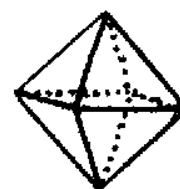


March 2003 Mineral of the Month: Diamond

“Diamond has been the center of intrigue, warfare, romance, and tradition on a scale unequaled by any other gem.”— Joel Arem, *Color Encyclopedia of Gemstones*

PHYSICAL PROPERTIES

Chemistry: C Carbon
Class: Native elements Subclass: Nonmetallic native elements Group: Carbon polymorph
Crystal System: Isometric
Crystal Habits: Mostly octahedral; less commonly dodecahedral; rarely cubic; usually with slightly curved faces; also as rounded and irregular grains
Color: Colorless; white; many grading shades of yellow, orange, red, blue, green, and brown; black
Luster: Adamantine, greasy
Transparency: Transparent to translucent
Streak: White
Refractive Index: 2.417-2.419
Cleavage: Perfect in four directions
Fracture: Conchoidal, brittle
Hardness: 10.0
Specific Gravity: 3.5
Luminescence: Some stones fluoresce
Distinctive Features and Tests: Best field marks are *extreme* hardness and greasy luster
Dana Classification Number: 1.3.6.1



NAME

The name diamond derives from the Greek *adamas*, meaning “invincible” or “hardest.” The correct pronunciation is DYE-ah-mond. The terms “bort” (also “boart” and “booart”), “ballas,” and “carbonado” denote specific types of natural, non-gem-quality diamonds. Bort refers to dark, imperfectly crystallized diamonds, and to minute fragments of gem diamonds; ballas to compact, spherical masses of tiny crystals; and carbonado to opaque, gray or black diamonds with no cleavage.

COMPOSITION

As its chemical symbol, C, indicates, diamond is composed solely of carbon, with only trace amounts of other elements such as nitrogen and boron that may impart colors. Understanding the chemistry of diamond requires a basic knowledge of the element carbon. A neutral carbon atom has four electrons in its outer electron shell, giving it a valence of four, since four electrons can be accepted to fill that shell. Diamond consists of repeating units of carbon atoms, each joined to four other carbon atoms by very strong covalent atomic bonds. Within their compact, rigid tetrahedral structures, each carbon atom is precisely equidistant from its neighboring atoms, thus imparting exceptional strength to the overall structure and accounting for diamond’s great hardness. The compactness of diamond’s structure accounts for its relatively high density (specific gravity 3.5).

Each diamond structural unit consists of eight carbon atoms which are fundamentally arranged in a cube—a shape represented by the isometric, face-centered form of the diamond crystal. Based on this cubic form and on its highly symmetrical arrangement of atoms, diamond crystals can assume several different shapes, or habits. The most common crystal habit is the eight-sided octahedron, followed by 12-sided dodecahedra, cubes, and combinations of these shapes.

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While diamonds have great hardness, they also have perfect cleavage in four directions, meaning a diamond will separate cleanly along these directions rather than fracture in an uneven manner. These cleavage lines form because diamond crystals have fewer atomic bonds along the planes of their octahedral faces than they have in other directions. Identifying cleavage directions is of great importance in cleaving and sawing diamonds.

Diamond and graphite provide a textbook example of how crystal structure determines physical properties. Diamond and graphite are both polymorphs of the element carbon (C) and share the same chemistry, yet different atomic structures endow them with radically different physical properties. Its compact, three-dimensional, isometric crystal structure makes diamond dense and extremely hard, while graphite, which crystallizes in the hexagonal system, is opaque, gray-black, very soft (Mohs 1-2), and has a very low density (specific gravity 2.2). The reason for this is graphite's two-dimensional, sheet-like structure, in which the flat sheets lie in a plane. Although the carbon bonds within the sheets are strong, the bonds *between* the adjacent sheets are weak, allowing the sheets to slide over each other and accounting for graphite's great softness. Diamond is also polymorphous with two other minerals: chaoite (C), a hexagonal mineral that forms as thin, black, microscopic lamellae alternating with graphite, named for Chinese-U.S. petrologist C. T. Chao (b. 1919), and not to be confused with charoite, the gorgeous lavender mineral from Siberia; and lonsdaleite (C), which has a hexagonal close-packing structure as opposed to the cubic close-packed structure of diamond, and forms as microscopic cubes, cubo-octahedrons, and polycrystalline aggregates, mixed with diamonds, named for English crystallographer Kathleen Lonsdale (1903-1971).

Because only extreme heat and pressure can force carbon atoms into the atomic configuration of diamond, diamonds form in the Earth's upper mantle approximately 100 miles below the surface, where temperatures reach 1,000° C. and pressures exceed 50 kilobars. Diamonds are carried upward in eruptions of kimberlitic magma that solidify into kimberlite pipes. Kimberlite pipes are very narrow at depth, but broaden, or "blow out," near the surface to form "carrot"-shaped intrusions. Kimberlite is a phaneritic, or even-grained, peridotite-type rock, with coarse crystals visible to the unaided eye. (Peridotite is a coarse-grained plutonic [formed at great depth] rock composed chiefly of olivine, with or without other mafic minerals such as pyroxenes, amphiboles, or micas, containing little or no feldspar.) Kimberlite, whether diamondiferous or not, usually contains emerald-green chrome diopside, red pyrope garnet, and black ilmenite-minerals which exploration geologists consider to be diamond "indicator" minerals.

By studying the ratio of carbon-12 and carbon-13 isotopes found in diamonds, researchers have determined that the carbon in most natural diamonds comes from the Earth's mantle. Far fewer diamonds contain carbon from surface sources that has been subducted deep into the mantle by tectonic plate movement. Most diamonds that originate in the Earth's mantle are about three billion years old. (A "baby" diamond, believed to be only 628 million years old, was identified from Mbuji Mayi by scientists, who theorized that diamonds are likely still forming in the Earth's mantle.) Much smaller numbers of diamonds, usually microdiamonds, form when surface carbon is subjected to the extreme temperatures and pressures generated by meteoric impact. Diamonds that were formed in space also occur in meteorites.

Diamonds occur in both primary and secondary deposits. The primary deposits are diamondiferous kimberlite pipes. After diamonds are freed from kimberlite pipes by weathering and erosion, their relatively high density (specific gravity 3.5) allows them to concentrate in secondary, placer-type deposits. Both primary and secondary deposits serve as commercial diamond sources.

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COLLECTING LOCALITIES

Because of diamond's inherent rarity, collecting localities are very limited. Of the approximately 20,000 known kimberlite pipes, just 10 percent are diamondiferous, and only two percent of these contain enough diamonds to warrant mining. The best known diamond-collecting locality in North America is Crater of Diamonds State Park near Murfreesboro, Arkansas, the site of a diamondiferous kimberlite pipe that was briefly mined commercially in the early 1900s, but was not high enough in grade to sustain mining operations. Crater of Diamonds State Park is maintained as a fee-collecting area.

Since the 1970s, collectors have had some success in the State Line Diamond District of north-central Colorado and adjacent Wyoming, where alluvial diamonds have weathered from a series of nearby kimberlite pipes. To date, geologists have discovered about a dozen pipes, one of which was mined briefly in the late 1990s and may be mined again in the future.

Africa is the greatest diamond-producing continent, with Botswana, the Republic of South Africa, and the Democratic Republic of the Congo all leading diamond sources. Diamonds, mostly from alluvial deposits, are also mined in Namibia, Tanzania, Sierra Leone, Angola, and Ghana.

Diamonds from both kimberlite pipes and alluvial deposits are mined in the Ural Mountains and Siberian regions of Russia. Western Australia's Argyle Mine, which exploits a kimberlite pipe, is an important source of pink diamonds. After a diamond-exploration rush in northern Canada, commercial mining began from kimberlite pipes there in 1998. Alluvial diamonds are also mined commercially in Brazil, Venezuela, Guyana, India, and Borneo.

JEWELRY & DECORATIVE USES

Without question, diamond is the ultimate gemstone. To begin, rarity assures the value of gem diamonds. At Mohs 10.0, the upper limit of the Mohs hardness scale, diamond is four times harder than the next hardest mineral, corundum (sapphire and ruby), and easily withstands the rigors of everyday ring wear.

Diamond excels in its optical qualities. Diamond is transparent over a greater range of wavelengths (from the ultraviolet into the far infrared) than any other mineral. Diamond's very high refractive index of 2.417-2.419 reflects its exceptional ability to bend light, and thus to show great brilliance when cut into gems. Diamond also has a very high index of dispersion of 0.044, indicating a great ability to divide white light into its spectral colors, a property that accounts for the characteristic "fire" of well-cut diamond gems.

The most familiar use of diamonds in jewelry is the diamond engagement ring, a tradition that may have originated in 1477 when Archduke Maximilian of Austria presented Mary of Burgundy with a diamond ring as a symbol of their betrothal. Today, diamond is also the symbolic gift for 60th and 75th wedding anniversaries.

HISTORY & LORE

Alluvial deposits in Borneo and more importantly near Golconda, India, were discovered about 800 B.C. and became the first significant sources of diamonds. Diamonds from India may have reached Europe as early as the third century B.C. The earliest clear historical reference to diamond, however, is found in Roman literature from the first century A.D.

For many centuries, rough diamonds were kept as talismans and rarely worn, although natural diamond

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octahedra were sometimes set into rings. A Hungarian queen's crown set with uncut diamonds and dating to 1074 may be the oldest known example of diamond jewelry. The use of diamond grit to polish diamonds and other gemstones originated in India in the 14th century. Diamond cutting began about the same time in the Mediterranean city-state of Venice. The art of diamond cutting was greatly advanced in Antwerp, Belgium, which by 1550 had become the world's diamond-cutting center. By then, all of Europe recognized diamonds as the ultimate symbol of wealth.

In 1725, as production from India's rich alluvial deposits declined, Portuguese prospectors discovered alluvial diamond deposits in Brazil's Minas Gerais region near the present-day city of Diamantina, which became the world's next major source of diamonds.

Until 1797, diamonds had been assumed to consist of a rare, mysterious material. But that year, British chemist Smithson Tennant (1761-1815) produced carbon dioxide by burning diamond in oxygen in an ashless reaction ($C^{+4} + 2O^2=CO_2$), proving that diamond consisted not of any mystical material, but of common elemental carbon.

The modern diamond-mining industry began with the discovery of alluvial diamonds in South Africa in the 1860s. In 1871, South African prospectors discovered a diamondiferous kimberlite pipe at Kimberley, the first lode source of diamonds ever found. Geological insight into the nature of kimberlite pipes gained at Kimberley revolutionized the search for diamonds.

Major new discoveries were made in Russia in the 1950s, west-central Africa in the 1960s, Australia and Botswana in the 1970s, and most recently in the Canadian Arctic in the 1990s. Geologists discovered the Canadian kimberlite pipes after refining the techniques of identifying and following "trails" of indicator minerals to their original lode sources in pipes.

In 2001, the world's mines turned out 117 million carats of rough diamonds, 48 million of which were gem quality. That year the leading producers, in order, were Australia, the Congo, Botswana, Russia, and South Africa.

Since the 1950s diamonds, either as rough crystals or cut gems, have appeared on dozens of postal stamps issued mainly by nations engaged in diamond mining or cutting. These nations include Andorra, Angola, Australia, Belgium, Botswana, Central Africa, Comoro Islands, Democratic Republic of the Congo, France, Ghana, Israel, Ivory Coast, Namibia, and Tanzania.

Metaphysicians believe that diamond is the purest expression of earth energies. Because diamonds are said to amplify the energies of other crystals, they are often used in conjunction with other crystals to enhance their effectiveness. Crystal-power advocates also believe that on their own, diamonds lend courage and hope, and help to balance one's mental, physical, spiritual, and emotional strengths, and energize the eyes, brain, and heart, and aid in general healing.

TECHNOLOGICAL USES

Extreme hardness makes industrial diamonds valuable as abrasive and cutting materials. Diamond-studded inserts are used in drill bits in mining, petroleum drilling, core drilling, and tunneling operations; diamond lathe inserts are used to machine exceptionally hard metal alloys; and diamond dies are vital in drawing metal wire. Diamond grit, dust, and powder, in a wide range of mesh sizes and grades, are bonded to saw blades or to lapping, polishing, and grinding wheels used to polish everything from superhard alloys to gemstones. The biggest single application of cutting diamonds is in the blades of

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highway-maintenance equipment used to saw through asphalt and concrete.

The greatest technological impact of diamonds has come not from their material use, but rather from the long and eventually successful effort to replicate the diamond crystal structure and to synthesize diamonds. Swedish researchers first synthesized diamonds in an unpublished effort in 1953. The General Electric Research Laboratory in Schenectady, New York, then synthesized diamonds in 1954 in a highly publicized experiment. Diamond synthesizing using high-temperature, high-pressure methods has since grown into a major industry. Synthetics now supply 80 percent of world industrial-diamond demand. The first gem-quality diamonds were synthesized in 1970, but were too costly to market. Recently, however, the costs of synthesizing gem-quality diamonds have fallen dramatically and quality synthetics are beginning to compete with natural diamonds on the retail market.

Diamond is now also synthesized by chemical vapor deposition (CVD), a newly developed, low-temperature, low-pressure method that deposits synthetic diamond films of microscopic thickness. CVD diamond films, which are as hard as natural diamond and have great potential in science and industry, have already been used as coatings to protect optical lenses and to enhance the cutting ability of surgical scalpels.

ABOUT OUR SPECIMENS

Our Deluxe-size diamond specimens are from Mbuji-Mayi (pronounced umm-BOO-gee MAHL-ye) in the central African nation of the Democratic Republic of the Congo (DRC). Mbuji-Mayi, located in Kasai Province in the south-central DRC some 600 miles southeast of the capital city of Kinshasa (formerly Léopoldville), is the nation's principal diamond-trading center.

Diamond mining in the Democratic Republic of the Congo is a story of remarkably rich deposits, great wealth and, unfortunately, no small measure of human tragedy. Diamonds were first discovered in the Belgian Congo (now the DRC) in 1918 at Bakwanga (now Mbuji-Mayi). Named the Bakwanga Hills deposit, the discovery consisted of a group of diamondiferous kimberlite pipes. Although the Mbuji-Mayi diamond fields contain larger stones in richer concentrations than those found in South Africa, only about six percent of the stones are of top gem quality. Another 30 percent are graded as "near-gem" and are also suitable for cutting. The remaining stones are industrial grade. Prodigious production from the pipes and nearby related alluvial deposits quickly established the Belgian Congo as an important source of both industrial and gem diamonds.

When World War II sent demand for industrial diamonds soaring, the Belgians, working in partnership with De Beers Consolidated Mines, Ltd., began large-scale production at Mbuji-Mayi. By the 1950s, the Belgian Congo was supplying 75 percent of the world's diamonds and 80 percent of the United States' supply of industrial diamonds.

Unfortunately, the political instability and massive corruption that followed Congo's independence in 1960 led to illegal diamond mining and rampant smuggling. Nevertheless, in 1985, the DRC managed to produce a record 30 million carats of diamonds, among them some 1.8 million carats of top gem-quality stones. But amid the political intrigue, foreign intervention, revolution, coups, and lawlessness in the diamond fields, more than half the diamonds were being smuggled out of the country or used to fund ongoing civil wars.

By 1997, as the population of Mbuji-Mayi surpassed 900,000, an estimated 60 percent of the city's working residents were involved with diamonds, either by mining or trading in mining supplies, or by

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buying, selling, and transporting rough stones. At that time, the Mbuji-Mayi mines were generating \$20 million per month in official sales, and at least that much more in trading on the black market. Mining was temporarily disrupted that year when rebel forces captured both the city and the mines.

Today, the DRC produces about 20 million carats of diamonds each year, second only to Australia, to account for 18 percent of world annual diamond production. About one-third of these stones come from kimberlite pipes near Mbuji-Mayi. Another third come from outlying diamond fields. These include the extensive alluvial deposits on the Kasai River and its tributaries 180 miles west of Mbuji-Mayi near the town of Tshikapa, where our Junior-size diamonds were collected. Diamonds also come from both pipe and alluvial deposits at Lodja, 160 miles to the north, and at Barunda 100 miles to the south. Virtually all the diamonds mined at Mbuji-Mayi, Tshikapa, Lodja, and Barunda are sold through the legal and illegal diamonds markets that flourish in Mbuji-Mayi.

DRC's only commercial diamond producer is Minière de Bakwanga (MIBA), which is headquartered in Mbuji-Mayi. MIBA is 80-percent owned by the DRC government and 20-percent owned by the Belgian company Sibeka, in which De Beers holds an interest. MIBA produces about six million carats, or one third of the DRC's annual diamond output. The remaining 13 million carats, amounting to two-thirds of national production, are mined by some 200,000 artisanal, or independent, miners who screen and wash gravels from both weathered kimberlitic soil and from extensive river-gravel deposits under the most primitive conditions. The DRC's artisanal miners face diseases such as cholera in their crowded, unsanitary camps, along with violence from organized bands of thieves and rebel groups and appalling working conditions that kill and injure hundreds of miners each year.

Recent international efforts are attempting to stem the African trade in so-called "blood," "war," or "conflict" diamonds that sustain civil wars rather than benefit the nation. But an estimated one-third of all DRC diamonds are still being sold on black markets and smuggled out of the country.

The most spectacular diamond to come from the Mbuji-Mayi area is the celebrated Incomparable, which MIBA mined in 1980. The rough stone weighed 890 carats and cut into an unusual triangular shape called a "triolette." At 407.48 carats, the finished gem is the third largest diamond ever cut, surpassed only by the Cullinan I and the Golden Jubilee. The Incomparable, which has a fancy, brownish-yellow-gold color, sold in 1988 for \$12 million.

Despite diamond's great hardness, the wear of alluvial travel will round its edges. Under a loupe or suitable magnifying glass, even worn alluvial diamonds will show a cubic, octahedral, or dodecahedral crystal habit, or individual faces related to those habits. Did you get a chance to examine your specimen under strong magnification? Those with Junior-size diamonds no doubt noticed that their specimen appears almost round. This is because the diamonds formed in the 12-sided dodecahedral crystal form common to garnets, and the edges of the faces are rounded, as is common in diamonds. The black color is caused by inclusions.

Those with Deluxe-size diamonds no doubt noticed that none of the crystal faces are smooth. Some of the features you might observe include striations, pits, growth hillocks, trigons, and twins. Depressed trigons of perfect equilateral outline are common on the octahedral faces of diamonds.

Knowing that some diamonds fluoresce in longwave ultraviolet light, we eagerly examined our specimens under the lamp. But since the crystals are so small, it is hard to observe anything, but some of the Deluxe-size diamonds did seem to appear blue on the top when viewed under longwave UV light. Check yours out! Some diamonds are also phosphorescent and triboluminescent.

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COAL

While diamond is clearly the most valuable natural form of carbon, at least on a weight basis, another natural form of carbon has far greater economic and industrial impact—coal. To put diamond mining and coal mining into perspective, about 25 standard tons of diamonds are mined worldwide each year, compared with four *billion* tons of coal.

Unlike diamond or graphite, which are both minerals, coal is correctly classified as a sedimentary rock. It forms through the destructive distillation of plant remains under the anaerobic conditions of deep burial. Variations in time, temperature, and pressure create distinct grades of coal with increasingly greater fixed carbon content. *Peat* is an accumulation of partly decomposed plant remains that have been subjected to little, if any, elevated temperature and pressure. Peat that has been compacted and minimally altered is called lignite, or “brown coal,” and has a carbon content of only 25 percent. Bituminous, or “soft,” coal has been subjected to deeper burial and elevated temperatures and pressures that drive off hydrogen, oxygen, sulfur, and other volatiles to leave a fixed carbon content as high as 65 percent. Anthracite, known as “hard” coal, is formed with deep burial at metamorphic temperatures and pressures sufficient to alter and deform adjacent rock. The fixed carbon content of anthracite is as high as 95 percent.

As the fixed carbon content of various coal grades increases, so, too, does hardness. Peat and lignite have a Mohs hardness no greater than 1.0 or 1.5, while the Mohs hardness of anthracite is as high as 2.5. Although lignite and bituminous coals have a dull luster and a splintery fracture, anthracite has a bright vitreous to submetallic luster and a pronounced conchoidal fracture.

Interestingly, if anthracite coal is subjected to even greater temperatures and pressures, it eventually metamorphoses into graphite, which is essentially pure carbon crystallized in the hexagonal system. And with the application of extreme temperatures and pressures far beyond those found in normal subsurface metamorphic environments, graphite can be forced to reconfigure into the cubic crystal form of diamond.

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