

March 2010 Mineral of the Month: Orthoclase

This month we are featuring the abundant feldspar mineral orthoclase in an unusual form—as Carlsbad-law twinned crystals from a classic collecting site in the Mojave Desert of southern California. Our write-up describes the various forms of orthoclase and explains the genesis and types of twinned crystals.

OVERVIEW

PHYSICAL PROPERTIES

Chemistry: KAlSi_3O_8 Potassium Aluminum Silicate (Potassium Aluminosilicate), usually containing some sodium

Class: Silicates

Subclass: Feldspars

Group: Alkali Feldspars (K-Feldspars, Potassium Feldspars, Potash Feldspars)

Crystal System: Monoclinic

Crystal Habits: Usually as short, prismatic crystals with square or rectangular cross sections; sometimes tabular; twinning common.

Color: White, colorless, brown, gray, green, pink, champagne, and yellowish

Luster: Vitreous

Transparency: Usually transparent to translucent, occasionally opaque

Streak: White

Cleavage: Good in two directions at a right angle

Fracture: Uneven

Hardness: 6.0

Specific Gravity: 2.5-2.6

Luminescence: Non-fluorescent; weakly thermoluminescent

Refractive Index: 1.518-1.524

Distinctive Features and Tests: No other similar silicate minerals exhibit right-angle cleavage; twinned crystals common. Unlike the plagioclase feldspars, orthoclase does not show twinning striations on fresh cleavage surfaces. Laboratory analysis is often necessary to distinguish orthoclase from other feldspar minerals.

Dana Classification Number: 76.1.1.1.1

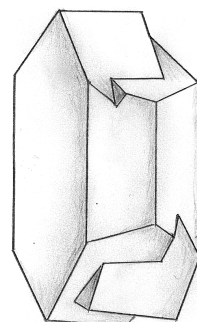


Figure 1. Twinned orthoclase crystals exhibiting Carlsbad twinning.

NAME Pronounced OR-tho-claze, this month's mineral takes its name from the Greek *orthos*, "upright," and *klasis*, "breaking," alluding to its prominent, right-angle cleavage. Orthoclase has also been known as "orthose," "argillite," "murchisonsite," "potassium feldspar," "K-feldspar," "potash feldspar," and "common feldspar." In European mineralogical literature, orthoclase appears as *ortoclase*, *ortoklas*, and *ortoclasio*. An iron-rich variety is called "ferruginous orthoclase." "Moonstone" is an adularescent (exhibiting an internal sheen) gemstone variety of orthoclase.

COMPOSITION: The chemical formula of orthoclase, KAlSi_3O_8 , shows that it contains the elements potassium (K), aluminum (Al), silicon (Si), and oxygen (O). The molecular weight of orthoclase consists of 14.05 percent potassium, 9.69 percent aluminum, 30.27 percent silicon, and 45.99 percent oxygen. Orthoclase is a member of the feldspar subclass, a group of abundant, tectosilicate minerals that make up 60 percent of the Earth's crust. Orthoclase is classified as an alkali feldspar, a sub-group of aluminosilicates that contains the alkali metals potassium and/or sodium. The feldspars are important rock-forming minerals and orthoclase is an essential component of all granitic rocks, as well as many volcanic and metamorphic rocks. As an allochromatic (other-colored) mineral, orthoclase colors are caused by traces of non-essential elements. Pure orthoclase is colorless or white, but traces of iron and other accessory elements produce soft colors ranging from brown and gray to green, yellow, and pink.

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Orthoclase commonly forms twinned crystals, with two or more individual crystals growing together in different orientations from a common plane according to rules of symmetry called “twinning laws.” Our specimens exhibit “Rotation twinning” and are called “Carlsbad twins”—you will have to read the comprehensive part of the write-up for descriptions of these!

COLLECTING LOCALITIES: Orthoclase is an abundant mineral found worldwide in many localities. In the United States, notable orthoclase sources are found in California, Nevada, Idaho, Colorado, Arkansas, Virginia, Maine, and New Mexico. Important foreign sources occur in Italy, the Czech Republic, Germany, Finland, Poland, Spain, Switzerland, Northern Ireland, England, Russia, Bolivia, Brazil, Mexico, and Japan.

HISTORY, LORE, & USES: Orthoclase and other feldspar minerals have been mined since the time of the Romans, initially for use in glassmaking. Transparent, champagne- and yellowish-colored orthoclase crystals are cut into attractive gems for both collector specimens and jewelry purposes. Moonstone, a milky, adularescent gemstone with a moon-like, internal sheen, is a layered intergrowth of orthoclase and the feldspar mineral albite. During medieval times, Europeans believed that moonstone protected women during pregnancy and childbirth, aided the digestive system, and guarded against obesity. Hindus attributed moonstone’s shifting, adularescent reflection to a spirit that lived within the stone and brought good fortune. Modern metaphysical practitioners believe that moonstone enhances passion, sensitivity, intuition, and general physical abilities, while bringing good fortune to its wearer. Non-gem orthoclase crystals are said to strengthen the heart. Today, 18 million metric tons of feldspar worth \$1 billion are mined worldwide each year. The United States mines about 750,000 metric tons each year in seven states. Most feldspar is used in powdered form to manufacture glass, ceramics, and glazes. Feldspar is also used in tiles, china, and oven ware, and in the fillers and extenders that are employed in the manufacture of paper, glossy cardboards, paints, plastics, and synthetic rubber.

ABOUT OUR SPECIMENS: Our specimens of twinned orthoclase were collected at Water Canyon, west of Cinco, an unincorporated highway stop in east-central Kern County, California. This popular collecting site is 20 road miles north of the city of Mojave. Water Canyon is part of the topography of the El Paso Mountains, which are the southern terminus of the Sierra Nevada range. The Cinco orthoclase site was discovered in 1908 by workers constructing the Owens Valley Aqueduct, a project to divert water from the Owens River to the Los Angeles area. The collecting site is a barren hill consisting of outcrops of the igneous rocks monzonite and grandiorite of the Sierra Nevada Batholith. This host rock has been intruded by rhyolite dikes containing large, well-developed, orthoclase phenocrysts (large crystals set in a fine-grained groundmass) from 0.3 inches to 3.0 inches in length. All our specimens are twinned, according to the Carlsbad law. Carlsbad twins are growth-penetration-type, rotation-twinned crystals, consisting of two parallel, individual, penetrating crystals that appear offset 180° from a common mirror plane, as illustrated in the drawing in Figure 1.

10 YEARS AGO IN OUR CLUB: Vesuvianite, Jeffrey Mine, Asbestos, Quebec, Canada. These were small but lovely specimens! This is another minerals we fell in love with as a result of featuring. The mine has been closed for some years now, so nice specimens are becoming rarer and dearer. We found an exceptional lot in Tucson this year, and snapped it up with a view to featuring it again. We seriously thought about doing it this month in honor of its 10-year anniversary as a featured mineral—our hearts wanted to, but our heads knew there was no way we could pull it off. So we’ll wait until later in the year, or perhaps hold them until March 2011. Here’s part of a quote from Joel Arem from the 1973 *Mineralogical Record*: “[Vesuvianite] is one of the most exhaustively studied, yet least understood, of all minerals . . . These uncertainties are still further complicated by the diverse range of conditions in which the mineral forms in nature . . . Even the name of the mineral is debated.” We can hardly wait to feature it again, and see if any of these questions have been answered satisfyingly!

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COMPREHENSIVE WRITE-UP

COMPOSITION

Though feldspar makes up such a major part of the earth's crust, we have featured only two feldspar group minerals so far—labradorite, in April 1997, and microcline, variety amazonite, in March 2007. Labradorite has since been discredited as an approved mineral species, so does that mean we have featured only one? Bring in the mineralogical philosophers to answer that question, related to the one about the tree falling in the forest and sound-making. Either way we would like to feature labradorite again!

So it goes without saying we are especially pleased to be featuring orthoclase, which, as shown by its chemical formula KAlSi_3O_8 , contains the elements potassium (K), aluminum (Al), silicon (Si), and oxygen (O). The molecular weight of microcline is made up of 14.05 percent potassium, 9.69 percent aluminum, 30.27 percent silicon, and 45.99 percent oxygen. As in all molecules, molecular stability in orthoclase requires an electrical balance between cations (positively charged ions) and anions (negatively charged ions). Orthoclase has a double cation consisting of one potassium ion (K^{1+}) and one aluminum ion (Al^{3+}) with a collective cationic charge of +4. The orthoclase anion is the silicate radical $(\text{Si}_3\text{O}_8)^{4-}$. Radicals are groups of two or more elements that act as a single chemical entity in chemical reactions. The $(\text{Si}_3\text{O}_8)^{4-}$ radical consists of three silicon ions (3Si^{4+}) and eight oxygen ions (8O^{2-}) with a collective anionic charge of -4. The -4 anionic charge balances the +4 cationic charge to provide the orthoclase molecule with electrical stability.

As a silicate, orthoclase is a member of the largest class of minerals. Silicates are built around the silica tetrahedron $(\text{SiO}_4)^{4-}$, in which a silicon ion is surrounded by, and covalently bonded to, four equally spaced oxygen ions. Silicate minerals fall into seven groups, according to the type of atomic bonding that links the tetrahedra together. Orthoclase is a framework silicate, or tectosilicate. In framework silicates, each tetrahedron shares all four of its oxygen ions with adjacent tetrahedra to form framework structures that extend indefinitely in three dimensions. Framework silicates are numerous because silicon is not the only ion that is stable within the silica tetrahedron. The aluminum ion Al^{3+} is also stable and can replace silicon ions. When an aluminum ion (Al^{3+}) replaces a silicon ion (Si^{4+}) within a tetrahedron, it creates a negative electrical charge. To reestablish electrical stability, the resulting aluminosilicate radical $(\text{AlSi}_3\text{O}_8)^{1-}$ must accept another positively charged ion. Positively charged ions with suitable radii to fit between the tetrahedra include potassium (K^{1+}), sodium (Na^{1+}), and calcium (Ca^{2+}). In framework silicates, the partial replacement of silicon ions by aluminum ions and the subsequent ionic bonding to potassium, sodium, or calcium ions create the feldspar mineral sub-class.

Feldspars are a group of closely related, abundant tectosilicate minerals that make up about 60 percent of the Earth's crust. The name "feldspar" derives from the German *Feld*, or "field," and the obsolete German *Spath* (later "spar"), referring to any cleavable, lustrous mineral. The literal translation of "feld spar"—"field stone"—alludes to the tendency of feldspars to weather into soil-building clays. The feldspars fall into two primary groups: **alkali feldspars** and **plagioclase feldspars**. The alkali feldspars, named for the content of the alkali metals potassium and/or sodium, have the same or similar chemical compositions, but their crystal structures vary with the temperatures at which they formed. The important alkali feldspars, along with their chemistries and crystal structures, are:

Anorthoclase	$(\text{Na,K})\text{AlSi}_3\text{O}_8$	Sodium potassium aluminum silicate	Triclinic
Sanidine	$(\text{K,Na})\text{AlSi}_3\text{O}_8$	Potassium sodium aluminum silicate	Monoclinic
Orthoclase	KAlSi_3O_8	Potassium aluminum silicate	Monoclinic
Microcline	KAlSi_3O_8	Potassium aluminum silicate	Triclinic

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It is easy to note the similarities in the chemical make-up of the group members. The different crystal structures among the alkali feldspars reflect the degree of ordering of the aluminum-ion and silicon-ion tetrahedral sites within their crystal lattices. Sanidine and anorthoclase, which crystallize at high temperatures and cool rapidly, have disordered structures with near-random placement of aluminum and silicon ions. Orthoclase, which crystallizes at intermediate temperatures and cools slowly, has a partially ordered structure. Microcline, which crystallizes at low temperatures and cools very slowly, has a perfectly ordered structure with aluminum and silicon ions occupying regular lattice positions. Orthoclase and microcline are polymorphic, which means they have identical chemistries, but different crystal structures. The plagioclase feldspars, named from the Greek *plagios*, “oblique,” and *klasis*, “breaking,” referring to their non-right-angle cleavage, include albite [sodium aluminum silicate, $\text{NaAlSi}_3\text{O}_8$] and anorthite [calcium aluminum silicate, $\text{CaAl}_2\text{Si}_2\text{O}_8$]. Labradorite, prior to its demotion, was considered an end-member of the plagioclase series—now it is defined as a variety of anorthite that consists of 50 to 70% anorthite. One might add the detail that it has a characteristic iridescent sheen not seen in any other mineral. The name comes from Paul’s Island, near Nain, Labrador, Canada, where it was first described.

In the orthoclase molecule, potassium ions occupy spaces between the aluminosilica tetrahedra. This creates a three-dimensional structure with omnidirectional bonding that provides orthoclase with an uneven fracture, while two planes of predominant weak ionic bonding account for its good, two-directional cleavage. The considerable hardness of Mohs 6.0 is due to the strong, oxygen-oxygen covalent bonding that dominates within the lattice. Orthoclase’s relatively low specific gravity of 2.5-2.6 (less than that of quartz) is due to loose atomic packing and subsequently large inter-tetrahedra spacing. Orthoclase crystallizes in the monoclinic system, which is characterized by three axes of unequal lengths. Two axes align in a plane and intersect at a right angle; the third axis intersects the plane of the other two at an inclined angle. Twinning, which occurs when two individual crystals grow in different directions from a common plane, is common in orthoclase and follows three twinning laws—Carlsbad, Baveno, and Manebach (see “The Twinning of Mineral Crystals”).

As an allochromatic (other-colored) mineral, orthoclase colors are created not by inherent chemical or physical properties, but by traces of non-essential elements. Pure orthoclase is colorless or white, but traces of such chromophoric elements as iron produce a range of soft colors from brown and gray to green, yellow, and pink. Higher iron levels create the more intense, yellow-brown colors of ferruginous (iron-rich) orthoclase.

Orthoclase and other alkali feldspars are important rock-forming minerals in many igneous intrusive, volcanic, and metamorphic rocks. Orthoclase is a major, essential component of all granites, in which its distinctive square or rectangular cross-sectioned phenocrysts (prominent, large crystals embedded in a fine-grained groundmass) contribute greatly to color and texture. Orthoclase also occurs in granite pegmatites and such other igneous intrusive rocks as syenite, nepheline syenite, monzonite, and grandiorite. Orthoclase is an essential component of the high-silica volcanic rocks rhyolite and trachyte, and the metamorphic rock gneiss. Orthoclase is everywhere! In shallow environments in contact with groundwater and atmospheric oxygen, orthoclase will eventually weather or alter into the clay mineral kaolinite [basic aluminum silicate, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$], a major component of most soils.

The Dana mineral-classification number 76.1.1.1 identifies orthoclase as a tectosilicate with an aluminum-silicon framework structure (76); the subclassification defines it as an alkali feldspar (1). Orthoclase then falls into the orthoclase group (1) as the first (1) of eight members. Other important orthoclase-group members include microcline [potassium aluminum silicate, KAlSi_3O_8], sanidine [potassium sodium aluminum silicate, $(\text{K},\text{Na})\text{AlSi}_3\text{O}_8$], hyalophane [potassium barium aluminum silicate, $(\text{K},\text{Ba})\text{AlSi}_3\text{O}_8$], celsian [barium aluminum silicate, $\text{BaAl}_2\text{Si}_2\text{O}_8$], and anorthoclase [sodium potassium aluminum silicate, $(\text{Na},\text{K})\text{AlSi}_3\text{O}_8$].

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COLLECTING LOCALITIES

Because orthoclase is abundant and occurs worldwide, we can list only those localities known for particularly well-developed or unusual specimens. Our specimens of twinned orthoclase were collected at Water Canyon, near Cinco in Kern County, California. Other California orthoclase localities include the mines near Bodie and the Champion Mine near Laws, both in the White Mountains of Mono County.

Among other notable orthoclase localities in the United States are the Goodsprings Quarry at Goodsprings, Clark County, Nevada; the Silver City mines in Owyhee County, Idaho; granite outcrops in the Climax District near Leadville, Lake County, Colorado; the Flambeau Quarry near Ladysmith, Rusk County, Wisconsin; the Diamond Jo and Blanche quarries at Wilson Springs, Garland County, Arkansas; the Champion and Jefferson mines at Amelia Court House, Amelia County, Virginia; and numerous pegmatite quarries near Newry and Paris, Oxford County, Maine. New Mexico's orthoclase sites include Embudo Canyon in the Sandia Mountains, Bernalillo County; the Chino copper mine in the Santa Rita district, Grant County; and the Organ district mines in the Organ Mountains of Doña Ana County.

European localities include the Seula Mine at Mount Carnoscio near Baveno, Verbano-Cusio-Ossola Province, Piemonte, and quarries on the island of Elbe, Livorno Province, both in Italy; the Karlovy Vary (Carlsbad) region, Bohemia, Czech Republic; the Meyersgrund deposit at Manebach in the Thuringian Forest, Thuringia, Germany; the Viitaniemi pegmatite at Eräjärvi, Etelä-Soumen, Lääni, Finland; the Sowie Mountain pegmatites at Bogatyn, Lower Silesia, Poland; the Santa Cecilia Mine at Guadalajara, Castile-La Mancha, Spain; Narèt in the Lavizzara Valley, Tessin, Switzerland; the Diamond Rocks area in the Mourne Mountains, County Down, Northern Ireland; and Heavitree near Exeter in Devon, and Shap near Westmoreland in Cornwall, both in England. Russian sites include Mount Puiva, Saranpaul, Tyumenskaya Oblast', Urals Region, and Mount Khibinpakchorr in the Khibiny Massif on the Kola Peninsula, Mumansk Oblast', Northern Region.

Other orthoclase localities are Ancohuma Peak in the Illampú Massif, Larecaja Province, La Paz Department, Bolivia; the Jaguaraçu pegmatite at Jaguaraçu, Minas Gerais, Brazil; the Chuqui Mine at Laguna Hansen, Tecate, California Baja Norte, Mexico; and the Tanokamiyama pegmatite at Otsu, Shiga Prefecture, in the Kinki Region of Honshu Island, Japan.

JEWELRY & DECORATIVE USES

Despite its relative softness of Mohs 6.0 (softer than quartz), orthoclase has two important gem forms. Transparent crystals are cut into attractive gems for both collector specimens and jewelry use. Usually weighing between 5 and 20 carats, these gems have a champagne color similar to that of citrine quartz or yellow beryl. Orthoclase gems, which are usually cut as ovals to best utilize the prismatic crystal shape, are both eye-catching and affordable, with six-carat gems available for about \$100. Another popular orthoclase gemstone is moonstone, a lamellar (layered) intergrowth of orthoclase and the plagioclase-feldspar mineral albite [$\text{NaAlSi}_3\text{O}_8$]. Moonstone is translucent to semi-transparent; its color can be milky shades of whitish-blue, yellow, peach, brown, or gray. The intergrowth of albite within the translucent orthoclase reflects light in a moving sheen called adularescence. Moonstone, which is cut as cabochons to best display its adularescence, reached its peak of popularity in jewelry during the Art Nouveau period a century ago. Mounted in silver, moonstone gems are usually worn as pendants, earrings, and brooches.

Well-developed orthoclase crystals, especially as Carlsbad, Baveno, and Manebach twins, and as both individual and composite specimens, are sought after by mineral collectors for both display and study purposes. In testimony to the popularity of twinned mineral crystals among mineral collectors, twins were selected as the theme of the prestigious Munich (Germany) gem and mineral show in 1999.

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HISTORY & LORE

Archaeologists have recovered orthoclase beads and carved objects dating to 2000 B.C. from tombs in Egypt, the Middle East, and central Russia. Although feldspars were recognized as a general mineral group in 1790, individual species remained confused until 1823, when German mineralogist and geologist Johann Friedrich August Breithaupt (1791-1873) employed new concepts of crystallography to differentiate orthoclase from microcline. The name “orthoclase” was assigned to the monoclinic alkali-feldspar polymorph in 1849. In 1866, orthoclase attracted much scientific attention when German mineralogist and petrologist Ferdinand Zirkel (1838-1912) devised an igneous-rock classification system based on the content and structure of orthoclase. A complete understanding of the orthoclase crystal structure came in 1920 with the use of newly introduced X-ray diffraction techniques.

Metaphysical lore has long focused on the moonstone variety of orthoclase. The Romans believed that moonstone consisted of trapped moonlight. During medieval times, Europeans believed that moonstone protected women during pregnancy and childbirth, aided the digestive system, and guarded against obesity. Hindus attributed moonstone’s shifting, adularescent reflection to a spirit living within the stone who brought good fortune. Even today, many Hindus consider moonstone to be a “dream stone” that facilitates beautiful dreams. According to modern metaphysical practitioners, moonstone enhances passion, sensitivity, intuition, and general physical ability, while non-gem orthoclase strengthen the heart.

Moonstone is Florida’s official state gem and the alternate birthstone for the month of June. Several types and varieties of feldspar minerals have appeared on postal stamps. Orthoclase was featured on the 42-pence stamp of the Bailiwick of Jersey (a British Crown Dependency) in 2007.

TECHNOLOGICAL USES

Feldspar minerals, primarily orthoclase and microcline, have been mined since Roman times, initially for use in glassmaking. Today, two-thirds of all mined feldspar is used in powdered form to manufacture glass, ceramics, and glazes, both as a source of silica and as a flux to lower the melting point of glass and glaze mixes. Feldspars also go into the manufacture of tiles, china, oven ware, and the fillers and extenders used in paper, glossy cardboards, paints, plastics, and synthetic rubber. Powdered feldspar is the abrasive agent in household scouring powders. Because its hardness of Mohs 6.0 is slightly less than that of many specialty glasses, feldspar-based scouring powders clean, but do not abrade glass surfaces. Mineral-resource statistics do not differentiate between individual feldspar species, but orthoclase, because of its inherent abundance, is believed to be the dominant type. World feldspar production stands at 18 million metric tons worth \$1 billion. Leading producers are Italy, Turkey, and China. The United States mines 750,000 metric tons of feldspar annually. Crude feldspar is worth about \$60 per ton; refined, powdered feldspar for glassmaking use costs about \$300 per ton.

The mineralogical understanding of twinning phenomena has been practically applied to many scientific disciplines, notably metallurgy and chemistry. Geophysicists also use natural orthoclase in geological and archaeological dating techniques. When buried and exposed to natural geophysical radioactivity, certain electrons within the orthoclase lattice are boosted to higher energy levels and become trapped in these new orbital positions for hundreds of thousands of years. Measuring these boosted energy levels can often indicate the length of time that such materials as man-made ceramics and natural lava and sediments have been buried. After excavation, the added electron energy is determined by measuring optical luminescence and thermoluminescence, thus providing an estimate of the duration of burial time. Geologists and archaeologists now use optical and thermoluminescent techniques to date the burial of orthoclase-containing materials from several hundred years to more than 100,000 years within an accuracy of five percent.

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THE TWINNING OF MINERAL CRYSTALS

Our orthoclase specimens are examples of twinned crystals, one of the most interesting and intriguing of all crystal forms. Before discussing twinned crystals and our twinned orthoclase specimens in depth, it is important to first understand the crystal arrangements that do not constitute twinning. Twinned crystals are not to be confused with common crystal clusters or pairs, in which closely associated, single crystals exhibit a random alignment of crystallographic axes resulting from coincidental growth—and which to the inexperienced eye may appear to be twins. Accidental crystallographic relationships such as two single crystals grown randomly side-by-side are not twins, nor are epitaxial overgrowths that occur when a different mineral grows onto and continues the original mineral's crystal structure. The terms “single” or “single crystal” refer to specifically to untwinned crystals.

Twinned crystals, on the other hand, are defined as rational, symmetrical intergrowths of two or more individual crystals of the same mineral species. In crystallography, the term “rational” means that twins share common lines, planes, or points; “symmetrical” means that the twinned crystals are related by definite rules of crystallographic symmetry. Crystallographers define “symmetry” as the correspondence of size, shape, and position of parts on opposite sides of a dividing line or median plane or about an axial center. The crystallographic term “individual” or “component” refers to one crystal unit of a twinned-crystal arrangement.

Twinned crystals form from errors or interruptions in the normal sequence of crystal growth. Crystals grow by adding layers of atoms or molecules in orderly, repetitive sequences so that each subsequent layer replicates the structure of the previous layer. As an example, in the three sequential crystal layers A, B, and C, the normal layering sequence is:

ABCABCABCABC

This normal growth results in single crystals. But when environmental conditions change during the layering sequence, usually through variations in temperature, pressure, chemistry, or mechanical stress, this layering sequence can be disrupted and altered, as in the sequence:

ABCABCACBACBA

In this example, a C layer rather than a B layer follows an A layer. The layering then continues in both the ABC and the CBA sequences, with the crystal developing along two directions until its growth is completed. Directly through the middle A layer, a mirror plane is produced and the left and right sides of the crystal develop as mirror images of each other. This mirror effect becomes clear if we replace the middle A with a vertical dividing line, as in:

ABCABC / CBACBA

The development of twinned crystals is strictly ordered and follows sets of well-defined rules called “twinning laws.” Among the more common of the many twinning laws are the Carlsbad law, Baveno law, Manebach law, Dauphin law, Japan law (we featured Japan-law twinned quartz crystals in September 2004), spinel law, and albite law. Each twinning law produces uniquely structured twin crystals and specifies the type and orientation of the median or mirror plane, as well as the type of symmetry operation.

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In the mineralogical context of twinning, "symmetry operation" refers to the mathematical process from which one form derives from another. Major types of symmetry operation include: (1) reflection across a common mirror plane; (2) rotation about a common axis; and (3) inversion through a common point.

Twinned crystals are categorized by both structure and nature of origin. Structurally, most twinned crystals fall into two broad categories: **contact twins** and **penetration twins**. **Contact twins** are characterized by a planar composition surface between two individual crystals. Contact twins can also occur as repeated or multiple twins. If the multiple compositional surfaces are parallel, they are called polysynthetic twins; if the multiple compositional surfaces are not parallel, they are known as cyclical twins. **Penetration twins**, unlike contact twins, exhibit irregular composition surfaces.

When categorized by origin, twins can be **growth twins**, **transformation twins**, or **deformation twins**. **Growth twins**, or primary twins, develop when errors in crystal growth cause a new crystal to develop from the face of an existing crystal. The new crystal shares common lattice points (thus qualifying as twins), but has a different orientation. **Transformation twins** develop when crystal growth is altered by changes in temperature or pressure, and usually involves minerals that have different structures (and thus symmetries) at different temperatures and pressures. **Deformation twins** form when mechanical stresses shift atoms from normal positions to new positions within the lattice structure.

Twinning can be a diagnostic feature in mineral identification. While some twins are immediately identifiable by their outward appearance, others are not and can be distinguished only by optical measurement. Twins can be recognized by opposing orientations of their component crystals, penetration angles, or notches in the edges of crystal faces. Twinning can dramatically change outward crystal symmetry by greatly increasing or decreasing the symmetry of a single crystal of the same species. As an example, twinned orthorhombic crystals can appear to be hexagonal, and twinned trigonal crystals can appear monoclinic.

Twinning occurs in many minerals, and is especially common in quartz [SiO₂], pyrite [FeS₂], chalcopyrite [CuFeS₂], fluorite [CaF₂], stibnite [Sb₂S₃], diamond [C], galena [PbS], spinel [MgAl₂O₄], chrysoberyl [BeAl₂O₄], and gypsum [CaSO₄·2H₂O]. It is also the cause of the familiar "cross" crystals of staurolite [(Fe,Mg,Zn)₃₋₄(Al,Fe)₁₈(Si,Al)₈O₄₈H₂₋₄].

The twinning phenomenon is especially common in the feldspar-group minerals (see "Composition"). All alkali feldspars, including orthoclase, anorthoclase, sanidine, and microcline, along with the plagioclase feldspars albite and anorthite and their solid-solution-series intermediate members, form either Carlsbad-law, Baveno-law, Manebach-law, or albite-law twins. Some feldspar species form all four twin-law crystals. These twinning laws are named after localities or minerals where, or in which, they were first observed. The Carlsbad law is named for the Karlovy Vary (Carlsbad) region in the Czech Republic; the Baveno law for Baveno in Piemonte, Italy; the Manebach law for Manebach in Thuringia, Germany; and the albite law for the mineral albite.

ABOUT OUR SPECIMENS

Our specimens of twinned orthoclase were collected at Water Canyon, three miles west of the unincorporated Cinco highway stop in Kern County, California. This popular collecting site is located in east-central Kern County, 20 road miles north of the city of Mojave. Cinco is 16 miles north of Mojave on California Route 14. A half-mile north of Cinco, a graded gravel road suitable for highway vehicles turns

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left (west) and proceeds 3.3 miles (follow the right-hand forks) to the site. The site elevation is about 2,800 feet, roughly 600 feet higher than Cinco. The collecting site is a low hill one-half mile north of the road and accessed by a well-traveled foot trail.

North of Mojave, California Route 14 crosses an arid, alluvial plain covered with creosote bushes and Joshua trees at the western edge of the Mojave Desert. West of the highway are the low ridges of the El Paso Mountains, the southern terminus of the Sierra Nevada range. The local country rock consists of monzonite and grandiorite that make up much of the Sierra Nevada Batholith. Batholiths are massive bodies of igneous rock that were intruded at depth and sometimes later exposed by surface erosion. The Sierra Nevada Batholith consists of numerous, smaller igneous intrusions called plutons which were emplaced between 115 million and 90 million years ago. Perhaps 20 million years ago, the Sierra Nevada Batholith hosted extensive volcanic activity, with rhyolitic magma rising upward through faults and fractures. Finally, some four million years ago, crustal stresses generated by tectonic plate collisions to the west uplifted the modern Sierra Nevada range. Erosion has since exposed parts of the Sierra Nevada Batholith and its associated volcanics. Monzonite and grandiorite are physically and chemically similar to granite, being medium- to coarse-grained, but are darker in color and contain somewhat less silica. Orthoclase is an essential mineral in both monzonite and grandiorite, as well as in the fine-grained, extrusive igneous (volcanic) rock rhyolite.

Cinco was founded as a way station on the Owenyo Branch of the Southern Pacific Railroad that linked the Owens Valley with Mojave. When construction of the Owens Valley Aqueduct, which diverted water from the Owens River to Los Angeles, began in 1905, Cinco, near the aqueduct route, grew rapidly and, by 1908, had become a boisterous boomtown with a population of 1,000. But Cinco's heyday was brief; the town faded away after the aqueduct was completed in 1913. The road west of Cinco, known locally as "Aqueduct Road," is now used to reach the orthoclase collecting site.

Aqueduct workers discovered the twinned orthoclase crystals near Cinco in 1908 and collected them as souvenirs. The aqueduct project also stimulated geological study. California state geologists published the first local survey in 1912. By 1928, after descriptions of the twinned orthoclase specimens had been published in technical journals, California mineral collectors began frequenting the site, while many museums and universities across the nation began obtaining specimens for their collections. Cinco, now a classic locality for orthoclase Carlsbad twins, remains a popular collecting site.

The collecting site is a barren hill consisting of weathered monzonite-grandiorite of the Sierra Nevada Batholith. This host rock is intruded by groups of rhyolite dikes from 8 to 10 feet thick, which sometimes contain large, well-developed orthoclase phenocrysts from 0.3 inches to nearly 3.0 inches in length. These phenocrysts occur in a fine-grained, rhyolitic groundmass consisting largely of orthoclase, plagioclase feldspars, quartz, and biotite-group minerals (dark iron-rich micas). Most of the phenocrysts are twinned. Both the rhyolitic dikes and the monzonite-grandiorite host rock are extensively weathered. Today, collectors use rock picks, chisels, and small pry bars to free the orthoclase crystals from the crumbly rhyolite. Various stages of weathering can be observed in both the rhyolite and the orthoclase. The rhyolite crumbles readily and many orthoclase phenocrysts have partially altered into the clay mineral kaolinite [basic aluminum silicate, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$], which is somewhat lighter in color than orthoclase, much softer at Mohs 2.0-2.5, and has a chalky texture. Some of our specimens are actually pseudomorphs of kaolinite-after-orthoclase, in which the kaolinite retains the outer shape of the original orthoclase crystal. Another interesting mineral in our specimens is quartz, occurring as colorless, bipyramidal phenocrysts within the rhyolitic groundmass. Although only rice-grain-sized, these are well-developed, doubly terminated crystals with little prism length separating the terminations. Examine the matrix of your specimen for such quartz crystals. (Silver-level members received loose crystals, extracted without matrix.) Our specimens were gathered by commercial specimen collectors with the equipment, personnel, and experience necessary to

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extract and clean the twinned orthoclase phenocrysts without damaging the specimens, obtaining the large number of specimens that we require for our many club members.

Our specimens consist of large, cream-colored, orthoclase phenocrysts in a matrix of fine-grained, brown rhyolite. Rhyolite from most other localities is a uniformly fine-grained rock. The presence of large phenocrysts in our specimens indicates that the rhyolitic magma cooled very slowly. Rapid cooling or “freezing” of magma creates fine-grained igneous rocks, but very slow cooling provides time for some of the magmatic components to crystallize on a mineral-by-mineral basis with excellent crystal development. When rhyolitic magma intruded the host rock at Cinco, existing conditions enabled the orthoclase component to crystallize first in large well-developed phenocrysts. The remaining magma then crystallized relatively quickly into a fine-grained groundmass in which the orthoclase phenocrysts were embedded. Our specimens also show varying degrees of weathering, which is particularly evident in the orthoclase itself. Orthoclase normally has a distinct, vitreous luster. In some of our specimens, surface weathering of the orthoclase into kaolinite has replaced the vitreous luster with a dull, earthy, surface texture. A knife blade will not scratch orthoclase, but will scratch kaolinite--not that we recommend scratching your piece.

Orthoclase often forms twinned crystals according to the Carlsbad, Baveno, or Manebach laws (see “The Twinning of Mineral Crystals”). All our specimens are twinned according to the Carlsbad law, which describes a type of penetration-growth-type twinned crystals. In our twinned crystals, the penetration-type intergrowth is apparent as one individual crystal appears to penetrate the second individual. Growth twins, or primary twins, develop when errors in crystal growth cause a new crystal to develop from the face of an existing crystal. The new crystal shares common lattice points, but has a different orientation. The best way to observe twinning features is to view the crystals longitudinally, that is, from the top down through the prismatic length of the crystal. In Carlsbad twins, two individual, penetrating crystals will appear parallel and offset 180° from a common mirror plane. In Baveno twins, which are also common to orthoclase, one of the two penetrating individual crystals will appear to have rotated about a common center axis, creating notched edges on certain crystal faces.

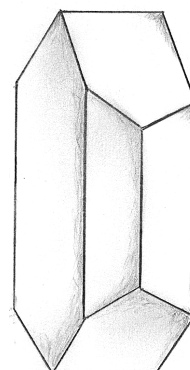


Figure 2.
Orthoclase crystal
as it would appear if
not twinned.

Another interesting feature of some of our pieces is the presence of dendrites (pronounced DEN-drites) on the orthoclase crystals. A dendrite is a branching crystal growth resembling a bush or tree that crystallized in or on another mineral or rock. Typically, the dendrites are comprised of manganese oxide minerals. Moss agate is a quartz variety that often contains dendrites. We hope to feature such dendrites that form intriguing patterns in a silty limestone from Germany next year. Yes, there certainly much to discover when closely examining this month's specimen! And much to appreciate about this abundant feldspar group mineral!

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