

May 2007 Mineral of the Month: Brookite

This month marks several firsts: our first mineral from an Alpine-cleft deposit, our first from Pakistan, and the first time we've seen so many excellent crystals of this rare mineral!

PHYSICAL PROPERTIES

Chemistry: TiO_2 Titanium Dioxide, often containing iron

Class: Oxides

Subclass: Simple Oxides

Group: Brookite

Crystal System: Orthorhombic

Crystal Habits: Tabular to platy, thin in one direction; sometimes sheet-like, with pseudo-hexagonal cross-sections, parallel striations, and small, brilliant termination faces. Less commonly as black, opaque, six-sided bipyramids (variety arkansite).

Twinning rare. Crystals usually less than one-quarter inch in size.

Color: Brown, yellow-brown, amber, orange, and reddish-brown.

Luster: Submetallic to adamantine

Transparency: Transparent to translucent and opaque

Streak: Yellowish-white

Cleavage: Poor in one direction

Fracture: Subconchoidal, brittle

Hardness: 5.5-6.0

Specific Gravity: 4.10-4.14

Luminescence: None

Refractive Index: 2.583-2.705

Distinctive Features and Tests: Submetallic luster, relatively high density, reddish-brown color, frequent association with rutile, anatase [both polymorphs of titanium dioxide, TiO_2], and quartz [silicon dioxide, SiO_2] in alpine-cleft-type deposits.

Dana Classification Number: 4.4.5.1

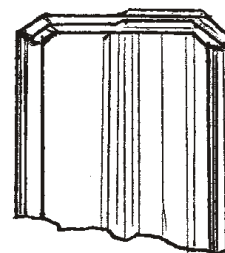


Figure 1. Brookite crystal

NAME

The name of this month's mineral is pronounced just as it is spelled—BROOK-ite, and is named after the English crystallographer and mineralogist Henry James Brook (1771-1857). Brookite is also known as "arkansite," "eumanite," "jurinite," "pyromelane," "acid titanium," "ortho-rutile," and "ortho-titanium." European mineralogists refer to brookite as "brookita" and "brookit."

COMPOSITION

Titanium and oxygen combine to form three distinct minerals, and possibly a fourth, as we will see. We featured the most common of these, rutile, in June 1999, as small specimens with golden radiating needles from Bahia, Brazil. We never thought we would be able to feature the other two, brookite and anatase, but now that we have done one, perhaps the other will become available in the future as well!

Brookite's chemical formula, TiO_2 , identifies its elemental components as titanium (Ti) and oxygen (O). Titanium makes up 59.94 percent of brookite's molecular weight, with oxygen accounting for the remaining 40.06 percent. The molecular weight of a mineral is the sum of the atomic weights of its constituent elements. The atomic weight of titanium is 47.88 and that of oxygen is 16.00. Brookite's molecular weight is therefore calculated as $47.88 + (2 \times 16.00) = 79.88$. To determine the weight percentage of titanium in brookite, divide the atomic weight of the single titanium ion by brookite's molecular weight

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(47.88/79.88=.5994). To determine the weight percentage of any elements in any mineral compound, simply obtain the atomic weights of the mineral's elemental constituents from a reference source and complete this calculation.

As a simple oxide, brookite consists of only a single metal combined with oxygen. The brookite molecule achieves electrical stability through the balance of the +4 charge of its titanium (Ti^{4+}) cation (positively charged ion) with the collective -4 charge of its double-oxygen (2O^{2-}) anion. Brookite crystallizes in the orthorhombic system, which has three mutually perpendicular axes of different lengths. When one axis is notably shorter than the others, as in brookite, the crystal is tabular, platy, or sheet-like. The brookite lattice consists of a three-dimensional arrangement of staggered pinacoidal structures with titanium ions at the corners and oxygen ions occupying the face or interior positions. The lattice is joined together mainly by strong, covalent, titanium-oxygen bonds that give brookite a substantial hardness of 5.5-6.0 and no pronounced cleavage planes. Because its oxygen ions do not completely shield its titanium ions, brookite exhibits a diagnostic submetallic luster. Brookite's considerable density (specific gravity 4.10-4.14) is due to the fact that titanium, a moderately heavy metal (atomic weight 47.88) comprises 59.94 percent of its molecular weight.

Unlike most minerals, brookite occurs only as crystals and never in compact masses or aggregates. It is usually associated with its polymorphs rutile and anatase (see "The Polymorphs of Titanium Dioxide") and attached to cavity walls in weathered igneous rocks. Most brookite occurs in alpine-cleft-type deposits (mineralized fissures in igneous rock) in association with anatase, rutile, titanite [calcium titanium oxysilicate (sphene), CaTiOSiO_4], quartz [silicon dioxide, SiO_2], albite [sodium aluminum silicate, $\text{NaAlSi}_3\text{O}_8$], and calcite [calcium carbonate, CaCO_3]. In metamorphic rocks, brookite is attached to the walls of clefts in gneiss and crystalline schists. Lesser amounts of brookite form by hydrothermal alteration. Brookite is also found as minute, isolated crystals in sedimentary rocks. Brookite's considerable density enables it to concentrate gravitationally in alluvial placer deposits in association with gold and other heavy minerals.

Brookite is an idiochromatic (self-colored) mineral, meaning that its characteristic reddish-brown color is due to its inherent chemistry and crystal structure. When pure, brookite has a high degree of transparency and a bright reddish-brown color. Impurities, usually of iron, create color variations and reduce transparency.

Brookite's abilities to refract and disperse light are among the highest in the Mineral Kingdom. Refraction, the ability to bend light, is measured by index of refraction (R.I.), which is the ratio between the speed of light in air and in a crystal. The R.I. of most mineral crystals and gemstones falls between 1.4 and 1.9. Higher numerical values indicate greater degrees of refraction and correspond directly to brightness and brilliance in gems. Diamond (carbon, C), known for its brilliance, has an unusually high R.I. of 2.417-2.419—which is still considerably less than that of brookite (R.I. 2.583-2.705).

Dispersion refers to the ability of a crystal or gemstone to disperse white light into its spectral colors. Dispersion is expressed numerically as the difference between the red and violet refractive indices. The particularly high color dispersion of diamond (dispersion index 0.044) produces a beautiful display of color called "fire." Yet the dispersion index of brookite—0.269—is six times higher. The ability to refract and disperse light is dependent primarily on crystal structure and to a lesser extent on density and chemistry. Unfortunately, even with these properties, brookite makes poor gemstones, as will see.

The Dana subclassification number 4.4.5.1 first identifies brookite as a simple oxide (4). The subclassification (4) next defines it by the general formula A^{4+}O_2 , in which " A^{4+} " is a quadrivalent metal cation. Finally, brookite is a member of the brookite group (5) as the first (1) and only member.

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THE POLYMORPHS OF TITANIUM DIOXIDE

The three polymorphs of titanium dioxide (TiO₂) are brookite, rutile, and anatase. These polymorphs have an identical chemistry, but different crystal structures. Rutile and anatase both crystallize in the tetragonal system, while brookite crystallizes in the orthorhombic system. Although rutile and anatase are both tetragonal minerals, their crystal habits are quite different. Rutile forms prismatic to acicular crystals with dipyramidal terminations and is often twinned, while anatase forms only tabular or dipyramidal crystals and does not twin. The following table points out the similarity in chemistry and the physical differences between the titanium-dioxide polymorphs.

	<u>Chemistry</u>	<u>Crystal System</u>	<u>Density</u>	<u>Hardness</u>	<u>Twinning</u>	<u>Cleavage</u>
Rutile	TiO ₂	tetragonal (prismatic)	4.25	6.0-6.5	common	2/good
Anatase	TiO ₂	tetragonal (tabular)	3.9	5.5-6.0	none	3/perfect
Brookite	TiO ₂	orthorhombic	4.1	5.5-6.0	none	1/poor

The titanium-dioxide polymorphs crystallize at different temperatures: Anatase crystallizes first and at very high temperatures, brookite next and at moderate temperatures, and rutile last and at low temperatures. Anatase and brookite crystallize only in precise conditions of temperature, pressure, and chemistry. Rutile crystallizes over a broader range of conditions, which explains why it is by far the most abundant of the three polymorphs and comprises most of the titanium dioxide in the Earth's crust. Rutile is the only stable polymorph of titanium dioxide; when subjected to high temperatures, both anatase and brookite undergo structural rearrangement of their lattices and convert to rutile.

Mineralogists are currently studying a very rare, not-yet-named mineral that may be recognized as the fourth polymorph of titanium dioxide. Referred to as "TiO₂B," this form of titanium dioxide has been found only in such shock-induced, very-high-pressure environments as meteor-impact sites. Its very tight lattice structure and high density reflect its formation under conditions of extreme pressure.

COLLECTING LOCALITIES

Our brookite specimens come from what is currently the world's finest source for this mineral, an alpine-cleft deposit in the Khârân District of the Balochistan Province of western Pakistan. Brookite is also collected in Russia at the Dodo Mine in the Subpolar Urals at Tyumenskaya Oblast' in the Western-Siberian Region, and at the Lovozero and Khibiny massifs on the Kola Peninsula in the Murmansk Oblast' of the Northern Region.

In England, exceptional specimens occur at the Cwmorthin and Manod quarries at Gwynedd in Wales, and the Shap Pink Quarry at Eastern Fells in Cumbria. In Austria, brookite is found in alpine-cleft deposits at the Eischl, Swartzkopf, and Grauleiten areas of the Hohe Tauern Mountains in Carinthia. Other Austrian sources are in Salzburg at quarries near Bockstein in the Anlauf Valley, and at Lohninger Quarry in the Rauris Valley, all in the Hohe Tauern Mountains. Small, well-developed crystals come from Plan-du-Lac at Bourg d'Oisans and the La Lauzière massif at Savoie, both near Isère in Rhône-Alpes, France. Fine, amber-colored crystals are found at the Clara Mine near Wolfach and the Artenburg Quarry in the Black

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Forest of Baden-Württemberg in Germany. Dark reddish-brown, half-inch-long brookite crystals occur in the Ramaceto and Bregaceto mountains at Borzonasca in Genova Province, Liguria, Italy. Another noted Italian source is Carrara in the Apuan Alps in Massa-Carrara Province in Tuscany. Swiss brookite sources include the Stalden, Lungen, Griesseren, Brunni, and Bänder valleys near Maderanertal in Uri, and the Cavradi Gorge and Russien and Vais valleys at Lugnez in Grischun. Small, well-formed brookite crystals associated with anatase are found at the Kristiansen Quarry at Grorud near Oslo, Norway.

In Brazil, brookite occurs at Serra do Mangeira in Bahia and Diamantina in Minas Gerais. Australian sources include the Bundaleer Reservoir quarry at Spalding in the Mount Lofty Range in South Australia, Kingsgate in New South Wales, and Lefroy in Tasmania. In Africa, brookite is found in the Bou Azzer District in the Souss-Massa-Draâ region of Morocco, and in the phosphate mines of the Glenover carbonatite deposit at Thabazimbi in South Africa's Limpopo Province.

In the United States, most brookite, including the rare, opaque arkansite variety, is found in the Magnet Cove area of Hot Spring County, Arkansas, notably at Union Carbide's Christy Vanadium Mine, Mo-Ti Corporation's pyrite prospects, Magnet Cove Rutile Company deposits, Kimzey Magnetite Mine, Kilpatrick & Adams Mine, and the Diamond Jo Quarry. Brookite occurs in New Jersey at the Buckwheat Pit in the Franklin Mining District of Sussex County; in New Hampshire at Mine Falls Park at Nashua in Hillsborough County; in Rhode Island at Grants Mills and Poker Hill at Ashton in Cumberland County; in New York at the Ellenville Lead Mine at Ellenville in Ulster County; and in Wisconsin at the Mosinee Hill quarries in the Wausau Pluton in Marathon County. Other sources include the Topeka No. 1, Silver Link, and Grizzly Bear mines in the Ouray District, Ouray County, Colorado; Georgetown in the Georgetown District of El Dorado County, California; the McCoy Mine in the McCoy District, Lander County, Nevada; and the Lugert Granite Quarry at Lugert in Kiowa County, Oklahoma. Brookite is collected in Canada, notably in Québec at Windsor and Sherbrooke, both in Sherbrooke County, and at the Poudrette, Uni-Mix, and Desourdy quarries at Mont Saint-Hilaire in Rouville County.

JEWELRY & DECORATIVE USES

One might expect that with brookite's very high indices of refraction and dispersion (2.583-2.705 and 2.690, respectively, as detailed under *Composition*), it would be a highly desired gemstone. Sadly, these outstanding properties are trumped by its rarity, its only moderate hardness (Mohs 5.5-6.0), and its intense brown-to-reddish-brown colors and partially reflective, submetallic luster that largely mask its desirable optical effects. In lighter color intensities, transparent brookite is occasionally faceted into collector gems of about two carats.

Collector demand for brookite specimens, including individual crystals, crystal clusters, and composite specimens on quartz, has grown considerably with the availability of material from the recent discovery in Khâran, Pakistan. Miniature specimens of well-developed, half-inch-long brookite crystals on quartz matrices sell for several hundred dollars.

HISTORY & LORE

Recognition of the mineral forms of titanium dioxide began with discovery of titanium as an element. In 1791, Church of England clergyman and mineralogist William Gregor (1761-1817) demonstrated that the heavy black sands on the Cornish beaches contained the oxide of an unknown element that he named "mennachanite." Four years later, German chemist Martin Heinrich Klaproth (1743-1817) discovered the same element in rutile, naming it "titanium," after the Titans, Greek mythology's family of giants. Although Gregor is credited with discovering titanium, Klaproth's choice of a name has endured.

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As knowledge of crystallography increased, anatase and rutile were recognized as separate minerals in 1801 and 1803, respectively. A third form of titanium dioxide was identified after British crystallographer and mineralogist Henry James Brook (1771-1857) advanced the study of polymorphs in the early 1820s. Borrowing from Brook's idea that titanium dioxide might occur in a crystal structure completely different from that of rutile or anatase, French mineralogist Armand Lévy identified the third polymorph in 1826, which he named "brookite," in honor of Henry James Brook. The 4.00 franc stamp of Monaco in 1990 featured an illustration of brookite crystals on a quartz matrix.

Modern metaphysical practitioners believe that brookite helps to dispel apathy and lethargy, and aids in dealing with difficult situations. According to one recently released metaphysical guide, brookite, and by complete coincidence, last month's mineral phenakite, are two of the "12 Synergy Stones."

TECHNOLOGICAL USES

Brookite is a minor ore of titanium. The primary titanium ores, rutile [titanium dioxide, TiO_2] and ilmenite [iron titanium oxide, FeTiO_3], are mined from beach-type alluvial deposits. These deposits contain small quantities of both brookite and anatase which are mined and processed as accessory ores. Titanium is a steel-colored metal that, in its pure form, burns in air. After aluminum, iron, and magnesium, it is the fourth most abundant structural metal in the Earth's crust. Although pure titanium is soft and ductile, it produces rigid, high-strength, lightweight structural alloys with very high melting points and excellent corrosion resistance. Titanium is heavily used in aviation; each new jetliner manufactured today contains some 20 tons of titanium alloys. Pure titanium metal is used to make biocompatible medical implants. Because its surface coating of inert titanium dioxide is resistant to attack from bodily fluids, titanium is the standard orthopedic material for replacement joints and for bone plates and screws.

The greatest use for titanium is in the dioxide form. With its chemical inertness, non-toxicity, and excellent "covering" power, titanium dioxide is the preferred white pigment for highway "white-line" paints and for all residential and industrial exterior paints. Large quantities of titanium dioxide are also used to whiten paper, ceramics, ink, and plastics.

Researchers have studied the formation and properties of the titanium dioxide polymorphs rutile, brookite, and anatase from both scientific and industrial perspectives. All three polymorphs are now synthesized in commercial quantities, and each is suited for specific applications. As examples, synthetic-rutile-based paints have a softer white reflectivity that is preferred for indoor use; synthetic-anatase-based paints have a more reflective, bluer color needed for highway and airport-runway uses; while brookite-type oxidation coatings on orthopedic implants provide the greatest levels of biocompatibility and corrosion resistance.

Each year, the world's titanium mines and mills, located mainly in Australia, China, Norway, and the United States, produce about 6.5 million metric tons of ilmenite-rutile-brookite-anatase concentrate from beach-deposit ores. This concentrate, which contains about 85 percent titanium dioxide, is chemically converted first to synthetic-rutile titanium dioxide, then to synthetic-anatase and synthetic-brookite forms as needed. Ilmenite-rutile-brookite-anatase concentrate is now worth about \$480 per metric ton, while one pound of titanium "sponge," the basic, pure form of titanium used for alloying, sells for \$12.

ABOUT OUR SPECIMENS

Our brookite specimens were collected in the Khârân District in the Balochistan province of the Islamic Republic of Pakistan. Pakistan is bordered by India on the east, China to the far northeast, Afghanistan to the north and northwest, Iran to the west, and the Arabian Sea to the south. Pakistan has a population of

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150 million. With an area of 310,000 square miles, it is roughly twice the size of California. The nation consists of four provinces, a capital district, and several federally administered tribal areas. The province of Balochistan is located in western Pakistan and borders Afghanistan and Iran.

In the past, we have always provided precise locations and detailed descriptions of the sources of our minerals. But for reasons that will be explained, we are not able to do so for this month's brookite specimens. The most concise location description available at this time is the Khârân District, which refers to a provincial administration district of 18,552 square miles in far western Pakistan. Specimens obtained from this same source are confusingly labeled as "Khârân Town," "Khârân Mountain," "Khârân Range," and "Khârân Desert."

The Khârân District has a basin-and-range topography with sandy basins that are separated by chains of 4,000-foot-high mountains. Water is scarce, vegetation is sparse, and the climate is marked by seasonal extremes of heat and cold. Poorly mapped and sparsely populated, Khârân, which is roughly the size of New Hampshire and Vermont combined, is one of Pakistan's most dangerous, foreboding, and least developed districts. The entire district has just 50 miles of paved roads, 200 registered motor vehicles, and 700 telephones. Ethnic-separatist groups and tribal chieftains periodically foment violence, while smugglers, refugees, and armed Afghan paramilitary groups freely cross the Khârân-Iran border. Armed robber bands attack truck caravans along the few and poorly maintained roads that cross the border. Taliban military units from Afghanistan take refuge in Khârân's mountains, which may also be serving as a hideout for the elusive Osama bin Laden. Among the Pakistan government's secret and highly sensitive facilities in or near Khârân are the Wazir Khan Khosa and Ros Koh nuclear-weapons test sites and the Sonmiani Sub-Orbital Rocket Range. Large areas adjacent to these sites are restricted and patrolled by the military.

Khârân has never before produced mineral specimens of any kind. Given the safety and security concerns, and with no active mining industry, it is surprising that Khârân is now providing quality brookite specimens. These brookite specimens began reaching western markets in June 2003 and attracted great attention at major shows the following year—mentioned four times so far in the *Mineralogical Record*! Some of these specimens were thin, wedge-terminated blades as long as two inches with excellent transparency and a deep brownish-to-reddish-brown color. They included individual, thumbnail-sized blades, flaring clusters of blades, and miniature- to cabinet-sized specimens of brookite on quartz, which normally sell for very high prices.

The degree of crystal development and mineralogical associations indicate that our brookite specimens were collected from an alpine-cleft deposit. In this usage, the term "alpine" does not refer to elevation, but to the orogenic (related to mountain-building) nature of the deposit. When blocks of solid basement rock are uplifted, stresses sometimes create clefts—also called "tension gashes" and "fissure veins"—within blocks of solid rock that appear as flattened cavities usually no more than 20 feet in length. Hydrothermal fluids of metamorphic origin sometimes mineralize these clefts. Alpine-cleft minerals are always related to the chemistry of the surrounding host rock in which these fluids evolved. Alpine-cleft minerals, which tend to have well-developed crystals, include rutile, brookite, anatase, quartz, epidote [basic calcium aluminum iron silicate, $\text{Ca}_2\text{Al}_2(\text{Fe,Al})\text{Si}_3\text{O}_{12}(\text{OH})$], fluorite [calcium fluoride, CaF_2], hematite [iron (ferric) oxide, Fe_2O_3], fluorapatite [calcium fluorophosphate, $\text{Ca}_5(\text{PO}_4)_3\text{F}$], and titanite [calcium titanium oxysilicate (sphene), CaTiOSiO_4]. Many mineralized alpine-cleft deposits occur in the Himalayas and associated ranges in northern Pakistan (see "The Gemstones and Minerals of Pakistan" on Page 7).

Our Khârân brookite most likely comes from a remote and fairly large alpine-cleft deposit that is exposed on the surface. The miners who collected our specimens probably visit this site infrequently, and they have good reasons for not divulging its location. (continued on Page 8)

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THE GEMSTONES AND MINERALS OF PAKISTAN

Anyone who has attended gem-and-mineral shows or kept up with developments in mineral collecting over the past two decades is aware of the growing numbers of superb mineral crystals coming out of Pakistan. Almost all these specimens come from a relatively small area in northern Pakistan near the borders of Afghanistan and China that includes parts of the North-West Frontier Province and the Gilgit and Skardu districts of the Northern Areas. Although currently administered by Pakistan, the Northern Areas is the subject of a territorial dispute with India.

The mineral richness of northern Pakistan and adjacent areas of Afghanistan is due to the extraordinarily complex geology associated with the convergence of three great mountain systems: the Himalaya, Hindu Kush, and Karakorum ranges. Dramatic uplifting, intensive metamorphism, and repetitive intrusions of magma into the fractured crust have created a remarkable concentration of gemstone and mineral-crystal occurrences. These occurrences are of three basic types: pegmatite, alpine-cleft, and limestone-to-marble metamorphic deposits.

Pegmatites are bodies of very coarse-grained granite that form when residual, intruded magma retains its heat to cool very slowly. Rather than quickly “freezing” into fine-grained granite, residual magma crystallizes on a fractional, or mineral-by-mineral, basis to form pods, lenses, pockets, and irregular dikes. As residual magma, which is often enriched with accessory or rare minerals, slowly solidifies, gases can create vugs, or mariolitic cavities, that provide space for exceptional crystal development. In northern Pakistan, pegmatite pockets yield such gemstones as beryl [beryllium aluminum silicate, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$], topaz [basic aluminum fluorosilicate, $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$], the tourmaline-group minerals elbaite [basic sodium aluminum lithium borosilicate, $\text{Na}(\text{Al}_{1.5}\text{Li}_{1.5})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$] and schorl [basic sodium iron aluminum borosilicate, $\text{NaFe}_3\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$], and the garnet-group minerals spessartine [manganese aluminum silicate, $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$] and almandine [iron aluminum silicate, $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$]. Other collectable minerals from northern Pakistan’s pegmatites are beryllonite [sodium beryllium phosphate, NaBePO_4], fluorite [calcium fluoride, CaF_2], hambergite [basic beryllium borate, $\text{Be}_2\text{BO}_3(\text{OH})$], pollucite [hydrous cesium sodium aluminum silicate, $(\text{Cs},\text{Na})(\text{AlSi}_2\text{O}_6) \cdot n\text{H}_2\text{O}$], and viitaniemiite [sodium calcium manganese aluminum fluorophosphate, $\text{Na}(\text{Ca},\text{Mn})\text{Al}(\text{PO}_4)\text{F}_2(\text{OH})$]. These minerals often form beautiful composite specimens with quartz [silicon dioxide, SiO_2], albite [sodium aluminum silicate, $\text{KAl}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$], and muscovite [basic potassium aluminum silicate, $\text{KAl}_2\text{AlSi}_3\text{O}_{10}$].

Alpine-cleft deposits (explained in “Composition”), the second most prolific source of specimens in northern Pakistan, yield such minerals as rutile [titanium dioxide, TiO_2], titanite [calcium titanium oxysilicate (sphenes), CaTiOSiO_4], zoisite and clinozoisite [polymorphs of basic calcium aluminum silicate, $\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH})$], and scheelite [calcium tungstate, CaWO_4]. The best-known of northern Pakistan’s alpine-cleft minerals is epidote [basic calcium aluminum iron silicate, $\text{Ca}_2\text{Al}_2(\text{Fe},\text{Al})\text{Si}_3\text{O}_{12}(\text{OH})$], which is considered by many to be the world’s finest. Of course, the epidote from Peru we featured in 1997 and again in June 2007 comes a very close second.

Northern Pakistan’s **limestone-to-marble metamorphic deposits**, created when limestone undergoes intensive regional and contact metamorphism, are a fine environment for gem-quality ruby and bluish-to-purple sapphire [both varieties of corundum, aluminum oxide, Al_2O_3]; blue, purple, and red spinel [magnesium aluminum oxide, MgAl_2O_4]; and emerald-green pargasite [basic sodium calcium magnesium aluminum silicate, $\text{NaCa}_2(\text{Mg}_4\text{Al})\text{Si}_6\text{Al}_2\text{O}_{22}(\text{OH})_2$].

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These deposits have provided gemstones to the nomadic kings of central Asia and the maharajahs of the Indian subcontinent for more than 1,000 years. But when the British partitioned the Indian subcontinent in 1947 to create Pakistan, gemstone mining nearly stopped. While the existence of these ancient gemstone deposits was well-known, the new government, facing poverty, ethnic-separatist strife, and territorial disputes with neighboring India, had no resources to direct to gemstone-mining development. Interest in gemstones revived in the 1970s with the Soviet military intervention in neighboring Afghanistan, when thousands of Afghan refugees, including many experienced gemstone miners, began arriving in northern Pakistan. Also, growing numbers of smuggled Afghani gemstones helped to revive the Pakistani gemstone markets.

Small numbers of Pakistani gemstones and mineral crystals, comparable in quality to the best Brazilian pegmatite specimens, began reaching western markets in the late 1970s. But because mining was conducted only by independent, artisan miners working with very limited resources in difficult mountain conditions, production remained somewhat sporadic. The gemstones and mineral specimens from dozens of small mines and diggings were smuggled to foreign cutters and dealers, resulting in little economic benefit for Pakistan.

Now the Pakistani government is taking steps to develop its gemstone industry. The Gem and Gemological Institute of Pakistan, established in 2001, is training 1,000 students in gemology and lapidary techniques. Pakistan is also promoting mining education and working to attract domestic and foreign investment to upgrade both mineral exploration and mining operations. Mine production is already increasing and new domestic cutting and marketing operations are making Pakistani gemstones and mineral specimens more readily available and affordable on world markets. Modern exploration is still needed to reveal the true extent of Pakistan's gemstone deposits. But based on recent discoveries of new deposits and increasing production, Pakistan is about to take its place among the world's leading sources of gemstones and fine mineral specimens.

(Continued from Page 6) With no way to protect the site in their absence, they could be concerned with rival mining groups. Or if the deposit is located in a restricted area, revealing its location could be incriminating. Some dealers suggest that the site is near Taftan, a small town on the Iranian border, while others point to the restricted Ros Koh nuclear-testing area.

Our brookite specimens represent the first mineral specimens ever to have come out of the Khârân District, which is about 800 miles to the southwest of Pakistan's major gemstone and mineral-crystal mining areas. While we do not know the exact location of the source of our brookite specimens, we do know that they represent an exciting new find in a part of Pakistan not previously known for mineral specimens. And with their sharp crystal forms and attractive association with quartz, we are delighted to be able to add such a high quality specimen of this rare mineral to our collection!

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