THREE OCCURRENCES OF OREGON SUNSTONE

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Figure 1. The sparsely populated high desert of eastern Oregon is home to three localities producing natural copper-bearing labradorite feldspar. In this view of Lake County's Dust Devil mine, the local source of the sunstone-bearing lavas is the group of rounded hills (Dudeck Ridge) in the background. Photo by Robert Weldon.

Over five days in late July 2013, we visited three important sources of gem-quality sunstone in eastern Oregon: the Ponderosa mine in Harney County, and the Dust Devil (figure 1) and Sunstone Butte mines, both of which are about 120 miles further south, in Lake County.

Oregon sunstone, the official state gemstone since 1987, is natural copper-bearing labradorite feldspar. Some examples exhibit red to green dichroism, and fine specimens (figure 2) larger than 5 ct can sell for more than $1,000 per carat.

Feldspars are silicate minerals that contain variable amounts of sodium (Na), potassium (K), and calcium (Ca). Labradorite belongs to the plagioclase feldspar series, which forms a solid solution between anorthite ($CaAl_2Si_2O_8$) and albite ($NaAlSi_3O_8$). Oregon sunstone, which contains substantially more calcium than sodium, has a composition of about 70% anorthite and 30% albite, or An^{70}/Ab^{30}. For more on feldspar classification and nomenclature, see box B in Rossman (2011).

No discussion of this topic would be complete without mention of the controversy surrounding treated copper-bearing feldspar; Rossman (2011) provides a chronology. In the early 2000s, Asian treaters perfected a method of diffusing copper into pale feldspar, flooding the market with low-priced, attractive red and green gems—which destabilized the market for Oregon sunstone. Promoted as "andesine" and purportedly from mines in Congo or Tibet, this material was subsequently found to be treated, but the resulting furor hindered the public's trust in natural copper-bearing feldspar. Despite this setback, Oregon sunstone miners have strived to rebuild the market, and there are signs of renewed consumer interest in their one-of-kind gem.

TRIP OBJECTIVES

This paper incorporates trip findings and previous GIA research to provide a comparative analysis of the

Figure 2. This superb 2.85 ct sunstone from Sunstone Butte displays the gem's most valued attributes: a blend of green and red bodycolor, with reflective spangles of native copper glittering in the interior. Photo by Robert Weldon.

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GEMS & GEMOLOGY, Vol. 49, No. 3, pp. 162–171,
http://dx.doi.org/10.5741/GEMS.49.3.162.

gem materials and their geological context and history. We also hope to initiate research that will answer some open questions:

- Are all the eastern Oregon sunstone occurrences the same age?
- How do sunstone occurrences correlate with the local geology?
- How did the very uneven color distribution develop in fractured crystals?
- Are sunstones from each of the three mines distinguishable?

In 2006, GIA collected gems from the Ponderosa and Dust Devil mines to characterize natural Oregon sunstone and help distinguish it from treated material (McClure, 2009). For the present study, we collected representative suites of gem materials and rock samples from each mine, documenting the GPS coordinates of each find. By performing argon-argon ($^{40}Ar/^{39}Ar$) dating on basalt samples and labradorite feldspar crystals from the Ponderosa mine, we hope to confirm the age of its sunstone-bearing basalt and compare that to the Lake County mining locations. We also intend to perform petrographic analyses to characterize the gem-bearing rocks from each deposit and determine their context within the surrounding geology.

We intend to publish the results of these studies in a future *G&G* feature article and on the GIA website.

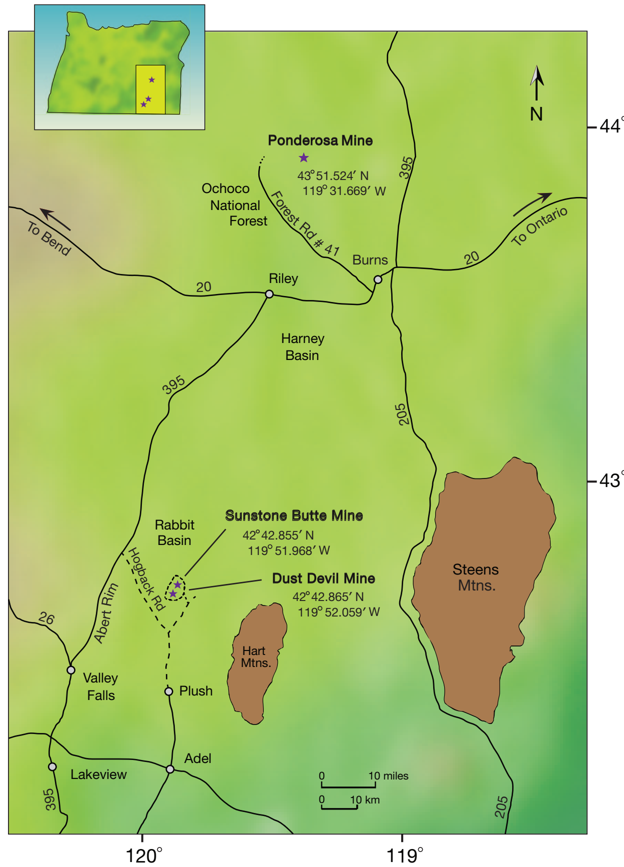

Figure 3. This map shows the location of the three mines visited in eastern Oregon. Illustration by Larry Lavitt.

LOCATION AND ACCESS

Past stratovolcanoes of the High Cascades and across Oregon's remote High Lava Plains lie three sunstone mines (figure 3). All three produce labradorite feldspar ranging from near-colorless to pale yellow to red and green, including bicolor specimens. The sunstone often contains tiny reflective platelets of native copper, referred to as "schiller."

From Portland, we drove five hours southeast to Ponderosa, near the town of Burns. We spent three days there before driving three hours southwest to spend the next two days at the Dust Devil and Sunstone Butte mines. These deposits are referred to in the literature as the Lakeview, Lake County, Plush, or Rabbit Basin occurrences.

GEOLOGIC CONTEXT

In eastern Oregon, sunstone occurs as *phenocrysts* in highly *porphyritic* basalt flows (see figure 4). They are a minor but fascinating part of the region's recent geologic history, likely originating during an episode of widespread basaltic volcanism that occurred 15–17 million years ago (Ma), during the Miocene epoch. Geologists debate whether the volcanic events were caused by melting of subducted oceanic crust or by a hot plume in the earth's mantle. The Steens Basalt of the Oregon Plateau (figure 5), where volcanic flow deposits can contain up to 50% large feldspar crystals (Walker, 1979), erupted around the same time as the more extensive Columbia River basalts further north. $^{40}Ar/^{39}Ar$ dating indicates the eruptions took place between 15.51 +/- 0.28 Ma and 16.59 +/- 0.10 Ma (Brueseke et al., 2007).

Considerable work has recently been done on the geology of eastern Oregon, principally under the aegis of the High Lava Plains Project, supported by the Carnegie Institute of Washington's Department of Terrestrial Magnetism (www.dtm.ciw.edu/research/HLP). This project sought to explain Oregon's recent (<20 Ma) volcanic history through the work of specialists in petrology, geochemistry, geochronology, and geophysics. Their studies provided a much better understanding of the dynamics of plate subduction and magmatism under the Pacific Northwest.

Figure 4. This specimen of basalt porphyry from Ponderosa shows a gem-quality sunstone phenocryst surrounded by smaller non-gem feldspar crystals. A porphyry *is an igneous rock consisting of large crystals (*phenocrysts*) in a finer-grained matrix or groundmass. Photo by Robert Weldon.*

According to Stewart (1966), the sunstone lavas within the Rabbit Basin are petrographically similar to plagioclase-rich flows within the Steens Basalt. They are also strikingly similar to lava flows exposed at the Abert Rim, a spectacular fault scarp some 760 meters (2,490 feet) high, located 10–15 miles southwest of the Rabbit Basin sunstone localities. Gunn and Watkins (1970) proposed that these lavas are part of the same volcanic episode, and that their feldspar phenocrysts might even have originated in the same magma chamber. In a future visit, we aim to collect representative samples from plagioclase-rich flows at Abert Rim and Steens Mountain and compare them with material from each of the three mines to see if we can confirm their relationships.

Feldspar phenocrysts that formed before eruption are surrounded by a finer-grained or glassy groundmass of the lava flow. Also contained in such groundmasses are smaller labradorite phenocrysts (An^{60}), usually just a few millimeters in size, that crystallized in the flow as it cooled. Stewart's analysis (1966) gave a composition of $An^{67.2}/Ab^{31.5}/Or^{1.3}$ for the larger feldspar phenocrysts and An^{60} for the smaller labradorite phenocrysts in the groundmass. We intend to perform Ar-Ar dating on samples of basalt and feldspar phenocrysts from all three mine locations to determine their relative ages.

The feldspar must have formed over time within a magma chamber of calcium-rich magma that cooled slowly, allowing it to reach considerable size. Stewart (1966) proposed that primary crystallization occurred at depth under relatively uniform conditions of about 1100°C. He cited a large lath-shaped

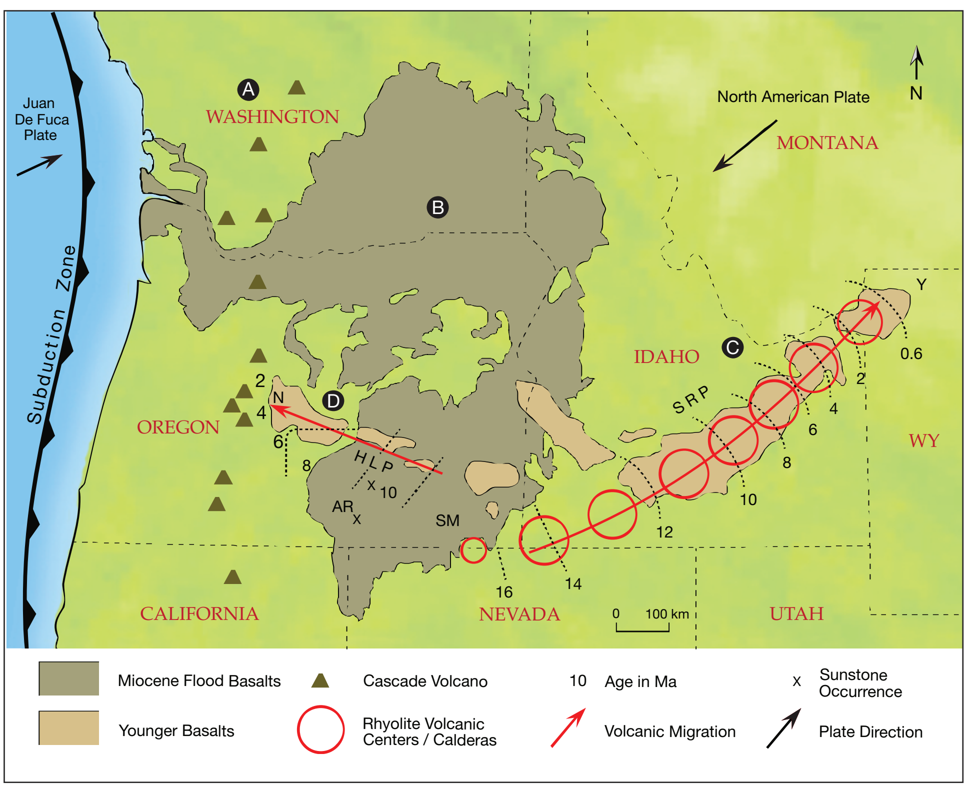

Figure 5. The High Cascade stratovolcanoes (A) are fueled by subduction under the Pacific Northwest. Flood basalts (B) inundated Oregon 15–17 million years ago. Sunstone occurrences (×) are linked to the local eruptive center of these basalts, Steens Mountain (SM) and Abert Rim (AR). As the basalts ebbed, new volcanic forces kindled a hot spot in the earth's mantle, spawning volcanic calderas (C) across Idaho's Snake River Plain (SRP) to the Yellowstone supervolcano (Y). Meanwhile, renewed activity (D) moved west across Oregon's High Lava Plains (HLP) to Newberry Caldera (N). Illustration by Larry Lavitt, adapted from Long (2009) and Grunder and Meigs (2009).

Figure 6. At a section of freshly dug pit wall in the red zone, red cores of fragmented sunstone crystals glint in the sun. Photo by Robert Weldon.

crystal measuring 8.3 × 2.6 × 0.8 cm. This is a substantial crystal by most standards, but we found larger, blockier ones at the Sunstone Butte mine. This might be because the crystals at Sunstone Butte cooled more slowly in a larger body of rock—within a cinder cone—and were not extruded in thinner lava flows, as elsewhere in the Rabbit Basin. As a result, there appears to be less fracturing due to thermal and mechanical shock, and intact crystals are recovered more frequently.

PONDEROSA MINE

The road to the Ponderosa mine gains in elevation as the scenery gradually changes from meadows to thick stands of tall ponderosa pines. It is classic volcanic highland, littered with cinder cones, extensive basalt flows, ashfall tuffs, and red cinder beds.

A map drawn by John Woodmark, Ponderosa's owner and the president of Desert Sun Mining & Gem Co., led us to the mine, where we stayed in a bunkhouse. Woodmark purchased the property in 2003. For earlier history of the Ponderosa mine, see Johnston (1991) and Sinkankas (1997).

The mine is located at an elevation of 1,753 meters (5,700 feet) on the southwest side of Donnelly Butte. The mining season runs from June to October, when the mine is free of snow. Because Woodmark owns the property, it is not subject to regulation from the Bureau of Land Management or other government agencies.

The mine site covers some 60 acres (just over 24 hectares). Although only one-fourth of an acre has been mined to a depth of 6 meters (20 feet), Woodmark said that sunstone occurs throughout the property.

Johnston (1991) reported on the Ponderosa mine and its gem materials, characterizing the labradorite as 70% anorthite and 30% albite, placing it at the labradorite/bytownite boundary.

The sunstone occurs in a localized, weathered basalt flow (figure 6). So far, this is the only one of four basalt flows examined at the site that contains sunstone. The basalt being mined is moderately to heavily weathered, reduced to reddish brown soil containing nuggets of harder basalt in sections of the pit. Currently, Woodmark is recovering higher than normal quantities of red to pink rough from a section of the pit—approximately 20% of the sunstone mined. In 2010, his estimated recovery rate of red to pink rough was around 2–4%.

The working area of the mine has more than doubled since being documented by Johnston (1991), but it still represents a relatively small area. This is because of the high concentration of feldspar in the decomposed basalt. Woodmark estimates a recovery rate of 1.5 kg of rough per cubic yard of earth moved and a possible reserve of more than a trillion carats of cuttable rough. In his opinion, this would make the Ponderosa one of the richest colored gemstone mines in the world.

Ponderosa produces 1 million carats of rough per year (figures 7–9) over the course of approximately 20 days (in three or four increments). Woodmark estimates he could mine 4–6 million carats per year, given sufficient demand. Currently there are only a handful of people to drive the loaders and operate and maintain the other equipment. The mine also employs Native

Figure 7. This loader transfers crushed basalt ore to a dry trommel, separating rock and feldspar crystals from the decomposed basalt, which is essentially dirt. Photo by Robert Weldon.

Figure 8. Pickers, including John Woodmark (foreground), load concentrate onto mesh screening tables at Ponderosa. They methodically sweep the table with a trowel, leaving "no stone unturned." Photo by Duncan Pay.

American teenagers from the nearby reservation. Woodmark pays the pickers $10 per kilogram of concentrate recovered. Each picker averages 1 kg per hour.

He personally grades the rough, first by color (red, orange, pink, yellow, colorless, green, bicolor, or schiller) and then by size. The strategy is geared toward providing a consistent supply of calibrated gems less than 7.0 mm in well-defined grades. These smaller stones are cut overseas. Woodmark does not trim or cob the rough, leading to lower yields (approximately 12% recovery, or 500–600 carats per kilogram). Larger fine-color or clear rough is supplied to designer cutters for high-priced, one-of-a-kind gems.

Woodmark stockpiles the colorless and yellow material because it is so easily treatable (Emmett and Douthit, 2009), and he is concerned it could harm the market for untreated Oregon sunstone. Woodmark is considering bead production as a source of revenue from this clear to champagne-colored rough.

Figure 9. During screening, sparks of red to pink rough sunstone glitter in the sun among pea-sized chunks of vesicular basalt. Photo by Robert Weldon.

DUST DEVIL MINE

The Rabbit Basin lies three hours south of Burns, through a desolately beautiful landscape of alkaline lakes, sand dunes, and volcanic ridges. Alt and Hyndman (1978) provide a brief summary of the roadside geology. At Hogback Road, the paved surface ends and 35 miles of gravel road begins, leading eventually to the Dust Devil mine.

Travel trailers punctuate the desert, marking the sites where miners are working claims. At 1,402 meters (4,600 feet), this is high desert country dotted with sagebrush. No permanent structures are permitted by the Bureau of Land Management, and mining activities are subject to strict environmental regulations. As with the Ponderosa mine, the weather dictates the mining season, which runs from mid-May to mid-October, when the first snows typically fall.

The sunstone-bearing basalts cover about seven square miles (18 km^2) at the northern end of the basin. They are a sequence of gray to strong reddish brown vesicular flows that form low rounded hills, reaching their highest point at Dudeck Ridge. The flows are typically only 3–6 meters (10–20 feet) thick, narrowing considerably toward the edges. The bedrock beneath the sunstone basalts is a gray-brown ashflow tuff of variable thickness. Underneath the tuff lies a vesicular black basalt (Peterson, 1972).

Figure 10. Left to right: Dust Devil employee Mark Shore, owners Terry Clarke and Don Buford, and gemologist Mariana Photiou, who works with the miners and helps market the gem. Photo by Robert Weldon.

Figure 12. Terry Clarke holds a screen up to the sun, letting transparent gems reveal themselves as glints in the light. Photo by Robert Weldon.

According to Don Buford, co-owner of the Dust Devil mine, thin flows cool rapidly, exerting pressure on crystals as they contract and causing extensive fracturing. Thicker flows cool more slowly, exerting less stress on the crystals and allowing them to retain their size. Phenocryst fracturing may also be due to movement and mechanical contact between crystals within the lava flow during emplacement (Peterson, 1972).

Buford and co-owner Terry Clarke (figure 10) have been very active in marketing untreated Oregon sunstone. Gems from Dust Devil have been used by notable artists such as Dalan Hargrave, Will Cox, Larry Winn, Larry Woods, Krista McMillan, and John Dyer to garner more than 15 American Gem Trade Association (AGTA) Cutting Edge awards. A pit operation with a modern separation plant (figures 11–14), the

Figure 11. Left: Mark Shore recovers a large sunstone crystal from its matrix as Don Buford observes. Right: Three principal stones with bodycolor or schiller totaling almost 300 carats, along with 500 carats of pale yellow stones, were recovered from this fragmented crystal; courtesy of Mark Shore, Dust Devil Mining Co. Photos by Robert Weldon.

Figure 13. Dust Devil uses heavy-duty excavators to mine the basalt ore, which is processed by a grizzly (a grille with evenly spaced bars to exclude larger rock). The basalt ore then passes through a sequence of conveyors to a shaker, a wet trommel, a hopper, and a belt for handpicking. Some of the ore goes to an optical sorting machine, depending on the mine's production needs. Photo by Robert Weldon.

mine is known for its variety of stone colors and sizes up to 1,093 ct—nearly as large as a tennis ball.

At the mine, we both witnessed and captured on video the careful recovery of crystal fragments by employee Mark Shore (figure 11, left). The fine sunstone crystal in figure 11 (right), mined from a decomposed basalt nodule, would have constituted an 841.74 ct stone if found in one piece.

This crystal is a telling example of the challenges facing the sunstone miner and the gem cutter: It is highly fractured and has the most desirable colors confined to zones in its interior, restricting the size and orientation of the gems that can be cut from it.

Figure 14. According to Don Buford, each ton of basalt from the Dust Devil mine yields one pound of sunstone rough—75% colorless or yellow, 25% red, green, bicolor, or blue, and less than 1% fine deep red. Photo by Duncan Pay.

These limit the cutter's choices and make it challenging to produce fine gems. The recovery yielded the following:

- 86.64 ct (3.5 × 3.3 × 1.7 cm): pale yellow rim with an orange-red core
- 110.99 ct (5.8 × 1.7 × 1.3 cm): pale yellow rim with an orange-red core and a touch of green on the periphery
- 101.63 ct (4.0 × 2.2 × 1.4 cm): orange-red core with intense schiller and a narrow green periphery
- The remaining pieces were pale yellow: one 45.29 ct specimen, three totaling 100.49 carats, four totaling 80.89 carats, and a bag of assorted yellow shards totaling 315.81 carats.

Rossman and Hofmeister (1985) confirmed a correlation between sunstone's copper concentration and its aventurescence and color. They proposed an excellent model for precipitation of native copper and subsequent development of red and green colors in sunstone during cooling, but their paper does not discuss color zones and distribution of schiller relative to conchoidal fractures within the gems.

Most crystals are fractured and therefore difficult to recover intact. Pough (1983) drew a correlation between sunstone's color distribution and its conchoidal fractures: Red and green colors—along with schiller—tend to be limited to the cores of phenocrysts, rarely reaching fracture surfaces (again, see figure 11, right).

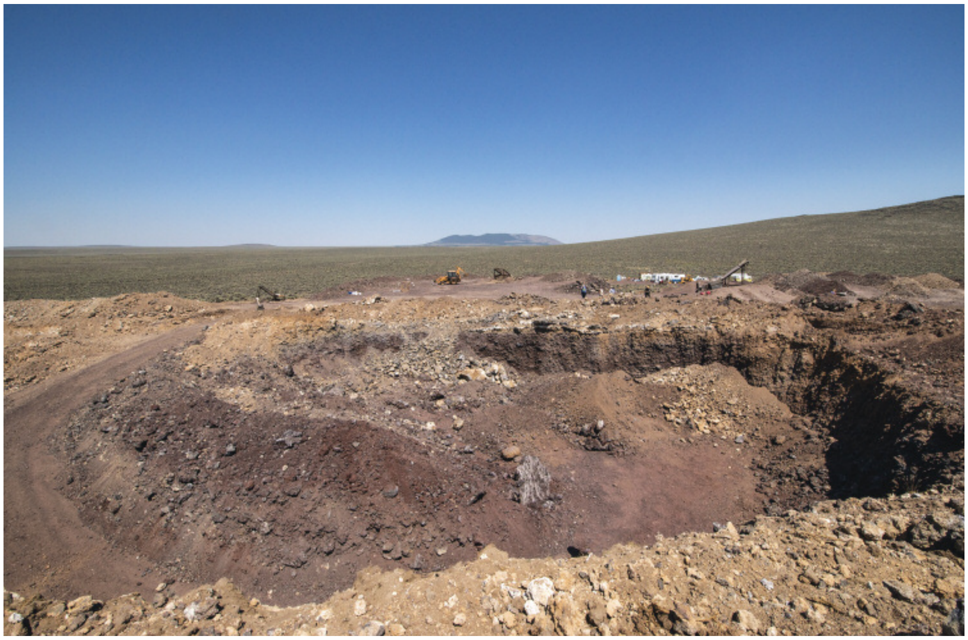

Figure 15. The main pit of the Sunstone Butte mine lies in a cinder cone that forms a small hill above the surrounding desert. Photo by Robert Weldon.

We plan to investigate whether copper can be leached from crystals after emplacement by a secondary process. The example shown in figure 11 would be ideal for chemical analysis, as we know that all its fragments came from a single crystal.

SUNSTONE BUTTE MINE

A new deposit, Sunstone Butte (figure 15), has become known among boutique jewelry designers since 2011 for its large green, red, and bicolor gems. According to mine owners Dave Wheatley and Tammy Moreau, 45–50% of the gem-bearing "ore" is volcanic cinder as opposed to the basalt flows at the other Rabbit Basin mines. They told us that the most notable aspects of the mine's production are the size of the crystals and their green colors. Crystals often reach 100 ct, and sometimes up to 500 ct (figure 16). About 75% of the sunstones have green coloration, many with bluish green "teal" hues.

The rock is far less decomposed than at the other locations we visited. The claim owners are essentially mining into the top of the cone. Possibly because it is a much thicker body of rock—which cooled more slowly than the thinner lava flows elsewhere in the basin—the crystals are much larger and often recovered whole. Some exceed 10 cm in length (figure 17),

Figure 16. This rough sunstone measures approximately 5 cm (2 inches) in length. Note how the green core follows the contours of the rough. The green core is characteristic of material from this mine. Photo by Duncan Pay.

Figure 17. This large, blocky labradorite feldspar crystal from the Sunstone Butte mine measures approximately 10 × 5 × 5 cm (4 × 2 × 2 inches). Photo by Duncan Pay.

Figure 18. Sunstone Butte co-owner Tammy Moreau taps on the back of a piece of volcanic matrix with a small hammer to release feldspar phenocrysts. Photo by Robert Weldon.

which is extraordinary for this type of deposit. Due to the slower cooling of the magma that contained them, they also seem much less internally fractured. The crystals may also have suffered less mechanical stress because they remained within the mass of the cinder cone rather than being extruded in a lava flow.

Wheatley mines the cinder cone using an excavator. Ore is transported to a separator and screened down to less than 20 cm in size and run through a small processing plant where crystals are removed from their volcanic matrix. From there, the material is reduced to fist-sized pieces with a small hammer, allowing the crystals to be handpicked (figure 18). Lastly, the miners remove any remaining volcanic residue—essentially a hard red crust—from the crystals by tumbling them in a cement mixer with water for a couple of hours.

The gems from Sunstone Butte are among the finest we have seen, notable for their size and clarity as well as their dichroic nature. In addition to exploring mining processes, we observed fashioned sunstones (figure 19) as both single pieces and suites of contemporary cuts, many featuring red, bicolor, or schiller stone pairings to maximize the appearance of yellow to colorless material. We collected more than 500 video segments and 1,500 photos, as well as several kilograms of samples for further study, including whole crystals and typical bicolor and red crystal fragments.

These samples will add to our understanding of these deposits and their unique gem materials. The emergence of new material from Sunstone Butte, adding to the consistent commercial supply from the Ponderosa and Dust Devil mines, indicates that the market for Oregon sunstone could grow.

Figure 19. These three gems from Sunstone Butte illustrate the range of colors the mine produces: a 2.40 ct green "Plush" cut, a 4.95 ct pale yellow "snowflake" cut, and a 7.95 ct "spinel-color" red gem. Photo by Robert Weldon.

REFERENCES

Alt D.D, Hyndman D.W. (1978) *Roadside Geology of Oregon*. Mountain Press Publishing Co., Missoula, MT.

Brueseke M.E., Heizler M.T., Hart W.K., Mertzman S.A. (2007) Distribution and geochronology of Oregon Plateau (U.S.A.) flood basalt volcanism: The Steens Basalt revisited. *Journal of Volcanology and Geothermal Research*, Vol. 161, No. 3, pp. 187–214, http://dx.doi.org/10.1016/j.jvolgeores.2006.12.004.

Emmett J.L., Douthit T.R. (2009) Copper diffusion in plagioclase. GIA Thailand, www.giathai.net/pdf/Red_Feldspar_2009_Emmett.pdf, August 21.

Gunn B.M., Watkins N.D. (1970) Geochemistry of the Steen Mountain Basalts, Oregon. *Geological Society of America Bulletin*, Vol. 81, No. 5, pp. 1497–1516.

Hofmeister A.M., Rossman G.R. (1985) Exsolution of metallic copper from Lake County labradorite. *Geology*, Vol. 13, No. 9, pp. 644–647, http://dx.doi.org/10.1130/0091-7613(1985)13<644:EOMCFL>2.0.CO;2.

Johnston C.L., Gunter M.E., Knowles C.R. (1991) Sunstone labradorite from the Ponderosa mine, Oregon. *G&G*, Vol. 27, No. 4, pp. 220–233, http://dx.doi.org/10.5741/GEMS.27.4.220.

McClure S.F. (2009) Observations on identification of treated feldspar. GIA Thailand, www.giathai.net/pdf/Red_Feldspar_2009_Mcclure.pdf, September 10.

Peterson N.V. (1972) Oregon sunstones. *Ore Bin*, Vol. 34, pp. 197–215.

Pough F.H. (1983) Heliolite, a transparent facetable phase of calcic labradorite. *Journal of Gemmology*, Vol. 18, No. 6, pp. 503–514.

Rossman G.R. (2011) The Chinese red feldspar controversy: Chronology of research through July 2009. *G&G*, Vol. 47, No. 1, pp. 16–30, http://dx.doi.org/10.5741/GEMS.47.1.16.

Sinkankas J. (1997) *Gemstones of North America: Volume III.* GeoScience Press Inc., Tucson, AZ.

Stewart D.B., Walker G.W., Wright T.L., Fahey J.J. (1966) Physical properties of calcic labradorite from Lake County. *The American Mineralogist*, Vol. 51, January–February, pp. 177–197.

Walker G.W. (1979) Revisions to the Cenozoic stratigraphy of Harney Basin, Southeast Oregon. *Geological Survey Bulletin 1475*, United States Department of the Interior, Washington DC, 35 pp. [see pubs.usgs.gov/bul/1475/report.pdf].

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ACKNOWLEDGMENTS

The authors would like to thank all the sunstone miners for their generosity of spirit and the time they committed to showing us every detail of their mining operations; nothing was too much trouble, and we were made to feel at home everywhere we visited. We thank John Woodmark and his crew at the Ponderosa mine; Don Buford, Terry Clarke, and Mark Shore at the Dust Devil mine; Dave Wheatley, Tammy Moreau, and David Grey at the Sunstone Butte mine; along with Nirinjan Khalsa and especially Mariana Photiou for their help liaising with the miners.