# THE CHALLENGE OF THE IDENTIFICATION OF A NEW MINERAL SPECIES: EXAMPLE "PEZZOTTAITE"

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## IDENTIFYING A NEW GEM MINERAL

In 2002, a new gem mineral of commercial importance was discovered. In accordance with the need for all new mineral discoveries to be scientifically characterized (see Nickel and Grice, 1998), the gemological community anxiously awaited the results of tests to positively identify the new mineral (Hawthorne et al., 2003, Hawthorne et al., submitted and Laurs et al., 2003). This period of analysis brought into play the question: Exactly what procedures are necessary for the positive characterization of a new mineral?

These principal steps of identification are illustrated in the following case study for identifying a new mineral of the beryl group - pezzottaite.

The identification of this new mineral provided two major challenges: first, the determination of the exact chemical composition, and secondly, the identification of its crystallographic structure (the geometrical arrangement of the atoms in three dimensions (see Box 1, Figs. P2 and P6). From special technique of analysis (Boxes 4 and 5A), the exact stoichiometric chemical formula, and the space group of this new mineral, have to be determined (Box 1). As soon as the mineral was characterized (Boxes 1-6), the differences between already existing minerals had also to be investigated (see Nickel and Grice, 1998 and Box 5B) and a decision had to be made regarding whether a new mineral had been found, and, if so, what would be its new name? (Hawthorne et al., 2003 and Box 6). In the case of pezzottaite, these analysis provided major challenges. As pezzottaite contains light elements - such as hydrogen, lithium, and beryllium, which cannot be directly analyzed by quantitative methods commonly used for mineral analysis such as electron microprobe (EMPA) or XRFanalysis - direct measurement by Laser Ablation Mass Spectroscopy was also used (see Box 4B and Fig. P16), as well as conventional methods used for chemical analysis (Box 4A). In addition to challenges in the analysis of chemical composition, determination of different atomic positions in the crystal structure was not trivial. A combination of various analytical techniques was necessary (Figs. P3 and P17) to finally elaborate the structural differences to beryl (Figs. P1 and P2 and Box 5B). It was discovered that the unit-cell of pezzottaite had unusually large dimensions, which is best described as a superstructure of conventional beryl (Figs. P1, P2 and P6). Also, the number of atoms necessary to define the crystal structure turned out to be unusually high in comparison with other beryl- group minerals (Boxes 1 and 5).

## ANALYZING THE CRYSTAL STRUCTURE

The secrets of the nature of a new mineral are so small we cannot even identify them with the help of microscopic magnification. One way to explore this atomic world is with X-rays (Figs. P3 and P17).

X-rays have a very short wavelength (with dimensions similar to atoms), allowing them to penetrate and interact with atoms in a mineral structure. As atoms group together at very short distances, X-rays are diffracted when passing through a crystal and change their direction when they interact with them. Furthermore, diffracted X-rays interfere with each other, just like water waves emerging from two ships. The interaction between atoms and X-rays depends, among other factors, on the geometrical arrangement of the atoms and can be interpreted with X-ray diffraction diagrams, and computer calculations. A

## THE SUPERSTRUCTURE: THE DIFFERENCE BETWEEN THE TWO MINERALS "BERYL" AND "PEZZOTTAITE"

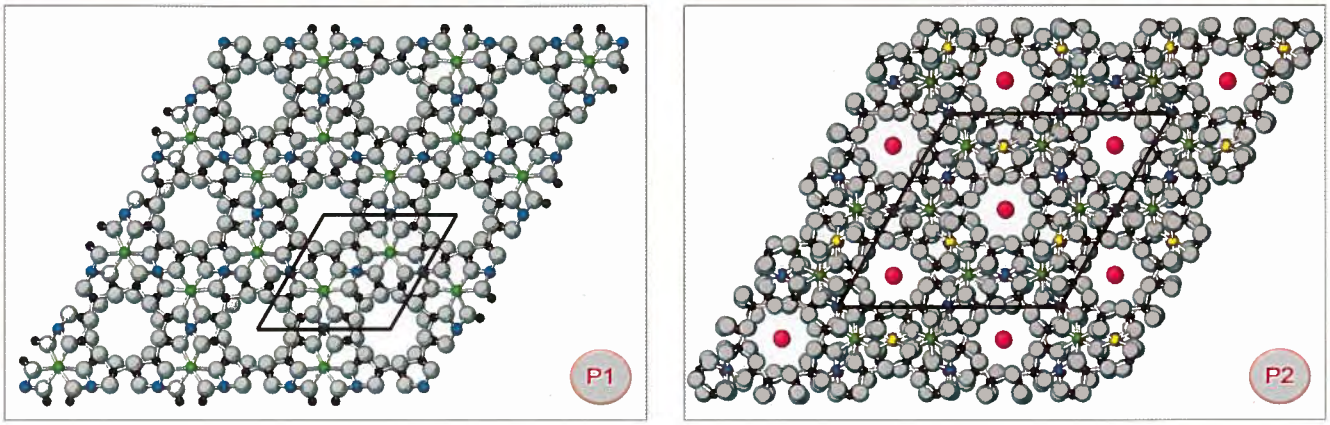



***Fig. P1-2*** *Ball-and-stick models of beryl (Fig. P1) and pezzottaite (Fig. P2). A projection of the crystal structure in the direction of the c-axis is shown in order to explain some details of the ring systems in these two minerals. The size and position of the unit-cell (as seen perpendicular to the c-axis) is also shown. Green balls = aluminium cations (Al), blue = beryllium (Be), yellow = lithium (Li), red = caesium (Cs), grey = oxygen (O), black = silicon (Si). The structure of beryl is characterized by six-membered rings of $SiO_4$ tetrahedra alternating along the c-axis with twelve-membered rings composed of alternating $BeO_4$ and $AlO_6$ polyhedra. In the mineral pezzottaite, an arrangement of beryl-like rings is found, but there are two different types of twelve-membered rings: (1) Those identical to the corresponding rings in beryl, and (2) those assembled of $LiO_4$, $BeO_4$ and $AlO_6$ polyhedra. To allow for the ordered (Be, Li) distribution in the structure of pezzottaite, the unit-cell had to be enlarged relative to beryl (compare P1 and P2). Both models are represented in hexagonal settings for better comparison. It must be remembered, however, that pezzottaite has a rhombohedral crystal lattice and beryl has a hexagonal lattice. In trigonal/rhombohedral symmetry, the highest symmetry element is a three-fold rotation axis, whereas in hexagonal symmetry a six-fold rotation axis is required.*

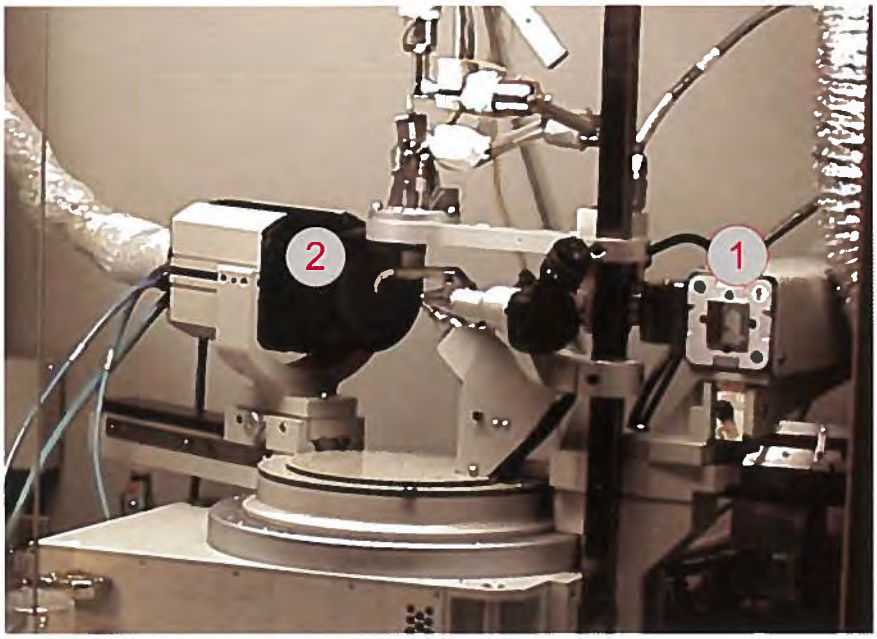



***Fig. P3 Single crystal X-ray diffractometer***
*One of the instruments used for the analysis of the crystal structure of the new mineral pezzottaite. Critical parts of the instrument include an X-ray generator (1), a multichannel X-ray detector (2), and utilizing the latest computer software for visualization and analyzing signals (not shown). X-ray can be used to compute the geometrical arrangement of atoms (Figs. P1,2 and P6) in a mineral. The result leads to the determination of crystal structure details (Box 5A).*

diffraction pattern of a single crystal consists of symmetrically arranged spots, where the spot separation determines the periodicity of the lattice (unit-cell dimensions) and the arrangement of the spots provides clues to the symmetry of the structure.

Finally, the unit-cell and the space group can be determined (Boxes 1 and 5A). This is a crystallographic code that identifies the crystallographic nature of a mineral.

## MATERIALS

The new gem material was first introduced to the international mineralogical community at the Tucson show in February 2003, where it was recognized as a mineral of unusual gemological properties not referenced in world literature (see Laurs et al., 2003). For details on materials tested, see Hawthorne et al. (submitted) and Laurs et al. (2003). Three of the totally tested samples are officially registered reference materials (Box 6). They are deposited in the USA, Canada and in Switzerland.

The samples analyzed by the Swiss team are shown in Figs. P4-P5, P7-8, P12-13 and Box 7. Three samples were investigated by chemical and crystallographic investigation. These include 0.5cm-sized samples obtained from the large mother piece (Fig. P5). One of the small fragments entered the collection as a type locality specimen (Box 6).

## THE APPLICATION TO THE COMMISSION ON NEW MINERALS AND MINERAL NAMES

The Swiss research group (authors 1-4) filed an application to the Commission on New Minerals and Mineral Names of the International Mineralogical Association (CNMMN, http://www.geo.vu.nl/users/ima-cnmmn/), stating that they had characterized a new mineral. The chairman of CNMMN informed the Swiss team that he had just received a proposal for the same mineral from a different research group (US-Canadian, authors 5-8). He further stated that both proposals were complementary to each other. An agreement was established that both groups' information and data should be merged and a new joint proposal should be submitted. Subsequently, CNMMN members decided unanimously that the new mineral should be accepted with the name 'pezzottaite'.

Box 1 to 6 summarized original data of the merged IMA application submitted by:

Hawthorne F.C., Cooper M.A., Peretti A., Simmons W.B., Armbruster T., Rossman G.R., Günther D., Laurs B.M., Grobéty B. (2003)

Check-list for new mineral proposals: Pezzottaite. Proposal submitted to the International Mineralogical Association, 8 pp. Application No. 2003-022.

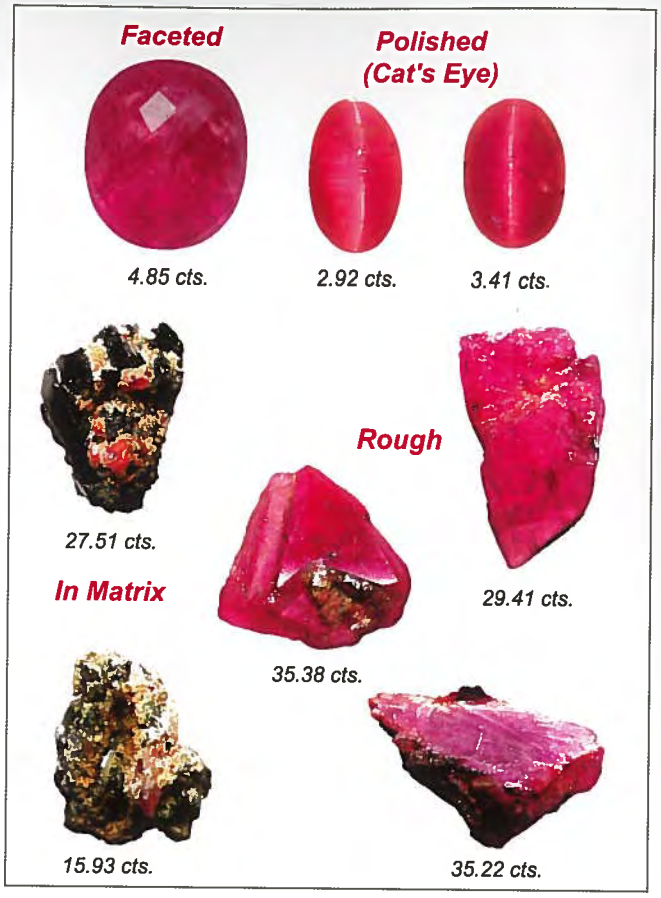



***Fig. P4*** *A reference set of pezzottaite including a faceted sample of 4.85 ct, 2 pezzottaite cat's eyes, 2 tabular rough crystals (35.38ct, 29.41ct), 1 large crystal fragment with matrix (35.22 ct), 2 tabular pezzottaite crystals with host rock, and one with tourmaline intergrowth (27.51 ct). On public display at the Natural History Museum of the University of Fribourg (Switzerland), GRS collection.*

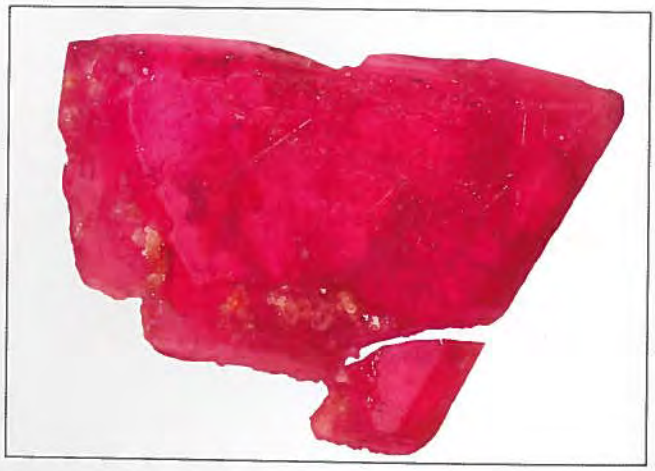
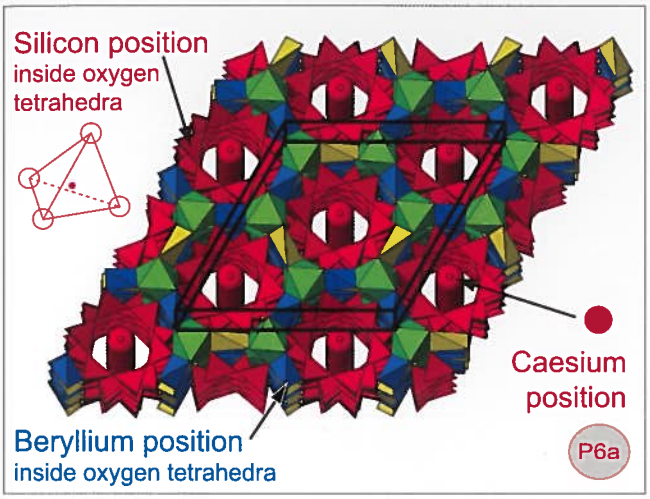
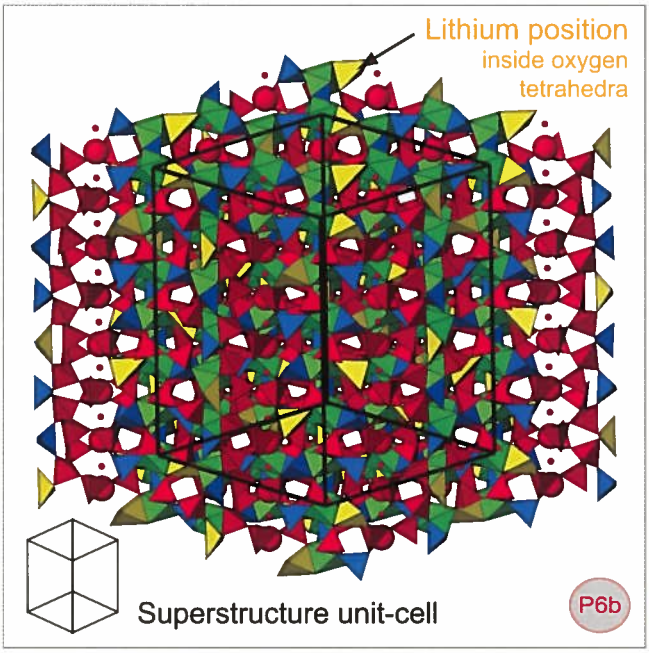


***Fig. P5*** *Pezzottaite tabular crystal of 29.41ct and a broken part of it (lower right), which served as the sample used for the Swiss team's detailed chemical and crystallographic investigations. The lower right piece parted in 3 different fragments which are currently at the University of Berne (see Box 6), the University of Fribourg, and the SFIT (Switzerland). The remaining motherpiece of 29.41 ct is in the GRS collection.*

# ROTATING PEZZOTTAITE CRYSTAL MODEL



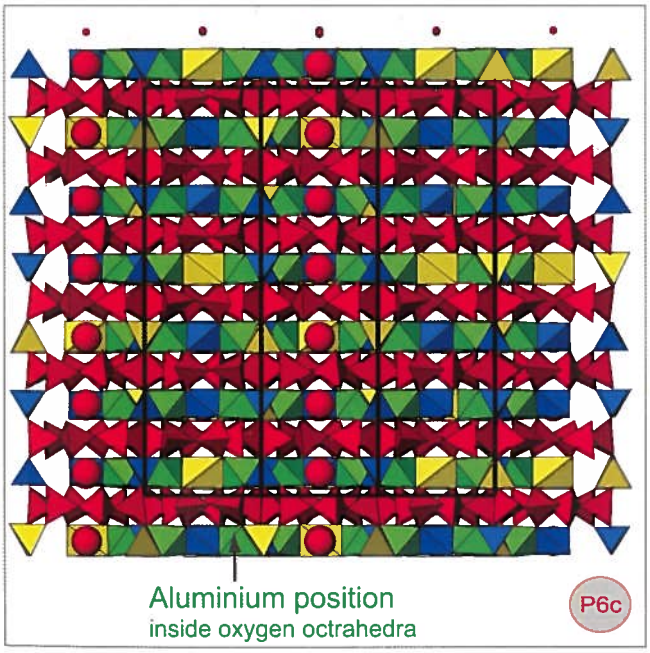




***Fig.P6a-c***
*NEW RHOMBOHEDRAL SUPERSTRUCTURE OF PEZZOTTAITE.*

*Crystal structure model with oxygen polyhedra surrounding a cat ion in the centre. Yellow oxygen tetrahedra: containing lithium (Li), blue tetrahedra with beryllium (Be), red tetrahedra with silicon (Si), green octahedra with aluminium (Al), and red spheres indicating caesium (Cs) positions. Solid outlines mark the superstructure cell. Substitutions in tetrahedral and octahedral positions by other elements such as Ti, Ca, Mn, Fe, Na, K, Rb and Sc see Laurs et al. (2003) and Box 4B.*

*Rotating the crystal model of pezzottaite (P6a-c) shows the arrangement of caesium (Cs) in the direction of the c-axis within the channels. The Cs atoms are surrounded by six-membered rings involving Si, and 2 different types of twelve-membered rings. One ring is composed of Be and Al and the second composed of Be, Al and Li. With further rotation of the unit-cell, the complexity of the pezzottaite crystal structure becomes more clearly visible and the third dimension of the complicated crystal structure is more exposed (Fig. P6b). In a view perpendicular to the c-axis (Fig. P6c), the arrangement of Cs in the channels in the direction of the c-axis become visible. In the case of beryl, channels may be partially occupied by $H_2O$, while in pezzottaite, the corresponding position is mainly occupied by Cs.*

## BOX 1
## CHEMISTRY AND CRYSTALLOGRAPHY
## (IMA Application)

MINERAL NAME: PEZZOTTAITE

CHEMICAL FORMULA:

$Cs(Be_2Li)Al_2Si_6O_{18}$

CRYSTAL SYSTEM: rhombohedral

SPACE GROUP: R3c

a = 15.946(2) Å  b =15.946(2) Å  c = 27.803(8) Å

*(a, b, c = unit-cell dimensions)*

$\alpha = 90°$  $\beta = 90°$  $\gamma = 120°$

*($\alpha$, $\beta$, $\gamma$ = angles of the unit-cell)*

V = 6122(2) Å$^3$

*(V = Volume of unit-cell, Å = in Ångstrom, $10^{-8}$ cm = 1Å)*

Z = 18

*(Z is number of formula units per unit-cell)*

## PEZZOTTAITE ROUGH, CUT AND IN MATRIX

***Fig. P7*** *A rough pezzottaite crystal of over 80ct and its final product after cutting reveals a gem quality cabochon of 59.98ct. Rough and cut stone courtesy of MJ3 Inc. (NY, USA), cut by G.E.O. LTD (Bangkok, Thailand).*

***Fig. P8*** *Mineral specimen of pezzottaite in matrix. Length of pezzottaite 10 mm. Collection GRS.*

## BOX 2 ORIGIN AND MINERALOGY (IMA)

### ORIGIN

The mine deposit is located in central Madagascar, about 140 km southwest of Antsirabe (Coordinates 20° 44.78' S and 46° 04.45' E and at an elevation of 920m (3020 feet). The route to the mine leads to Ambatofinandrahana and passes through Amborompotsy and Mandrosonoro.

### ASSOCIATED MINERALS

Boron-bearing minerals: tourmaline, danburite.
Lithium-bearing minerals: lepidolite and spodumene (kunzite)
Other silicates or oxides: quartz, K-feldspar (amazonite), albite (clevelandite)

### OCCURRENCE OF PEZZOTTAITE

Pezzottaite occurs in a miarolitic cavity in a mixed-feature granitic pegmatite (such pegmatites are fairly common in this region (Pezzotta 2001)). Pezzottaite crystallized from fluids in the cavity over a relatively large time-span forms both relatively early and late-stage crystals, the latter having (in some cases) Cs-enriched margins.

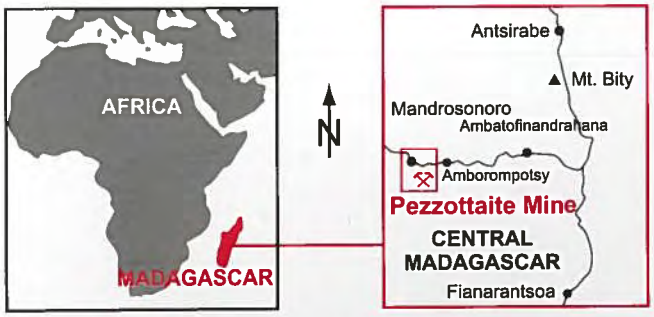



***Fig. P9*** *The position of the Pezzottaite mine within Central Madagascar*

***Fig. P10*** *Occurrence of pezzottaite in Li, Be, B and Cs-bearing pegmatites. The pockets containing pezzottaite are excavated in small shafts and tunnels. (Picture P10 and P11 as of spring 2003, courtesy of MJ3 Inc.,New York)*

***Fig. P11*** *The mining camp and a view of the topography next to the mining site where the new gem mineral pezzottaite was found.*

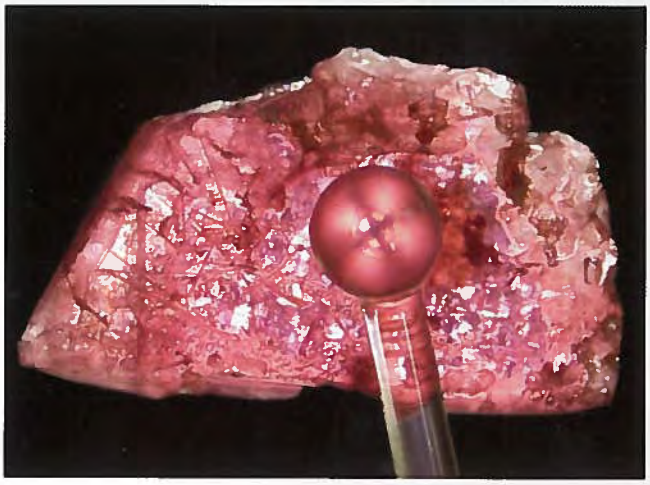


***Fig. P12*** *Natural cat's eye pezzottaite*

*Cutting of pezzottaite as a cabochon intersecting the direction of the growth tubes produces a so-called cat's eye effect (see white line produced by a directed light source perpendicular to the direction of the c-axis).*

***Fig. P13*** *Pezzottaite rough of 29.41ct (see also Fig. P5) is shown as seen through crossed polarizers. A projection sphere is introduced to show the uniaxial property of "pezzottaite" (Cross pattern if viewed in the direction of the c-axis).*

## BOX 3 PHYSICAL AND OPTICAL PROPERTIES (IMA)

APPEARANCE AND PHYSICAL PROPERTIES

Pezzottaite occurs as usually isolated crystals that range in color from whitish pink to a deep raspberry red. There are three distinct types of crystals: (1) Irregularly-shaped flat masses (up to 8 cm in diameter) that fill cavities between clevelandite, quartz and tourmaline; (2) subhedral-to-euhedral hexagonal tabular crystals (up to 7 cm in diameter); (3) small (< 0.5 cm in diameter) euhedral flat-to-elongated crystals attached to faces of large tourmaline crystals.

| | | | |
|---|---|---|---|
| COLOUR (megascopic) | raspberry pink to red | CLEAVAGE | {001} imperfect |
| Moderate dichroism is present: | | PARTING | none observed |
| | orange-pink (red); | TENACITY | brittle |
| | purplish pink (red) to purple | FRACTURE | irregular and conchoidal |
| STREAK | colorless to white | DENSITY (meas.) | 3.09 - 3.11 g/cm³ |
| LUSTRE | vitreous | DENSITY (calc.) | 3.06 g/cm³ (using unit-cell) |
| TRANSPARENT to TRANSLUCENT | | OPTICAL PROPERTIES | |
| FLUORESCENCE | inert to long- and short-wave | WAVELENGTH = | Na light |
| | UV radiation | UNIAXIAL (B) | ω 1.615-1.619, ε 1.607-1.610 |
| HARDNESS: | Mohs': 8 | BIREFRINGENCE | 0.008 - 0.009 (negative) |
| RADIOACTIVITY: | None | PLEOCHROISM | strong (ε) orange pink (red) to (ω) purple |

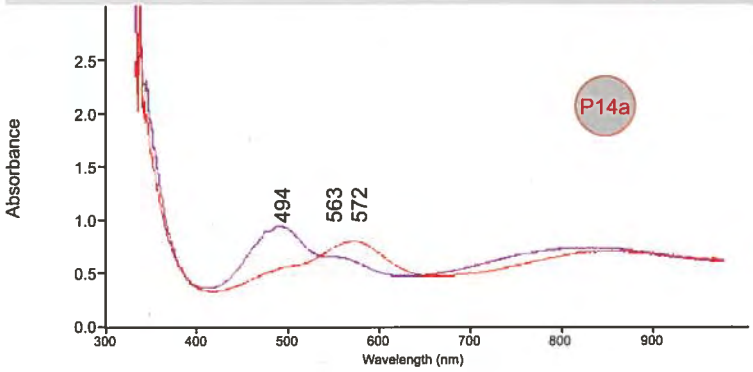



***Fig. P14a:*** *Polarized UV-VIS-NIR spectra on a 6 mm thick slice of pezzottaite which was used for chemical and crystal structure analysis. Note: Absorption bands at 494 and 563 (polarized perpendicular to the c-axis) and 572 nm (polarized parallel to the c-axis).*


***Fig. P14b:*** *Pleochroism of pezzottaite with orange-red to purple is shown which is distinctively different from other minerals of the beryl group, such as pink beryl "morganite" (see Laurs et al., 2003).*

## BOX 4A EMPA ELECTRON MICROPROBE ANALYSIS (IMA Application)


***Fig.P15 Example of an Electron Microprobe. University of New Orleans, USA (A.U. Falster).***

***Explanation of method****. The method is used to analyze the chemical composition. For analytical purposes, the analyzed mineral must be coated with an electron-conducting layer and positioned in a highly evacuated vacuum chamber (1). The mineral is bombarded by electrons, which have previously been produced and accelerated in an electron gun (2).The different atoms in the mineral react to the impacting electrons by creating signals. These signals include X-rays, which can be detected by various kinds of detectors, such as WDS (3). From the responding signals, the chemical composition can be determined, providing standard materials (materials of known composition or "Probe Standards") are analyzed for comparison. Light elements such as beryllium or lithium are determined by other methods.*

ELECTRON MICROPROBE WDS 20 kV 10 nA beam: 5 Fm

NOTE: $H_2O$ was determined by LOI and a value of 1.72 wt.% was obtained. However, the crystals are riddled with tubules that are occupied by a fluid; the paragenesis (granitic pegmatite) indicates that the fluid will be an aqueous fluid which will therefore result in an anomalously high value of $H_2O$. The crystal-structure refinement gives the total scattering within the channel, and this value minus the scattering from the channel constituents determined by EMPA gives the amount of ($H_2O$) in the channel: ~0.1 apfu, 0.28 wt.% $H_2O$. Li by ICP.

ANALYTICAL RESULTS: Number of analyses: 8

| Constituent | Wt.% | Range | Standard Deviation | Probe Standard |
|---|---|---|---|---|
| $SiO_2$ | 56.52 | 55.8 - 57.2 | 0.59 | Spessartine |
| $Al_2O_3$ | 15.60 | 14.9 - 17.0 | 0.65 | Spessartine |
| $Sc_2O_3$ | 0.03 | 0.02 - 0.04 | 0.01 | Thortveitite |
| FeO | 0.01 | 0.00 - 0.02 | 0.01 | Clinopyroxene |
| MnO | 0.09 | 0.07 - 0.11 | 0.02 | Rhodonite |
| $Na_2O$ | 0.52 | 0.41 - 0.61 | 0.06 | Clinopyroxene |
| $K_2O$ | 0.15 | 0.13 - 0.19 | 0.03 | Adulina |
| $Rb_2O$ | 0.76 | 0.70 - 0.80 | 0.03 | Synthetic Rb-leucite |
| $Cs_2O$ | 13.57 | 13.39 - 13.72 | 0.11 | Pollucite |
| $Li_2O$ | 2.16 | - | - | |
| BeO | 8.05* | - | - | |
| Total | 97.46 | | | |

* The BeO content was calculated from the relation Be = 3 - Li.

EMPIRICAL FORMULA $(Cs_{0.62}\ Rb_{0.05}\ K_{0.02}\ Na_{0.11})_{S=0.80}\ (Be_{2.07}\ Li_{0.93})_{S=3}\ (Al_{1.97}\ Mn_{0.01})_{S=1.98}\ Si_{6.05}\ O_{18}$

BASIS OF CALCULATION 18 O-atoms

SIMPLIFIED FORMULA $(Cs,\square)\ (Be,Li)_3\ Al_2\ Si_6\ O_{18}$

## BOX 4B LA-ICP-MS CHEMICAL ANALYSIS (IMA Application)

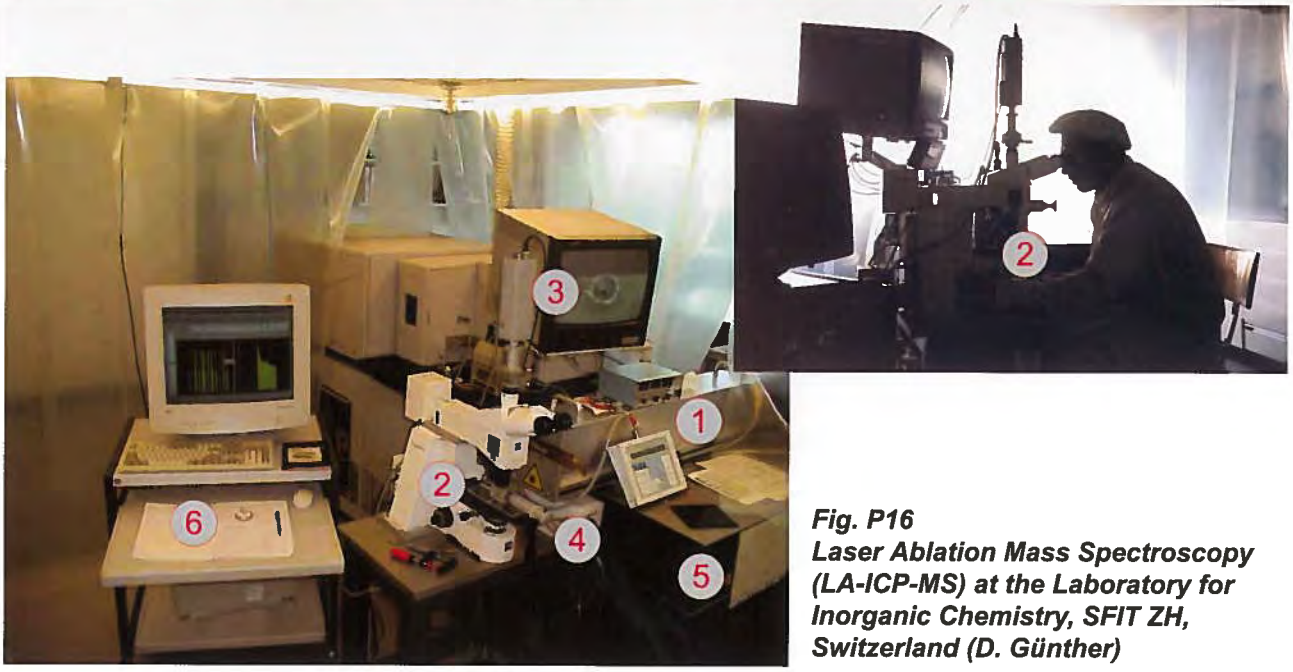



***Fig. P16***
***Laser Ablation Mass Spectroscopy (LA-ICP-MS) at the Laboratory for Inorganic Chemistry, SFIT ZH, Switzerland (D. Günther)***

***Explanation of method***

*The laser ablation technique (LA) uses a 193 nm excimer laser (1) which is focused onto the sample surface via microscope lenses (2). The laser is ablating (carrying away) the material (crater diameter 4 to 80 microns) (3). The mobilized material is suspended in a carrier gas (4) and transported via transport tube into an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) (5). The material/elements (except those that cannot be ionized, such as gases and fluorine) are vaporized, atomized and ionized within the ICP . The created ions are then transferred to the mass spectrometer and separated by their mass divided by charge (5). The detector allows measuring major, minor and trace elements within a single analysis. Very light elements, such as boron, lithium or beryllium, can be detected, along with a large series of other elements at concentrations of less then 1 ppm. The quantification at low concentrations is possible by LA-ICP-MS due to a matrix-independent calibration, e.g. glass standard was used for quantification of pezzottaite including special computer analysis and specific software (6). The use of complementary solid-analysis methods (such as EMPA and XRF) for comparison and validation purposes (e.g. for quantitative measurement of silicon and aluminium) must be applied (see Box 4A).*

LA-ICP mass-spectrometry
ANALYTICAL RESULTS

| Constituent | Wt.% |
|---|---|
| $SiO_2$ | 54.58 |
| $Al_2O_3$ | 16.88 |
| $Sc_2O_3$ | n.d. |
| FeO | 0.02 |
| MnO | 0.02 |
| $Na_2O$ | 0.46 |
| $K_2O$ | 0.14 |
| CaO | 0.22 |
| $Rb_2O$ | 0.44 |
| $Cs_2O$ | 18.23 |
| $Li_2O$ | 2.12 |
| BeO | 8.14 |
| Total | 101.26 |

EMPIRICAL FORMULA

$(Cs_{0.833}\ Rb_{0.030}\ K_{0.019}\ Na_{0.095})\ (Be_{2.098}\ Li_{0.917})\ Al_{2.00}\ Si_{5.86}\ Al_{0.135}\ O_{18}$

SIMPLIFIED FORMULA $Cs\ Be_2\ Li\ Al_2\ Si_6\ O_{18}$

IONS PER 18 OXYGENS, ANHYDROUS BASIS

| | | | |
|---|---|---|---|
| Si | 5.860 | Be | 2.098 |
| Ti | 0.001 | Li | 0.917 |
| Al | 0.139 | ΣBe+Li | 3.016 |
| Σtetrahedral | 6.000 | Al | 1.996 |
| Na | 0.095 | Ca* | 0.025 |
| K | 0.019 | Sc | nd |
| Rb | 0.030 | Mn | 0.002 |
| Cs | 0.833 | Fe2+ | 0.001 |
| Σchannel | 0.977 | Σoctahedral | 2.024 |

** Ca is assumed present at the octahedral site, but it may occur elsewhere in the pezzottaite structure. n.d. = not determined*

# BOX 5A CRYSTALLOGRAPHIC ANALYSIS (IMA)

## SINGLE-CRYSTAL STUDY

| | | |
|---|---|---|
| METHOD | 4-circle | |
| CRYSTAL SYSTEM | rhombohedral (hexagonal setting) | |
| SPACE GROUP | R3c | |
| CELL PARAMETERS | a 15.946(2) Å | α 90° |
| | b 15.946(2) Å | ß 90° |
| | c 27.803(8) Å | γ 120° |
| | V 6122(2) Å$^3$ | Z = 18 |

## POWDER DATA CuKα

Diffractometer

CELL PARAMETERS REFINED FROM POWDER DATA

| | | |
|---|---|---|
| CRYSTAL SYSTEM | rhombohedral (hexagonal setting) | |
| SPACE GROUP | R3c | |
| | a 15.973(4) Å | α 90° |
| | b 15.973(4) Å | ß 90° |
| | c 27.850(11) Å | γ 120° |
| | V 6153(3) Å$^3$ | Z = 18 |

*See Table 1 for X-ray Powder-Diffraction Data*

| | |
|---|---|
| CRYSTAL STRUCTURE | R = 2.9% |
| MORPHOLOGY | |
| HABIT | tabular |
| FORMS | {001} dominant, {100}, {110} |
| TWINNING | none observed |
| c:a | 1 : 1.7436 |
| | (from unit-cell parameters) |

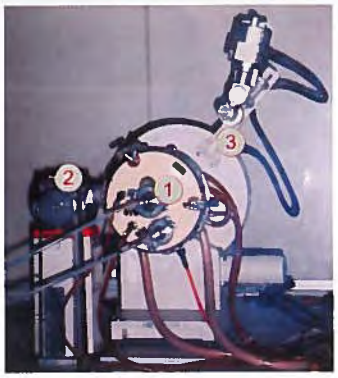



***Fig. P17***
***X-ray diffraction analysis.***

***Explanation of method.*** *The method is used to investigate the crystal structure (atomic positions and geometry). A small crystal fragment of usually 0.1 mm size is investigated by exposing the mineral to X-rays (single crystal analysis see also fig. P3). Instead of using a single crystal, a small sample is groun into a powder. This powder is mounted in such a way that the target consists of many extremely small crystal fragments which are oriented in random fashion (1). A monochromatic X-ray beam (e.g. CuKα) is focused on the sample (2). The interaction of the X-rays with the numerous randomly oriented particles yields an X-ray powder-diffraction pattern. These interference signals are collected at different diffraction angles by using an X-ray sensitive detector (3). The signals can be used to obtain information about the unit-cell parameters and to collect characteristic 'fingerprints' for each mineral structure (d-values, hkl). The relative intensity of the X-ray signal (0-100) as well as the d-values are listed in reference manuals for identification purposes (such as below).*

TABLE 1. X-RAY POWDER-DIFFRACTION DATA FOR PEZZOTTAITE

| Intensity | d measured | d calculated | h | k | l | Intensity | d measured | d calculated | h | k | l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 4.642 | 4.643 | 0 | 0 | 6 | 3 | 1.834 | 1.834 | -4 | 8 | 6 |
| 10 | 4.611 | 4.617 | 0 | 3 | 0 | 6 | 1.801 | 1.801 | -2 | 7 | 9 |
| 2 | 4.013 | 4.010 | -1 | 2 | 6 | 12 | 1.749 | 1.749 | -3 | 6 | 12 |
| 2 | 3.993 | 3.993 | -2 | 4 | 0 | 12 | 1.743 | 1.743 | -3 | 9 | 0 |
| 100 | 3.271 | 3.272 | 0 | 3 | 6 | 10 | 1.713 | 1.713 | -3 | 9 | 3 |
| 41 | 3.027 | 3.028 | -2 | 4 | 6 | 9 | 1.704 | 1.704 | -1 | 8 | 6 |
| 29 | 3.019 | 3.019 | -1 | 5 | 0 | 14 | 1.636 | 1.635 | 0 | 6 | 12 |
| 52 | 2.871 | 2.872 | -1 | 5 | 3 | 6 | 1.632 | 1.632 | -3 | 9 | 6 |
| 9 | 2.662 | 2.662 | -3 | 6 | 0 | 2 | 1.581 | 1.582 | -1 | 5 | 15 |
| 6 | 2.321 | 2.321 | 0 | 0 | 12 | 3 | 1.577 | 1.577 | -1 | 8 | 9 |
| 6 | 2.309 | 2.309 | -3 | 6 | 6 | 2 | 1.547 | 1.547 | 0 | 0 | 18 |
| 4 | 2.305 | 2.305 | 0 | 6 | 0 | 11 | 1.518 | 1.519 | -3 | 9 | 9 |
| 12 | 2.229 | 2.229 | -1 | 2 | 12 | 1 | 1.514 | 1.514 | -4 | 8 | 12 |
| 14 | 2.215 | 2.215 | -2 | 7 | 0 | 4 | 1.509 | 1.509 | -2 | 10 | 0 |
| 6 | 2.155 | 2.155 | -2 | 7 | 3 | 2 | 1.490 | 1.490 | -8 | 10 | 3 |
| 9 | 2.065 | 2.065 | 0 | 6 | 6 | 7 | 1.467 | 1.467 | 0 | 3 | 18 |
| 2 | 1.999 | 1.999 | -2 | 7 | 6 | 6 | 1.459 | 1.459 | 0 | 9 | 6 |
| 5 | 1.840 | 1.840 | -1 | 5 | 12 | 2 | 1.443 | 1.443 | -2 | 4 | 18 |

## BOX 5B RELATIONS TO OTHER MINERAL SPECIES (IMA)

RELATIONSHIP TO OTHER SPECIES

Pezzottaite is related to the beryl group (see table 2), but differs in having a superstructure involving ordering of Be and Li in tetrahedral coordination (see Fig. P1, P2 and P6).

TABLE 2. THE MINERALS OF THE BERYL GROUP: (2a) $Be_3$ $Al_2Si_6O_{18}$ $(H_2O)<1$

| | Beryl [1] | Bazzite [2] | Stoppaniite [3] | Indialite [4] | Pezzottaite [5] |
|---|---|---|---|---|---|
| a (Å) | 9.210 | 9.521 | 9.397 | 9.800 | 15.946 |
| c (Å) | 9.194 | 9.165 | 9.202 | 9.345 | 27.803 |
| V ($Å^3$) | 675.4 | 719.5 | 703.7 | 777.3 | 6122 |
| ε | 1.577 | 1.602 | 1.619 | 1.532 | 1.608 |
| ω | 1.580 | 1.622 | 1.625 | 1.537 | 1.616 |
| D ($g/cm^3$) | 2.66 | 2.77 | 2.79 | 2.51 | 3.06 |
| Z | 2 | 2 | 2 | 2 | 18 |
| 2a | - | - | - | - | [Cs] |
| Be | $Be_3$ | $Be_3$ | $Be_3$ | $Al_2Si$ | [$Be_2$ Li] |
| Al | $Al_2$ | $Sc_2$ | $Fe^{3+}{}_2$ | $Mg_2$ | [$Al_2$] |

[1] Aurisicchio et al. (1988); [2] Armbruster et al. (1995); [3] Della Ventura et al. (2000), Ferraris et al. (1998); [4] Meagher & Gibbs (1977); [5] Hawthorne et al.(submitted).

End-member formulae

| | | | | | |
|---|---|---|---|---|---|
| Beryl: | □ | $Be_3$ | $Al_2$ | $Si_6$ | $O_{18}$ |
| Bazzite: | □ | $Be_3$ | $Sc_2$ | $Si_6$ | $O_{18}$ |
| Stoppaniite: | □ | $Be_3$ | $Fe^{3+}{}_2$ | $Si_6$ | $O_{18}$ |
| Indialite | □ | ($Al_2Si$) | $Mg_2$ | ($Al_2Si_4$) | $O_{18}$ |
| Pezzottaite: | Cs | $Be_2Li$ | $Al_2$ | $Si_6$ | $O_{18}$ |


Armbruster T., Libowitzky E., Diamond L., Auernhammer M., Bauerhansl P., Hoffmann C. , Irran E., Kurka A., Rosenstingl H. (1995) Crystal chemistry and optics of bazzite from Furkabasistunnel (Switzerland). Mineralogy and Petrology, Vol. 52, pp. 113-126.

Aurisicchio, C., Fioravanti, G., Grubessi, O. & Zanazzi, P.F. (1988): Reappraisal of the crystal chemistry of beryl. American Mineralogist 73, 826-837.

Della Ventura G., Rossi P., Parodi G.C., Mottana A., Raudsepp M., Prencipe M. (2000) Stoppaniite, $(Fe,Al,Mg)_4(Be_6Si_{12}O_{36})^*(H_2O)_2(Na,□)$, a new mineral of the beryl group from Latium (Italy). European Journal of Mineralogy, Vol.12, pp.121-127.

Ferraris, G., Prencipe, M. & Rossi, P. (1998): Stoppaniite, a new member of the beryl group: crystal structure and crystal-chemical implications. European Journal of Mineralogy, Vol.10, pp.491-496.

Hawthorne F.C., Cooper M.A., Simmons W.B., Falster A.U., Laurs B.M., Armbruster T., Rossman G.R., Peretti A., Günther D., Grobéty B. : Pezzottaite, $Cs(Be_2Li)Al_2Si_6O_{18}$, a spectacular new mineral related to the beryl group, from Madagascar. Mineralogical Record. Submitted.

Meagher, E.P. & Gibbs, G.V. (1977): The polymorphism of cordierite: II. The crystal structure of indialite. Canadian Mineralogist, Vol.15, pp.43-49.


## BOX 6 MISCELLANEOUS (IMA)

NAME

Named after Federico Pezzotta, Museo Civico, Milano, Italy; born 1967. Dr. Pezzotta has played a major role in characterizing the granitic pegmatites of Madagascar and their constituent minerals. He has made major contributions to our knowledge of the paragenesis of tourmaline-group minerals, particularly in Elba, Italy.


Pezzotta, F., Ed. (2001) Madagascar, a Mineral and Gemstone Paradise. Extralapis English, No. 1. Lapis International LLC, East Hampton, 100pp.


TYPE MATERIAL

Smithsonian Institution

Canadian Museum of Nature, PO Box 3443, Station D, Ottawa, Ontario, Canada

Natural History Museum Bern, Bern, Switzerland

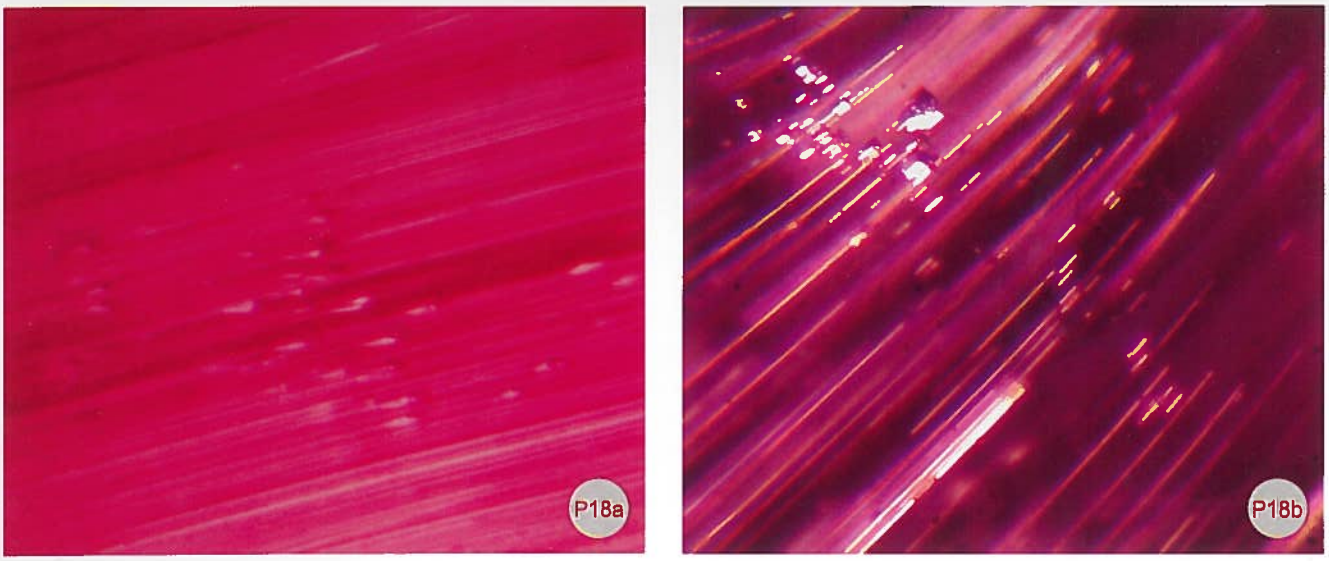



***Fig. P18a/b*** *Microfeatures observed in pezzottaite. Negative crystal in connection with growth tubes (P18a) and growth tubes of various length parallel to the c-axis (P18b). Images taken at 40-60x microscopic magnification (microphotographs A. Peretti).*

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## BOX 7 PEZZOTTAITE GEMSTONE EXAMPLES

*Natural Pezzottaite*
*Weight: 59.98 ct*
*Dimensions: 26.38 x 18.75 x 14.32 mm*
*Cut: Cabochon/sugar loaf*
*Shape: Rectangular cushion*
*Color: Pinkish-red*

*Natural Cat's Eye Pezzottaite*
*Weight: 8.85 ct*
*Dimensions: 13.65 x 8.3 x 9.05 mm*
*Cut: Cabochon/partially polished*
*Shape: Oval*
*Color: Pinkish-red*

*Natural Cat's Eye Pezzottaite*
*Weight: 5.74 ct*
*Dimensions: 14.07 x 8.41 x 5.64 mm*
*Cut: Cabochon*
*Shape: Oval*
*Color: Pinkish-red*

*Natural Pezzottaite*
*Weight: 10.07 ct*
*Dimensions: 13 x 12.4 x 8.96 mm*
*Cut: Faceted/step*
*Shape: Cushion*
*Color: Pink*
*RI: 1.61-1.620*
*SG: 3.11*

*Natural Pezzottaite*
*Weight: 5.27 ct*
*Dimensions: 11.39 x 8.68 x 6.82 mm*
*Cut: Faceted/step*
*Shape: Cushion*
*Color: Pink*
*RI: 1.61-1.20*
*SG: 3.11*

*Natural Cat's Eye Pezzottaite*
*Weight: 4.16 ct*
*Dimensions: 8.92 x 8.31 x 6.9 mm*
*Cut: Cabochon/partially polished*
*Shape: Oval*
*Color: Pink*
*RI Spot: 1.62*
*SG: 3.09*

*Natural Pezzottaite Rough Crystal*
*Weight: 4.36 ct*
*Length: 10.4 mm*

*Natural Pezzottaite Rough Crystal*
*Weight: 9.33 ct*
*Length: 16.5 mm*

*Natural Pezzottaite Rough Crystal*
*Weight: 7.25 ct*
*Length: 13.0 mm*

## *Selected Literature*


Brendan M. Laurs, William B. (Skip) Simmons, George R. Rossman, Elizabeth P. Quinn, Shane F. McClure, Adolf Peretti, Thomas Armbruster, Frank C. Hawthorne, Alexander U. Falster, Detlef Günther, Mark A. Cooper, and Bernard Grobéty (2003): PEZZOTTAITE FROM AMBATOVITA, MADAGASCAR: A NEW GEM MINERAL. Gems&Gemology, Vol 39, No. 4, pp. 284-301..

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