GEM-QUALITY RED BERYL FROM THE WAH WAH MOUNTAINS, UTAH

By James E. Shigley and Eugene E. Foord

A detailed investigation of the gem-quality red beryl from the southern Wah Wah Mountains, Utah, has confirmed the unique mineralogical and gemological character of this material. At the Violet Claims, red beryl is found associated with minor bixbyite in a volcanic rhyolite host rock. Analytical data gathered on the red beryl indicate relatively high contents of the minor or trace elements Mn, Ti, Zn, Sn, Li, Nb, Sc, Zr, Ga, Cs, Rb, B, and Pb, which are generally low or absent in other gem beryls. Measured refractive indices (1.564–1.574), specific gravity (2.66–2.70), and unit-cell parameters (a = 9.222 Å, c = 9.186 Å) of the red beryl are distinct from most other beryls. The red beryl is thought to have crystallized along fractures, in cavities, or within the host rhyolite from a high-temperature gas or vapor phase released during the latter stages of cooling and crystallization of the rhyolite magma.

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Acknowledgments: The present owners of the Violet Claims, Rex and Ed Harris, provided specimens and information on the deposit; additional material was loaned to us by John Barlow and Allen James. John Koivula, Robert Kane, Bill Kerr, and Chuck Fryer assisted in various aspects of the project. The geological content of the manuscript was greatly improved by reviews from W. Griffitts, K. Dutweiler, and P. Modreski of the U.S. Geological Survey.

Among the varieties of beryl used for gemstone purposes, the rarest by far is the deep-red variety from western Utah (figure 1). Red beryl was first noted in Utah early in this century (Hillebrand, 1905). However, the first crystals suitable for faceting were found only a few years ago in a single area in the Wah Wah Mountains. Except for several short articles (Barlow, 1979; Ream, 1979; Miley, 1980; Flamini et al., 1983), a detailed examination of this gem locality and the red beryl found there has not been made. In addition to its spectacular color, red beryl is unique among gem beryls in its geological occurrence and mineralogical characteristics. The present article summarizes both the geology of the best known red beryl deposit in the Wah Wah Mountains (the Violet Claims), and also the more important chemical, physical, and gemological properties of this material. Although red beryl was initially called "bixbite" by Eppler (1912), because of the confusion of this name with that of another valid mineral species (bixbyite), it has never come into general usage.

Hillebrand (1905) first described red beryl from an occurrence in the Thomas Range in Juab County (figure 2), where it is found as small, translucent (but rarely gemmy) crystals in a rhyolite host rock (see Palache, 1934). It has also been reported from several other places in Utah, one locality in the Black Range of New Mexico (Kimbler and Haynes, 1980), and a little known occurrence in the state of San Luis Potosí, Mexico (R. V. Gaines, pers. comm., 1984). In the late 1950s, gemmy, transparent crystals were discovered at a new locality in the southern Wah Wah Mountains in Beaver County (again, see figure 2). These larger and better quality crystals are far superior for cutting purposes to the original, smaller material from the Thomas Range. Thus far, red beryl has not been found anywhere else in the world, and appears to be unique to western North America.

Figure 1. This faceted stone (1.15 ct) and crystal (16 mm high and 9 mm in diameter) represent the finest-quality red beryl currently being mined at the Violet Claims in the Wah Wah Mountains, Utah. Photo © Harold and Erica Van Pelt.

While gem beryls are common in pegmatites (aquamarine, morganite) and in certain metamorphic rocks (emerald), beryls of any sort are very uncommon in rhyolites. Rhyolites are light-colored, fine-grained igneous rocks that represent the solidified products of rhyolitic magmas or ash flows. They are found in many parts of the world, including numerous areas within western North America, where they are indicative of earlier volcanic activity. Rhyolites ordinarily lack gem minerals, but sometimes contain gem topaz and garnet. The presence of gem red beryl in such rocks in western Utah suggests some unusual conditions for gemstone formation.

The Wah Wah Mountains are accessible by good paved and dirt roads from the nearby towns of Delta, Milford, and Cedar City (figure 2). Local elevations vary from 1500 to 2200 m. This high altitude combined with the limited rainfall and semi-arid climate give the region a high-desert vegetation. Temperatures range from 80° to 100°F (25° to 40°C) in the summer to 10° to 20°F (−12° to −5°C) or lower in the winter. Access to the area is limited during the winter months. The recent article by Ream (1979) provides the best description of gem mineral collecting in the Wah Wah, Thomas, and other nearby mountain ranges in this part of the state.

GEOLOGY

Southwestern Utah lies along the eastern margin of a large geologic region known as the "Basin and Range" physiographic province, which covers Nevada and parts of the surrounding states and takes its name from the alternating mountain ranges and parallel alluvial valleys that dominate the topog-

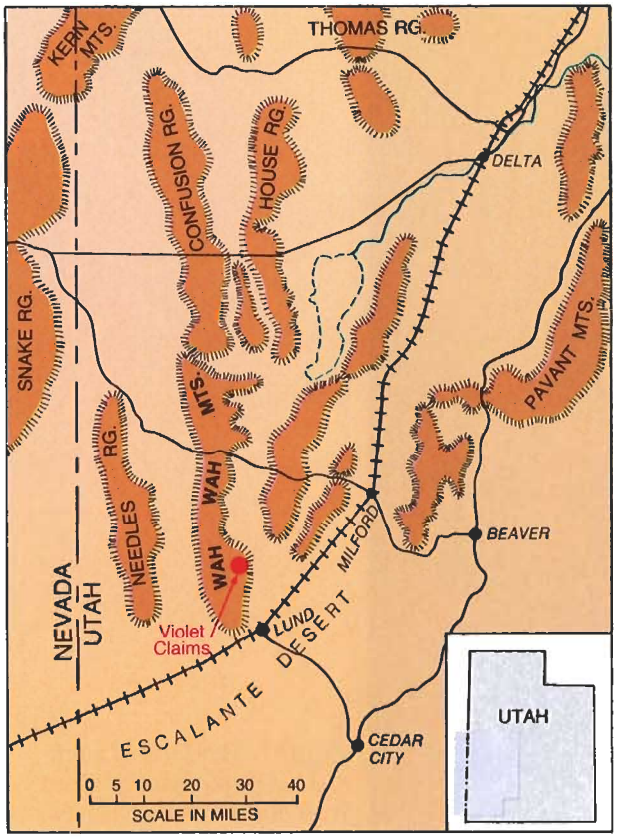

Figure 2. Index map of southwestern Utah (adapted from Miller, 1966), with the general location of the red beryl deposit at the Violet Claims indicated. The Thomas Range, site of the original red beryl discovery, lies at the top center portion of the map, while the Wah Wah Mountains are located near the left center.

raphy. On the basis of the work of various investigators (Miller, 1966; Rowley et al., 1978; Lemmon and Morris, 1979; Weaver, 1980; Christiansen, 1980; Abbott et al., 1981; Steven and Morris, 1983), the geologic history of the southern Wah Wah Mountains can be briefly summarized as follows.

In this area of southwestern Utah, shallow marine carbonate and continental sediments were deposited on crystalline basement rocks during the Paleozoic and Mesozoic eras. Subsequent mountain-building events during the Upper Cretaceous and Lower Tertiary periods produced large, low-angle thrust faults that placed carbonate-dominated sediments over Mesozoic continental rocks.

Approximately 30 million years ago, in the Middle Tertiary, explosive volcanic activity took place over a broad area in this region. The resulting calc-alkaline volcanic rocks (andesites, dacites), which formed large calderas, lie unconformably over the remnants of the thrust-faulted sedimentary units.

In the Wah Wah Mountains, the nature of this continuing volcanic activity then changed abruptly about 23 million years ago. During this period, potassium- and silica-rich trachyandesites and rhyolites were emplaced in the form of numerous subvolcanic intrusions, small volcanic domes, or short lava flows. These rocks are locally rich in fluorine, and small deposits of uranium, beryllium, and fluorine minerals (including gem topaz and red beryl) are associated with them. Although rhyolitic volcanic activity has continued into the Quaternary, basaltic volcanism has been volumetrically more important in this area since about 15 million years ago.

The southern Wah Wah Mountains lie just within the northern edge of the Blue Ribbon lineament (Rowley et al., 1978), a prominent east-west structural zone in southern Utah and Nevada that cuts across the north-south trending mountain ranges and valleys of the Basin and Range province. This lineament is believed to be a deep crustal fault zone along which mineralizing magmas and fluids, including those that formed the beryllium-containing rhyolites that host the red beryl, were able to migrate toward the upper levels of the crust.

The red beryl occurrence is located just north of Blue Mountain, a peak that itself is situated near the intersection of the Blue Ribbon lineament and an area of extensive faulting. In this immediate area, recent geologic mapping has revealed a large subsurface elliptical dome structure of volcanic origin (Weaver, 1980), which apparently resulted from the emplacement of a body of silica-rich magma. The gem red beryl deposit occurs in rhyolite that may have vented to the surface as a lava from this magma chamber along a ring fracture system at the northern edge of the buried dome.

DESCRIPTION OF THE DEPOSIT

The red beryl deposit is collectively referred to as the Violet Claims and is located approximately 40 km (25 mi.) WSW of Milford in Beaver County. It is situated along a mountain ridge that is composed of rhyolite and other light-colored volcanic rocks and is capped by a layer of dark basalt. Along the

Figure 3. View (looking south) of the Violet Claims and the lower rhyolite occurrence that has become more exposed as a result of recent mining activity for red beryl. Blue Mountain is in the distance. Photo by Ed Harris.

ridge, the rhyolite forms a number of small, rounded hills, some of which have produced red beryl (figure 3).

The rhyolite consists of a small number (usually less than 10%, but sometimes up to 20%) of phenocrysts (2–3 mm) of sanidine, plagioclase, quartz, and minor biotite set in a fine-grained, granophyric groundmass of these minerals. The rock is massive, grossly uniform in texture and mineralogy, and varies in color from light gray to light reddish gray. Small, open (miarolitic) cavities are widespread but not abundant. Locally the rock is cut by small fractures that may be stained by oxide alteration minerals. In some portions of the rhyolite, thin, parallel flow bands or ash layers of lighter and darker pyroclastic material of differing texture occur. Some areas of the rhyolite are quite fresh, but those portions that contain the red beryl are often partly altered to clay minerals (chiefly smectites). All of these features are typical of the type of rhyolites known as "topaz-bearing" rhyolites which are found scattered in several areas of the western United States (see Burt et al., 1982; Christiansen et al., 1983). Age dating of the rhyolites at the Violet Claims area indicates that they are 20–22 million years old or younger (Christiansen, 1980; Burt et al., 1982). The rocks are thought to have crystallized at 650°– 800°C (Christiansen, 1980). Table 1 presents chemical data for an unaltered rhyolite sample from the Violet Claims.

So far, only two prominent outcrops of rhyolite within the claims area have produced red beryl. Each outcrop differs slightly in the mode of occurrence and the nature of the red beryl. In the upper outcrop, the red beryl crystals occur along or within a few centimeters of several narrow, steeply dipping fractures or veins filled with later-formed oxide and clay minerals. In contrast, the crystals from the lower outcrop are found in small, scattered cavities, within the solid rhyolite, or in areas of fractured and altered rhyolite (figure 4). For additional details, see Ream (1979).

In contrast to the occurrence in the Thomas Range (Palache, 1934; Ream, 1979), the red beryl from the Violet Claims is not found with gem topaz, although small amounts of topaz have been collected locally. The most obvious associated

mineral is bixbyite $(Mn,Fe)_2^{3+}O_3$ in the form of rounded, irregular grains. The lack of topaz at the Violet Claims may be due to a lower fluorine content in the rhyolites of this area in comparison to those of the Thomas Range (see data in Christiansen et al., 1983), or to the conditions of mineral crystallization.

CHARACTERIZATION OF RED BERYL

With the exception of the recent study by Flamini et al. (1983), there have been no detailed descriptions of red beryl from the Violet Claims. The following section summarizes the results of our investigation (see box).

Figure 4. Red beryl matrix specimen from the lower rhyolite outcrop. The crystal, approximately 1 cm in diameter, occurs in a small cavity in the rhyolite. Photo by Ed Harris.

TABLE 1. Chemical composition of a rhyolite sample from the Violet Claims, Wah Wah Mountains, Beaver County, Utah.

Major/minor elements[a] (weight percent)		Major/minor/trace elements[b] (parts per million)	
SiO_2	70.6	Al	70,000
Al_2O_3	17.2	Fe	7,000
Fe_2O_3	1.01	Mg	300
MgO	< 0.10	Ca	700
CaO	0.08	Na	15,000
Na_2O	1.61	K	30,000
K_2O	4.15	Ti	150
TiO_2	0.03	Mn	700
P_2O_5	< 0.05	B	20
MnO	0.07	Ba	7
F	0.26	Be	30
Cl	< 0.01	Cu	3
Loss (900°C)	4.36	Nb	150
		Pb	70
	99.53	Sn	15
−O = F, Cl	0.11	Sr	7
		Y	15
Total	99.42	Zr	150
		Ga	70
		Li	150
		Yb	3

Looked for but not detected: Ag, As, Au, Bi, Cd, Co, Cr, La, Mo, Ni, Pd, Pt, Sb, Sc, Te, W, Zn, P, Ce, Ge, Hf, In, U, V, Re, Ta, Th, Tl

[a] *Values determined using X-ray fluorescence spectrophotometry by Joseph Taggart. Fluorine and chlorine were determined separately by E. Brandt and Harriet G. Neiman, all of the U.S. Geological Survey. These results are consistent with rhyolite data in Christiansen (1980), Burt et al. (1982), and Christiansen et al. (1983). According to the classification method of De la Roche et al. (1980), rocks of this composition are correctly termed rhyolites or alkali rhyolites. Loss (900°C) on ignition.*

[b] *Values determined using semiquantitative six-step spectrographic analysis by Nancy M. Conklin of the U.S. Geological Survey. The following trace elements are unusual in rhyolites: Mn, Be, Nb, Pb, Zr, and Li.*

Morphology. Red beryl occurs as euhedral crystals that display typical beryl morphology. Some of the crystals are well formed, transparent, and gemmy (figure 5), but most are less well formed and are translucent to opaque as a result of numerous fractures and inclusions. An elongate, prismatic crystal habit is more common than a shortened, tabular shape. Some crystals have an unequal development of prism faces. Pinacoid terminations may be slightly concave in shape, show a slight growth spiral, be capped by a second crystal in parallel arrangement, or exhibit other interesting growth-related surface characteristics (see Flamini et al., 1983). In contrast, prism faces typically lack these features and display no striations, but may exhibit a slight outward bulge to give the crystal a somewhat barrel-shaped appearance. No distinctive etch figures or other corrosion features frequently seen on other types of beryl crystals are apparent, although some red beryls have partially frosted surfaces. Twinned crystals have not been found, but multiple crystal groups are sometimes encountered. Individual crystals may be as much as 2.5 cm long and 1 cm wide, but they average about 1 cm × 0.5 cm. Doubly terminated crystals are relatively common, but most crystals show an

SUMMARY OF MINERALOGICAL DATA ON RED BERYL FROM THE VIOLET CLAIMS

Morphology: euhedral, prismatic crystals to several centimeters in maximum size (average about 1 cm); crystal forms—{0001} basal pinacoid and{10$\bar{1}$0} 1st order prism (common), {11$\bar{2}$1} and{11$\bar{2}$2} 2nd order dipyramids (moderately common), {11$\bar{2}$0} 2nd order prism (rare),{10$\bar{1}$1} 1st order dipyramid (very rare); some crystals doubly terminated; some multiple crystal groups

Chemistry: distinct from other beryls in terms of relatively high contents of Mn, Ti, Zn, Sn, Cs, Li, Rb, B, Pb, Nb, Sc, Zr, and Ga

Physical properties: transparent to translucent or opaque, conchoidal fracture, vitreous luster, S.G. 2.66–2.70 (heavy liquid and hydrostatic methods), indistinct 0001 cleavage, brittle, some color zoning

Unit-cell parameters: measured for core and rim portions of a color-zoned crystal from Debye-Scherrer powder diffraction films with a silicon metal internal standard
core—$\underline{a}$ = 9.229(1) Å, $\underline{c}$ = 9.212(1) Å
rim—$\underline{a}$ = 9.234(1) Å, $\underline{c}$ = 9.204(3) Å

Optical properties:
Refractive indices—ϵ = 1.564–1.569, ω = 1.568–1.572 (Duplex II refractometer) ϵ = 1.567–1.568, ω = 1.574 (grains in R.I. liquids)
Color—light to medium dark in tone; very slightly grayish to strong in saturation; orange-red to purplish red in hue (GIA colored stone grading system)
Birefringence—usually 0.006 to 0.008; sometimes as low as 0.004
Pleochroism—ϵ = purplish red, ω = orange-red to red
Optical sign—uniaxial negative

U.V. fluorescence: inert to LW and SW

Color filter: inert reaction

Spectrum: absorption bands at 425, 480, 530, 560, and 810 nm depending on crystal orientation (see figure 9); with a hand spectroscope, bands at 430 (weak) and 490–510, 560–580 (strong) are usually visible

Microscope observations: numerous healed and unhealed fractures; some color zoning and banding; symmetric growth banding and other growth features; several types of inclusions—two-phase, colorless quartz, black bixbyite, minute unidentified inclusions; some iron oxide staining (see figures 10–13)

Figure 5. The finest gem-quality red beryl crystal (12 × 22 mm, about 30 ct) yet recovered from the Violet Claims. Photo by Michael Havstad.

apparent point of attachment to the rhyolite. Crystals are commonly fractured both perpendicular and parallel to their c-axis; however fractures parallel to the c-axis are often confined to the central core of the crystal, leaving a cleaner, gemmy exterior.

Bixbyite is not only the major associated miarolitic-cavity mineral in the deposit, but it also forms prominent inclusions in some red beryl crystals. A single grain of bixbyite sometimes occurs at the center or central edge of a doubly terminated crystal or, in the case of a crystal with a single termination, near the center of the point of attachment of the crystal to its host rock (figure 6). This positioning suggests to us that the bixbyite may have acted as a "seed" on which subsequent crystallization of the red beryl took place.

Physical and Optical Properties. The beryl crystals range in color from orange-red to purplish red (most commonly the latter) with medium tones and moderate saturation levels. Although most of the purplish red crystals appear to be uniform in color, a number exhibit a distinct color zonation.

Figure 6. The broken point of attachment of a small red beryl crystal showing three included bixbyite grains symmetrically arranged around the central axis of the crystal. In most crystals with bixbyite inclusions, only one bixbyite grain is present near the center or edge of the crystal. In such instances, the included grain(s) of bixbyite may have acted as the sites from which crystallization of the red beryl was initiated. Photo by Ed Harris.

This zoning is evident as a brownish orange-red core surrounded by a purplish red rim; in some instances, a crystal will exhibit a more complex, concentric color zoning (figure 7). If such a crystal is sliced parallel to the c-axis, however, the width of this orange-red inner zone is seen to taper from one end of the crystal to the other, creating a light-colored central area shaped like an inverted triangle (figure 8). In a few instances, however, we observed doubly terminated crystals in which the color zoning was more fully developed, creating an "hourglass" appearance with the light-colored central zones decreasing in width from both ends toward the middle (see also Flamini et al., 1983). The light-colored triangular areas generally do not meet at the center of the crystal, but rather are separated by a narrow horizontal zone of dark red color. In addition, a bixbyite inclusion, if present, is often located close to the corners of these two triangular areas near the center of the crystal. No other type of internal color zonation was noted. These marked color differences reflect important changes in chemical composition during crystal growth. They can be correlated with variations in other physical properties such as refractive index. They also affect the faceting of red beryl to give the best color appearance.

Depending on the inclusions and fractures in the individual crystals, the degree of transparency varies. Red beryl has a vitreous luster that is uniform over all crystal faces and broken surfaces. No chatoyancy or asterism was noted. There is no obvious cleavage, but, as mentioned earlier, frac-

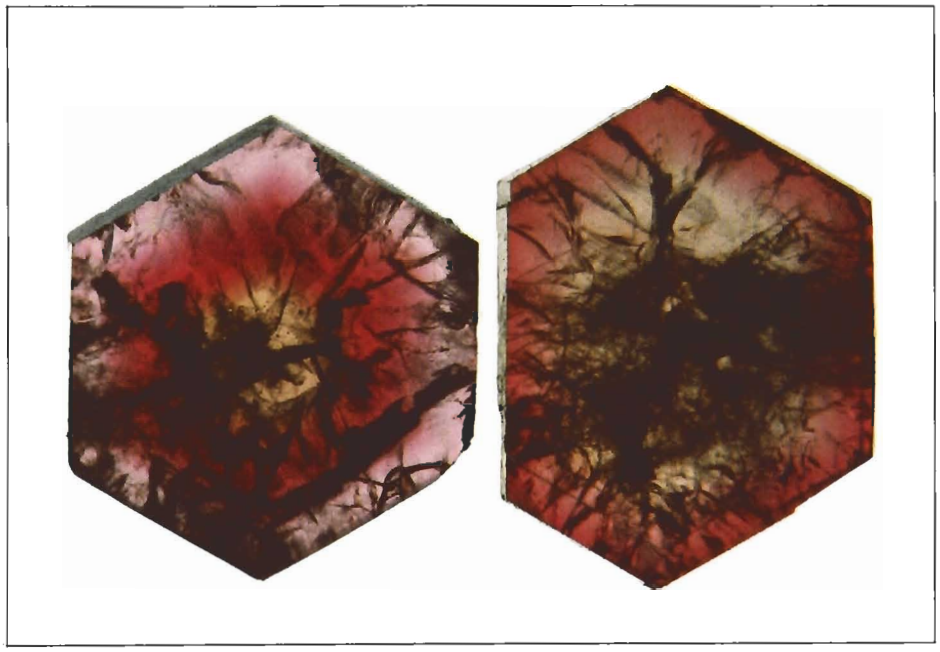

Figure 7. Sections cut perpendicular to the c-axis through two red beryl crystals that show concentric color zoning. The crystal on the left has an orange-red core and a purplish red rim. The one on the right has several zones. Both crystals are about 0.5 cm in diameter. Transmitted light, magnified 10×. Photo by John Koivula.

Figure 8. A section cut parallel to the c-axis through a red beryl crystal. Here the width of the light-colored, triangular, central zone decreases from the upper end of the crystal to the bottom (where an included bixbyite grain would most likely be located if it were present). The crystal is about 0.5 cm long. Transmitted light, partial shadowing, magnified 15 ×. Photo by John Koivula.

tures are common. In many instances, the fractures have a pattern that appears to be related to the color zoning described earlier; that is, the fractures are often located along the boundaries between color zones, or are restricted to the light-colored inner portions of crystals (see figures 7 and 8). When broken, the material exhibits conchoidal or uneven fracture.

The measured specific gravity of 2.66–2.70 for red beryl is within the lower range of values reported for beryl (Deer et al., 1962, cite 2.66–2.83; while Sinkankas, 1981, gives 2.63–2.91). Our measurements are consistent with the data given by Nassau and Wood (1968), Miley (1980), and Flamini et al. (1983). The crystals display no fluorescence when exposed to long-wave (366.0 nm) or short-wave (253.7 nm) ultraviolet radiation.

Red beryl is optically uniaxial negative with refractive indices that are among the lowest values known for beryls. Deer et al. (1962) list indices of $\epsilon = 1.565–1.590$ and $\omega = 1.569–1.598$, with a birefringence range of 0.004–0.008, for the beryl group as a whole (also see Arem, 1977; Sinkankas, 1981). Our refractometer measurements on crystals and cut stones of uniform coloration were $\epsilon = 1.564–1.569$, $\omega = 1.568–1.572$ and a birefringence of about 0.007. For color-zoned crystals, the following values were obtained by the "Becke line" method: for the light-colored material in the central core of the crystal, $\epsilon = 1.567$, $\omega = 1.574$, and for the dark-colored material from a crystal rim, $\epsilon = 1.568$, $\omega = 1.574$. These indices agree with those for red beryl reported by Nassau and Wood (1968), Schmetzer et al. (1974 a and b), Miley (1980), Bank and Bank (1982), and Flamini et al. (1983). The crystals we examined have a pronounced pleochroism, with ϵ = purplish red and ω = orange-red to red.

Figure 9 illustrates absorption spectra for one of our crystals. The ϵ spectrum has absorption bands at 560 and 425 nm, while the ω spectrum has bands at 810, 530, 480, and 425 nm. Nassau and Wood (1968) and Schmetzer et al. (1974b) published similar spectral curves.

Chemical and X-Ray Data. Table 2 presents chemical analyses of a representative red beryl sample from the Violet Claims that are consistent with the results obtained by Flamini et al. (1983). The composition of these crystals is unique among beryls. In terms of minor elements, red beryl is relatively rich in Mn, Ti, Zn, Sn, and Li, and low in Na and Mg, as compared to other beryls (Sinkankas, 1981). Whereas most beryls contain some water—Sinkankas (1981) reported beryl analyses with water contents up to 4 wt.%—the red beryls are noted for their virtual absence of water (Nassau and Wood, 1968). Our analysis of one red beryl sample gave a value of only 0.36 wt.% water.

As noted by Staatz et al. (1965), the trace-element content of these crystals is also very distinctive among beryls. In addition to the minor elements mentioned above, the Wah Wah red beryl contains significant amounts of B, Nb, Pb, Sc, Cs, Zr, Ga, and Rb—most of which (excluding Cs and Rb) are generally absent in beryls from other geological environments. The similar suite of trace elements in both the red beryl and the host rhyolite (compare tables 1 and 2) illustrates how

the composition of the red beryl reflects that of the volcanic rhyolite.

Another interesting feature is the marked difference in chemistry within the color-zoned crystals described earlier. Proceeding from the rim to the core of such a crystal, we found that there is an increase in Al, K, Zn, and Na, but a decrease in Ti, Si, Fe, Mn, Sn, and Cs. These changes are most pronounced at the core-rim boundary where the marked change in color occurs; they reflect compositional variations as the beryl crystal grew, and can be related to differences in physical properties noted earlier.

There is an additional distinctive aspect of red beryl chemistry. As noted by Nassau and Wood (1968), the content of the common alkali elements (K, Na, Li) in red beryl is very low in comparison to other beryls. This is consistent with its low specific gravity and refractive indices (Palache, 1934; Sinkankas, 1981). Thus, graphical relationships which allow one to estimate the alkali content of a beryl from its refractive indices (see Černý and Hawthorne, 1976) do not apply to red beryl.

X-ray powder diffraction films (114 mm Debye-Scherrer camera) were prepared for both core and rim samples of a color-zoned crystal as well as for a crystal of uniform color. Least-squares computer refinement of the resulting data yielded the following unit-cell dimensions: for the core material—$\underline{a}$ = 9.229(1) Å, $\underline{c}$ = 9.212(1) Å; for the rim material—$\underline{a}$ = 9.234(1) Å, $\underline{c}$ = 9.204(3) Å. Additional data for an unzoned crystal gave $\underline{a}$ = 9.222(2) Å, $\underline{c}$ = 9.186(4) Å. Similar findings were reported by Nassau and Wood (1968) for a Thomas Range red beryl. These values are slightly larger than the unit-cell dimensions of many other beryls

Figure 9. Polarized visible-light absorption spectra for red beryl. Absorption bands occur at 425 and 560 nm in the ε spectrum, and at 425, 480, 530, and 810 nm in the ω spectrum. Transmission of light by the crystal takes place in the red portion of the spectrum and to a lesser extent in the violet, but in the yellow-blue-green region there is general absorption. Spectra were obtained with a Pye-Unicam PU8800 UV-VIS spectrophotometer using a 10-nm bandwidth. Path lengths through the samples were approximately 2 mm.

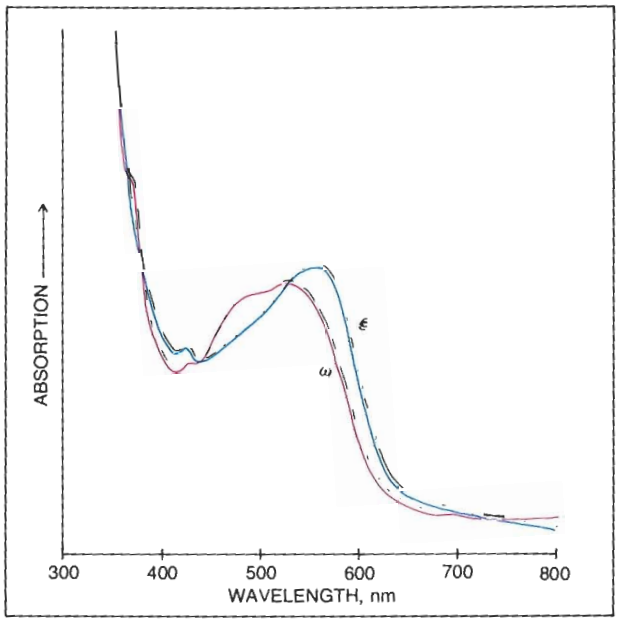

TABLE 2. Chemical composition of a color-zoned red beryl crystal from the Violet Claims, Wah Wah Mountains, Beaver County, Utah.

Major/minor elements[a] (weight percent)			Major/minor/trace elements[b] (parts per million)	
	Rim	Core	Ti	150
SiO_2	66.8	66.1	Fe	15,000
Al_2O_3	17.6	18.3	Mn	2,000
TiO_2	0.4	0.0	Zn	700
K_2O	0.1	0.2	Sn	150
FeO	1.8	1.5	Cs	2,000
MnO	0.3	0.1	Na	300
ZnO	0.08	0.2	Mg	700
SnO_2	0.02	0.0	Ca	50
Cs_2O	0.25	0.12	B	70
Na_2O	0.03	0.1	Ba	7
MgO	0.1	0.1	Cr	1.5
H_2O	0.36	0.36	Cu	7
			Nb	30
	87.84	87.08	Pb	100
BeO	12.16	12.92	Sc	70
			Zr	70
Total	100.00	100.00	Ga	70
			Rb	500
			Li	150

Looked for but not detected: Ag, As, Au, Bi, Cd, Co, Mo, Ni, Sb, Sr, Te, U, V, W, Ge, Hf, In, Re, Ta, Th, Tl, La, Ce, Y, P, Pd, Pt

[a] *Microprobe analyses by E. Foord. ARL EMX-SM instrument, operating voltage 15kV; natural beryl used as a standard for Na and Cs, pure elements or synthetic oxides used as standards for remaining constituents. Water determined using a microcoulometric technique by E. Brandt and Harriet G. Neiman of the U.S. Geological Survey. BeO content calculated by difference. Data refinement carried out using the MAGIC-IV computer program of Colby (1968). Microprobe results substantiated by analyses of other crystals by Carol Stockton. Red beryl crystals that are uniform in color have compositions similar to the one for the rim of the crystal listed here.*

[b] *Values determined using semiquantitative six-step emission spectrographic analysis by Nancy M. Conklin of the U.S. Geological Survey.*

Figure 10. Various types of "fingerprint" inclusions and partly healed fractures originating from a central portion of a red beryl crystal. Dark-field and oblique illumination, magnified 20×. Photo by Robert Kane.

(Sinkankas, 1981). Available data are insufficient to establish a correlation between the differences in minor- and trace-element chemistry and unit-cell parameters of the core and rim areas of a crystal, although such a relationship probably exists.

Inclusions. Several types of inclusions are present in red beryl. Some are typical of inclusions in gem beryls, while others seem unique to red beryl and its particular environment of formation. Healed fractures—in the form of "fingerprints"—as well as unhealed fractures are quite common, especially along the central portions of the crystals or along color-zone boundaries (figure 10). Two-phase inclusions of unknown identity are frequently observed along flat planes (figure 11), and groups of the smaller two-phase inclusions often form flat or curved "fingerprint" patterns. Also observed in several red beryl crystals were well-formed "comet-tail" inclusions that trail behind the edges of the fingerprint-like patterns (figure 12). These are probably a result of directional growth disturbances caused by the inclusions that they trail behind. Distinct color zoning and growth features are also frequently seen in red beryl (figure 13). Finally, various solid inclusions are present—in particular quartz and bixbyite.

The identification of red beryl should present little difficulty for the jeweler. Other common red gem materials (ruby, spinel, garnet, tourmaline, zircon) have basic gemological properties that differ sufficiently from those of red beryl. The R.I.,

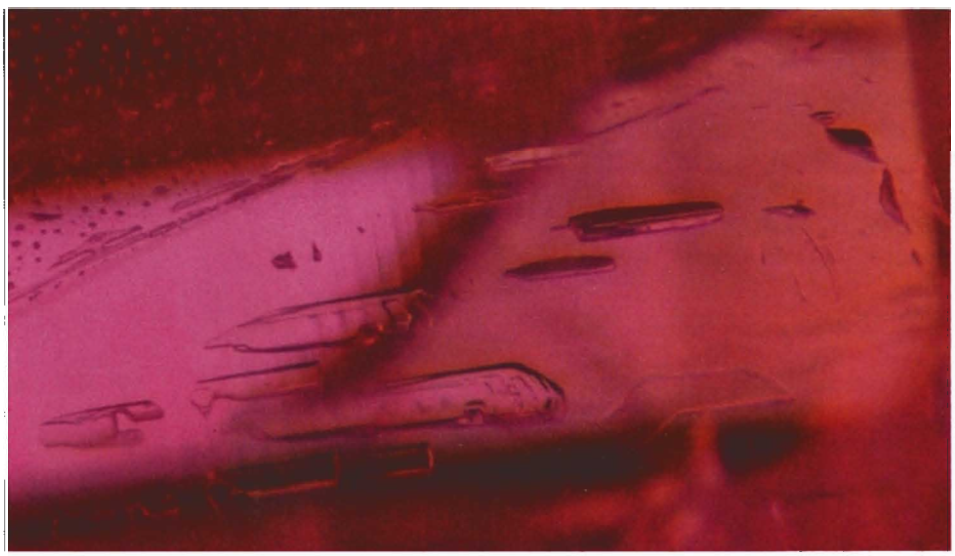

Figure 11. Distinctly formed two-phase inclusions oriented in several different planes in red beryl. Dark-field and oblique illumination, magnified 35×. Photo by Robert Kane.

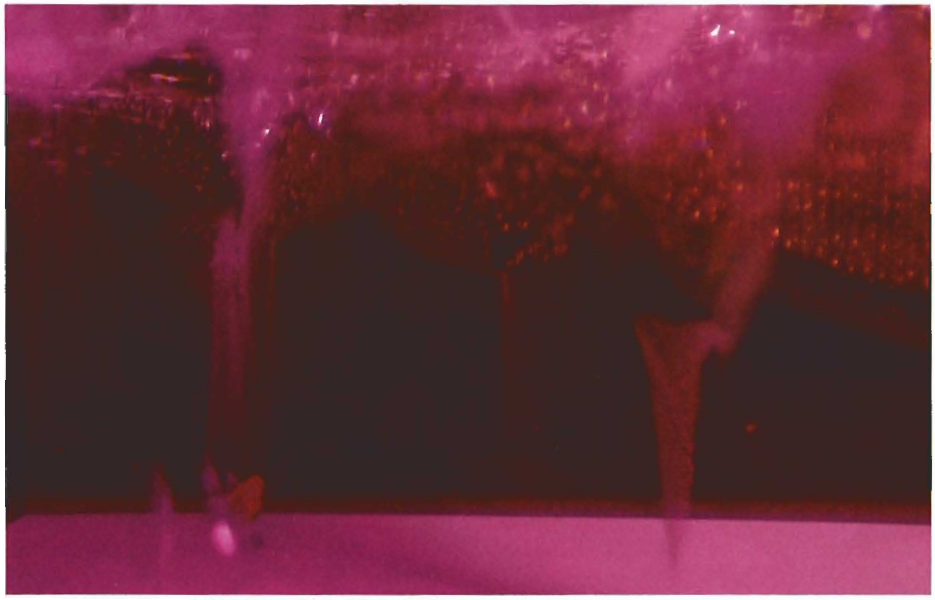

Figure 12. This faceted stone is host to dense concentrations of minute, white particles forming "comet tail" inclusions which are seen trailing behind "fingerprint" inclusions. Dark-field and oblique illumination, magnified 25×. Photo by Robert Kane.

S.G., color, and absorption spectrum of red beryl are quite diagnostic.

FACETING RED BERYL

As with the faceting of other gem beryls, the orientation of the cut stone relative to the c-axis of the crystal has a great influence on both the color and durability of red beryl. Stones cut with their table parallel to this axis are more purplish red in hue, but they may show some color gradation across the table as a result of the "hourglass" color zoning. This orientation is used for crystals that have a highly fractured inner zone but are more transparent around the outer rim. In contrast, stones cut with the table perpendicular to the c-axis display a more uniform orange-red hue. This is the preferred orientation for the best overall color. In either case, the color of the stone is improved if it is cut with the culet located near the center portion of the crystal. During faceting, stones may fracture in either cutting orientation because of the growth characteristics of the original crystals. It is also important to note that the red color of these crystals does not seem to be affected by heating to temperatures of several hundred degrees centigrade for an extended period.

PRODUCTION

While only a limited number of red beryl crystals recovered from the Violet Claims have been suitable for cutting, those that have been faceted exhibit a spectacular color (figure 14). From the initial discovery of the deposit in the late 1950s until the property was acquired by the present owners in the mid 1970s, mining activity (mainly for mineral specimens) was sporadic. Recent mining for gem material has been carried out entirely on the surface by several individuals using earth-moving equipment and some blasting. For the most part, gem crystal recovery involves breaking up promising pieces of rhyolite one at a time in the search for red beryl. The current mining operation generates a sufficient number of crystals to produce 80–100 faceted stones per year, a level that is likely to continue for the foreseeable future. Cut stones are generally less than 0.5 ct, with an average of 0.15 ct. However, stones weighing several carats have occasionally been cut. Most of the red beryl crys-

Figure 13. Well-formed angular growth features reflect the original growth and hexagonal crystal symmetry of the red beryl. Dark-field and oblique illumination, magnified 30×. Photo by Robert Kane.

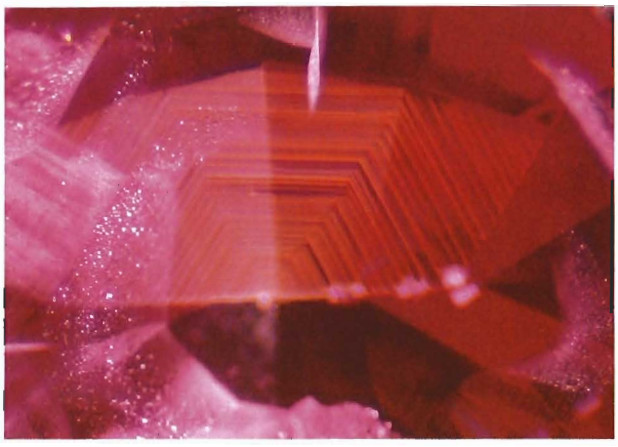

Figure 14. Faceted red beryl has appeared in a variety of jewelry forms, such as this necklace set with a 0.52-ct red beryl and the ring, with a 0.54-ct red beryl as the center stone. Jewelry courtesy of Rex and Ed Harris. Photo © 1984 Harold & Erica Van Pelt.

tals produced at the Violet Claims find a ready market as mineral specimens.

DISCUSSION

Red beryl possesses the same desirable gemological characteristics of beauty, hardness, and durability as do the more common gem beryls emerald and aquamarine. Its most conspicuous feature is the intense red color. The absorption spectra of beryls have been investigated in some detail (Wood and Nassau, 1968; Schmetzer et al., 1974 a and b; Sinkankas, 1981). As with certain other gem minerals, the coloration of red beryl is primarily due to trace elements incorporated within the beryl crystal structure. In the case of red beryl from the Thomas Range, Nassau and Wood (1968) concluded that manganese is the principal coloring agent. Iron and titanium do not seem to play a significant role. They related the spectrum of red beryl to that of pink morganite, whose paler color is also attributed to this same element (Wood and Nassau, 1968). Differences in the intensity of color between red beryl and morganite could be due to a higher level of manganese in the former (by two or three orders of magnitude), or to differences in the valence state of this element. However, slight variations among the spectra of these and other pink or reddish manganese-colored compounds prevented Nassau and Wood from fully explaining the observed spectral features of red beryl. On the basis of the similar spectra and chemistry, it appears that the same cause of color exists for red beryl from the Wah Wah Mountains. According to G. Rossman (pers. comm., 1983), more recent studies

of absorption spectra of red beryl have substantiated the general conclusions of Nassau and Wood (1968), although specific details still require further investigation. These studies suggest that manganese in the 3+ valence state is the cause of the deep red color.

Many of the characteristic features of the red beryl result from its formation within a rhyolite host rock under conditions of low pressure and high temperature in a volcanic environment. The similar trace-element chemistry of both the rhyolite and red beryl substantiate their common origin (see tables 1 and 2). Red beryl occurs in "topaz-bearing" rhyolites, a class of silica-rich volcanic rocks that are geochemically distinct in terms of the presence of topaz and the high content of fluorine and certain other elements. At present the petrogenesis of this type of volcanic igneous rock, and the crystallization of the gemstones found therein, seems reasonably well understood (see Bikun et al., 1980; Burt et al., 1982; Christiansen et al., 1983) and can be summarized as follows.

Topaz rhyolites are derived from magmas that originate in the lower portions of the earth's crust. Certain areas of the crust, such as in the Basin and Range province, have been involved in large-scale regional crustal extension and thinning, and are marked by high heat flow, seismic activity, extensive faulting, and volcanism. Under these conditions, some lower crustal rocks undergo partial melting, which produces rhyolitic magmas preferentially enriched in silica and other constituents relative to the original rock. One of the most important of these is fluorine, which experimental studies have shown to have a pronounced effect on the properties and crystallization of magmas (Bailey, 1977). With time, these rhyolitic magmas rise to the upper levels of the crust, where they are emplaced as shallow, subsurface domes, or they erupt at the surface to form lavas or pyroclastic ash flows. On the surface, the magma crystallizes under conditions of low pressure, high temperature (about 800°C or less), low water content, but relatively high fluorine content. Such conditions favor the release of a gas or vapor phase from the rhyolite magma during its cooling and crystallization. If the appropriate elements are present, minerals such as gem topaz, garnet, and red beryl can crystallize from this gas phase in miarolitic cavities, along fractures, or within the rhyolite itself.

The composition of this gas phase is likely to differ somewhat from that of the rhyolite magma as a consequence of the preferential enrichment of each element in either the magma or the gas. This segregation of elements would have an important influence on the composition of the red beryl. In particular, the marked difference in beryllium content between the red beryl and the host rhyolite suggests that this element was concentrated in the gas. The same can presumably be said for certain other elements in the red beryl, such as cesium, rubidium, scandium, and tin. In contrast, the low content of the alkali elements sodium and potassium in the red beryl as compared to the rhyolite may suggest that these were retained in the magma.

CONCLUSIONS

Red beryl is now—and is likely to remain—the rarest of all gem beryls. Its occurrence in rhyolite in the Wah Wah, Thomas, and possibly other mountain ranges in western Utah represents a geologic setting that differs from that of all other gem beryls, and so far appears to be unique in the world. Material from the Violet Claims provides both spectacular gemstones and mineral specimens. The red beryl crystallized from a gas or vapor phase given off by a rhyolitic magma as it was cooling after having been erupted from volcanic centers. Crystallization under these conditions and from this type of host rock resulted in the unusual chemistry of red beryl, which in turn provided for the distinctive color as well as other physical and optical properties. Red beryl is currently being mined at the Violet Claims in the Wah Wah Mountains, and the likelihood of continued limited production is good.

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