AMETHYST FROM FOUR PEAKS, ARIZONA

Jack Lowell and John I. Koivula

For more than a century, the Four Peaks mine in Maricopa County, Arizona, has produced gem-quality amethyst from crystal-lined or crystal-filled cavities and fractures in a brecciated quartzite host rock. Crystals from the deposit exhibit a range of purple colors, uneven color zoning, and variable transparency, which present challenges for obtaining a steady supply of material suitable for faceting. Faceted material may display fluid inclusions and tiny reddish brown hematite flakes, growth zoning, and Brazil-law twinning, all of which provide visual clues to separating the Four Peaks material from synthetic amethyst. Recovery of amethyst at this deposit continues at this time on a limited basis.

The most important commercial source of gem-quality amethyst in the United States is the Four Peaks mine in Maricopa County, Arizona (figure 1). Discovered by accident in the early 1900s by a gold prospector, this deposit has been worked intermittently on a small scale ever since. Good-quality amethyst from a U.S. occurrence has special value in the marketplace, but the challenge at this deposit has been to produce sufficient quantities of commercial-grade material on a continuing basis to satisfy market demand.

The mine's restricted accessibility and remote location in the rugged Mazatzal Mountains of central Arizona, combined with the low market value of amethyst from all sources, has limited production in the past. In the late 1990s, the mine was reopened with the prospect of providing a regular supply of calibrated material in a range of sizes and shapes (Lurie, 1998, 1999; Johnson and Koivula, 1998). Currently, it is owned and operated by Four Peaks Mining Co. LLC of Ocean Grove, New Jersey. The deposit is again producing good-quality amethyst, with some of the cut stones exceeding 20 ct.

This article provides a brief description of the geologic occurrence of amethyst at the deposit and summarizes the gemological properties of this material. Although previous descriptions of the deposit and local geology can be found in Sinkankas (1957, 1976, pp. 373–374), Lowell and Rybicki (1976), Estrada (1987), Chronic (1989, pp. 174–175), and Lieber (1994, p. 122), this article provides the first gemological characterization of Four Peaks amethyst.

LOCATION AND ACCESS

The Four Peaks mine is named for the mountain area where it is located. The Four Peaks are four prominent, steep-sided mountains aligned north-south near the southern end of the 80-km-long Mazatzal mountain range (figure 2). This area is approximately 75 km (46 miles) east-northeast of Phoenix (and is visible from the city) within the Four Peaks Wilderness area of the Tonto National Forest (figure 3). The amethyst deposit is located on a 20-acre patented mining claim that lies below the second peak from the south (again, see figure 2) at an elevation of 1,980

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Figure 1. These two cut stones (19.25 and 17.02 ct) are excellent examples of the fine-quality amethyst obtained from the Four Peaks mine in Maricopa County, Arizona. Courtesy of Jack Lowell; photo © Jeff Scovil.

m (6,500 ft) above sea level. The area has sparse vegetation and an arid, high-desert climate.

The workings consist of an elongate open cut and a tunnel that penetrates about 10 m into the mountainside (figures 4 and 5). Because of the very rugged terrain and location in a wilderness area, access is limited to foot travel or helicopter. Except during the winter months, when the peaks are sometimes covered with snow, the area can be approached by vehicle on U.S. Forest Service roads from State Route 188 or Highway 87. A narrow trail then climbs approximately 760 m over a distance of 7.2 km to the mine. Entrance to the tunnel is closed when the mine is not in operation, and at all times prior permission from the mine owners is required to enter the property.

GEOLOGY

The Four Peaks are eroded remnants (what geologists call "roof pendants") of Precambrian-age metasedimentary rocks that were intruded from below by a granitic batholith. The amethyst mineralization occurs within one stratigraphic unit of

Figure 2. This aerial photograph, taken in 1994 toward the northeast, shows the Four Peaks mountains at the southern end of Mazatzal Range. The tallest, on the far left, is known as Browns Peak. The trail and mine are visible in the right foreground. Photo by Todd Photographic Services; courtesy of Commercial Mineral Co.

Figure 3. The amethyst deposit is located within the Four Peaks Wilderness area, approximately 75 km east-northeast of Phoenix.

these rocks: the Mazatzal Formation, a light-colored quartzite consisting of a tough, closely packed aggregate of cemented, angular quartz fragments. This quartzite and other sedimentary units were uplifted during the intrusion of the batholith in the middle Proterozoic; the uplifting was accompanied by faulting and brecciation of zones in the quartzite.

Figure 4. An elongate open cut (in the center and upper right) can be seen from the trail approaching the Four Peaks mine. Rugged outcrops are formed by the Mazatzal quartzite. Photo by J. E. Shigley.

Erosion since Precambrian times has exposed portions of both the granite batholith and the overlying Mazatzal Formation.

Quartz deposition (colorless and smoky quartz, as well as amethyst) is thought to have occurred in several stages along fractures and cavities in the brecciated quartzite. These crystal-lined spaces are irregular in form and can vary from several centimeters to a few meters in maximum dimension. Smaller openings are completely filled with interlocking amethyst crystals (figure 6), whereas larger cavities often contain either crystal druses attached to cavity walls, or loose crystals suspended in a vug-filling alteration material. The amethyst appears to have formed along fractures by crystallization of silica-containing hydrothermal solutions thought to have been derived from the cooling granite batholith. Fractured zones within the quartzite exhibit evi-

Figure 5. A short tunnel penetrates about 10 m from this entrance. All the Four Peaks amethyst produced in the past seven years has come from the underground workings. Courtesy of Commercial Mineral Co.

dence of hydrothermal alteration from these or other solutions. This evidence includes not only the quartz mineralization, but also the occurrence of fine-grained apatite, hematite, and unidentified clay minerals within open spaces (Sinkankas, 1957).

MINING

Recovery of amethyst for both mineral specimens and gemstones has taken place on a limited scale and intermittent basis. Initial work was carried out from surface outcrops of the amethyst-mineralized zones. Later, mining by open-pit methods employed hand tools and (unsuccessfully) a bulldozer. More recently, a tunnel was driven by hand to access productive areas of the deposit. Several measures have recently been implemented so that the operation is legally compliant with mine safety regulations. A crew of three miners is working the deposit within the horizontal tunnel. Explosives are rarely used, and only to break up boulders when needed. Otherwise, the miners use a hand-held pneumatic chisel for digging. Challenging conditions are caused by the remoteness of the location as well as hot summer temperatures and the lack of water and power at the mine. Gem material is taken out on foot or by helicopter.

Since 1998, Commercial Mineral Co. of Scottsdale, Arizona, has had an exclusive arrangement with the mine owner to acquire the mined material. However, a certain amount of illegal mining has occurred over the years, with the material periodically sold to local gem cutters.

Figure 6. Amethyst mineralization occurs along fractures and cavities in the brecciated quartzite, as shown in this May 2004 image. Courtesy of Commercial Mineral Co.

DESCRIPTION OF THE AMETHYST

The amethyst crystals from this locality display a morphology that is typical of gem amethyst worldwide. Rhombohedral faces are predominant, while the prism faces are either poorly developed or absent (figure 7). This habit is common for quartz crystals

Figure 7. Amethyst crystals from the Four Peaks mine display a typical morphology for amethyst, consisting mainly of rhombohedral faces. Facetable material varies from light to dark purple, and generally only small portions of the crystals are suitable for faceting. The cut stones shown here range from 3.83 to 13.00 ct. Courtesy of Commercial Mineral Co.

that grew simultaneously on the walls of open cavities. The best cutting material shows dissolution basal pinacoid (c) faces, which are rare in natural amethyst. Euhedral crystals of good form and with lustrous faces are seen rarely at this deposit; when found, they range from a few centimeters to about 20 cm in maximum dimension. More typically, crystals (or crystal fragments) are etched and corroded due to attack from late-stage hydrothermal solutions. These solutions appear to have preferentially attacked the joints between adjacent crystals, thereby loosening the crystals and perhaps causing them to break away from a small point of attachment at the base. Crystal faces are normally frosted or coated by apatite or hematite. Some display internal areas that have a hazy or translucent fog-like appearance.

Four Peaks amethyst crystals show great variability in the distribution and quality of color, which can range from light to dark purple and includes some purplish red material. Most crystals display an uneven color distribution (figure 8), with darker purple areas separated by sharp boundaries from areas that are lighter or near-colorless. Color banding is oriented parallel to the rhombohedral crystal faces, with most crystals showing the strongest color zones under the larger rhombohedral faces.

Figure 8. Distinctive color zoning is evident in this amethyst crystal fragment (5 cm in diameter). Virtually all the material from the Four Peaks mine shows color zoning in certain orientations. Photo by J. Lowell.

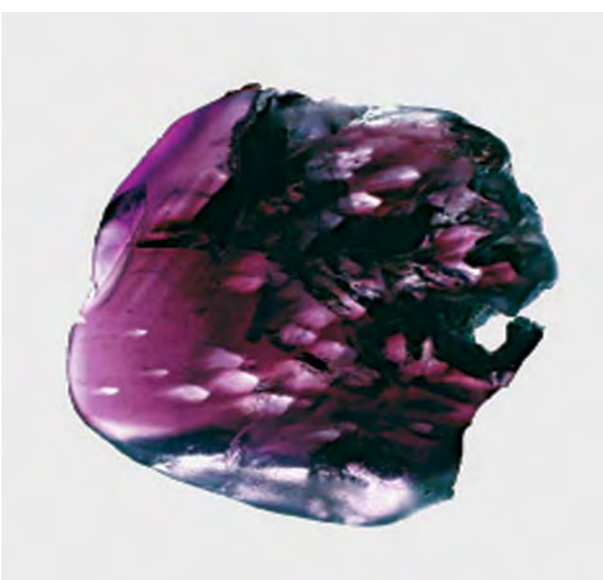

Figure 9. This 68.39 ct amethyst from Four Peaks is the largest faceted stone from the deposit known to the authors. Photo by J. Lowell.

MANUFACTURING AMETHYST FOR JEWELRY PURPOSES

Four Peaks amethyst crystals also vary in size and quality. The rough is cobbed or trim sawn to produce relatively clean, darker pieces suitable for faceting. Because of the color zoning, even large crystals often contain only small portions that are of suitable color and transparency for faceting. The cuttable areas are usually near the pyramidal crystal terminations. These areas can sometimes be best examined after acid cleaning and application of mineral oil. More commonly, however, because of the corroded or encrusted nature of the crystal faces, the gem material is judged after the crystal has been sawn or broken into pieces. Only a small percentage of the total production exhibits intense, even coloration and good clarity. Polished stones of good color can also be created by positioning the zones of best color in the culet. A significant amount of Four Peaks material shows red overtones and/or a deep reddish purple bodycolor when faceted; these stones are known in the gem trade as "Siberian" quality.

All of the material cut by Commercial Mineral Co. has come from the underground workings and is faceted overseas. Material not suitable for faceting is stockpiled for future carving or cabbing. According to Mike Romanella (pers. comm., 2004), vice president of Commercial Mineral Co., the amethyst is faceted in both calibrated and free sizes. The non-calibrated amethyst ranges from 4 to 15 ct;

fine-quality stones in the 15–20 ct range are quite rare. The calibrated goods range from 4 mm (0.25 ct) to 8–10 mm (~3 ct). The material is classified into three quality grades, and at press time the company had thousands of carats of the high-quality faceted stones in its inventory. The largest faceted stone known to the authors weighs 68.39 ct (figure 9). A few pieces have been carved to utilize the color zoning to good effect.

Like amethyst from other localities (e.g., Brazil), some material from Four Peaks is heated to lighten the color. According to Mr. Romanella (pers. comm., 2004), 20–30% of the amethyst he has faceted is over-dark, so this material is heated to 350–450°C. The treatment has about a 50% success rate; the remainder becomes unsalable due to fracturing. Although Sinkankas (1957) reported that heating of some Four Peaks amethyst can result in a pale green color, the present authors have been unable to verify or reproduce this behavior.

MATERIALS AND METHODS

Gemological properties were measured on five faceted amethyst samples using standard gem-testing instruments. These samples, ranging from 1.25 to 3.71 ct (figure 10), are representative of the material currently being produced from the Four Peaks mine.

Refractive indices were obtained with a Duplex II refractometer and a near-monochromatic light source. Birefringence reactions were observed with a polariscope and a calcite dichroscope. Reactions to ultraviolet radiation were checked in a darkened room with conventional four-watt long-wave (366 nm) and short-wave (254 nm) Ultra-Violet Products lamps. Observation of absorption spectra was made with a Beck prism spectroscope. The visual features of the study samples were observed with a gemological microscope. Photomicrographs were taken with a Nikon SMZ-10 photomicroscope under various lighting conditions. A polished amethyst plate oriented perpendicular to the optic axis was prepared to allow for better observation of twinning patterns.

A solid mineral inclusion was identified using a Raman Renishaw 1000 microspectrometer. Mid-infrared absorption spectra for two of the samples were recorded at room temperature with a Nicolet Magna-IR Fourier-transform infrared (FTIR) spectrometer over the range 400–6000 cm^{-1}, with a resolution of 1.0 cm^{-1}. Qualitative chemical analyses of the same two samples were obtained with a Kevex (now Thermo-Electron) Omicron X-ray fluorescence (EDXRF) system operating at accelerating voltages of 10, 25, and 35 kV, and beam currents of 1.70, 2.15, and 3.30 mA.

RESULTS AND DISCUSSION

The refractive indices of each of the seven samples studied were 1.543 (ω) and 1.551 (ε). The birefringence calculated from these values is 0.008. With the polariscope, a uniaxial "bull's-eye" optic figure was seen in all samples; slight distortions of this optic figure were seen near the edges of twinning boundaries (a feature noted before in amethyst). Purple and bluish purple dichroic colors were seen

Figure 10. These faceted samples of Four Peaks amethyst (1.25–3.71 ct) were examined for this study. The amethyst is typically faceted to minimize the appearance of color zoning in the face-up position (left). When viewed table-down (right), the color zoning of these samples becomes apparent. Photos by Maha Tannous.

Figure 11. Primary fluid inclusions, such as those shown here, were common in the Four Peaks amethyst examined. The largest inclusion measures 0.7 mm long. Photomicrograph by J. I. Koivula.

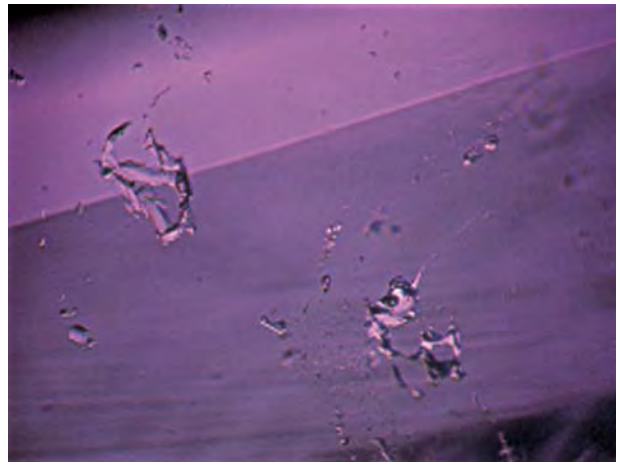

Figure 12. Many of the primary fluid inclusions in the amethyst samples examined also contained tiny anhedral solid phases, as shown in the lower right of this image. Photomicrograph by J. I. Koivula; magnified 25×.

through a calcite dichroscope. All the samples were inert to both long- and short-wave UV radiation, and they displayed no absorption spectra when examined with a Beck spectroscope.

Both primary and secondary fluid inclusions were observed in the samples studied. The former were relatively small, the largest being 0.7 mm in length (figure 11), and they showed minimal negative crystal form. While some of the primary fluid inclusions appeared to be two-phase with liquid and gas components, many others appeared to contain tiny anhedral solid phases (figure 12). No birefringence was evident in these solid phases when they were examined in transmitted light between crossed polarizers. The secondary fluid inclusions exhibited typical veil-like patterns, and they were often seen in association with the larger primary fluid inclusions (figure 13).

Other than the tiny anhedral solid phases in fluid inclusions, the only mineral inclusions observed within the amethysts were small reddish

Figure 13. Veil-like patterns of secondary fluid inclusions were commonly observed in the amethyst samples studied. Photomicrograph by J. I. Koivula; magnified 20×.

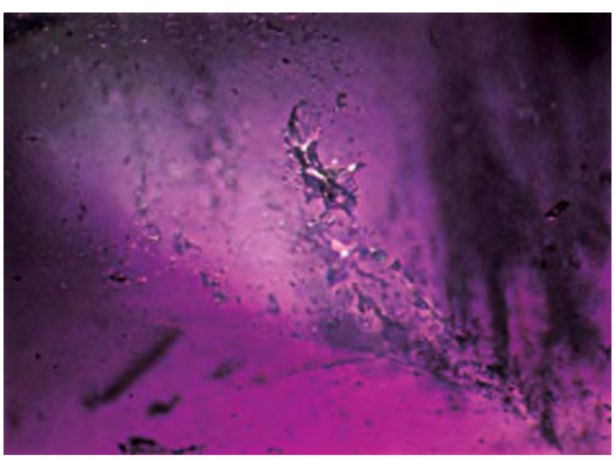

Figure 14. Where dense accumulations of reddish brown hematite flakes were seen, the host amethyst material tended to be a lighter purple. Photomicrograph by J. I. Koivula; magnified 15×.

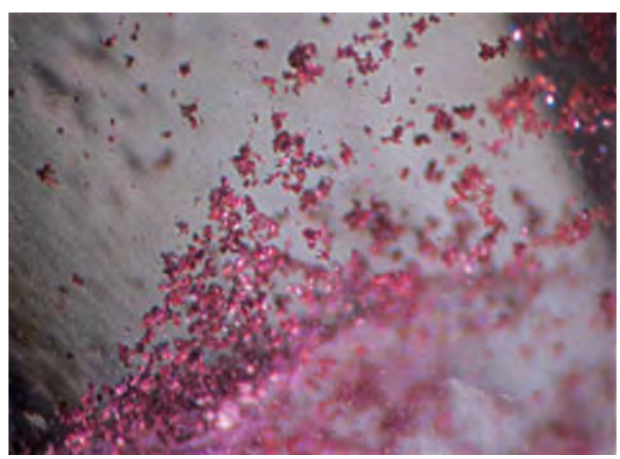

Figure 15. This photomicrograph, taken in transmitted light between crossed polarizers, shows the Brazil-law twinning pattern observed in a polished plate oriented perpendicular to the optic axis of the amethyst. The opaque areas are dense accumulations of hematite inclusions. Photomicrograph by J. I. Koivula; magnified 2×.

brown grains of hematite (identified by Raman analysis). These either occurred in dense accumulations (figure 14) or were sparsely scattered. To the best of our knowledge, such dense accumulations of hematite inclusions have not been reported in amethyst from other localities. Where hematite was present in considerable amounts, the color of the amethyst tended to be lighter purple, whereas darker-color material had fewer of these inclusions.

In transmitted light between crossed polarizers, Brazil-law twinning was obvious in all the samples studied (see, e.g., figure 15). In many of the Brazil-law-twinned crystals and faceted stones, there were sufficiently large untwinned areas to suggest that it would be possible to cut Four Peaks amethysts that would not show this form of optically active twinning.

The most unusual visual feature was a white, wedge-shaped zone that was seen oriented parallel to the rhombohedral direction in a 27.13 ct heart-shaped faceted stone (figure 16). While only slightly visible in darkfield illumination, this zone became

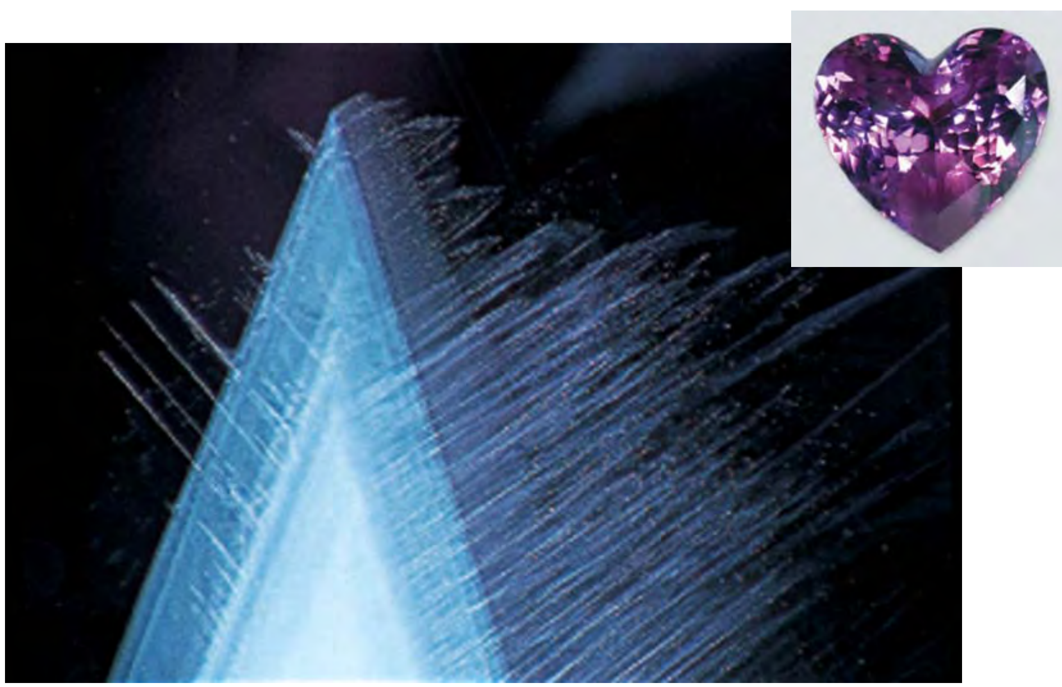

Figure 16. This 27.13 ct cut stone (inset; photo by J. Lowell) displayed an unusual white, wedge-shaped growth zoning pattern that was especially visible in reflected light when the sample was illuminated with a fiber-optic light source. Photomicrograph by J. I. Koivula; magnified 5×.

Figure 17. The Four Peaks amethyst mine has supplied attractive material for the gem trade. This white gold jewelry features a 6.89 ct Four Peaks amethyst in the ring. Courtesy of Commercial Mineral Co.

much more apparent in reflected light from a fiber-optic light source. The cause of this unusual type of decorated growth zoning is unknown, and such fog-like inclusions have not been reported in amethyst from other localities.

EDXRF analysis of two faceted amethyst samples detected silicon (as expected for quartz) and a weak fluorescence peak due to iron. IR spectra of these same two samples did not show the 3543 cm^{-1} peak that is characteristic of most synthetic amethyst (although also seen in some natural amethyst, such as that from Caxarai, Brazil; Kitawaki, 2002).

The Four Peaks amethyst tested exhibited inclusions, growth zoning, and Brazil-law twinning that should enable gemologists to separate this material from its synthetic counterpart. If needed, infrared spectroscopy can provide additional evidence that the material is not laboratory grown (Balitsky et al., 2004). When present, dense accumulations of reddish brown hematite platelets and wedge-shaped fog-like zones (again see figures 14 and 16) not only prove that an amethyst is natural, but they also strongly suggest that it originates from the Four Peaks deposit.

CONCLUSION

The Four Peaks mine in Maricopa County, Arizona, has sporadically produced fine-quality amethyst since the early 1900s, and it continues to supply commercial quantities of amethyst for the jewelry industry (figure 17). Usually the color is typical of material from most other localities, but a small percentage of Four Peaks amethyst exhibits red overtones and/or a deep reddish purple body color, a color sometime described in the trade as "Siberian." Future production will likely remain limited due to the small size of the deposit and its remote location.

ABOUT THE AUTHORS
Mr. Lowell is a geologist and gem cutter living in Tempe, Arizona (www.coloradogem.com), and Mr. Koivula is chief research gemologist at the GIA Gem Trade Laboratory in Carlsbad, California.

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