SAN CARLOS PERIDOT

By John I. Koivula

Each year basalt-topped Peridot Mesa, on the San Carlos Apache Reservation, is a major source for thousands of carats of gem-quality peridot in sizes suitable for use in modern jewelry. Marketed throughout the world, San Carlos material is often confused with, and sold as, peridot from localities that are better known and documented. Peridot Mesa resulted from a single volcanic eruption and basalt flow over an already existing conglomerate base; it is thought to be of late Tertiary or Quartenary age. The peridot is found in irregularly shaped nodules within the basalt. The gemological properties and color range of these Arizona gems suggest an olivine that is rich in the magnesium forsterite end member. Inclusions documented are chromite, chromian spinel, negative crystals, "lily pad" cleavages, glass blebs, chrome diopside, biotite, and smoke-like veiling.

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For over a century, the San Carlos Apache Reservation in Gila County, Arizona, has been a major source of gem-quality olivine (peridot) in sizes that are very suitable for jewelry (figure 1). Yet very little has been published about the principal gem locality on the reservation, Peridot Mesa, or the peridot that is mined there by the Apache Indians, who have exclusive rights to the deposit. Through the kind permission of the Apache Nation Tribal Council, however, the author was permitted to examine the deposit and collect the specimens that served as the basis for this report. The observations about the area and the results of gemological tests reported in this article were derived from a series of experiments performed by the author on gem-quality olivine collected at Peridot Mesa.

HISTORY OF THE DEPOSIT

Many years before the Peridot Mesa deposit was recognized by the international trade as a gem source (Kunz, 1904), the area was mined by the Apache Indians and the stones were used exclusively among tribal members (Kunz, 1882, 1892). From 1904 to 1909, however, mining was carried out at an almost feverish pace, and soon the market was choked with an excess of available gems. This tended to reduce prices and hold them down, while decreasing buyer interest in the stone (Sterrett, 1909).

Consequently, mining activity declined rapidly and for many years was almost nonexistent. Gems continued to trickle from the reservation to a worldwide market, but much of this material had been extracted some years previously. In spite of its tremendous potential, the deposit has been worked only sporadically by the Indian residents during the last 72 years. Even today, mining of the peridot is done only intermittently by any of a number of Apache families who claim sections of the mesa as their own, although by Indian law all members of the tribe are al-

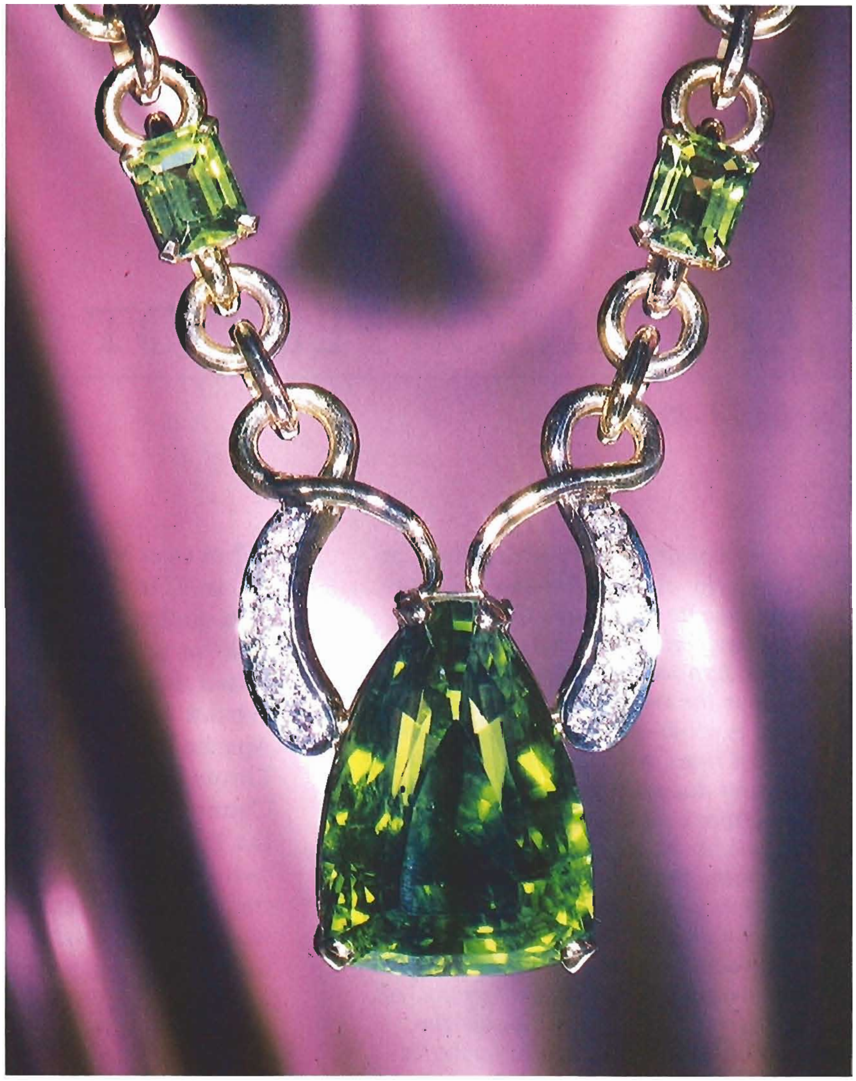


Figure 1. This 34.65-ct. peridot is one of the largest fine Arizona stones in existence. It is complimented by two 3.74-ct. peridots that are more typical in size of the stones found on the San Carlos Apache Reservation. This necklace, which was designed by Aldo Cipullo, is part of the American Gemstone Jewelry Collection of the American Gem Society. Photograph © 1978 Harold and Erica Van Pelt — Photographers, Los Angeles, CA.

lowed to mine. Only when the weather is suitable and the single access road to and from the mesa is passable will one or more of these families be found working their mines.

No records of any kind are kept concerning the amount of peridot mined each year from Peridot Mesa. The majority of the material is sold through the Apache Nations Peridot Enterprise, the Peridot Trading Post on the reservation, and another trading post just off the reservation between Globe and San Carlos. The material is sold directly to private individuals, wholesalers, and retailers alike. Little is known about any other peridot deposits in the area, and Peridot Mesa is the only one that is worked.

THE LOCATION

The San Carlos Apache Reservation is located in east central Arizona (see figure 2; Bromfield and Shride, 1956). Globe, the nearest major city off the reservation, lies approximately 18 miles (28.8 km) due west of Peridot Mesa. San Carlos, the main reservation town and local Bureau of Indian Affairs headquarters, lies 2.5 miles (4 km) northeast of the mesa.

Peridot Mesa and its surroundings are in a desert environment that supports various cacti and low-growing bushes and shrubs. The mesa rises above the lower desert by as much as 90 m and, like other mesas on the reservation, is easily visible, breaking the horizon of the otherwise flat terrain.

The two-lane road from San Carlos to the base of the mesa is paved blacktop. From the base, a bulldozed dirt road snakes up the side of the mesa. There is only one main dirt road across the surface of the mesa, with many forks branching from it to the various mining sites.

MINING METHODS

Peridot Mesa is dotted with numerous small open pit mines that break the uniformity of the essentially level mesa surface like so many small craters. Although the basalt is tough and does not yield readily to hand tools, blasting is done sparingly and only when absolutely necessary because explosive shocks can easily shatter the rocks and scatter the friable peridot in the nodules. A light bulldozer is sometimes used to work freshly blasted areas, remove top soil, and maintain or build roads; otherwise, no heavy equipment is employed and the vast majority of the mining is done almost entirely by hand. The most commonly used hand tools are large, long, heavy-stock picks and pry bars, smaller splitting chisels and wedges, various heavy-weight hammers (like the large-head Nevada-type long striking hammers), long- and short-handled shovels, hand rakes, and a variety of sizing sieves.

In working the basalt, the miners take advantage of any naturally occurring fractures or pits in the rock. Chisels and sledge hammers are used first to widen any existing separations in the rock or to create new ones (figure 3). Once a fracture or series of fractures is started in the basalt, wedges and long, heavy-weight pry bars are used (figure 4) together with the chisels and hammers to break the basalt into small chunks. In this way, the peridot nodules are freed from the host rock.

Once the rock is broken down and the peridot nodules are freed, the chunks of peridot with their rock matrix are shoveled into first a one-half-inch and then a one-fourth-inch mesh sizing sieve (figure 5). The material left in the sieve is then hand-sorted and the loose matrix and undesirable minerals are quickly discarded. Exceptionally large or fine peridot grains are put aside to be sold individually. Once sieved for size, the mine-run peridot is stored in some type of sturdy container, usually a bucket or small tin can (figure 6).

Some of the rock faces being worked for peridot appeared dangerous inasmuch as the basalt was loose and broken and certain faces had been undercut with shallow tunnels. None of the workers in these areas was wearing any head pro-

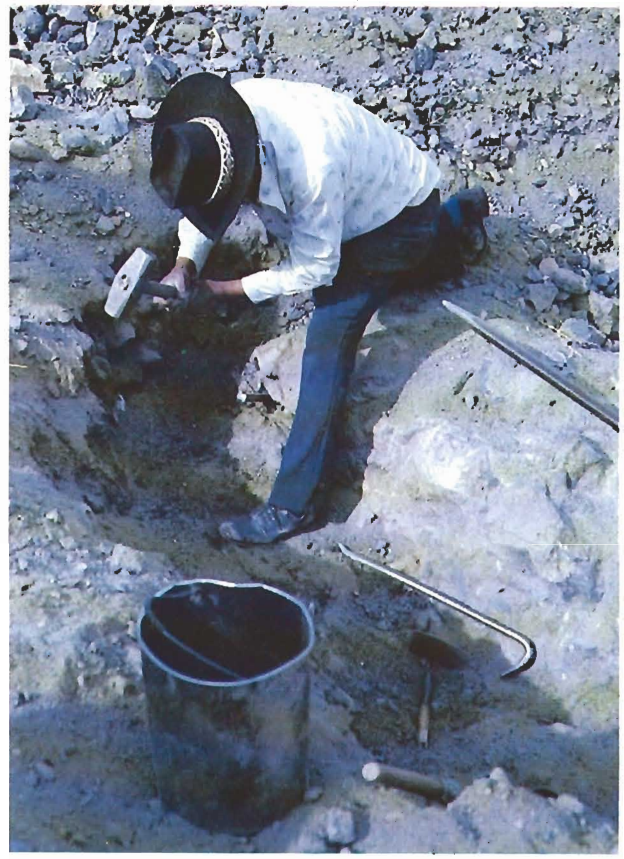


Figure 3. An Apache miner uses a chisel and sledge hammer to work a hand-dug peridot pit in the hard basalt.

Figure 2. San Carlos location map. (Adopted from Basso, 1977.)

Figure 4. Tools used to break the fractured basalt into small chunks.

Figure 5. The freed chunks of peridot on matrix are shoveled into a sizing seive.

tection. In addition, very few of the miners observed on the mesa were wearing any type of eye protection, which is extremely important when hammering rock with chisels. Nevertheless, anyone who has ever worked basalt can surely appreciate the efforts of the Apache peridot miner.

GEOLOGY OF PERIDOT MESA

The basalt capping the mesa is a vesicular, fine-grained, hard rock that is dark gray to black on

Figure 6. Mine-run San Carlos peridot.

fresh surfaces. It appears to have been extruded as the result of a single volcanic event. It extends approximately three and one-half miles (5.6 km) in a northeast direction and about two and three-fourths miles (4.4 km) along a northwest-southeast axis. The cone that produced the flow lies at the far southwestern end of the mesa (Lausen, 1927; see figure 7). The basalt ranges in thickness from 3 m near the cone vent to over 30 m where the flow filled natural depressions in the underlying Gila conglomerate, a flat horizontal to slightly folded sedimentary structure of early Pleistocene age. Thicker portions of the flow show rudimentary columnar structure, while thinner areas nearer the cone display a somewhat platy and/or concentric structure that developed in the flow during cooling and consolidation. The basalt is thought to be of late Tertiary or Quaternary age (Bromfield and Shride, 1956). Exposed contacts between the basalt and underlying sedimentary rocks show a definite baked or heat-altered zone.

Two theories have been proposed for the origins of the vesicles in the basalt: (1) gas (carbon dioxide?) expansion caused by heat and diminishing pressure as the lava rose in the cone throat and poured out on the ground, and/or (2) water vapor expansion if the surface of the ground was wet when the flow emplaced.

The vesicles range in size from microscopic (the most common) to several centimeters in their longest dimension; they are spherical to subspherical or ovoid in shape, with some stretched into elongated tubes by the flow of the fluid lava. In general, the vesicles are larger as they near the surface of the flow.

Under the petrographic microscope, the rock proved to be a typical olivine basalt (Lausen, 1927). Plagioclase feldspar (labradorite) is present as

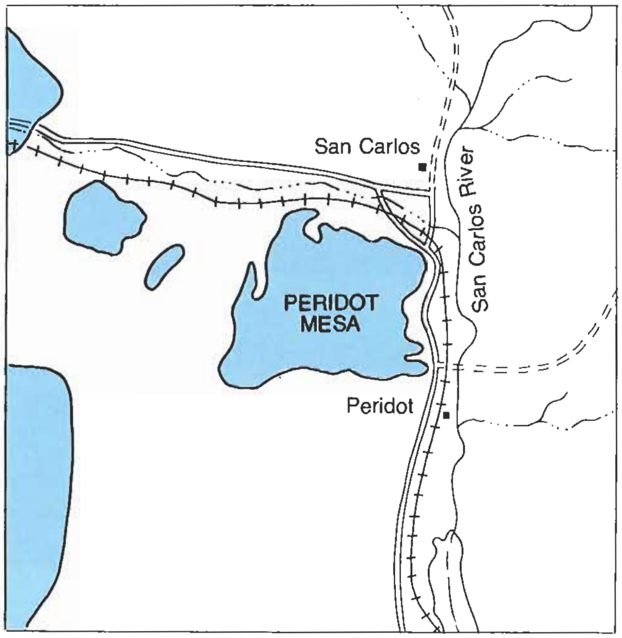


Figure 7. Generalized geological map of Peridot Mesa and vicinity, including the location of the basalt outcrops. (Adopted from Lausen, 1972.)

Figure 8. Basalt face showing typical olivine nodules. The largest is over 25 cm in longest dimension.

slender laths, along with olivine and augite in subhedral to anhedral grains. In addition, magnetite, apatite, analcime, diopside, chromite, biotite, and hornblende have been identified as accessories. Small blebs of volcanic glass of a dark brown to black translucent to nearly opaque transparency also occur in the basalt.

OCCURRENCE OF THE PERIDOT NODULES AND THEIR ORIGIN

Peridot occurs as spherical, ovoid, semi-angular included masses in the vesicular basalt (see figure 8). Such masses range in size from 1 cm or less to 30 cm or more in longest dimension. In the richest mining areas, the nodules may be found within a few centimeters of one another throughout large volumes of the basalt (again, see figure 8); elsewhere they may occur as isolated units, separated from one another by a meter or more of barren rock. The masses are composed chiefly of granular olivine with most of the peridot crystals no larger than a grain of sand; even the largest are scarcely over a few cubic centimeters in volume (see figure 9). The nodules closely resemble peridotite in composition and texture and, therefore, may represent fragments torn at depth from a peridotite rock mass through which the basaltic lava was forced. The random distribution of the nodules in the basalt tends to support this theory (Sterrett, 1909; Lausen, 1927). A thin shell of spongy basalt containing hornblende and augite envelopes each of the peridot nodules; this may represent a thermal reaction zone that formed as a result of limited magmatic differentiation, chemical alteration, and fractional crystallization within the boundaries of the alteration zone.

DESCRIPTION AND GEMOLOGICAL PROPERTIES OF SAN CARLOS PERIDOT

The mode of formation of the olivine nodules precludes the existence of extremely large single crystals and solid masses such as those from Burma and the classic locality of St. John's Island (Zabargad) in the Red Sea. Faceted San Carlos gems typically are small in size; the average weight is between one-half and three carats. Gems over three carats are somewhat rare, and stones over five carats should be considered collectors' pieces.

In color, the peridot ranges from a very dark brown to brownish green to a very pleasing bright lime green from which lively, attractive gems are cut (figure 10). The darker gems are higher in iron content than their lighter counterparts. A chemical analysis of San Carlos peridot (Anthony, Williams, and Bideaux, 1977) by S.S. Goldich (USNM 86128) showed 49.78% MgO, 40.90% SiO_2, 8.24% FeO, 0.59% Fe_2O_3, 0.30% NiO, 0.22% Al_2O_3, 0.12% MnO, and minor traces of TiO_2, CaO, Cr_2O_3, and H_2O. John Sinkankas (1976) reported analytical percentage ranges of 48.34 to 49.49 MgO, 41.11 to 41.96 SiO_2, 8.67 to 10.37 FeO, 0.09 to 0.18 MnO, 0.09 to 0.16 CaO, 0.03 to 0.06 Cr_2O_3, and 0.01 to 0.02 TiO_2. The 0.30% NiO reported by Anthony, Williams, and Bideaux, as compared to the absence of this chemical in the Sinkankas analysis, suggests that in some cases nickel might play a part in the coloration of peridot.

Tests performed by the author on the 12 sam-

Figure 9. San Carlos peridot in vesicular basalt matrix, 18 cm in longest dimension.

ple stones pictured in figure 10 indicate that both refractive index and specific gravity vary slightly with color depending on the percentage of iron present. Refractive indices of the test gems were obtained using a GEM Duplex II refractometer and a sodium light source. The lightest colored gem was biaxial positive with a refractive index of 1.649 alpha, 1.665 beta, and 1.686 gamma, and a corresponding birefringence of 0.037. The darkest specimen was biaxial positive with a refractive index of 1.653 alpha, 1.671 beta, and 1.691 gamma, and a birefringence of 0.038.

From these numbers, it is apparent that not only does the refractive index increase with a darkening of color and a rising iron content, but the beta (intermediate) index also shifts numerically away from the alpha index toward the gamma index. This movement of the beta index suggests that if enough iron substitutes for magnesium in the structure, not only will the refractive index increase substantially, but the material will also become biaxial negative in optic character, as the iron-rich end member fayalite proves.

Specific gravity, as well, varied with color. Through the use of a specially modified Arbor 306 electronic balance, a specific gravity range of 3.28 to 3.38 was established for the test stones, with lighter colored gems tending to cluster toward the lower numerical value while darker stones showed higher specific gravities. However, chromite, with a specific gravity of approximately 4.80 (and possibly magnesiochromite, with a specific gravity of 4.20), is commonly present as an inclusion in peridot, frequently in abundance. Its presence as an inclusion in any significant amount will produce a higher than normal specific gravity for the stone. In fact, the highest reading, 3.38, was obtained from a light green gem that contained numerous chromite octahedra.

On the GEM spectroscope unit, the visible light absorption spectrum observed in both the light and dark San Carlos gems was determined to be typical of peridots in general and to match lines already observed and recorded in the gemological literature, namely, at 4520, 4730, 4880, 4960, and 6400 Å. The 4880 Å and 4960 Å lines together usually appear as a single broad band. Using GIA's Zeiss PMQ_3 spectrophotometer, Stephen C. Hofer of GIA's Research Laboratory confirmed the spectrum and showed that the 4880 Å and 4960 Å lines were in fact separate absorption points in the spectrum. A weak, smudged line at 5200 Å seen in the darkest gems did not appear in the spectrophotometric scan.

INCLUSIONS IN SAN CARLOS PERIDOT

The inclusions found in San Carlos peridot are limited in variety. When present, though, they are usually quite interesting and often gemologically diagnostic. Thus far, the following inclusions have been identified: chromite and chromian spinel, negative crystals, "lily pad" cleavages, glass blebs, chrome diopside, biotite, and smoke-like veiling.

Chromite and Chromian Spinel. The most common inclusions are dark reddish-brown to black euhedral to subhedral octahedrons of chromite ($FeCr_2O_4$) or chromian spinel [$(Mg,Fe)(Cr,Al)_2O_4$].

Figure 10. This selection of 12 cut gems, averaging 2.5 cts. each, illustrates the color range common to San Carlos peridot. The rough that produced these cut stones was collected from the road bed on the mesa in less than 30 minutes.

Carol Stockton of GIA's Research Laboratory used the scanning electron microscope–energy dispersive spectrometer to perform chemical analyses on two randomly selected inclusions and found both to be chrome-rich spinel phases, possibly chromite (and referred to in this article as chromite). Dunn (1974) identified other similar inclusions as a close cousin to chromite: chromian spinel (magnesiochromite). Although no chromian spinels were identified in this study, it seems chemically possible for chromite and chromian spinel both to be present as inclusions in a single Peridot Mesa peridot. In the stones examined for this study, the chromites were randomly distributed as single crystals or as small groups of crystals and were almost always associated with tension fractures that resulted from the expansion of the chromite crystals against their host (see figure 11).

Negative Crystals. Negative crystals, as described by Eppler (1966), were very abundant in the San Carlos peridots (see figure 12). Under magnification, with liquid nitrogen used as a cooling agent, condensation and freezing of the fluid gas components in the negative crystals were observed by the author. Although no actual analyses were performed on the contents of the negative crystals,

Figure 11. A grouping of octahedral chromite inclusions. Dark-field illumination, magnified 40×.

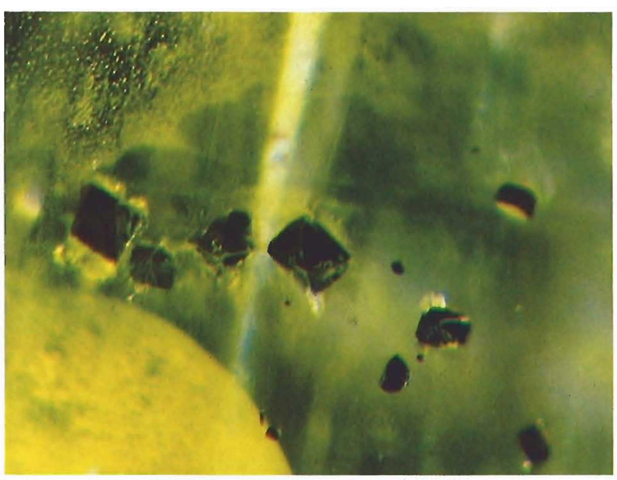
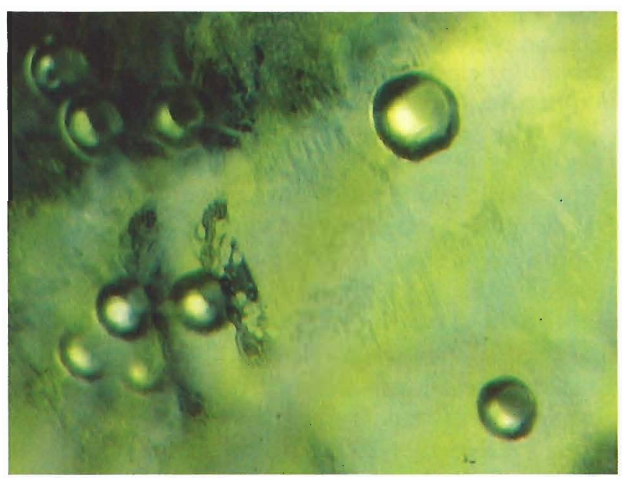


Figure 12. Negative crystals in San Carlos peridot. Oblique and transmitted light, magnified 100×.



the author theorizes that the primary component might be carbon dioxide (CO_2), as identified in similar negative crystals by Roedder (1965,1976) in experiments that he performed on peridots from a number of localities.

"Lily Pad" Cleavages. The lily pad–like, disc-shaped inclusions commonly associated with peridot are abundant in Peridot Mesa gems (see figure 13). "Lily pads" in San Carlos peridots are all oriented along one of two directions of imperfect cleavage: the planes designated [010], the most common orientation for the lily pads, and [100]. These cleavages result from the rupturing of a negative crystal and appear as circular to oval-shaped discs surrounding a transparent to whitish negative crystal that may appear dark or even black under certain lighting conditions. It is hypothesized that rupturing of the negative crystals

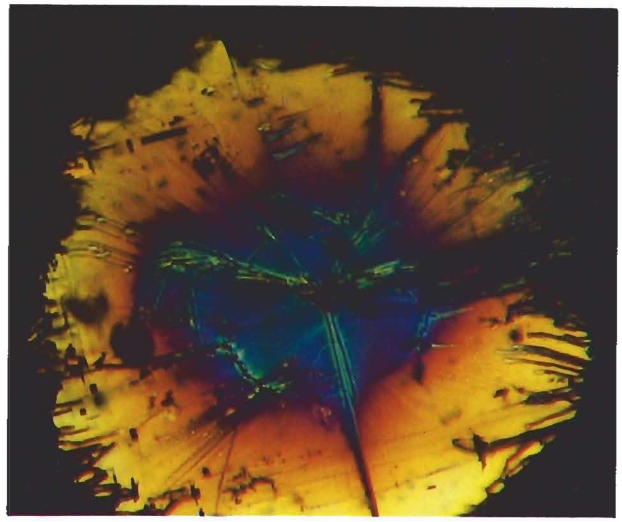


Figure 14. "Lily-pad" inclusion as viewed under reflected light, "thin film" conditions. Oblique illumination, magnified 70×.

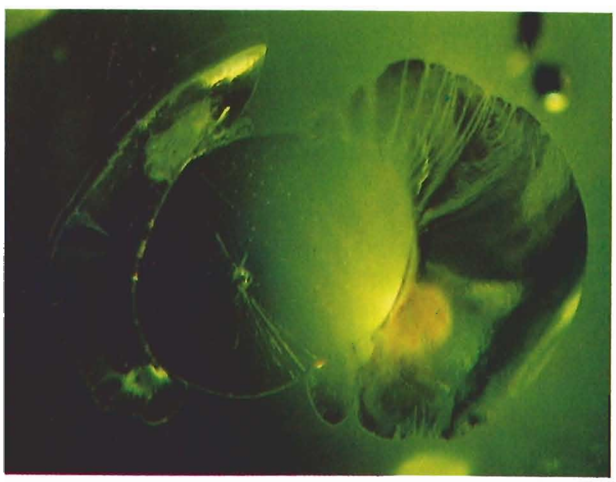
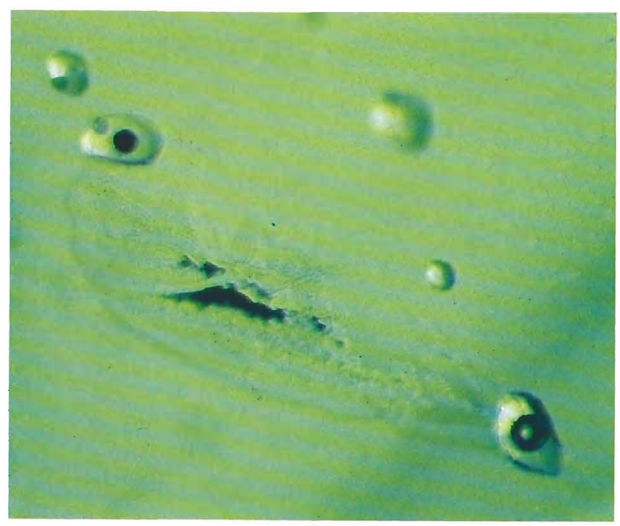


Figure 13. Typical San Carlos "lily-pad" inclusion with central negative crystal and surrounding cleavage disc. Dark-field illumination, magnified 45×.

is the result of heat and diminishing pressure as the peridot is brought to the surface by the basalt. As pressure falls off and the peridot is continually heated by the molten basalt, fluids (possibly CO_2) that filled the negative crystals at a much greater pressure push outwardly against their peridot host until the pressure is released through the formation of a cleavage around the negative crystal. When viewed in reflected light, as in figure 14, the details of the cleavage surface and any subsequent healing that may have taken place are easily studied.

Glass Blebs. The peridots from Peridot Mesa contain numerous tiny glass blebs that are very similar in appearance to those described by Roedder (1965, 1976) and Gübelin (1974, pp. 168–169) in Hawaiian peridots. Microscopic examination of the glass inclusions shows that they often contain one or more shrinkage gas bubbles (see figure 15).

Figure 15. Blebs of natural glass in San Carlos peridot often contain one or more gas bubbles. Transmitted light, magnified 150×.



Movement of the gas bubbles in the glass beads was brought about by carefully heating the peridot host to a temperature between 800° and 900° C. At these temperatures, the glass beads melt and the gas bubbles are free to move. Such heating, however, often results in the explosive rupturing of these fluid inclusions. Cooling experiments performed on the gas bubbles, with liquid nitrogen as the cooling agent, indicate that the gas filling the bubbles may be carbon dioxide. When cut through during lapidary treatment, some of the glass inclusions show themselves to be underdeveloped negative crystals lined with only a very thin shell of glass.

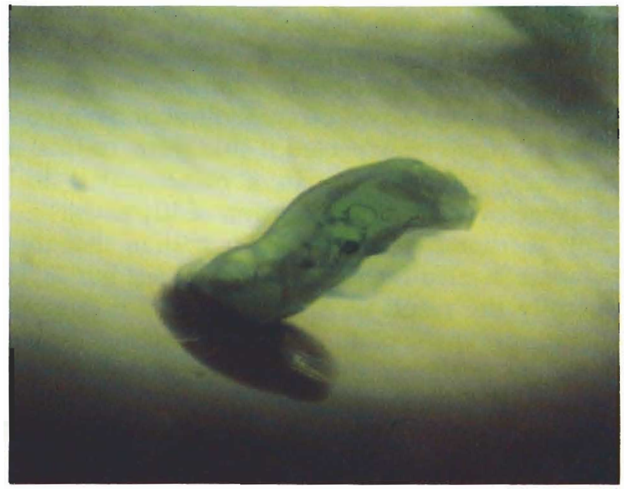


Figure 16. The deep green of this protogenetic crystal of chrome diopside contrasts with the lighter green of its peridot host. Transmitted light, magnified 50×.

Chrome Diopside. Included crystals of chrome diopside can easily pass unnoticed in a microscopic examination of San Carlos peridot unless they are somewhat large, because they show virtually no interfacing and their color (see figure 16) and refractive index are very near those of peridot (Koivula, 1980). In polarized light, however, they are readily revealed as rounded subhedral to anhedral protogenetic included crystals. Thus far these crystals have not been reported in peridot from any other locality and may, therefore, be diagnostic of the San Carlos material.

Biotite. As described by Gübelin (1974), biotite mica is a rare inclusion in San Carlos peridot. Only one small, euhedral, flat, brown, translucent, tabular crystal was noted by the author during this study.

Smoke-Like Veiling. Never before described or photographed, and yet very common in San Carlos peridot, the smoke-like veiling shown in figure 17 at first appears to be a simple form of healing fracture. However, it should be noted that no individual healing tubes or the tiny negative crys-

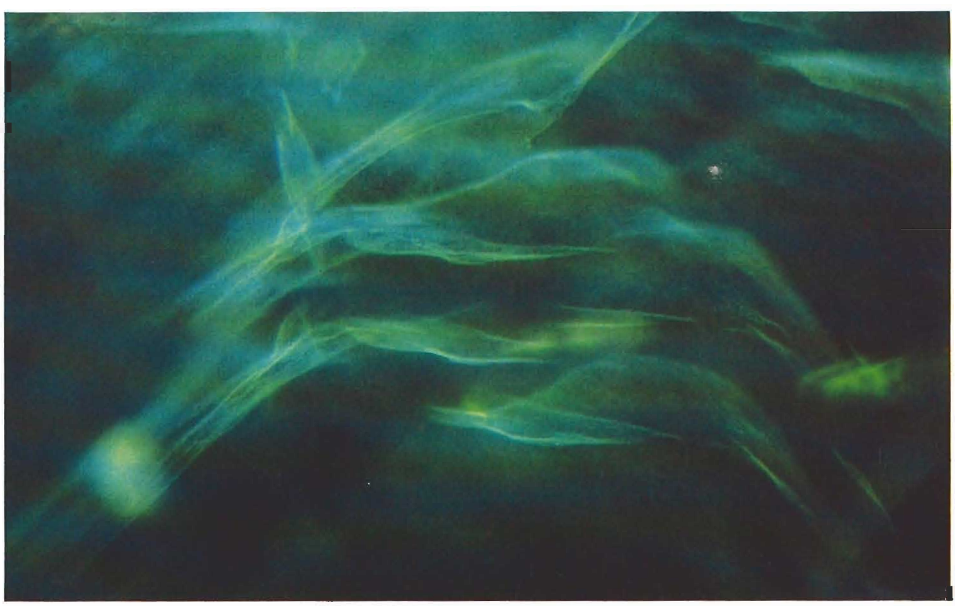


Figure 17. Characteristic of peridot from the San Carlos locality, this smoke-like veiling is possibly the result of solid-solution unmixing or decorated dislocations. Dark-field illumination, magnified 60×.

tals that are commonly associated with healing fractures can be microscopically resolved in any of the smoke-like wisps. In addition, the veiling never follows the two cleavage directions in peridot, as would be expected if this were, in fact, a fracturing phenomenon in a mineral that had cleavage (witness the formation of lily pads).

It is, therefore, this author's opinon that this is not a healed-fracture phenomenon, but it is possibly the result of a solid-solution unmixing that occurs as the peridot is brought to the surface and cools in the basalt. Other possibilities would be olivine dislocation decoration as described by Kohlstedt et al. (1976), who picture inclusions somewhat similar to that shown in figure 17, or a combination of solid-solution unmixing and decorated dislocations.

It should be noted that the image in figure 17, which was selected because it is so highly photogenic, is an exceptionally sharp example of smoke-like veiling in peridot. In general, the effect is much more ghost-like, with the wisps so fine and sometimes so concentrated as to fill the entire host peridot completely, rendering it slightly milky.

CONCLUSIONS

Peridot mining on the San Carlos Apache Reservation is an erratic affair, with most of the work done by hand by the Indians who hold the rights to the deposits. Once the peridot is freed from its basalt host, it is sorted and marketed locally to wholesale and retail customers alike. While few, if any, formal production records have been kept, the author viewed thousands of carats of gem-quality material during his visit.

The gemological properties obtained from 12 test gemstones of San Carlos peridot are almost classic textbook values. With the exception of chrome diopside, which seems to be a diagnostic inclusion in San Carlos material, and the smoke-like veiling shown in figure 17, all other inclusions noted in this paper have been documented in peridot from other localities. This suggests a very similar paragenesis between peridot from San Carlos and that from other mining areas.

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