

PYROPE FROM THE DORA MAIRA MASSIF, ITALY

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Large pyrope crystals containing gem-quality portions have been collected since the early 1990s from the Dora Maira Massif, Western Alps, Italy. These crystals have yielded pale purple to purplish pink gemstones typically up to 1 ct. The chemical composition and physical properties compare favorably to those reported for near-end-member pyrope. Absorption spectra suggest that the color is related to Fe^{2+} and Mn^{2+} . The pyrope formed in a mica schist-quartzite layer within Paleozoic basement rocks that underwent an Alpine high-pressure/low-temperature metamorphic event. The deposit appears extensive, but future production undoubtedly will be limited due to environmental restraints. Currently about 100 carats per year enter the marketplace.

For several years, large pyrope crystals have been known from the Varaita Valley in the Dora Maira Massif (a massive topographic and structural feature, particularly within a mountain range) in Italy's Western Alps (Schert et al., 1994). Since the early 1990s, local mineral collectors have recovered and cut crystals containing gem-quality portions. Although the gemstones have rarely exceeded 1 ct (the largest known to date are about 2 ct), a few hundred good-quality faceted Dora Maira pyropes have entered the Italian gem collector's market. The distinctive features of these gem pyropes are their pale purplish pink color (figure 1), near-end-member composition, and mineral inclusions. Of particular interest are inclusions of ellenbergerite, for which Dora Maira is the type locality.

LOCATION AND ACCESS

The Dora Maira Massif is located in the Piedmont region, 50 km (31 miles) southwest of Turin (figure 2). Pyrope is found in the Varaita Valley, between the villages of Brossasco and Martiniana Po. Gem pyropes have been collected in several outcrops over an extended area (about 15 km long) from high-grade quartz-phengitic metamorphic rocks. Large-scale mining is forbidden by environmental policy, but local collectors do considerable hand digging.

GEOLOGIC SETTING

The Dora Maira Massif consists of Paleozoic basement rocks with an overlying Mesozoic series of rocks that are characterized by an Alpine high-pressure/low-temperature metamorphic overprint. The pyrope crystals occur in a light-colored phengitic schist-quartzite layer, measuring a few meters thick, which was referred to as "micascisti splendenti" by Stella (1895) and Franchi (1900). The quartzite layer contains large flakes of phengite (a high-pressure mica; Mandarino, 1999) and pale purplish pink pyrope crystals that reach 25 cm in diameter. Vialon (1966) mapped the quartzite layer over a distance of about 15 km, and suggested that the protolith (original unmetamorphosed rock) was a leucocratic granitic vein that was strongly deformed by metamorphism. Other rocks in the area include fine-grained felsic paragneisses that are associated with lenses of marble and metabasite. In describing

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the mineralogy and petrogenesis of the quartzitic layer, Chopin (1984) pointed out the presence of coesite, a mineral indicative of extreme metamorphic conditions (pressures over 28 kilobars and temperatures up to 700°–750°C).

DESCRIPTION OF THE CRYSTALS

The pyrope crystals have a rounded shape formed by rough trapezohedron faces (figure 3). The crystals are heavily fractured and always covered by a thin layer of white to pale green phengite. As noted above, some of the pyrope crystals contain clear portions that can be faceted into attractive gemstones.

MATERIALS AND METHODS

We examined 11 faceted Dora Maira pyropes (0.24–0.85 ct; see, e.g., figure 4), which were obtained from the gem collection of the Natural History Museum of Milan and loaned by L. Merlo Pich. All of the samples are from the Brossasco and Martiniana Po areas, and they show a range of color



Figure 1. Pyrope from the Dora Maira Massif in Italy's Western Alps has been mined since the early 1990s by local mineral collectors. The 0.85 ct stone on the left was loaned by L. Merlo Pich, and the 0.76 ct gem on the right belongs to the Natural History Museum of Milan. Photo by R. Appiani.

and intensity that is representative of the material from this region. These samples also were selected on the basis of their distinctive inclusions. Mr. Pich

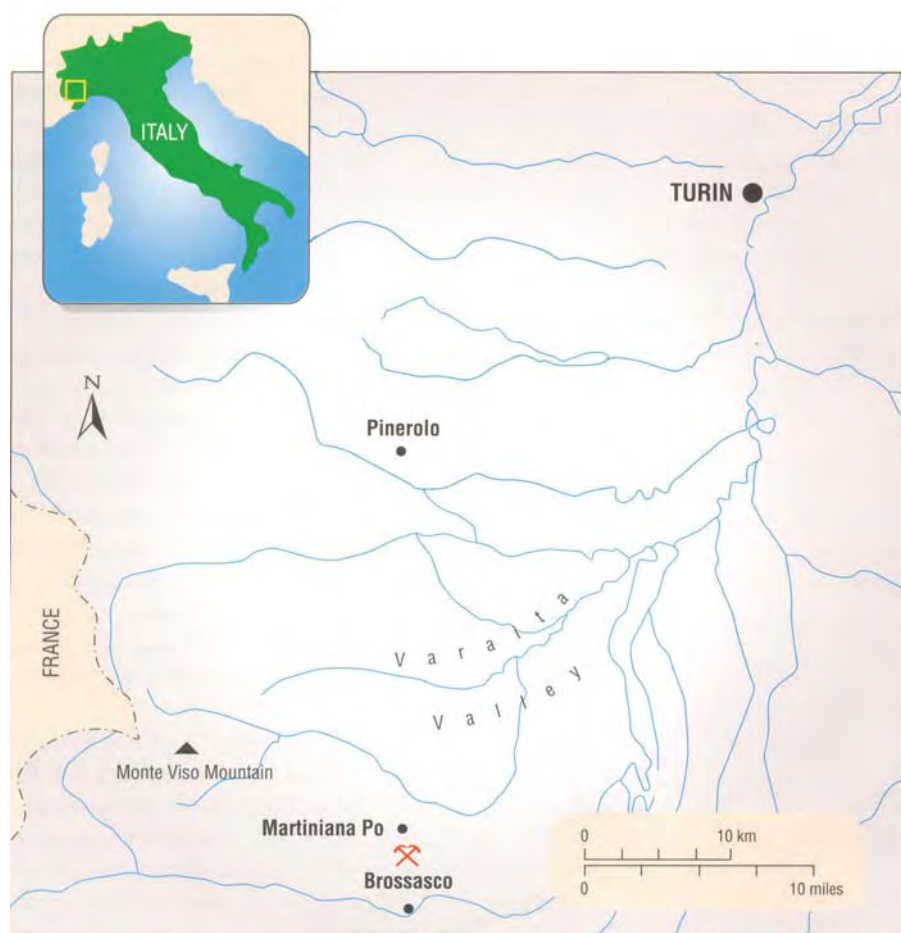


Figure 2. Pyrope is mined from several outcrops over an extended area (about 15 km long) near the villages of Brossasco and Martiniana Po.



Figure 3. The pyrope crystals (here, 4 cm across) are typically formed by rounded trapezohedron faces that are covered by a thin layer of white to pale green phengite. The crystals are heavily fractured (see inset; the larger specimen weighs 30 grams), although some contain clear portions that can be faceted into attractive gemstones. Specimens from the L. Merlo Pich collection; photos by R. Appiani.

provided fragments (from the same crystals used to facet some of the gems) for electron-microprobe and X-ray diffraction analyses.

The following tests were conducted on all 11 of the faceted gems. Refractive indices were measured on a Krüss refractometer with a monochromatic sodium-equivalent light source. Specific gravity was measured by the hydrostatic method, with a Sauter MC1 RC 210 D digital balance (three sets of measurements per sample). We observed internal features with a stereozoom microscope (up to 50×

Figure 4. Eight of the Dora Maira pyropes used in this study (0.24–0.50 ct) were photographed with Macbeth Spectralight (daylight equivalent, 6500K) illumination. Courtesy of the Natural History Museum of Milan; photo by A. Donini.



magnification), using several illumination techniques. We made color measurements using Munsell color charts and a Macbeth Spectralight (daylight equivalent, 6500 K). We tested for ultraviolet fluorescence with 8 watt short-wave (254 nm) and long-wave (365 nm) UV lamps.

Absorption spectra of all the faceted samples were obtained with a Lambda 9 Perkin-Elmer UV-Vis spectrophotometer. Infrared spectra of all samples were measured with a Nicolet 510 spectrometer at a resolution of 2 cm⁻¹. To identify the mineral inclusions, we used a Renishaw 1000 laser Raman microspectrometer with an Ar163-C4210 Spectra Physics laser source. Quantitative chemical analyses were performed on 10 pyrope fragments with an ARL-SEMQ electron microprobe that was equipped with a wavelength-dispersive X-ray spectrometry unit. To identify some of the inclusions in the fragments, we performed single-crystal X-ray diffraction analysis using an Enraf-Nonius CAD4 diffractometer.

RESULTS AND DISCUSSION

Visual Appearance. The faceted pyropes were purple to purplish pink in hue, with very low to moderate saturation. We obtained Munsell color values of 2.5RP 9/2, 5RP 8/4 to 7/4, 5RP 9/2 to 9/1, and 10RP 7.5/4 (table 1). In many of the gems, the color was not homogeneously distributed. All of our samples showed some color (in both fluorescent and incandescent light), although near-colorless gem pyrope is known from the Brossasco area.

Physical Properties. The refractive indices ranged from 1.717 to 1.730, with the lowest values measured on the palest samples (again, see table 1). The low values come close to the R.I. (1.714) reported by Deer et al. (1992) for a natural pyrope with a near-end-member composition, and approach the theoretical end-member value of 1.705 reported by Webster (1994). The range of R.I. values obtained in this study correlates to the iron content (manganese is close, and chromium is below, the detection limit of the electron microprobe for these elements, which is 0.02 wt. % oxide).

Specific gravity ranged from 3.58 to 3.67; in general, the lowest values were obtained for the palest stones. The lowest value is identical to that reported in the literature for a near-end-member pyrope (Deer et al., 1992), but is significantly higher than the 3.51 reported by Webster (1994) for the theoretical end member. The highest S.G. values

correspond to the greatest concentrations of iron. However, some gemstones with a moderately intense purplish pink color contained abundant heavy inclusions (rutile), which prevents a straightforward correlation between specific gravity and chemical composition.

All of the samples were inert to both short- and long-wave UV radiation.

Internal Features. Microscopic examination with cross-polarized light revealed undulatory extinction in some areas of the pyrope gemstones (figure 5), which is apparently due to strain caused by tectonic deformation subsequent to peak metamorphism (see, e.g., Hofmeister et al., 1998).

The pyrope samples contained several types of microcrystalline inclusions (see, e.g., figure 6), most of which we were able to identify by Raman analysis. Crystals of rutile were commonly disseminated throughout the gemstones. These minute crystals

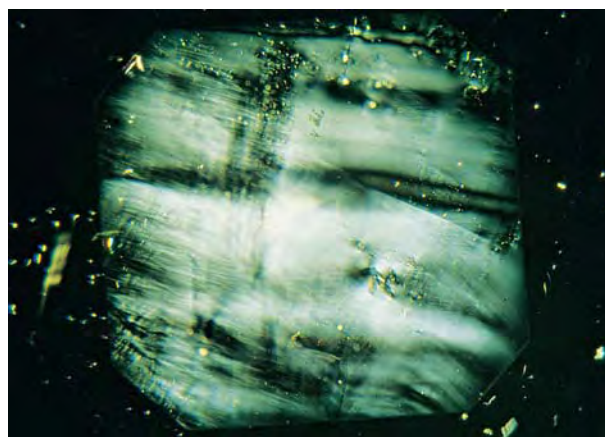


Figure 5. Undulatory extinction was seen in some areas of the Dora Maira pyropes with cross-polarized light. Photomicrograph by A. Donini; magnified 50 \times .

were translucent dark orange (figure 7), or metallic black with dark red internal reflections (figure 8). Apatite occurred as colorless subhedral crystals with a rounded shape. Swarms of extremely thin laminar crystals, usually formed along small healed fractures, were identified as mica (probably phen-gite; see figure 9). Also present were colorless elongated subhedral zircon crystals (figure 10). Infrequently seen were thin, colorless, rectangular kyanite crystals.

Some extremely thin, needle-like, parallel inclusions could not be identified (figure 11). No fluid inclusions were observed in the cut samples.

Figure 6. A variety of mineral inclusions were present in the Dora Maira pyropes (here, 0.49 ct). Courtesy of the Natural History Museum of Milan; photo by R. Appiani.



TABLE 1. Properties of sample pyropes from the Dora Maira Massif, Italy.

Weight (ct)	Color (Munsell)	R.I.	Specific gravity	UV-Vis absorption bands (nm)
0.76	Pale purplish pink (2.5 RP 9/2)	1.717	3.61	Fe ²⁺ : 502, 522, 575 Mn ²⁺ : 365, 419, 460
0.27	Pale purplish pink (5RP 9/2)	1.718	3.58	Fe ²⁺ : 495, 525, 579 Mn ²⁺ : 363, 396, 421, 437, 458
0.32	Pale purple to purplish pink (5RP 9/2 to 9/1)	1.718	3.59	Fe ²⁺ : 501, 522, 575 Mn ²⁺ : 421
0.50	Pale purplish pink (5RP 9/2)	1.719	3.59	Fe ²⁺ : 503, 523, 577 Mn ²⁺ : 365, 377, 397, 422
0.26	Pale purplish pink (5RP 9/2)	1.719	3.62	Fe ²⁺ : 522, 577 Mn ²⁺ : 367, 419, 479
0.28	Pale purplish pink (5RP 8/4)	1.719	3.63	Fe ²⁺ : 502, 524, 575 Mn ²⁺ : 366, 419, 460
0.49	Pale purplish pink (5RP 9/2)	1.720	3.62	Fe ²⁺ : 502, 524, 576 Mn ²⁺ : 394, 421, 462
0.25	Pale purplish pink (5RP 8/4)	1.720	3.64	Fe ²⁺ : 503, 521, 575 Mn ²⁺ : 365, 398, 422, 458
0.24	Pale purplish pink to grayish purplish pink (5RP 8/4 to 7/4)	1.721	3.66	Fe ²⁺ : 503, 522, 576 Mn ²⁺ : 365, 398, 422, 458
0.85	Moderate purplish pink (10RP 7.5/4)	1.728	3.67	Fe ²⁺ : 503, 523, 575 Mn ²⁺ : 367, 420, 479
0.60	Moderate purplish pink (10RP 7.5/4)	1.730	3.67	Fe ²⁺ : 495, 525, 579 Mn ²⁺ : 366, 398, 421, 462

^aFor comparison, Stockton (1988) reports R.I. values of 1.714–1.742 and absorption bands at 410, 421, 430, 504, 520, and 573 nm for colorless to light orange and pink pyropes.

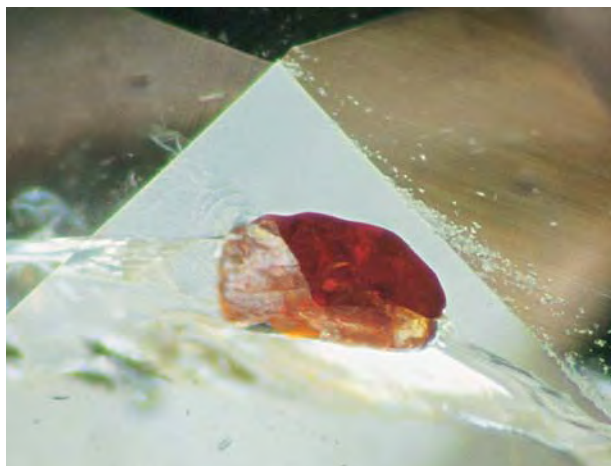


Figure 7. This translucent dark orange rutile inclusion in a Dora Maira pyrope measures 0.22 mm long. Photomicrograph by A. Donini.

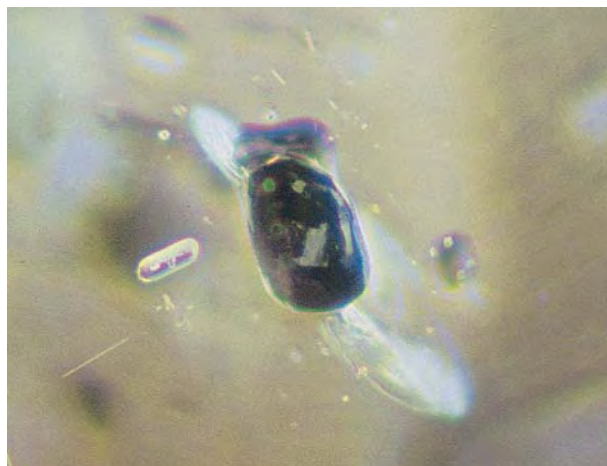
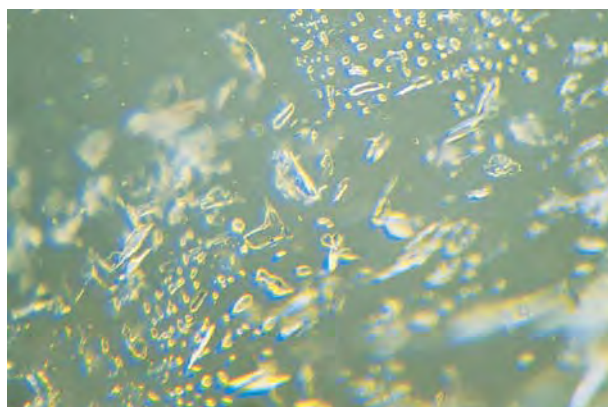


Figure 8. Rutile inclusions in the pyropes also appeared metallic black (here, 0.18 mm long), sometimes with dark red internal reflections. Photomicrograph by A. Donini.

Elongate (up to 0.15 mm) pinkish purple crystals were seen in one of the stones, but we could not identify them by Raman analyses because there was no matching spectrum in our Raman library. We selected inclusions with the same appearance from the rough pyrope fragments left after cutting this stone (figure 12), and identified them as ellenbergerite using X-ray diffraction analysis. This very rare silicate of magnesium, aluminum, titanium, and zirconium was described for the first time by Chopin et al. (1986) from rocks at Martiniana Po.

Absorption Spectra and Chemistry. Absorption bands measured with the UV-Vis spectrophotometer are reported in table 1 and shown in figure 13.

Figure 9. Formed along small healed fractures, these thin laminar inclusions were identified by Raman analysis as mica (probably phengite). The field of view is 1.2 mm wide; photomicrograph by A. Donini.



As indicated by Stockton (1988), bands around 501–503 and 521–524 nm can be correlated to Fe^{2+} , while those at 419–422 nm are related to Mn^{2+} . Other bands listed in table 1 are related to Fe^{2+} (i.e., 495 and 575–579 nm) or Mn^{2+} (i.e., 363–365, 398, and 458–462 nm). Rossman et al. (1989) studied the infrared spectra of Dora Maira pyrope, and found four sharp bands in the $3660\text{--}3600\text{ cm}^{-1}$ region due to a hydrous component that has not been reported in pyrope from other localities. The same IR features were obtained on our samples (see, e.g., figure 14).

Electron microprobe analyses of four purplish pink (low to moderate saturation) gem-quality pyrope fragments are presented in table 2, together

Figure 10. This colorless elongated zircon inclusion measures 0.20 mm long. Photomicrograph by A. Donini.



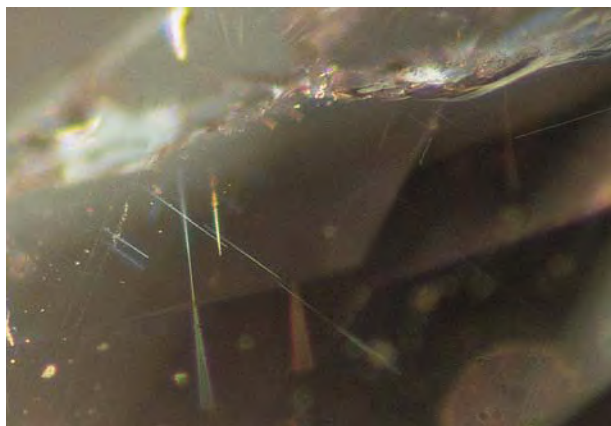


Figure 11. These extremely thin, needle-like inclusions could not be identified. The field of view is 0.07 mm wide; photomicrograph by A. Donini.

with analyses on two areas of a single Dora Maira crystal reported by Chopin (1984) for comparison. The pyrope shows the following range in composition: 87.8–97.5 mol.% pyrope, 1.8–10.2 mol.% almandine, and 0.2–2.6 mol.% grossular. Our results suggest that the color is strongly influenced by the iron content, with the darker gemstones having greater FeO (up to 5.18 wt.%).

IDENTIFICATION OF DORA MAIRA PYROPE

Pyrope gemstones with a near-end-member composition are very unusual, and the pale-colored

Figure 13. This representative UV-Vis absorption spectrum of purplish pink pyrope from the Dora Maira Massif shows bands that can be correlated to Fe²⁺ (e.g., 501–503 and 521–524 nm) and Mn²⁺ (e.g., 419–422 nm).

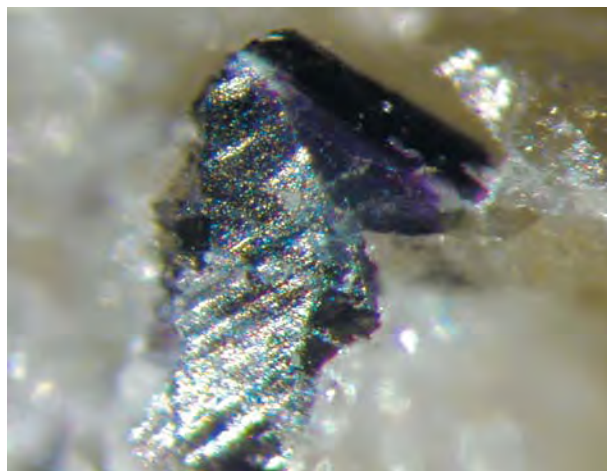
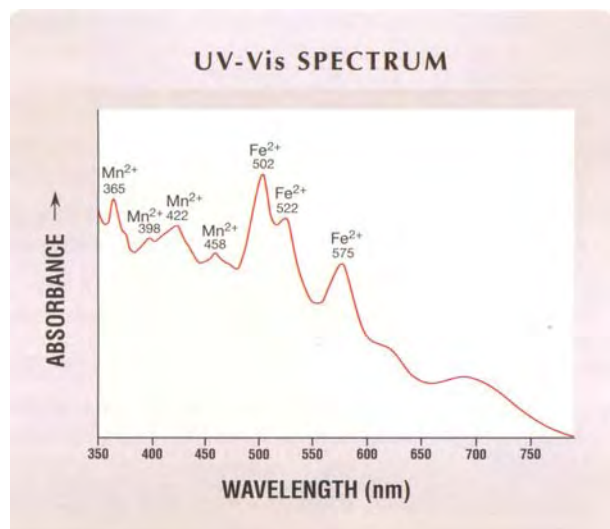


Figure 12. The rare mineral ellenbergerite (here, 0.2 mm long) was identified as inclusions in pyrope from the Dora Maira Massif. Photomicrograph by A. Guastoni.

stones from Dora Maira—which are unfamiliar to most gemologists—are commonly misidentified as grossular. However, these garnets can be separated correctly on the basis of their visible spectrum and refractive indices, as indicated by Stockton (1988). The refractive indices of the Dora Maira pyropes we examined here approach the lowest R.I. values reported for pyrope by Stockton (1988). Furthermore, the UV-Vis absorption spectrum and characteristic inclusions provide additional criteria for the identification of Dora Maira pyrope. The infrared spectra show four sharp bands in the

Figure 14. The four sharp bands in this infrared spectrum (3660–3600 cm⁻¹ range) are unique to pyrope from Dora Maira.

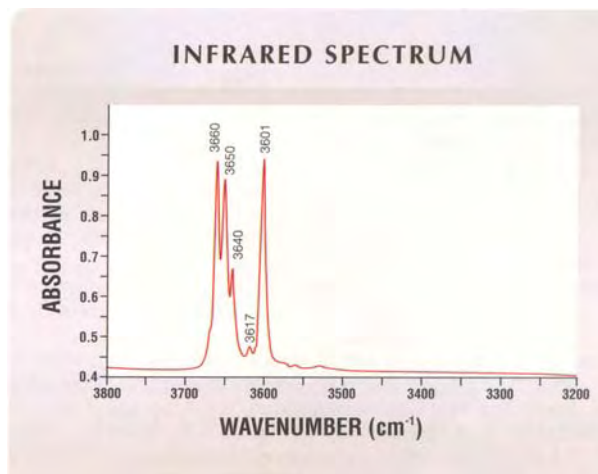


TABLE 2. Electron microprobe analyses of pyrope from the Dora Maira Massif, Italy.

Hue	Purplish pink ^a	Purplish pink ^b	Purplish pink ^c	Purplish pink ^d	Not reported ^e	Not reported ^f
Saturation	Low	Low	Low to moderate	Moderate		
Oxide (wt.%)						
SiO ₂	44.46	44.13	44.02	43.52	45.21	45.13
TiO ₂	0.02	0.01	0.04	0.03	0.00	0.02
Al ₂ O ₃	26.07	25.81	25.72	25.61	25.55	25.39
FeO ^g	1.48	2.50	3.33	5.18	0.91	1.35
MnO	0.02	0.05	0.05	0.08	0.02	0.03
MgO	27.97	27.16	26.41	25.02	28.83	28.98
CaO	0.59	0.61	0.94	0.77	0.28	0.09
Total	100.61	100.27	100.51	100.21	100.80	100.99
Mol. % end-members						
Pyrope	95.7	92.6	91.2	87.8	97.5	97.2
Almandine	2.9	4.8	6.4	10.2	1.8	2.6
Grossular	1.5	2.6	2.4	2.0	0.7	0.2

^a Average of 6 analyses of crystal fragments from the same material as the 0.27, 0.32, and 0.76 ct gemstones in table 1.

^b Average of 10 analyses of crystal fragments from the same material as the 0.26, 0.49, and 0.50 ct gemstones in table 1.

^c Average of 7 analyses of crystal fragments from the same material as the 0.24 and 0.25 ct gemstones in table 1.

^d Average of 9 analyses of crystal fragments from the same material as the 0.60 and 0.85 ct gemstones in table 1.

^e From Chopin (1984): rim of a 2 mm pyrope crystal.

^f Core of the crystal mentioned in footnote e.

^g Total iron as FeO.

3660–3600 cm⁻¹ region that are unique for this pyrope, and inclusions of ellenbergerite provide unequivocal evidence that a pyrope is from Dora Maira.

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CONCLUSION

Pyrope from the Dora Maira Massif has been faceted into pale purple to purplish pink gemstones that rarely exceed 1 ct. Although production to date has been minor, these gem pyropes add to the gemological significance of the Alpine area, with their unusual color and attractiveness.

The deposit appears to be extensive, but future production will undoubtedly continue to be limited by environmental restrictions on mining. Currently, about 100 carats per year enter the marketplace, and no more than a few hundred carats have been cut. Much of the faceted pyrope is sold to private gem collectors, with only a few having been set in jewelry.

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