

July 2007 Mineral of the Month: "Rainbow" Pyrite

Who would expect to pick up a nondescript ball of clay and find a rainbow of multicolored metallic crystals inside? Only one who understood how concretions and septarian nodules form, and what causes iridescence, as you will understand when you finish reading this information . . .

PHYSICAL PROPERTIES

Chemistry: Iron Disulfide FeS_2 Usually contains small amounts of nickel, cobalt, manganese, and sometimes silver and gold.

Class: Sulfides

Group: Pyrite

Crystal System: Isometric (Cubic)

Crystal Habits: Usually as cubes and pyritohedra (pentagondodecahedra, or dodecahedra with pentagonal faces), less commonly as octahedra, or combinations thereof in both individual crystals and crystal clusters; often twinned and striated; also as granular, globular, radiating, drusy (encrusting), fibrous, mammillary, and stalactitic masses, and as nodules and aggregations.

Color: Pale brass-yellow or yellowish-gray to gray; may tarnish to yellow-brown; occasionally iridescent.

Luster: Metallic

Transparency: Opaque

Streak: Greenish-black

Cleavage: None

Fracture: Conchoidal, brittle

Hardness: 6.0-6.5

Specific Gravity: 4.9-5.2

Luminescence: None

Distinctive Features and Tests: Best field indicators are pale, brass-yellow color, hardness, striated crystal faces, ability to spark on sharp impact with metal objects and to become weakly magnetic upon heating. Pyrite is sometimes mistaken for native gold, but it is brittle and much harder. Pyrite is also confused with chalcopyrite [copper iron disulfide, CuFeS_2] and certain other metal sulfides.

Dana Classification Number: 2.12.1.1

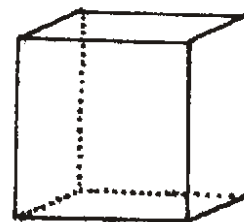


Figure 1. Pyrite cube.

NAME

Correctly pronounced "PIE-rite," the name stems from the Greek *pyr*, meaning "fire," and translates as "fire mineral," a reference to its tendency to spark when struck with metal. The antiquated term "pyrites" refers generally both to similar-appearing metal sulfides and to various types of sparking flints used in early firearms. Because of its abundance and widespread distribution, pyrite has many alternative names, the most familiar of which is "iron pyrite." Another is "fool's gold," which refers to the color similarity with certain hues of native gold. Nineteenth-century names for pyrite include "schwefelkies," "kaltschedan," "leber pyrites," "lebereisener," "leberschlag," "marchasita," "sideropyrite," "vitriolkies," and "yellow pyrite."

Pyrite also has a number of varietal names. This month's pyrite specimens are known as "iridescent pyrite" or "rainbow pyrite," names which describe their unusual play of colors. "Iron crosses" and "iron-cross twins" refer to penetration twins of pyrite pyritohedra with shapes reminiscent of Maltese crosses, while the flat, disc-like, radiating forms of pyrite associated with coal shale are called "pyrite dollars" or "pyrite suns." The silver-gray, cobalt- and nickel-rich varieties are known respectively as "cobaltian pyrite" and "nickelian pyrite."

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COMPOSITION

July 2007 marks the fourth time we have featured this brilliant metallic mineral. The close-to-perfectly-symmetrical pyrite cubes from Spain were our choice for our first featured mineral when we started our Club in March 1996, and we featured them again for our tenth anniversary in March 2006. In October 2003, we featured the clusters of highly lustrous, intergrown pyrite from Peru. And now these small iridescent crystals in septarian nodules from Russia—amazing! In the future, we hope to obtain enough of the pyrite-replaced ammonites, coincidentally also from Russia, to feature pyrite again!

As always, let's begin at the atomic level. With its chemical formula FeS_2 , pyrite contains the elements iron (Fe) and sulfur (S). Iron makes up 46.55 percent of pyrite's molecular weight, and sulfur the remaining 53.45 percent. Within the pyrite molecule, the +2 charge of its single ferrous ion $[\text{Fe}^{2+}]$ balances the -2 charge of its two covalently bonded sulfur ions $[(2\text{S})^2]$. Single sulfur ions normally carry an ionic charge of -2, +4, or +6. But in pyrite and certain other metal disulfides, the two sulfur ions behave electrically as a polyatomic ion. The covalent sharing of electrons within this double sulfur ion results in a single charge of -2, which balances the +2 charge of the ferrous ion to provide electrical balance in the molecule. A number of metal ions, notably those of cobalt, nickel, manganese, silver, and gold, can replace some of the iron in pyrite to the extent that they alter its hardness, density, and color. Cobalt substitutes so readily for iron that pyrite forms a solid-solution series with cattierite [cobalt disulfide, CoS_2], the intermediate grades of which are called cobaltian pyrite.

Pyrite is the most abundant of the more than 350 sulfide minerals. Sulfides, in which sulfur combines with one or more metals, tend to be dense, brittle, dark in color, and metallic in luster. Superficially, pyrite closely resembles several other sulfides. Its brassy color and metallic luster are very similar that of chalcopyrite [copper iron disulfide, CuFeS_2 , our November 2003 featured mineral], cobaltite [cobalt sulfarsenide, $(\text{Co,Fe})\text{AsS}$], cattierite [cobalt disulfide CoS_2], and marcasite [iron disulfide, FeS_2]. Marcasite is actually a pyrite polymorph—a mineral with an identical chemistry, but which crystallizes in a different system (in this case orthorhombic).

Pyrite occurs in virtually all mineralogical environments from pegmatites and hydrothermal vein deposits to carbonatites (low-silica, carbonate-rich igneous rocks), regional metamorphic rocks, skarns (metamorphic deposits characterized by calc-silicate rocks), and sedimentary rocks. In hydrothermal-vein and replacement deposits, pyrite is frequently associated with quartz and such sulfide ore minerals as chalcopyrite, galena [lead sulfide, PbS], and sphalerite [zinc sulfide, ZnS], and to a lesser extent with most other metal sulfides.

In pyrite's cubic crystal lattice, iron ions occupy the eight corners of a cube and the middle of its six faces. Two covalently bonded sulfur ions are located midway along each edge. The inherent rigidity of the cubic structure, along with strong iron-sulfur covalent bonding, accounts for pyrite's considerable hardness of Mohs 6.0-6.5. The weaker covalent sulfur-sulfur bonding within the polyatomic sulfur ion explains pyrite's chemical instability and tendency to oxidize in water and atmospheric oxygen into iron ions and sulfuric acid. The oxidation of pyrite creates gossan, or deposits of limonite (a variable mixture of iron oxides and hydroxides) that overlie lower bodies of unoxidized pyrite. In highly mineralized areas, the effects of pyrite oxidation are readily apparent. The oxidation produces sulfuric acid which acidifies surface water and dissolves large quantities of iron and other metals. As dilution eventually decreases this acidity, the iron precipitates out of solution as “yellow boy,” an iron hydroxide that stains creek banks and beds a characteristic, bright yellow-orange color. Mining often accelerates pyrite oxidation by exposing large volumes of pyrite to atmospheric oxygen and water to create the environmental problem known as mine-drainage pollution.

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Pyrite crystallizes in the isometric (cubic) system, which is defined by three axes of equal length that intersect at the crystal center and are perpendicular to their opposing faces. Variations of this basic cubic shape are the 4-faced tetrahedron, 8-faced octahedron, 12-faced dodecahedron, and 24-faced cubic trapezohedron. Because crystals can assume any of these forms or any combination thereof, pyrite exhibits many crystal habits. The dodecahedral habit alone has four basic forms that are categorized by face shape—symmetrical and asymmetrical pentagonal faces (five-sided polygons), delta-shaped faces (four-sided polygons), and rhombic faces (four-sided, diamond-shaped polygons). Pentagonal dodecahedrons are termed “pyritohedrons” because they are most commonly found on pyrite. Parallel lines called striations are common on the faces of pyrite crystals. These diagnostic striations form by the twinning of cubic and pyritohedral crystals and the subsequent convergence or juxtaposition of two or more faces. During crystal growth, faces become truncated or “overgrown” by other faces, leaving visible edges, or stria. Most stria form by repetitively juxtaposing internal pyritohedron edges on cube faces. Pyrite striations are always perpendicular to those on adjacent faces; although usually parallel, they can also be triangular or crossed.

As an idiochromatic or “self-colored” mineral, the basic, pale brass-yellow color of pyrite is due to its essential elemental components and the nature of its crystal structure. Pyrite, except in very thin section, is opaque, meaning it reflects but does not transmit light. Because sulfur ions do not completely shield the iron ions, the pyrite crystal lattice has a substantial degree of metallic bonding, in which all iron ions share a pool of free-moving electrons. The manner in which these free electrons interact with light accounts for pyrite’s opacity, color, and metallic luster. When struck by incident light, the surface electrons absorb all the light to become energized. To return to their normal levels, these free electrons release their excess energy in wavelengths that we perceive as yellow. And because the free electrons are in constant motion throughout the pyrite lattice and not restricted to a single molecule, the yellow light they emit appears metallic or “brassy.”

The Dana classification number 2.12.1.1 first establishes pyrite as a sulfide (2). Next, pyrite is subclassified (12) by the general formula AX_2 , in which the “A” cation can be iron, zinc, mercury, gold, cobalt, copper, manganese, nickel, platinum, palladium, ruthenium, iridium, or osmium, while the “X” anion can be sulfur, arsenic, antimony, bismuth, selenium, or tellurium. Finally, the Dana system assigns pyrite to the pyrite group (1) as the first (1) of 19 members. All group members have isometric crystal structures and related chemistries, but vary widely in physical properties. Pyrite itself is the group’s only abundant and generally familiar mineral. Other pyrite-group members include vaesite [nickel disulfide, NiS_2], cattierite [cobalt disulfide, CoS_2], villamaninite [copper disulfide, CuS_2 , a cubic polymorph of chalcocite], and hauerite [manganese disulfide, MnS_2].

COLLECTING LOCALITIES

As an abundant mineral found in virtually all mineralogical environments, pyrite has many collecting localities worldwide. Our pyrite specimens, which are rare because of the combination of nodular occurrence and iridescence, were collected in the Volga River near the city of Ulyanovsk in Ulyanovsk Oblast’ (Province) in western Russia. Another Russian source for unusual pyrite specimens is Verkhnyaya, Krasnoyarskii, Siberia.

In Europe, pyrite occurs in brilliant, near-perfect cubic crystals at Navajun, La Rioja, Spain, the mine we visited during our trip to Spain in April, where our March 1996 and March 2006 specimens originated. Other noted Spanish pyrite sources are the Rio Tinto mines at Huelva and the mines in the “pyrite belt” of metal-sulfide deposits west of Seville in Andalusia. Sharp-edged, cubic pyrite crystals also occur at Rio Marina, Elba, Italy. In England, pyrite is found in the mines at Callington in Cornwall and at Nenthead in

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Cumbria. German sources include the mines at Neustädtel in the Schneeberg District of Saxony. Large pyrite cubes are found at the Cassandra Mine in Chalkadiki Prefecture, Macedonia Department, Greece.

In Australia, excellent pyrite specimens are found in the mines of the New England District in New South Wales and at the Golden Mile gold mine at Kalgoorlie in Western Australia. Fine specimens are also recovered in Canada in the Alberni, Atlin, Cariboo, Liard, and Kamloops districts in British Columbia, and the Algoma and Cochrane districts in Ontario.

South America is known for fine pyrite specimens, the best coming from the Huanzalá Mine in Dos de Mayo Province in Huanuco Department, Peru, where our October 2003 specimens were collected. This locality vies with the Navajun locality in Spain for the title of “World’s Best Pyrite.” Other notable Peruvian specimens come from the Cerro de Pasco District in Alcides Carrión Province in Pasco Department. The finest Brazilian specimens are found at the pegmatite mines of Galiléia in Governador Valadares, and at Conselheiro Pena in Minas Gerais. In Bolivia, excellent pyrite specimens come from the Atocha-Quechisla District, Sud Chichas Province, Potosí Department, and the mines at Ciudad Oruro, Cercado Province, Oruro Department.

Many metal-mining districts in the United States are known for fine pyrite specimens. These include the American Mine at Bingham Canyon and the mines at Park City, both in Utah. Superb Colorado specimens have come from the Leadville district and the nearby Climax Mine, as well as the Gilman, Alma, Silverton, Ouray, Rico, and Telluride districts. The Tri-State zinc-lead mining district of southwestern Missouri and adjacent sections of Kansas and Oklahoma have yielded many large, well-developed pyrite cubes. Bright “pyrite dollars” are found in coal-seam shales at Sparta, Illinois. Fine cubes and dodecahedra have come from the Huff Quarry at Huntsville, Ohio, and unusual, distorted octahedra from Pennsylvania’s French Creek Mine.

JEWELRY & DECORATIVE USES

Some of the oldest known pyrite jewelry has been found in 4,000-year-old Egyptian tombs. Although pyrite has long been used in jewelry, it achieved its greatest popularity as a gemstone in Britain during the Victorian era of the late 1800s, when faceted pyrite was mounted in pendants, brooches, necklaces, and bracelets. One particularly popular Victorian jewelry style featured hundreds of tiny, glittering, faceted pyrite gems mounted in large, elaborate, sterling-silver settings. This jewelry style later regained popularity in the United States and Europe during the Art Deco period, and we still see it offered at the large gem and jewelry shows today. Ironically, it is usually called marcasite rather than pyrite.

Pyrite is still seen in jewelry today, most often as drilled and polished beads in necklaces, bracelets, and dangling earrings. Drusy “rainbow” pyrite, represented by our specimens this month, has recently gained in popularity as a gemstone since reliable supplies of quality material became available in the late 1990s. Rainbow pyrite, which is never treated or color-enhanced, is cut in cabochon shapes for mounting in pendants and brooches. The color and glitter provided by the thousands of tiny, iridescent pyrite crystals is very distinctive and eye-catching, ideal for use in one-of-a-kind, designer jewelry.

As a decorative stone, pyrite is sometimes cut into small “rosettes” for such uses as edging picture frames. Larger crystals, usually in their natural form, have long been popular as paperweights. Abundance, affordability, and a wide variety of crystal habits make pyrite one of the most collectible of all minerals. In fact, it is often the first mineral that many young collectors acquire! Pyrite has a broad price range, from small clusters of crystals that cost only a few dollars to rare cabinet specimens that sell for thousands of dollars each.

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HISTORY & LORE

In ancient China, the symbol for Earth was a golden cube that anthropologists believe was patterned after natural cubic pyrite crystals. Pyrite, as both natural crystals and worked amulets, has been found in the archaeological sites of the Greeks, Romans, and other ancient cultures. The first written reference to pyrite appears in the treatise *Peri Lithon* (*On Stones*), in which the Greek philosopher and naturalist Theophrastus (ca. 372-ca. 287 B.C.) describes tiny, glittering grains of pyrite embedded in lapis lazuli. In South America, the ancestors of the Incas polished the smooth faces of large pyrite cubes into mirror surfaces, believing that the reflected self-images provided a look into one's soul. In North America, tribal healers and seers carried pyrite cubes as “medicine” and possibly used their reflective crystal faces to help conjure shamanistic visions.

In medieval times, physicians administered elixirs containing finely ground pyrite to treat throat and circulatory ailments. The first practical use for pyrite appeared about 1400 A.D., when European alchemists roasted finely ground pyrite over charcoal fires to drive off the sulfur as sulfur dioxide [SO₂], a gas that they then dissolved in water to make sulfuric acid [H₂SO₄]. Sulfuric acid has many metallurgical and chemical uses, and was an important reagent during the centuries of experimentation that eventually culminated in the emergence of modern chemistry.

In the late 1400s, pyrite's well-known ability to emit sparks when struck sharply with an iron implement or flint-type rocks was put to use to generate sparks in early wheel-lock firearms. Pyrite sparks when a sharp impact produces extreme mechanical pressure within a tiny area, thus parting its covalent sulfur-sulfur bonds with an instantaneous release of heat and light energy in the form of a spark.

In the early 1700s, pyrite was among the first minerals that European chemists qualitatively identified by its elemental components, iron and sulfur. A century later, researchers used pyrite as a chemical model to help determine the previously unknown elemental compositions of similar metal sulfides. True pyrite then became known as “iron pyrite” or “yellow pyrite,” and chalcopyrite as “copper pyrite,” differentiating terms which still have limited usage today.

Pyrite has sometimes been mined as a source of iron in places without deposits of such primary iron ores as magnetite [ferrous-ferric oxide, FeFe₂O₄] and hematite [ferric oxide, Fe₂O₃]. But the sulfur component of pyrite had far greater commercial value. By the mid-1800s, pyrite mining was an important industry in regions lacking deposits of native sulfur. During World War I, soaring industrial and military demand for sulfur made pyrite a strategic mineral in the United States, Great Britain, and Germany, where its sulfur component was vital in the manufacture of vulcanized rubber, fertilizers, medicines, and explosives.

Metaphysical practitioners believe that pyrite supplements physical energy with the energy of the sun, increases stamina, stimulates the intellect, and helps transform thought into intelligent action. Pyrite is also thought to shield its wearer from negativity and physical risk.

Postage stamps that have featured pyrite specimens include the 60-centavo and 2,600-sucre stamps of Ecuador in 1960 and 1997, respectively; the 3-cent stamp of New Zealand in 1982; the 170-dram stamp of Armenia in 1998; the 15-cent stamp of Cyprus in 1998; and the 29-peseta stamp of Spain in 1994.

TECHNOLOGICAL USES

Pyrite's greatest use today is as a coloring agent in the production of brown glass for beverage bottles. Researchers also use pyrite as a model in the study of mineral-crystal structure and pyrite-oxidation

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chemistry, the latter a key to understanding pyrite's mineralogical origin and the mechanism of its alteration into other minerals and chemical compounds. Knowledge of pyrite-oxidation chemistry helps to determine the weathering tendencies of such pyrite-containing structural stones (building stones) as granite and marble, and to better understand the role of oxidation in mine-drainage pollution for the purpose of devising prevention and remediation methods.

SEPTARIAN NODULES & IRIDESCENCE

Of pyrite's many different forms, one of the rarest is drusy coatings of iridescent pyrite crystals on septarian nodules. Both the formation of septarian nodules and the phenomenon of mineral iridescence are worthy of special examination.

Sedimentary geologists refer to nodules as “concretions,” a term that derives from the Latin con, “together,” and cresco, “to grow.” A concretion is a volume of sedimentary rock in which mineral cement fills the pores between the sediment grains. Concretions can be spherical, ovoid, elongated, or irregular in shape and range in size from microscopic to many feet in diameter. They form within layers of sedimentary strata soon after deposition and before the sediments have lithified. Concretions are most common in such sedimentary rock as shale, siltstone, and sandstone.

Common concretionary cements include calcite [calcium carbonate, CaCO_3], apatite [mainly fluorapatite, calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$], siderite [iron carbonate, FeCO_3], gypsum [hydrous calcium sulfate, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$], barite [barium sulfate, BaSO_4], and silica [quartz, silicon dioxide, SiO_2]. Depending upon specific environmental conditions, concretions can undergo either concentric or pervasive growth. In concentric growth, the concretion grows slowly, usually around an organic nucleus, as a succession of concentric layers accrete to its surface. In pervasive growth, cementing minerals fill all the pore spaces simultaneously within a limited volume of sediment. Different types of concretions are large calcite “cannonballs”; iron oxide concretions called “moqui marbles”; elongated concretions that form in strong, directional groundwater flows; “Kansas pop rocks,” which consist largely of pyrite or its polymorph marcasite (and which burst when heated); and septarian concretions.

Septarian concretions are roughly spherical and contain angular cavities or cracks called “septaria.” The term “septaria” derives from the Latin septem, meaning “seven,” in reference to the internal crack pattern which often, but not always, has seven primary branches. The process or processes that create septaria are uncertain. But the possibilities are dehydration and shrinkage of a clay- or organic-rich matrix, the expansion of gases produced by decay of organic matter, or fracturing by the force of burial compaction. Septaria are typically filled with minerals that crystallize from circulating solutions, such as calcite, quartz, barite, and siderite. When cut in cross section to exhibit the intricate internal patterns, septarian nodules, such as those from Utah, make interesting and attractive decorative objects. The origin of the drusy pyrite on our specimens is explained in “About our Specimens.”

The other distinguishing feature of this month's pyrite specimens is iridescence—the rainbow-like flash of colors that reflect from the faces of the pyrite crystals. Iridescence is created by the phenomenon of optical interference which occurs in everything from soap bubbles and oil layers on wet pavement to the shells of certain insects and the crystal faces of certain minerals. The principle of optical interference was first explained in 1815 by the French physicist Augustin-Jean Fresnel (1788-1827). Optical interference is caused by differential reflection and reinforcement of visible light waves. Interference occurs when two or more light waves overlap. Its effects vary with frequencies, relative phases (the relative position of wave

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crests and troughs), and amplitude. Interference can be destructive or constructive. Destructive interference occurs when two light waves of the same frequency are out of phase and cancel each other out. Constructive interference—the cause of iridescence—occurs when the overlapping waves are in phase and reinforce each other. Reinforcement increases wave amplitude (light intensity) and produces colors that are structural, rather than spectral. Unlike spectral colors, structural colors have an unusually vivid, "electric" character.

For interference to occur, a surface must have at least two superposed, closely positioned, parallel reflective planes. In pyrite and certain other minerals, notably the copper iron sulfide minerals bornite [Cu_5FeS_4] and chalcopyrite [CuFeS_2], this is achieved by chemical weathering of the surface. Atmospheric oxidation causes the surface of pyrite, depending upon the specific chemical environment, to oxidize into such iron minerals as goethite [$\text{FeO}(\text{OH})$], hematite [Fe_2O_3], and limonite [a variable mixture of ferric and ferrous oxides and hydroxides] that form a microscopically thin surface film parallel to the surface of the underlying, unoxidized pyrite. This oxide film reflects part of the light that strikes it. But because it is microscopically thin, it also transmits a portion of the light, which is, in turn, reflected by the lower surface of unoxidized pyrite. This produces two separate beams of reflected light that travel in the same direction. When the waves of these two beams are in phase and constructively reinforce each other, the result is iridescence. The intensity and type of iridescent color depends largely upon the microscopic distance between the upper oxide and lower sulfide reflecting surfaces. Rotating an iridescent-mineral specimen effectively changes the distance (in terms of actual light travel) between the two reflecting layers, thus creating shifts in the reinforced wavelengths that produce a dazzling range of structural colors.

ABOUT OUR SPECIMENS

Our pyrite specimens were collected from the Volga River near the city of Ulyanovsk in Ulyanovsk Oblast' (Province) of western Russia. The 2,300-mile-long Volga River, which flows east of the Ural Mountains, is Europe's longest river. From its source midway between the cities of Moscow and Saint Petersburg, the Volga flows generally in a southeasterly direction to the Caspian Sea. Along its length, dams impound eight major hydroelectric reservoirs, but locks make the river navigable for most of its length. In cultural and economic importance, the Volga is to Russia what the Mississippi is to the United States.

The city of Ulyanovsk, the administrative capital of Ulyanovsk Oblast', is located roughly 500 miles southeast of Moscow and the same distance upstream from the city of Volgograd (formerly Stalingrad). Ulyanovsk was founded in 1648 as the fortress town of Simbirsk on what was then the Russian Empire's southeastern frontier. Over the centuries, it grew into an important trading center and river port. The city is the birthplace and childhood home of Vladimir Ulyanov, better known as the Russian Communist leader Vladimir Ilyich Lenin (1870-1924). Upon Lenin's death, Simbirsk was renamed Ulyanovsk in honor of Lenin's family name. Today, Ulyanovsk, population 680,000, is a major manufacturing center, notably of automobiles and aircraft, and a busy river port. Because of the construction in the 1950s of the Kuybyshev hydroelectric dam 60 miles downriver, the section of the Volga that flows past Ulyanovsk is now part of the 150-mile-long Kuybyshev Reservoir. Near Ulyanovsk, the width of the impounded Volga River ranges from 3 to as many as 20 miles.

Our specimens of pyrite-encrusted septarian nodules were collected from the mud banks and flats of the Volga River. These banks and flats consist largely of marine sediments of late Jurassic and early Cretaceous age (140-100 million years ago). During that time, what is now western Russia was submerged beneath a shallow sea which accumulated thick sedimentary strata that are known today as the Ermolynskaya, Kolomenskaya, and Koloshinskaya formations. The original sediments of these

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formations contained large amounts of carbon from decaying shoreline vegetation, along with similar amounts of calcium and phosphorus in the form of fluorapatite [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$] from the remains of tiny, invertebrate marine organisms. Chemical alteration produced calcite [calcium carbonate, CaCO_3] and various phosphate compounds, all of which acted as cementing agents that formed septarian nodules (see "Septarian Nodules and Iridescence").

After eons of burial, crustal stresses generated by distant tectonic collisions uplifted the basement rock and overlying marine sediments throughout western Russia. As the seas receded, erosion began to uncover the nodule-rich marine limestones and shales. In the greater Volga Valley, the enormous glacial runoffs of the Quaternary Period (the Pleistocene ice ages that began three million years ago) eroded the marine sediments and freed their contained nodules, redepositing this material in river benches. Because the nodules are slightly more dense than the loose sediments, they concentrated gravitationally in certain strata of the river benches.

At some point, the chemistry of the circulating groundwater had changed. Whether this occurred before or after the nodules had eroded from their original Jurassic-Cretaceous formations is uncertain. But water with much more dissolved iron began circulating through the sediments. Because the nodules were richer in both sulfur and carbon than the surrounding sediments, they chemically precipitated much of the iron as pyrite. The dissolved iron contacted the sulfur to form pyrite, while the carbon and carbon-containing compounds within the nodules induced precipitation on the surface and within the seams of the nodules.

Recent bank erosion caused by seasonal variations in water levels of the Volga has exposed these pyrite-encrusted nodules in mud banks and mudflats just north of Ulyanovsk. Concentrations of nodules were discovered there during dredging operations in the mid-1990s. The nodules quickly came to the attention of mineral dealers who brought them to European gem-and-mineral shows. With their drusy coating of iridescent pyrite, these nodules became so popular among mineral collectors that Ulyanovsk entrepreneurs began "mining" them to sell to dealers. Some miners now contract with commercial dredging operations to sift through and screen dredged river-bottom mud. Individual nodule collectors wait until water levels are low in autumn, then dig into banks, benches, and mudflats, shoveling the mud onto screens and washing it with water to reveal the nodules.

From there, it's just a matter of breaking open, cleaning, and grading the material, then bringing it to shows around the world where eager gemstone cutters and mineral collectors can snap them up! The Russian exporter meticulously reconstructs the nodules so that they can be shipped over whole. Once they are opened up again, the inner beauty of the iridescent crystals is revealed. With your 10x loupe, it is easy to see the individual crystals, some nearly cubic in shape, others that were modified during growth. Notice the change in iridescent color as you slowly rotate your piece in your hand—marvelous! Who would have thought such a plain outer shell would contain such dramatic and dynamic colors inside! And how glad we are to add such a wonder to our collections!

References: *Manual of Mineralogy*, Klein and Hurlbut, John Wiley & Sons; *Dana's New Mineralogy*, Eighth Edition; *Encyclopedia of Minerals*, Second Edition, Roberts, et al, Van Nostrand Reinhold Company; *2004 Glossary of Mineralogical Species*, J. A. Mandarino and Malcolm E. Back, The Mineralogical Record, Inc.; *Mineralogy*, John Sinkankas, Van Nostrand Reinhold Company; *Rocks and Minerals*, Joel Arem, Geoscience Press; *Gemstone and Mineral Data Book*, John Sinkankas, Geoscience Press; *Gemstones of the World*, Walter Schumann, Sterling Publishing Company; "Pyrite," Bob Jones, *Rock & Gem*, October 1994; "Pretty, Problematic Pyrite," Steve Voynick, *Rock & Gem*, May 1998; "The Crystal Forms of Pyrite," R. I. Gait, *The Mineralogical Record*, July-August 1978; "Origins of Color in Minerals," Kurt Nassau, *American Mineralogist*, Volume 63, 1978; "The Internal Structure of Concretions in Mudrocks; Evaluation of the Conventional Concentric Model of Concretion Growth," P. S. Mozley, *Sedimentary Geology*, Volume 103, 1996; "Septarian Nodules," Earl Spendlove, *Rock & Gem*, October 1992.