

## A Case Study on Distribution of Gemstone in Bela Ophiolite, District Khuzdar, Balochistan

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**Abstract:** Bela Ophiolite and suture zone host several types of gemstones in the underlain and overlain rocks such as garnet (demantoid and almandine), quartz, brucite, malachite, chrysocolla, azurite, calcite, natrolite, green chert, jasper, serpentine, agate, epidote, augite and prehnite. However, the rare gemstones including demantoid garnet are found as dodecahedron green crystals associated with the altered peridotite rocks such as serpentinite. Brucite is found in the botryoidal habit in the ultramafic rocks of Bela Ophiolite associated with the chromite mines in the Baran Lak and Amorzai area of Wadh in the host rock dunite. The serpentine is found in several locations associated with the altered ultramafic rocks formed after the serpentinization of peridotite. Furthermore, one of the rare gemstones such as petroleum and diamond quartz is formed due to the hydrothermal intrusion in the sedimentary rocks such as limestone; calcite also occurs in limestone as dogtooth crystals. While azurite, malachite and chrysocolla are formed as secondary deposits in the oxidized zone of copper and sulphide mines in the Manjawi, Nal and Sonaro associated adjacent to basalt. Moreover, epidote is found as green crystals having porphyritic texture in the host rock granite mainly in the Bakhalo area, Wadh. Agate, jasper, green chert and several other kinds of chert are found associated with the basalt chert unit in the mélangé and gossan. In addition to that natrolite is found in the Nal ophiolite mainly in the Hazarghanji town found associated with the cracks and vugs of dolerite dykes as fibrous and cylindrical crystals. In metamorphic sole rocks of Bela Ophiolite in the Sonaro area, marble and quartzite are associated with the metamorphic rocks such as greenschist and amphibolite facies that are formed during the evolution period of the ophiolite. In pegmatite gabbro, the elongated and prismatic black crystals of augite are found in the host rock gabbro near the Ornach cross area, and the prehnite gemstone is found associated with the basalt and gabbroic rocks transition zone in the Ornach area.

**Keywords:** Bela ophiolite, gemstone, metamorphic rock, demantoid garnet, quartz.

### Introduction

Gemstone is defined widely as the material used for decoration, that has specific characteristics of being very hard, rare and highly tough to resistance (Fritsch and Rondeau, 2009). Gemstone has been prized for hundreds to thousands of years because of its durability, transparency, colour, lustre and high value to Volume ratio (Fritsch and Rondeau, 2009; Groat and Laurs, 2009). Gemstone in nature is formed as faceted and then its beauty is enhanced by several treatment processes (Voudouris et al., 2019). Mainly the natural gemstone is a single grain of natural minerals, although many other gems are amorphous such as opal and natural glass or obsidian. Some gemstones are formed by solid solution series i.e. peridot, garnet and others are formed in the rocks like jade and lapis and some gemstone are associated with organic materials such as pearl, coral and amber (Fritsch and Rondeau, 2009). Gemstone is a mineral having prominent beauty among other minerals or rocks. Amongst these the most important gemstones are ruby, sapphire, emerald and diamonds. The mineral

forms of gemstones are tanzanite, chrysoberyl, tsavorite, beryl, tourmaline and topaz (Groat, 2012).

Gemstones of Pakistan are generally found in the Himalayas fold belt including the Main Karakorum Thrust and Main Mantle Thrust. Emerald in Mingora associated with Ophiolitic mélangé (Kazmi and Donoghue, 1990). Peridot occurred in the Sapat mafic-ultramafic complex (Kausar and Khan, 1996). According to Kazmi and Abbas (2001). Several types of quartz were reported from the northern suture zone, pegmatite and hydrothermal vein-type deposits. Other gemstones such as fluorite, spinel, pargasite, pyrite, malachite and azurite were found associated with granitic and gabbroic intrusions in the pegmatite fields. Gemstones of Balochistan are generally associated with the suture zone in the western part of the Indian plate. Gemstones are located in the suture zone including Peridot, Garnets, malachite, azurite, chrysocolla, quartz, calcite, and brucite which are found associated with Muslim Bagh ophiolite (Munir and Ahmed, 1985; Mahmood et al., 1995; Kakar, 2014 b; Ahmed et al.,

2017). Smoky quartz, amethysts and natrolite are associated with basaltic rock units of Bagh complex mélangé in the Muslim Bagh ophiolites, and also associated with Bela Ophiolite (Mahmood et al., 1995; Naeem et al., 2014). Similarly, the gemstones in the Bela ophiolite are generally hosted by the Bela ophiolite underlain and overlain rocks of (ophiolite including suture zones (ophiolite sequence), mélanges, metamorphic sole rocks, pegmatite and deposition in sedimentary rocks of Indian Plate continental margin sediments. However, based upon the gemology, this paper highlights the field features, while discussing the kind, arrangement, distribution and origin of the gemstones deposited adjacent to the Bela Ophiolite zone.

### **Geology of the Study Area**

The regional geology of Bela Ophiolite Khuzdar district and adjacent area is generally divided from eastward to the westward into three main zones including: Indian platform sediments, the Suture zone of Bela Ophiolite including underlying mélangé and also the overlying flysch sediments (Fig.1, Qazi et al., 2018). Bela Ophiolite is exposed along the western margin of the Indian plate, forming a narrow 380 km long belt (Zaigham and Mallick, 2000). Bela ophiolite is the largest ophiolite in Pakistan, it is important to understand the western margin of the Indian plate, particularly the collisional history of Indian and Eurasian plates (Xiong et al., 2011). The Bela ophiolite is part of the Alpine-Himalayan orogenic belt. The rock units in this belt were formed in both MORB and supra-subduction zone settings, and include ultramafic and mafic compositions (Bashir et al., 2009). It consists of layered gabbro, foliated gabbro, isotropic gabbro, sheeted and volcanic dikes (Ahsan et al., 1988). The ultramafic rocks were serpentinized after harzburgite. Bela ophiolite is considered one of the leading ophiolites in terms of the largest ophiolite in Pakistan. It originated from the collision of the Indian plate under the Eurasian plate (Xiong et al., 2011). Bela Ophiolite has formed during Aptian, however tectonically the Jurassic divergence and rifting were emplaced during Eocene on the western margin of the Indian plate (Gnos et al., 1998). Bela ophiolite rocks were formed in both MORB and supra-subduction zone settings (Bashir et al., 2009) including ultramafic and mafic compositions. It is located in the southern part of Pakistan and is exposed mainly on a wide range that starts from Khuzdar up to Karachi north-south orientation (Qazi et al., 2018), with thickness of about 10-40 km or more, and 380 km in length (Gnos et al., 1998). The geological contributions proposed that the Bela ophiolite consists

of two units, the upper and lower units. The upper unit represents the slice of the overriding plate, while the lower unit signifies the piece of the subducting plate (under thrusting) which was adjacent to the Indian plate. Bela ophiolite is generally divided into two main units which are the upper and lower portion of the ophiolite (Khan, 2018, a). The upper unit is located in the northern portion of ophiolite that contains oceanic lithosphere portion and its dismember part is comprised of mantle rocks, sheeted dikes and gabbroic rocks, pillow lava, mafic rocks, crustal granitic rocks, and metamorphic sole rocks that are exposed in the area of Wadh, Ornach and Sonaro (Gnos et al., 1998). The lower unit lies in the southern part of ophiolite generally comprise 3 to 5 km thick sedimentary succession. The lava flowing in the southern portion of Bela ophiolite mainly contains the trench and accretionary prism deposits that consist of 50-1500 meters thick and 500 meters broad imbricated sheeted dykes or pillow lavas overlain by sedimentary rock units of chert, limestone, shale, dolerite and gabbroic dykes (Jones, 1961; Sarwar, 1992; Khan, 1998; Qazi et al., 2018).

Stratigraphic units are exposed in Bela ophiolite ranging in age from Jurassic to Miocene (Khan et al., 2003). It contains the Shirinab Formation that is Triassic-Jurassic comprised mainly of interbedded limestone, sandstone and shale (Fatmi, 1977) which is overlying Parh Group (Sember Formation, Goru Formation and Parh limestone), However, in the Bela area, Goru Formation and Parh limestone is missing due to mélangé formation (Sarwar, 1981) and Sember Formation characterize all Cretaceous strata under the Kanar mélangé (Sarwar and DeJong, 1984). Sember Formation consists of shale of light-dark grey or olive greenish shale with minor limestone which is overlying by Pab Sandstone having an age of Late Cretaceous, brownish sandstone with minor limestone (Fatmi, 1977). Pab Sandstone is overlying by Thar Formation consisting of mudstone, reddish-purple (maroon) sandstone and muddy limestone of late Cretaceous to Paleocene. The Thar Formation is overlying by Wadh Limestone having transitional contact with Late Paleocene that is generally comprised of limestone with minor sandstone (Jones, 1961). Thar Formation observed the process of emplacement whereas Nal Limestone (Oligocene) was deposited after obduction (Khan et al., 2003). Furthermore, Wadh Limestone has unconformable contact with the overlying Kasria Group which is Eocene to Oligocene in age consist of calcareous shale, limestone and sandstone (Jones, 1961). The Bela Ophiolite has unconformable contact with overlying Nal limestone with an age of Eocene to Oligocene consist mainly of highly fossiliferous massive, bedded

limestone, minor shale, marl and sandstone with a shallow transgressive marine depositional environment. Moreover, Nal limestone has transitional contact with the overlying Hinglaj Formation with an age of Miocene to Pleistocene usually consists of sandstone, silt and shale (Qazi et al., 2018).

## Materials and Methods

After the discovery, reporting and collection of nineteen gemstones samples, all these were brought for analysis and evaluation to the Pakistan Gems and Jewelry Training and Manufacturing Centre (PGJTMC), Quetta and National Centre of Excellence in Geology (NCEG), the University of Peshawar for Raman Spectroscopy for analyzing and determining the gemological characteristics. However gemstone specimens that were brought from the study area were then cut and polished for laboratory experimentation. The gemstones were analyzed with tools including hydrostatic balance (specific gravity testing tool) it is used to check the specific gravity of the gemstone, however every gemstone has its specific gravity. Refractometer tests the gemstone internal reflection of rays having a specific reading scale and identifies whether the gemstone is single or double refraction and its birefringence is noted. Furthermore, the gemstones were analyzed with the help of Polariscope for testing whether the gemstone is single refractive (SR), double

refractive (DR) or Opaque/aggregate (Agg). For checking its phosphorescence and fluorescence ultraviolet lamp is used and the hardness of gemstone is checked by the hardness testing pencils compared with the hardness scale of Moh's. Pleochroism of the transparent and translucent gemstones was checked with the help of a dichroscope. However, the internal inclusions of transparent and translucent gemstones were checked with the help of a gemological microscope and by checking the composition of internal inclusions it was analyzed with the help of Raman spectroscopy whether it is solid, liquid or gas (Table 1).

## Results and Discussion

During the field, gemstones were collected and studied from the Ophiolite sequence including flysch belts, sedimentary zones with adjacent mélanges and calcareous belts from the underlying and overlying succession of the Bela ophiolite (Fig. 1). The outcrops and rocks of the Bela ophiolite contain several gemstone deposits including the garnet (demantoid and almandine), quartz (diamond and petroleum quartz), brucite, malachite, chrysocolla, azurite, calcite, natrolite, green chert, marble, jasper, quartzite, serpentine, agate, epidote, augite and prehnite. Garnet species including almandine and demantoid are found in the host rock serpentinite in the Amorzai area, Wadh of Bela ophiolite.

Table 1 Gemological properties of the gemstones of the study area.

Mineral Group	Gemstone	Chemical Formula	Other Mineralogical Properties				
			Color	Luster	S.G	R.I	Hardness
Silicate	Demantoid Garnet	$\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$	Green	Vitreous	3.65	1.737	7
Silicate	Almandine Garnet	$\text{Fe}_3\text{Al}_2\text{Si}_3\text{O}_{12}$	Reddish orange	Sub-adamantine	4.05	1.790	7
Silicate	Quartz (petroleum & diamond)	$\text{SiO}_2$	Colorless	Vitreous	2.65	1.544-1.553	7
Oxide	Brucite	$\text{Mg}(\text{OH})_2$	Yellow	Vitreous	2.39	1.58-1.60	3
Carbonate	Malachite	$\text{Cu}_2\text{CO}_3(\text{OH})_2$	Banded in two or more tones of green	Dull	3.96	1.655-1.909	3-4
Silicate	Chrysocolla	$\text{Cu}_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4$	Blue to light green	Dull	2.4	1.53-1.54	3.5
Carbonate	Azurite	$\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$	Dark blue to violet-blue	Dull	3.82	1.730-1.836	4
Carbonate	Calcite	$\text{CaCO}_3$	White	Sub-vitreous	2.70	1.486-1.658	3
Silicate	Natrolite	$\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} \cdot 2\text{H}_2\text{O}$	White	Vitreous	2.24	1.480-1.493	5.5
Silicate	Green chert	$\text{SiO}_2$	Green	Dull	2.65	1.541-1.552	7
Carbonate	Marble	$\text{CaCO}_3$	White	Vitreous	2.7	1.530-1.575	3
Silicate	Jasper	$\text{SiO}_2$	Brownish red	Waxy	2.63	1.543-1.552	6.5
Silicate	Quartzite	$\text{SiO}_2$	Creamy white to grey	Vitreous	2.75	1.544-1.553	7
Silicate	Antigorite Serpentine	$(\text{Mg}, \text{Fe}, \text{Ni}, \text{Al}, \text{Zn}, \text{Mn})_{2-3} (\text{Si}, \text{Al}, \text{Fe})_2 \text{O}_5 (\text{OH})_4$	Green	Dull	2.57	1.560-1.570	5.5
Silicate	Agate	$\text{SiO}_2$	Blue to Brown	Greasy	2.64	1.542-1.551	7
Silicate	Epidote	$\text{Ca}_2(\text{Al}, \text{Fe})_2(\text{SiO}_4)_3(\text{OH})$	Dark green	Vitreous	3.41	1.729-1.768	7
Silicate	Augite	$(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe}, \text{Al}, \text{Ti})(\text{Si}, \text{Al})_2 \text{O}_6$	Greenish black	Vitreous	3.56	1.671-1.774	5.5
Silicate	Prehnite	$\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$	Yellowish green	Vitreous	2.95	1.661-1.673	6

**Garnet**

Garnet is a gemstone formed in high temperature and pressure conditions (Kazmi and Donoghue, 1990). The process of serpentinization and alteration can host minerals such as talc and asbestos (Simandl and Ogden, 1999), cryptocrystalline magnesite, brucite, rare nickel minerals, garnet and hydro-garnet (Frost and Beard, 2007). There are two species of garnet group gemstones found in field areas such as demantoid and almandine garnet. From both, the demantoid garnet is one of the rare varieties found associated with highly altered serpentinite rocks of Bela ophiolite (Fig.2A). Whereas almandine garnet is found in between the chromite mines and serpentinite in the same area. The colour ranges from red to deep red having translucent to opaque crystals in the field area, where the demantoid is found. The colour of the gemstone is light to dark green with transparent to semi-translucent having perfect cubic crystals (Fig.3E) including the Raman Spectroscopy results of demantoid garnet displayed in the graph.

under the microscope (Fig. 3B) with its Raman Spectroscopy graphical results (Fig. 3C). The Raman Spectroscopy results of solid inclusions of tourmaline in the tourmalinated quartz are shown in the graph (Fig. 3D).

**Brucite**

Brucite is broadly distributed in the ultramafic rocks (Khan et al., 1971; Hora, 1998). Brucite’s fibrous variety is nemalite found in ultramafic rocks that coexist with chrysotile (Khan et al., 1971; Ross and Nolan 2003). The new depositional environment of brucite has been discovered on the seafloor (Kelley et al., 2001; Green et al., 2003). The economically essential deposits are formed at shallow igneous injections and intrusions in magnesium-rich sedimentary or metamorphic rocks (Simandl et al., 2007). It is usually formed in a magnesium-rich depositional environment by the retro gradational alteration of periclase or by serpentinization of dunit (Liu et al., 2004). Its importance is due to its high magnesium and mineral weight content and so far industries are taking a keen interest in its exploration but it is well known as a collector gemstone due to its beauty and rarity. Brucite is found associated with the peridotite of the mantle section and abundant in the surroundings of the magnesite mines in ophiolite (Ahmed et al., 2017). Brucite was found in various localities associated with mantle rocks of Bela ophiolite such as near the chromite and magnesite mines of Baran Lak area and Amorzai, Wadh and also in the surroundings of magnesite and chromite mines of adjacent areas. Brucite is found in different hues including yellow, blue, green and white (Fig. 2B). The size of crystals ranges from 5 to 8cm mostly in the botryoidal form.

**Malachite**

Malachite is thought to form by hydrothermal processes. The associated minerals with the malachite such as azurite and chrysocolla are usually considered to form as secondary minerals as a result of primary copper sulphide (Thomas, 1949). Malachite is usually present in the oxidation zone of copper sulphide ore bodies in varying temperatures and as surface stains on outcrops that had copper sulphides (Beane et al., 1981). Malachite is found associated with the copper and sulphide mines in the Manjawi, Sonaro and other copper mines surrounding the ophiolite. In the Manjawi area, malachite occurs as secondary fillings in cracks and bedding planes of milky quartz associated with chrysocolla, azurite, calcite and other secondary copper minerals. In the Sonaro area, the metamorphic rocks of Bela ophiolite had stains of malachite, found associated with chrysocolla and azurite in copper mines in rocks

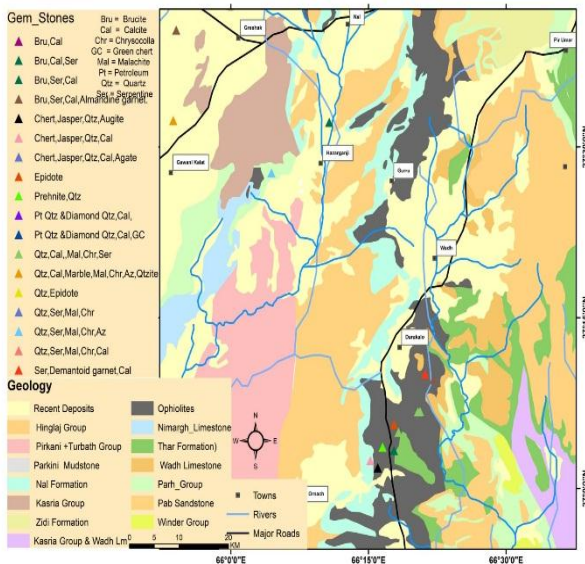


Fig. 1 Geological map of Bela ophiolite complex showing the underlying calcareous zone and overlying flysch belt with locations of gemstones. (Jones, 1961).

**Quartz**

Several varieties of quartz are found in the field area especially diamond and petroleum quartz which is found in the limestone in Shirinab and Thar formations and Wadh limestone with a well-developed crystal usually 2 to 3cm in size or more. Both varieties are considered rare worldwide however other varieties are also found such as terminated, crystalline, faden, double terminated and milky quartz. Petroleum fluid inclusions can be seen in the rough specimens of petroleum quartz from the field area (Fig. 3A) including petroleum quartz

such as marble, quartzite, amphibolite and greenschist (Fig. 2C).

### **Chrysocolla**

Chrysocolla is generally found in various locations of Bela ophiolite associated with copper and sulphide mines, highly oxidized mélangé zones, basalt chert units and carbonate minerals including the malachite and azurite. In Manjawi Wadh, chrysocolla occurs as veins in highly oxidized dunite in gossan, oxidized part may be composed of goethite, hematite, limonite and siderite. The chrysocolla mineralization is deformed and is <0.5mm up to 7mm in size. However, the lower part of mineralization, in dunite, is strongly deformed and altered. In the Sonaro area, chrysocolla is found associated with malachite and azurite as an altered product of primary copper in the copper mine in metamorphic sole rocks (Fig. 2C).

### **Azurite**

Azurite and chrysocolla are copper carbonate minerals formed from the ores of copper hosted by basalt formed by the hydrothermal process (Khan et al., 2018 b). In the field area, it is associated with the malachite and chrysocolla, as an altered product of malachite, it forms veins, as fibrous, massive and sometimes as minor specks associated with malachite. In the Manjawi area, chrysocolla occurs as secondary fillings in the veins of host rocks such as copper and sulphide ores, highly oxidized zones and carbonates. In the Sonaro area, massive habits of azurite occur in the oxidized sulphide and copper mines near oxidized greenschist, amphibolite and marble.

### **Calcite**

Calcite is widely distributed in several locations throughout the overlying and underlying depositions of Bela Ophiolite. It is abundant in the Volcanic rocks and gabbro as irregular cross-cutting veins in Manjawi. In Amorzai, Wadh calcite is deposited as a solution and recrystallization has the thickness of 2-4cm in size or more in the marl Wadh limestone with well-developed crystals having milky white colour (Fig. 2D).

### **Natrolite**

It is found in the prismatic, cylindrical and radiating growth habit in the dolerite dyke. Natrolite is a variety of zeolite that is formed in low metamorphosed conditions found in several settings and variations such as basalts, shallow intrusive bodies, and ophiolites which occurred in the sedimentary rocks as an altered product in rare cases. Furthermore, natrolite occurs as a

product of late-stage metasomatism or deuteric alteration of alkaline intrusion such as nepheline syenite (Deer et al., 2004). In the field area, it is usually found as white prismatic, cylindrical and radiating growth secondary filling hydrothermal veins in the vugs and cracks of dolerite dykes of the Hazarganji area tehsil Nal, Khuzdar Bela ophiolite whereas the size of crystals ranges from about 4cm to 8cm and more.

### **Augite**

Augite is generally found near the Ornach cross-area of Bela ophiolite associated with gabbroic rocks. In the field area, augite is found in small veins of pegmatite gabbro that are exposed in the crustal gabbro of Bela ophiolite having large crystals of augite is dark green to black however the crystals of augite range in size from 2mm to 5cm or more (Fig.2E).

### **Green Chert**

Green chert is found in various localities of Bela ophiolite. In Chedai Wadh, green chert is found associated with other types of chert in the basalt chert unit (Fig.2F). In the Kanoji area Wadh, occurs associated with jasper and agate and is usually interbedded with the basalt and several other varieties of chert are also deposited.

### **Jasper**

Jasper is usually found in several areas adjacent to Volcanic rocks it is interbedded with basalts in Kanoji and Chedai` areas in Wadh. Jasper is found associated with the chert and agate in the basalt chert unit and near the oxidized iron ores most likely in the mélangé and gossan area with the weathered basalt (Fig.2G). The basalts are eroded while the chert, banded agate, chert and jasper remain in situ and mostly red to orange in colour.

### **Epidote**

It is formed by an extensive range of pressure and temperature due to its composition variation and is observed as a hydrothermal replacement in igneous rocks (Franz, 2004). The formation of amphibole and epidotes in veins is a consequence of retrograde metamorphism (Guilmette et al., 2005). Epidote is found in the host rock granite as elongated crystals with interlocking, porphyritic and myrmekite texture (Qazi et al., 2018). Epidote usually occurs in the Bakhalo area of Bela ophiolite associated with granite and crustal gabbroic rocks. The colour of epidote is pistachio green, green to dark green, which shows usually granular, tabular and prismatic crystal growths of a few centimetres. Both in the outcrop and hand specimens of



granite, epidote is found as large grains and crystals in fracture veins (Fig. 2H).

**Serpentine**

Serpentine is usually found with all deformed and altered ultramafic rocks due to the hydrothermal activities, slab subduction and strike-slip faulting and also is formed by alteration of olivine in ultramafic rocks (Mustard et al., 2005; Schulte et al., 2006; Khan et al., 2017). Serpentine is one of the abundant minerals and it is widely distributed in Nal, Wadh and Bela areas and is mainly found as a highly oxidized and altered product of peridotite. In the field area, antigorite variety of serpentine is found in most locations and Manjawi and Amorzai areas. It is found associated with the copper and sulphide mines which are also formed from the alteration of olivine and pyroxene (Fig.2I). The colour is light to dark green with platy habit and greasy and soapy touch whereas the thickness ranges from about 2 meters to 4 meters or more in size.

**Prehnite**

Prehnite is found in various locations of Bela ophiolite associated mainly with the altered basalt or with the transition zone between gabbro and volcanic rocks. In the Ornach area of Bela ophiolite, it is found associated with the basalt near the transition between gabbro and basalt (Fig.2J) The color of the gemstone varies from light green to bluish-green and the size of crystals ranging from 2cm to 12 cm or more.

**Marble**

Marble is generally found in the metamorphic sole rocks of the Sonaro area, Bela ophiolite. It is found as beds/layers near the oxidized copper mine in greenschist facies rocks (Fig.2K). The colour of marble is white to milky white and its beds range in size from about 8cm to 100 cm or more in size.

**Quartzite**

Quartzite is usually found in the metamorphic sole rocks of Bela Ophiolite in the Sonaro area. It is found as layers associated with the amphibolite and greenschist facies rocks of the metamorphic sole rocks in the Sonaro area (Fig.2L). The colour ranges from white, light grey to yellowish-grey and the thickness of layers ranges from about 1 cm to 100 cm.

**Agate**

Agate is found in several locations of Bela ophiolite including the mélangé, gossan, sedimentary and volcanic rocks. In the field area, agate is found in the

mélange area associated with the jasper and chert in the Manjawi area. It also occurs in the basalt chert unit area in vugs and cavities of basalt interbedded with the jasper in the gossan. The colour of agate varies from red to brown and thickness from about 5 to 2 m.



Fig. 2: Field features of host rock of Bela Ophiolite that contains gemstone: (A) Garnet (Demantoid) mine hosted by serpentinite rock. (B) Brucite mine in the ultramafic rocks mainly hosted by dunite and in the small picture shows the brucite specimen. (C) Specimen of malachite and chrysocolla from the copper and sulphide mines of Sonaro area. (D) Dogtooth calcite crystals in the hydrothermal vein in limestone.

Fig. 2 Continued: (E) Black augite gemstone crystals in pegmatite gabbro near the Ornach cross. (F) Green chert veins interbedded other types of chert. (G) Red jasper is associated with the chert near the basalt chert unit. (H) Green epidote crystals in the host rock granite.



Fig. 2 continued: (I) Oxidized serpentine associated with chromite mine in host rock dunite. (J) Prehnite crystallized in the altered area in the hydrothermal vein in the alteration zone between basalt and gabbro. (K) Marble deposits as massive bed underlying oxidized schist in the oxidized zone of metamorphic sole rocks of Bela ophiolite near Sonaro. (L) Quartzite beds with quartz veins in the metamorphic sole rocks.

### Gemological Characteristics

The gemological characteristics of the reported and analyzed gemstones in the laboratory such as demantoid and almandine garnet which were tested with the Raman Spectroscopy are single refractive (SI) gemstones having a refractive index ranging from 1.737 to 1.790 with vitreous, lustre and hardness of 7 (Table 1). Mainly two rare varieties of quartz that is, petroleum and diamond quartz were tested with the Raman Spectroscopy having a specific gravity of 2.65, the hardness of 7 and the refractive index of 1.544-1.553 which is double refractive (DR) in nature (Table 1). Brucite with several colours including yellow, blue and green has a hardness of 3 with a refractive index of 1.58-1.60, it is double refractive and rare in nature.

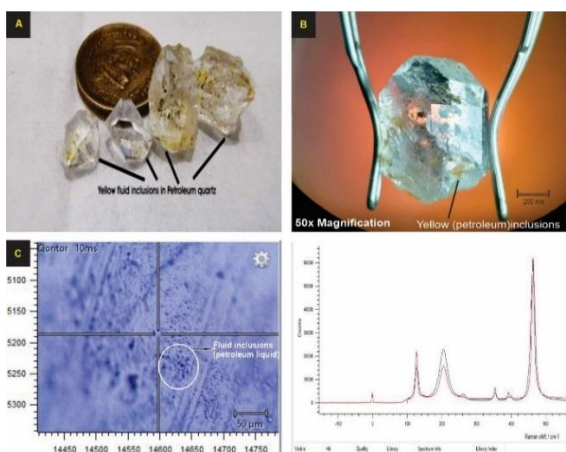


Fig. 3 A-D: Evaluation and assessment of transparent gemstones with Raman spectroscopy: A) Specimen of petroleum quartz in rough that shows yellow colour inclusions of petroleum B) Petroleum quartz under the microscope shows the petroleum inclusions under 50x-300x magnification C) Raman spectroscopy data of petroleum fluid inclusions in given picture and graph.

Malachite, chrysocolla and azurite are collectively opaque in diaphaneity and are double refractive with vitreous, earthy to silky lustre, malachite and azurite which has the hardness of 3-4, however chrysocolla is 3.5 on Moh's hardness scale. Moreover, calcite with white colour subvitreous lustre and translucent gemstone with a specific gravity of 2.70 has 3 hardness. Natrolite with a hardness of 5.5 and refractive index of 2.24 is double refractive with vitreous luster.

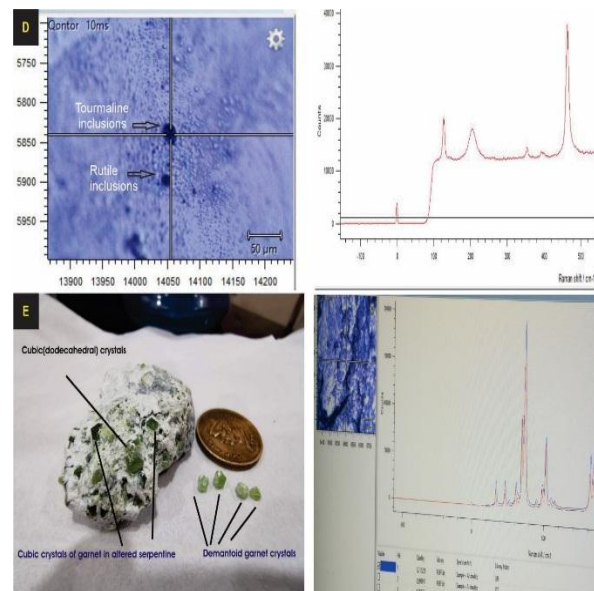


Fig. 3 D) Raman spectroscopy data of rutile and tourmaline mineral inclusions in given picture and graph; E) The specimen show the cubic demantoid (andradite) garnet crystals in host rock serpentinite and the picture on its right side shows the Raman spectroscopy data in the graph.

Green chert, agate and jasper are most likely opaque in diaphaneity that show aggregate under the polariscope with hardness of 7 (Table 1) Agate is double refractive; whereas, green chert is dull in lustre, and jasper is a brownish red to orange-red. Additionally, marble is white with double refractive vitreous lustre and a hardness of 3.. Quartzite is double refractive and opaque with creamy grey color. It has a specific gravity of 2.75 and has a hardness of 7. Likewise, serpentine is also opaque in diaphaneity having a specific gravity of 2.57 (Table 1), hardness of 5.5 and a dull lustre. Epidote in a green hue with a specific gravity of 3.41 (Table 1) and hardness of 7, is a double refractive gemstone having vitreous lustre. Furthermore, augite is brownish-green, greenish-black, and brown with specific gravity of 3.56 and hardness of 6 and a refractive index of 1.680-1.774 (Table 1). In addition, Raman Spectroscopy analysis has also been mentioned in this paper. Figure 4 shows the details of fluid inclusions in diamond and petroleum quartz with identification and detailed graph of demantoid quartz (andradite).



## Conclusion

Bela Ophiolite, district Khuzdar and adjacent areas possess the reported gemstones including demantoid and almandine garnet, petroleum and diamond quartz, brucite, malachite, chrysocolla, azurite, calcite, natrolite, green chert, marble, jasper, quartzite, serpentine, agate, epidote, augite and prehnite.

Amongst the gemstones brucite, augite, prehnite, azurite, malachite, chrysocolla, serpentine and natrolite are mostly vein-type filling due to hydrothermal fluids that are formed by primary or secondary filling deposits. Gemstones such as agate, jasper and several types of chert are found associated with the basaltic rocks as alterative or interconnected with it. These are also formed in marine environments from the silica brine sediments under calcium carbonate compensation depth (CCD). However, gemstones such as calcite and quartz mainly (diamond and petroleum quartz) are found in limestone by secondary intrusions including hydrothermal fluids replacement or due to metasomatic process.

Metamorphic gemstones such as garnet is found as dodecahedron crystals in host rock serpentinite while quartzite and marble are found in the oxidized zone associated with the greenschist and amphibolite rocks in metamorphic sole rocks of Bela Ophiolite near the Sonaro area that may be occurred during the ophiolite emplacement.

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