts of other elements such as iron, titanium, or chromium can give corundum blue, yellow, pink, purple, orange, or greenish color. Pink-orange sapphires are also called **padparadscha**. Pure chromium is the distinct impurity of rubies. However, a combination of e.g. chromium and titanium can give a sapphire of a color distinct from red.

Sapphires are commonly worn as jewelry. Sapphires can be found naturally, by searching through certain sediments or rock formations, or they can be manufactured for industrial or decorative purposes in large crystal boules. Because of the remarkable hardness of sapphires (and of aluminum oxide in general), sapphires are used in some non-ornamental applications, including infrared optical components, such as in scientific instruments; high-durability windows (also used in scientific instruments); wristwatch crystals; and very thin electronic wafers, which are used as the insulating substrates of very special-purpose solid-state electronics (most of which are integrated circuits).

Natural sapphires

An uncut/rough yellow sapphire found at the Spokane Sapphire Mine near Helena Montana

The sapphire is one of the two or three gem-varieties of corundum, with another one being the red or deep pink ruby. Although blue is their most well-known color, sapphires are made up of any color of corundum except for red (red ones are called rubies). Sapphires may also be colorless, and they are also found in shades of gray and black.

The cost of natural sapphires varies depending on their color, clarity, size, cut, and overall quality – as well as their geographic origin, oddly enough. Significant sapphire deposits are found in Eastern Australia, Thailand, Sri Lanka, Madagascar, East Africa, and in North America in a few locations, such as at "Gem Mountain", and in or near the Missouri River in the region around Helena, Montana. Sapphire and rubies are often found together in the same area, but one gem is usually more abundant.

Blue sapphire

The 423-carat (85 g) blue Logan sapphire

Color in gemstones breaks down into three components: hue, saturation, and tone. Hue is most commonly understood as the "color" of the gemstone. Saturation refers to the vividness or brightness or "colorfulness" of the hue, and tone is the lightness to darkness of the hue. Blue sapphire exists in various mixtures of its primary (blue) and secondary hues, various tonal levels (shades) and at various levels of saturation (brightness).

Blue sapphires are evaluated based upon the purity of their primary hue. Purple, violet, and green are the most common secondary hues found in blue sapphires. Violet and purple can contribute to the overall beauty of the color, while green is considered to be distinctly negative. Blue sapphires with up to 15% violet or purple are generally said to be of fine quality. Blue sapphires with any amount of green as a secondary hue are not considered to be fine quality. Gray is the normal saturation modifier or mask found in blue sapphires. Gray reduces the saturation or brightness of the hue and therefore has a distinctly negative effect.

The color of fine blue sapphires can be described as a vivid medium dark violet to purplish blue where the primary blue hue is at least 85% and the secondary hue no more than 15% without the least admixture of a green secondary hue or a gray mask.

The 423-carat (85 g) Logan sapphire in the National Museum of Natural History, in Washington, D.C., is one of the largest faceted gem-quality blue sapphires in existence.

Fancy color sapphire

Pink sapphire

Yellow and green sapphires are also commonly found. Pink sapphires deepen in color as the quantity of chromium increases. The deeper the pink color the higher their monetary value as long as the color is trending towards the red of rubies.

Sapphires also occur in shades of orange and brown, and colorless sapphires are sometimes used as diamond substitutes in jewelry. Padparadscha sapphires often draw higher prices than many of even the finest blue sapphires. Recently, more sapphires of this color have appeared on the market as a result of a new artificial treatment method that is called "lattice diffusion".

Padparadscha

Faceted padparadscha

Padparadscha is a pink-orange corundum, with a low to medium saturation and light tone, originally being mined in Sri Lanka, but also found in deposits in Vietnam and Africa; Padparadscha sapphires are very rare and highly valued. The name derives from the Sinhalese word for lotus blossom. Along with rubies, they are the only type of corundum to be given their own name instead of being called a particular colored sapphire. Padparadscha used to be a subvariety of ruby. The rarest of all padparadschas is the totally natural variety, with no sign of treatment.

Star sapphire

The 182 carats (36 g) Star of Bombay star sapphire

A *star sapphire* is a type of sapphire that exhibits a star-like phenomenon known as asterism. Star sapphires contain intersecting needle-like inclusions (often the mineral rutile, a mineral composed primarily of titanium dioxide) that cause the appearance of a six-rayed "star"-shaped pattern when viewed with a single overhead light source.

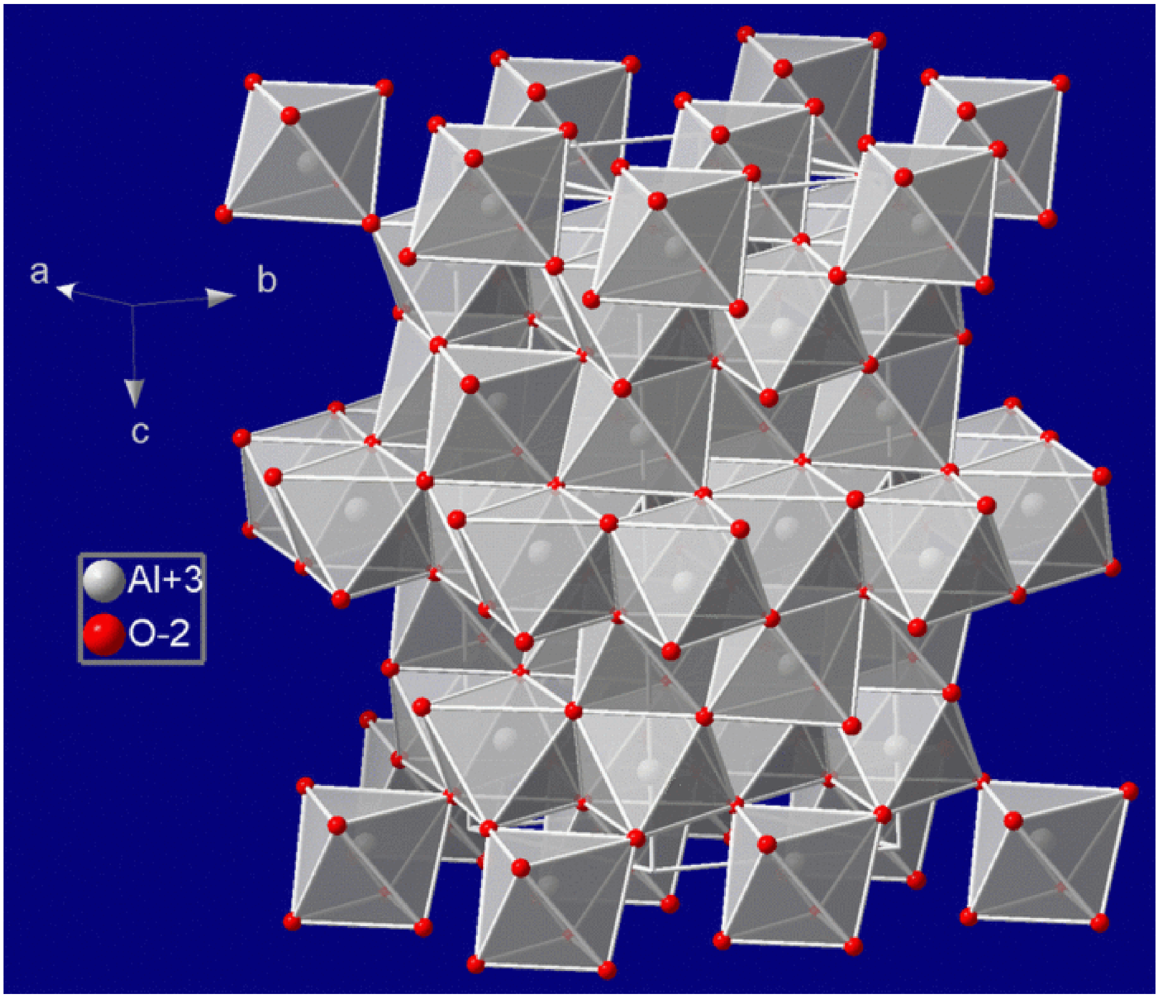
The Black Star of Queensland is believed to be the largest star sapphire that has ever been mined, and it weighs 733 carats. The Star of India (weighing 563.4 carats) is thought to be the second-largest star sapphire, and it is currently on display at the American Museum of Natural History in New York City. The 182-carat Star of Bombay, located in the National Museum of Natural History, in Washington, D.C., is an example of a blue star sapphire. The value of a star sapphire, however, depends not only on the weight of the stone but also the body color, visibility and intensity of the asterism.

Color change sapphire

A rare variety of sapphire, known as color change sapphire, exhibits different colors in different light. Color change sapphires are blue in outdoor light and purple under incandescent indoor light; they may also be pink in daylight to greenish under fluorescent light. Some stones shift color well and others only partially, in that some stones go from blue to bluish purple. While color change sapphires come from a variety of locations, the gem gravels of Tanzania is the main source.

Certain synthetic color-change sapphires are sold as “lab” or “synthetic” alexandrite, which is accurately called an alexandrite simulant (also called alexandrium) since the latter is actually a type of chrysoberyl—an entirely different substance whose pleochroism is different and much more pronounced than color-change corundum (sapphire).

Source of color



Crystal structure of sapphire

Red rubies are corundum which contain chromium impurities that absorb yellow-green light and result in deeper ruby red color with increasing content. Purple sapphires contain trace amounts of vanadium and come in a variety of shades. Corundum that contains ~0.01% of titanium is colorless. If trace amounts of iron are present, a very pale yellow to green color may be seen. If both titanium and iron impurities are present together, however, the result is a magnificent deep-blue color.

Unlike localized ("interatomic") absorption of light which causes color for chromium and vanadium impurities, blue color in sapphires comes from intervalence charge transfer, which is the transfer of an electron from one transition-metal ion to another via the conduction or valence band. The iron can take the form Fe^{2+} or Fe^{3+}, while titanium generally takes the form Ti^{4+}. If Fe^{2+} and Ti^{4+} ions are substituted for Al^{3+}, localized areas of charge imbalance are created. An electron transfer from Fe^{2+} and Ti^{4+} can cause a change in the valence state of both. Because of the valence change there is a specific change in energy for the electron, and electromagnetic energy is absorbed. The wavelength of the energy absorbed corresponds to yellow light. When this light is subtracted from incident white light, the complementary color blue results. Sometimes when atomic spacing is different in different directions there is resulting blue-green dichroism.

Intervalence charge transfer is a process that produces a strong colored appearance at a low percentage of impurity. While at least 1% chromium must be present in corundum before the deep red ruby color is seen, sapphire blue is apparent with the presence of only 0.01% of titanium and iron.

Treatments

Sapphires may be treated by several methods to enhance and improve their clarity and color. It is common practice to heat natural sapphires to improve or enhance color. This is done by heating the sapphires in air to temperatures between 500 and 1800 °C for several hours, or by heating in a nitrogen-deficient atmosphere oven for seven days or more. Upon heating, the stone becomes a more blue in color but loses some of the rutile inclusions (silk). When high heat temperatures are used, the stone loses all of the silk and becomes clear under magnification. Evidence of sapphire and other gemstones being subjected to heating goes back to, at least, Roman times. Un-heated stones are quite rare and will often be sold accompanied by a certificate from an independent gemological laboratory attesting to "no evidence of heat treatment".

Diffusion treatments are somewhat more controversial as they are used to add elements to the sapphire for the purpose of improving colors. Typically beryllium is diffused into a sapphire with very high heat, just below the melting point of the sapphire. Initially (c. 2000) orange sapphires were created with this process, although now the process has been advanced and many colors of sapphire are often treated with beryllium. It is unethical to sell beryllium-treated sapphires without disclosure, and the price should be much lower than a natural gem or one that has been enhanced by heat alone.

Treating stones with surface diffusion is generally frowned upon because when stones chip or are repolished/refaceted the 'padparadscha' colored layer can be removed. (There are some diffusion treated stones in which the color goes much deeper than the surface, however.) The problem lies in the fact that treated padparadschas are at times very difficult to detect, and they are the reason that getting a certificate from a reputable gemological lab (e.g., Gubelin, SSEF, AGTA, etc.) is recommended before investing in them.

According to Federal Trade Commission guidelines, in the United States, disclosure is required of any mode of enhancement that has a significant effect on the gem's value.

Mining

Sapphire from Madagascar

Sapphires are mined from alluvial deposits or from primary underground workings. The mining locations include Burma, Madagascar, Sri Lanka, Australia, Thailand, India, Pakistan, Afghanistan, Tanzania, Kenya, and China. The Logan sapphire, the Star of India, and the Star of Bombay originate from Sri Lankan mines. Madagascar is the world leader in sapphire production (as of 2007) specifically its deposits in and around the city of Ilakaka. Prior to the opening of the Ilakaka mines, Australia was the largest producer of sapphires (such as in 1987). In 1991, a new source of sapphires was discovered in Andranondambo, southern Madagascar. That area has been exploited for its sapphires started in 1993, but it was practically abandoned just a few years later – because of the difficulties in recovering sapphires in their bedrock.

In North America, sapphires have been mined mostly from deposits around Helena, Montana. A few gem-grade sapphires and rubies have also been found in the area of Franklin, N.C.

The sapphire deposits of Kashmir are still well-known in the gem industry, despite the fact that the peak production from this area mostly took place in a relatively short period at the end of the 19th and early 20th centuries.

In December 2008, a 12.11 kg (60,500 carats) "rock consisting primarily of corundum, and possible additional minerals" was found in the Dodoma Region of Tanzania.

Synthetic sapphire

Synthetic star sapphire

Synthetic sapphire

In 1902, the French chemist Auguste Verneuil developed a process for producing synthetic sapphire crystals. In the Verneuil process, named for him, fine alumina powder is added to an oxyhydrogen flame, and this is directed downward against a mantle. The alumina in the flame is slowly deposited, creating a teardrop shaped "boule" of sapphire material. Chemical dopants can be added to create artificial versions of the ruby, and all the other natural colors of sapphire, and in addition, other colors never seen in geology. Artificial sapphire material is identical to natural sapphire, except it can be made without the flaws that are found in natural stones. The disadvantage of Verneuil process is that the grown crystals have high internal strains. Many methods of manufacturing sapphire today are variations of the Czochralski process, which was invented in 1916. In this process, a tiny sapphire seed crystal is dipped into a crucible made of the precious metal rhodium, containing molten alumina, and then slowly withdrawn upward at a rate of one to 100 mm per hour. The alumina crystallizes on the end, creating long carrot-shaped boules of large size, up to 400 mm in diameter and weighing almost 500 kg.

Synthetic sapphire is industrially produced from agglomerated aluminum oxide, sintered and fused in an inert atmosphere (hot isostatic pressing for example), yielding a transparent polycrystalline product, slightly porous, or with more traditional methods such as Verneuil, Czochralski, flux method, etc., yielding a single crystal sapphire material which is non-porous and should be relieved of its internal stress.

In 2003, the world's production of synthetic sapphire was 250 tons (1.25×10^9 carats), mostly by the United States and Russia. The availability of cheap synthetic sapphire unlocked many industrial uses for this unique material:

The first laser was made with a rod of synthetic ruby. Titanium-sapphire lasers are popular due to their relatively rare capacity to be tuned to various wavelengths in the red and near-infrared region of the electromagnetic spectrum. They can also be easily mode-locked. In these lasers, a synthetically-produced sapphire crystal with chromium or titanium impurities is irradiated with intense light from a special lamp, or another laser, to create stimulated emission.

Transparent and tough

One application of synthetic sapphire is *sapphire glass*. Here *glass* is a layman term which refers not to the amorphous state, but to the transparency. Sapphire is not only highly transparent to wavelengths of light between 170 nm (UV) and 5.3 µm (IR) (the human eye can discern wavelengths from about 380 nm to 750 nm), but it is also five times stronger than glass and ranks a 9 on the Mohs Scale, and much tougher than tempered glass, although not as much as synthetic stabilized zirconium oxide (such as yttria-stabilized zirconia). Along with zirconia and aluminium oxynitride, synthetic sapphire is used for shatter resistant windows in armored vehicles and various military body armor suits, in association with composites.

Sapphire "glass" (although being crystalline) is made from pure sapphire boules by slicing off and polishing thin wafers. Sapphire glass windows are used in high pressure chambers for spectroscopy, crystals in high quality watches, and windows in grocery store barcode scanners since the material's exceptional hardness and toughness makes it very resistant to scratching.

Cermax xenon arc lamp with synthetic sapphire output window

One type of xenon arc lamp (originally called the "Cermax" its first brand name), which is now known generically as the "ceramic body xenon lamp", uses sapphire crystal output windows that tolerate higher thermal loads – and thus higher output powers when compared with conventional Xe lamps with pure silica window.

Use as substrate for semiconducting circuits

Thin sapphire wafers are also used as an insulating substrate in high-power, high-frequency CMOS integrated circuits. This type of IC is called a silicon on sapphire or "SOS" chip. These are especially useful for high-power radio-frequency (RF) applications such as those found in cellular telephones, police car and fire truck radios, and satellite communication systems. "SOS" allows for the monolithic integration of both digital and analog circuitry all on one IC chip.

The reason for choosing wafers of artificial sapphire, rather than some of other substance, for these subtrates is that sapphire has a quite low conductivity for electricity, but a much-higher conductivity for heat. Thus, sapphire provides good electrical insulation, while at the same time doing a good job at helping to conduct away the significant heat that is generated in all operating integrated circuits. Thus, the choice of sapphire material for these substrates was not an arbitrary one, but rather, it is a choice that is made for serious electronics engineering reasons.

Wafers of single-crystal sapphire material are also used in the semiconductor industry as a non-conducting substrate for the growth of devices based on gallium nitride (GaN). The use of the sapphire material significantly reduces the cost, because this has about one-seventh the cost of germanium. Gallium nitride on sapphire is commonly used in blue light-emitting diodes (LEDs).

Historical and cultural references

- Some etymologists propose an old Sanskrit origin to the Semitic word "sappir": a dark colored precious stone called "Shanipriya" from "shani" meaning "Saturn" and "priya" precious, i.e. "precious to Saturn".
- According to Rebbenu Bachya, and in many English Bible translations, the word "Sapir" in the verse Exodus 28:18 means "sapphire" and was the stone on the Ephod representing the tribe of Issachar. However, it has been suggested that the English word "sapphire" stems from the Hebrew word "sapir" (ריפס) (via the Greek word "sapphiros"; σάπφειρος). Sapphires were actually not known as a distinct stone before the time of the Roman Empire. They were earlier considered to be forms of the mineral jacinth, rather than needing a word of their own. Prior to the time of the Roman Empire, "sapphiros" referred to any blue gem in general.

Chapter- 4

Emerald

Emerald

Emerald crystal from Muzo, Colombia

General	
Category	Beryl variety
Chemical formula	$Be_3Al_2(SiO_3)_6$
Crystal symmetry	(6/m 2/m 2/m) – Dihexagonal Dipyramidal
Unit cell	a = 9.21 Å, c = 9.19 Å; Z = 2

Identification	
Molar mass	537.50
Color	Green shades

Crystal habit	Massive to well Crystalline
Crystal system	Hexagonal (6/m 2/m 2/m) Space group: P6/mcc
Cleavage	Imperfect on the [0001]
Fracture	Conchoidal
Mohs scale hardness	7.5–8
Luster	Vitreous
Streak	White
Diaphaneity	Transparent to opaque
Specific gravity	Average 2.76
Optical properties	Uniaxial (-)
Refractive index	$n_\omega = 1.564–1.595$, $n_\varepsilon = 1.568–1.602$
Birefringence	$\delta = 0.0040–0.0070$
Ultraviolet fluorescence	None (some fracture filling materials used to improve emerald's clarity do fluoresce, but the stone itself does not)

Emerald is a variety of the mineral beryl ($Be_3Al_2(SiO_3)_6$) colored green by trace amounts of chromium and sometimes vanadium. Beryl has a hardness of 7.5–8 on the 10 point Mohs scale of mineral hardness. Most emeralds are highly included, so their toughness (resistance to breakage) is classified as generally poor.

Etymology

The word "Emerald" is derived (via Old French: Esmeraude and Middle English: Emeraude), from Vulgar Latin: Esmaralda/Esmaraldus, a variant of Latin Smaragdus, which originated in Greek: σμάραγδος (smaragdos; "green gem"); its original source being either the Hebrew word *אזמרגד izmargad* meaning "emerald" or "green" or the Sanskrit word marakata meaning "green." The name could also be related to the Semitic word baraq (בָּרָק; البُراق; "lightning" or "shine") (cf. Hebrew: ברקת bareqeth and Arabic: برق barq "lightning"). It is the same source for the names Persian (زمرّد zomorrod), Turkish (zümrüt), Sanskrit (maragdam), Georgian (ზურმუხტი; zurmukhti), Russian (изумруд; izumrud) and Armenian zmruxt.

Properties determining value

Cut emeralds

Emeralds, like all colored gemstones, are graded using four basic parameters – the four Cs of Connoisseurship: *Color*, *Cut*, *Clarity* and *Crystal*. The last C, *crystal* is simply used as a synonym that begins with C for transparency or what gemologists call *diaphaneity*. Before the 20th century, jewelers used the term *water* as in "a gem of the finest water" to express the combination of two qualities, color and crystal. Normally, in the grading of colored gemstones, color is by far the most important criterion. However, in the grading of emerald, crystal is considered a close second. Both are necessary conditions. A fine emerald must possess not only a pure verdant green hue as described below, but also a high degree of transparency to be considered a top gem.

In the 1960s the American jewelry industry changed the definition of 'emerald' to include the green vanadium-bearing beryl as emerald. As a result, *vanadium emeralds* purchased as emeralds in the United States are not recognized as such in the UK and Europe. In America, the distinction between traditional emeralds and the new vanadium kind is often reflected in the use of terms such as 'Colombian Emerald.'

Color

Scientifically speaking, color is divided into three components: *hue*, *saturation* and *tone*. Yellow and blue, the hues found adjacent to green on the spectral color wheel, are the normal secondary hues found in emerald. Emeralds occur in hues ranging from yellow-green to blue-green. The primary hue must, of course, be green. Only gems that are medium to dark in tone are considered emerald. Light-toned gems are known by the species name, *green beryl*. In addition, the hue must be bright (vivid). Gray is the normal saturation modifier or mask found in emerald. A grayish green hue is a dull green.

Clarity

Emerald tends to have numerous inclusions and surface breaking fissures. Unlike diamond, where the loupe standard, i.e. 10X magnification, is used to grade clarity, emerald is graded by eye. Thus, if an emerald has no visible inclusions to the eye (assuming normal visual acuity) it is considered flawless. Stones that lack surface breaking fissures are extremely rare and therefore almost all emeralds are treated, "oiled", to enhance the apparent clarity. Eye-clean stones of a vivid primary green hue (as described above) with no more than 15% of any secondary hue or combination (either blue or yellow) of a medium-dark tone command the highest prices. This relative crystal non-uniformity makes emeralds more likely than other gemstones to be cut into cabochons, rather than faceted shapes.

Treatments

Most emeralds are oiled as part of the post lapidary process, in order to improve their clarity. Cedar oil, having a similar refractive index, is often used in this generally accepted practice. Other liquids, including synthetic oils and polymers with refractive indexes close to that of emerald such as *Opticon* are also used. The U.S. Federal Trade Commission requires the disclosure of this treatment when a treated emerald is sold. The use of oil is traditional and largely accepted by the gem trade. Other treatments, for example the use of green-tinted oil, are not acceptable in the trade. The laboratory community has recently standardized the language for grading the clarity of emeralds. Gems are graded on a four step scale; *none*, *minor*, *moderate* and *highly* enhanced. Note that these categories reflect levels of enhancement not *clarity*. A gem graded *none* on the enhancement scale may still exhibit visible inclusions. Laboratories tend to apply these criteria differently. Some gem labs consider the mere presence of oil or polymers to constitute enhancement. Others may ignore traces of oil if the presence of the material does not materially improve the look of the gemstone.

Given that the vast majority of all emeralds are treated as described above, and the fact that two stones that appear to be similar in quality may actually be quite far apart in treatment level, a consumer considering a purchase of an expensive emerald is well advised to insist upon a treatment report from a reputable gemological laboratory. All other factors being equal, a high quality emerald with an enhancement level graded *moderate* should cost 40–50% less than an identical stone graded *none*.

Emerald localities

Spanish emerald and gold pendant exhibited at Victoria and Albert Museum.

Emeralds in antiquity were mined by the Egyptians and in Pakistan and Austria.

A rare type of emerald known as a *trapiche* emerald is occasionally found in the mines of Colombia. A trapiche emerald exhibits a "star" pattern; it has raylike spokes of dark carbon impurities that give the emerald a six-pointed radial pattern. Emeralds come from three main emerald mining areas in Colombia: Muzo, Coscuez, and Chivor. Emeralds are also found in other countries, such as Afghanistan, Australia, Austria, Brazil, Bulgaria, Cambodia, Canada, China, Egypt, Ethiopia, France, Germany, India, Italy, Kazakhstan, Madagascar, Mozambique, Namibia, Nigeria, Norway, Pakistan, Russia, Somalia, South Africa, Spain, Switzerland, Tanzania, United States, Zambia and Zimbabwe. In the US, emeralds have been found in Connecticut, Montana, Nevada, North Carolina and South Carolina. In 1998 emeralds were discovered in the Yukon.

Synthetic emerald

Emerald showing its hexagonal structure

Emerald is a rare and valuable gemstone and, as such, it has provided the incentive for developing synthetic emeralds. Both hydrothermal and *flux-growth* synthetics have been produced, and a method has been developed for producing an emerald overgrowth on colorless beryl. The first commercially successful emerald synthesis process was that of Carroll Chatham. Because Chatham's emeralds do not have any water and contain traces of vanadate, molybdenum and vanadium, a lithium vanadate flux process is probably involved. The other large producer of flux emeralds was Pierre Gilson Sr., which has been on the market since 1964. Gilson's emeralds are usually grown on natural colorless beryl seeds which become coated on both sides. Growth occurs at the rate of 1 mm per month, a typical seven-month growth run producing emerald crystals of 7 mm of thickness. Gilson sold his production laboratory to a Japanese firm in the 1980s, but production has ceased since; so did Chatham's, after the San Francisco earthquake in 1989.

Hydrothermal synthetic emeralds have been attributed to IG Farben, Nacken, Tairus, and others, but the first satisfactory commercial product was that of Johann Lechleitner of Innsbruck, Austria, which appeared on the market in the 1960s. These stones were initially sold under the names "Emerita" and "Symeralds", and they were grown as a thin layer of emerald on top of natural colorless beryl stones. Although not much is known about the original process, it is assumed that Leichleitner emeralds were grown in acid conditions. Later, from 1965 to 1970, the Linde Division of Union Carbide produced completely synthetic emeralds by hydrothermal synthesis. According to their patents, acidic conditions are essential to prevent the chromium (which is used as the colorant) from precipitating. Also, it is important that the silicon-containing nutrient be kept away from the other ingredients to prevent nucleation and confine growth to the seed crystals. Growth occurs by a diffusion-reaction process, assisted by convection. The largest producer of hydrothermal emeralds today is Tairus in Russia. They have succeeded to synthesize emeralds that have similar chemical composition as emeralds in alkaline deposits in Colombia, hence they are called “Colombian Created Emeralds” or “Tairus Created Emeralds”. Luminescence in ultraviolet light is considered a supplementary test when making a natural vs. synthetic determination, as many, but not all, natural emeralds are inert to ultraviolet light. Many synthetics are also UV inert.

Synthetic emeralds are often referred to as "created", as their chemical and gemological composition is the same as their natural counterparts. The U.S. Federal Trade Commission (FTC) has very strict regulations as to what can and what cannot be called "synthetic" stone. The FTC says: "§ 23.23(c) It is unfair or deceptive to use the word "laboratory-grown," "laboratory-created," "[manufacturer name]-created," or "synthetic" with the name of any natural stone to describe any industry product unless such industry product has essentially the same optical, physical, and chemical properties as the stone named."

Emerald in different cultures, and emerald lore

The Gachala Emerald is one of the largest gem emeralds in the world, at 858 carats (172 g). This stone was found in 1967 at La Vega de San Juan mine in Gachalá, Colombia. It is housed at the National Museum of Natural History of the Smithsonian Institution in Washington, D.C.

Emerald is regarded as the traditional birthstone for May, as well as the traditional gemstone for the astrological signs of Taurus, Cancer and sometimes Gemini. One of the more quaint anecdotes on emeralds was by the 16th-century historian Brantôme, who referred to the many impressive emeralds the Spanish under Cortez had brought back to Europe from Latin America. On one of Cortez's most notable emeralds he had the text engraved *Inter Natos Mulierum non sur-rexit mayor* ("Among those born of woman there hath not arisen a greater"; Man. XI, 11) which referred to John the Baptist. Brantôme considered engraving such a beautiful and simple product of nature sacrilegious and considered this act the cause for Cortez's loss of an extremely precious pearl (to which he dedicated a work *A beautiful and incomparable pearl*) and even for the death of King Charles IX of France who died soon after.

In some cultures, the emerald is the traditional gift for the 55th wedding anniversary. It is also used as a 20th and 35th wedding anniversary stone.

The Authorized King James Version of the Bible, in Exodus 28:18 and 39:11, lists "emerald" as one of the precious stones in the breastplate of the high priest of the Jews; but modern consensus is that this is probably a mistranslation.

Ireland is often referred to, especially in America, as the "Emerald Isle".

In L. Frank Baum's *The Wonderful Wizard of Oz*, the city where the wizard rules is made of emerald and is called the Emerald City. The sixth book in the series is named after it.

Notable emeralds

Emerald	Origin
Chalk Emerald	Colombia
Duke of Devonshire Emerald	
Gachala Emerald	
Mogul Mughal Emerald	
Bahia Emerald	Brazil

Left to right: The Indian Emerald Necklace, the Gachala Emerald crystal and the Mackay Emerald Necklace, all pieces from the U.S. National Museum of Natural History.

The Chalk Emerald ring, containing a top-quality 37-carat emerald, also in the U.S. National Museum of Natural History.

The Hooker Emerald Brooch, containing a 75-carat square-cut emerald, also in the U.S. National Museum of Natural History.

Emerald crystal (about 1 cm) in calcite matrix, Muzo, Colombia.

A top-quality 5-carat emerald from Muzo.

Typical low quality emerald.

Chapter- 5

Tanzanite

Tanzanite

Tanzanite rough stone and cut stone

General	
Category	Mineral Variety
Chemical formula	$(Ca_2Al_3(SiO_4)(Si_2O_7)O(OH))$

Identification	
Color	Purple to Blue
Crystal habit	Crystals flattened in an acicular manner, may be fibrously curved
Crystal system	Orthorhombic
Cleavage	Perfect {010} imperfect {100}
Fracture	Uneven to conchoidal
Mohs scale hardness	6.5
Luster	Vitreous, pearly on cleavage surfaces

Streak	White or colorless
Specific gravity	3.10–3.38
Optical properties	biaxial positive
Refractive index	1.69–1.70
Birefringence	0.006–0.018
Pleochroism	Present, dichroism or trichroism depending on color.

Tanzanite is the blue/purple variety of the mineral zoisite (a calcium aluminium hydroxy silicate) which was discovered in the Meralani (Merelani) Hills of Northern Tanzania in 1967, near the city of Arusha. It is used as a gemstone. Tanzanite is noted for its remarkably strong trichroism, appearing alternately sapphire blue, violet and burgundy depending on crystal orientation.

Tanzanite in its rough state is usually a reddish brown color. It requires artificial heat treatment to 600 °C in a gemological oven to bring out the blue violet of the stone. Tanzanite is a rare gem. It is found mostly in the foothills of Mount Kilimanjaro. The mineral is named after Tanzania, the country in which it was discovered.

Commercial history

Manuel de Souza, a Goan tailor and part-time gold prospector living in Arusha (Tanzania), found transparent fragments of vivid blue and blue-purple gem crystals on a ridge near Mererani, some 40 km southeast of Arusha. He decided that the mineral was olivine (peridot) but quickly realized that it was not, so he took to calling it "dumortierite", a blue non-gem mineral. Shortly thereafter, D'Souza showed the stones to John Saul, a Nairobi-based consulting geologist and gemstone wholesaler who was then mining aquamarine in the region around Mount Kenya. Saul, with a Ph.D. from M.I.T., who later discovered the famous ruby deposits in the Tsavo area of Kenya, eliminated dumortierite and cordierite as possibilities, and sent samples to his father, Hyman Saul, vice president at Saks Fifth Avenue in New York. Hyman Saul brought the samples across the street to the Gemological Institute of America who correctly identified the new gem as a variety of the mineral zoisite. Correct identification was also made by mineralogists at Harvard University, the British Museum, and Heidelberg University, but the very first person to get the identification right was Ian McCloud, a Tanzanian government geologist based in Dodoma.

Originally called "blue zoisite" it was renamed as part of a campaign by Tiffany & Co., who wanted to capitalize on the rarity of the gem, then only found in Tanzania, but who thought that "blue zoisite" (which might be pronounced like "blue suicide") wouldn't sell well. From 1967 to 1972, an estimated two million carats of tanzanite were mined in Tanzania. The mines were later nationalized by the Tanzanian government.

World's largest tanzanite

The world's largest faceted tanzanite is 737.81 carats. One of the most famous large tanzanites (242 carats) is the "Queen of Kilimanjaro". It is set in a tiara and accented with 803 brilliant cut tsavorite garnets and 913 brilliant cut diamonds. Because tanzanite is relatively soft, it is usually set in necklaces and earrings, so the tiara is truly a rarity. The tiara is currently on display in the Gallery of Gold and Gems at the Royal Ontario Museum in Toronto, Ontario, Canada. The exhibition is from the private collection of Michael Scott, the first CEO of Apple Computers.

Recent developments

In June 2003, the Tanzanian government introduced legislation banning the export of unprocessed tanzanite to India (like many gemstones, most tanzanite is cut in Jaipur). The ban has been rationalized as an attempt to spur development of local processing facilities, thereby boosting the economy and recouping profits. This ban was phased in over the next two years, until which time only stones over 0.5 grams were affected.

This is a serious situation for the city of Jaipur, as one-third of its annual gem exports are of tanzanite. Some members of the industry fear the ban will set a precedent, leading Tanzania to ban the export of *all* raw gem material, including the country's production of tsavorite, diamond, and ruby.

In April 2005, a company called TanzaniteOne Ltd. publicly announced that they had taken control of the portion of the tanzanite deposit known as "C-Block" (the main deposit is divided into five blocks). Prices for rough material on the open market have increased steadily for the last several years as the company has solidified its control of the market. In August 2005, the largest-ever tanzanite crystal was found in the C-Block mine. The crystal weighs 16,839 carats (3.4 kg) and measures 8.7 in x 3.1 in x 2.8 in (22 cm × 8 cm × 7 cm).

The mining of tanzanite nets the Tanzanian government approximately US$20 million annually. The finished gems are sold mostly on the US market: sales total approximately US$500 million annually.

A rough sample of tanzanite

Factors affecting value: grading

There is no universally accepted method of grading colored gemstones. TanzaniteOne, a major commercial player in the tanzanite market, through its no-profit subsidiary, The Tanzanite Foundation, has introduced its own color-grading system. The new system's color-grading scales divide tanzanite colors into a range of hues, between blue violet and violet blue.

The normal primary and secondary hues in tanzanite are blue and purple, not violet. Purple is a modified spectral hue that lies halfway between red and blue. Tanzanite is a trichroic gemstone, meaning that light that enters the stone is divided into three sections, each containing a portion of the visible spectrum. After heating, tanzanite becomes dichroic. The dichroic colors are red and blue. The hue range of tanzanite is blue-purple to purple-blue.

Clarity grading in colored gemstones is based on the eye-clean standard, that is, a gem is considered flawless if no inclusions are visible with the unaided eye (assuming 20x20 vision). The Gemological Institute of America classifies tanzanite as a Type I gemstone, meaning it is normally eye-flawless. Gems with eye-visible inclusions will be traded at deep discounts.

Heat treatment

Excepting a few stones that were found close to the surface in the early days of the discovery, Tanzanite is universally heat-treated to produce a range of hues between bluish-purple to purplish-blue. Since heat treatment is universal, it has no effect on price, and finished gems are assumed to be heat-treated. Rarely, tanzanite is found in other colors, green being the rarest, although technically it would be called 'green zoisite' rather than tanzanite. Tanzanite may be subjected to other forms of treatment as well. Recently coated Tanzanites were discovered and tested by the AGTA and AGL laboratories. A thin layer of coatings was applied to improve the color of the Tanzanite. Tanzanite is heat treated in the furnace keeping the furnace from 550 to 700 degrees Celsius. It is important that it should not have any crack or bubble in it, otherwise there is ample chance that it will break or the cracks or bubble can be increased.

Chapter- 6

Topaz

Topaz	
 A group of topaz crystals on matrix	
General	
Category	Silicate mineral
Chemical formula	$Al_2SiO_4(F,OH)_2$
Identification	
Color	Clear (if no impurities), blue, brown, orange, gray, yellow, green, pink and reddish pink.

Crystal system	orthorhombic
Cleavage	[001] Perfect
Fracture	conchoidal
Mohs scale hardness	8 (defining mineral)
Luster	glassy
Streak	white
Diaphaneity	Transparent
Specific gravity	3.49–3.57
Optical properties	Biaxial (+)
Refractive index	n_α = 1.606–1.629 n_β = 1.609–1.631 n_γ = 1.616–1.638
Birefringence	$\delta = 0.010$
Pleochroism	Weak in thick sections
Other characteristics	Fluorescent, short UV=golden yellow, long UV=cream

Topaz is a silicate mineral of aluminium and fluorine with the chemical formula $Al_2SiO_4(F,OH)_2$. Topaz crystallizes in the orthorhombic system and its crystals are mostly prismatic terminated by pyramidal and other faces.

Color and varieties

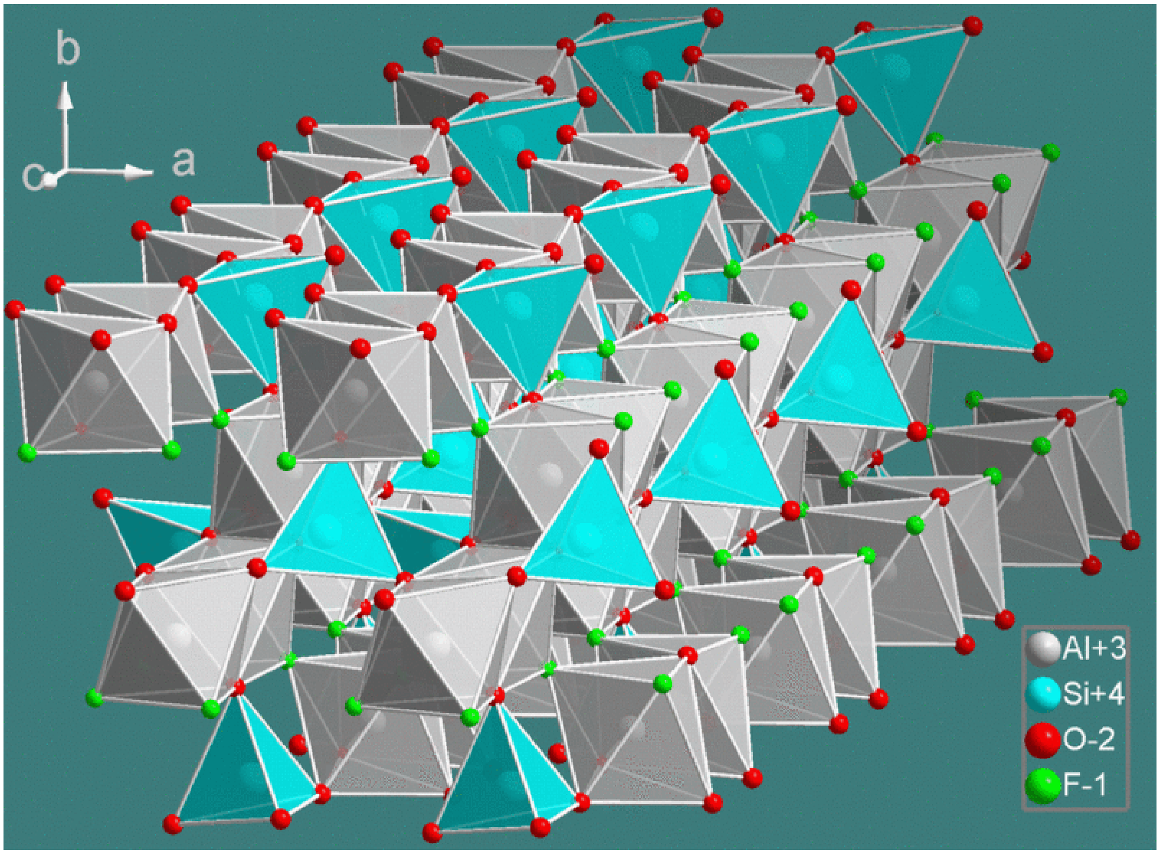
Pure topaz is colorless and transparent but is usually tinted by impurities; typical topaz is wine, yellow, pale gray or reddish-orange, blue brown. It can also be made white, pale green, blue, gold, pink (rare), reddish-yellow or opaque to transparent/translucent.

Orange topaz, also known as precious topaz, is the traditional November birthstone, the symbol of friendship, and the state gemstone for the US state of Utah.

Imperial topaz is yellow, pink (rare, if natural) or pink-orange. Brazilian Imperial Topaz can often have a bright yellow to deep golden brown hue, sometimes even violet. Many brown or pale topazes are treated to make them bright yellow, gold, pink or violet colored. Some imperial topaz stones can fade on exposure to sunlight for an extended period of time. *Blue topaz* is the US state Texas' gemstone. Naturally occurring blue topaz is quite rare. Typically, colorless, gray or pale yellow and blue material is heat treated and irradiated to produce a more desired darker blue.

Mystic topaz is colorless topaz which has been artificially coated giving it the desired rainbow effect.

Localities and occurrence



Crystal structure of topaz

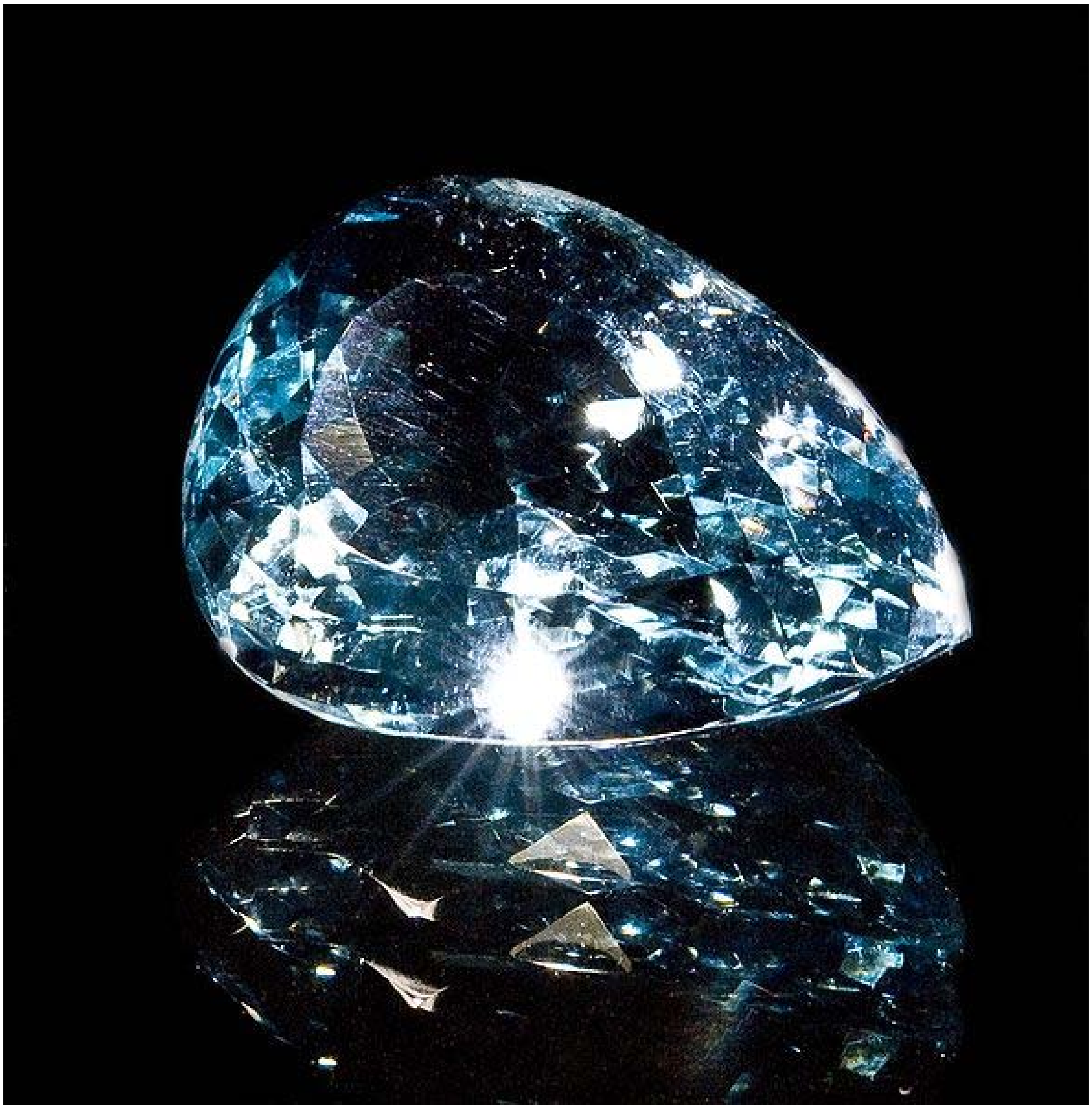
Topaz Mountain, Utah

Topaz is commonly associated with silicic igneous rocks of the granite and rhyolite type. It typically crystallizes in granitic pegmatites or in vapor cavities in rhyolite lava flows like those at Topaz Mountain in western Utah. It can be found with fluorite and cassiterite in various areas including the Ural and Ilmen mountains of Russia, in Afghanistan, Sri Lanka, Czech Republic, Germany, Norway, Pakistan, Italy, Sweden, Japan, Brazil, Mexico, Flinders Island, Australia, Nigeria and the United States.

Some clear topaz crystals from Brazilian pegmatites can reach boulder size and weigh hundreds of pounds. Crystals of this size may be seen in museum collections. The Topaz of Aurungzebe, observed by Jean Baptiste Tavernier measured 157.75 carats.

Colorless and light-blue varieties of topaz are found in Precambrian granite in Mason County, Texas within the Llano Uplift. There is no commercial mining of topaz in that area.

Colorless topaz, Minas Gerais, Brazil



A cut blue topaz

A red topaz

Imperial Topaz Gem

Facet Cut Topaz Gemstones in various colors, including mystic.

Etymology and historical and mythical usage

Etymology

The name "topaz" is derived (via Old French: Topace and Latin: Topazus) from the Greek *Τοπάζιος* (Topázios) or *Τοπάζιον* (Topázion), the ancient name of St. John's Island in the Red Sea which was difficult to find and from which a yellow stone (now believed to be chrysolite: yellowish olivine) was mined in ancient times; topaz itself (rather than *topazios*) wasn't really known about before the classical era.

Pliny says that Topazos is a *legendary* island in the Red Sea and the mineral "topaz" was first mined there. The word topaz might be related to the Arabic word زابوت which meant "the subject of the search" or Sanskrit word "tapas" meaning "heat" or "fire."

History

Nicols, the author of one of the first systematic treatises on minerals and gemstones, dedicated two chapters to the topic in 1652. In the Middle Ages, the name topaz was used to refer to any yellow gemstone, but in modern times it denotes only the silicate described above.

Biblical background, etymology, and analysis

Many modern English translations of the Bible, including the King James Version mention *Topaz* in Exodus 28:17 in reference to a stone in the Hoshen: "And thou shalt set in it settings of stones, even four rows of stones: the first row shall be a sardius, a topaz, and a carbuncle (Garnet): this shall be the first row."

However, because these translations as *topaz* all derive from the Septuagint translation *topazi[os]*, which as mentioned above referred to a yellow stone that was not topaz, but probably chrysolite, it should be borne in mind that topaz is likely not meant here. The masoretic text (the Hebrew on which most modern Protestant Bible translations of the Old Testament are based) has *pitdah* as the gem the stone is made from; some scholars think it is related to an Assyrian word meaning 'flashed'. More likely, pitdah is derived from Sanskrit words (pit = yellow dah = burn), meaning "yellow burn" or, metaphorically, "fiery".

Chapter- 7

Tourmaline

Tourmaline	
 Schorl Tourmaline	
General	
Category	Silicate mineral group
Chemical formula	$(Ca,K,Na,[])(Al,Fe,Li,Mg,Mn)_3(Al,Cr,Fe,V)_6(BO_3)_3(Si,Al,B)_6O_{18}(OH,F)_4$
Identification	
Color	Most commonly black, but can range from brown, violet, green, pink, or in a dual-colored pink and green.
Crystal habit	Parallel and elongated. Acicular prisms, sometimes radiating. Massive. Scattered grains (in granite).
Crystal system	Trigonal

Cleavage	Indistinct
Fracture	Uneven, small conchoidal, brittle
Mohs scale hardness	7–7.5
Luster	Vitreous, sometimes resinous
Streak	White
Specific gravity	3.06 (+.20 -.06)
Density	2.82–3.32
Polish luster	Vitreous
Optical properties	Double refractive, uniaxial negative
Refractive index	nω=1.635–1.675, nε=1.610–1.650
Birefringence	-0.018 to -0.040; typically about .020 but in dark stones it may reach .040
Pleochroism	typically moderate to strong Red Tourmaline: Definite; dark red,light red Green Tourmaline: Strong; dark green, yellow-green Brown Tourmaline: Definite; dark brown, light brown Blue Tourmaline: Strong; dark blue, light blue
Dispersion	.017
Ultraviolet fluorescence	pink stones—inert to very weak red to violet in long and short wave
Absorption spectra	a strong narrow band at 498nm, and almost complete absorption of red down to 640nm in blue and green stones; red and pink stones show lines at 458 and 451nm as well

as a broad band in the green spectrum

Tourmaline is a crystal boron silicate mineral compounded with elements such as aluminium, iron, magnesium, sodium, lithium, or potassium. Tourmaline is classified as a semi-precious stone and the gem comes in a wide variety of colors. The name comes from the Sinhalese word "Thuramali" or "Thoramalli" which applied to different gemstones found in Sri Lanka.

History

Brightly colored Sri Lankan gem tourmalines were brought to Europe in great quantities by the Dutch East India Company to satisfy a demand for curiosities and gems. At the time it was not realised that **schorl** and tourmaline were the same mineral.

Tourmaline species and varieties

- Dravite species: from the Drave district of Carinthia
    - Dark yellow to brownish black—dravite
- Schorl species:
    - Bluish or brownish black to Black—schorl
- Elbaite species: named after the island of Elba, Italy
    - Rose or pink—rubellite variety (from ruby)
    - Dark black—schorl (from indigo)
    - Light blue to bluish green—Brazilian indicolite variety
    - Green—verdelite or Brazilian emerald variety
    - Colorless—achroite variety (from the Greek "άχρωμος" meaning "colorless")

Schorl

The most common species of tourmaline is **schorl**. It may account for 95% or more of all tourmaline in nature. The early history of the mineral schorl shows that the name "schorl" was in use prior to 1400 because a village known today as Zschorlau (in Saxony, Germany) was then named "Schorl" (or minor variants of this name). This village had a nearby tin mine where, in addition to cassiterite, black tourmaline was found. The first description of schorl with the name "schürl" and its occurrence (various tin mines in the Saxony Ore Mountains) was written by Johannes Mathesius (1504–1565) in 1562 under the title "Sarepta oder Bergpostill". Up to about 1600, additional names used in the German language were "Schurel", "Schörle", and "Schurl". Beginning in the 18th century, the name *Schörl* was mainly used in the German-speaking area. In English, the names *shorl* and *shirl* were used in the 18th century. In the 19th century the names *common schorl*, *schörl*, *schorl* and *iron tourmaline* were used in the Anglo-Saxon area. The word tourmaline has two etymologies, both from the Sinhalese word *turamali*, meaning "stone attracting ash" (a reference to its pyroelectric properties) or according to other sources "mixed gemstones".

Dravite

Black Dravite on a grey matrix

The name **dravite** was used for the first time by Gustav Tschermak (1836–1927), Professor of Mineralogy and Petrography at the University of Vienna, in his book *Lehrbuch der Mineralogie* (published in 1884) for magnesium-rich (and sodium-rich) tourmaline from the village Unterdrauburg, Drava river area, Carinthia, Austro-Hungarian Empire. Today this tourmaline locality (type locality for dravite) at the village Dravograd (near Dobrova pri Dravogradu), is a part of the Republic of Slovenia. Tschermak gave this tourmaline the name dravite, for the Drava river area, which is the district along the Drava River (in German: Drau, in Latin: Drave) in Austria and Slovenia. The chemical composition which was given by Tschermak in 1884 for this dravite approximately corresponds to the formula $NaMg_3(Al,Mg)_6B_3Si_6O_{27}(OH)$, which is in good agreement (except for the OH content) with the endmember formula of dravite as known today.

Elbaite

A lithium-tourmaline (**elbaite**) was one of three pegmatitic minerals from Utö, Sweden, in which the new alkali element lithium (Li) was determined in 1818 by Arfwedson for the first time. Elba Island, Italy, was one of the first localities where colored and colorless Li-tourmalines were extensively chemically analysed. In 1850 Rammelsberg described fluorine (F) in tourmaline for the first time. In 1870 he proved that all varieties of tourmaline contain chemically bound water. In 1889 Scharitzer proposed the substitution of (OH) by F in red Li-tourmaline from Sušice, Czech Republic. In 1914 Vernadsky proposed the name *Elbait* for lithium-, sodium-, and aluminum-rich tourmaline from Elba Island, Italy, with the simplified formula $(Li,Na)HAl_6B_2Si_4O_{21}$. Most likely the type material for elbaite was found at Fonte del Prete, San Piero in Campo, Campo nell'Elba, Elba Island, Livorno Province, Tuscany, Italy. In 1933 Winchell published an updated formula for elbaite, $H_8Na_2Li_3Al_3B_6Al_{12}Si_{12}O_{62}$, which is commonly used to date written as $Na(Li_{1.5}Al_{1.5})Al_6(BO_3)_3[Si_6O_{18}](OH)_3(OH)$. The first crystal structure determination of a Li-rich tourmaline was published in 1972 by Donnay and Barton, performed on a pink elbaite from San Diego County, California, USA.

Chemical composition of the tourmaline group

The tourmaline mineral group is chemically one of the most complicated groups of silicate minerals. Its composition varies widely because of isomorphous replacement (solid solution), and its general formula can be written as

$XY_3Z_6(T_6O_{18})(BO_3)_3V_3W$,

where:

X = Ca, Na, K, vacancy

Y = Li, Mg, Fe^{2+}, Mn^{2+}, Zn, Al, Cr^{3+}, V^{3+}, Fe^{3+}, Ti^{4+}, vacancy

Z = Mg, Al, Fe^{3+}, Cr^{3+}, V^{3+}

T = Si, Al, B

B = B, vacancy

V = OH, O

W = OH, F, O

Large pink elbaite crystal on quartz, Cryo-Genie Mine, San Diego Co., California, USA.

The 14 recognized minerals in the group (endmember formulas)

Buergerite	$NaFe^{3+}_3Al_6Si_6O_{18}(BO_3)_3O_3F$
Chromdravite	$NaMg_3Cr_6Si_6O_{18}(BO_3)_3(OH)_4$
Dravite	$NaMg_3Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Elbaite	$Na(Li_{1.5},Al_{1.5})Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Feruvite	$CaFe^{2+}_3(MgAl_5)Si_6O_{18}(BO_3)_3(OH)_4$
Foitite	$(Fe^{2+}_2Al)Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Liddicoatite	$Ca(Li_2Al)Al_6Si_6O_{18}(BO_3)_3(OH)_3F$
Magnesiofoitite	$(Mg_2Al)Al_6Si_6O_{18}(BO_3)_3(OH)_4$

Olenite	$NaAl_3Al_6Si_6O_{18}(BO_3)_3O_3OH$
Povondraite	$NaFe^{3+}{}_3(Fe^{3+}{}_4Mg_2)Si_6O_{18}(BO_3)_3(OH)_3O$
Rossmanite	$(LiAl_2)Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Schorl	$NaFe^{2+}{}_3Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Uvite	$CaMg_3(MgAl_5)Si_6O_{18}(BO_3)_3(OH)_3F$
Vanadiumdravite	$NaMg_3V_6Si_6O_{18}(BO_3)_3(OH)_4$

Tri-color elbaite crystals on quartz, Himalaya Mine, San Diego Co., California, USA

Physical properties

Crystal structure

Tourmaline belongs to the trigonal crystal system and occurs as long, slender to thick prismatic and columnar crystals that are usually triangular in cross-section. The style of termination at the ends of crystals is asymmetrical, called hemimorphism. Small slender prismatic crystals are common in a fine-grained granite called aplite, often forming radial daisy-like patterns. Tourmaline is distinguished by its three-sided prisms; no other common mineral has three sides. Prisms faces often have heavy vertical striations that produce a rounded triangular effect. Tourmaline is rarely perfectly euhedral. An exception was the fine dravite tourmalines of Yinnietharra, in western Australia. The deposit was discovered in the 1970s, but is now exhausted. All hemimorphic crystals are piezoelectric, and are often pyroelectric as well.

Color

Tourmaline gemstones

Tourmaline has a variety of colors. Usually, iron-rich tourmalines are black to bluish-black to deep brown, while magnesium-rich varieties are brown to yellow, and lithium-rich tourmalines are almost any color: blue, green, red, yellow, pink etc. Rarely, it is colorless. Bi-colored and multicolored crystals are common, reflecting variations of fluid chemistry during crystallisation. Crystals may be green at one end and pink at the other, or green on the outside and pink inside; this type is called watermelon tourmaline. Some forms of tourmaline are dichroic, in that they change color when viewed from different directions.

Physics explains color in terms of the wavelength of radiation. A spectrograph that only identifies the position of spectral lines will perfectly differentiate between a radiation at 0.530 μ and an another at 0.532 μ, where our eyes will only perceive the same green.

The pink color of tourmalines from many fields is the result of a continued natural irradiation. During their growth, these tourmalines incorporate Mn^{2+}, whereas initially they are by nature very pale. Their granitic environment exposes to them a natural gamma ray exposure due to radioactive decay of ^{40}K, causing the gradual formation of the Mn^{3+} ions responsible for a pink to red color.

Treatments

Some tourmaline gems, especially pink to red colored stones, are altered by irradiation to improve their color. Irradiation is almost impossible to detect in tourmalines, and does not impact the value. Heavily-included tourmalines, such as rubellite and Brazilian paraiba, are sometimes clarity-enhanced. A clarity-enhanced tourmaline (especially paraiba) is worth much less than a non-treated gem.

Geology

Tourmaline is found in two main geological occurrences. Igneous rocks, in particular granite and granite pegmatite and in metamorphic rocks such as schist and marble. Schorl and lithium-rich tourmalines are usually found in granite and granite pegmatite. Magnesium-rich tourmalines, dravites, are generally restricted to schists and marble. Tourmaline is a durable mineral and can be found in minor amounts as grains in sandstone and conglomerate, and is part of the ZTR index for highly-weathered sediments.

Bi-colored tourmaline crystal, 0.8 inches long (2 cm).

Tourmaline localities

Gem and specimen tourmaline is mined chiefly in Brazil and Africa. Some placer material suitable for gem use comes from Sri Lanka. In addition to Brazil, tourmaline is mined in Tanzania, Nigeria, Kenya, Madagascar, Mozambique, Namibia, Afghanistan, Pakistan, Sri Lanka, and Malawi.

United States

Some fine gems and specimen material has been produced in the United States, with the first discoveries in 1822, in the state of Maine. California became a large producer of tourmaline in the early 1900s. The Maine deposits tend to produce crystals in raspberry pink-red as well as minty greens. The California deposits are known for bright pinks, as well as bicolors. During the early 1900s, Maine and California were the world's largest producers of gem tourmalines. The Empress Dowager Tz'u Hsi of China loved pink tourmaline and bought large quantities for gemstones and carvings from the then new Himalaya Mine, located in San Diego County, California. It is not clear when the first tourmaline was found in California. Native Americans have used pink and green tourmaline as funeral gifts for centuries. The first documented case was in 1890 when Charles Russel Orcutt found pink tourmaline at what later became the Stewart Mine at Pala, San Diego.

Brazil

Watermelon Tourmaline mineral on quartz matrix (crystal approximately 2 cm wide at face)

Almost every color of tourmaline can be found in Brazil, especially in the Brazilian states of Minas Gerais and Bahia. In 1989, miners discovered a unique and brightly colored variety of tourmaline in the state of Paraíba. The new type of tourmaline, which soon became known as paraiba tourmaline, came in unusually vivid blues and greens. These colors were often described as "neon" since they appeared to glow. Brazilian paraiba tourmaline is usually heavily included. Much of the paraiba tourmaline from Brazil actually comes from the neighboring state of Rio Grande do Norte. Material from Rio Grande do Norte is often somewhat less intense in color, but many fine gems are found there. It was determined that the element copper was important in the coloration of the stone.

Africa

In the late 1990s, copper-containing tourmaline was found in Nigeria. The material was generally paler and less saturated than the Brazilian materials, although the material generally was much less included. A more recent African discovery from Mozambique has also produced beautiful tourmaline colored by copper, similar to the Brazilian paraiba. While its colors are somewhat less bright than top Brazilian material, Mozambique paraiba is often less included and has been found in larger sizes. The Mozambique paraiba material usually is more intensely colored than the Nigerian. There is a significant overlap in color and clarity with Mozambique paraiba and Brazilian paraiba, especially with the material from Rio Grande do Norte. While less expensive than top quality Brazilian paraiba, some Mozambique material sells for well over $5,000 per carat, which still is extremely high compared to other tourmalines.

Tourmaline mineral (approximately 10 cm tall)

Another highly valuable variety is chrome tourmaline, a rare type of dravite tourmaline from Tanzania. Chrome tourmaline is a rich green color due to the presence of chromium atoms in the crystal; chromium also produces the green color of emeralds. Of the standard elbaite colors, blue indicolite gems are typically the most valuable, followed by green verdelite and pink to red rubellite. There are also yellow tourmalines, sometimes known as canary tourmaline. Zambia is rich in both red and yellow tourmaline, which are relatively inexpensive in that country. Ironically the rarest variety, colorless achroite, is not appreciated and is the least expensive of the transparent tourmalines.

Afghanistan

Extra fine indicolite (blue tourmaline) and verderite (green tourmaline) are found in the Nuristan region (Ghazi Abad district) and Pech Valley (Pech and Chapa Dara districts) of Kunar province. Gem-quality tourmalines are faceted (cut) from 0.50–10 gram sizes and have unusually high clarity and intense shades of color.

Chapter- 8

Amethyst

Amethyst

Amethyst cluster from Magaliesburg, South Africa.

General

Category	Mineral variety
Chemical formula	Silica (silicon dioxide, SiO_2)

Identification

Color	Purple, violet
Crystal habit	6-sided prism ending in 6-sided pyramid (typical)
Crystal system	rhombohedral class 32
Twinning	Dauphine law, Brazil law, and Japan law
Cleavage	None
Fracture	Conchoidal
Mohs scale	7–lower in impure varieties

hardness	
Luster	Vitreous/glossy
Streak	White
Diaphaneity	Transparent to translucent
Specific gravity	2.65 constant; variable in impure varieties
Optical properties	Uniaxial (+)
Refractive index	n_ω = 1.543–1.553 n_ε = 1.552–1.554
Birefringence	+0.009 (B-G interval)
Pleochroism	None
Melting point	1650±75 °C
Solubility	insoluble in common solvents
Other characteristics	Piezoelectric

Amethyst is a violet variety of quartz often used in jewelry. The name comes from the Ancient Greek ἀ *a-* ("not") and *μέθυστος methustos* ("intoxicated"), a reference to the belief that the stone protected its owner from drunkenness; the ancient Greeks and Romans wore amethyst and made drinking vessels of it in the belief that it would prevent intoxication.

Chemistry

Amethyst is the violet variety of quartz; its chemical formula is SiO_2.

In the 19th century, the color of amethyst was attributed to the presence of manganese. However, since it is capable of being greatly altered and even discharged by heat, the color was believed by some authorities to be from an organic source. Ferric thiocyanate has been suggested, and sulfur was said to have been detected in the mineral.

The color in amethyst is due to irradiation, which caused the iron ions present as impurities in quartz to rearrange themselves in the crystal lattice affecting the color in a reversible process. Synthetic amethyst is thus man-made by gamma-ray, x-ray or electron beam irradiation of clear quartz which has been first doped with ferric impurities.

On exposure to heat, the irradiation effects can be partially cancelled and amethyst generally becomes yellow or even green, and much of the citrine, cairngorm, or yellow quartz of jewelry is said to be merely "burnt amethyst".

Synthetic amethyst is made to imitate the best quality amethyst. Its chemical and physical properties are so similar to that of natural amethyst that it can not be differentiated with absolute certainty without advanced gemnological testing (which is often cost-prohibitive). There is one test based on "Brazil law twinning" (a form of quartz twinning where right and left hand quartz structures are combined in a single crystal) which can be used to identify synthetic amethyst rather easily. It is possible to synthesize twinned amethyst, but this type is not available in large quantities in the market.

Composition

Amethyst is composed of an irregular superposition of alternate lamellae of right-handed and left-handed quartz. It has been shown that this structure may be due to mechanical stresses.

Because it has a hardness of seven on the Mohs scale, amethyst is suitable for use in jewelry.

Hue and tone

Amethyst occurs in primary hues from a light pinkish violet to a deep purple. Amethyst may exhibit one or both secondary hues, red and blue. The ideal grade is called "Deep Siberian" and has a primary purple hue of around 75–80%, 15–20% blue and (depending on the light source) red secondary hues. Green quartz is sometimes called green amethyst. Other names for green quartz are prasiolite, vermarine or lime citrine.

Faceted amethyst

The inside of an amethyst geode

Faceted green amethyst

History

Roman intaglio engraved gem of Caracalla in amethyst, once in the Treasury of Sainte-Chapelle.

Amethyst was used as a gemstone by the ancient Egyptians and was largely employed in antiquity for intaglio engraved gems.

The Greeks believed amethyst gems could prevent intoxication, while medieval European soldiers wore amethyst amulets as protection in battle – the reason for this being that amethysts are believed to heal people and keep them cool-headed. Beads of amethyst were found in Anglo-Saxon graves in England.

A large geode, or "amethyst-grotto", from near Santa Cruz in southern Brazil was presented at the 1902 exhibition in Düsseldorf, Germany.

Amethyst is the traditional birthstone for February.

Mythology

The Greek word "amethystos" may be translated as "not drunken", from Greek *a-*, not + *methustos*, intoxicated. Amethyst was considered to be a strong antidote against drunkenness, which is why wine goblets were often carved from it. In Greek mythology, Dionysus, the god of intoxication, and of wine, was pursuing a maiden named Amethystos, who refused his affections. Amethystos prayed to the gods to remain chaste, a prayer which the goddess Artemis answered, transforming her into a white stone. Humbled by Amethystos's desire to remain chaste, Dionysus poured wine over the stone as an offering, dyeing the crystals purple.

Variations of the story include that Dionysus had been insulted by a mortal and swore to slay the next mortal who crossed his path, creating fierce tigers to carry out his wrath. The mortal turned out to be a beautiful young woman, Amethystos, who was on her way to pay tribute to Artemis. Her life was spared by Artemis, who transformed the maiden into a statue of pure crystalline quartz to protect her from the brutal claws. Dionysus wept tears of wine in remorse for his action at the sight of the beautiful statue. The god's tears then stained the quartz purple. Another variation involves the titan Rhea presenting Dionysus with the amethyst stone to preserve the wine-drinker's sanity.

Geographic distribution

An amethyst cluster from Artigas, Uruguay. Size: 15.9×15.6×10.6 cm.

Amethyst is produced in abundance from the state of Minas Gerais in Brazil where it occurs in large geodes within volcanic rocks. Many of the hollow agates of southwestern Brazil and Uruguay contain a crop of amethyst crystals in the interior. Artigas, Uruguay and neighboring Brazilian state Rio Grande do Sul are large world producers exceeding in quantity Minas Gerais, as well as Mato Grosso, Espirito Santo, Bahia, and Ceará states, all amethyst producers of importance in Brazil.

It is also found and mined in South Korea. The largest opencast amethyst vein in the world is in Maissau, Lower Austria. Much fine amethyst comes from Russia, especially from near Mursinka in the Ekaterinburg district, where it occurs in drusy cavities in granitic rocks. Many localities in south India yield amethyst. One of the largest global amethyst producers is Zambia in southern Africa with an annual production of about 1000 tonnes.

Amethyst occurs at many localities in the United States. Among these may be mentioned: the Mazatzal Mountain region in Gila and Maricopa Counties, Arizona; Amethyst Mountain, Texas; Yellowstone National Park; Delaware County, Pennsylvania; Haywood County, North Carolina; Deer Hill and Stow, Maine and in the Lake Superior region of Minnesota, Wisconsin, Michigan, and Ontario in Canada. Amethyst is relatively common in Ontario, and in various locations throughout Nova Scotia. The largest amethyst mine in North America is located in Thunder Bay, Ontario.

Value

Up to the 18th century, amethyst was included in the cardinal, or most valuable, gemstones (along with diamond, sapphire, ruby, and emerald). However since the discovery of extensive deposits in locations such as Brazil, it has lost most of its value.

Collectors look for depth of color, possibly with red flashes if cut conventionally. The highest grade amethyst (called "Deep Russian") is exceptionally rare and therefore its value is dependent on the demand of collectors when one is found. It is however still orders of magnitude lower than the highest grade sapphires or rubies (padparadscha sapphire or "pigeon's blood" ruby).

Chapter- 9

Chalcedony

Chalcedony	
 A cut and polished Chalcedony geode	
General	
Category	Oxide mineral
Chemical formula	Silica (silicon dioxide, SiO_2)
Identification	
Molar mass	60 g / mol
Color	Various
Crystal system	Trigonal
Cleavage	Absent
Fracture	Uneven, splintery, conchoidal
Mohs scale hardness	6 - 7
Luster	Waxy, vitreous, dull, greasy, silky
Streak	White
Diaphaneity	Translucent

Specific gravity 2.59 - 2.61

Chalcedony is a cryptocrystalline form of silica, composed of very fine intergrowths of the minerals quartz and moganite. These are both silica minerals, but they differ in that quartz has a trigonal crystal structure, whilst moganite is monoclinic. Chalcedony's standard Chemical structure (Based on the chemical structure of quartz) is SiO_2 (Silicon Dioxide).

Chalcedony has a waxy luster, and may be semitransparent or translucent. It can assume a wide range of colors, but those most commonly seen are white to gray, grayish-blue or a shade of brown ranging from pale to nearly black.

The name "chalcedony" comes from Latin *calcedonius*, the word used to translate the Greek word *khalkedon*, found only once, in the *Book of Revelation*; according to the OED a connection with the town of Chalcedon in Asia Minor is "very doubtful". There is no reason to assume that the precious stone referred to by this name in the Bible is the same as what is now understood by the name.

Varieties

Chalcedony occurs in a wide range of varieties. Many semi-precious gemstones are in fact forms of chalcedony. The more notable varieties of chalcedony are as follows:

Agate

Agate

Agate is a variety of chalcedony with multi-colored curved or angular banding. Fire agate shows iridescent phenomena on a brown background; iris agate shows exceptional iridescence when light (especially pinpointed light) is shone through the stone. Landscape agate is chalcedony with a number of different mineral impurities making the stone resemble landscapes.

Aventurine

Aventurine (Unknown scale)

Aventurine is a form of quartz, characterised by its translucency and the presence of platy mineral inclusions that give a shimmering or glistening effect termed *aventurescence*.

Aventurine (*unknown scale*)

The most common colour of aventurine is green, but it may also be orange, brown, yellow, blue, or gray. Chrome-bearing fuchsite (a variety of muscovite mica) is the classic inclusion, and gives a silvery green or blue sheen. Oranges and browns are attributed to hematite or goethite. Because aventurine is a rock, its physical properties vary: its specific gravity may lie between 2.64-2.69 and its hardness is somewhat lower than single-crystal quartz at around 6.5.

Aventurine (*unknown scale*)

Aventurine feldspar or **sunstone** can be confused with orange and red aventurine quartzite, although the former is generally of a higher transparency. Aventurine is often banded and an overabundance of fuchsite may render it opaque, in which case it may be mistaken for malachite at first glance.

The name *aventurine* derives from the Italian "a ventura" meaning "by chance". This is an allusion to the lucky discovery of **aventurine glass** or **goldstone** at some point in the 18th century. Although it was known first, goldstone is now a common imitation of aventurine and sunstone. Goldstone is distinguished visually from the latter two minerals by its coarse flecks of copper, dispersed within the glass in an unnaturally uniform manner. It is usually a golden brown, but may also be found in blue or green.

The majority of green and blue-green aventurine originates in India (particularly in the vicinity of Mysore and Madras) where it is employed by prolific artisans. Creamy white, gray and orange material is found in Chile, Spain and Russia. Most material is carved into beads and figurines with only the finer examples fashioned into cabochons, later being set into jewellery.

Main markets for aventurine are landscape stone, building stone, aquaria, monuments, and jewellery.

Carnelian

Carnelian

Carnelian (also spelled **cornelian**) is a clear-to-translucent reddish-brown variety of chalcedony. Its hue may vary from a pale orange, to an intense almost-black coloration. Similar to carnelian is **sard**, which is brown rather than red.

Chrysoprase

Chrysoprase

Chrysoprase (also spelled **chrysophrase**) is a green variety of chalcedony, which has been colored by nickel oxide. (The darker varieties of chrysoprase are also referred to as **prase**. However, the term prase is also used to describe green quartz, and to a certain extent is a color-descriptor, rather than a rigorously defined mineral variety.)

Heliotrope

Heliotrope, or bloodstone

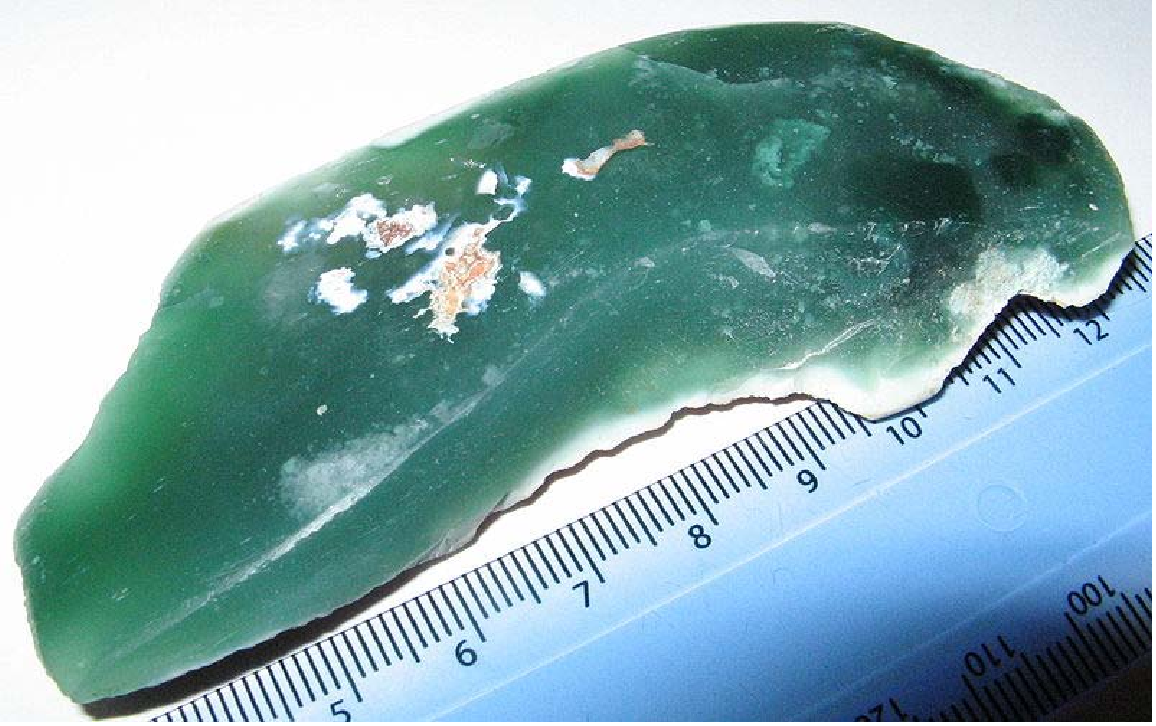
Heliotrope is a green variety of chalcedony, containing red inclusions of iron oxide. These inclusions resemble drops of blood, giving heliotrope its alternative name of **bloodstone**. A similar variety, in which the spots are yellow instead of red is known as **plasma**.

Moss agate

Mree agate

Moss agate contains green filament-like inclusions, giving it the superficial appearance of moss or blue cheese then there is also Tree Agate which is similar to Moss Agate except is is solid White with Green filaments where as Moss Agate usually has a transparent background, so you can see the "moss" in 3D. It is not a true form of agate, as it lacks agate's defining feature of concentric banding.

Mtorolite



Mtorolite

Mtorolite is a green variety of chalcedony, which has been colored by chromium. It is principally found in Zimbabwe.

Onyx

Several onyx forms

Onyx is a variant of agate with black and white banding. Similarly, agate with brown, orange, red and white banding is known as sardonyx.

History

Chalcedony cameo of Titus head, 2nd Century AD

As early as the Bronze Age chalcedony was in use in the Mediterranean region; for example, on Minoan Crete at the Palace of Knossos, chalcedony seals have been recovered dating to circa 1800 BC. People living along the Central Asian trade routes used various forms of chalcedony, including carnelian, to carve intaglios, ring bezels (the upper faceted portion of a gem projecting from the ring setting), and beads that show strong Graeco-Roman influence.

Fine examples of first century objects made from chalcedony, possibly Kushan, were found in recent years at Tillya-tepe in north-western Afghanistan. Hot wax would not stick to it so it was often used to make seal impressions. The term *chalcedony* is derived from the name of the ancient Greek town Chalkedon in Asia Minor, in modern English usually spelled Chalcedon, today the Kadıköy district of Istanbul.

Chalcedony knife, AD 1000-1200

At least three varieties of chalcedony were used in the Jewish High Priest's Breastplate. (Moses' brother Aaron wore the Breastplate, with inscribed gems representing the twelve tribes of Israel). The Breastplate included jasper, chrysoprase and sardonyx, and there is some debate as to whether other agates were also used.

In the 19th century Idar Oberstein became the world's largest chalcedony processing center, in particular agates. Most of these agates were sourced in Latin America, in particular Brazil. Originally the agate carving industry around Idar and Oberstein was driven by local deposits that were mined in the 15th century. Several factors contributed to the re-emergence of Idar-Oberstein as agate center of the world: ships brought agate nodules back as ballast, thus providing extremely cheap transport. Cheap labor and a superior knowledge of chemistry allowing them to dye the agates in any color with processes that were kept secret.

Each mill in Idar Oberstein had four or five grindstones. These were of red sandstone, obtained from Zweibrücken; and two men ordinarily worked together at the same stone.

Geochemistry

Structure

Chalcedony was once thought to be a fibrous variety of cryptocrystalline quartz. More recently however, it has been shown to also contain a monoclinic polymorph of quartz, known as moganite. The fraction, by mass, of moganite within a typical chalcedony sample may vary from less than 5% to over 20%. The existence of moganite was once regarded as dubious, but it is now officially recognised by the International Mineralogical Association.

Solubility

Chalcedony is more soluble than quartz under low-temperature conditions, despite the two minerals being chemically identical. This is thought to be because chalcedony is extremely finely grained (cryptocrystalline), and so has a very high surface area to volume ratio. It has also been suggested that the higher solubility is due to the moganite component.

Solubility of quartz and chalcedony in pure water

This table gives equilibrium concentrations of total dissolved silicon as calculated by PHREEQC using the llnl.dat database.

Temperature	Quartz Solubility (mg/L)	Chalcedony Solubility (mg/L)
0.01°C	0.68	1.34
25.0°C	2.64	4.92
50.0°C	6.95	12.35
75.0°C	14.21	24.23
100.0°C	24.59	40.44

Chapter- 10

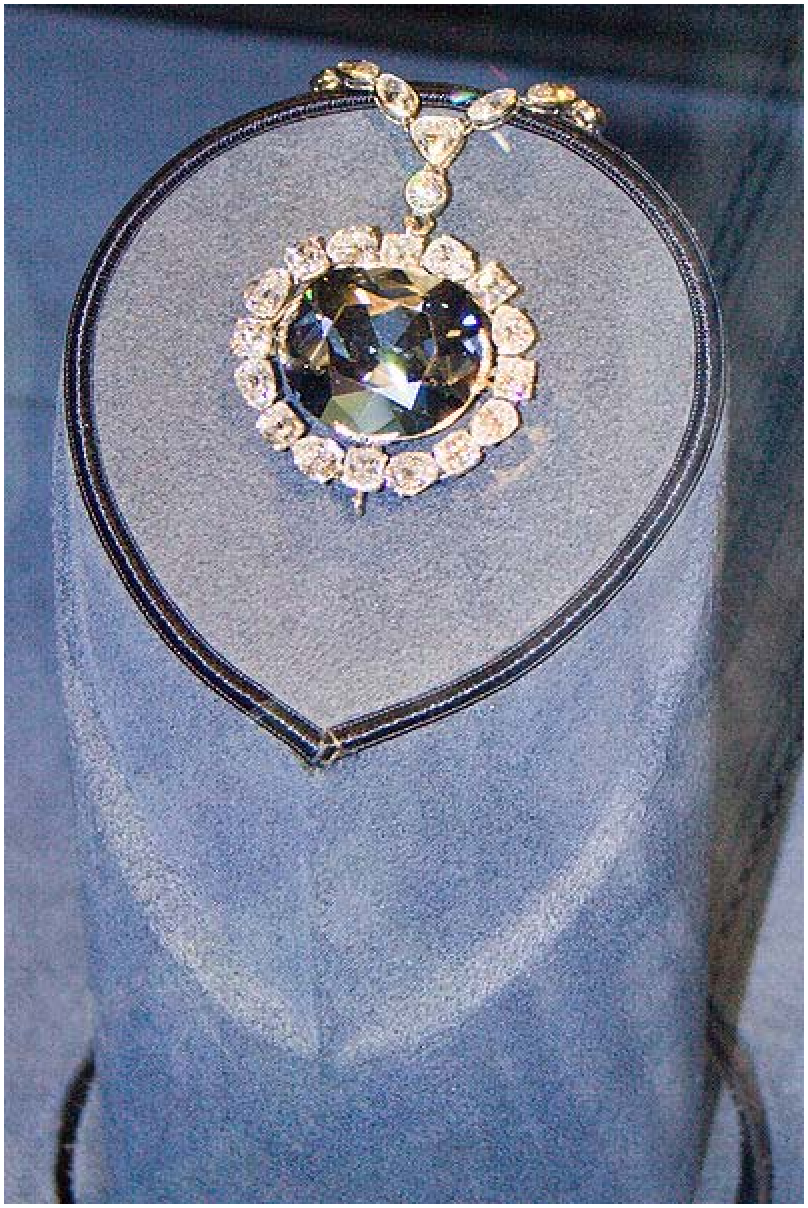
Diamond (gemstone)

A **diamond** (from the ancient Greek ἀδάμας – *adámas*, meaning "unbreakable," "proper," or "unalterable") is one of the best-known and most sought-after gemstones. Diamonds have been known to humankind and used as decorative items since ancient times; some of the earliest references can be traced to India.

The hardness of diamond and its high dispersion of light – giving the diamond its characteristic "fire" – make it useful for industrial applications and desirable as jewelry. Diamonds are such a highly traded commodity that multiple organizations have been created for grading and certifying them based on the *four Cs*, which are *carat*, *cut*, *color*, and *clarity*. Other characteristics, such as presence or lack of fluorescence, also affect the desirability and thus the value of a diamond used for jewelry.

Perhaps the most famous use of the diamond in jewelry is in engagement rings, which became popular in the early to mid 20th century due to an advertising campaign by the De Beers company, though diamond rings have been used to symbolize engagements since at least the 15th century. The diamond's high value has also been the driving force behind dictators and revolutionary entities, especially in Africa, using slave and child labor to mine blood diamonds to fund conflicts.

History



The Hope Diamond. Its deep blue coloration is caused by trace amounts of boron in the diamond

Early references to diamonds in India come from Sanskrit texts. The *Arthashastra* of Kautilya mentions diamond trade in India. Buddhist works dating from the 4th century BC describe the diamond as a well-known and precious stone but don't mention the details of diamond cutting. Another Indian description written in the beginning of the 3rd century describes strength, regularity, brilliance, ability to scratch metals, and good refractive properties as the desirable qualities of a diamond. Golconda served as an important center for diamonds in central India.

Diamonds eventually spread throughout the world, even though India had remained the only major source of the gemstone until the discovery of diamonds in Brazil. A Chinese work from the 3rd century BC mentions: "Foreigners wear it [diamond] in the belief that it can ward off evil influences". The Chinese, who did not find diamonds in their country, initially did not use diamond as a jewel but used as a "jade cutting knife". The diamonds reached ancient Rome from India. Diamonds were also discovered in 700 AD in Borneo, and were used by the traders of southeast Asia. With the depletion of India's diamond resources, the exploration for seeking out and finding diamonds from other parts of the world began, which led to discoveries in Brazil (1725) and South Africa (Kimberley, 1867). South Africa became the favored center for diamond resources, and quickly rose as the world's biggest diamond producer.

Diamonds were traded to both the east and west of India and were recognized by various cultures for their gemological or industrial uses. In his work *Naturalis Historia*, the Roman writer Pliny the Elder noted diamond's ornamental uses, as well as its usefulness to engravers because of its hardness. It is however highly doubtful that Pliny actually meant diamonds and it is assumed that in fact several different minerals such as corundum, spinel, or even a mixture with magnetite were all referred to by the word "adamas".

Today, 92% of the world's diamonds are cut and polished in India, mostly in the city of Surat. Some 85% of the world's rough diamonds, 50% of cut diamonds, and 40% of industrial diamonds are traded in Antwerp, Belgium - the diamond center of the world. Antwerp's association with diamonds began in the late 15th century when a new technique to polish and shape the gems evolved in this city. The diamond cutters of Antwerp are world renowned for their skill. More than 12,000 expert cutters and polishers are at work in the Diamond Quarter, at 380 workshops, serving 1,500 firms and 3,500 brokers and merchants.

In the 21st century, the technology to produce perfect diamonds synthetically was developed. Diamonds produced by the latest technologies are visually identical to mined, naturally-occurring diamonds. It is too early to assess the effect of future wide availability of gem-quality synthetic diamonds on the diamond market, although the traditional diamond industry has already taken steps to try to create a distinction between diamonds dug from the ground and diamonds made in a factory, in part by downplaying the fact that diamonds from both sources are actually visually identical.

Gemological characteristics

The most familiar usage of diamonds today is as gemstones used for adornment - a usage which dates back into antiquity. The dispersion of white light into spectral colors is the primary gemological characteristic of gem diamonds. In the twentieth century, gemologists have developed methods of grading diamonds and other gemstones based on the characteristics most important to their value as a gem. Four characteristics known informally as the *four Cs* are now commonly used as the basic descriptors of diamonds: *carat*, *cut*, *color*, and *clarity*.

Most gem diamonds are traded on the wholesale market based on single values for each of the four Cs; for example knowing that a diamond is rated as 1.5 carats (300 mg), VS2 clarity, F color, excellent cut round brilliant, is enough to reasonably establish an expected price range. More detailed information from within each characteristic is used to determine actual market value for individual stones. Consumers who purchase individual diamonds are often advised to use the four Cs to pick the diamond that is "right" for them.

Other characteristics also influence the value and appearance of a gem diamond. These include physical characteristics such as the presence of fluorescence as well as the diamond's source and which gemological institute evaluated the diamond. *Cleanliness* also dramatically affects a diamond's beauty.

There are two major non-profit gemological associations which grade and provide reports, (informally referred to by the term *certificate* or *cert*, which is a misnomer for many grading reports) on diamonds; while carat weight and cut angles are mathematically defined, the clarity and color are judged by the trained human eye and are therefore open to slight variance in interpretation. These associations are listed below.

- Gemological Institute of America (GIA) was the first laboratory in America to issue modern diamond reports, and is held in high regard amongst gemologists for its consistent, conservative grading.
- Diamond High Council (HRD) Official certification laboratory of the Belgian diamond industry, located in Antwerp.

Within the last two decades, a number of for-profit gemological grading laboratories have also been established, many of them also based in Antwerp or New York. These entities serve to provide similar services as the non-profit associations above, but in a less expensive and more timely fashion. They produce certificates that are similar to those of the GIA.

Carat

The *carat weight* measures the mass of a diamond. One carat is defined as 200 milligrams (about 0.007 ounce avoirdupois). The *point* unit—equal to one one-hundredth of a carat (0.01 carat, or 2 mg)—is commonly used for diamonds of less than one carat. All else being equal, the price per carat increases with carat weight, since larger diamonds are both rarer and more desirable for use as gemstones.

The price per carat does not increase linearly with increasing size. Instead, there are sharp jumps around milestone carat weights, as demand is much higher for diamonds weighing just more than a milestone than for those weighing just less. As an example, a 0.95 carats (190 mg) diamond may have a significantly lower price per carat than a comparable 1.05 carats (210 mg) diamond, because of differences in demand.

A weekly diamond price list, the Rapaport Diamond Report is published by Martin Rapaport, CEO of Rapaport Group of New York, for different diamond cuts, clarity and weights. It is currently considered the de-facto retail price baseline. Jewelers often trade diamonds at negotiated discounts off the Rapaport price (e.g., "R -3%").

In the wholesale trade of gem diamonds, carat is often used in denominating lots of diamonds for sale. For example, a buyer may place an order for 100 carats (20 g) of 0.5 carats (100 mg), D–F, VS2-SI1, excellent cut diamonds, indicating a wish to purchase 200 diamonds (100 carats (20 g) total mass) of those approximate characteristics. Because of this, diamond prices (particularly among wholesalers and other industry professionals) are often quoted per carat, rather than per stone.

Total carat weight (t.c.w.) is a phrase used to describe the total mass of diamonds or other gemstone in a piece of jewelry, when more than one gemstone is used. Diamond solitaire earrings, for example, are usually quoted in t.c.w. when placed for sale, indicating the mass of the diamonds in both earrings and not each individual diamond. T.c.w. is also widely used for diamond necklaces, bracelets and other similar jewelry pieces.

Clarity

Clarity is a measure of internal defects of a diamond called *inclusions*. Inclusions may be crystals of a foreign material or another diamond crystal, or structural imperfections such as tiny cracks that can appear whitish or cloudy. The number, size, color, relative location, orientation, and visibility of inclusions can all affect the relative clarity of a diamond. The Gemological Institute of America (GIA) and other organizations have developed systems to grade clarity, which are based on those inclusions which are visible to a trained professional when a diamond is viewed under 10x magnification.

Diamonds become increasingly rare when considering higher clarity gradings. Only about 20% of all diamonds mined have a clarity rating high enough for the diamond to be considered appropriate for use as a gemstone; the other 80% are relegated to industrial use. Of that top 20%, a significant portion contains one or more visible inclusions. Those that do not have a visible inclusion are known as "eye-clean" and are preferred by most buyers, although visible inclusions can sometimes be hidden under the setting in a piece of jewelry.

Most inclusions present in gem-quality diamonds do not affect the diamonds' performance or structural integrity. When set in jewelry, it may also be possible to hide certain inclusion behind mounting hardware such as prongs in a way that renders the defect invisible. However, large clouds can affect a diamond's ability to transmit and scatter light. Large cracks close to or breaking the surface may increase the likelihood of a fracture.

Diamonds are graded by the major societies on a scale ranging from flawless to imperfect.

Color

Jewelers sometimes set diamonds in groups of similar colors

The Darya-I-Nur Diamond

The most fine quality as per color grading is totally colorless which is Graded as "D" color diamond across the globe which means it is absolutely free from any color. The next is very slight traces of color which can be observed by any expert Diamond valuer/grading laboratory. However when studded in the jewellery these very light colored diamonds do not show any color or it is not possible to make out color shades. These are graded as E color or F color Diamonds. Diamonds which show very little traces of color are graded as G or H color diamonds. Slightly colored diamonds are graded as I or J or K color. A diamond can be found in any other color also other than colorless. Some of the color diamonds such as pink are very rare diamonds and are priceless.

A chemically pure and structurally perfect diamond is perfectly transparent with no hue, or *color*. However, in reality most gem-sized natural diamonds are imperfect. The color of a diamond may be affected by chemical impurities and/or structural defects in the crystal lattice. Depending on the hue and intensity of a diamond's coloration, a diamond's color can either detract from or enhance its value. For example, most white diamonds are discounted in price as more yellow hue is detectable, while intense pink or blue diamonds (such as the Hope Diamond) can be dramatically more valuable. The Aurora Diamond Collection displays a spectacular array of naturally colored diamonds, which occur in every color of the rainbow.

Most diamonds used as gemstones are basically transparent with little tint, or *white diamonds*. The most common impurity, nitrogen, replaces a small proportion of carbon atoms in a diamond's structure and causes a yellowish to brownish tint. This effect is present in almost all white diamonds; in only the rarest diamonds is the coloration from this effect undetectable. The GIA has developed a rating system for color in white diamonds, from "D" to "Z" (with D being "colorless" and Z having a bright yellow coloration), which has been widely adopted in the industry and is universally recognized, superseding several older systems. The GIA system uses a benchmark set of natural diamonds of known color grade, along with standardized and carefully controlled lighting conditions. Diamonds with higher color grades are rarer, in higher demand, and therefore more expensive, than lower color grades. Oddly enough, diamonds graded Z are also rare, and the bright yellow color is also highly valued. Diamonds graded D-F are considered "colorless", G-J are considered "near-colorless", K-M are "slightly colored". N-Y usually appear light yellow or brown.

In contrast to yellow or brown hues, diamonds of other colors are more rare and valuable. While even a pale pink or blue hue may increase the value of a diamond, more intense coloration is usually considered more desirable and commands the highest prices. A variety of impurities and structural imperfections cause different colors in diamonds, including yellow, pink, blue, red, green, brown, and other hues. Diamonds with unusual or intense coloration are sometimes labeled "fancy" in the diamond industry. Intense yellow coloration is considered one of the fancy colors, and is separate from the color grades of white diamonds. Gemologists have developed rating systems for fancy colored diamonds, but they are not in common use because of the relative rarity of such diamonds.

Cut

Diamond cutting is the art and science of creating a gem-quality diamond out of mined rough. The *cut* of a diamond describes the manner in which a diamond has been shaped and polished from its beginning form as a rough stone to its final gem proportions. The cut of a diamond describes the quality of workmanship and the angles to which a diamond is cut. Often diamond cut is confused with "shape".

There are mathematical guidelines for the angles and length ratios at which the diamond is supposed to be cut in order to reflect the maximum amount of light. Round brilliant diamonds, the most common, are guided by these specific guidelines, though fancy cut stones are not able to be as accurately guided by mathematical specifics.

The techniques for cutting diamonds have been developed over hundreds of years, with perhaps the greatest achievements made in 1919 by mathematician and gem enthusiast Marcel Tolkowsky. He developed the round brilliant cut by calculating the ideal shape to return and scatter light when a diamond is viewed from above. The modern round brilliant has 57 facets (polished faces), counting 33 on the *crown* (the top half), and 24 on the *pavilion* (the lower half). The girdle is the thin middle part. The function of the crown is to diffuse light into various colors and the pavilion's function to reflect light back through the top of the diamond.

Tolkowsky defined the ideal dimensions as:

- Table percentage (table diameter divided by overall diameter) = 53%
- Depth percentage (overall depth divided by the overall diameter) = 59.3%
- Pavilion Angle (angle between the girdle and the pavilion) = 40.75°
- Crown Angle (angle between the girdle and the crown) = 34.5°
- Pavilion Depth (depth of pavilion divided by overall diameter) = 43.1%
- Crown Depth (depth of crown divided by crown diameter) = 16.2%

The culet is the tiny point or facet at the bottom of the diamond. This should be a negligible diameter, otherwise light leaks out of the bottom. Tolkowsky's ideal dimensions did not include a culet. However, a thin culet is required in reality in order to prevent the diamond from easily chipping in the setting. A normal culet should be about 1–2% of the overall diameter.

The further the diamond's characteristics are from the Tolkowsky's ideal, the less light will be reflected. However, there is a small range in which the diamond can be considered "ideal". Today, because of the relative importance of carat weight in society, many diamonds are often intentionally cut poorly to increase carat weight. There is a financial premium for a diamond that weighs the magical 1.0 carat (200 mg), so often the girdle is made thicker or the depth is increased. Neither of these tactics make the diamond *appear* any larger, and both greatly reduce the sparkle of the diamond. So a poorly cut 1.0 carat (200 mg) diamond may have the same diameter and appear as large as a 0.85 carats (170 mg) diamond. The *depth percentage* is the overall quickest indication of the quality of the cut of a round brilliant. "Ideal" round brilliant diamonds should not have a depth percentage greater than 62.5%. Another quick indication is the *overall diameter.* Typically a round brilliant 1.0 carat (200 mg) diamond should have a diameter of about 6.5 mm. Mathematically, the diameter in millimeters of a round brilliant should approximately equal 6.5 times the cube root of carat weight, or 11.1 times the cube root of gram weight, or 1.4 times the cube root of point weight.

Ideal cuts can be controversial as the definitions of brilliance and beauty are very subjective. Tolkowsky's mathematical model is now superseded by the GIA Facetware software that is the culmination of 20 years of studies on diamond cuts. New diamond cuts are now all the rage in the diamond industry as for example a design invented in 2003 and called the Genesis cut. This cut differs in shape from the more traditional cuts in its concave surfaces and angles and resembles a 4-pointed star.

Shape

Diamonds do not show all of their beauty as rough stones; instead, they must be cut and polished to exhibit the characteristic fire and brilliance that diamond gemstones are known for. Diamonds are cut into a variety of shapes that are generally designed to accentuate these features.

Diamonds which are not cut into a round brilliant shape are known as "fancy cuts." Popular fancy cuts include the *baguette* (French, meaning *rod* or loaf of bread), *marquise*, *princess cut* (square outline), *heart*, *briolette* (a form of the rose cut), and *pear* cuts.

Newer cuts that have been introduced into the jewelry industry are the "cushion" "radiant" (similar to princess cuts, but with rounded edges instead of square edges) and Asscher cuts. Many fancy colored diamonds are now being cut according to these new styles. Generally speaking, these "fancy cuts" are not held to the same strict standards as Tolkowsky-derived round brilliants and there are less specific mathematical guidelines of angles which determine a well-cut stone. Cuts are influenced heavily by fashion: the baguette cut—which accentuates a diamond's luster and downplays its fire—was all the rage during the Art Deco period, whereas the princess cut — which accentuates a diamond's fire rather than its luster — is currently gaining popularity. The princess cut is also popular amongst diamond cutters: of all the cuts, it wastes the least of the original crystal. The past decades have seen the development of new diamond cuts, often based on a modification of an existing cut. Some of these include extra facets. These newly developed cuts are viewed by many as more of an attempt at brand differentiation by diamond sellers, than actual improvements to the state of the art.

Quality

The quality of a diamond's cut is widely considered the most important of the four Cs in determining the beauty of a diamond; indeed, it is commonly acknowledged that a well-cut diamond can appear to be of greater carat weight, and have clarity and color appear to be of better grade than they actually are. The skill with which a diamond is cut determines its ability to reflect and refract light.

In addition to carrying the most importance to a diamond's quality as a gemstone, the cut is also the most difficult to quantitatively judge. A number of factors, including proportion, polish, symmetry, and the relative angles of various facets, are determined by the quality of the cut and can affect the performance of a diamond. A diamond with facets cut only a few degrees out of alignment can result in a poorly performing stone. For a round brilliant cut, there is a balance between "brilliance" and "fire." When a diamond is cut for too much "fire," it looks like a cubic zirconia, which gives off much more "fire" than real diamond. A well-executed round brilliant cut should reflect light upwards and make the diamond appear white when viewed from the top. An inferior cut will produce a stone that appears dark at the center and in extreme cases the setting may be seen through the top of the diamond as shadows.

Several different theories on the "ideal" proportions of a diamond have been and continue to be advocated by various owners of patents on machines to view how well a diamond is cut. These advocate a shift away from grading cut by the use of various angles and proportions toward measuring the performance of a cut stone. A number of specially modified viewers and machines have been developed toward this end. Hearts and Arrows viewers test for the "hearts and arrows" characteristic pattern observable in stones exhibiting high symmetry and particular cut angles. Closely related to Hearts and Arrows viewers is the ASET which tests for light leakage, light return, and proportions. The ASET (and computer simulations of the ASET) are used to test for AGS cut grade. Proponents of these machines argue they help sellers demonstrate the light performance of the diamond in addition to the traditional 4 Cs. Detractors, however, see these machines as marketing tools rather than scientific ones. The GIA has developed a set of criteria for grading the cut of round brilliant stones that is now the standard in the diamond industry and is called Facetware.

Process

The famous 253 carats (51 g) Oppenheimer Diamond, at a 2001 diamond exhibition in Paris. An uncut diamond does not show its prized optical properties.

The process of shaping a rough diamond into a polished gemstone is both an art and a science. The choice of cut is often decided by the original shape of the rough stone, location of the inclusions and flaws to be eliminated, the preservation of the weight, popularity of certain shapes amongst consumers and many other considerations. The round brilliant cut is preferred when the crystal is an octahedron, as often two stones may be cut from one such crystal. Oddly shaped crystals such as macles are more likely to be cut in a *fancy cut*—that is, a cut other than the round brilliant—which the particular crystal shape lends itself to.

Even with modern techniques, the cutting and polishing of a diamond crystal always results in a dramatic loss of weight; rarely is it less than 50%. Sometimes the cutters compromise and accept lesser proportions and symmetry in order to avoid inclusions or to preserve the carat rating. Since the per carat price of diamond shifts around key milestones (such as 1.00 carat (200 mg)), many one-carat diamonds are the result of compromising "Cut" for "Carat." Some jewelry experts advise consumers to buy a 0.99 carats (200 mg) diamond for its better price or buy a 1.10 carats (220 mg) diamond for its better cut, avoiding a 1.00 carat (200 mg) diamond which is more likely to be a poorly cut stone.

Light performance

In the gem trade, the term light performance is used to describe how well a polished diamond will return light to the viewer. There are three light properties which are described in relation to light performance: brilliance, fire, and scintillation. Brilliance refers to the white light reflections from the external and internal facet surfaces. Fire refers to the spectral colors which are produced as a result of the diamond dispersing the white light. Scintillation refers to the small flashes of light that are seen when the diamond, light source or the viewer is moved. A diamond that is cut and polished to produce a high level of these qualities is said to be high in *light performance*.

The setting diamonds are placed in also affect the performance of light through a diamond. The 3 most commonly used settings are: Prong, Bezel, and Channel. Prong settings are the most popular setting for diamond jewelry. The prong setting consists of four or six 'claws' that cradle the diamond, allowing the maximum amount of light to enter from all angles, allowing the diamonds to appear larger and more brilliant. In bezel settings the diamond or gemstone is completely surrounded by a rim of metal, which can be molded into any shape to accommodate the stone. Used to set earrings, necklaces, bracelets, and rings, bezel settings can have open or closed backs, and generally can be molded to allow a lot of light to pass through. Channel settings set the stones right next to each other with no metal separating them. This setting is mostly used in wedding and anniversary bands. The outer ridge is then worked over the edges of the stones to create a smooth exterior surface. This also protects the girdle area of the stone.

Fluorescence

About a third of all diamonds will glow under ultraviolet light, usually a blue color which may be noticeable under a black light or strong sunlight. According to the GIA, who reviewed a random sample of 26,010 natural diamonds, 65% of the diamonds in the sample had no fluorescence. Of the 35% that did have fluorescence, 97% had blue fluorescence of which 38% had faint blue fluorescence and 62% had fluorescence that ranged from medium to very strong blue. Other colors diamonds can fluoresce are green, yellow, and red but are very rare and are sometimes a combination of the colors such as blue-green or orange. Some diamonds with "very strong" fluorescence can have a "milky" or "oily" look to them, but they are also very rare and are termed "overblues." Their study concluded that with the exception of "overblues" and yellow fluorescent diamonds, fluorescence had little effect on transparency and that the strong and very strong blue fluorescent diamonds on average had better color appearance than non-fluorescent stones. Since blue is a complementary color to yellow and can appear to cancel it out, strong blue fluorescence had especially better color appearance with lower color graded diamonds that have a slight yellowish tint such as "I" color or "J" color but had little effect on the more colorless "D" through "F" color grades.

Cleaning

Cleanliness significantly affects a diamond's beauty. A clean diamond is more brilliant and fiery than the same diamond when it is "dirty". Dirt or grease on the top of a diamond reduces its luster. Water, dirt, or grease on the bottom of a diamond interferes with the diamond's brilliance and fire. Even a thin film absorbs some light that could have been reflected to the viewer. Colored dye or smudges can affect the perceived color of a diamond. Historically, some jewelers' stones were misgraded because of smudges on the girdle, or dye on the culet. Current practice is to clean a diamond thoroughly before grading its color.

Maintaining a clean diamond can sometimes be difficult as jewelry settings can obstruct cleaning, and oils, grease, and other hydrophobic materials adhere well to a diamond. Many jewelers use steam cleaners. Some jewelers provide their customers with ammonia-based cleaning kits; ultrasonic cleaners are also popular.

Symbolism and lore

Mary of Burgundy is the first known recipient of a diamond engagement ring, in 1477.

Historically, it has been claimed that diamonds possess several supernatural powers:

- A diamond gives victory to he or she who carries it bound on his left arm, no matter the number of enemies.
- Panics, pestilences, enchantments, all fly before it; hence, it is good for sleepwalkers and the insane.
- It deprives lodestone and magnets of their virtue (i.e., ability to attract iron).

- Arabic diamonds are said to attract iron greater than a magnet.
- A diamond's hardiness can only be broken by smearing it with fresh goat's blood.
- In traditional Hinduism one should avoid contact with a diamond whose surface area is damaged by a crack, a crowfoot, a round, dull, speckled area, or which is black-blue, flat, or is cut other than the (ideal) hexagonal shape.

Because of their extraordinary physical properties, diamonds have been used symbolically since near the time of their first discovery. Perhaps the earliest symbolic use of diamonds was as the eyes of Hindu devotional statues. In Hinduism Indra uses Vajrayudham or the thunderbolt as his primary weapon. *Vajra* is the word for diamond and *ayudham* means weapon in Sanskrit. Another name for it was *Agira* which means *fire* or the *sun*. In fact there are 14 names counted to be given to a diamond in traditional Hinduism.

The oldest dated printed book in the world is called the *Diamond Sutra*, a Chinese text dates from AD 868 and was found in the Mogao Caves. Sutras are most used to describe the teachings of Buddha. In this case the title of the Sutra refers not to the diamond itself but to a 'diamond blade that will cut through worldly illusion to illuminate what is real and everlasting'. Jewel imagery forms a central part of Buddhism: the triple-jewel represents 'Buddha', his teachings 'Dharma' and the spiritual community 'Shangha'. The book presently resides in the British Library.

Many cultures use *divine intervention* to explain the origin and creation of gemstones, and diamonds were no exception to this. In Greek mythology for example it was the youth on the island of Crete that disturbed Zeus and who were then (as a form of punishment) transformed into the *adamas*.

Philosophers however had a more *naturalistic approach* to explain the origin of gems: Plato for example believed gemstones were a consequence of fermentation in the stars, where a diamond actually formed the kernel of gold-bearing mass. In fact often diamonds were linked to gold, which may have found its origin in the joint occurrence of diamonds with quartzite, quartz veins and an occasional occurrence of gold in them.

In later times, Robert Boyle actually believed that gems (including a diamond) were formed of clear, transparent water, and that their colors and characteristics were derived from their metallic spirit.

The diamond is the birthstone for people born in the month of April, and is also used as the symbol of a sixty-year anniversary, such as a Diamond Jubilee. In a system of heraldry by gemstone occasionally used in the past for the arms of nobles, diamond was used to represent the color sable, or black.

Diamond rings

1.13 carats (230 mg) round diamond engagement ring.

The origin of the custom to use diamonds in rings, and more recently, in engagement rings, can be traced back to the Middle Ages and even the Romans. The Romans valued the diamond entirely on account of the supernatural powers they ascribed to it. Pliny wrote that a diamond baffles poison, keeps off insanity, and dispels vain fears. The medieval Italians copied these beliefs and added some to it: they called it the "Pietra della Reconciliazone" (stone of reconciliation) because it maintained concord between husband and wife. On this account it was recommended as the stone to be set in wedding (or espousal) rings—not on account of its beauty therefore, which was described by Isidore of Seville as a small stone devoid of beauty.

In more recent times a Parisian Oracle of mystic subjects, the Baron d'Orchamps, announced the diamond, if worn on the left (hand) warded off evil influences and attracted good fortune and since he had fashionable clients the word spread and the wearing of the diamond on the left hand became in itself a fashion.

One of the first occurrences of the diamond engagement (or wedding) ring can be traced back to the marriage of Maximilian I (then Archduke of Austria) to Mary of Burgundy in 1477. Other early examples of betrothal jewels incorporating diamonds include the *Bridal Crown of Blanche* (ca. 1370–80) and the *Heftlein* brooch of Vienna (ca. 1430–40), a pictorial piece depicting a wedding couple.

The popularity of the diamond ring as an engagement ring for a much wider audience can be traced directly to the marketing campaigns of De Beers, starting in 1938. Such a campaign had become necessary to sell the large quantity of diamonds suddenly available because of the large diamond finds particularly in South Africa.

"Blood" diamonds

In some of the more politically unstable central African and west African countries, revolutionary groups have taken control of diamond mines, using proceeds from diamond sales to finance their operations. Diamonds sold through this process are known as *conflict diamonds* or *blood diamonds*. Major diamond trading corporations continue to fund and fuel these conflicts by doing business with armed groups. In response to public concerns that their diamond purchases were contributing to war and human rights abuses in central Africa and West Africa, the United Nations, the diamond industry and diamond-trading nations introduced the Kimberley Process in 2002, which is aimed at ensuring that conflict diamonds do not become intermixed with the diamonds not controlled by such rebel groups, by providing documentation and certification of diamond exports from producing countries to ensure that the proceeds of sale are not being used to fund criminal or revolutionary activities. Although the Kimberley Process has been moderately successful in limiting the number of conflict diamonds entering the market, conflict diamonds smuggled to market continue to persist to some degree (about 2–3% of diamonds traded today are possible conflict diamonds). According to the 2006 book *The Heartless Stone*, two major flaws still hinder the effectiveness of the Kimberley Process: the relative ease of smuggling diamonds across African borders and giving phony histories, and the violent nature of diamond mining in nations that are not in a technical state of war and whose diamonds are therefore considered "clean."

The Canadian Government has set up a body known as Canadian Diamond Code of Conduct to help authenticate Canadian diamonds. This is a very stringent tracking system of diamonds and helps protect the 'conflict free' label of Canadian diamonds.

Currently, gem production totals nearly 30 million carats (6 tonnes) of cut and polished stones annually, and over 100 million carats (20 tonnes) of mined diamonds are sold for industrial use each year, as are about 100 tonnes of synthesized diamond.