Year 1, Issue 2, Tir 1405, pages 126 to 133

The Formation, genesis and exploration implication of garnet in Serpentinites of Bagh Borj (Kerman Province, Iran)

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Abstract

Gem-quality transparent to semi-transparent crystals of demantoid from Bagh Borj, were examined by different conventional and advanced gemological methods. (XRD, EDXRF, XRF, Raman).

This study focuses on garnets sourced from Bagh Borj (Kerman), using standard and advanced gemological methods as well as chemical analyses, XRD, energy dispersive X-ray fluorescence (EDXRF) and Raman spectroscopy.

The results of XRF showed that the content of Cr and V in most samples is high, with some samples containing a Cr_2O_3 content up to 0.032%. This suggests that Cr is the primary chromogenic element of Bagh Borj area demantoid, but the role of vanadium cannot be ignored.

Raman spectroscopy revealed absorption peaks near 868 cm^{-1}, 816 cm^{-1} and 517 cm^{-1}, associated with $(Si–O)_{Str}$ vibrations (Si–O stretching vibration), and absorption peaks are displayed near 358 cm^{-1}, related to the rotation of $SiO_4–R(SiO_4)^{4-}$, and the peaks near 517 cm^{-1} are related to (Si–O)bend vibrations (Si–O bending vibration). Additionally, related absorption peaks near 164 cm^{-1} are attributed to the translation of $SiO_4–T(SiO_4)^{4-}$, and absorption peaks near 226 cm^{-1} are associated with the translation of $X^{2+}–T(X^{2+})$ (X^{2+} represents divalent ions).

The high pressure mineral assemblage (amphibolite, garnet-amphibolite, kyanite-garnet-amphibolite, hornblendite and epidote-amphibolite), indicated that the studied garnet from serpentinite was formed through high pressure metamorphism, during the subduction zone serpentinization.

Key words: Bagh Borj area, demantoid garnet, inclusions.

https://doi.org/10.22067/gemiran.2026.48050

Introduction

Garnet is one of the most useful minerals in Earth sciences providing key information on mantle, metamorphic, metasomatic, and igneous processes (Baxter et al., 2013). Garnet is commonly found in various types of skarn deposits. Hydrothermal activity during skarn formation alters both intrusive body and calcareous wall rock, and produces endoskarn and exoskarn, respectively. Garnet forms a zone that straddles both endoskarn and exoskarn. Commonly endoskarn and exoskarn garnets are andradite-rich and grossular-rich, respectively (Somarin, 2012).

Demantoid, the variety of Ca-Fe-rich green andradite (a member of the garnet group of minerals), is a high quality gemstone, discovered in southeast of Iran. Its chemical formula is $[Ca_3Fe_2^{3+}(SiO_4)_3]$, and it often contains admixtures of Cr, Ti, V, Al, and Mg.

One of the rarest garnet varieties, demantoid can have a green color that rivals emerald and a fire that exceeds diamond (Arem and Clark, 2024). It’s the most well-known andradite garnet and one of the most valuable garnets of any variety. Even with the discovery of new sources since the 1990s, demantoid remains very rare. Clean, facetable stones command very high prices per carat. However, demantoids with horsetail inclusions wavy, golden, and fibrous are especially coveted by collectors (Arem and Clark, 2024).

From the perspective of geological genesis, demantoid garnet can be broadly divided into two petrogenetic groups: Skarn-hosted and serpentinite-hosted, with the majority originating from serpentinite environments (Palke and Pardieu, 2014).

In recent years, there has been increasing interest in the geographic origin determination of demantoid garnet, with research focusing mainly on chemical analyses and chemometric methods (Schwarzinger, 2019; Bindereif et al., 2020), as well as inclusion characteristics (Lewis, 2018).

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Geological setting

The study area has a very complex geological structure and is characterized by a geological formation known as an ophiolite complex. The sequence are partially to completely serpentinized peridotite, specifically harzburgite and dunite.

Skarn deposits are formed by the interactions between high-temperature magmatic–hydrothermal fluids and reactive (e.g., carbonate) rocks, supplying various commodities including Cu-Au, Ag-Zn-Pb, and Fe (Meinert, 1992).

Amphibolites, one of the common metabasic rocks in metamorphic terranes from Precambrian to Phanerozoic, can provide valuable information for the study of geological processes (Barker, 1990). Amphibolite can be formed by metamorphism of mafic igneous rock (ortho-amphibolite) or sedimentary tuff (para-amphibolite).

The amphibole group of minerals represents one of the most compositionally diverse mineral groups, and this diversity is reflected in the very different rock types, tectonic environments, and wide range of P–T conditions in which they occur (Welch, 2020). Amphibole-rich mafic and ultramafic intrusive rocks could be a 'hidden' amphibole reservoir in the arc crust, and therefore amphibole plays a major role in the petrogenesis and differentiation of many arc magmas (Tiepolo et al., 2012).

Field Occurrence

The study area is characterized by a geological formation known as an ophiolite complex. The sequence are partially to completely serpentinized peridotite, specifically harzburgite and dunite.

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Analytical Methods

All rock samples and mineral identification were first studied by a polarized light microscope. Representative samples were used for further investigation by X ray diffraction (XRD), X ray flourscence (XRF),scanning electron microscope (SEM) analysis and micro-Raman spectroscopy methods.

Ten original crystals of transparent to transluscent andradite (var. Demantoid) were separated from the host rock and faceted. The faceted samples were examined by standard and advanced gemmological methods to characterize their physical and optical properties.

Raman spectroscopic measurements were performed on a Edinburch RM5 microspectrometer instrument, connected to an Zeiss microscope with confocally coupled monochromator (focal length 800 mm) at the central lab of Ferdowsi university of Mashhad.

Raman spectroscopy was performed at the central laboratory of Ferdowsi University of Mahhad. The instrument model is a LabSpec 6 laser Raman spectrometer. The experimental conditions are as following: the wavelength of the excitation laser was 532 nm, the exposure time was 1 s, and the scanning wave number range was 100~2000 cm-1.

Inclusions in 5 of the samples from Bagh Borj were analyzed by Raman spectroscopy using a Thermo Scientific DXR Raman microscope with 532 nm laser excitation.

Scanning electron microscopy (SEM-EDS) analyzes of inclusions in two samples from Takab were performed using a scanning electron microscope. Measurements were taken at 15 kV, with a 40 s acquisition time for each analysis and a 3 µm spot size. Ten pieces of transparent garnets were separated from the host rock.

Results

As an indicator mineral, garnet composition and texture can effectively reveal the physical and chemical properties of ore-forming fluids and record hydrothermal fluid evolution and water–rock reactions (Gaspar et al., 2008). Moreover, garnet chemistry is widely used to reveal skarn formation processes such as the metasomatism mechanism (Xiao et al., 2018).

The result of chemical composition and trace elements of garnets showed that the 3 major sources of demantoid of Iran, Kerman (Gabri), Bagh Borj, and Takab, could be distinguished by using a plot of the Mn/Ti ratio versus the sum of Cr and V in combination with the Al content (Table 1).

The chemical compositions established by XRF and ICP. The samples are andradite with a very low content of Al. Fe is the main component of demantoid and plays a crucial role in its coloration as an end member.

From the trace elements detected, Cr was the most abundant, along with minor concentrations of Mn, Ti, and V.

The heavy mineral garnet can be used for the identification of the potential lithologies exposed in the source area. Garnet is a particular useful mineral in provenance research because of its wide range of major element composition, its high importance in defining metamorphic conditions, and its comparative stability during transport and burial diagenesis (Deer et al., 1992).

Garnet chemistry also has important provenance applications in gemology, where the mineral chemical composition is used as a fingerprint to trace the source of gemstone garnet (Mathis et al., 2008).

Garnet has been widely applied to estimate the P-T conditions of mantle rocks, the P-T-t metamorphic history of metamorphic rocks based on the temperature-dependent (e.g., Fe, Mg) and pressure-sensitive (e.g., Ca) elements exchange experiments between garnet and coexisting mineral phases (Caddick and Kohn, Sun and Liang, 2015).

Inclusions in garnet are useful indicators of metamorphic grade (Krippner, 2014). certain garnet compositions are most likely related to specific source rocks such as high-grade metamafic rocks, granulite-facies metasedimentary rocks, granitoids, and skarn deposits (e.g., Morton et al., 2004, Mange and Morton, 2007, Aubrecht et al., 2009).

Hydrothermal garnets recorded the process of fluid-rock interactions and can therefore reveal the physicochemical conditions of hydrothermal mineralization, which include the fluid temperature, oxygen fugacity, fluid flow rate, pH, and chemical compositions (Jamtveit et al., 1993, Park et al., 2017, Xiao et al., 2018). Some researchers suggested that garnets from Cu-dominated skarns have higher Cu contents than those from other types of skarns (Karimzadeh Somarin, 2004), and W-Sn skarns have high Sn content in their garnets (Zhou et al., 2017). These studies provide new insights into using garnet trace element chemistry to classify skarn deposits and mineral exploration.

Garnets in different areas have different texture and mineralogical characteristics. Demantoid garnet in the study area comprises 4 types: :1) Garnet andradite in the serpentinite zones, 2) Garnet andradite in the contact skarn, 3) Oscillatory-zoned Garnet andradite in proximal skarn, 4) Garnet andradite in distal skarn.

Table 1. XRF analysis results (wt.%) of garnets from the study area.

	SiO_2	CaO	FeO	Fe_2O_3	Al_2O_3	MnO	MgO	TiO_2	Cr_2O_3	Total
Dark gray	36.7	33.91	15.83	-	7.84	0.15	0.29	0.71	1.18	96.61
bright gray	35.6	31.99	1.4	24.75	2.78	0.15	-	-	-	96.68

Gemological properties of garnet

The samples underwent examination utilizing standard and advanced gemological methods to determine their physical and optical properties (Table 2). The samples were transparent to transluscent, with a vitreous luster and green color.

Their microscopic characters, specfic gravity, refractive indices, densities and ultraviolet fluorescence.

The samples were investigated for ultraviolet fluorescence under long (365 nm) and short (254 nm) wavelength ultraviolet light. X-ray fluorescence (XRF) was performed using an EDX-7000.

Raman spectroscopy was performed at the depaartment of applied gemology and industrial minerals of Fersdwsi University of Mashhad, Mashhad, Iran. The instrument model is a LabSpec 6 laser Raman spectrometer produced by Horiba Scientific, Osaka, Japan. The experimental conditions are as follows: the exposure time was 1 s, the wavelength of the excitation laser was 532 nm, and the scanning wave number range was 100~2000 cm^{-1}.

Table 2) Gemological properties of Bagh Borj samples

	T_1	**T_2**	**T_3**	**T_4**
Color	Deep green	Green	Deep green	Green
Luster	Glassy	Bright glassy	Glassy	Glassy
R.I	>1.81	>1.81	>1.81	>1.81
Density	3.83	3.86	3.83	3.83
Diaphaneity	Transparent	Transparent	Transparent	Transparent

Garnet has a homogeneous composition of $Alm_{66–71}Grs_{14–17}Prp_{9–12}Sps_{3–5}$, amphibole is ferro-hornblende, biotite belongs to the ferro-biotite species and pyroxene is dominated by orthopyroxene with few clinopyroxene.

The minor and trace elements of demantoids from different areas were measured and differentiate the chemical diversity by using advanced methods to determine the origin of demantoids.

Demantoid of Bagh Borj has a unique geological origin resulting from the interaction of geological processes and regional tectonic activities as well as serpentinization and skarnization processes.

Raman spectroscopy (Fig. 1) revealed absorption peaks near 868 cm^{-1}, 816 cm^{-1} and 517 cm^{-1}, associated with $(Si–O)_{Str}$ vibrations (Si–O stretching vibration), and absorption peaks are displayed near 358 cm^{-1}, related to the rotation of SiO_4–$R(SiO_4)^{4-}$, and the peaks near 517 cm^{-1} are related to (Si–O)bend vibrations (Si–O bending vibration). Additionally, related absorption peaks near 164 cm^{-1} are attributed to the translation of SiO_4–$T(SiO_4)^{4-}$, and absorption peaks near 226 cm^{-1} are associated with the translation of X^{2+}–$T(X^{2+})$ (X^{2+} represents divalent ions).

The common inclusions found in Bagh Borj demantoid consist of a combination of calcite, magnetite and hematite. This combination of inclusions differentiates Bagh Borj demantoids (Fig. 2) from demantoids sourced from Kerman and Takab area.

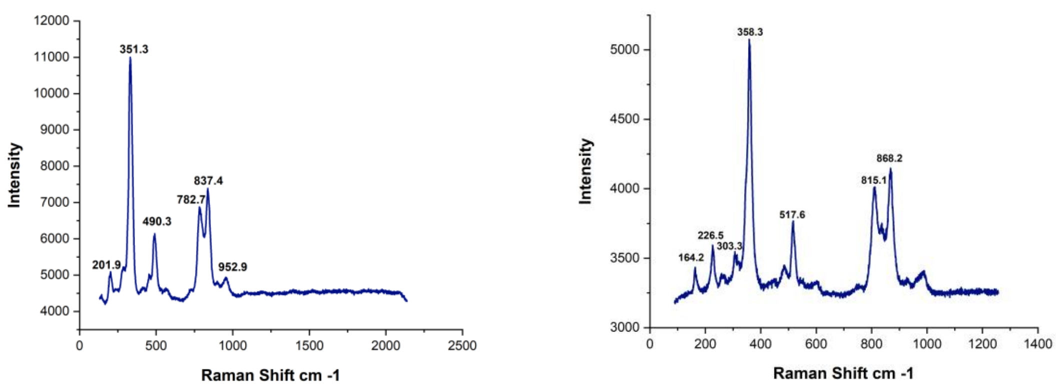

Fig. 1) Raman spectrum of demantoid from Bagh Borj.

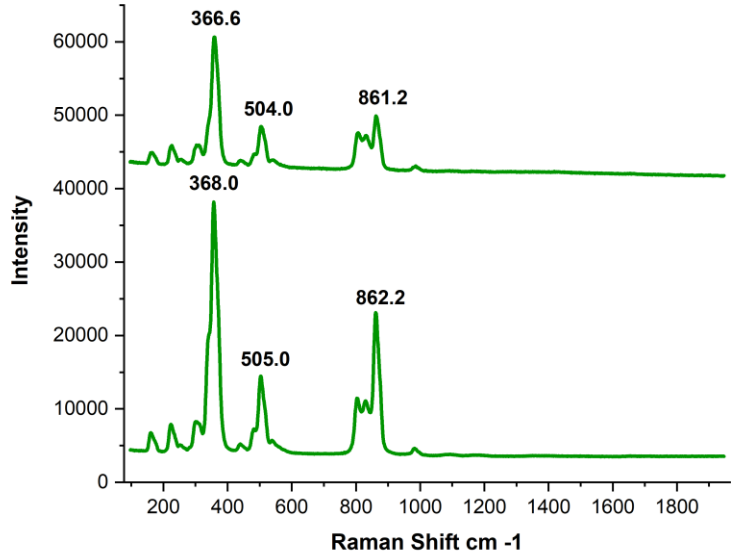

Fig. 2) Comparison of different demaantoids from Bagh Borj

Conclusion

Demantoid garnet in the study area, is formed under complex geological process and geochemical conditions. The geological formation of demantoid garnet involves a complex interplay of different processes, (e,g. suitable parent rocks, chemical reactions, metamorphic processes, hydrothermal activities and time).

The parent rocks from which demantoid garnet originates is serpentinite or other ultramafic rocks rich in Mg, Fe and Cr, which are essential components for the formation of garnet. The green color of demantoid is related to the presence of Cr and/or iron within its crystal structure. Pre-existing rocks were subjected to high pressure and temperature conditions within the area. As metamorphism progresses, faulting and fracturing become favorable conditions for the crystallization of garnet within the rock. Hydrothermal fluids rich in Ca, Al and other elements infiltrated the metamorphic rocks, providing the necessary ingredients for demantoid growth.

References

Ahmad Zadeh, S. (2009) Investigation of petrography, geochemistry and thermodynamic conditions of formation of metamorphic rocks of Alam Kandi complex in west of Mahenshan, northwest of Iran. MSc thesis. University of Tabriz.

Arem, J. E. and Clark, D. (2024) Demantoid Garnet Value, Price, and Jewelry Information. International Gem Society.

Babakhani and Ghalamghash, (1991) Geological map of Takhte Solieman.

Barker, A.J. (1990) Introduction to Metamorphic Textures and Microstructures; Blackie: Glasgow, UK.

Baxter, E. F.; Caddick, M. J. and Ague, J. J. (2013) Garnet: Common mineral, uncommonly useful. Elements 9: 415–419.
Bindereif, S., Rüll, F., Schwarzinger, S. & Schwarzinger, C. (2020) Chemometric modeling of trace element data for origin determination of demantoid garnets. Minerals, 10(12), article 1046 (15 pp.).
Giuliani, G.; Pignatelli, I.; Fallick, A.; Boyce, A.; Andriamamonjy, A.; Razafindratsimba, S. and Khan, T. (2017) Gem Andradite Garnet Deposits Demantoid Variety. InColor. 36.
Krippner, A.; Meinhold, G.; Morton, A. C. and Eynatten, H. (2014) Evaluation of garnet discrimination diagrams using geochemical data of garnets derived from various host rocks. Sedimentary Geology, Vol. 306, Pages 36-52
Lewis, Z. 2018. Beyond 'horse tails' in demantoid garnet. Gems&Jewellery, 27(4), 32–35.
Palke, A. C. and Pardieu, V. (2014) Demantoid from Baluchistan Province in Pakistan. Gems Gemol. 50, 302–303.
Meinert, L. D., (1992) Skarns and skarn deposits. Geosci. Canada, 19 (1992), pp. 145-162.
Schwarzinger, C. (2019) Determination of demantoid garnet origin by chemical fingerprinting. Monatshefte für Chemie - Chemical Monthly, 150(5), 907–912.
Somarin, A. K. (2012) Use of garnet as a mineral exploration tool. In Garnet: Metamorphic History, Composition and Crystallization. Schweitzer, H. and Metzger, J. (eds). Nova Science Publishers Inc., New York, 225-239.
Tiepolo, M.; Langone, A.; Morishita, T.; Yuhara, M. (2012) On the Recycling of Amphibole-rich Ultramafic Intrusive Rocks in the Arc Crust: Evidence from Shikanoshima Island (Kyushu, Japan). J. Petrol. 53, 1255–1285.
Welch, D.M. (2020) Amphiboles. In Encyclopedia of Geology, 2nd ed.; Elias, S., Alderton, D., Eds.; Academic Press: Cambridge, MA, USA; pp. 297–300.
Zhang, J. Y., Li, G., Tian, Y. and Schmitz, F. (2024) Inclusions and Spectral Characterization of Demantoid from Baluchistan, Pakistan. Crystals.
Xiao, X.; Zhou, T.F.; Noel, C.W.; Zhang, L.J.; Fan, Y.; Wang, F.Y.; Chen, X.F. (2018) The formation and trace elements of garnet in the skarn zone from the Xinqiao Cu-S-Fe-Au deposit, Tongling ore district, Anhui Province, Eastern China. Lithos, 302–303, 467–479.