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Gem potential and mineralogical features of apatite from Hormuz Island, southern Iran

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ABSTRACT

Hormuz salt dome (Hormuz Island) is one of the right places for the crystallization of gem minerals, where idiomorphic apatite crystals have been formed under a hydrothermal condition. This island is located in the northern area of the Persian Gulf, south of Iran. The Hormuz Island is composed of salt, anhydrite, sandstone-siltstone, dolomite, limestone, and volcanic horizons. In this research, the Hormuz apatite is assessed in terms of gem potential and mineralogical characteristics. The apatite crystals are formed 2-3 cm in size, mostly transparent and yellow to green, which indicate their gem quality. Considering thermal sensitivity and the moderate hardness of this mineral, the best methods and tools for cutting were selected through multiple testing methods. According to our research, the best approach to a fantasy or cabochon cut is the use of a 0.3 mm thin edge, 220 or 240 grit sanding discs, a 400 grit abrasive for scratch removing and 800, 1200 and 2500 grit abrasives for polishing. Respectively, use of water in all stages of sawing, cutting and polishing is necessary.

1. Introduction

Apatite is less famous and abundant compared to other well-known gems such as garnets and other gem minerals. The moderate hardness of apatite and low thermal resistance are the main inhibiting factors of its gem potential. However; in the recent years, its exploration and gem processing has increased its fame around the world. Moreover; the beautiful and various colors of the Hormuz apatite draws every gem-collector or gem-lover's attention to this mineral. Brazil is one of the most significant countries to hold colorful apatite stones with gem potential with cut samples presented in global markets (Boehm, 2014; O'Donoghue, 2006). Afghanistan and America also have presented outstanding samples of apatite. The Phalaborwa mine in South Africa possesses ruby-like blue apatite. Apatite samples as large as a bottle can also be seen in Zimbabwe. Moreover; apatites with neon green and blue colors can be found in Madagascar.

The chemical formula of apatite, $Ca_5(PO_4)_3(F,Cl,OH)$, cholorapatite, fluorapatite or hydroxylapatite is formed depending on whether the chlorine, fluorine or hydroxyl group is placed within the hexagonal ring. However; in most cases, a combination of two or three elements together forms a complex. Most apatite samples including a gem potential are subspecies of fluorapatite, but in some other subspecies there is a possibility of a manganoapatite presence caused by a partial replacement of calcium with iron (Thomas, 2008). The latter samples are usually dark bluish green with a high refractive index. The Hormuz Island is located in the northern area of the Persian Gulf, in the south of Iran (Figure 1). Apatite from the southern part of the Hormuz island (Fig. 1) is transparent and idiomorphic. Despite the abundance and coarseness of the Hormuz apatite, which is found alongside the beautiful and common samples of geology and natural history museums, few researches been conducted on them.

The apatites, in exception of those used for collections, are definitely worth cutting and can be used as gems. Similar samples (e.g., Esfordi apatite) have more or less such potential. In the paper, we have addressed the mineralogical and gem features of the Hormuz apatite and investigated its potential as a gem.

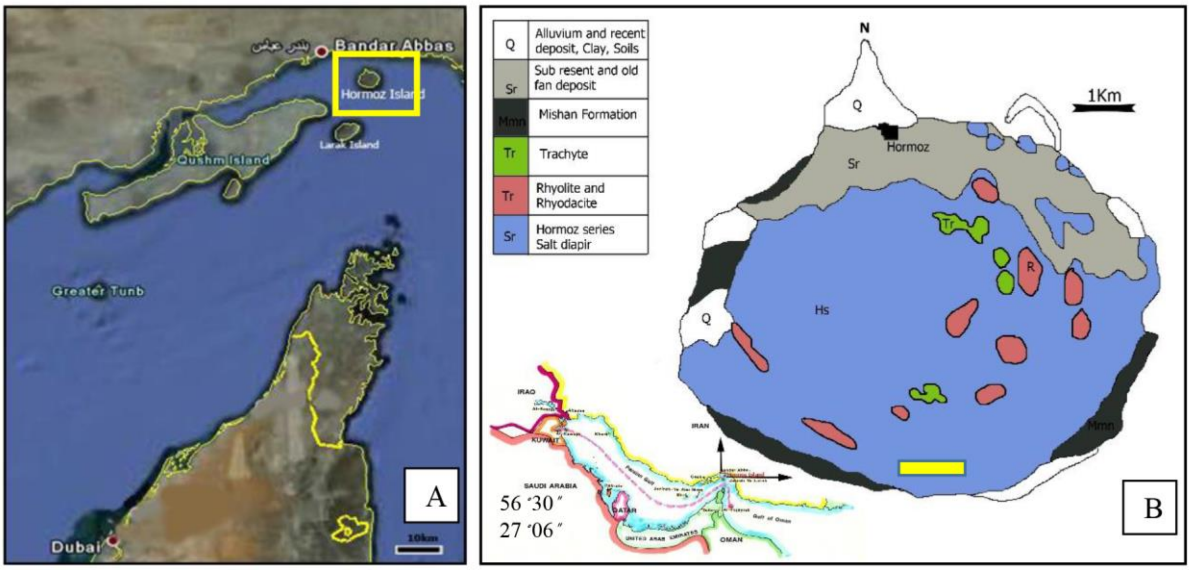

Fig. 1. A) Satellite image of the Hormuz Island. B) Revised geological map of Hormuz Island. Adopted from Elyasi et al. (1977). Apatite crystals are located in the yellow zone.

1.1. Geology

The salt domes of southern Iran are not uniformly distributed and are divided into two regions. One is the Sarvestan-Bandar Abbas region including 101 domes and diapirs, and the other is in the south of Kazeroon which only consists of 14 domes and diapirs. These dome complex are called the Hormuz series. The Hormuz series consist of four units including salt, sandstone-siltstone, anhydrite, limestone, dolomite, and volcanic units. Igneous rocks of the Hormuz series include tuffs and lavas which are accompanied by other Hormuz series units. The second category of the igneous rocks of the Hormuz series are subvolcanic microgabbroic dykes and stocks, which are transitional and sometimes acidic and seem younger than the four other units of the Hormuz series (Ahmadzadeh Heravi et al., 1991) (Fig. 2). The Hormuz apatite has developed in semi-intrusive igneous rocks in the southern part of the island. These rocks consist of variable compositions from dacite-trachyte to quartz-diorite, with iron oxides. Apatite crystals have occurred within the joints and the fractures of the above mentioned igneous complex (Elyasi et al., 1977). Apatite as an idiomorphic and coarse mineral, is often found in pegmatites and hydrothermal veins (Thomas, 2008). Also some skarn-placer deposit and iron mines contain small apatite grains (Dill and Veber, 2013). The Sfordi mine in central Iran possesses apatite-bearing Fe-oxide deposits related to alkaline igneous rocks (syenite) (Rahimzadeh and Sheikhi Gheshlaghi, 2016). This mine is significant for apatite including large crystals (up to 20 cm) with gem quality. The Hormuz apatite belongs to the hydrothermal group (Padyar et al., 2012). Recently, due to host rock erosion, apatites are dispersed in the form of distinct grains in a bed covered by ocher and salt. According to Rostami et al. (2013) the Hormuz apatite is formed by oxidized type-I granitoid magma. A high level of Fe_2O_3 / FeO ratio represents the oxidation of the parent magma, and its negative correlation with manganese in the Hormus apatite indicating a moderate differentiation of the granitoid magma (Rostami et al., 2013). However; research on fluid inclusions shows that the apatite apatite formed in a reduction environment (Padyar et al., 2012).

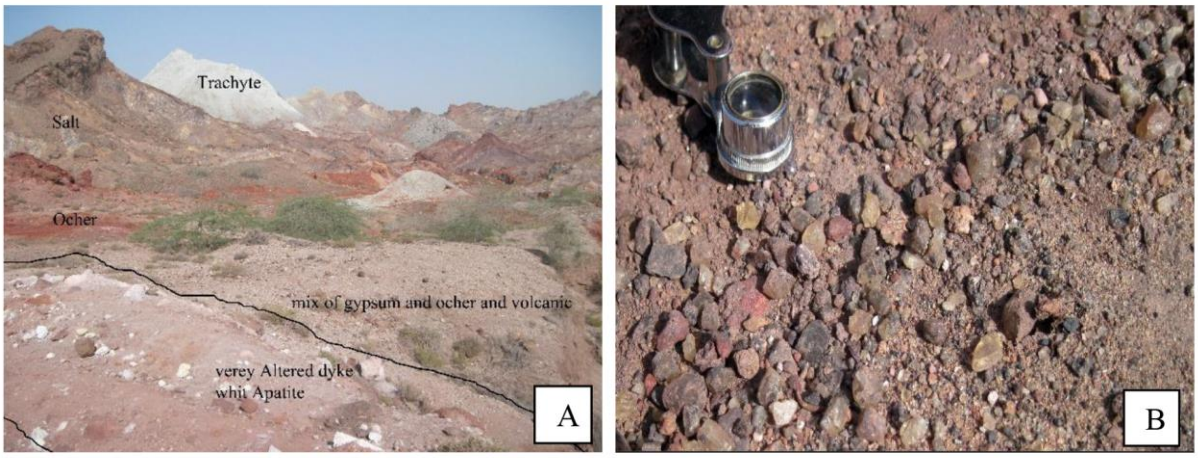

Fig. 2. A) A view of the Hormuz Island. B) Apatite grains dispersed in a mixture of ocher, hematite, and salt (Rahimzadeh and Sheikhi Gheshlaghi, 2016).

2. Material and Methods

During field study, 6 representative apatite samples collected. Samples cut indifferent shapes and polished. Ordinary gemological testing performed including; specific gravity (SG), fluorescence intensity, refractive indices (RI), impurities grading with 10X loupe, long-wave and short-wave ultraviolet (UV). Results summarized in table 1.

Table 1. Mineralogical Characteristics of Hormuz Apatite

S.N.	A-Fantesic	B- Pear	C- Fantesic	D- Cabochon	E-Pear	F-facet
Transparency	TP	TP	STP-TP	TP	TL	TP
Luster	Vitreous	Vitreous	Vitreous	Vitreous	Resinous	Vitreous
R.I. Birefringence	***Moderately High 1.635-1.640***	***Moderately High 1.631-1.635***	***Moderately High 1.625-1.630***	***Moderately High1.631-1.635***	***Moderately High 1.635-1.640***	Moderately High 1635-1.640
Cleavage-Fracture	No-No	No-No	No-No	Imperfect-Minor	No-Severe	No-No
Optical Character	Biaxial	Biaxial	Biaxial	Biaxial	Biaxial	Biaxial
SR: ADR: **DR**: AGG	Negative	Negative	Negative	Negative	Negative	Negative
Clarity Grade	SI	EC	HI	EC	Sev I	SI
Specific Gravity	3.14	3.15	3.17	3.13	3.14	3.14

TP: transparent, TL: translucent, STP: semi-transparent, EC: Eye Clean, SI: Slightly Included, HI: Highly Included, Sev I: Severely Included.

3. Results and discussion

3.1. Mineralogical Characteristics

Apatite has absorption lines in 5855, 5772 and 5742 Å (yellow-green spectrum) and 5120, 5070 and 4910 Å (blue spectrum) (Thomas, 2008). Based on Padyar et al. (2012) research, three different inclusions can be found in the Hormuz apatite including gas-rich fluid inclusion types with a high homogenization temperature of 380-580 ^{0}C and salinity of 8-17 wt% NaCl equiv, three-phase inclusions with 295-370 ^{0}C homogenization temperature and a salinity in the range of 25-45 wt% NaCl equiv, and liquid-rich fluid inclusions with lower temperatures of 117-209 ^{0}C and 8-12% wt% NaCl equiv salinity. A detailed thermobarometric comparison between these findings and the results presented by previous researchers (Sheets, 1997; Broman et al., 1999) reveal that the Hormuz apatite have formed by a hydrothermal process of Kiruna type. The type of inclusions indicate that apatite originated from an alkaline environment (Padyar et al., 2012). Well shaped natural apatites with a size up to 12 cm with gem quality has been reported. (Rostami et al., 2013). The apatite samples are mainly idiomorphic, but some fractures have appeared within them during geological events which affect its quality during cut and polishing processes (Figures 3-A to 3-E). However, most of the crystals have a cutting capability. The Hormuz apatite is yellow to green in color, where the yellow type is obviously more

atractivet (Fig. 3A). Generally, Fe, Co, V, Cu, Ni, Cr, Ti and Mn have been known as dyeing agents in apatite gems (Haj Alilu, 2009). Macroscopic evidence and the fact that hematite can be clearly seen in the rims of some apatite crystals imply that iron is the source of the green color (Fig. 3B).
Most of the apatite samples are yellow in the center and can be crystallized with iron during their growth. Crystals with hematite inclusions at the core, which are completely green, can rarely be observed. Green color can either be the result of SO_3-TR (Ce) complex changes or of Pr, Nd, Cr and Fe elements (Gaft et al., 2005). Ocher which is a secondary product of hematite has penetrated into the crystal joints and fractures after the apatite formation which sometimes has led to a red brick color. The amount of rare earth elements, which are important dyeing agents, in the Hormuz apatite is about 22.1 to 25.2 wt% of the whole mineral (Rostami et al., 2013). Therefore, yellow and greenish yellow colors have most likely been developed due to the presence of rare earth elements such as Pr, Pm and Tb.

Fig. 3. Images of Hormuz Island Apatite Samples. A) Yellow to green color of Hormuz apatite. B) Zoned apatite which is yellow in the core and green in the rim. C) pale yellow apatite. D) Transparent dark yellow apatite (Rahimzadeh and Sheikhi Gheshlaghi, 2016). E: Pyramidal idiomorphic apatite.

3.2. Gem Potential

The low hardness of apatite has limited the use of this mineral as a gem. But recently, variety and vivid colors of this mineral have enhanced its use. On the other hand, most gems do not have an everyday use and are often used in formal ceremonies, therefore the risk of scratching is minimal for minerals with a hardness of 5 on the Mohs hardness scale. Thus, the use of apatite in jewelry and trading began in the past two decades. Blue apatite (Boehm, 2014) and Cat's Eye cuts with green and yellow colors have been found in Brazil (O'Donoghue, 2006). In June 2013, the Gemological Institute of Tucson presented the Brazilian green-blue apatite with ocular structure (Precious Resources Ltda., Teófilo Otoni, Brazil). Rough samples have a zoned colorful structure, but colorless specimens can also be seen along with this type of apatite. Other apatites such as purple and pink apatites can be found in Russia and North America (Altman, 2012). The price of cut gems depending on the gem quality is 90 to 190 US$ for 1 to 3 carats gems and 115 to 200 US$ for 3-5 carats gems (Matlins, 2012). The Hormuz apatite, as mentioned before, is found in yellow to green colors. The yellow color comes in a larger variaty which is extended from very pale to very dark to orangish yellow with various degrees of color saturation. Transparency of this mineral is also highly variable; therefore, apatite samples can be found in transparent to opaque forms. Although, transparent apatite is usually faceted, but some of them are cut in cabochon. In the present research, selected samples were cut in cabochon, faceting and fantasy styles (Fig. 4).

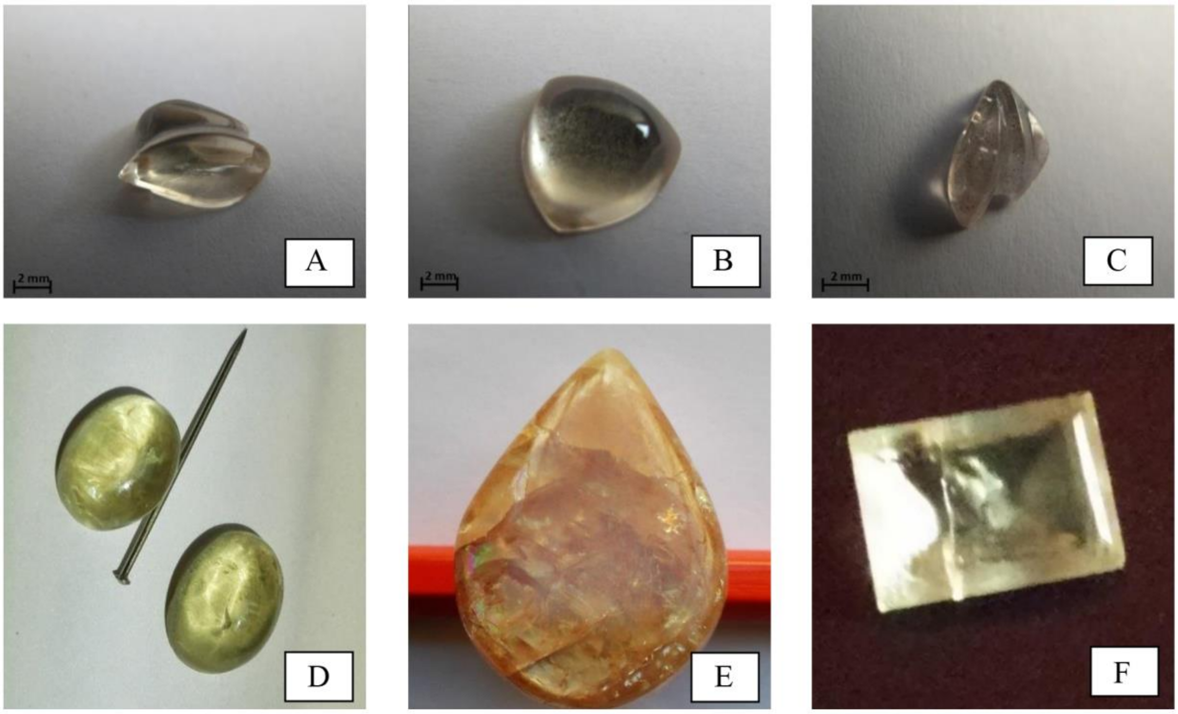

Fig. 4. Images of cut apatite samples. A) Fantasy apatite in pale yellow-green color. B) Apatite cabochon that show pale yellow-green color. C) Yellow-green fantasy sample together with inclusion. D) Cabochon specimens in pure yellow color (Rahimzadeh and Sheikhi Gheshlaghi, 2016). E) Semi-transparent cracked samples with orangish-yellow color, and iridescent phenomena similar to fire opal, F) Yellow faceted apatite (sample length is 6 mm).

Based on the gemological testing results in Table 1, sample colors are yellow, green and yellow-green. Most samples have a very high level of transparency, except for the sample E, which has a lower degree of transparency. Samples mainly have a vitreous luster and often lack any cleavage and fracture except for the sample E which has a resinous luster and some conchoidal fractures. I n terms of clarity, 4 samples are eye clean and 2 samples have impurities such as iron oxides. The refractive index of the Hormuz apatite increases from green to yellow. Hence, the refractive indices of green, yellowish green and greenish yellow, and yellow apatites are 1.625-1.630, 1.631-1.635 and 1.635-1.640, respectively. Moreover; all samples are inert to fluorescence radiation. Apatites often have a negative biaxial optical property. Nevertheless; in cases where more accurate measurements have been carried out different features have been observed at different crystalline levels. The research of the Liallagua apatites by Rakovan and Reeder (1994) showed that in 0001 crystalline surface they show negative uniaxial, while in the levels of 1011, 1121 and 1010 they are biaxial. The optical properties including the distribution of REEs in apatite are controlled through structural surfaces during mineral crystallization (Rakovan and Reeder, 1994). In this paper, as measurements were taken after cutting, the measured levels were not specified. Using the polaroscope to detect the optical character. Apatite which blinks from dark to light four times during a 360^0 rotation indicates a DR type (Fig. 5). Also; in other tests, all measured samples show a negative uniaxial refractive index (Fig. 6 and Table 1). Investigating fluorescence properties via ultra-violet (UV) device showed that Hormuz samples are inert to fluorescent radiation. This character is due to the presence of iron in the Hormuz apatite (Haj-Alilu, 2009). Basically, idiomorphic crystals in a certain area should not differ in specific gravity. Typically, samples with a higher refractive index have a higher specific gravity. However, specific gravity differences are quite clear in Hormuz apatites and even samples with higher specific gravity have lower refractive index. This is caused due to the presence of iron oxides in the green samples which have significantly increased specific gravity.

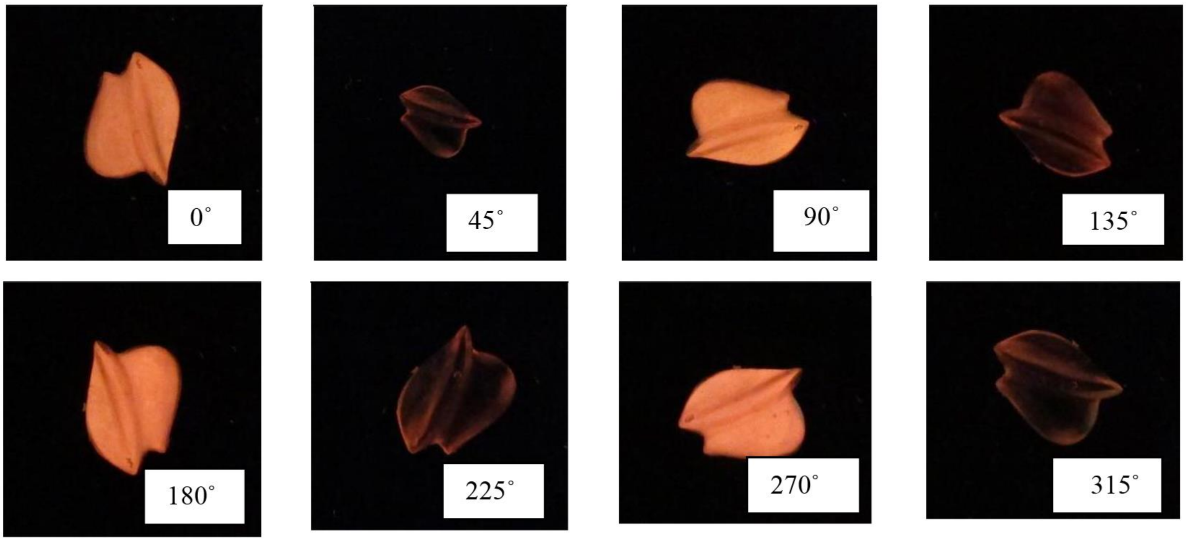

Fig. 5. Apatite under the polariscope which blinks from dark to light four times during a 360^0 rotation which is indicative of a DR (doubly refractive) optical type (the sample length is 8 mm).

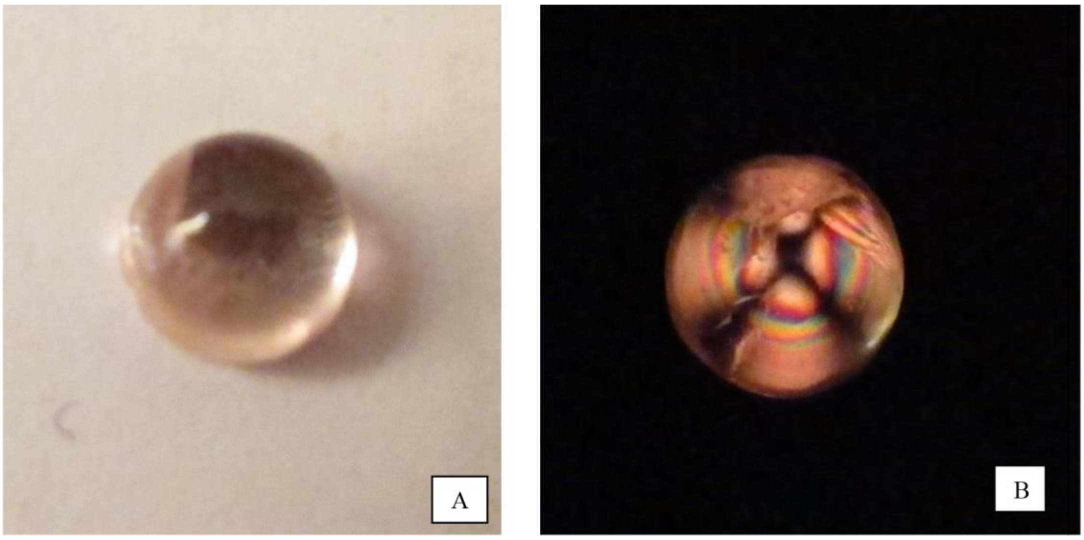

Fig. 6. A) A cabochon cutting sample in plane light. B) According to the optical pattern of the Hormuz apatite under the polariscope, it is concluded that these gems are uniaxial (the sample size is 0.5 cm).

3.3. Hormuz Apatite Cutting And Processing

To evaluate the apatites resistance during the cutting process and to achieve a method which gives the best color and the highest polish quality in the shortest time with a minimal cost, 10 samples of Hormuz apatite were examined with a variety of cabochon, cushion and fantasy cutting styles. Most of the selected samples were approximately 2 cm or smaller. In this experiment, some samples were cut with the table parallel to c-axis and other perpendicular to c-axis. The obtained results are:

1. In the first step during the sample cutting, thin cutting blades, with the best of which of 0.3 mm thickness, were used.
2. In the next step, due to the low hardness and small sizes of the samples soft sanding discs were used for the shaping and abrasion. Considering the hardness and sensitivity of the mineral, 220 or 240 grit sanding discs are the best abrasives which can be used.
3. In the final step where the polishing and scratch removing are performed using

abrasives, the best meshes for polishing are 400 (for scratch removing), 800, or 1000 and 2500 grit, respectively. Using these meshes not only give the greatest finish quality, but also because of fewer sanding steps more time could be saved. The samples are polishable up to 5000 meshes, but the improvement of polishing quality caused by these meshes is too trivial to affect the quality of sample final polishing and its price only increases the time needed and the cutting cost. Using abrasives with meshes less than 400 (e.g., 260 grit) in the early stages of polishing also increases the number of sanding steps.

Because of the observed fractures in the apatite context and also its low thermal resistance, it would be better to use water as a coolant even during the polishing stage. To achieve this goal, it is the best to dry samples after each time using water and to carry out the same polishing process again because the dry method leads to powder production and increases the polishing quality so that there would be no need to use chemical agents to achieve the highest luster. During the tests, diamond powder and aluminum oxide were used as polishing agents, which had no effect on raising the finish quality because the samples had reached their final polish quality. In addition, the engine velocity of polishing machine is also effective in enhancing the quality of polishing. To do so, the best angular velocity of the abrasive which can be applied is 16000 rpm or more. Another factor that influences the finish quality is the cutting style to the extent that cabochon and cushion cuts with more curved surfaces have higher polish quality compared to other samples. Green apatite shows a color saturation less than the yellow samples. This must be taken into consideration during the cutting process where the selected cuts for green samples should not be thin because it can decrease their color intensity. Also, cutting the gem with the table parallel to c-axis reveals the highest saturation of colors and polish quality. The subtlety of facet cutting is far more than manual cutting. The high percentage of breaking and chipping in faceting machines available in the country is because cases such as the vibration of the motor and sanding discs are less controlled. Thus, it seems necessary to use less vibrating and more accurate devices with water. On the other hand, to reduce the heat on the samples, each surface can be polished in two or three steps. Moreover; abrasive discs with a roughness of 600 to 800 are required for a higher accuracy.

4. Conclusion

Hormuz Island is one of the places where idiomorphic crystals of yellow to green apatite have been formed under a hydrothermal condition. Apatite samples have an average size of 2-3 cm, are often transparent, and some of them have the potential to be a gem. The specific gravity and refractive index of this mineral are 3.13-3.17 and 1.625-1.640, respectively. The refractive index increases from yellow to green samples. Also, the specific gravity of the green apatite is higher than the yellow samples, which is caused due to the presence of iron oxides.

The best cutting method involves using thin cutting blades, abrasives of 220-2500 grit and a 16000 rpm engine velocity. Considering the samples thermal sensitivity, water usage in all stages of sawing, cutting and polishing is necessary. Cutting the gem with the table parallel to c-axis gives the highest color saturation and polish quality upon work completion compared to cutting it with the table perpendicular to this axis. Altogether, according to the obtained results, some of the apatite samples have an excellent polishing capability as a gem. In some cases, even samples with fractures have enough hardness for cutting and polishing.

References

Ahmadzadeh Heravi, M., Houshmandzadeh, A., Nabavi, M.H., 1991. New Concepts of Hormuz Formations, Stratigraphy And The Pproblem of Salt Diapirism in The South of Iran. International Journal of Geosciences: 3, 1–22.

Altman, J., Jones, H.S., Overton, W.T., 2012. Gem and Stone: Jewels of Earth, Sea, and Sky, Chronicle Books.

Boehm, E., 2014. The Gemological Association of Great Britain. The Journal of Gemology: 34 p.

Broman, C., Nyström, J.O., Henríquez, F., Elfman, M., 1999. Fluid Inclusions in Magnetiteapatite Ore from a Cooling Magmatic System at El Laco, Chile. GFF: 121, 253-267.

Dill, H.G., Weber, B., 2013. Gemstones And Geosciences in Space And Time. Digital Maps to The “Chessboard Classification Scheme of Mineral Deposits”. Earth Science Reviews: 127, 262-299.

Elyasi, J., Amin Sobhani, A., Behzad, A., Moein Vaziri, H., Meysami, A., 1977. Geology of Hormoz Island. Proceedings of Iran’s Second Symposium of Geology, 31-72 (In Persian).

Gaft, M., Reisfeld, R., Panczer, G., 2005. Modern Luminescence Spectroscopy of Minerals and Materials, first ed, Springer-Verlag, Berlin Heidelberg.

Haj Alilu, B., 2009. Gemology, Second Edition, Payame Noor Publication, Tehran (In Persian).

Matlins, A. L., 2012. Colored Gemstones: The Antoinette Matlins Buying Guide: How to Select, Antiques & Collectibles, third ed, Gemstone Press.

O'Donoghue, M., 2006. Gems: Their Sources, Descriptions and Identification, Sixth ed. Butterworth-Heinemann, Oxford.

Padyar, F., Borna, B., Qurbani, V., Alizadeh, V., Jafarzadeh, N., 2012. Study of Fluid Inclusions and Raman Microspectrometry of Hormuz Island Apatites, The 30th Conference of Geosciences, Geological Survey and Mineral Exploration of Iran, Tehran (In Persian-abstract in English).

Rahimzadeh, B., Sheikhi Gheshlaghi, R., 2016. Apatite from Hormuz Island, Iran (Gem Notes). The Journal of Gemology: 35, 6-7.

Rakovan, J., Reeder, R.J., 1994. Differential Incorporation of Trace Elements And Dssymmetrization in Apatite: The Role of Surface Structure during Growth. American Mineralogist: 79, 892-903.

Rostami, A., Bazamad, M., Haj Alilu, B., Moazzen, M., 2013. Investigating The Geochemical Behavior of Rare Earth Elements in Hormuz Island Apatites, Journal of Economic Geology: 6, 71-85 (In Persian-Abstract in English).

Sheets, S.A., 1997. Fluid Inclusion Study of the El Laco Magnetite Deposits, Chile, M.Sc. Thesis, Dartmouth College, Hanover, New Hampshire, 94 p.

Thomas, A., 2008. Gemstones, Properties, Identification and Use, New Holland Publisher Ltd, London.