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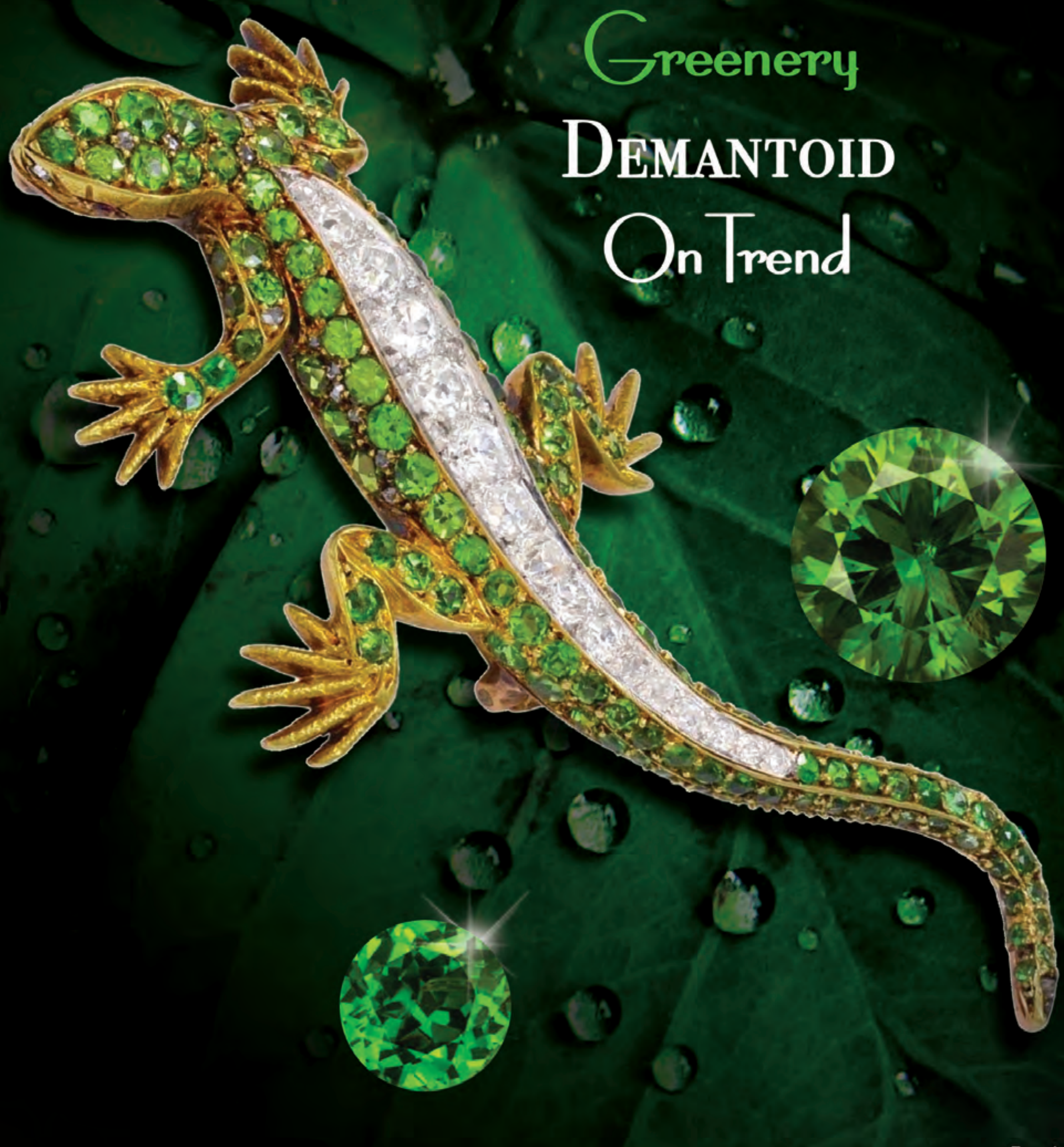

The Spirit of Greenery
Demantoid On Trend

A Publication of the International Colored Gemstone Association

Gem Andradite Garnet Deposits Demantoid Variety

The objective of this short review and update is to present the state-of-the-art on the geology and gemology of demantoid garnet deposits. The different studies conducted over the last thirty years provide the opportunity to unravel the features of the gem andradite, a green variety of garnet through field and laboratory research, including geology, petrography, gemology, fluid inclusions and stable isotopes. The different features are compared in order to approach the question of the geological and geographical origins of the rare demantoid garnet.

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Andradite Garnet and Demantoid Variety

The garnet mineral supergroup belongs to the nesosilicates group (Grew et al., 2013), with the general formula $X_3Y_2(ZO_4)_3$ in which Z, Y and X represent sites occupied by cations respectively in coordination 4 (Si, Al, Fe^{3+}, Ti), 6 (Al, Fe^{3+}, Cr, V, Ti) and 8 (Ca, Mn, Mg, Fe^{2+}). Six end-members are used to describe almost all gem garnets, which are divided into two series: (i) garnets with Al^{3+} in the Y-site i.e. the pyralspite series including pyrope, almandine and spessartine garnets; and (ii) garnets with Ca^{2+} in the X-site for the ugrandite series named for uvarovite, grossular and andradite garnets (Image 1).

Andradite garnet was named in 1868 by J.D. Dana in the honor of the Brazilian mineralogist J.B. de Andrada e Silva. Ideally, $Ca_3Fe^{3+}_2(SiO_4)_3$ andradite garnet has a theoretical composition of 35.47 wt% SiO_2, 31.42 wt% Fe_2O_3 and 33.11 wt% CaO. It crystallizes in the cubic system (space group $Ia\bar{3}d$) and it is thus isotropic. The hardness is between 6.5 and 7 and the density of 3.86 g/cm^3. The colors of andradite garnet varieties are in the brownish-yellow to brown (topazolite), yellow-green to deep green (demantoid), brownish-red to red (rainbow garnet) and black (melanite).

Demantoid is a green andradite variety appreciated for its color, brilliance and rarity (Image 2). The luster is adamantine to resinous and the scintillating nature of the demantoid garnet results from its high refractive index (n = 1.887) and dispersion (0.057), which is higher than that of diamond (0.044). In fact, the name demantoid comes from "diamond like," in allusion to those optical properties. Demantoid crystals are small-sized with most between 2 to 10 mm in diameter. Green euhedral crystals up to 2 to 3 cm are found mostly in Italy, Iran and Madagascar. Cut gems are generally 1 carat, and fine demantoids above 5 carats are considered world class.

Unfortunately, their scratch resistance (6.5) is on the verge of what is acceptable for a set stone. The variations in color for demantoid garnet are due to substitutions in the octahedral Y site of the crystal structure by different cations of similar size and charge. Traces of chromium (Cr^{3+}) are generally responsible for the deep green color of demantoid garnet (Stockton & Manson, 1983; Adamo et al., 2011). Also, Fe^{2+}-Ti^{4+} intervalence charge transfer can play a secondary role in the tint (Flies, 2008), as well as the Fe^{2+}-Fe^{3+} interactions (Moore & White, 1972). Demantoid garnets from Antetezambato in Madagascar, however, do not contain Cr^{3+}, and their color is attributed to the presence of Fe^{3+} in the octahedral sites (Rondeau et al., 2009; Pezzotta et al., 2011; Bocchio et al., 2010).

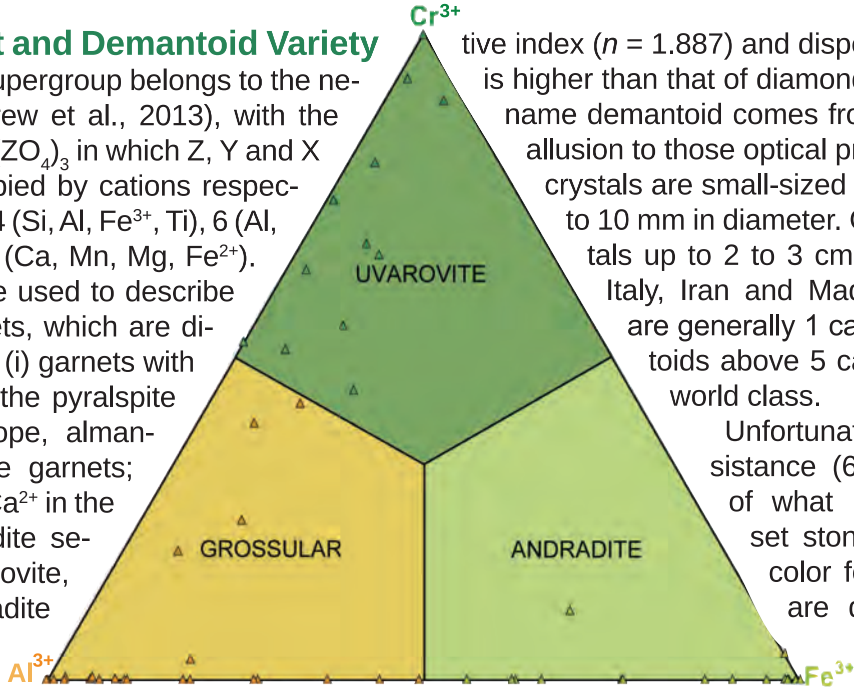


Image 1. Chemical ternary diagram Cr^{3+}-Fe^{3+}-Al^{3+} of the ugrandite series. The reported points are from the compilation in Deer et al. (1997).

TYPE OF DEPOSIT	SERPENTINITES		SKARNS	
Deposit	Bagh Borj (Iran)	Val Malenco (Italy)	Antetezambato (Madagascar)	Erongo Mountains (Namibia)
Genetic Model	MM	MM-HM	M-HM	M-HM
Formation and/or Series	Haji-Abad ophiolites Zagros ophiolites belt	Alpine ophiolites Val Malenco ophiolites	Alkaline Ambato granitoid intruding the Mesozoic sedimentary Isalo formation	Erongo Alkaline complex intruding a Neoproterozoic metamorphic sequence
Host Rock	serpentinites asbestos lenses	asbestos rocks, talc-schists, serpentinites	metasomatized rocks: *metamorphic skarn *fissural hydrothermal skarn	metamorphic skarn hydrothermal skarn
Wall Rocks	asbestos rocks, talc rocks, serpentinites	asbestos rocks, fractures in asbestos rocks and serpentinites, soapstone rocks	fractures in metasomatic rocks, voids, lenses in grossular skarn and metasomatized feldspathic sandstones and limestones	marbles, calc-silicates, fractures in the skarn rock
Mineralization Control	disseminations, fractures	disseminations, fractures	hydrothermal metasomatism, voids, fractures, pockets, fossils	hydrothermal metasomatism, fractures, veins, pockets
Typical Mineral Assemblage	asbestos, serpentine, Cr-magnetite, chromite antigorite, chrysotile	serpentine, asbestos, Cr-magnetite, talc, ilmenite horsetails of chrysotile	quartz, amethyst, calcite, Ca-stilbite, topazolite, pyrite, wollastonite (?)	calcite, diopside, quartz sphalerite, topazolite, prehnite, wollastonite
Metamorphism	P and T = unknown	T = 370°C 0.5 < P < 1.5 kilobars	P and T = unknown	P and T = unknown
Age of the Mineralization	Alpine-Himalayan orogeny Cenozoic	Alpine orogeny Cenozoic	Cenozoic magmatism (≈25 Ma) with coeval metamorphism and metasomatism	Mesozoic magmatism and coeval metamorphism and metasomatism
Chemistry Garnet Cr_2O_3 (wt. %) Fe_2O_3 (wt. %) Al_2O_3 (wt. %)	0.01 - 9.1§ 23.78 - 31.69 0.01 - 0.15	0.00 - 5.54¤ 25.92 - 30.60 0.00 - 0.15	0.00 § 23.65 - 33.39 0.00 - 5.90	0.00 -0.01¤ 31.34 - 31.72 0.00 - 0.16
$\delta^{18}O$ andradite (‰, V-SMOW)	$4.7 < \delta^{18}O < 6.2$ (n=3)	$3.6 < \delta^{18}O < 4.6$ (n=3)	$-1.8 < \delta^{18}O < 0.9$ (n=5)	$5.0 < \delta^{18}O < 6.5$ (n=5)

§: Data from Barrois et al. (2013); ¤ data from Adamo et al. (2009, 2015);
MM: metamorphic-metasomatic; HM: hydrothermal-metasomatic.

Table 1. Main geological, mineralogical and isotopic characteristics of Types I and II demantoid garnet deposits.

Demantoid Garnet Deposits

Historical Discoveries

The oldest known deposit is the historical Russian demantoid garnet—also called "Czar of the Garnet Family" in reference to its discovery in 1853 in the Central Ural Mountains. It was a symbol of Russian jewelry until 1917 (Phillips & Talantsev, 1996).

In 1876, another traditional demantoid garnet source was discovered in the Val Malenco area in the Italian Lombardy region (Cossa, 1880), and afterwards exploited in other valleys such as Val d'Ala in Piedmont. In 1997, rough demantoid garnet from the Erongo Mountains in central Namibia circulated in the trade market (Cairncross & Bahmann, 2006).

In 2001, demantoid garnet from Iran was discovered in Kerman province in the southeast of the country (Du Toit et al., 2006), as well as in the Kaghan Valley in northern Pakistan (Milisenda et al., 2001). In 2009, high quality green to yellow demantoid garnets were found in a mangrove swamp at Antetezambato, Ambato peninsula in northern Madagascar (Mocquet et al., 2009), and this has since formed the most economic deposit worldwide.

Minor occurrences of demantoid garnet are known in various countries (Image 3) and exploited worldwide by small-scale miners (see: https://www.mindat.org/demantoid), such as in Bolochistan, Pakistan (Adamo et al., 2015).

Image 2. Demantoid garnets from serpentinite and skarn-related deposits. **A)** Val Malenco, Italy, serpentinite deposit, crystal 6.9x4.6 cm. Collection Mines Paris-Tech n° 15736. **B)** Crystals of demantoid garnet filling a cavity from the Antetezambato skarn deposit, Madagascar, sample 3.9x2.6 cm. Collection Polychrom France, L. Thomas. **C)** Demantoid garnet from Belqeys, Takab, West Azerbaijan Province, sample 2.5x2.8 cm, Ø crystal = 1.3cm. Collection F. Escaut. **D**) Lac d'Amiante mine, Black Lake, Thetford mines, Québec, 5.4x2.8x2.5 cm. Collection M. Amabili. **E**) demantoid garnet crystals from the Bagh Borj ophiolites, Kerman Province, Iran, sample 1.8x1x1 cm. Collection Ch. Lolon. (Photos: L.-D. Bayle/le Règne Minéral.)

Types of Deposits

Most economic primary and secondary (placer) deposits are associated with two types of rocks (Adamo et al., 2011; Barrois et al., 2013): (i) serpentinized ultramafic rocks, e.g. from Val Malenco-Val d'Ala (Italy), Nizhny Tagil and Sysert in the Ural Mountains (Russia), Bagh Borj in the Kerman area (Iran), and Kaghan Valley (Pakistan); (ii) skarns, e.g. from Antetezambato (Madagascar) and the Erongo Mountains (Namibia). The two rock associations define two types of metamorphic deposits: the serpentinite (Type I) and the skarn (Type II).

Ultramafic rocks (UMR) are igneous or meta-igneous rocks with silica and magnesium contents less than 45 wt% and more than 18 wt%, respectively. UMR intrusives include mantle-related rocks, i.e. dunites, peridotites and pyroxenites. Metamorphism of UMR in the presence of water and/or carbon dioxide results in two types of rocks, typically talc-carbonate and serpentinite. Metamorphic fluids with less than 10% molar proportion of carbon dioxide favor the serpentinization resulting in a chlorite-serpentinite-amphibole assemblage. These metamorphic rocks are found in ophiolite complexes, which represent portions of oceanic crust and upper mantle from former oceans. These pieces of oceanic plates have been thrust (or obducted) onto the edge of continental plates during oceanic-continental plate subductions.

Skarns are calcium-bearing calc-silicate rocks containing skarn minerals such as wollastonite,

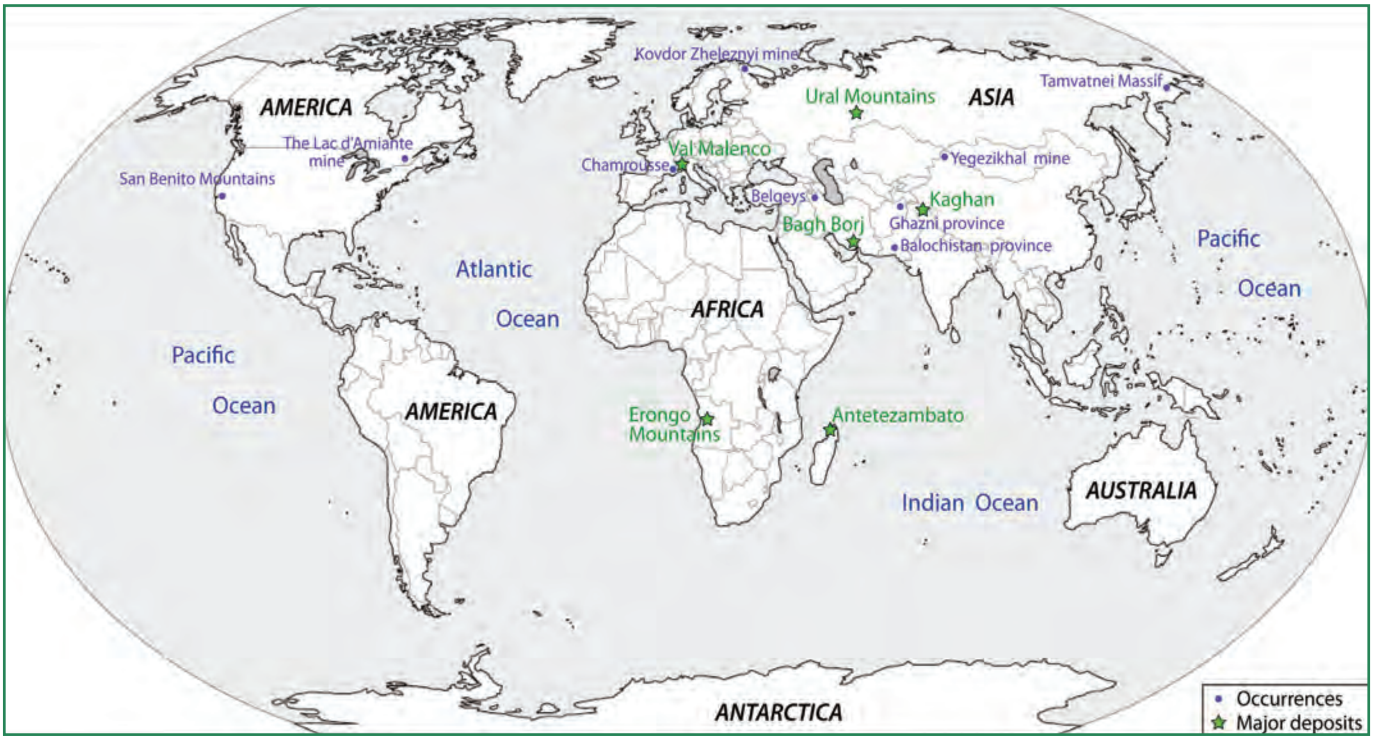


Image 3. Location of the demantoid garnet deposits and occurrences worldwide.

pyroxene, amphibole, phlogopite, vesuvianite and epidote. They are formed mostly at the contact zone between granitic magma intrusions and either limestone and/or dolostone or mudrocks. Heat and fluids derived from the magmas rich in silica, iron and aluminum react with calcium and magnesium-rich limestone or marble forming a skarn rock in a metamorphic process called metasomatism.

Type I vs. Type II Demantoid Garnet Deposits

The comparison of the geological and mineralogical features between the two types of deposits will include, for Type I, the deposits of Val Malenco-Val d'Ala (Italy), Nizhny Tagil and Sysert (Russia), Bagh Borj (Iran), Kaghan Valley and Bolochistan (Pakistan), and for Type II, the deposits of Antetezambato (Madagascar) and Erongo Mountains (Namibia).

(1) Geological Setting of the Deposits

Type I deposits are associated with ophiolitic sequences formed at different geological times. The formation of demantoid garnet is not precisely dated, but it occurred during extensional low- to medium-temperature (T ~300-400°C) metamorphic episodes. For example, at Val Malenco, garnets formed at T = 370°C and a pressure P between 0.5 and 1.5 kilobars (Amthauer et al., 1974). The oldest demantoid garnet-bearing ophiolites are those from the southern Ural Mountains, which formed around 400 million years (400 Ma) ago, i.e. the Devonian during Paleozoic time. The UMR are located within the ophiolitic suture zone, which represents fragments of an oceanic crust that pre-dates the Paleozoic continental collision between Kazakhstan and East European continents at 320 Ma when the Ural Mountains formed. The age of 400 Ma for the Russian ophiolites is identical to that of the ophiolites from Chamrousse in the French Alps where occurrences of demantoid are also found (Demargne, 2015).

The Bagh Borj, Kaghan and Val Malenco demantoid garnet deposits are associated with metamorphosed ophiolites linked to the Tethys Ocean closure and the Alpine-Himalayan orogenic belts:

(i) Closure of the Tethys Ocean and the collision between the Central Iran and Arabian plates formed the Zagros Orogen. The Bagh Borj demantoid garnet deposit is located in the Late Cretaceous (72-81 Ma) Zagros outer ophiolitic belt, and more precisely in the Haji-Abad ophiolites.

The mantle sequence includes harzburgite (a variety of peridotite with 40% to 90% of olivine, Ca-rich pyroxene and Cr-rich spinel) and residual dunite (90% of olivine, and pyroxene, chromite, magnetite and pyrope garnet) with the presence of deposits of magnetite, podiform chromitite, and demantoid garnet in the serpentinites.

(ii) The Kaghan demantoid garnet deposit is associated with ophiolitic mélanges and imbricated structure of the Indus-Tsango suture zone. The Indus suture, at 80-100 Ma, represents an accretionary wedge formed during the subduction of the Thetys Ocean beneath the Asian margin. These metamorphic rocks pre-date the continental collision between the Indian and Eurasian plates around 57 Ma.

(iii) The Val Malenco demantoid garnet deposits are in serpentinites produced by the metamorphism of ophiolites during the Alpine orogeny. These ophiolites are relics of the oceanic seafloor from the Thetys Ocean at 160 Ma before the subduction of the oceanic plate between 100 Ma and 45 Ma. Deformation and metamorphism occurred between 45 and 35 Ma with the uplift of the Alps Mountains at 34-32 Ma.

Type II deposits are characterized by the intrusion of felsic alkaline plutons or volcanic rocks into Ca-Mg-bearing rocks. At Antetezambato, the deposits are related to the intrusions of the Ambato Cenozoic granite and associated trachytic dykes at around 25 Ma. The trachytic dykes intruded the Mesozoic sedimentary formations of the Isalo (163-174 Ma) formed by a succession of sandstones, limestones and mudstones.

At the Erongo Mountains, the deposits are within a metamorphosed Neoproterozoic sequence (750-450 Ma) transformed into a succession of schists, calc-silicate rocks and marbles. During Cretaceous time (66-145 Ma), the sequence was intruded by granitic rocks from the Erongo alkaline complex with a concomitant thermal metamorphism and injection of granitic dykes. The demantoid garnet is found in marble as well as in calc-silicate rocks along the contact to the magmatic dykes and plugs (Lind et al., 1998).

(2) Geometry and Paragenesis of the Mineralization

Primary Type I mineralization is located in serpentinites, which have a variable mineral paragenesis following the nature of the initial composition of UMR. It consists of ± antigorite, ± Cr-magnetite or Cr-free magnetite, ± diopside, ± talc, ± chrysotile, and ± brucite. The demantoid garnet is found in variable geometrical structures:

(i) in lenses (or nodules) within the serpentinites such as described in Russia, of 1.5 to 2.5 m, rarely 5 m in strike length, and with a thickness from 0.5 to 3.5 cm with bulges up to 10 cm (Kievlenko, 2003). At Bagh Borj, demantoid garnet occurs as clusters presenting botryoidal habit (Image 4) or euhedral crystals in lenses of asbestos rocks within the ser-

Image 4. Demantoid garnets from the serpentinite Type I deposits. **A)** Euhedral demantoid garnets on asbestos rock from Sferlun mine, Val Malenco in Lombardia, Italy, sample 6.3x4.2, Ø crystal = 7 mm. Collection D. Boël. (Photo: L.-D. Bayle/le Règne Minéral) **B)** Botryoidal habit formed by aggregates of demantoid garnets from Kerman Province, Iran. Collection M. Douman. (Photo: S. Karampelas)

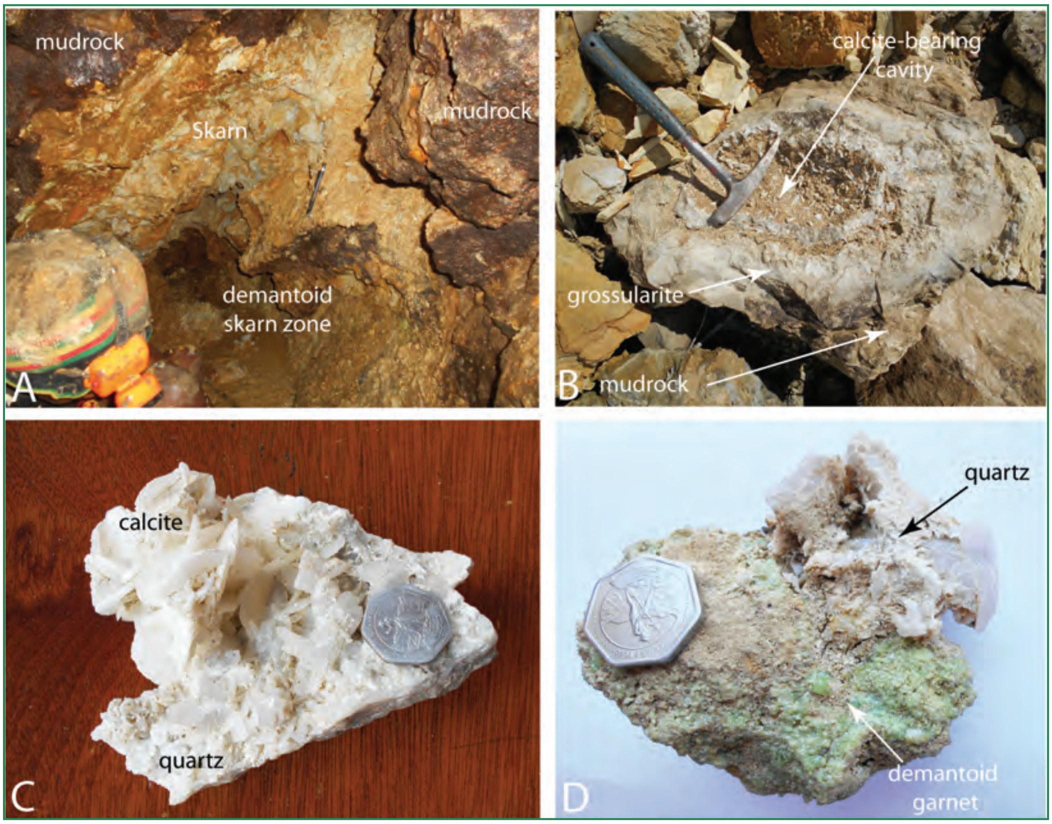


Image 5. The demantoid garnet skarn deposit from Antetezambato, Madagascar.
A) Garnet-bearing cavity formed in a skarnified mudrock.
B) Calcite-bearing cavity (skarn 2) formed in a grossularite (skarn 1) resulting from the metasomatism of the limestone.
C) Calcite and quartz infilling a veinlet.
D) Quartz and demantoid garnet filling a void.

pentinites while at Kaghan the lenses are talc-rich;

(ii) as disseminated crystals associated with magnetite and ludwigite ($Mg_2Fe^{3+}BO_5$) in serpentine matrix at Kaghan (in Adamo et al., 2011) or in banded layers with apatite, calcite and amphibole at Bagh Borg;

(iii) in veins, fractures and faults in all the deposits. At the Tochilny Kluch deposit in Russia, demantoid garnet formed around grains of chromite in highly fractured contact zones between chrysotile veins and serpentinites (Kievlenko, 2003). The garnets are of lentil or drop-like form.

At Sysert, they occur either in 1 to 2 cm wide chrysotile veins in serpentinitized pyroxenites or in the walls of fractures filled by fibrous serpentine-magnetite-antigorite. At Val Malenco, three types of mineralization are described by Bedogné et al. (1999) for the demantoid garnet: talc-bearing faults that crosscut serpentinites (Image 4), chrysotile filling fractures within serpentinites where the most appreciated gem demantoid garnets of this locality are found, and finally in fine-grained soapstones called "pietra ollare," formed of talc-clinoclore-Cr-magnetite, ilmenite and pyrite at the contact with serpentinites.

Secondary (placer) deposits of Type I are known, but generally demantoid garnet does not support stream transportation because of its relatively low hardness. The most famous alluvial deposit was found in the mid-19th century at Nizhniy-Tagilsk in the Ural Mountains. In 1995, the pebbles of demantoid garnet were exploited in sandy gravels from the Pleistocene terraces (< 2.6 Ma). The size of the main placer was 500 m long and between 20 to 100 m wide along the Bobrovka valley (Phillips & Talantsev, 1996).

Type II mineralization is characterized by huge fracturing and fluid-rock interactions due to the intrusion of magmas into (meta) sedimentary formations. The Antetezambato deposit is a case study detailed by Pezzotta (2010), Pezzotta et al. (2011) and Andriamamonjy et al. (2016). The skarn presents two stages of formation (Image 5): (1) thermal metamorphism of the sedimentary strata with the formation of a very fined-grained whitish grossularite at the contact with the Ca-mudrocks; (2) hydrothermal metamorphism related to high fracturing and fluid circulation, which heated the surrounding rocks and modified their whole chemical composition.

The metasomatic process preserved the original structures of the sediments and fossils such as lamellibranch bivalves and ammonites (Pezzotta, 2010). Demantoid garnet crystallized in fractures, veinlets and all the voids of the sedimentary formations. The episode of fracturing was accompanied by the circulation of fluids and deposition of garnet. The crystals are a few mm to 3 cm in diameter and the size of the garnet depends on the size of the cavities. Garnet is associated with quartz (± amethyst), calcite, Ca-stilbite, wollastonite (?) and pyrite (Pezzotta, 2010).

In the Erongo Mountains, demantoid garnets are found in calc-silicate rocks in a calcic gangue together with quartz and other silicates. They occur sometimes as euhedral crystal associated with prehnite in veins and pockets (Koller et al., 2002).

(3)Morphological and Chemical Features

Anhedral demantoid garnets are known to be found in Type I deposits—demantoid pebbles are typical of Russian deposits (Phillips & Talantsev, 1996) and botryoidal demantoid garnets are observed in Iran (Karampelas et al., 2007).

Euhedral crystals are found in both Types I and II deposits and they are commonly bounded by twelve crystallographic equivalent {110} faces resulting in the rhombododecahedral habit (Image 6A).

Other habits have been reported and/or are recognizable in the images available in literature. For instance, the polyhedral habit of some crystals discovered in Val Malenco appears as a combination of {110}, {*hhl*} with *h* < *l* and {*hkl*} faces. The latter have multiplicity of 24 and 48, respectively, and are likely {112} and {123} according to the indexing in the Goldschmidt's Atlas (Goldschmidt, 1913). The main morphological difference between crystals coming from the two types of deposits, however, is the morphological complexity.

The demantoid garnets found in the skarns of Madagascar are known to have the most complex habits (Pezzotta, 2010). For example, some crystals are bounded by rhombododecahedral {110} faces in association with the hexaoctahedral {*hkl*} faces and two kinds of {*hhl*} faces—the tetragonotrioctahedral {*hhl*} faces with *h* < *l*, i.e. {112}, and the trigonotrioctahedral {*hhl*} ones with *h* > *l*, i.e. {332} (Image 6B). It is worth noting that the crystals with the same habit can look different because of the unequal development of the faces. The development reflects the growth rates of the faces and is related to the growth conditions.

The chemical compositions of demantoid garnet were investigated for major and trace elements by EMPA and LA-ICP-MS (Amthauer et al., 1974; Stockton & Manson, 1983; Adamo et al., 2009; 2011; 2015; Bocchio et al., 2010; Pezzotta et al., 2011; Barrois et al., 2013). The garnets are almost pure andradite (Adr > 97 mol%), but Cr and Al substitutions in the Y sites generate compositions within the andradite-uva-

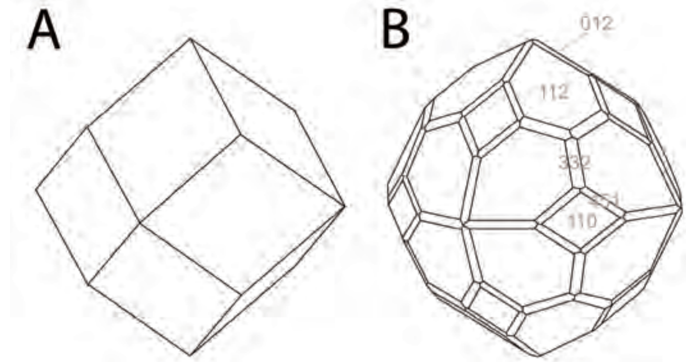


Image 6. Habits of demantoid garnets according to the indexing reported in the Atlas of Goldschmidt (1913). **A)** The rhombododecahedral habit. **B)** One of the complex habits observed for the Antetezambato crystals (Pezzotta, 2010).

rovite (Adr > 81 mol%) or andradite-grossular end-members (Adr > 91 mol%).

The composition of Type I demantoid garnet is characterized by the presence of chromium (Cr^{3+}. (Image 7). The abundance in Cr ranges from less than 0.01 up to 5.5 wt% Cr_2O_3 for the euhedral crystals from Val Malenco (Bocchio et al., 2010). The intensity of the green color is proportional to the quantity of chromium in the garnet (Karampelas et al., 2006), which can be up to 9.1 wt% in the deep green botryoidal demantoid of Bagh Borj (Barrois et al., 2013). In this last case, the globule of garnet presents a systematic zoning evidenced by SEM (Image 8). It has concentric zoning showing Cr and Fe variations from the center to the periphery, respectively, from 0.01 to 9.1 wt% Cr_2O_3 and 31.7 to 22.4 wt% Fe_2O_3. Type I demantoid garnet contains MgO up to 0.21 wt% in Balochistan (Adamo et al., 2015). TiO_2 is highly variable from nil up to 0.2 wt% in Bagh Borj garnet (Barrois et al., 2013) as well as V_2O_3 up to 0.03 wt% in Balochistan. Aluminum and manganese can be found up to respectively 0.25 wt% of Al_2O_3 for Bagh Borj and 0.06 wt% MnO for Val Malenco garnets.

The chemical compositions of Type II demantoid garnet are very different from those of Type I. For Antetezambato garnet, Cr and V were not detected by EPMA and only 3 ppm of Cr and less than 1 ppm of V were measured by LA-ICP-MS (Pezzotta et al., 2010). The main trace elements are Mg up to 1420 ppm, Al up to 5400 ppm and Mn up to 90 ppm. Nevertheless, SEM images have shown zoned crystals (Image 9A) characterized by Al-rich zones with contents up to 5.9 wt% Al_2O_3 alternating with Al-free ones (Barrois et al., 2013.) (Image 7). For the Erongo Mountains garnet, the chemical compositions approach those from Antetezambato (Bocchio et al., 2010; Koller et al., 2012) although the content of Cr_2O_3 is up to 530 ppm.

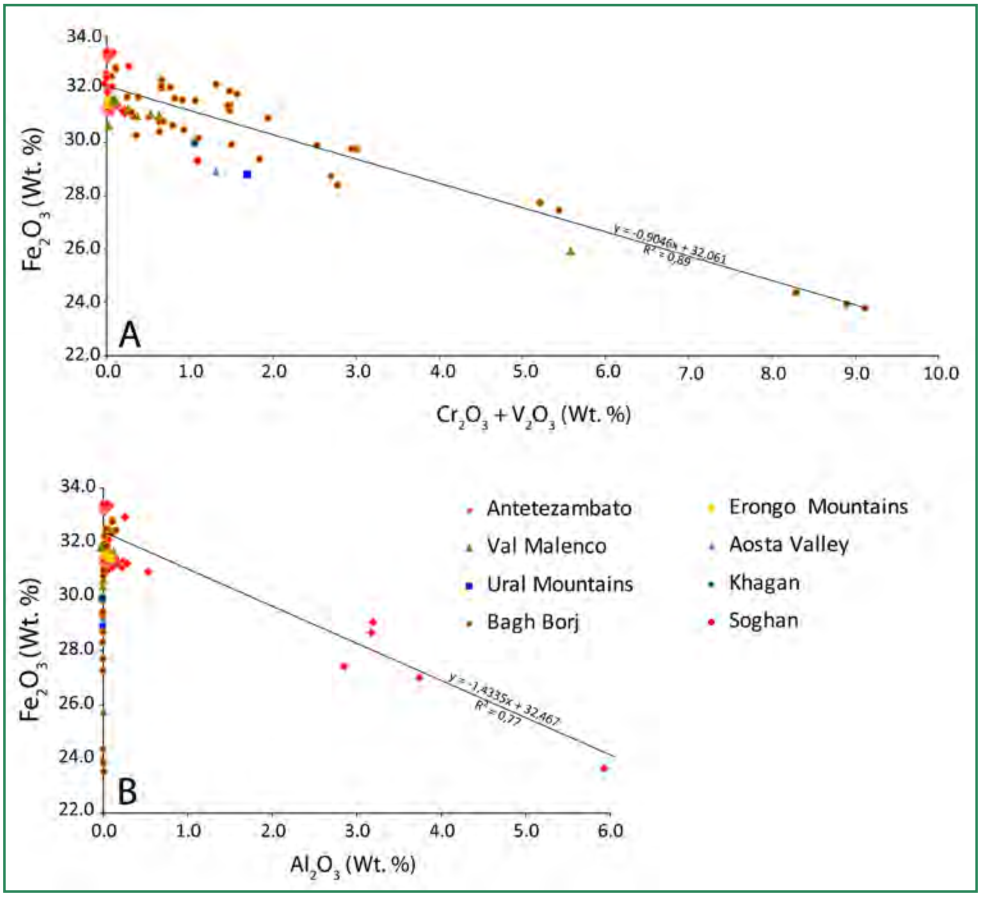


Image 7. Chemical composition of demantoid garnets from Type I deposits (Val Malenco and Aosta Valley, Italy; Ural Mountains, Russia; Kaghan Valley, Pakistan, Bagh Borj and Soghan, Iran) and Types II (Antetezambato, Madagascar and Erongo Mountains, Namibia) deposits. **A)** Diagram Cr_2O_3 + V_2O_3 vs. Fe_2O_3 showing the increase of chromium for garnet from serpentinite-related deposits.
B) Al_2O_3 vs. Fe_2O_3 showing the enrichment in aluminum of the Antetezambato demantoid garnets from skarn deposits.

(4) Solid Inclusions

The solid inclusions found for Type I deposits are classically fibrous needles of chrysotile (Image 9B), exceptionally associated with diopside (Krezmnicki, 1999), which display sometimes a radiating pattern called “horsetail” inclusions. The fibres and needles grew and diverged from a seed-crystal, usually chromite, Mg-chromite or Cr-magnetite (Image 9C). Similar inclusions have been described for demantoid garnets from Ural Mountains (Phillips & Talantsev, 1996), Val Malenco and Balochistan (Adamo et al., 2015), whereas they were not observed in Iran and Pakistan. The other solids trapped by demantoid garnet include brucite, antigorite, talc, asbestos, forsterite, and apatite.

The solid inclusions of Type II deposits are Ca-bearing minerals, typical of skarn paragenesis (Cairncross & Bahmann, 2006; Pezzotta et al., 2011; Barrois et al., 2013; Andriamamonjy et al., 2016). At Antetezambato, solid inclusions are wollastonite (?), diopside (Image 9D), F-vesuvianite (Image 9E), calcite, fluorite, pyrite and F-As-bearing apatite (Image 9D).

The F-apatite is arsenic rich (up to 2 wt% As_2O_3) and similar to that described in the ophiolitic complex of the Aosta Valley in Italy (Perseil et al., 2000). The F-rich vesuvianite contains up to 2.3 wt% fluorine, and 4.7 and 4.6 wt% of MgO and FeO, respectively (Barrois et al., 2013). At Erongo Mountains, the solids are calcite, diopside, wollastonite, quartz and sphalerite.

(5) Fluid Inclusions and Oxygen Isotopes

Fluid inclusions (FI) have rarely been described for Type I demantoid garnet. Adamo et al. (2009) reported fractures healed by liquids in the crystals of Val Malenco while Milisenda et al. (2001) have shown healing planes with strings of negative crystals in the demantoid garnet of Kaghan Valley. On the contrary, FI have been described for Type II.

At Antetezambato, FI are observed in all the garnets, such as liquid veils and sometimes two-phase FI (Pezzotta et al., 2011; Image 9E). A giant primary two-phase (liquid + vapor around 2 mm across) FI trapped by a crystal (size 1.5 x 0.6 cm) was investigated by X-ray computed tomography (Giuliani et al., 2015). The 3D tomography images show a unique fluid inclusion cavity (Image 10A) with morphology like a negative crystal with polygonal outlines parallel to the faces of the host garnet crystal (Image 10B). The

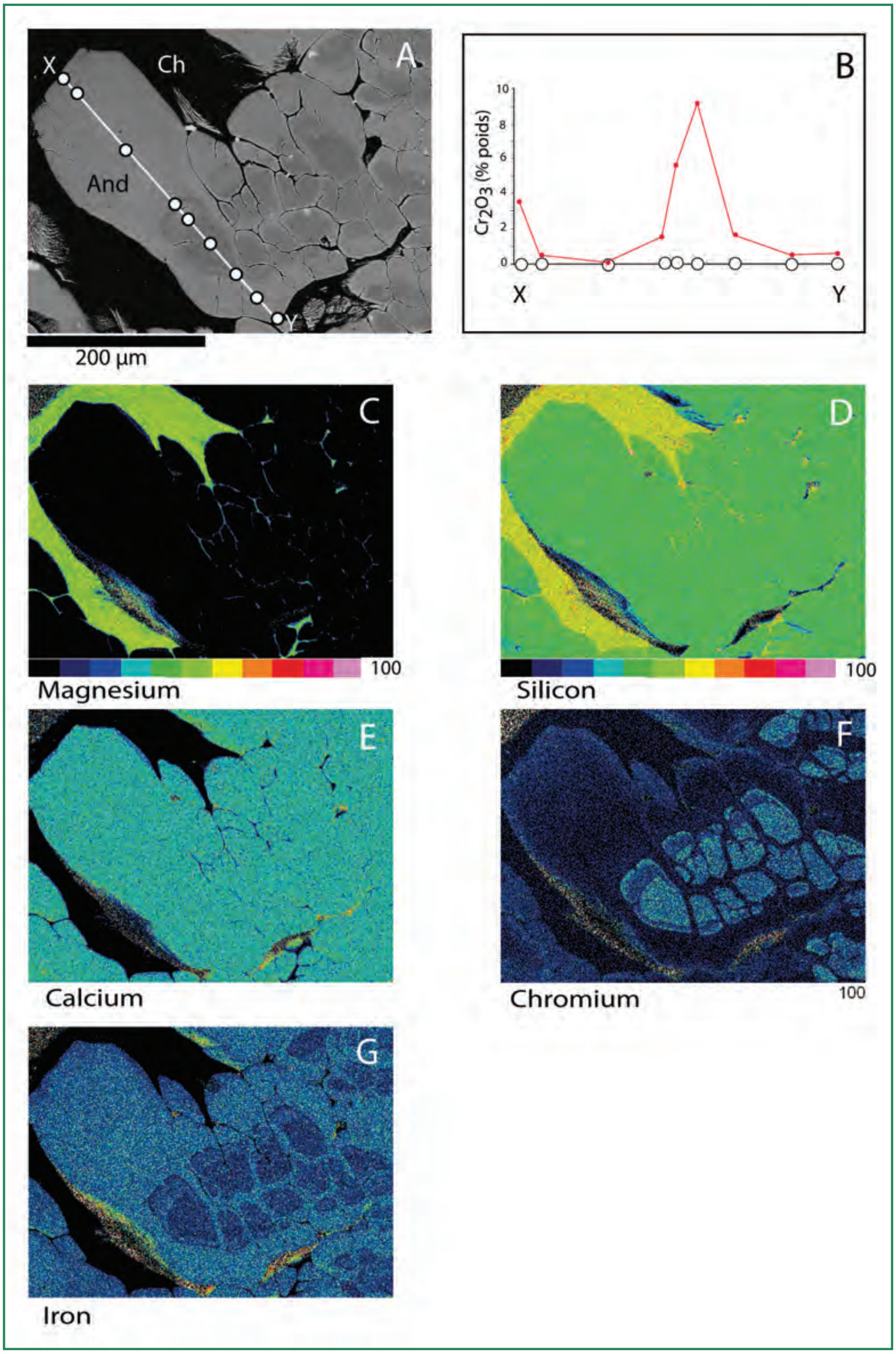


Image 8. Chemical zoning of the Bagh Borj demantoid garnet, Iran. **A)** SEM image showing the different chemical zones of a botryoidal crystal (differences mainly for iron and chromium). x-y = chemical section analyzed by EMPA and represented in image 8B. **B)** x-y cross-section of the crystal from image 8A. The deep gray zones are Cr-rich while the light ones are iron-rich. **C to G**) EDX maps of magnesium, silicon, calcium, chromium and iron distribution.

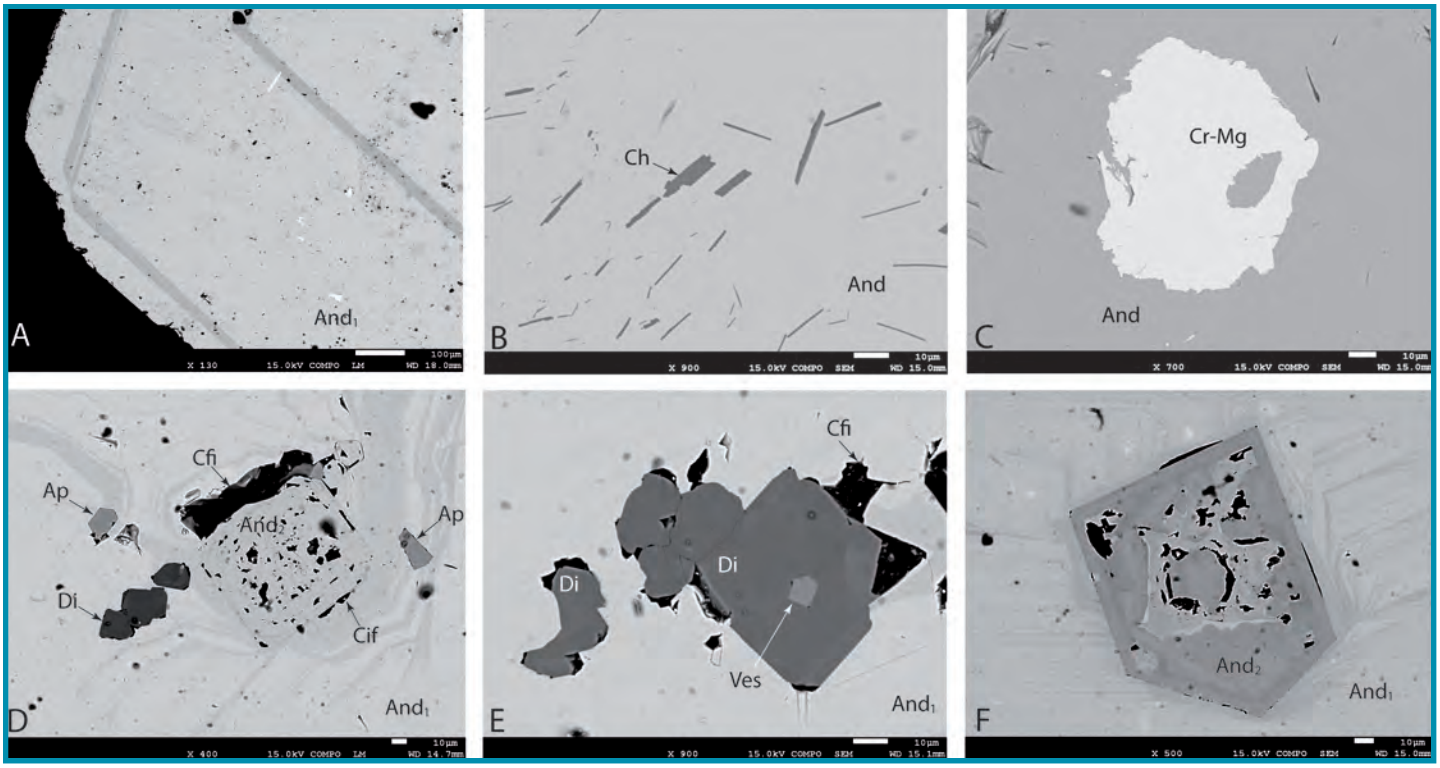


Image 9. SEM images of the demantoid garnets from skarn (Antetezambato, A, D to F) and serpentinite (Bagh Borj, B and D). **A)** Andradite of first generation (And1) showing a clear zoning. The deep gray bands are Al-rich while the light gray bands have nil or very small Al contents. **B)** Aspect of fibrous chrysotile (Ch) in the Cr-rich andradite (And) of Bagh Borj. **C)** Inclusion of a chromiferous magnetite (Cr-Mg) in the Bagh Borj demantoid garnet (And). **D)** The two generations of andradite garnet from Antetezambato deposit. The Al-rich zoned andradite (And1) is affected by dissolution and formation of a second generation of andradite (And2) in cavities. This episode is accompanied by the formation of diopside (Di), F-apatite (Ap) and the trapping of fluid inclusion cavities (Cfi). **E)** The cavities due to dissolution (Cfi) were filled by fluids and marked by the deposition of diopside (Di) and vesuvianite (Ves) in the andradite of first generation (And1). **F)** Zoned andradite from second generation (And2) in a cavity formed in the andradite of first generation (And1).

total volume of the garnet was 896.1 mm^3, of which 6.2 vol% was occupied by the FI cavity. The volume of the liquid phase was 52.16 mm^3 and the volume of the vapor phase was 3.52 mm^3. Raman spectrometry data has shown that the fluid was free of CO_2 and other volatiles. The FI was a primary two-phase aqueous FI in the H_2O-NaCl system with a salinity about 8 wt% equivalent NaCl.

In the Erongo Mountains, three generations of secondary FI were trapped along fractures (Koller et al., 2012). All the FI belong to the H_2O-$CaCl_2$ ± (CH_4) system with a salinity between 6 to 8 wt% equivalent $CaCl_2$.

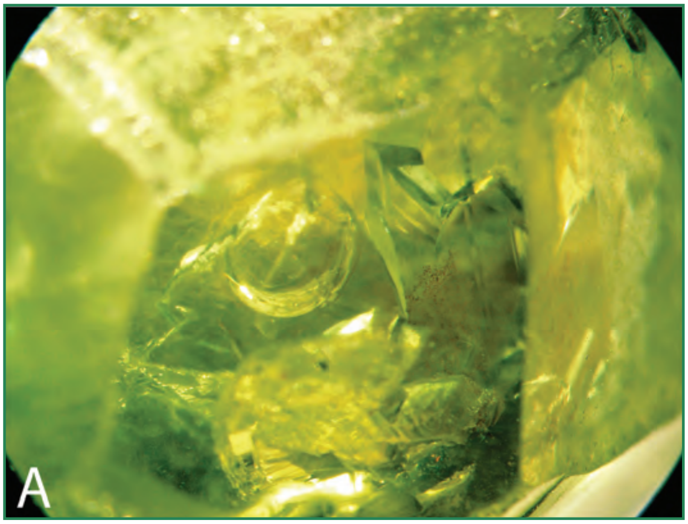
Oxygen isotope ratios of demantoid garnet reported in this work represent the first dataset for some of these deposits (Image 11). Type I deposits at Val Malenco and Bagh Borj have a range of $\delta^{18}O$ values between 3.6 and 4.6‰ (n = 3), and 4.7 and 6.2‰ (n = 3). Data for Type II deposits include the two main skarn type deposits. Oxygen isotope ratios are different with, respectively, values between -1.8 and 0.9‰ (n = 5) for the Antetezambato crystals and 5.0 to 6.5 (n = 5) for those from the Erongo Mountains.

Discussion and Perspectives

The demantoid garnet metamorphic deposits define two contrasted geological types in terms of geological setting, mineralogical and chemical fingerprints (Table 1). Type I are associated with serpentinites and Type II are linked to skarns.

The demantoid garnets are andradites where Fe is one of the main components (Fe_2O_3 ~ 31 wt%). Andradites of Type I have variable Cr contents which influence the green color of garnet with values up to 9 wt% of Cr_2O_3 for the deep green botryoidal garnet from Bagh Borj. Chromium contents are nil or very few in Type II demantoid garnets and the color is due to the cation Fe^{3+}.

The skarn type garnets have zoning characterized by high alumina contents, up to 5.9 wt% of Al_2O_3. The mineralogical fingerprints are also very different in terms of solid inclusions: (i) for Type I, fibrous chryso-



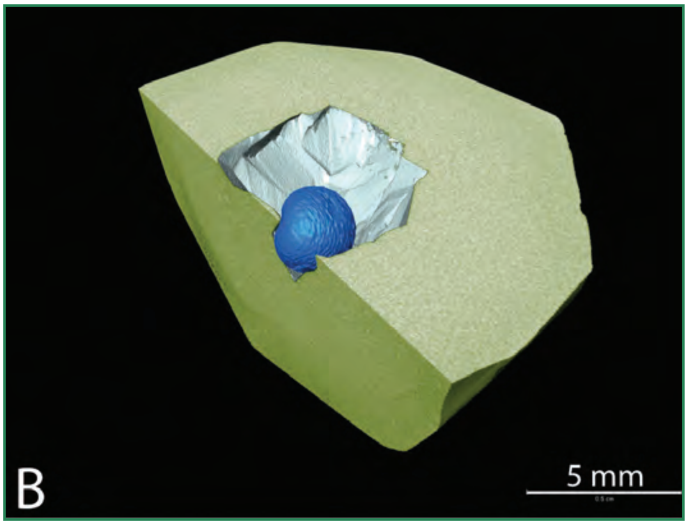


Image 10. Giant fluid inclusion trapped by a demantoid garnet from Antetezambato deposit. **A)** The fluid inclusion contains a two-phase (vapor + liquid) fluid inclusion. The bubble's diameter is around 2 mm. (Photo: M. Cathelineau) **B)** 3-D tomographic section of the garnet (green) showing the negative crystal morphology of the cavity with polygonal outlines parallel to the faces of the host crystal as well as the bubble phase (blue). (Photo Ch. Morlot)

tile arranged sometimes in horsetail inclusions, and minerals associated with the metamorphism of mafic and ultramafic rocks such as antigorite, talc, asbestos, Cr-magnetite, chromite; (ii) for Type II, Ca-Si ±Mg minerals such as wollastonite, diopside and vesuvianite, and apatite, calcite and quartz, formed during fluid-rock interactions due to the intrusion of alkaline granitoids either into limestone or marble followed by a huge hydro-fracturing of the rocks.

The source of chromium for Type I deposits is either chromite- or magnetite-bearing serpentinites, and the source of iron for Type II deposits on the example of Antetezambato, are the Fe-rich (Fe_2O_3 ~ 10 wt%) alkaline (Na_2O + K_2O ~ 8 wt%) magmatic rocks. The metasomatic fluids issued from these fluorine and phosphorus- alkaline magmas favored the formation of fluorite and F-apatite trapped by demantoid garnet.

The first oxygen isotope data indicate that the skarn type deposits from Antetezambato and the Erongo Mountains can be distinguished by their $\delta^{18}O$ values. Val Malenco and Bagh Borj demantoid garnets also have significantly different oxygen isotope values.

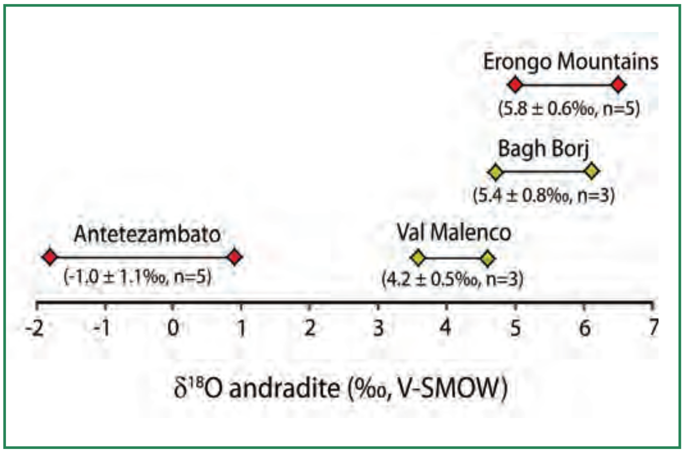


Image 11. Oxygen isotope ranges ($\delta^{18}O$ in ‰ V-SMOW) of demantoid garnets from the skarn type (Antetezambato and Erongo Mountains deposits) and the serpentinite type (Bagh Borj and Val Malenco) deposits.

Type I demantoid garnet is potentially present in all oceanic suture and ophiolitic zones worldwide where are located metamorphosed mafic and ultramafic rocks accompanied sometimes by deposits of chromite and/or magnetite.

Type II demantoid garnet is strictly associated with alkaline magmas crosscutting Ca-Mg rocks. Future deposits will be found in orogenic unconsolidated zones enriched in fluids and volatiles. Such zones of alkaline complexes are found on the Kola Peninsula in Russia where demantoid garnet from Zheleznyi was found at the contact between alkaline magmas and dolomitic rocks.

The northern part of Madagascar is a promising area for the discovery of new garnet demantoid deposits, like that of Antetezambato, because alkaline intrusions are numerous as well as carbonate formations in the Ampasindava and Ambato Peninsulas.

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Demantoid from Russia

As early as 1819-21, attention was being paid to a green gem discovered in a gold-platinum placer of the Bobrovka River near the village of Elizavetinskoe, located 40 km southwest of the city of Nizhny Tagil in the Ural Mountains of Russia. Incorrectly identified as peridot, it was later determined to be a new mineral. Because of its high refractive index and dispersive powers, it was given the name "demantoid," meaning "diamond-like."

By Alexey Burlakov and Evgeny Burlakov, Curator, Ural Geological Museum, Yekaterinburg, Russia

When visiting Russia in 1856, the respected Finnish mineralogist, Nils von Nordensheld studied the mineralogical properties of the new green gems from the Urals. He determined that they were, in fact, not peridot but a new mineral. In February 1864, he spoke to the St. Petersburg Mineralogical Society pronouncing this new discovery to be an andradite variety of garnet.

Later, in 1884, A. V. Kalugin and his son found demantoid in the gold-bearing sands of the Bobrovka River, near the village of Poldnevaya in the Polevskoy district. They did not know about Nordenscheld and his determination, and decided that the green gem was chrysolite (peridot). Under this name, Poldnevaya demantoid remained for a long time classified as "chrysolite" in the jewelry business.

Figure 1. Overview map showing the locations of deposits of demantoid in the Ural Mountains of Russia.

Mining engineer A. A. Lesh determined the chemical composition of the Poldnevaya "chrysolite" to be calcareous iron garnet. He announced his discovery in 1887 at a meeting of the Imperial St. Petersburg Mineralogical Society [1]. The same definition of the chemical composition for the demantoid gems from the Bobrovka River near Elizavetinskoye was made by Professor P. Nikolaev in 1881 [1].

By an incredible coincidence, the first two deposits of demantoid were discovered in the gold-bearing sands of two completely different rivers under the same name of Bobrovka, which is separated by more than 200 km (Figure 1). Therefore, when mentioning the deposits of demantoid, nearly always two names are specified: Poldnevaya Bobrovka or Nizhny Tagil (or Elizavetinskoye).

Figure 2. An Imperial Fabergé egg *Spring Flowers* from 1899, on display at the Fabergé Museum in Saint Petersburg. (Photo: Fabergé Museum)

In 1887, demantoid was presented at the Ural Industrial Exhibition as a new gemstone. Following the event, exports of the gems increased, and so did the prices, which grew rapidly.

After the Paris Exhibition in 1898, prices for demantoid reached their highest level yet [2]. This led to sharply increased mining for the gem, reaching its maximum production in 1913 of 104 kg.

From 1875 to 1920, demantoid was very popular both in Russia and abroad. It was during this time that the green gem was used in jewelry and *objets d'art* by the famous Peter Carl Fabergé (Figure 2).

Starting in 1920 and continuing up to the late 1980s, demantoid fell into relative oblivion. For the geologists of the “Uralkvartssamotsvety” association (Department of the Ministry of Geology of the USSR), it seemed to cease to exist. Nevertheless, the gem maintained quite a bit of interest for collectors, aficionados, gemologists and scientists.

The most significant work at this time was done by A. N. Aleksandrov. He first studied the impurities in demantoid and established that the green color was due to the chromium content. Aleksandrov also made the most complete description of the Ural demantoid.

In the late 1980s, there was renewed interest in the green gems and the opportunity to conduct geological explorations. That resulted in the discovery of a new primary deposit at Korkodin, located just 7 km south of the Poldnevaya deposit.

Figure 3. Example of a modern-day Fabergé ring featuring demantoid. (Photo: Fabergé)

Because of the geological surveys and prospecting in the Urals, many new deposits of demantoid were found, beginning with the Polar Urals (the Hadota River, the Syum-Kehu Massif), the Subpolar Urals (the “Svetlana” manifestation in the Khulga River basin and placers in the Sertyni River) and the Southern Urals (a number were found near the cities of Verkhny Ufaley and others).

These deposits have not, however, been sufficiently studied and explored to determine if the extraction of demantoid is economically feasible. Currently, geological exploration and mining are occurring only at two deposits: Korkodin and Poldnevaya.

The Korkodin Deposit

From the end of the 19th century to the early 20th century, demantoid deposits were known at locations several kilometers south of the upper reaches of the Bobrovka River [13]. In 1991, as a result of prospecting within the Korkodinsky massif at the Uralkvartsamotsvety, a primary deposit was discovered 2 km northeast of the railway station at Korkodin [9].

Figure 4. View of the Poldnevaya mine. (Photo: Corp Mayak Ltd)

The deposit currently belongs to Gran Ltd and is being actively mined. We can only estimate the share of Gran Ltd in the production of faceted Ural demantoids. According to some experts and dealers, it is about 75% of the total.

The Poldnevaya deposit belongs to Corp Mayak Ltd (Figure 4), which began to develop the field in 2013. From 2013 to 2016, only preparatory work was carried out. Geological exploration and associated extraction are now underway.

Presently, the company produces 23% to 24% of the entire Russia production of faceted demantoid. In the opinion of industry experts, Corp Mayak Ltd does not produce less rough demantoid than Gran Ltd, and its share of finished products may reach 40% to 45% of all Russian demantoid output in the near future.

The remaining 1% to 2% of faceted gems is the result of illegal mining operations on both Bobrovka Rivers (Figures 5 and 6).

Geology of the Korkodin and Poldnevaya Deposits

The Korkodin and Poldnevaya deposits (as well as others in the Urals) are confined to the suture zone of the Main Ural Fault and are localized within the hyperbasite massifs.

The two fields are separated only by 7 km. They are situated within a single hyperbasite massif and the zone of one thrust fault. The geological position of the deposits and the complex of rocks in which they are localized are in many respects the same. There are, however, some differences in the localization of productive mineralization.

Figure 5. Artisanal mining at the Elizavetinskoye mine. (Photo: A. Burlakov)

Figure 6. An artisanal miner looks for demantoid at the Elizavetinskoye mine. (Photo: A. Burlakov)

The Korkodin deposit is confined to the southern part of the Korkodinsky gabbro-peridotite massif, which is irregular in shape and elongated in the meridional direction by 12 km, with a width of up to 5 km. The massif is a serpentinite plate, which is the remnant of the Ufalei serpentinite massif, pushed to the phyllites and quartz-sericite schists of the Central Ural uplift.

The area of the deposit is dominated by serpentinized dunites and magnetite-antigorite serpentinites. To the northeast and southeast, small bodies of granodiorites and plagiogranites are mapped. In the central part of the site, a series of eccentric arranged vein bodies of diallagites can be traced, stretching 30 to 60 degrees. The fall is steep—70 to 80 degrees to the south. The length of the bodies is 10 to 100 m, with a thickness of 0.2 to 1.5 m.

The demantoid mineralization is confined to the field of distribution of diallagites and is controlled by crushing zones that are oriented at right angles to the

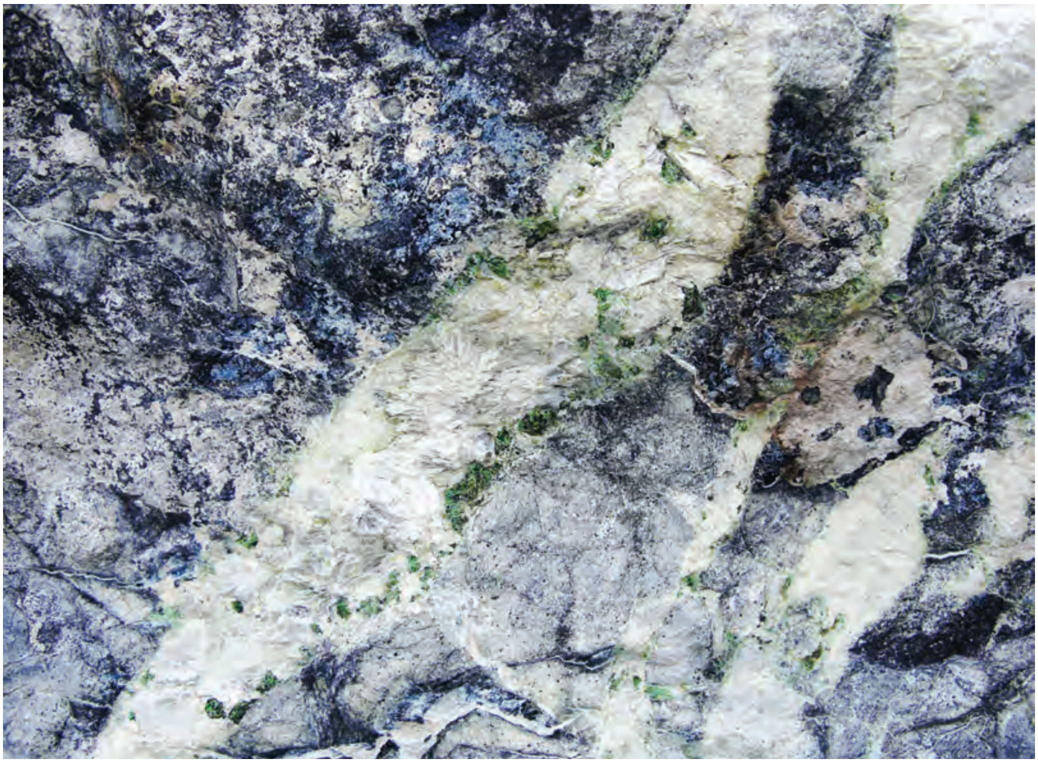

Figure 7. View of a productive vein of demantoid. Size is 30 cm by 7 cm. (Photo E. Burlakov)

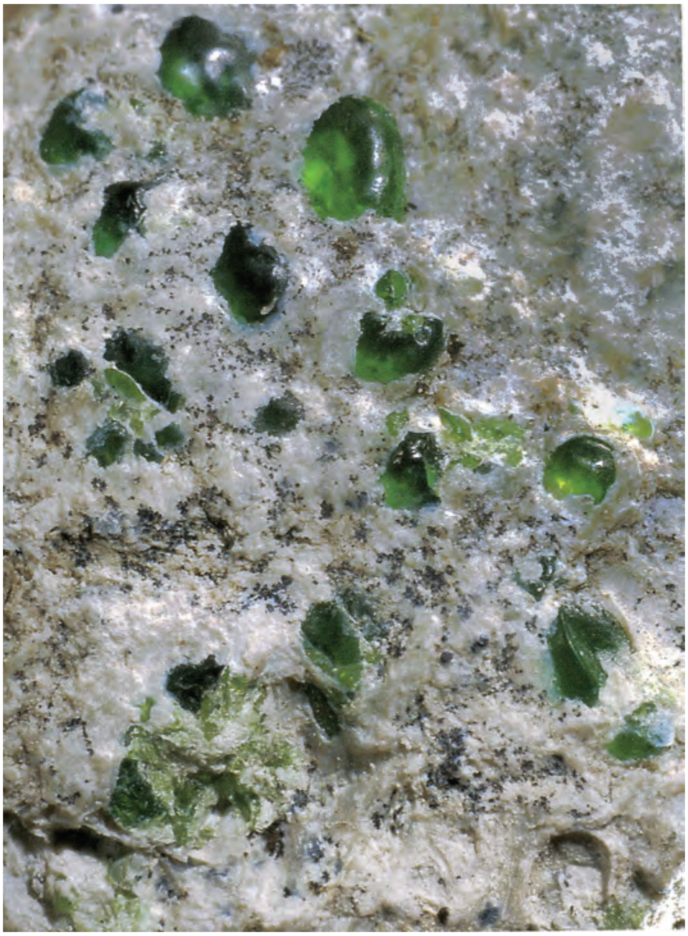

Figure 8. Demantoid embedded in mother rock. Nodules are 3 to 5mm. (Photo V. Kuznetsov)

diallagites. The zones consist of a system of vertical mineralized cracks with a thickness of 1 to 20 mm. Demantoid crystallizes on the walls of the cracks in the form of single individuals or intergrowths, or is part of a fracture in paragenesis with antigorite, tremolite, diopside, scaly serpentine, magnetite, chrome spinel and other fracture minerals [8,10]. Sometimes, the size of mineralized veins increases to 5 to 15 cm (Figure 7).

Most often, demantoid is in the form of rounded grains of 3 to 10 mm (Figure 8) in size or in splices and granular masses up to 5 to 7 cm in size (Figure 9). Very rarely, they are in the form of fine smoothed crystals represented by a rhombic dodecahedral or a combination of a tetragonal trioctahedral with a rhombic dodecahedral.

The color of demantoid varies widely, from greenish-yellow, brownish-green to bright dark green. Often, color changes are observed within a single grain, with the central part usually showing more green than the edges. Sometimes, the color zoning has sharp color transitions (Figure 10).

The host rocks of the Poldnevaya deposit are serpentinized dunites and antigorite serpentinites. The main productive mineralization of the site is concentrated within long steeply falling veins of the chrysotile-antigorite-carbonate composition (Figure 11).

Along the zone, the veins are traced reliably from 45 to 86 m, along the fall of 6 to 12 m. The thickness

Figure 9. Granular masses and splices of demantoid, 25 by 10 cm. (Photo: A. Burlakov)

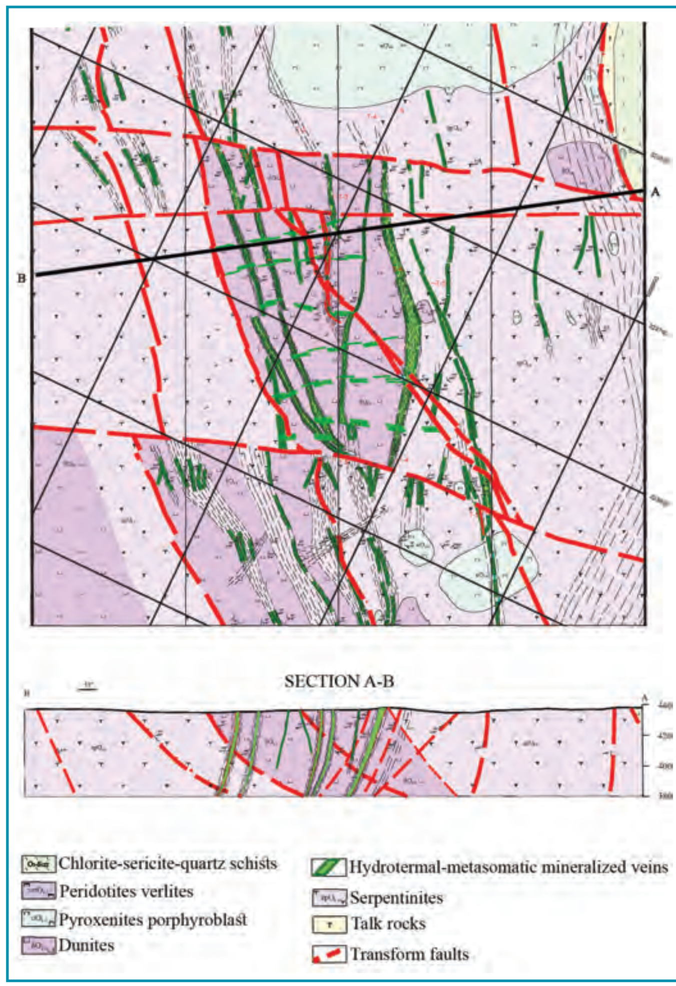

Figure 11. Simplified geological map of the Poldnevaya deposit. (Image provided by Corp Mayak Ltd)

Figure 10. Polished demantoid rough displaying color transitions and a horsetail inclusion. Private collection. (Photo E. Burlakov)

Figure 12. Horsetail in a 4.26 -ct demantoid (Photo: E. Burlakov)

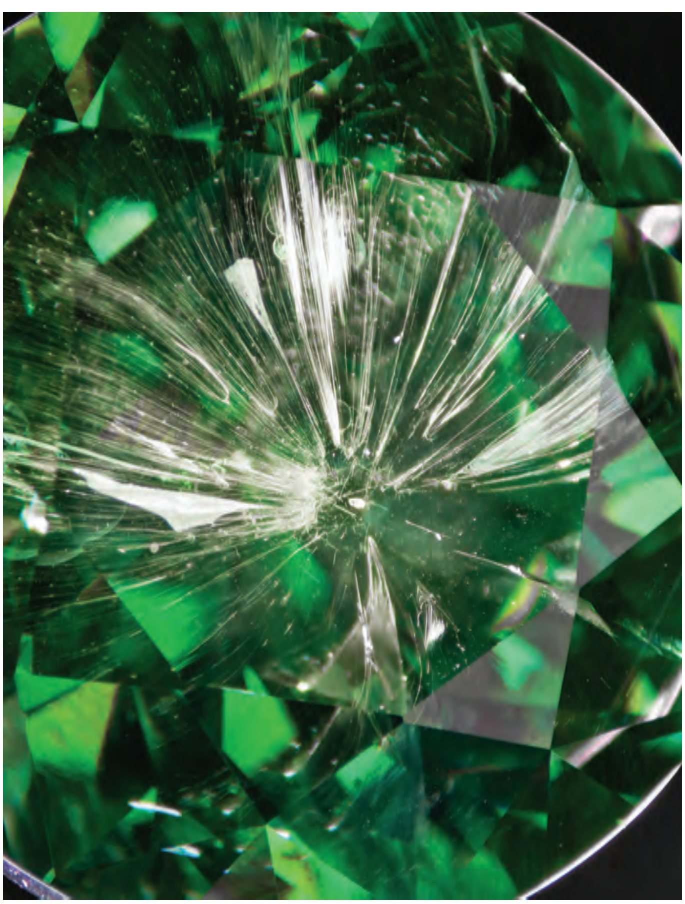

Figure 13. Horsetail inclusion in a 7.8 ct demantoid. (Photo: A. Irsutti)

of the veins is 0.7 to 1.1 m, up to 1.5 m. In genesis, these are typical veins of the alpine type. They are made of a fine-grained aggregate of antigorite, picrolite, clinochrysotil and calcite. Within the veins are extremely rare and unevenly localized mineralized pockets with demantoid.

Microprobe studies of differently colored demantoids made it possible to establish variations in the material composition of the gem from its coloration. The change in the color is due to the ratio of the content of chromium oxide and total iron oxide.

Gemology of Demantoid

Demantoid is an andradite garnet of green to yellowish-green color, according to the standards of GemSet, tone 2-6 [6]. According to A. Kisin [6], demantoids from the lower Tagil Bobrovka River have a color that ranges from a strongly yellowish-green (styG) to a slightly yellowish green (slyG), tone 2-4. Demantoids from the Poldnevaya deposit occur in all possible colors. Demantoid from the Korkodin area are characterized by dark tones (tone 5-8). According to this study, some of the material from the Korkodin area requires heat treatment to remove secondary tones. This low temperature heat treatment results in a constant and stable color.

There is a somewhat different situation with the demantoid from both the Poldnevaya and Elizavetinskoye deposits as most of it does not need any treatment. Moreover, all the heating experiments did not give visible results, which makes this operation useless.

Despite the long history of studying demantoid, questions still remain about the nature of the horsetail-type inclusions that are found in the gem from the Urals (Figures 12 and 13).

These inclusions are the main sign in the identification of demantoid. Until recently, there were two main points of view: (1) Inclusions are represented by byssolite (actinolite-asbestos) [9] and (2) inclusions are represented by chrysotile-asbestos [1,9].

A third point of view, presented by A. Kisin, appeared in the 1990s [5] and was supported by new interesting data in 2015 [7]. According to him, inclusions of the “horsetail” type are tubular hollow formations, sometimes containing inclusions of chrysotile or bissolite, or filled with clay minerals of nesting limonite, serpentine, etc. The appearance of such “pseudo-inclusions” is explained by the specifics of the split growth of the sub-units of the demantoid grains and the propagation of growth defects.

In our opinion, the question of the nature of these inclusions is still open. Very likely, all three types of inclusions take place. In a number of cases, when the inclusions in the demantoid are sufficiently large, it is easy to diagnose them with X-ray structural methods as inclusions of actinolite-tremolite composition (Figure 14).

At the same time, some data confirm the presence of inclusions of chrysotile asbestos. And, of course, Kisin's new data [7] should also be taken into account. In many ways, the same can be said about the nature of the color of the demantoid. The initial conclusions about the dependence of the intensity of the green color on the content of trivalent chromium [1] are recognized by most researchers.

More detailed studies indicate, however, a much more complex relationship [4,10]. The specific color of the demantoid is a consequence of the relationship of two and trivalent iron and trivalent chromium. Even in the presence of a high content of chromium, the green color is "quenched" by two and trivalent iron in a certain proportion. Only with a certain ratio of all three components is the purest green color achieved, and this ratio is still not fully understood.

Figure 14. Rough demantoid ,25x23x11 mm in size, with acicular actinolite-tremolite inclusions. Private collection. (Photo: E. Burlakov)

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Green Dragon Mine Demantoid from Namibia

A semi-desert, coastal country in southwest Africa, Namibia is known internationally for its beautiful scenery and its quality diamonds. But, it also has its fair share of colored gemstones and Demantoid Garnet is one of them.

By Stephan Reif

Until the mid-1990s, demantoid garnet was perceived as a uniquely Russian gemstone. While there were other deposits documented outside of Russia, they were of little commercial importance.

This situation changed dramatically when a goat herder was wandering in central Namibia near the famous *Spitzkoppe*—a 120-million-year-old group of bald granite peaks known as the *Matterhorn of Namibia*. Ater he stumbled over a rock with green shiny crystals, so began the discovery of the Namibian demantoid fields.

Soon, the crystals he found were passed on and identified as demantoid garnet. This triggered a mine rush and several claims near the village of Tubusis. The original claims, which formed the foundation of the mine known as Green Dragon Mine were pegged during this time. Interestingly, evidence of a Namibian demantoid deposit had apparently been known much earlier, when the finding of a tin-bearing andradite from the David Ost 61 farm was reported some 70 years earlier (Miller 2008).

Location and Geology

The Green Dragon Mine is situated approximately 30 km north of Usakos, along the D2306 dirt road to Okombahe, in Karibib District, in the Erongo Region. The approximately 10-km long small track to the mine is suitable only for pick-ups and four-wheel drive vehicles.

Initial demantoid formation in Namibia took place roughly 500 million years ago, during the regional Damara metamorphic event, especially if it was enhanced by contact metamorphism due to intruding granitic bodies (Miller 2008). These granitic dikes are visible at the Green Dragon Mine as well. This type of mineralization is along calcsilicate and other meta-sediments bands. The mineralization is strike parallel, but seldom exceeds a few tens of meters.

The demantoid garnets are embedded in calcsilicates and marbles, and the crystals can be up to a few centimeters in size. They can also vary greatly in color and quality. Most of these garnets suffered stress, due to the subsequent tectonic events, seen in the fractured rough. Associated minerals are brown andradite garnet, calcite and quartz. (Koller 2012).

After years of exposure and decomposition of the metasediments, the garnets were liberated, particularly in the case of the secondary garnet formation, where humic acids—produced by vegetation—decomposed calcite crystals within the garnetiferous pockets. The liberated garnets formed minor alluvial occurrences for a few square meters or, if they were transported by smaller streams, the gems created elongated and broader alluvial deposits.

At times, demantoid is found in pockets with perfect gem quality crystals. The crystals can be individual or multiple growths and can vary in color. Color zoning is often encountered within individual crystals. At depths of five meters or below, these pockets often contain calcite, phenite, quartz and apophyllite crystals. The percentage of clean, gem quality demantoid from these pockets is well above the overall production average.

Demantoid in brown marble and calc silicate.
(Photo: A.G. Palfi)

Gemology

Demantoid garnet is the green variety of andradite garnet, a calcium and iron-rich garnet with a refractive index of 1.88 and a dispersion, which is greater than that of diamond. There are hardly any pure garnet end members and most garnets found at the Green Dragon Mine are actually composed of andradite with a grossular content.

Green demantoids are very close to pure andradite end members with a low Ti, Cr, Mn and Mg content, whereas some of the reddish-brown colored garnets can have a major grossular component. The chrome content is lower than in Russian or Iranian demantoid, ranging between 0.01 – 0.15 wt% Cr_2O_3. This is in line with previous tests conducted. (Lind et al. 1997). The color is, in general, therefore lighter than Russian demantoid, while the dispersion is more evident in Namibian demantoid.

Opposite: Very fine faceted 11.63-ct demantoid.
(Photo: Stephan Reif)

Common inclusions are fingerprints, fissures, negative crystals with two-phase inclusions, fine needles and mineral inclusions. Color zoning is a common feature and can have a dramatic multicolor affect. *Horsetails*, a typical characteristic of Russian demantoid have not been witnessed by the author in Namibian demantoid.

Some Russian demantoid/andradite can be heated at a low temperature in a reducing environment in order to eliminate the brown hue and subsequently enhance the more valuable green body color.

Demantoid and andradite from the Green Dragon Mine do not respond well to heat treatments. On the contrary, tests on some specimens have proven to increase the brown hue and drive out the green color. These negative responses to heating have also been reported in demantoid from Madagascar (Chatagnier 2012).

Mining

The Green Dragon Mine is an open-pit mine and the concession currently covers more than 1300 hectares of a selected geologically investigated demantoid-bearing area. Exploration programs have been conducted since 1999 and numerous areas have been successfully sampled and demantoid outcrops identified.

The mining season lasts all year with the exception of Christmas and New Year closures. The sometimes harsh weather, with its extreme high and low temperatures, can be challenging. Water and food need to be transported to the mine. The often-difficult mining conditions in the main pit, where the first demantoid was found, involves a stretch of more than 130 meters in length at a maximum depth of 23 meters.

The Green Dragon Mine is a mechanized mine and the extraction of the garnets is done in cycles. First, holes are drilled into the hard rock and loaded with explosives. After blasting, the area is cleaned and the overburden is then removed by excavators and trucks.

Gem-bearing rocks are either dismantled by hand tools or are transported to the crushing and screening plant, which has an operating capacity of 30 tons per hour. The plant consists of primary, secondary and tertiary ore bins and the rocks are eventually screened into several sizes.

Finally, the garnets are washed and sorted into various qualities and sizes. Part of the production is sent directly for cutting and the rest is kept in stock for further use.

Excavating the pit at the Green Dragon Mine.
(Photo: Stephan Reif)

Bluish-green demantoid from the Green Dragon Mine set in white gold with diamond accents.
(Photo: Stanton Color)

Drilling into the hard rock at the Green Dragon Mine.
(Photo: Herb Kaiser)

Crusher and screening plant at the Green Dragon Mine.
(Photo: Stephan Reif)

The environmental aspects associated with the ongoing mining activities at the Green Dragon Mine were identified at an early stage and measures were taken to reduce the environmental impact to a minimum. No chemicals are used in the mining process and a waste management program is in place.

Part of the energy consumption is provided by solar energy and, apart from the earth-moving equipment, diesel generators are used only as backup.

As a result, Namibia's Ministry of Environment and Tourism has issued an environmental clearance certificate, showing that the Green Dragon Mine is one of the most environmentally friendly colored gemstone mines in Africa.

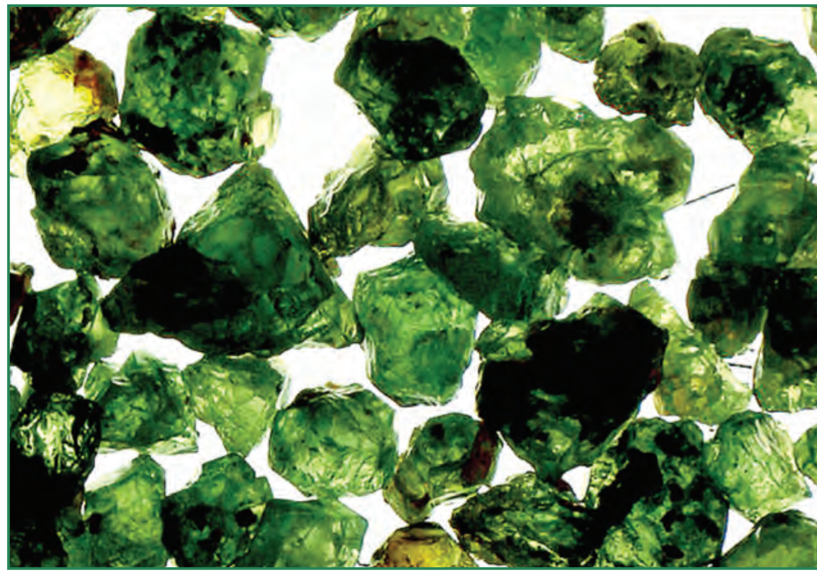
The Demantoid Market

Since the discovery of the Namibian deposit, many unique pieces of jewelry have been created with demantoid from the Green Dragon Mine. Popular choices are multi-pavé settings with diamonds. Demantoids are also popular as accent stones for other colored gems, as center stones or as matched pairs for earrings.

Due to the small crystal size and the abundance of inclusions in the rough, the majority of faceted gems

Demantoid and diamond earrings set in 18K rose gold by Erica Courtney using Green Dragon Mine demantoids.
(Photo: Erica Courtney)

Demantoid bracelet and brooch.
(Photo: Smithsonian)



Rough demantoid from the Green Dragon Mine.
(Photo: Stephan Reif)

are below half a carat. Demantoids over one carat are becoming increasingly more difficult to find and the price jumps significantly for sizes over two, three and five carats. Demantoid garnet over five carats is very, very rare.

The mine produces a consistent supply of calibrated demantoids from 1.5 mm and up in fine cutting. Demantoid over one carat are generally cut in free sizes due to their increased rarity. The most popular shapes are rounds, modified cushions and ovals. Brilliant cuts are often preferred over step cuts.

It is the experience of this author that many customers are not willing to pay more for an inclusion and actually prefer demantoids without horsetails. They want good clarity and as much brilliance and fire as possible. In the end, it is the dispersion and luster that set demantoid apart from other green gems, and what make demantoid the diamond of colored stones.

Another consumer trend, which has increased over the past few years, is the request for traceable and conflict-free gems. The end-client wants to know where her jewels come from and how the gems are mined and distributed. This consumer awareness relating to the ethical production of gemstones will only increase in the future. The transparent mine-to-market strategy practiced by the Green Dragon Mine fulfills this demand.

Demantoid has evolved over time from being a collector stone to find its own niche in the gem world. There is a timeless demand for natural stones, for their rarity, their thrilling history and their exquisite beauty. Demantoid has all these ingredients. It is a gem that will thrive as long as there is enough supply to support and grow the demand.

The Green Dragon Mine has the potential to provide a regular and consistent supply of demantoid garnet to the world market for several years to come. Green is the hope and sparkly seems to be the future. (www.demantoid.co)

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