PEZZOTTAITE FROM AMBATOVITA, MADAGASCAR: A NEW GEM MINERAL

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Pezzottaite, ideally $Cs(Be_2Li)Al_2Si_6O_{18}$, is a new gem mineral that is the Cs,Li–rich member of the beryl group. It was discovered in November 2002 in a granitic pegmatite near Ambatovita in central Madagascar. Only a few dozen kilograms of gem rough were mined, and the deposit appears nearly exhausted. The limited number of transparent faceted stones and cat's-eye cabochons that have been cut usually show a deep purplish pink color. Pezzottaite is distinguished from beryl by its higher refractive indices (typically n_o=1.615–1.619 and n_e=1.607–1.610) and specific gravity values (typically 3.09–3.11). In addition, the new mineral's infrared and Raman spectra, as well as its X-ray diffraction pattern, are distinctive, while the visible spectrum recorded with the spectrophotometer is similar to that of morganite. The color is probably caused by radiation-induced color centers involving Mn^{3+}.

Beginning with the 2003 Tucson gem shows, cesium-rich "beryl" from Ambatovita, Madagascar, created excitement among gem collectors and connoisseurs due to its deep purplish pink color (figure 1) and the attractive chatoyancy displayed by some of the material. Although it was sold during and after the Tucson gem shows as "raspberyl," "red beryl," "pink beryl," "hot pink-red beryl," and especially "raspberry beryl," subsequent examinations (see, e.g., Simmons et al., 2003) revealed properties that were anomalous for beryl and were associated with very high concentrations of cesium (Cs). In September 2003, the International Mineralogical Association approved the name *pezzottaite* (pe-zó-ta-ite) for this new species of the beryl group. It is named after Dr. Federico Pezzotta (Natural History Museum, Milan, Italy), who was among the first to investigate this new mineral, in recognition of his scientific contributions to the mineralogy of Madagascar (Hawthorne et al., 2003).

With the addition of pezzottaite—ideally $Cs(Be_2Li)Al_2Si_6O_{18}$—the beryl group consists of four members. The other three (all hexagonal) are: beryl ($Be_3Al_2Si_6O_{18}$; Aurisicchio et al., 1988), bazzite ($Be_3Sc_2Si_6O_{18}$; Armbruster et al., 1995), and stoppaniite ($Be_3Fe_2Si_6O_{18}$; Ferraris et al., 1998; Della Ventura et al., 2000). Pezzottaite, which is rhombohedral, is not a Cs-rich beryl but rather a new mineral species that is closely related to beryl. Another mineral, indialite ($[Al_2Si]Mg_2[Al_2Si_4]O_{18}$; Meagher and Gibbs, 1977), is also sometimes included in the beryl group. Of these, only beryl and pezzottaite have been found in gem quality. (Note: In this article, "beryl" refers to the mineral species, rather than the group, unless otherwise specified.)

Pezzottaite has been confirmed from just one deposit in Madagascar, the Sakavalana granitic pegmatite located near Ambatovita in a remote area of the central highlands. In addition to material from this locality, a sample of Cs-rich "morganite" from Afghanistan described by Hänni and Krzemnicki (2003) has now been recognized as pezzottaite (H. Hänni, pers. comm., 2003). Observations of the crystal morphology of pezzottaite from Madagascar

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Figure 1. Pezzottaite, a new gem mineral from Madagascar, is a Cs,Li–rich member of the beryl group. Small quantities have been cut into attractive faceted stones and cat's-eye cabochons (here, 1.01–6.26 and 3.05 ct, respectively). These are some of the samples used for this study. Photo by Robert Weldon, © GIA; courtesy of Tom Cushman.

were presented by Warin and Jacques (2003), and the chemical composition was investigated by Abduriyim and Kitawaki (2003). This article provides information on the history, geology, composition, and properties of pezzottaite, as a follow-up to the initial description of the material provided by Simmons et al. (2003). A separate article that will formally describe the new mineral (Hawthorne et al., in preparation) and will be submitted to the *Mineralogical Record*.

HISTORY

As recounted by Dr. Pezzotta (pers. comm., 2003), mining of the Sakavalana pegmatite (for tourmaline) by French colonists began in the 1940s. Subsequently, intermittent digging by local people with hand tools occasionally produced tourmaline and other minerals. In mid-November 2002, the local miners discovered a large crystal-bearing cavity that contained multicolored tourmaline prisms of carving or slabbing quality, as well as gem-quality spodumene crystals in green, blue, and purple hues. The production eventually reached the capital city of Antananarivo, where it was seen by gem dealer Laurent Thomas in early December 2002. He noticed some unusual deep pink crystals with a color that resembled tourmaline but with a morphology similar to tabular morganite. Mr. Thomas measured a refractive index of 1.619 on a shiny pinacoidal face on one of these crystals. Recognizing that this was too high for beryl, he sent samples to Dr. Pezzotta in Italy.

Preliminary chemical analyses of two samples with energy-dispersive X-ray spectrometry (by Dr. Alessandro Guastoni of the Natural History Museum, Milan) revealed very high concentrations of Cs, and calculation of the unit-cell parameters (by Dr. Franco Demartin of the University of Milan) yielded data consistent with a beryl-like mineral with extreme Cs enrichment. After the 2003 Tucson gem shows, the customs department of Madagascar temporarily froze the export of the material due to confusion over its identity and the rumor that it might be a new mineral. Subsequent studies proved that it was, indeed, a new mineral (see, e.g., Laurs, 2003; "Newly discovered beryl . . . ," 2003).

Some of the initial production was mistakenly sold in Madagascar as tourmaline (F. Pezzotta, pers. comm., 2003). Soon, rumors that it represented a new source of red beryl (such as that from Utah) spurred local traders to call it "bixbite," after the outdated trade term for such material. Due to the excitement of the discovery and strong demand, dealers frequently have encountered exorbitant prices for gem rough and crystal specimens, even in Madagascar.

LOCATION AND ACCESS

Dr. Pezzotta guided the senior author to the mine in July 2003. It is located about 140 air-km (87 miles) southwest of Antsirabe, in central Madagascar (figure 2). Paved roads lead from Antsirabe to Ambatofinandrahana, a distance of approximately 160 km that requires about six hours of driving time. From there, a rough dirt track proceeds approximately 140 km to the town of Mandrosonoro, and then another 25 km to the

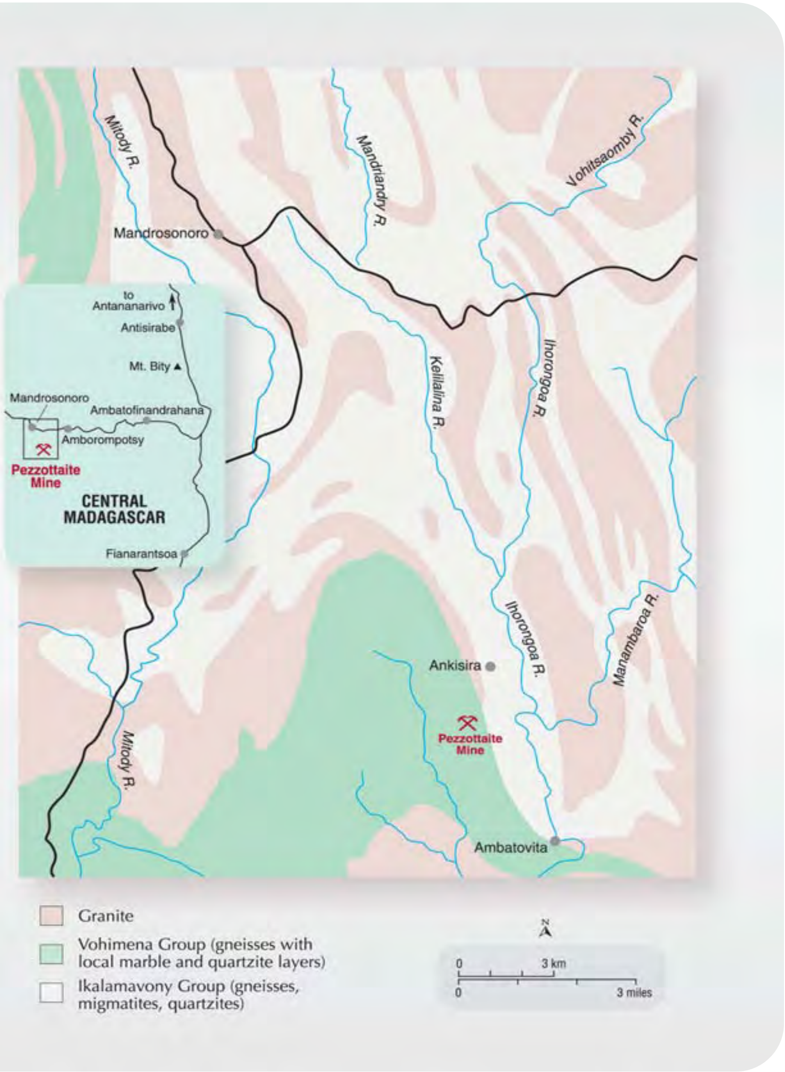


Figure 2. The pezzottaite deposit is located in central Madagascar, about 140 air-km southwest of Antsirabe and 130 km northwest of Fianarantsoa. From Antsirabe, a paved road leads south to Ambositra and west to Ambatofinandrahana, followed by a rough dirt track that passes through Amborompotsy and Mandrosonoro. The pegmatite is hosted by marbles, on the limb of a syncline that is composed mainly of quartzitic gneisses of the Vohimena Group. Geology from Chantraine (1966).

mine. The assistance of local guides was necessary for both navigational and safety reasons. This drive usually takes about 14 hours, although we encountered considerable delays due to multiple vehicular breakdowns caused by the rough terrain (figure 3). Our excursion was undertaken in "ideal" conditions during the dry season; the road is hazardous to impassible during the rainy season, from December to April.

The mine is situated on a low hill (figure 4), at coordinates 20° 44.78′ S and 46° 04.45′ E and an elevation of 920 m (3,020 feet). It is located a few kilometers northwest of the village of Ambatovita and southwest of the village of Ankosira, both of which lie along the Manambaroa River. Most of the miners live on-site, in several huts above the workings (figure 5).

GEOLOGY

The Sakavalana pegmatite, which hosts the pezzottaite, is located in the northern part of the famous Ampandramaika-Malakialina pegmatite district, one of many areas in central Madagascar that have produced gem minerals (see Pezzotta, 2001). A brief review of the regional geology of these pegmatites was provided by Dirlam et al. (2002). The geology of the Mandrosonoro-Ambatovita area was described and mapped by Chantraine (1966). The Sakavalana pegmatite is hosted by impure marbles that Chantraine (1966) assigned to the Vohimena Group, on the eastern limb of a synform that is composed mainly of quartzitic gneisses (again, see figure 2). This amphibolite-grade metasedimentary sequence is surrounded mostly by deformed granites. Pegmatites occur sparingly in the synform, but are much more abundant within mica schists that form the upper facies of the Vohimena Group, about 20 km to the west. This area (Malakialina)

Figure 3. Mechanical breakdowns were common because of the rough terrain, which required the use of a high-clearance four-wheel-drive vehicle. Photo by Brendan Laurs.

once was the most important producer of industrial beryl in Madagascar (Pezzotta, 2001).

Pezzottaite occurs at Sakavalana within a "mixed feature" granitic pegmatite—that is, one that has characteristics of both the LCT (lithium, cesium, and tantalum) and NYF (niobium, yttrium, and fluorine) families of the Rare-Element and Miarolitic classes (see Černý, 1991). The pegmatite (figure 6) is a subvertical dike that measures at least 4–6 m wide and more than 200 m long. The outer portion consists mostly of K-feldspar, quartz, plagioclase, and black mica, whereas the core zone consists of K-feldspar (green amazonite; figure 7), zoned crystals of black and purple mica, and smoky quartz, with traces of albite (bladed "cleavelandite" aggregates), danburite, zircon, and Nb-Ta oxides. In places, black tourmaline is intergrown with these minerals in the core zone, along with minor beryl, spessartine, and spodumene. Crystal-lined cavities are also locally present in the core zone, and they contain the core-zone minerals as well as pezzottaite in places. The paragenetic relations of the pocket minerals indicate that pezzottaite crystallized from the fluids in the cavities as late-stage crystals. Observations of numerous mineral samples by Dr. Pezzotta and some of the authors indicate that post-crystallization fluids caused etching or extensive corrosion on many of the pezzottaite crystals.

The main pezzottaite find occurred about 6 m below the surface, within a large cavity that may have measured up to 3.0 × 3.0 × 1.2 m. Below this pocket was a zone containing numerous vugs with smaller crystals of pezzottaite. All the pezzottaite produced to date came from this rather limited area within the pegmatite.

MINING AND PRODUCTION

The mine area consists of pits, shafts, and open cuts that explore at least one steeply south-dipping pegmatite dike. These workings were probably dug only with hand tools, although bulldozers available in the early days of mining may have been used. Illumination in the underground workings is by candlelight, and logs are used as crude scaffolding near the opening of the deepest shafts (approximately 30 m). Flooding is a problem in the lowermost shaft (which produced only tourmaline). The underground workings where the pezzottaite was mined (see, e.g., figure 8) consist of two small rooms, which are accessed from above and below by tunnels that are several meters long.

Figure 4. In this view (looking southwest) of the pezzottaite mining area, on the left are some of the miners' huts and on the right is a small open cut that has been worked for multicolored tourmaline since the 1940s. Photo by Brendan Laurs.

In the rush that followed the original find, approximately 120 people (including 60 miners and their families) lived at the deposit. Most of them left the area in April 2003 due to lack of production. As of July 2003, only about 20 people were actively working the pegmatite. Most of the pezzottaite-bearing zone appeared to have been mined

Figure 5. At the pezzottaite mine, most of the miners live on-site in several huts above the workings. One of the entrances to the pezzottaite-bearing part of the pegmatite is visible on the lower right (without a significant mine dump below it). Photo by Brendan Laurs.

Figure 6. The Sakavalana pegmatite is visible in this open cut as the light-colored dike on the left. The miners are standing in front of a 13-m-deep shaft that produced multicolored tourmaline crystals. The entrance to a separate tunnel that leads upward to the pezzottaite workings is visible behind the man on the far left. The green color of portions of the pegmatite and mine dump is due to the presence of amazonite feldspar. Photo by Brendan Laurs.

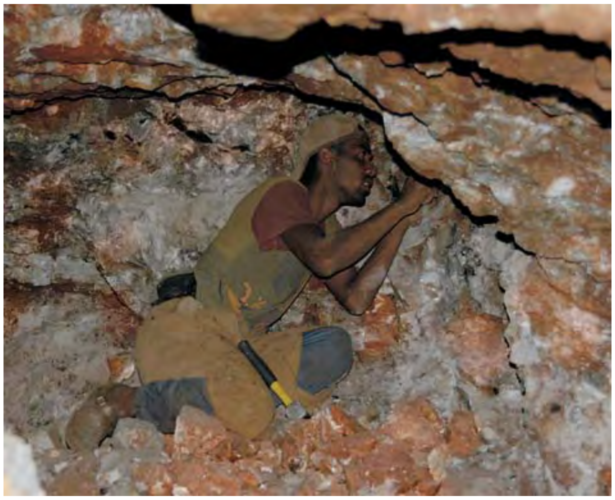


Figure 8. Numerous pezzottaite-bearing vugs were mined from this area, using simple hand tools and candlelight. Fractures in the pegmatite are coated by iron-stained clay, which obscures observation of the mineralogy and also causes stability problems in the ceiling, resulting in unsafe conditions. Photo by Brendan Laurs.

out, and the remaining areas were difficult to work with the hand tools available. Small amounts of pezzottaite were available at the mine, as well as elsewhere in Madagascar, but the material shown to us was of low quality. After another visit to the mine in November 2003, Dr. Pezzotta reported that the underground workings were in poor condition due to rockfalls and backfill generated by contin-

Figure 7. The core zone of the pegmatite is marked by concentrations of green amazonite. Note also the large crystals of black tourmaline above the miner. Photo by Brendan Laurs.

Figure 9. This pezzottaite specimen has been cleaned of dirt and clay, but otherwise shows the appearance as recovered from the mine. The pezzottaite crystal measures 3.6 cm in diameter, and is associated with "cleavelandite" feldspar (bladed albite, here partially covered with Mn-oxides) and quartz. Courtesy of Federico Pezzotta; photo by Brendan Laurs.

ued mining activities. Apparently this work produced little (if any) additional pezzottaite.

According to Dr. Pezzotta (pers. comm., 2003), the main pezzottaite pocket produced a total of about 700 kg of smoky quartz (in crystals up to 50 kg), 280 kg of tourmaline (multicolored, with a black "skin"), >40 kg of pezzottaite (see, e.g., figure 9), and 25 kg of transparent spodumene (see, e.g., figure 10). The three largest tourmaline crystals weighed 15, 25, and 50 kg, and reportedly were purchased by a Korean dealer for carving purposes. The pezzottaite was recovered as crystals, fragments, and masses typically weighing a few grams, and rarely up to 1,000 grams. In addition to the 40 kg mentioned above, there were many tens of kilograms of low-quality fragments and deeply corroded crystals. Pieces of gem-quality pezzottaite are rare and typically small (less than 1–2 grams). Much of the gem material is of carving quality only, although some contains abundant tubes oriented parallel to the c-axis that produce attractive chatoyancy in cabochons. One gem dealer estimated that perhaps 10% of the rough will produce the cat's-eye effect when cut ("Rare pink-red beryl. . . ," 2003).

The total amount of pezzottaite produced so far from the pegmatite is difficult to estimate. According to dealers Fabrice Danet, Denis Gravier, Dudley Blauwet, and Mark Kaufman (pers. comms., 2003), the total production may range up to 150 kg, with no more than 25% containing areas that could yield cabochons and faceted stones. Rarest of all are attractive specimen-quality crystals (see, e.g., figure 11). Most of the production was sold in Antananarivo in December 2002–February 2003, to European and American dealers. Additional smaller, lower-quality parcels were sold until September 2003. It is not clear how much of this material came from the original find, and how much resulted from later mining. African, Japanese, Thai, and Indian traders also bought the material directly in Madagascar or through local buyers. The largest transparent faceted pezzottaite of good quality known to the authors weighs approximately 11.31 ct, and the largest good-quality cat's-eye cabochon is 17.36 ct (see figure 12). Examples of other large pezzottaite gems seen at the GIA and GRS laboratories include faceted stones weighing 5.27, 6.26, and 10.07 ct, and cat's-eye cabochons weighing 7.98, 8.78, and 8.85 ct.

As of November 2003, Dr. Pezzotta reported there was practically no material available in the mine area, and only small, lower-quality material could be found in Antsirabe and Antananarivo.

Figure 10. Fine crystals of spodumene, some bicolored in violet and yellow as shown here (24.9 cm long), were recovered from the same pocket with pezzottaite (here, 4.9 × 3.1 cm). Courtesy of Brian Cook (pezzottaite) and the Brooke Collection (spodumene); photo by Maha Tannous.

MATERIALS AND METHODS

The samples and analytical techniques used in this study are summarized in table 1. Gemological properties were obtained on 19 samples (see, e.g., figure 1) using standard gemological instruments.

Figure 11. Attractive crystals of pezzottaite are relatively rare, particularly on matrix. This specimen measures 4.7 × 4.2 cm, and consists of bright pink pezzottaite, feldspar, smoky quartz, and black tourmaline. GIA Collection no. 30113; photo by R. Appiani.

Figure 12. At 17.36 ct, this is the largest good-quality cat's-eye pezzottaite known to the authors. Courtesy of K&K International; photo by Maha Tannous.

Internal features were examined with a gemological microscope, and absorption spectra were observed with a desk-model Beck prism spectroscope. The documentation of additional samples examined by one of the authors (AP) will be published in a separate article; these results are in general agreement with those obtained at GIA.

To test for color stability, one sample was sawn into four parts. Heating and irradiation experiments were conducted on three parts, while the other one was retained as a control.

Quantitative chemical analysis by electron microprobe was performed on 11 pezzottaite samples from which a total of 49 point analyses were obtained. Nearly all of these analyses were done on fragments that were donated for research; two of the gemstones mentioned above that could be borrowed long enough for chemical analysis also were analyzed. Analyses were obtained using an ARL-SEMQ electron microprobe with 15 kV (for sodium) and 25 kV accelerating voltages, 15 nA beam current, and 3 μm beam diameter. The measurements were calibrated with natural mineral and synthetic compound standards, and a ZAF correction procedure was applied to the data. Morphological observations of eight etched crystals also were performed.

Quantitative chemical analysis by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) using a GeoLas 193 nm excimer laser in combination with an Elan 6100 ICP-DRC (dynamic reaction cell) mass spectrometer was carried out on one sample. The water content of two additional fragments was determined by measuring the weight lost after heating them to 900°C. In addition, the lithium contents were measured in two other samples using an ARL 3520 AES inductively coupled plasma spectrometer.

Visible–near infrared spectra of pezzottaite and, for comparison, morganite and red beryl were obtained using a custom-built diode array spectrometer consisting of a tungsten-halogen source coupled to a microscope spectrometer. The detector, a 1025 element silicon diode array, was attached to a grating optical spectrograph that received its signal through fiber optics from the microscope.

Infrared spectra of pezzottaite, morganite, and red beryl were collected with a SensIR DuraScope diamond window attenuated total reflectance (ATR) apparatus. Spectra were obtained from a 0.1-mm-diameter area of finely powdered sample and were referenced to a blank window. These spectra closely resemble those obtained with the use of KBr pellets, but are considerably more convenient to obtain.

Raman spectra of pezzottaite, aquamarine, morganite, and red beryl were obtained with a Renishaw 1000 microRaman system. Spectra were generated with both a 514.5 nm argon-ion laser and a 782 nm laser diode. Similar spectra were obtained with both lasers, although less fluorescence was excited with the 782 nm laser. In no case, however, did the fluorescence hinder the measurement. All spectra were obtained with a depolarizer positioned before the samples, in orientations both parallel and perpendicular to the c-axis. The sloping baseline in the spectra was corrected using a built-in Grams software function and normalized to the intensity of the ~684 cm^{-1} band.

Powder X-ray diffraction analyses of pezzottaite and aquamarine were performed using a Scintag instrument with an accelerating voltage of 35 kV and a beam current of 15 mA.

RESULTS

Crystal Forms and Visual Appearance. *Rough.* The pezzottaite crystals showed hexagonal symmetry and consisted of three main forms in various degrees of prominence: the pinacoid *c* {0001}, pyramid *d* $\{10\bar{1}2\}$, and prism *m* $\{10\bar{1}0\}$ (figures 13 and 14). Although not present on our samples, small second-order pyramid and prism faces have been documented (Warin and Jacques, 2003). The samples showed

TABLE 1. Samples of pezzottaite from Ambatovita, Madagascar, and other samples analyzed for this study.

Samples (pezzottaite unless otherwise noted)	Method of analysis	Analyzed at:[1]	Notes
19 total, all purplish pink: 10 faceted (0.89–6.26 ct) 7 cabochons (1.16–8.78 ct) 1 crystal (7.5 grams) 1 partially polished fragment (1.64 ct)	*Gemological characterization:* R.I., S.G.[2], optic character, Chelsea filter reaction, UV fluorescence, absorption spectroscopy, and microscopic examination	GIA	Two of the faceted stones (1.18 and 3.42 ct) were analyzed by electron microprobe at UNO.
4 purplish pink fragments (~2 mm), derived from one crystal	*Color stability:* One fragment held as a control, one fragment irradiated but not heated, and two fragments heated in air for 2 hours at different temperatures: 250, 350, and 450°C. The 450°C sample was irradiated by 6 Mrads of Cs-137 gamma rays, at 0.9 Mrads per day	Caltech	Another piece of this sample was also used for ATR IR spectroscopy.
11 total, all purplish pink: 3 faceted (0.31, 1.18, and 3.42 ct) 6 polished fragments 1 polished plate (5.08 mm thick) 1 sliced crystal	Chemical analysis by electron microprobe (total of 49 point analyses)	UNO	R.I. values were obtained at UNO on the fragment with the lowest Cs content. Polished plate also used for Vis-NIR spectroscopy.
8 purplish pink etched crystals (0.15–1 g)	Morphological observations	UNO	
2 fragments (~300 mg each)	Loss on ignition (for H_2O)	UNO	
2 samples (275.6 and 21.0 mg)	Inductively coupled plasma spectrometry (for Li)	UNO	
1 purplish pink fragment (~1 ct)	Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS)	ETH	R.I. values and density (measured by a Berman balance) were obtained at GRS Swisslab on this fragment, which had the highest Cs content measured in this study.
1 purplish pink polished plate (5.08 mm thick)	Visible-NIR spectroscopy[3]	Caltech	Spectrum reported in Simmons et al. (2003).
1 polished plate of pale pink morganite, Brazil (1.97 g)			Same sample was used for Raman spectroscopy.
1 polished plate of red beryl, Wah Wah Mts., Utah (0.38 g)			Same sample was used for Raman spectroscopy.
1 polished plate of red beryl, Thomas Range, Utah			
1 purplish pink powdered sample	Attenuated total reflectance (ATR) IR spectroscopy	Caltech	
1 powdered sample of pale pink morganite, Brazil			From the same sample used for Vis-NIR and Raman.
1 powdered sample of red beryl, Wah Wah Mts., Utah			
2 purplish pink polished plates (6.9 and 0.4 mg)	Raman spectroscopy	Caltech	
1 polished plate of pale pink morganite, Brazil (1.97 g)			
1 polished plate of red beryl, Wah Wah Mts., Utah (0.38 g)			
1 polished plate of pale blue aquamarine, Minas Gerais, Brazil (0.38 g)			
1 purplish pink powdered sample (~80 mg) 1 powdered sample of pale blue aquamarine, Erongo Mts., Namibia (~80 mg)	X-ray powder diffraction	UNO	

[1] Abbreviations: Caltech = California Institute of Technology, ETH = Eidgenössische Technische Hochschule, UNO = University of New Orleans.

[2] Note that the S.G. value of the partially polished fragment was not included, owing to inconsistent results that were probably due to trapped air bubbles within surface irregularities.

[3] Spectra were obtained at approximately 1.5 nm resolution.

varying degrees of etching and corrosion, with residual light-colored spongy masses present along the prism areas of some crystals. The underlying vitreous surfaces (seen where the spongy masses broke off or were entirely removed by corrosion) commonly showed a series of microsteps in reflected light. Warin and Jacques (2003) interpreted these surfaces as resulting from the original crystal growth, rather than corrosion, but this interpretation is not supported by our observations.

Besides the spongy corroded areas mentioned above, all of the samples were purplish pink. Dichroism (described below) was not readily seen when observing our samples with the unaided eye (due to their relatively small size), but it is quite obvious in larger samples (see, e.g., figures 14 and 15).

Polished. The polished stones we examined were transparent to translucent, deep purplish pink, and evenly colored with no eye-visible color zoning (again, see figure 1). They displayed moderate to strong dichroism: pinkish orange to pink-orange when viewed down the c-axis (ω ray) and purplish pink to pink-purple perpendicular to the c-axis. In some larger stones, depending on how they were cut relative to the optic axis, the pink-orange pleochroism could be observed with the unaided eye.

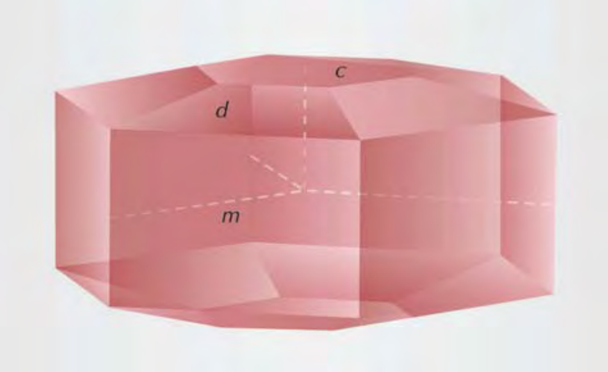
GEMOLOGICAL CHARACTERISTICS

Physical and Optical Properties. The results of gemological testing are summarized in table 2. The refractive indices of the faceted stones generally were n_o = 1.615–1.619 and n_e = 1.607–1.610 (birefringence 0.008–0.009), with the cabochons giving a spot reading of 1.61. As expected, the R.I. values of the fragment with the lowest Cs content (as analyzed by electron microprobe) were somewhat lower than those obtained on the faceted stones, at n_o = 1.612 and n_e = 1.601. The samples yielded S.G. values of 3.09–3.14. Although the S.G. values of our cabochons were not significantly influenced by the presence of growth tubes, it would not be surprising to obtain a lower S.G. for samples containing large numbers of them.

Pezzottaite is uniaxial negative, although several samples were anomalously biaxial in their optic figures, where the "brushes" were seen to come together and move apart slightly as a stone was rotated around the optic axis. This effect was most likely due to strain, which was visible in some of the samples when viewed parallel to the optic axis between crossed polarizing filters. The samples appeared faint orangy pink to pink-orange when viewed through a Chelsea color filter with a diffused light source; too strong a light source overpowered the reaction and the stone appeared yellow-green. All samples were inert to long- and

Figure 14. This well-formed crystal of pezzottaite (4.1 cm tall) exhibits a large pinacoid and subordinate pyramid faces. The small prism faces are not visible in this orientation, looking down the c-axis. Note the slightly pink-orange color that is typically seen down this axis. Corrosion resulted in the linear etch features on the crystal and the spongy matrix material that is stained brown by iron oxides. Courtesy of Dudley Blauwet Gems; photo © Jeff Scovil.

Figure 13. This idealized diagram shows the prominent faces of pezzottaite crystals, which consist of c *{0001},* d *{10$\bar{1}$2}, and* m *{10$\bar{1}$0} forms. The drawing was generated using Kristall2000 software that was developed by Klaus Schilling.*



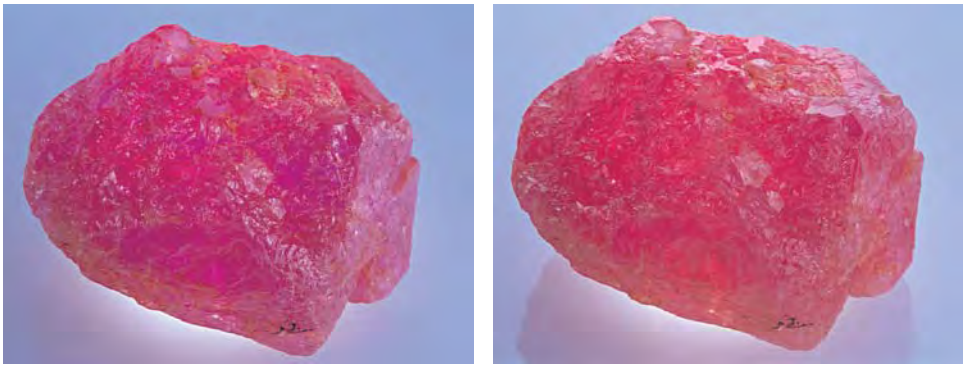


Figure 15. Pleochroism in purplish pink and pink-orange is clearly visible in this large piece of pezzottaite, which measures 4.9 × 3.1 cm. Photos by Maha Tannous.

short-wave UV radiation, although one sample did fluoresce a weak chalky yellow in the fractures, which indicated the presence of a filling material.

All samples displayed oriented absorption spectra with the desk-model spectroscope. When the spectrum was viewed with the stone parallel to the c-axis (down the optic axis), diffuse lines were visible at 465 and 477 nm, along with a band at approximately 485–500 nm. In some samples, these three features converged into a single broad absorption band. When viewed perpendicular to the c-axis, bands at approximately 485–500 and 550–580 nm were visible. In all other orientations, combinations of the above-listed absorption features were observed with varying intensities.

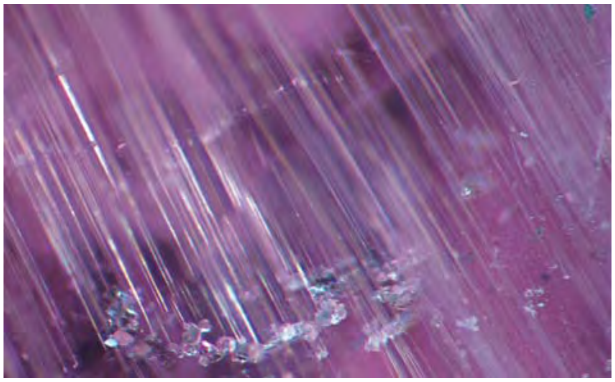
TABLE 2. Properties of pezzottaite from Madagascar.

Property	Description
Color	• Purplish pink • Moderate to strong dichroism: pinkish orange to pink-orange (ω ray) and purplish pink to pink-purple (ε ray)
Diaphaneity	Transparent to translucent
R.I.	• n_o = 1.615–1.619, n_e = 1.607–1.610 (faceted stones); spot reading = 1.61 (cabochons) • n_o = 1.612, n_e = 1.601 for polished fragment with the lowest Cs content • n_o = 1.620, n_e = 1.611 for polished fragment with the highest Cs content
Birefringence	0.008–0.009
Optic character	Uniaxial negative, with several samples showing anomalously biaxial optics
S.G.	Typically 3.09–3.11, with faceted stones—3.09–3.14, cat's-eye cabochons—3.09–3.11, and crystal—3.09
Chelsea filter reaction	Faint orangy pink to pink-orange
UV fluorescence	Inert to long- and short-wave UV radiation[a]
Spectroscope spectra	• Viewed parallel to optic axis: diffuse lines at 465 and 477 nm plus a band at 485–500 nm • Viewed perpendicular to optic axis: bands at approximately 485–500 nm and 550–580 nm
Internal features	Growth tubes, fractures, "fingerprints," and fluid inclusions (and, rarely, noticeable two-phase inclusions); transparent, near-colorless, low-relief birefringent crystals; transparent, grayish green tourmaline crystals; strain; rare color zoning

[a] *Weak chalky yellow fluorescence in fractures of one sample suggested the presence of a filling.*

Internal Features. All of the 19 samples we examined contained numerous fine growth tubes (figure 16) oriented parallel to the c-axis. When abundant, these tubes are responsible for the chatoyancy seen in cat's-eye pezzottaite. Some of these tubes had negative crystal "flare outs" along their length (figure 17). These features are indicative of an abrupt change in the growth environment (i.e., slower growth; J. I. Koivula, pers. comm., 2003). The intensity of strain seen between crossed polarizers seemed to increase with the number of growth tubes. Fractures, "fingerprints," and fluid inclusions also were present in all of the samples. Some of the samples contained transparent, near-colorless, low-

Figure 16. All of the pezzottaite samples examined contained numerous fine growth tubes oriented parallel to the c-axis. Some of the tubes shown here can be seen emanating from included crystals (identified as tourmaline). Photomicrograph by John I. Koivula; magnified 15×.



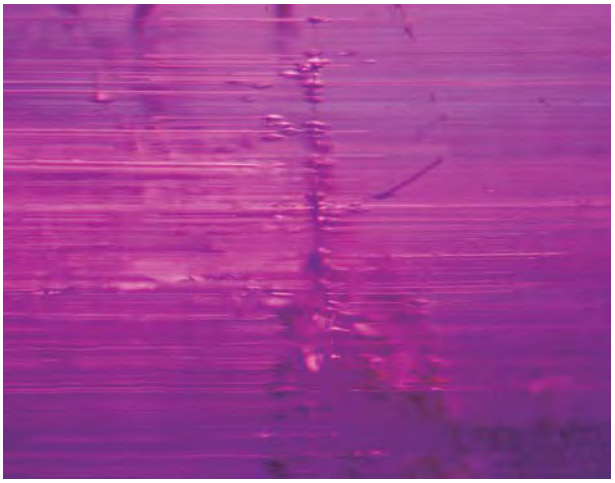
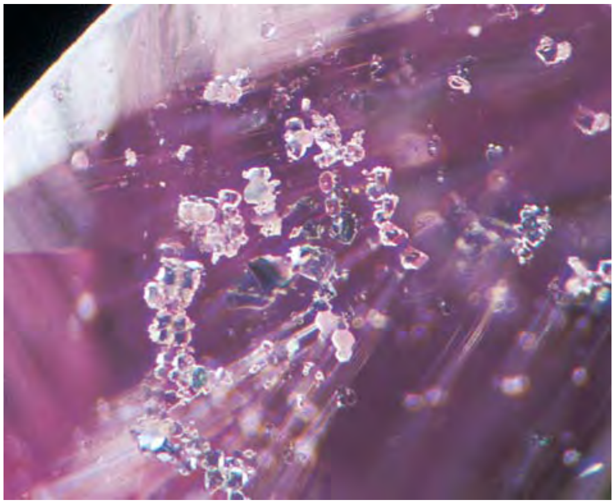


Figure 17. Negative crystal "flare outs" were sometimes seen along growth tubes in pezzottaite. Note the bipyrimidal form of these minute negative crystals. Photomicrograph by John I. Koivula; magnified 40×.

relief birefringent crystals, which could not be identified due to their small size and their position within the stones. A few samples contained transparent, grayish green, birefringent crystals that were identified (by Raman analysis) as tourmaline (figure 18). One sample contained obvious two-phase fluid and gas inclusions. This sample also showed color zoning, but we observed no notable growth or color zoning in the other samples.

Although the dealers who supplied the samples were not aware of any clarity enhancement, many of the samples showed fractures of low relief, some of which contained air bubbles that contracted when exposed to a thermal reaction tester, indicating the presence of a filling substance. Subsequently, we learned from Dudley Blauwet (pers. comm., 2003) that all of the pezzottaite rough he has purchased was oiled by the local Madagascar dealers. He reported that the oiling enables them to see into the rough easier (because of the slight etching on most of the crystal surfaces). While this may be true, pezzottaite, like many gem materials that tend to be fractured, can easily be clarity enhanced with oil or resin to improve its appearance.

Figure 18. Raman analysis identified the grayish green inclusions in this pezzottaite as tourmaline. Photomicrograph by John I. Koivula; magnified 15×.



Heating and Irradiation Experiments. When heated at 450°C, a purplish pink fragment of pezzottaite suffered a near-total loss of color, although no effect was noted at lower temperatures. The sample regained nearly all of its purplish pink color on irradiation with gamma rays.

CHEMISTRY

The highest Cs content was obtained on the sample analyzed by LA-ICP-MS: 18.23 wt.% Cs_2O (table 3). The 11 samples analyzed by electron microprobe had cesium contents ranging from 11.23 to 15.13 wt.% Cs_2O (again, see table 3). A similar range also was obtained from four samples analyzed by electron microprobe at the University of Manitoba by one of the authors (FCH; unpublished data). Calculations of Cs ions per formula unit yielded 0.504 to 0.833.

Minor amounts of Rb and Na were also measured in all samples. Manganese, the chromophoric element in pink beryl, ranged up to 0.19 wt.% MnO, with the average being 0.11 wt.%. Mg, K, Sc, Ti, and Fe were either below the detection limit or present only in trace amounts in some samples. Many other elements were looked for, but not detected (see footnote to table 3). To view all 49 electron microprobe analyses, see table 1 in the *Gems & Gemology* Data Depository at www.gia.edu/gemsandgemology.

SPECTROSCOPY

Vis-NIR. With the beam oriented down the c-axis (or E⊥c), the Vis-NIR absorption spectrum of purplish pink pezzottaite is dominated by a band centered at 494 nm, with a distinct shoulder at 476 nm (figure 19). A second absorption band at 563 nm appears in the same polarization, along with a

TABLE 3. Chemical analyses of pezzottaite from Ambatovita, Madagascar, by LA-ICP-MS and electron microprobe.[a]

	LA-ICP-MS	Electron microprobe[b]		
		Lowest Cs[c]	Highest Cs[d]	Average[e]
Oxide (wt.%)				
SiO_2	54.58	57.01	56.27	56.77
TiO_2	0.01	bdl	bdl	bdl
Al_2O_3	16.88	16.69	16.11	15.99
Sc_2O_3	nd	0.05	0.01	0.03
BeO	8.14	8.25	8.09	8.14
FeO	0.02	bdl	bdl	bdl
MnO	0.02	0.18	0.11	0.11
CaO	0.22	bdl	bdl	bdl
Li_2O	2.12	2.16	2.16	2.16
Na_2O	0.46	0.43	0.26	0.41
K_2O	0.14	0.08	0.10	0.11
Rb_2O	0.44	0.78	0.77	0.85
Cs_2O	**18.23**	**11.23**	**15.13**	**13.55**
H_2O	nd	1.72	1.72	1.72
Total	101.26	98.58	100.74	99.84
Ions per 18 oxygens, anhydrous basis				
Si	5.860	6.001	6.004	6.030
Ti	0.001	0.000	0.000	0.000
Al	0.139	0.000	0.000	0.000
tet.	6.000	6.001	6.004	6.030
Be	2.098	2.086	2.073	2.077
Li	0.917	0.914	0.927	0.923
Be+Li	3.016	3.000	3.000	3.000
Al	1.996	2.070	2.026	2.000
Ca[f]	0.025	0.000	0.000	0.000
Sc	nd	0.005	0.001	0.002
Mn	0.002	0.016	0.010	0.010
Fe^{2+}	0.001	0.000	0.000	0.000
oct.	2.024	2.091	2.037	2.012
Na	0.095	0.087	0.054	0.085
K	0.019	0.011	0.014	0.015
Rb	0.030	0.053	0.052	0.058
Cs	**0.833**	**0.504**	**0.688**	**0.617**
channel	0.977	0.655	0.808	0.775

[a] *Abbreviations: nd = not determined, bdl = below detection limit.*

[b] *For the electron microprobe data, values for lithium (by ICP) and water (by LOI) were measured for two samples (Simmons et al., 2003). The measured Li_2O value was then used as the best approximation for calculating beryllium (Be+Li = 3) and the other ions per formula unit for all samples analyzed. The H_2O value is considered anomalously high due to the presence of microscopic tubules that are filled with an aqueous fluid (consistent with the granitic pegmatite environment). The low analytical totals (as calculated without water) are attributed to the abundance of these fluid-rich inclusions. Crystal structure refinement of a sample by FCH indicated only 0.28 wt.% H_2O in the channels. The following were analyzed by electron microprobe but were below the detection limits (shown in wt.%): MgO (0.01), TiO_2 (0.002), FeO (0.02), CaO (0.07). In addition, the following were checked for (scanned), but not detected: Cr_2O_3 (0.03), Bi_2O_3 (0.03), V_2O_3 (0.03), PbO (0.01), ZnO (0.08), BaO (0.03), Cl (0.04), F (0.05).*

[c] *Fragment of a purplish pink sample.*

[d] *Polished plate used for Vis-NIR spectroscopy reported in Simmons et al. (2003).*

[e] *Average of 49 analyses of 11 samples.*

[f] *Ca is assumed present in the octahedral site, but it may occur elsewhere in the beryl structure.*

broad band that is centered at 820 nm in the near-infrared region. The maximum transmission occurs near 630 nm (orange-red) and in the low-400 nm range (deep violet), which provides the pinkish orange pleochroic color in this direction. When the beam is oriented perpendicular to the c-axis (i.e., E||c), the spectrum is dominated by a band centered at 572 nm. A weak absorption band in the near-infrared region is also present at 820 nm. Transmission in the other regions of the spectrum combine to produce a purplish pink color for light polarized in this direction.

Other Methods. The infrared and Raman spectra, as well as X-ray diffraction patterns, of pezzottaite are briefly described here, and can be viewed in the *Gems & Gemology* Data Depository.

The ATR infrared spectrum generally resembled that of beryl (i.e., morganite and red beryl), with some shifts in wavenumbers and relative intensities. The most prominent differences were evident at higher wavenumbers; the absorption in the 1400–1100 cm^{-1} region occurs at a much higher wavenumber in pezzottaite than in the other minerals. The absorption in the region from about 1200 to 800 cm^{-1} correlates to various Si–O and Be–O bands (Hofmeister et al., 1987).

The characteristic feature of the pezzottaite Raman spectrum was the 1100 cm^{-1} band, which has not been observed in the spectra of other pink or red beryls or pale aquamarine. This band was present in Raman spectra obtained from both the (0001) and the ||c face.

In the X-ray diffraction pattern of pezzottaite, some important peaks typical of beryl were absent or very much weaker in intensity. Indexing of these patterns indicated that the affected peaks corresponded principally to *h*00 type reflections.

DISCUSSION

Cs in Beryl and Pezzottaite. Alkali beryls containing Cs have been informally referred to in the literature by some mineralogists as *vorobievite*—commonly for the pink Li-Cs variety—and *rosterite*—typically for the near-colorless Na-Li type (Beus, 1966; see also Zambonini and Caglioti, 1928; Rossovskiy, 1981). *Morganite* is the most common term used to refer to gem-quality pink beryl; this color variety commonly contains Cs. The amount of Cs (and other alkalis) that is incorporated into beryl has been correlated to the local abundance of

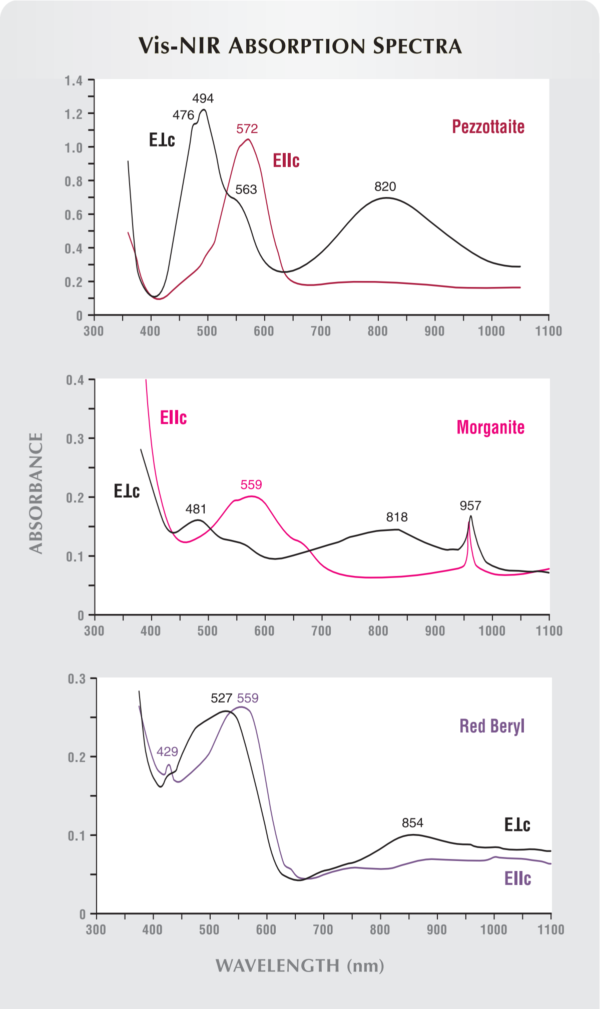


Figure 19. Representative polarized Vis-NIR spectra are shown here for a 5.08-mm-thick slice of pezzottaite (top), a 10.79-mm-thick slice of morganite from Brazil (middle), and a 0.72-mm-thick slice of red beryl from the Thomas Range, Utah (bottom). The pezzottaite is dominated by bands centered at 494 and 563 nm when the beam is oriented down the c-axis (or E⊥c), and a band centered at 572 nm when the beam is oriented perpendicular to the c-axis (i.e., E∥c). The difference in these absorptions accounts for pezzottaite's moderate dichroism in purplish pink and pink-orange. The morganite shows similar absorptions that are shifted somewhat and not as intense. This relatively thick sample also shows overtones of the water absorption near 957 nm. The red beryl shows intense absorptions centered at 527 and 559 nm; the minimal difference between the two red beryl spectra corresponds to the lack of noticeable pleochroism in this material.

such elements in the growth environment (Černý, 1975). The alkalis reside in the channel site, and are accommodated into the beryl structure through coupled substitutions (see box A).

The concentrations of the alkali elements Cs, Rb, and Li have been measured in beryl from a variety of geologic environments (Staatz et al., 1965). The greatest amounts of these elements have been found in beryl from the inner zones of granitic pegmatites, since this is where such elements—which are incompatible with common pegmatite minerals such as quartz and feldspar—are concentrated during crystallization (Beus, 1966; Černý, 1975; Zagorsky et al., 1999; Černý et al., 2003). Geochemically, pegmatitic beryl samples with the highest Cs contents generally also show low values of Na/Li. Typically, high-Cs beryls range up to 4 wt.% Cs_2O, although there are a few notable exceptions (table 4). At 11.3 wt.% Cs_2O, it is probable that the Madagascar sample studied by Evans and Mrose (1966) was pezzottaite. Furthermore, Černý (1972) reported that minute crystals of late hydrothermal beryl from the Tanco pegmatite had R.I. values exceeding those reported by Evans and Mrose (1966). Although they were not chemically analyzed, and specific R.I. values were not reported, these crystals also may have corresponded to pezzottaite.

According to Dr. H. A. Hänni (pers. comm., 2003), the Afghanistan sample with 9.70 wt.% Cs_2O reported by Hänni and Krzemnicki (2003) is actually pezzottaite (based on its unit-cell dimensions). Therefore, this sample has the lowest Cs content found in pezzottaite so far. The highest concentration of Cs measured in pezzottaite was obtained on samples from Madagascar by Abduriyim and Kitawaki (2003), who measured 19.76–21.33 wt.% Cs_2O by X-ray fluorescence spectroscopy and up to 23.37 wt.% Cs_2O by LA-ICP-MS.

Early studies showed a strong relationship between alkali content and refractive indices (as well as specific gravity) in beryl from Madagascar (see, e.g., Ford, 1910; Lacroix and Rengade, 1911; Lacroix, 1912). More recently, the relationship between composition and optical/physical properties was documented in beryl from several localities (reviewed by Deer et al., 1997).

Černý and Hawthorne (1976) pointed out that factors in addition to alkali content can influence R.I. values, so a simple mathematical relationship between them is impossible to generalize. This is shown by the high R.I. values reported for Cs-rich beryl in the literature (table 4). (Note that the high properties of the Arizona sample were attributed to enriched contents of both Fe [4.69 wt.% "oxides"] and Cs.) Since Cs is a relatively heavy element, significant concentrations of it would be expected to

BOX A: STRUCTURE OF BERYL AND PEZZOTTAITE, AND DEFINITION OF THE MINERAL

How is Cs (a relatively large ion) incorporated into the beryl structure? This mechanism was studied by Hawthorne and Černý (1977), and examined in more detail (particularly for lithium) by Sherriff et al. (1991). A useful review of beryl crystal chemistry was provided by Černý (2002), and the current consensus was summarized by Černý et al. (2003, p. 1006): "lithium substitutes for Be^{2+} in the tetrahedra linking the six-membered Si_6O_{18} rings, with the charge balance assured by Na^+ and Cs^+ in the channels passing through the centers of the vertically stacked rings. Sodium is accommodated in the centers of the individual rings of [silicate] tetrahedra, but the larger Cs^+ is located halfway between these centers" along the c-axis. The increase in charge caused by the incorporation of alkalis into the channel is compensated by replacement of Be by Li at a tetrahedral site.

Pezzottaite, ideally $Cs(Be_2Li)Al_2Si_6O_{18}$, is not isostructural with beryl, ideally $Be_3Al_2Si_6O_{18}$. However, the arrangement of the atoms in each structure is very similar, so the structures can be considered as very closely related. In beryl, the three Be atoms indicated in the formula occupy three symmetrically related positions. In pezzottaite, these three positions are occupied in an ordered fashion by Be_2Li rather than Be_3 (as in beryl). Thus, these positions in pezzottaite are no longer related by symmetry, so the symmetry of the mineral must change. As a result, pezzottaite differs from other members of the beryl group by having a different symmetry (rhombohedral rather than hexagonal) and a larger unit cell.

Further studies are needed to characterize the dividing line between pezzottaite and Cs-rich beryl, which is influenced by factors such as composition (Be-Li ordering), symmetry, and unit cell dimensions.

raise S.G. values as well. By comparison to the values reported in table 4, the theoretical specific gravity of beryl that has been calculated using X-ray diffraction measurements is 2.661 (Deer et al., 1997).

Origin of Color. An early study by Wood and Nassau (1968) attributed the color of morganite to Mn^{2+} and that of red beryl to Mn^{3+}, an assignment that Schmetzer et al. (1974) reiterated. Platonov et al. (1989) re-examined the spectra of manganese-containing beryls and concluded that Mn^{3+} is responsible for the color of both red beryl and morganite. Likewise, Solntsev and Bukin (1997) concluded that the pink morganite from Mozambique is colored by Mn^{3+} (specifically, *d-d* transitions in Mn^{3+} in the aluminum site).

In the visible range of the spectrum, the most significant difference between pezzottaite and morganite is the overall greater absorption intensity of pezzottaite, corresponding to its deeper color (figure 19). In fact, the spectra of the pezzottaites we studied have 5.3 times greater absorbance per centime-

TABLE 4. Properties of high-Cs beryls and pezzottaite.[a]

Description	Wt.% Cs_2O	n_o	n_e	S.G.	Reference
"Bluish" beryl from Arizona	6.68	1.608	1.599	2.92	Schaller et al. (1962)
Beryl from Tanco, Bernic Lake district, Canada	7.16	nr	nr	nr	Černý (1972)
Morganite from Madagascar	7.52	nr	nr	nr	Cabell and Smales (1957)
Pezzottaite from Afghanistan	9.70	1.604	1.598	2.91	Hänni and Krzemnicki (2003)
Pezzottaite from Madagascar	11.23	1.612	1.601	nd	This study (lowest Cs)
"Cesium beryl" from Antsirabe area, Madagascar	11.3	1.608	1.601	3.01	Evans and Mrose (1966)
Pezzottaite from Madagascar	18.23	1.620	1.611	3.09	This study (highest Cs)

[a] *nr = not reported, nd = not determined*

Figure 20. As seen in the photo on the left, cat's-eye pink tourmaline (left stone, 9.59 ct) is very similar in appearance to pezzottaite (right stone, 8.78 ct). However, they can be readily separated by their pleochroism, which is stronger in pezzottaite. This effect can be seen in the center and right photos, which were taken through a polarizing filter at different orientations. The pezzottaite is courtesy of William Pinch and the tourmaline is from the GIA Collection (no. 5738); photos by Maha Tannous.

ter than the one for morganite presented in Platonov et al. (1989). The spectrum of our morganite was similar to the Platonov et al. data, but was a factor of 10 less intense. While the spectrum of red beryl (again, see figure 19) shows absorption bands at generally the same wavelengths, their intensity distribution is distinct. The stability of the color of red beryl at high temperatures suggests that its color is not due to irradiation, and thus leads to the speculation that manganese in red beryl was originally present as Mn^{3+} during crystallization. In contrast, the instability of the manganese-derived color in morganite and pezzottaite at modest temperatures leads to the speculation that these gems originally formed containing Mn^{2+}, but became pink as a result of exposure to natural ionizing radiation after crystallization. The presence of such radiation in the Sakavalana pegmatite is demonstrated by the common association of smoky quartz with morganite and pezzottaite in the gem-bearing cavities; the radiation may be derived from radioactive trace minerals or the isotope ^{40}K in K-feldspars.

Previous studies (Nassau, 1984) have shown that some pink beryls, when decolorized by heat, regain their color upon irradiation with X-rays or gamma rays. This is consistent with our results for pezzottaite, and the sensitivity to heating and irradiation supports our proposal that the color of pezzottaite is caused by radiation-induced color centers involving Mn^{3+}.

It may be tempting to correlate the pink color of pezzottaite (as well as high-Cs morganite) with cesium, but this element has been ruled out as a chromophore in beryl (Ristic and Eichoff, 1955; Sinkankas, 1981). Although Cs-rich beryls do commonly have a pink color, this is probably due to the simple fact that Cs and Mn follow each other geochemically toward the end of crystallization in granitic pegmatites (see Černý et al., 1985). Thus, it is likely that both Cs and Mn will be present during the crystallization of beryl (or pezzottaite) in pegmatite pockets.

Identification. The identification of pezzottaite should be straightforward once the gemologist is familiar with its properties and a flat surface for an R.I. reading is available. The optical and physical properties of pezzottaite are distinct, particularly when compared to the varieties of beryl that it resembles—morganite and red beryl.

All of the samples of pezzottaite we examined were purplish pink. Although they varied somewhat in tone and saturation, their color was never the same as typical red beryl from Utah or its synthetic counterpart. This fact alone should prevent any confusion with these materials. In addition, the R.I. and S.G. values of pezzottaite are significantly higher than those of red beryl, for which the typical published values are n_o = 1.568–1.572, n_e = 1.564–1.569, and S.G. = 2.66–2.70 for natural material (Shigley and Foord, 1984), and n_o = 1.576–1.580, n_e = 1.569–1.573, and S.G. = 2.67–2.70 for the synthetic counterpart (Shigley et al., 2001). So far, pezzottaite has not been synthesized in the laboratory; the highest cesium content in synthetic beryl known to these authors is 2.39 wt.% Cs_2O (Shatskiy et al., 1981).

Some morganite may have a color similar to pezzottaite. However, the two can easily be separated gemologically by the distinctly lower R.I. and S.G. values of morganite (typically with R.I. values of n_o = 1.572–1.592 and n_e = 1.578–1.600, and S.G. = 2.71–2.90; Arem, 1987). Compared to pezzottaite, even high-Cs beryls have lower values (e.g., generalized by Schaller et al., 1962, as n_o = 1.599, n_e = 1.590, and S.G. ≈ 2.86).

The color of pezzottaite is almost the same as some tourmaline (figure 20, left). Pink tourmaline presents a more significant identification challenge than do other beryls, particularly since many of the finest examples of pezzottaite are cat's-eyes. When encountering a pink cat's-eye, the gemologist is likely to think of tourmaline, since there are few other materials of this color that show chatoyancy. The refractive index of a pezzottaite cabochon measured by the spot method will read ~ 1.61, which is very close to the 1.62 that one would expect from tourmaline. Microscopically, the inclusions in pezzottaite also resemble those in tourmaline, being mostly parallel acicular tubes and planes of liquid inclusions. Even if the equipment is available for measuring the S.G. hydrostatically, the value will fall into the range of tourmaline (typically 3.01–3.06 for pink to red material [Arem, 1987]).

So, how does one separate these two materials? A faceted stone should not pose a problem, since an accurate refractive index measurement will clearly separate the two gem minerals. If a gemologist is good at taking spot R.I. readings, a value of 1.61 should be enough to warrant closer inspection. The pleochroism in pezzottaite is more pronounced than in pink tourmaline (figure 20, center and right). The purplish pink and pink-orange pleochroic directions also are different for these two materials, and their visibility in a sample will depend on the orientation of the polarizer. The best way to check the pleochroism would be to compare an unknown sample with a known piece of pink tourmaline. A desktop spectroscope can also be very useful, since the two minerals have distinctly different spectra; pink to red tourmaline typically shows narrow lines at 450 and 458 nm, and a broad region of absorption that is centered at ~ 525 nm (Webster, 1994). Of course, the best way to avoid misidentifying a pezzottaite cat's-eye as tourmaline is to be aware of the existence of this new mineral.

Additional Comparisons to Morganite and Utah Red Beryl. The chemical compositions of pezzottaite, morganite, and red beryl are distinct. Besides being virtually anhydrous, red beryl contains much higher amounts of Fe, Ti, Mn, and other trace elements (Shigley et al., 2003; see also table 2 in the *G&G* Data Depository). Morganite shows ranges of Fe, Ti, and Mn similar to those of pezzottaite, although the latter may contain significantly more Mn (typically <0.05 wt.% in morganite, vs. an average for this study of 0.11 wt.% MnO in pezzottaite).

Differences between pezzottaite and beryl in the infrared and Raman spectra, as well as in X-ray diffraction patterns (again, see Data Depository), appear distinctive and therefore provide additional criteria for separating the two minerals. What is not known at this time is how these properties vary with Cs content, and if beryls with intermediate levels of Cs can be distinguished from pezzottaite on the basis of these techniques.

Figure 21. Although considered a collector's stone due to its rarity, pezzottaite has been set into some attractive jewelry. This gold ring, containing a 5.25 ct pezzottaite, was created by Francis Bonnet of Polychrome France Co., Chambray-lès-Tours. Courtesy of Laurent Thomas.

Although these authors do not have first-hand experience with mounting pezzottaite in jewelry, the material is expected to behave similar to beryl in normal manufacturing, wear, and care conditions.

CONCLUSION

Due to its high Cs and Li contents and a structure that shows differences from beryl, pezzottaite has now been recognized as the fourth mineral of the beryl group. Unlike most new mineral species identified in recent years, pezzottaite was found as relatively large, well-formed crystals and fragments, and some of the rough proved suitable for cutting attractive gems (figure 21). The enriched Cs content gives rise to some of its properties, which permit a straightforward separation from beryl and other pink gem minerals, except for cabochons of pink tourmaline, which can be identified by their dichroism and absorption spectra.

Significant amounts of gem-quality pezzottaite thus far have been found only at the Sakavalana pegmatite in a remote area of central Madagascar. Although the pegmatite has been mined since the 1940s for tourmaline, pezzottaite was not recovered there until mid-November 2002. The mineralized area has been mostly mined out by artisanal methods, so any future production of pezzottaite will depend on the use of mechanized mining and systematic exploration of the deposit. With the recognition of this material as a new gem mineral, it is also possible that it will be identified in other granitic pegmatites.

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