

July 2010 Mineral of the Month: Quartz, variety Jasper Pseudomorph after Aragonite

This month's mineral is the chalcedony (jasper) variety of quartz in the pseudomorphic form of quartz-after-aragonite. Our specimens were collected in the Patagonia region of Argentina, and our write-up details their unusual geological origin and explains the mineralogical phenomenon of pseudomorphism.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: SiO₂ Silicon Dioxide

Class: Silicates

Subclass: Tectosilicates

Group: Quartz

Crystal System: Hexagonal

Crystal Habits: As a microcrystalline variety of quartz, chalcedony usually occurs as botryoidal or mammillary crusts in the interior of geodes and vein cavities; in massive, compact, granular, and nodular forms; as fillings between sand grains in sediments; and as smooth, rounded, alluvial pebbles.

Color: White, gray, near-black, tan, brown, brownish-red, red, pink, yellow, and green; rarely blue.

Luster: Waxy and vitreous to dull

Transparency: Translucent to opaque

Streak: White

Refractive Index: 1.55

Cleavage: None

Fracture: Conchoidal to subconchoidal and irregular; brittle to tough.

Hardness: Mohs 7.0

Specific Gravity: 2.65

Luminescence: Impurities sometimes produce a weak, greenish-white fluorescence.

Distinctive Features and Tests: Chalcedony is difficult to confuse with other minerals. Best field marks are hardness, botryoidal or granular form; relatively low specific gravity, and wide range of colors.

Dana Classification Number: 75.1.3.1.1



Figure 1. Quartz (Jasper) pseudomorph after Aragonite.

NAME The name “quartz,” pronounced QWORTZ, is derived from the German *Quarz*, which is thought to have originated from the Slavic word *kwardy*, meaning “hard.” “Chalcedony,” pronounced “cal-SEH-don-ee,” is derived from Chalcedon, an ancient Greek city on the Strait of Bosphorus in present-day Turkey. “Jasper” derives from the Greek *iaspis*, their name for a green-colored precious stone, while “aragonite” is named for its type locality at Molina de Aragón, Guadalajara, Castilla-La Mancha, Spain.

COMPOSITION: Quartz, chemical formula SiO₂, consists of the semimetal silicon (Si) and oxygen (O). Its molecular weight is made up of 46.74 percent silicon and 53.26 percent oxygen. Quartz is a member of the silicates, a mineral group in which silicon and oxygen combine with one or more metals or semimetals. The basic building block of the silicates is the silica tetrahedron (SiO₄)⁴⁻, in which a silicon ion is surrounded by four equally spaced oxygen ions positioned at the corners of a tetrahedron (a four-faced polyhedron). Quartz, which occurs in virtually all igneous, metamorphic, and sedimentary rocks, forms in three ways: as a component of crystallized magma in intrusive and extrusive (volcanic) formations; by the crystallization of silica-rich, hydrothermal fluids; and by precipitation of silica from silica-rich groundwater.

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Because of omnidirectional covalent bonding, quartz crystals have neither cleavage planes nor a center of symmetry. Quartz's substantial hardness of Mohs 7.0 is due to its close atomic packing which strengthens the covalent bonding within its crystal lattice. The light atomic weights of silicon (28.09) and oxygen (16.00) explain quartz's relatively low specific gravity of 2.65. Your specimen of quartz-after-aragonite is a pseudomorph, which is defined as a mineral that has replaced an original mineral while retaining the exterior crystalline shape of the original mineral.

COLLECTING LOCALITIES: In both its macrocrystalline and microcrystalline (chalcedonic) forms, quartz is found worldwide. The jasper variety of chalcedony is especially abundant and widely distributed. Argentina, Canada, Cuba, Germany, China, Russia, Australia, and Mexico all have notable sources of jasper. In the United States, important jasper localities are found in Oregon, California, South Dakota, Idaho, Missouri, Colorado, and New Mexico.

HISTORY, LORE, & USES: Anthropologists consider the microcrystalline quartz varieties of jasper, chert, and flint the most valuable mineral materials during the Stone Age. Because of their conchoidal fracture, these materials flaked easily into weapons with needle-like points and tools with sharp, knife-like edges. Warriors associated carnelian, the red subvariety of jasper, with the blood of battle and often carried carnelian amulets to enhance their prowess in combat. The ancient Egyptians engraved jasper amulets with verses from the *Book of the Dead* to assist the deceased in their journey into the netherworld. Medieval physicians used elixirs of powdered jasper to treat ailments of the kidneys, stomach, and intestines, and advised wearing jasper pendants to protect against drowning, lung ailments, and scorpion bites. In 1824, scientists proved that, contrary to traditional belief, the macrocrystalline and microcrystalline varieties of quartz were the same mineral. Because of its bright colors, abundance, workability, fine grain, and ability to take a high polish, jasper has long been valued as a gemstone and decorative stone. Today, jasper is widely used in jewelry and decorative items and may be the most popular of all quartz gemstones.

ABOUT OUR SPECIMENS: Our specimens were collected near the town of Las Plumas in Valle de las Plumas, Paso de Indios Department, Chubut Province, in the Patagonia region of southern Argentina. The local geology consists of complex sedimentary formations overlying deeper igneous and volcanic rocks. During the mid-Cretaceous Period some 100 million years ago, large, closed, lacustrine basins deposited thick layers of calcium- and iron-rich sediments that later lithified into the intermixed layers of marl, sandstone, shale, and clay of the Cañadón Asfalto Formation. The earthy marl was rich in calcium carbonate which sometimes formed large, well-developed aragonite crystals. During the late Cretaceous Period, colliding tectonic plates uplifted the Andes Mountains and triggered extensive regional volcanism. The acidic, silica- and iron-rich solutions that accompanied this volcanic activity dissolved the aragonite crystals within the Cañadón Asfalto marl layers, leaving behind hollow molds in the shape of the original pseudo-hexagonal aragonite crystals. These voids then filled with silica-rich solutions that precipitated grains of chalcedony. After the voids had filled with individual grains of reddish jasper, a final precipitation stage deposited additional silica as a reddish, intergranular cement that bound the grains together. The mass of chalcedony assumed the external shape of the original aragonite crystals to create our pseudomorph specimens of quartz-after-aragonite.

10 YEARS AGO IN OUR CLUB: Jade, Jade Cove, Monterey County, California. This was a marvelous month—putting together the write-up was challenging as we wanted to discuss both minerals called jade, so we ended up discussing both nephrite and jadeite! Our beautiful polished pieces were supplied by a jade diver who has since passed away, though his son has followed in his footsteps.

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COMPREHENSIVE WRITE-UP

COMPOSITION

The most ubiquitous of all minerals, quartz is abundant, widely distributed, and occurs in many interesting and beautiful forms. We have featured a number of these forms in the past, including amethyst, the purple gem variety of quartz (December 1996); citrine, the golden gem variety (February 2000); quartz scepters (June 2003); Japan-law quartz twinned-crystals (September 2004); quartz geodes (January 2009); chrysoprase, the green gem variety of quartz (August 2009); and three chalcedonic varieties, Ocean jasper (October 2001), Mookaite jasper (August 2008), and Brazilian agate (October 2009). This month, we are pleased to featuring quartz in yet another unusual form—as a pseudomorph masquerading as the mineral aragonite. Before discussing pseudomorphism, some background on quartz would be appropriate.

Quartz occurs in two distinct forms: macrocrystalline and microcrystalline. Macrocrystalline quartz, which consists of visible, well-developed crystals, includes such familiar forms as amethyst, rock crystal, and the milky, smoky, and rose color varieties. Macrocrystalline quartz forms large, transparent-to-translucent, individual crystals or groups of crystals. Microcrystalline quartz or chalcedony, on the other hand, is a compact or massive form of silica made up of interlocked, microscopic silica grains or fibrous silica crystals. The most familiar types of chalcedonic quartz are chert, jasper, and agate.

The chemical formula SiO_2 shows that quartz contains two elements: the semimetal silicon (Si) and oxygen (O). Its molecular weight is made up of 46.74 percent silicon and 53.26 percent oxygen. The cation or positively charged ion in the quartz molecule is the silicon ion (Si^{4+}) with a +4 charge. The anion or negatively charged ion consists of two oxygen ions (2O^{2-}) with a collective -4 charge. The balance of the +4 cationic and -4 anionic charges provides the quartz molecule with electrical stability.

In the past, quartz has been classified both as an oxide and a silicate. Chemically, quartz clearly qualifies as an oxide, a mineral in which metals or semimetals are combined with oxygen. But quartz also qualifies as a silicate, a group in which silicon and oxygen combine with one or more metals or semimetals and in which the basic building block is the silica tetrahedron $(\text{SiO}_4)^{4-}$. Because modern mineral-classification systems prioritize structure above chemical composition, quartz is now formally classified as a silicate. Since silicon and oxygen are the most abundant elements in the Earth's crust, making up 75 percent of its total weight, the silicates mineral class is by far the largest of the mineral classes. The silica tetrahedron $(\text{SiO}_4)^{4-}$ consists of a silicon ion surrounded by four equally spaced oxygen ions positioned at the corners of a tetrahedron. In the quartz-crystal lattice, each silica tetrahedron shares all four of its oxygen ions, which bond covalently to silicon ions of adjacent tetrahedra. In this configuration, each silicon ion is surrounded by four oxygen ions, and each oxygen ion is surrounded by two silicon ions. Because this "four-oxygen-coordination" arrangement satisfies the -4 charge of each individual tetrahedron, no other ions are needed for electrical stability. The result is the infinite, three-dimensional structure of quartz, in which each electrically balanced molecular unit within the lattice is described by the formula SiO_2 .

In the silicate minerals, silica anions join together with metallic or semimetallic cations in repeating chains to form seven types of structures: independent tetrahedral silicates (nesosilicates); double tetrahedral silicates (sorosilicates); single- and double-chain silicates (inosilicates); ring silicates (cyclosilicates); sheet silicates (phyllosilicates); and framework silicates (tectosilicates). Quartz is a framework silicate or tectosilicate, a large subclass that includes the abundant feldspar group of complex aluminum silicates containing potassium, calcium, and/or sodium minerals.

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Quartz, which is present in virtually all igneous, metamorphic, and sedimentary rocks, forms in three basic ways: as a component of crystallized magma in both intrusive and extrusive (volcanic) rocks; by the crystallization of silica-rich, hydrothermal fluids; and by the downward percolation of silica-rich groundwater. The largest and best-developed quartz crystals occur in granite pegmatites and hydrothermal-emplacment veins. Pegmatites, which form from the slow cooling of pockets of residual granitic magmas, often have hollow, central voids that provide space for the unrestricted growth of large mineral crystals. Large quartz crystals can also develop in hydrothermal-emplacment environments, in which pressure forces superheated, aqueous, silica-rich solutions into the voids of faults and fissures. Microcrystalline quartz forms primarily from the crystallization of silica-rich groundwater in shallow environments characterized by low pressure and temperature.

Quartz crystallizes in the hexagonal system, which is defined by four axes, three of which are of equal length and lie in a plane. The fourth axis, which is unique to the hexagonal system, is perpendicular to the plane of the other three axes and is of variable length. The most common hexagonal habit, the hexagonal or six-sided prism in which all six prismatic faces are parallel to the unique axis, is dominant in quartz. Quartz crystals usually terminate as hexagonal pyramids or dihexagonal (12-sided) pyramids. Quartz and other minerals with simple chemical compositions often crystallize in the hexagonal system.

Atomic bonding within the quartz lattice is exclusively covalent with oxygen ions bonded only to silicon ions. Because covalent bonding exerts omnidirectional strength, quartz crystals have neither cleavage planes nor a center of symmetry. This lack of cleavage planes together with the high bonding strength derived from close atomic packing account for quartz's substantial durability and hardness (Mohs 7.0). Yet despite its close atomic packing, the light atomic weights of silicon (28.09) and oxygen (16.00) give quartz a relatively low specific gravity of 2.65. Quartz is the most highly resistant of all detrital (fragmented) minerals. While most minerals eventually abrade and grind into fine particles, huge quantities of hard, durable quartz sand accumulate in beaches, sea bottoms, desert soils, dune fields, and other formations that consist mainly of silica. These granular silica deposits often lithify into sandstones, which in turn can metamorphose into quartzite, an extremely tough, hard, compact rock that is capable of enduring most weathering processes.

As an allochromatic (other-colored) mineral, quartz colors are caused not by its essential elemental components or the nature of its crystal structure, but rather by traces of nonessential, color-producing elements called chromophores. Pure quartz, or rock crystal, is colorless or "water clear." But traces of chromophores such as iron, manganese, and nickel, as well as exposure to natural geophysical radiation, disrupt the symmetry of the quartz crystal lattice to impart a wide range of colors.

The Dana mineral classification number 75.1.3.1 first identifies quartz as a tectosilicate or framework silicate (75). The subclassification (1) next defines it by the chemical formula SiO_2 and four-oxygen coordination in which four oxygen ions are bound to each silicon ion. Quartz is then assigned to the quartz group (3) as the first (1) and only member. The subclassification (defined by the chemical formula SiO_2 and four-oxygen coordination) includes several other minerals that are polymorphs of quartz. These minerals, which have identical chemistries but different crystal structures, are cristobalite (tetragonal), tridymite (triclinic), coesite (monoclinic), and stishovite (tetragonal).

COLLECTING LOCALITIES

In both its macrocrystalline and microcrystalline forms, quartz occurs worldwide. The jasper variety of chalcedony is especially abundant and widely distributed. Jasper sources tend to be poorly documented,

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because they often occur within large sedimentary formations and are not site-specific. Jasper that weathers free of its host formation has sufficient hardness and durability to endure alluvial transport over long distances. Chalcedony also lacks sufficient density to concentrate gravitationally in alluvial deposits (placers). Thus, jasper and other chalcedony varieties are typically found scattered atop the alluvia of riverbeds, plains, and valleys. For all these reasons, we can list only those jasper localities that are of special interest or have commercial importance.

Our specimens of pseudomorphic quartz-after-aragonite were collected near the town of Las Plumas in Valle de las Plumas, Paso de Indios Department, Chubut Province, in the Patagonia region of southern Argentina. Other notable jasper sources are Vancouver Island, British Columbia, and the north shores of the Great Lakes in Ontario, both in Canada; Bayate, Santiago de Cuba, Cuba; the historic Nahe River quarries at Idar-Oberstein, Rheinland-Phalz, Germany; and the greater Altai Mountain region near the common border of China, Russia, and Mongolia. In Africa, jasper is collected in the Llorin area of southern Nigeria; in the Nile River gravels and the Red Sea beach gravels in Egypt; and in the Mtwara region of southeastern Tanzania. In Australia, gem-quality specimens of the green jasper sub-variety chrysoprase are mined at Yerilla, Menzies Shire, Western Australia; and at the Marlborough chrysoprase mine near Capricorn, Queensland. Commercial jasper sources in Mexico include Isla de Santa Catalina in Baja California Sur and numerous sites in Chihuahua.

In the United States, jasper is found in California at Morgan Hill in Santa Clara County, Point Bonita Beach near the Golden Gate Bridge in Marin County, and the Mojave Desert in San Bernadino County. Other localities include the Grants Pass, Lake Owyhee, Biggs Junction, and Rogue River areas of Oregon; the Sioux Falls area of Minnehaha County, South Dakota; Willow Creek near Eagle, Ada County, Idaho; the Canton area in Lewis County, Missouri; the Joseph City and Petrified Forest National Park areas near Holbrook, Navajo County, Arizona; the Sage Mine in Humboldt County, Nevada; the Quemado area in Catron County, New Mexico; and the Sedalia Mine at Salida, Chaffee County, Colorado.

JEWELRY & DECORATIVE USES

Jasper has long been valued as a gemstone and a decorative stone because of its bright colors, abundance, workability, fine grain, and ability to take a high polish. Because jasper is not transparent, it is never faceted, but is instead cut and polished into cabochons and beads for use in jewelry. Jasper cabochons are set into rings, tie tacks and cuff links, while beads are strung in necklaces and bracelets. Jasper jewelry, usually in silver mountings, is available over a wide price range and is generally quite affordable.

The most valuable chalcedonic gemstones are apple-green chrysoprase, red carnelian, and varicolored stones such as Mookaite jasper (our Mineral of the Month for August 2008). Jasper is also fashioned into spheres, boxes, bowls, paperweights, figurines, bookends, polished slabs, and other decorative items. Much gem-quality jasper is tumble-polished and sold at tourist, souvenir, and rock shops. Because of its many gem and decorative uses, jasper is the most popular of all quartz gemstones. Each year, many tons of jasper are cut and polished into gems and decorative items. Because of its natural porosity, jasper is often color-enhanced by immersion in various chemical solutions. Jasper is also the material of choice for “knappers”—craftsmen who fashion arrowheads and other objects through the ancient process of flaking. Many jasper occurrences have become legendary among collectors, such as Biggs Jasper from Idaho, Oregon, and Washington; Morgan Hill Poppy Jasper from Morgan Hill, California; Morrisonite Jasper from Owyhee Rover Canyon, Oregon; Bruneau Jasper from eastern Idaho; Wild Horse Jasper from Idaho and Oregon; and Imperial Jasper from Mexico.

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HISTORY & LORE

The microcrystalline quartz varieties of jasper, chert, and flint were the most valuable mineral materials in antiquity. Because of their conchoidal fracture, these materials were easily flaked into weapons with needle-like points and sharp, knife-edged tools. Primitive jasper axes recovered from cultural sites in Ethiopia's Omo Valley are among mankind's oldest artifacts. By 1800 B.C., many Mediterranean cultures were using jasper for intaglio seals, because wax did not adhere to its polished surface. The quartz varieties jasper, carnelian, agate, and amethyst were among the twelve gems set in the Breastplate of Aaron, the high priest of Jehovah God in Israel. The name of one of Israel's twelve tribes was inscribed on each of these stones. By 1500 A.D., large, nearby deposits of high-quality jasper had made the Idar-Oberstein area, in present-day Rheinland-Phalz, Germany, the world's leading stonecutting center.

Ancient superstitious beliefs concerning the power of jasper abound. Some early civilizations believed that the red carnelian sub-variety of jasper cured insomnia, promoted prudence and caution, and brought strength and victory in battle. Carnelian has long been associated with the blood of battle, and warriors often carried carnelian amulets to enhance their prowess in combat. During the second and third centuries B.C., Egyptians engraved red jasper amulets with verses from the *Book of the Dead* in hopes of assisting the deceased on their journey into the netherworld.

In medieval times, physicians used elixirs of powdered jasper to treat ailments of the kidneys, stomach, and intestines, and advised wearing jasper pendants to protect against drowning, lung ailments, and scorpion bites. When engraved with a scorpion's image, jasper was thought to stop bleeding; when engraved with the image of a dog or stag, it was thought to cure demonic possession. Several Native American cultures believed that jasper could bring rain and alleviate the effects of snakebites.

According to modern metaphysical beliefs, jasper balances physical, emotional and intellectual states, and instills an appreciation of nature. Jasper, which is an alternate birthstone for the month of January, is featured on New Zealand's 5-cent stamp of 1982, Russia's 4-kopek stamp of 1963, Uruguay's 5-peso stamp of 1972, and Cyprus's 10-cent stamp of 1973.

Until the early 1800s, scientists believed that macrocrystalline and microcrystalline quartz were different minerals. In 1780, Swedish chemist Torbern Olaf Bergmann (1735-1784), a pioneer in the study of quartz, noted a chemical similarity between quartz and chalcedony, but nevertheless concluded that they were different species. Furthermore, because he could not decompose silica, he proposed that silica was itself a chemical element. Finally in 1824, Swedish chemist Jöns Jacob Berzelius (1779-1848) succeeded in decomposing quartz into its elemental components, oxygen and a new semimetallic element that he named silicon. The realization that all forms of silica consisted of silicon dioxide finally enabled mineralogists to categorize the microcrystalline and macrocrystalline varieties of quartz varieties into their current classifications.

TECHNOLOGICAL USES

One of early man's greatest technological advancements was learning to flake jasper and other forms of microcrystalline quartz into projectile points and cutting tools. Both as rough stones and finished tools, jasper was an important trading commodity in prehistoric times. As recently as the early 20th century, flaked jasper tools were still used by isolated, primitive cultures. Because jasper colors, patterns, and textures are sometimes source-specific, archaeologists use jasper artifacts as clues to identifying prehistoric trade patterns and routes.

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THE PHENOMENON OF MINERAL PSEUDOMORPHISM

Your quartz-after-aragonite specimen is a classic example of a pseudomorph, which is defined as a mineral that has replaced, altered, or coated a previously deposited mineral while retaining the exterior crystalline shape of the original mineral. Derived from the Greek terms *pseudēs*, "to lie," and *morphē*, meaning "form," the word "pseudomorph" literally means "false form." Pseudomorphic relationships among minerals are conventionally written in two ways. With "A" representing the original mineral and "B" representing the replacement mineral, they can be expressed as A>B or as B-after-A. Our specimens may therefore be described as "aragonite>quartz," meaning "aragonite to quartz" or, more commonly, as "quartz-after-aragonite." Our quartz-after-aragonite specimens formed when quartz replaced aragonite crystals. Replacement or substitution is one of several types of pseudomorphism, in which different types of pseudomorphs form in different ways. Pseudomorphism, which can be mechanical, chemical, or structural in nature, is caused by changes in the physical and chemical environment after the crystallization of the original mineral. The ability of one mineral to replace another mineral while retaining the original mineral's external shape is divided into two general processes: paramorphism and pseudomorphism.

Paramorphism: Paramorphism (literally "creation of closely related forms"), involves structural, but not chemical, change. It occurs when a mineral alters its internal crystal structure while retaining both its original chemical composition and its external crystal shape. A common example of paramorphism involves the minerals calcite and aragonite [both calcium carbonate, CaCO_3] and produces the pseudomorph calcite-after-aragonite. Calcite and aragonite are polymorphs that share the same chemistry, but have different crystal structures. While both consist of calcium carbonate, calcite crystallizes in the rhombohedral system and aragonite in the orthorhombic system. Because it is structurally unstable, aragonite eventually converts to calcite to create paramorphs with calcite's internal rhombohedral structure and aragonite's external orthorhombic shape.

Pseudomorphism: Pseudomorphism involves chemical change and can occur by **replacement** (substitution), **alteration**, or **incrustation**. In pseudomorphism by **replacement**, a mineral with a different chemistry and internal crystal structure completely replaces the original mineral. Our quartz-after-aragonite specimens are an example of pseudomorphism by replacement. Another example is gypsum-after-glauberite, our January 2005 featured mineral. Both gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$] and glauberite [sodium calcium sulfate, $\text{Na}_2\text{Ca}(\text{SO}_4)_2$] crystallize in the monoclinic system. The resulting gypsum-after-glauberite pseudomorph consists of gypsum with the external shape of a glauberite crystal habit. In pseudomorphism by replacement, the two minerals involved always have substantially different levels of solubility, which enables the original mineral to dissolve before or while it is being replaced by the second mineral. One familiar example of pseudomorphism by replacement is a mineral form that isn't usually thought of as a pseudomorph at all—petrified wood, in which silica has replaced wood on a cell-by-cell basis to retain the external form of the original wood.

In pseudomorphism by **alteration**, the original mineral is altered by chemical oxidation or reduction into a secondary mineral that retains at least one elemental component of the original mineral. The original mineral can be completely or partially altered, with changes to both its chemistry and its crystal structure. An example is malachite-after-azurite, specimens of which are usually partially altered and contain both mineral species. Malachite [basic copper carbonate, $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$] and azurite [basic copper carbonate,

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$Cu_3(CO_3)_2(OH)_2$ have similar—but not identical—chemistries. Both crystallize in the monoclinic system, but in different crystal habits. In the pseudomorph malachite-after-azurite, azurite has chemically oxidized into malachite, which retains the exterior shape of the original azurite crystal habit. Another example of pseudomorphism by alteration is the chemical reduction of cuprite [copper oxide, Cu_2O] into native copper [copper, Cu] to produce the pseudomorph copper-after-cuprite, in which elemental copper exhibits the exterior shape of a cuprite crystal habit.

In pseudomorphism by **incrustation**, a new mineral coats an original mineral with a thin film. An example is chalcocite-after-pyrite, a pseudomorph that forms when chalcocite [copper sulfide, Cu_2S], which crystallizes in the orthorhombic system, coats pyrite [iron disulfide, FeS_2], a mineral that crystallizes in the isometric (cubic) system. In chalcocite-after-pyrite, dark-gray chalcocite appears in the shape of the cubes and pyritohedrons typical of pyrite. In pseudomorphism by incrustation, the incrusting minerals are called epimorphs or “outer forms,” while the enclosed minerals are called endomorphs or “inner forms.”

Endomorphs can sometimes dissolve away, leaving behind hollow cavities or “negative molds” called perimorphs or “enclosed forms.” Epimorphs, endomorphs, and perimorphs often have interesting relationships. Consider, as an example, a calcite crystal (an endomorph) encased in a matrix of dolomite [calcium magnesium carbonate, $CaMg(CO_3)_2$]. If the calcite dissolves away, it will leave a hollow, epimorphic dolomite shell in the shape of the original calcite crystal. This void could then fill with another mineral such as halite [sodium chloride, $NaCl$], a mineral which crystallizes in the isometric system. The result is halite-after-calcite, in which halite has the rhombohedral exterior shape of the original calcite crystal and is correctly described as a pseudomorph of perimorphic origin.

Many minerals have pseudomorphic relationships, with quartz alone being involved in more than 100. Because of its chemical stability, low solubility, and durability, quartz is rarely replaced, but is almost always the secondary mineral that replaces an original mineral or material. Some common quartz pseudomorphs are quartz after such minerals as anhydrite [calcium sulfate, $CaSO_4$], barite [barium sulfate, $BaSO_4$], calcite [calcium carbonate, $CaCO_3$], enargite [copper arsenic sulfide, Cu_3AsS_4], epidote [basic calcium aluminum iron silicate, $Ca_2Al_2(Fe,Al)Si_3O_{12}(OH)$], fluorite [calcium fluoride, CaF_2], gypsum [hydrous calcium sulfate, $CaSO_4 \cdot 2H_2O$], thomsonite-Ca [hydrous calcium sodium aluminosilicate, $Ca_2Na(Al_5Si_5O_{20}) \cdot 6H_2O$], wollastonite [calcium silicate, $CaSiO_3$], and wulfenite [lead molybdate, $PbMoO_4$]. Quartz also creates fossil pseudomorphs after such materials as coral, bone, and wood.

As evidenced by their increasing appearance in museum exhibits and private mineral collections, pseudomorphs have in recent years become quite popular among mineral collectors. Some collectors build extensive collections that focus exclusively on pseudomorphic specimens. The theme of the 2009 Tucson (Arizona) Gem & Mineral Show was “Mineral Oddities” and most of the theme exhibits featured spectacular examples of mineral pseudomorphs.

ABOUT OUR SPECIMENS

As noted, our quartz-after-aragonite specimens were collected near the town of Las Plumas in Valle de las Plumas, Paso de Indios Department, Chubut Province, in the southern Patagonia region of southern Argentina. Although Chubut, one of Argentina’s 23 provinces, is the size of Utah, its population is only 500,000. Paso de Indios, one of Chubut’s 15 departments, is located near the center of the province. Although equal in area to the state of Vermont, Paso de Indios is very sparsely populated with just 2,000 residents. Most are of European descent, mainly Welsh and Italian, and cultivate fruit orchards along the

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Río Chubut. The average elevation of Paso de Indios is 1,600 feet and its topography is dominated by low hills and heavily eroded, arid, sparsely vegetated, steppe-like plains.

Valle de las Plumas (Valley of the Feathers), a gentle depression in the Patagonian Plateau, is the middle of three major valleys along the 510-mile-long Chubut River. Spanish explorers named the valley in the late 1500s after observing that the Tehulche natives used feathers extensively in their religious ceremonies. The town of Las Plumas, population 700, lies at the eastern end of Valle de las Plumas at 43°50' south latitude and 67°20' west longitude. Las Plumas is roughly 850 miles southwest of Argentina's capital city of Buenos Aires. The climate is cool and dry, with the daily high temperature averaging 79° F. (26.2° C.) in January (the southern summer), and the daily high temperature averaging 27° F. (-2.6° C.) in July. Only eight inches of precipitation fall each year.

The local geology consists of complex sedimentary formations overlying deeper igneous and volcanic rocks. The granite basement rock was intruded some 450 million years ago during the early Paleozoic Era and was later covered by a 1,000-foot-thick layer of basalt. During the mid-Cretaceous Period some 100 million years ago, large, closed, lacustrine (lake-filled) basins deposited thick layers of calcium- and iron-rich sediments that later lithified into the intermixed marl, sandstone, shale, and clay strata of the Cañadón Asfalto Formation. The marl was originally a crumbly earth rich in calcium carbonate that sometimes formed large, well-developed aragonite crystals. During the late Cretaceous Period some 70 million years ago, colliding tectonic plates dramatically altered the topography of western South America. As the Pacific Plate collided with and slid beneath the South American Plate, resultant crustal stresses uplifted huge volumes of basement rock, basalt, and overlying sediments to form the Andes Mountains. Accompanying this uplift were earthquakes and extensive volcanism, both of which continue today. These tectonic stresses also fractured the crust near present-day Las Plumas, just 200 miles east of the Andean crest, triggering an ancient sequence of minor volcanic activity.

This ancient volcanic activity continued for many millions of years, not as major eruptions, but rather as small volcanoes and associated fumaroles (volcanic vents), with the rising and falling magma accompanied by the circulation of acidic, silica- and iron-rich solutions. These solutions permeated the marl strata of the Cañadón Asfalto Formation, dissolving the aragonite crystals and leaving behind hollow, pseudohexagonal molds. As the dissolving aragonite decreased the acidity of the solutions, silica precipitated in microcrystalline, granular form. After the molds had filled with individual grains of reddish jasper, a final precipitation stage deposited additional quantities of silica as a reddish, intergranular cement that bound the grains together. Each mass of granular, microcrystalline quartz that filled the molds assumed the external shape of the original aragonite crystals—the origin of our pseudomorphic quartz-after-aragonite specimens.

Surface erosion has since exposed sections of the Cañadón Asfalto Formation marl strata, along with their now-extinct volcanic conduits. In the late 1990s, near Las Plumas, local landowner Don Maximo Ruperto Orellana was searching for flagstones when he stopped to investigate a small, "fossil" volcanic formation and discovered quartz-after-aragonite pseudomorphs that had weathered free from the adjacent marl strata. Orellana eventually showed these specimens to mineral dealers in Buenos Aires. Impressed by their quality and potential marketability, these dealers offered to purchase all the specimens that Orellana could collect. But because few specimens remained scattered on the surface, Orellana hired the small mining company SEGMAR (Argentine Geological Mining Service) to excavate the marl strata to recover commercial quantities of specimens. The Orellanita Mine, as the operation is known locally, consists of surface excavations and a small, portable screening plant that separates the pseudomorphs from the marl matrix. The mine also makes another collectible recovery—volcanic "bombs", which are

July 2010 Mineral of the Month: Quartz, variety Jasper Pseudomorph after Aragonite

actually geodes consisting of red jasper. When these ancient volcanoes were active, they ejected masses of molten, reddish silica that solidified in the air to form geodes. The exterior of these geodes, known as “crater agates” or “Orellanites,” is an unremarkable, dark, reddish-purple jasper; the interiors, however, consist of an eye-catching, bright-red, botryoidal jasper.

Before discussing your quartz-after-aragonite specimen, we would like to clarify the difference between *crystal structure* and *external crystal shape*. Quartz crystallizes in the hexagonal system, most often as hexagonal prisms with pyramidal terminations. Aragonite crystallizes in the orthorhombic system, usually as twinned crystals consisting of three intergrown, individual crystals. Called “trillings,” these twinned aragonite crystals always have flat terminations. (For a complete discussion of aragonite, see our Aragonite write-up for July 2009.) These orthorhombic, twinned crystals appear as six-sided prisms that are correctly described as “pseudo-hexagonal” (“false hexagonal”).

When examining your quartz-after-aragonite specimen, note first that its external shape is that of a six-sided (hexagonal) prism with flat terminations. Remember that quartz forms hexagonal prisms with pyramidal terminations, and that aragonite forms pseudo-hexagonal prisms with flat terminations. The flat terminations of your quartz-after-aragonite specimen reflect the shape of the original aragonite crystal. For an interesting comparison of crystal shapes, study your quartz-after-aragonite specimen side-by-side with your aragonite specimen from July 2009. Notice how your quartz-after-aragonite specimen closely replicates the general external shape of your aragonite specimen. Even the smaller, secondary, flatly terminated aragonite crystals seen on your aragonite specimen are replicated in quartz on the prismatic faces of your pseudomorphous quartz-after-aragonite specimen. Now observe the rough granular texture of your quartz-after-aragonite specimen. Close inspection of the surface will reveal its granular composition, which consists of many individual jasper grains cemented together with silica. Finally, the deep, reddish color of your specimen is due to the presence of significant amounts of hematite [iron oxide, ferric, Fe_2O_3]. The remarkable replication of original external shapes by secondary minerals of different chemistries and structures makes pseudomorphs one of the most interesting of all mineral forms.

Knowing that jaspers often fluoresce due to impurities, we looked at some of our pieces and picked up a faint green fluorescence in some specimens under shortwave ultraviolet light, and a smattering of very faint salmony-peach and even fainter yellow in longwave ultraviolet light. We noticed the fluorescence primarily in specimens that had been cut in half and polished to show off their beautiful interior. We obtained these especially to offer to our Platinum members, but have enough for anyone who would like to order one.

While pondering this month’s singular formation, we thought of well-known quartz aficionados Si & Ann Frazier, and a Google search led to this link containing a fascinating article of theirs on pseudomorphism: http://www.mineralsocal.org/bulletin/2005/2005_jan.htm—how long this link will remain active, of course, is unknown. Check it out while you can, if you become enamored of this unusual formation with the long name requiring two lines on our header: “Quartz, Variety Jasper Pseudomorph After Aragonite!”

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