

June 2005 Mineraloid of the Month: Opal

“Opal has been called the ‘Queen of Gems.’ Few descriptions are adequate to describe the finest opals: a white, snowy landscape dotted with fireflies of red, gold, blue, purple, and green; a black night streaked with rainbow lightning; the aurora borealis captured in stone. Mysterious, elusive, varied, and delicate, opal has been treasured since ancient times for its unique properties and beauty.”

*–Joel E. Arem, *Gems and Jewelry**

PHYSICAL PROPERTIES

Chemistry: $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ Hydrated Silicon Dioxide (Silicon Dioxide Hydrate) Contains varying amounts of water and often traces of iron and aluminum.

Class: Silicates

Subclass: Tectosilicates (Framework Silicates)

Group: Opal (Hydrated Tectosilicates)

Crystal System: None (amorphous)

Crystal Habits: None. Opal occurs as glass-like veins and cavity fillings, coatings, reniform aggregates, nodules, and replacements of other minerals or wood.

Color: Colorless and white to yellow, red, pink, brown, green, gray, and blue; opalescent varieties exhibit a rich, internal play of colors.

Luster: Vitreous to dull

Transparency: Transparent to translucent and opaque

Streak: White

Cleavage: None

Fracture: Conchoidal, brittle

Hardness: 5.5-6.0

Specific Gravity: Average 2.09; varies with water content from 1.9-2.3.

Luminescence: Fluorescent, greenish-yellow with short-wave ultraviolet light, white with long-wave ultraviolet light; also phosphorescent.

Refractive Index: 1.44-1.46

Distinctive Features and Tests: Opalescence in many varieties, low density, fluorescence, and lack of crystal faces and cleavage surfaces.

Dana Classification Number: 75.2.1.1

NAME

The name “opal,” pronounced “OH-pul,” comes from the Latin *opalus*, the Roman word for “opal” which derives, in turn, from the Sanskrit *upala*, meaning “stone” or “jewel.” Other names for opal are “opalite,” “opalite,” and “gel-quartz.”

Because of its many colors and varieties and long use as a gemstone, opal has dozens of alternate names. The three general types of opal are “precious opal,” “common opal,” and “fire opal.” Precious opal exhibits opalescence, explained in the box on page 3. “Fire opal” has an orange-to-red body color and may or may not be opalescent. Non-opalescent “common opal” is usually translucent to opaque with a wide range of colors. Variety names include “black opal,” which has a black, dark blue, green, or gray body color; and “white opal,” with its white or light body color. Names referring to specific types and colors of opalescence include “flash opal,” “harlequin opal,” “flame opal,” “pinfire opal,” “gold opal,” and “blue opal.” Common-opal names include “agate opal” (alternating layers of agate and opal), “wood opal” (opalized wood), “honey opal” (yellow), “milk opal” (white, translucent), “porcelain opal” (white, opaque), “wax opal” (yellow-brown, waxy luster), “prase opal” (green), “hydrophane” (semi-translucent opal that becomes translucent or transparent when immersed in water), and “hyalite” (colorless opal). “Boulder

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opal” is used for ironstone concretions with opal fillings, sometimes with bands of precious opal alternating with common opal, while “Jelly opal” is transparent colorless opal with bluish iridescence.

COMPOSITION

The chemical formula $\text{SiO}_2 \cdot n\text{H}_2\text{O}$ identifies opal as hydrous silicon dioxide containing the elements silicon (Si), oxygen (O), and hydrogen (H). Opal’s atomic weight and the percentile weights of its elemental components vary with the amount of water present. Between 1 and 30 percent of opal weight consists of water (H_2O). As an example, the molecular weight of opal with the empirical formula $\text{SiO}_2 \cdot .5\text{H}_2\text{O}$ consists of 40.58 percent silicon, 57.98 percent oxygen, and 1.44 percent hydrogen, and contains 86.96 percent silica (SiO_2) and 13.04 percent water. In the opal molecule, the +4 charge of the silicon cation (Si^{4+}) balances the collective -4 charge of the double-oxygen anion [$(\text{O}^{2-})_2$]. Variable numbers of water molecules (in “ $n\text{-H}_2\text{O}$,” n is a variable quantity) are bound to the silica molecules (SiO_2). These molecules are called “water of hydration” and are bound as integral water molecules that retain their characteristic composition and structure. Water of hydration consists of electrically neutral water molecules and does not affect the electrical balance of the molecule.

Water of hydration is attached by weak hydrogen bonds. In water molecules, oxygen atoms share electrons to covalently bond to two hydrogen atoms. Water molecules are asymmetrical, because the two hydrogen ions group together on one side of the large oxygen ions. The two grouped hydrogen ions retain a small positive charge, while the opposite side of the molecule retains a small negative charge. Hydrogen bonding, or polar bonding, occurs when the faintly positive poles of water molecules attract the electrons of other atoms. In opal, water molecules are attracted to the negatively charged oxygen ions of the silica anions.

As a silicate, the basic building block of opal is the silica tetrahedron (SiO_4)⁴⁻. Silica tetrahedra consist of a silicon atom surrounded by four equally spaced oxygen atoms at the corners of a tetrahedron. Silicates fall into seven groups according to the number and type of atomic bonds that link their tetrahedra together into a lattice. Opal falls into the tectosilicate or “framework” silicate group, in which tetrahedrons share their oxygens with other tetrahedra to form repeating, rigid, compact, three-dimensional frameworks.

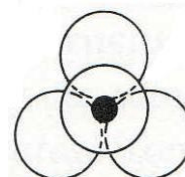


Figure 1 Silica tetrahedron.

Tectosilicates include the familiar mineral quartz (silicon dioxide, SiO_2). Opal is similar to quartz in that both contain silica tetrahedra. But unlike quartz, opal has no orderly, closely packed, repeating atomic structure and thus no crystal form. Accordingly, the physical properties of quartz and opal are quite different. Quartz is hard at Mohs 7.0, but opal, at Mohs 5.5 to 6.0 is much softer and brittle. And with an average specific gravity of 2.09, opal is much less dense than quartz (s.g. 2.65).

The Dana mineral-classification number 75.2.1.1 identifies opal as a tectosilicate (75). The subclassification (2) defines it as a tectosilicate containing water and organics such as carbon (C) and methane (CH_4). Next, opal is assigned to the opal group (1, tectosilicates containing water), as the only member (1). Despite its mineral-classification number, opal is not technically a mineral, because it lacks a crystal structure. Opal is considered a mineraloid, a naturally occurring substance that, while possessing distinctive properties, does not meet the full requirements for classification as a mineral. Opal is an amorphous, layered, solidified, colloidal silica gel. It consists of randomly arranged, hydrated silica molecules interspersed with layers of microscopic silica spherules. Because the water of hydration is held only by weak hydrogen bonding, most opal, over long periods of geological time, will dehydrate and convert to agate, jasper, or other forms of microcrystalline quartz. Mining and cutting accelerates this process and sometimes results in “crazing” (internal cracking) and in the fading of color and opalescence.

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OPALESCENCE AND COLOR

Precious opal is characterized by opalescence, an iridescent, rainbow-like play of light called “fire” that was initially thought to be caused by refraction (bending) of light within thin layers of opal. Then, in the 1960s, Australian researchers studied opal with 20,000-power electron microscopes and identified tiny silica spherules less than 1/1,000th of a millimeter in diameter. Composed of randomly arranged, hydrated silica tetrahedra, these variably sized spherules create three-dimensional structures with a network of voids between adjacent spherules. Opalescence occurs when the spherule diameters approximate the wavelengths of visible light, enabling the spherule-void interfaces to act as diffraction gratings that separate (diffract) light into its spectral red, orange, yellow, green, blue, and violet components. The smaller silica spherules with diameters of roughly 140 nanometers diffract blue wavelengths, while the larger spherules with diameters of 240-300 nanometers diffract red wavelengths. (A nanometer is a metric unit of length equal to one billionth of a meter.) Because diffraction angles vary with viewing angles, a precious opal, when rotated, displays a full range of spectral colors. The complex structure of precious opal also reflects and refracts these diffracted spectral components. This often creates an interference effect, in which various wavelengths of light reinforce each other to produce unusually brilliant and pure spectral colors—the “fire” of precious opal.

Common opal and non-opalescent fire opal are either devoid of these silica-spherule structures, or they contain silica spheres that are too large or too small to diffract light. Pure opal, no matter what the variety, has no base color at all. Common opal is allochromatic (other-colored), meaning its broad range of colors and degrees of transparency or translucency are due to the trace presence of nonessential chromophoric (color-causing) elements such as iron and aluminum. Precious opal, however, exhibits *both* allochromatic and idiochromatic (self-colored) properties. Its body color is allochromatic, but the opalescence colors are idiochromatic, due to the interaction of light passing through its silica-spherule structures.

As a low-temperature (epithermal) silicate, opal develops as fracture and cavity fillings from the slow solidification of siliceous solutions under specific conditions of chemistry and temperature. Opal does not precipitate on a molecule-by-molecule basis as do crystalline minerals. Instead, it solidifies or “freezes” into layers with random molecular arrangement. Certain layers consist largely of silica spherules that form three-dimensional, stacked structures that cause the opalescence of precious opal (see box above).

Opal forms in sedimentary and volcanic environments. Sedimentary opal, which occurs in Australia and Brazil, forms when water percolates through sandstone formations to dissolve quantities of silica. These siliceous solutions continue seeping downward by gravity until they reach a stratum of claystone or other impermeable rock, where they move horizontally atop the impermeable layer to fill voids or fractures. In proper conditions of temperature and evaporation, the siliceous solutions will concentrate and eventually solidify to form opal. Some mineralogists suggest that microbe activity plays a role in opal deposition. This idea is based on the observation that opal-bearing claystones almost always contain fossilized organic matter, especially the remains of anaerobic bacteria. The metabolic processes of these bacteria, while they were living, could have created localized conditions favorable to the later deposition of opal. This theory is supported by the fact that opal readily replaces (opalizes) wood cells and clamshells.

Most opal deposits, excluding those in Australia and Brazil, occur in volcanic environments when surface water percolates downward through such extrusive rocks as basalt, andesite, and rhyolite to collect in voids, eventually solidifying into opal amygdules, nodules, and fracture fillings.

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COLLECTING LOCALITIES

While the lesser grades of opal are relatively abundant, sources of gem-quality common, fire, and precious opal are few. Most precious-opal sources are located in Australia. In New South Wales, opal is mined at Lightning Ridge; Rocky Bridge Creek; the Angledool, Collarenebri, Cumborah, and Walgett opal fields; and at White Cliffs. Other sources include the Mintabie opal field in Northern Territory, the Yowah opal field in Queensland, and Coober Pedy and the Andamooka opal fields in South Australia. Opal also occurs at several sites in Western Australia, Victoria, and Tasmania.

In Japan, opal is collected at the Yamato-Seguín Mine in Nara Prefecture and the Kawazu and Rendaizi mines in Shizuoka Prefecture. Brazilian sources include the Amazon Opal Mine at Porto Velho in Rondônia state, the Bodó Mine at Lajes Pintadas in Rio Grande do Norte state, the famed Boi Morto Mine at Pedro II in Piauí state, and the Manoel Ambrósio Ranch at São Geraldo do Araguaia in Pará state. Among Mexico's sources are the Cerro de Mercado Mine near the city of Durango and the Barranca Mine at Coneto de Comonfort, both in the state of Durango; the Lomo Deltoro Mine in Zimapan, Hidalgo; the Buena Vista Mine at La Yesca, Nayarit; and the Santín Mine at Santa Catarina in Guanajuato. In Honduras, opal is obtained from a deposit at Erandique in the Lempira Department.

In the United States, opal localities exist in 32 states, most notably in Nevada, Oregon, and Idaho. Nevada's many sources include mines in the Ivanho, Delano, and Rock Creek mining districts in Elko County; the Fish Lake Valley and Tonopah districts in Esmeralda County; and the Opalite and Virgin Valley districts in Humboldt County. Oregon localities include Opal Butte in Morrow County (see *About Our Specimens*), Hart Mountain in Lake County, the Durkee Opal Mine in Baker County, and the Butte Creek district in Jackson County. In Idaho, specimens are still obtained from the Moscow Opal Mine near Moscow in Latah County, a site that opened in 1891 as the first commercial American opal mine.

JEWELRY & DECORATIVE USES

Opal is a popular gemstone that is mounted in pendants, earrings, brooches, and even in rings, despite its only moderate hardness of Mohs 5.5-6.0. Virtually all opal gems are cut *en cabochon*, the exception being certain colors of transparent common and fire opal that are faceted. Most cut opals weigh at least three carats, and stones of 10 to 20 carats are not unusual. In Australia, which produces some 90 percent of the world's opal, opal mining is a \$160-million-per-year-industry.

As mentioned, Precious opal, the variety that displays brilliant flashes of color, is far and away the most valuable kind of opal. Its value depends on color intensity, color distribution, kinds and number of colors, and cabochon shape. Play of color is extremely important, especially when two or even three colors are present; exciting colors like red, blue, green, intense purple or gold, are considered best. One expert recommends holding a gem opal at arm's length in ordinary light (not direct sunlight or under jeweler's lights) and observing if color flashes are clearly visible. Stones that pass this test are of high quality.

A delicate and brittle gemstone, opal is hydrous, and dehydration can eventually cause it to "craze," or develop an internal network of fine cracks. Because crazing is most likely to affect opals stored in dry environments, stones are sometimes stored in moist cotton in sealed containers or even immersed in water. Dehydration can actually shrink the physical size of an opal, causing it to loosen in its setting. Water of hydration also makes opal vulnerable to thermal shock, and rapid, extreme temperature changes (such as sudden immersion in hot water) should be avoided.

Depletion of many opal mines has sharply reduced the availability of large-sized rough for cutting. Rough

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with good opalescence is often too thin to cut into traditional cabochons. Such thin sections are now cemented to colored backing material of common opal or obsidian to provide structural strength and intensify the opalescent color. Such composite stones are known as doublets. When a clear quartz cabochon is cemented atop a doublet, the gem is called a triplet. Triplets make good ring stones because of the protective hardness of the top quartz layer. Also, the constriction caused by cementing tends to reduce crazing. Doublets and triplets are now used in virtually all mass-produced opal jewelry.

Bits of opal too small for cutting are often made into “floating opal” pendants, in which the bits are suspended in tiny, glycerine-filled quartz spheres. Opal can also be treated to enhance its color and wearability. After soaking white or gray opal in sugar solutions, immersion in sulfuric acid carbonizes the sugar, thus darkening the stone’s body color to resemble black opal. Opal is also dyed, impregnated with artificial resins to seal in the water of hydration, and cemented to glittery, artificial backings to create the illusion of opalescence.

Crude, laboratory-made opal made its appearance around 1900 as a spin-off of early attempts to synthesize quartz. But it was French synthetic gem manufacturer Pierre Gilson who “grew” the first commercial, synthetic gem opal in the 1960s, and only after research had revealed the nature of the stone’s internal structure. Today, Gilson has been joined by Russian, Chinese, and Japanese manufacturers who produce many synthetic opal varieties which are fashioned into doublets and triplets.

Opal has always been popular among mineral collectors and museum curators. In the past, exceptional opals have even been given individual names. Most such stones are from Australia. They include the 127-ounce, uncut *Olympic Australis* from Coober Pedy; the 205-carat oval *Noolinga Nera* from Andamooka; and the 252-carat *Light of the World* and 711-carat *Pandora*, both from Lightning Ridge. The National Museum of Natural History (Smithsonian Institution) in Washington, D.C., displays the *Roebling Opal*, a 2,610-carat specimen from Nevada’s Virgin Valley district. Other Smithsonian displays include white-opal gems of 345, 155, and 83 carats and black-opal gems of 58, 54, and 44 carats from Australia; a 355-carat, black-opal gem from Nevada; a 143-carat, orange precious opal and a 56-carat, colorless precious opal from Mexico; and a 39-carat, pale-yellow precious opal from Brazil.

HISTORY & LORE

Opal has been known since antiquity. The oldest known opal artifacts have been recovered from Kenyan caves and date to 4000 B.C. According to ancient Arab folktales, opal originated when it fell from heaven in flashes of lightning. The Greeks believed that opal bestowed powers of foresight and prophecy upon its owner. Later, the Romans valued *opalus* highly as a token of hope and purity. The Roman scholar Pliny the Elder (Gaius Plinius Secundus, A.D. 23-79) described opal, which was then mined in what is now present-day Slovakia, as having the best characteristics of all gemstones—the fine sparkle of almandine, the shining purple of amethyst, the golden-yellow of topaz, and the deep blue of sapphire, “so that all the colors shine and sparkle together in a beautiful combination.” Roman legend tells how Mark Antony (Marcus Antonius, ca 82-30 B.C.), a general and powerful member of Caesar’s court, envied the superb, walnut-sized opal of a Roman senator named Nonius and demanded to buy the stone as a gift for Egyptian Queen Cleopatra (69-30 B.C.). Forced by Antony to choose between selling the opal or going into exile, the senator chose the latter and was eventually buried with the stone. Pliny puts the value of this legendary opal at 2,000,000 setsterces, at least \$5 million by modern standards.

To English dramatist and poet William Shakespeare (1564-1616), the shifting beauty of opal represented unpredictability. In *Twelfth Night; Or, What You Will*, he likened opal’s play-of-color to the changeability of the human mind. In a classic literary use of gemstone symbolism, Shakespeare’s jester says to the

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mercurial duke, "Now the melancholy God protect thee, and the Tailor make thy garments of changeable taffeta, for thy mind is opal."

Opal remained popular in Europe throughout the 18th century. The best opals then came from the ancient Roman source, an andesite deposit at Czerwenitz, Hungary (now Dubnica, Slovakia), where a force of 300 miners provided rough for Constantinople cutters. The finished gems were then sold in Europe as "oriental opal." The largest stone from this source, mined in 1770 and weighing 21 ounces, is displayed at the Imperial Natural History Museum in Vienna, Austria.

But opal's popularity suddenly plummeted in the early 1800s. One reason was the marketing of a large supply of inferior Russian opal that soon cracked and faded. Another was the novel *Anne of Geierstein*, by Scottish author and poet Sir Walter Scott (1771-1832), in which the leading character wore a dazzling opal in her hair. But her life became bound up with the beauty of the opal, and as the stone's fire faded, so, too, did her life. This widely read novel convinced many Europeans that opal was unlucky.

Until the late 1800s, when prospectors discovered huge opal deposits in Australia and smaller deposits in the western United States and Mexico, opals were relatively rare. With increased availability, opal subsequently became more affordable and regained its popularity. Expert gem-cutters at Idar-Oberstein, Germany, began turning out superb cabochons of Australian opal that further stimulated demand. British Queen Victoria (Alexandrina Victoria, 1819-1901) also focused attention on opal by wearing it in jewelry and giving it as wedding gifts. By the late 1920s, art-deco-style jewelry made extensive use of opal, and the popularity of the stone has never waned since.

Medieval physicians administered finely ground opal internally as a healing tonic and to prevent nightmares, and recommended prolonged gazing into opals to prevent eye disease. Blonde Scandinavian women believed that opal necklaces would keep their hair from fading. Australian aboriginal shamans gazed into opals to conjure spiritual visions. According to modern metaphysical thought, opal wards off diseases and enhances love among faithful lovers, but, because opal intensifies all thoughts and actions, including those that are negative, it must be worn judiciously.

Opal has appeared on the Australian eight-cent and nine-cent stamps of 1973 and 1974, the \$1.20 stamp of 1995, and the \$2.50 stamp of 1998, as well as on the 600-franc stamp of Central Africa in 1998. Opal is the birthstone for October, the national gemstone of Australia, and one of two Nevada state gemstones.

TECHNOLOGICAL USES

Apart from serving as a model for opal synthesis, opal has no technological uses.

ABOUT OUR SPECIMENS

Though we have featured several minerals from western states like California, Nevada, and Arizona, this is our first (and probably only) to come from Oregon. Nicknamed the Beaver state due to the popularity of beaver hats in the early 19th century, Oregon contains some of the most beautiful scenery in the United States as well as some of the nation's most fertile soils and richest timberlands. The tenth largest state in the U.S. boasts a land mass of 97,132 square miles and a population of 3,521,515 in the year 2000.

Our specimens come from northeastern Oregon, about 35 miles south of the little town of Heppner, Morrow County, Oregon, population 1410, near the base of the Blue Mountains. At 5015 feet, Opal Butte is almost mile-high, part of the Blue Mountain Range, which covers much of northeastern Oregon. The

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opal-producing mine is on the western slope of Opal Butte at 4700 feet. Summers are dry and hot, winters snowy, which limits mining to May through November.

Opal was discovered here in the winter of 1889-1890 by a shepherd tending his flocks on Opal Butte, then known as Peter's Butte. Two pretty geodes caught his eye, and he broke them open by striking them together, revealing an even more colorful inside! He contacted a man named Levi Shaner, and before long they showed the pieces to a lapidary, who confirmed the material inside as opal. What happened to the shepherd we do not know, but Levi Shaner quickly made claims on the area, word got out, and soon prospectors were digging all over Opal Butte. By 1893, \$20,000 worth of opal had been mined and sold!



Figure 3 Moving earth on Opal Butte.



Figure 2 Thundereggs at Opal Butte.

A couple of factors dampened the excitement of these early miners, as it soon became apparent that very little precious opal, by far the most valuable form of opal, was to be found on Opal Butte, and that crazing was a major problem— as mentioned under *Composition*, opal has a tendency to lose some of its water of hydration, causing it to crack or craze, rendering it virtually valueless. Though these factors discouraged commercial mining, local rockhounds and others continued to work the Butte, occasionally encountering precious opal and finding many thundereggs, a special kind of spherical agate-filled nodule that occur in the perlite or

decomposed perlite beds of many western states, and in British Columbia, Canada, and Australia. (Perlite is a natural volcanic glass similar to obsidian but having distinctive concentric cracks and a relatively high water content.) We would love to feature thundereggs as a future mineral, and delve into their unique formation and properties.

In the 1930's, Opal Butte was acquired by a logging company, Kinzua Pine Mills, who for decades continued to allow rockhounds to dig opal, until the site was so thrashed that it was no longer safe. In 1986, gemstone cutter/dealer Dale Huett and geologist/jewelry designer Kevin Lane Smith formed West Coast Mining and obtained permission to begin working the deposit commercially, being the first to use a bulldozer with a backhoe to uncover the opal-bearing nodules, gradually digging a large open pit. The ultimate goal, of course, is to find



Figure 4 Mining at Opal Butte.

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precious opal, but there is precious little of the valuable gemstone found here, as seen in the chart in Figure 5.

The most common gem-quality opal varieties found at Opal Butte are hyalite (colorless opal) and rainbow opal (facettable clear opal with pools of reflected color shimmering on the surface). Less commonly found are the Precious Opal varieties *contra luz*, meaning "against the light," where the spectral colors are seen when held against the light; hydrophane, which becomes almost transparent in water, except for its rainbow colors; and crystal opal, a transparent to translucent opal where the color play is visible both on the surface and in the interior. And rarely encountered is fire opal, a real misnomer, which has red or red-orange body color, sometimes with play of color; and dendritic opal, clear opal with fern or treelike patterns inside. Stones of incredible beauty and value have been cut from all the varieties found at Opal Butte.

The specimens we picked out for Club members are of the common opal variety, as Precious opal from Opal Butte is scarce and expensive,

as you might glean from the chart in Figure 5. Actually, "Common" is a very poor choice of words as there is plenty of lovely color to go around in what some might call "Common Opal"—we have shades of white, yellow, orange, blue, and reddish brown among our specimens. When we applied shortwave ultraviolet light, we found that the clearer zones were the ones that fluoresced bright green. We noticed no fluorescence under longwave UV, nor any phosphorescence. We were so moved by a close examination of our specimens that we had to have more sent in order to have some on hand at all times!

References: *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *2004 Fleischer's Glossary of Mineral Species*, J. A. Mandarino; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Manual of Mineralogy*, 21st Edition, Cornelius Klein and Cornelius S. Hurlbut, Jr., John Wiley & Sons; *Color Encyclopedia of Gemstones*, Joel E. Arem, Van Nostrand Reinhold Company; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; *Gems and Jewelry*, Joel E. Arem, Geoscience Press; *The World of Opals*, Allan W. Eckert, John Wiley & Sons; *The Curious Lore of Precious Stones*, George Frederick Kunz, Newcastle Publishing Company; *Gem & Lapidary Materials*, June Culp Zeitner, Geoscience Press; *Sinkankas' Standard Catalog of Gem Values*, John Sinkankas, Geoscience Press; ; *Gemstones of North America*, John Sinkankas, Geoscience Press; "Opal," Bob Jones, *Rock & Gem*, March-April 1971; "The Microstructure of Precious Opal," J. V. Sanders and P. J. Darraugh, *The Mineralogical Record*, November-December 1971; "Precious Opal," Bob Jones, *Rock & Gem*, October, 2004; "Opals from Opal Butte, Oregon," Kevin Lane Smith, *Gems & Gemology*, Winter 1988; "A Centennial Celebration," Dale E. Huett, *Lapidary Journal*, November 1990. Photos and chart courtesy of West Coast Mining, Inc.

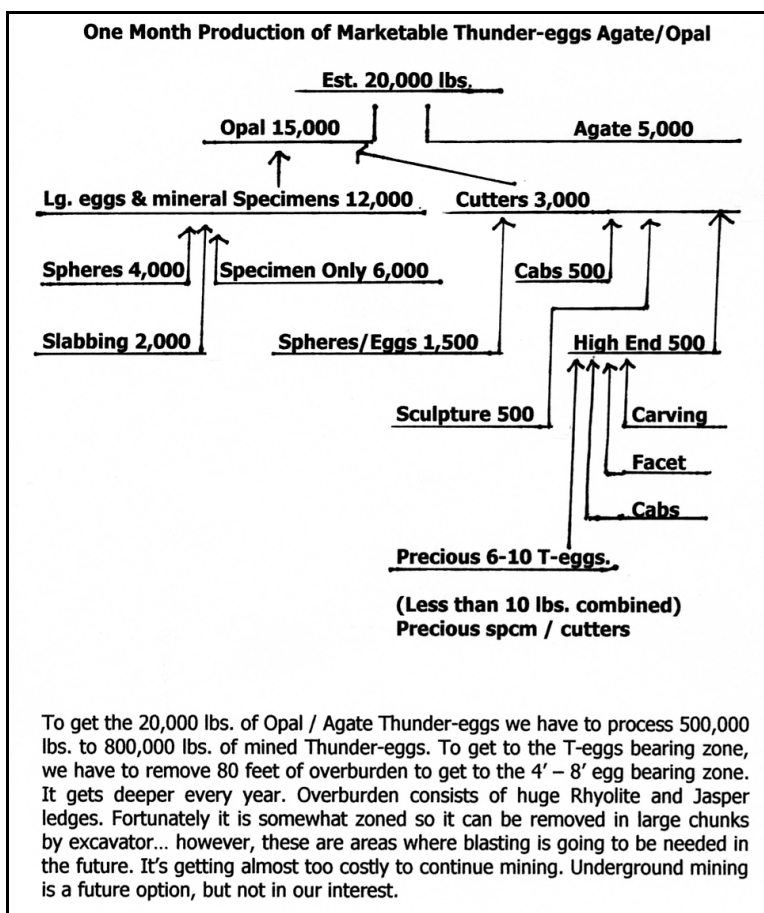


Figure 5 Opal Butte production chart.