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# Optical effects produced in gemstones from the feldspar group

## *Efeitos ópticos produzidos em gemas do grupo dos feldspatos*

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**Abstract:** This article reviews the optical effects of feldspars, a group of minerals with various applications, including jewelry. Feldspars are divided into alkali and plagioclase, and exhibit effects such as adularescence, labradorescence and aventurescence, depending on the mineral intergrowth. The article discusses the gem varieties of feldspar, such as moonstone, labradorite and sunstone, and highlights the importance of crystal orientation in cutting to maximize the optical effects. The article concludes that more research on the optical properties of feldspar can improve gem processing techniques and mineralogical knowledge.

**Keywords:** Optical Effects; Gemstone; Feldspar.

**Resumo:** Este artigo revisa os efeitos ópticos dos feldspatos, um grupo de minerais com várias aplicações, incluindo a joalheria. Os feldspatos são divididos em alcalinos e plagioclásios, e apresentam efeitos como adularescência, labradorescência e aventurescência, dependendo do intercrescimento mineral. O artigo discute as variedades de gemas de feldspato, como pedra da lua, labradorita e pedra do sol, e destaca a importância da orientação do cristal na lapidação para maximizar os efeitos ópticos. O artigo conclui que mais pesquisas sobre as propriedades ópticas do feldspato podem melhorar as técnicas de processamento de gemas e o conhecimento mineralógico.

**Palavras-chave:** Efeitos Ópticos; Gema; Feldspato.

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## 1. Introduction

The great dispersion of knowledge and the scarcity of technical and bibliographical references in Portuguese related to gemological feldspar crystals with optical effects makes it difficult for the gem, jewelry and related sectors to access information that can significantly modify the final value of a gem.

Feldspar crystals represent a group of rock-forming minerals classified as tectosilicates (KLEIN and DUTROW, 2012).

According to Deer, Howie and Zussman (2010), they are the most abundant constituents of igneous rocks (e.g. simple pegmatites). They are common in mineral veins, but also occur as mineralogical components of metamorphic and sedimentary rocks. In metamorphic rocks, they are the main constituents of gneisses and migmatites, in addition to being present in rocks of regional metamorphism. In sedimentary rocks, they are present immediately after quartz in terms of abundance in the form of detrital grains.

Common compositions can be expressed in terms of the system $KAlSi_3O_8$ (orthoclase – Or) – $NaAlSi_3O_8$ (albite – Ab) – $CaAl_2Si_2O_8$ (anorthite – An) and, in addition to these, the barium – Ba feldspars such as Celsian Ba[Al2$Si_2O_8$].

Given the chemical compositions they can assume [(K, Na, Ca) $(Si, Al)_4$ $O_8$], their industrial applications include the glass and ceramics production industries, agricultural additives and, whether as components of magmatic, metamorphic or sedimentary rocks, in the coatings production industry. According to DNPM (2016), Turkey (23.1%), Italy (21.7%) and China (9.7%) are the three largest producers of industrial feldspars in the world.

In addition to their use in industry, rarer specimens with characteristic aesthetic patterns are used by the jewelry sector in the production of jewelry. In this sector, characteristics such as rarity, beauty and color are what determine the value of the pieces, whether they are raw or polished.

## 2. Objectives

This study aims to compile information on the optical effects of crystals from the feldspar group used in jewelry making and seeks to provide specific guidance on the positioning of structures and features to maximize the potential of these minerals in cutting.

## 3. Materials and methods

This study followed the methodology below:

a. Search for references on feldspars and their optical effects in gemstones.
b. Selection by topic of gemological interest.
c. Complementary research on topics with few references.
d. Compilation and structuring of works into chapters.
e. Image editing with CorelDraw.
f. Writing and formatting in accordance with technical standards and dictionaries.

## 4. General aspects of feldspar group crystals

Tectosilicates, which account for more than 60% of the volume of rocks in the Earth's crust, have a crystalline structure composed of $Si(Al)O_4$ tetrahedra where Si atoms are often replaced by Al and are surrounded by four O atoms (VLACH, 2002).

As aluminosilicates $(Si,Al)O_4$, they incorporate cations to neutralize the negative charge of Al, and the chemical composition and the order or disorder of Al-Si define the types of feldspar. Rapidly cooled crystals have disordered Al-Si and slowly cooled crystals have ordered Al-Si. Therefore, they are divided into two subgroups: alkaline or potassium feldspars (microcline, orthoclase and sanidine) and plagioclase (albite-anorthite series).

Sanidine, monoclinic and disordered at high temperature and low pressure, is normally used as an example of the structure for crystals of the feldspar group; orthoclase is monoclinic and poorly ordered at intermediate temperature; and microcline is triclinic and ordered at low temperature. Microcline is typical of deep rocks and pegmatites, that is, of slow cooling; orthoclase, of intrusive rocks and of intermediate cooling; and sanidine of rapid cooling extrusive lavas (KLEIN and DUTROW, 2012).

The general structure of the plagioclase series is very similar to the structure of microcline. Its Na-rich end member (albite) is triclinic and presents two types of Al-Si distribution; one ordered (low temperature) and the other completely disordered (high temperature).

The Ca-rich end member (anorthite) is also triclinic and shows perfect Al-Si ordering. These temperature relationships alter the way Al-Si organizes itself as polymerization progresses and are also responsible for the development of cleavage planes and for twinning. Furthermore, physical parameters such as density and hardness are also defined by this organization (Figure 5).

In figure 1, it is possible to observe compositions that help in understanding textures and other structural features. In the Or – Ab reaction series, K-rich feldspars have proportions between $Or_{37}$ and $Or_{100}$, anorthoclase can present between $Or_{10}$ and $Or_{37}$ and albite can contain up to $Or_{10}$.

The diagram shows the solid solution intervals between Ab-An in the plagioclase series. Figure 2 provides greater detail on the conditions below 800 ºC, showing a miscibility gap between potassium feldspars and albite, as well as three miscibility gaps in the plagioclase series: Peristerite region ($An_0$ to $An_{25}$, below 600 ºC); Boggild intergrowth region ($An_{47}$ to $An_{58}$, below 800 ºC) and; Hutten Locher region ($An_{60}$ to $An_{90}$, close to 800 ºC).

Miscibility gaps such as Peristerite and the Boggild intergrowth region are, respectively, important in the development of optical effects of adularescence (moonstone or adularia, although studies related to exsolutions between potassium feldspars and plagioclases are more common) and labradorescence (labradorite) (KLEIN AND DUTROW, Op. Cit).

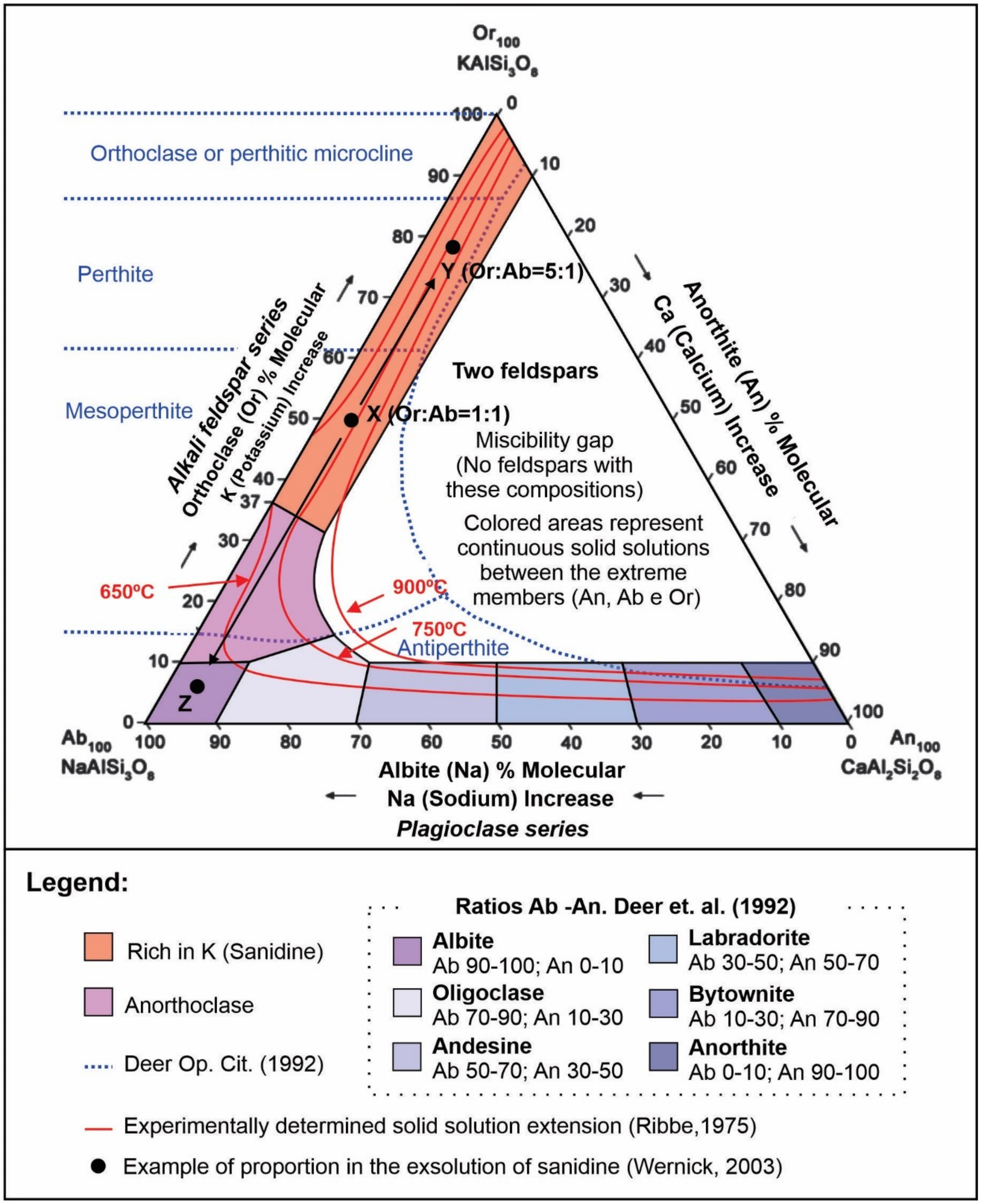



*Figure 1 – Ternary composition diagram based on Or, Ab and An contents.*
*Source: Adapted from Deer, Howie and Zussman (2010), Ribbe (1975) and Wernick (2003).*

Gaps occur due to the exsolution of an initially homogeneous solid solution, which is not stable under certain temperature conditions, and is divided into two or more different crystalline minerals without the addition or removal of elements in the system (KLEIN and DUTROW, 2012).

As the temperature drops during crystallization, considering a sanidine crystal at high temperatures (Point X - Figure 1), for example, there comes a time when the solid solution is no longer stable and an exsolution occurs between the albite content incorporated at high temperatures and the albite content within the orthoclase or microcline structure at lower temperatures (Point Y - Figure 1). The composition of the exsolved feldspar is then point Z in Figure 1, rich in albite (WERNICK, Op.Cit.).

Potassium feldspars containing exsolved albite are called perthites (Figure 3). When the potassium feldspar is very rich in perthites it is called mesoperthite and; potassium feldspars exsolved in plagioclase are called antiperthite.

In addition to these classifications, a perthite has irregular patches or lamellae of sodium feldspar within the potassium alkali feldspar; however, the term perthite is often used to describe all types of exsolution in feldspars. Perthite that can only be observed with the aid of a microscope is known as microperthite (PANDIT, 2015).

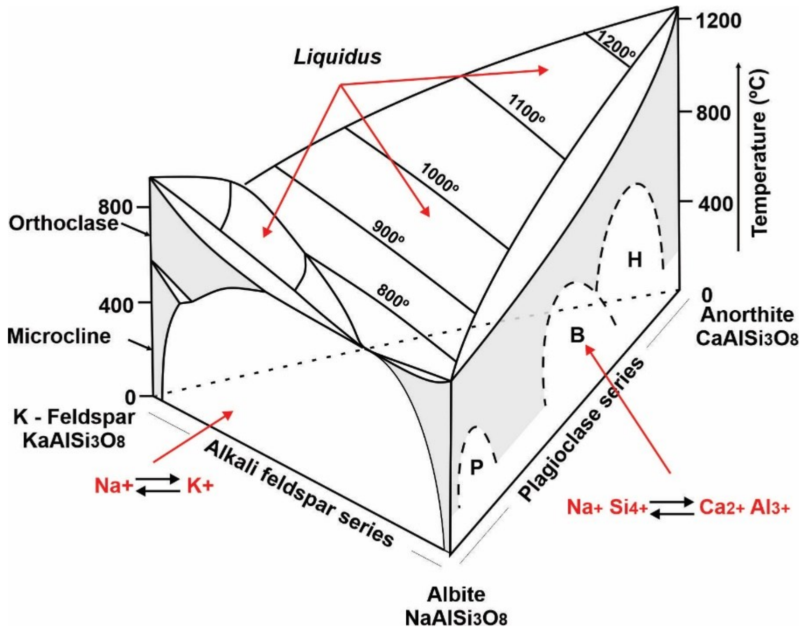



*Figure 2 – Diagram of the potassium feldspar – albite – anorthite system. Key to table: Gray – solid solution; P – Peristerite; B – Boggild intergrowth; H – Hutten Locher intergrowth.*
*Source: Adapted from Klein and Dutrow (2012).*

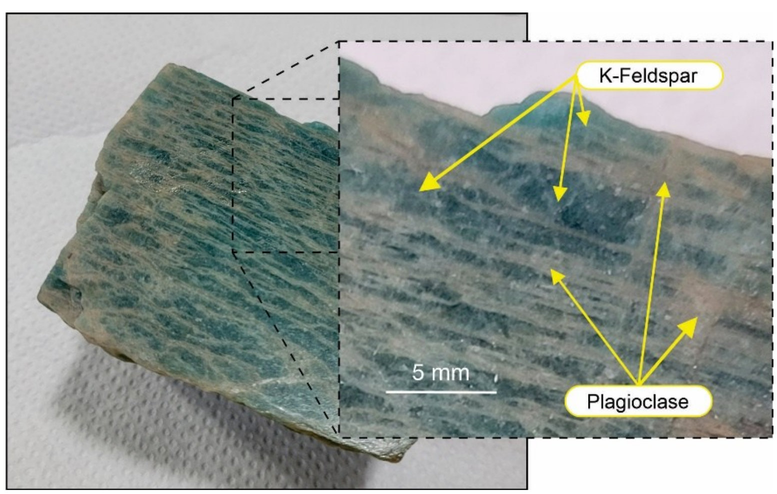



*Figure 3 – Macroscopic perthites in "amazonite" potassium feldspar.*
*Source: Authors (2024).*

Deer, Howie and Zussman (2010) classify perthites according to their textural aspect (Figure 4), but warn that not all perthites originate from exsolution. In granitic pegmatites, potassium feldspar (perthitic microcline) as well as sodium feldspar, presents coarse intergrowths of quartz with a runic texture originating from simultaneous crystallization, known as graphic texture (Figure 5). Xua et al. (2015) provide evidence of topotaxial intergrowth of quartz induced by the crystallographic feldspar lattice.

In plagioclase, between albite and anorthite, substitutions between Na and Ca occur in proportions (Figure 1) that characterize other minerals and make up the so-called plagioclase continuous series. According to Sial and McReath (1984), the most calcic members are present in mafic and ultrabasic rocks. The more sodic members are present in felsic rocks.

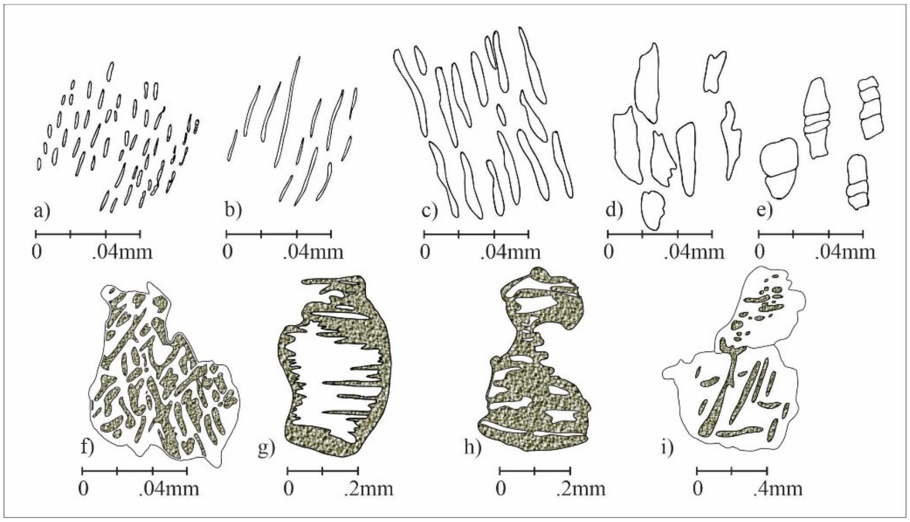



*Figure 4 – Textural classification for perthites: a) fillets; b) venules; c) bars; d) droplets; e) fractured droplets; f) interconnected; g) interpenetrated; h, i) replacement.*
*Source: Adapted from Deer, Howie and Zussman (2010).*

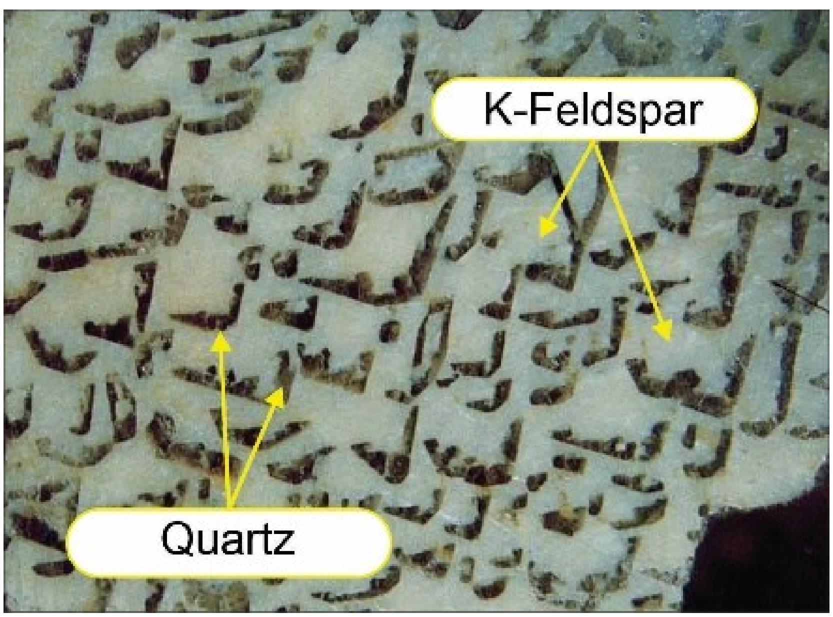



*Figure 5 – Graphic texture.*
*Source: Adapted from MacKenzie et al. (1988).*

Compositions in terms of oxides of major elements show that plagioclase structures admit small quantities of the molecule $KAlSi_3O_8$ (potassium feldspars) and that there is also the possibility of incorporation of $Fe^{3+}$ (SIAL and McREATH, 1984).

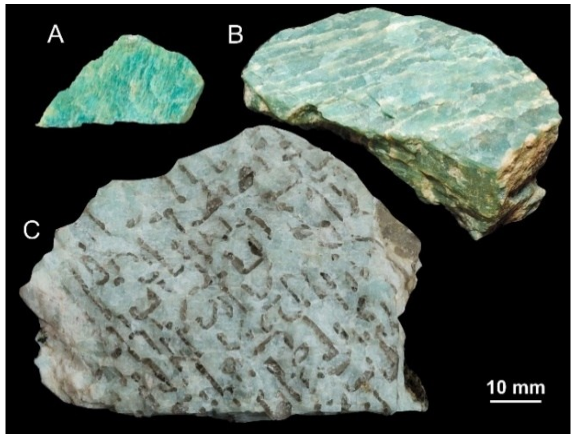



*Figure 6 – Examples of intergrowth in amazonite. Key to table: A – Small venules (SEPPEL, 2015); B – Larger venules (HELEBRANT, 2021); C – Graph: exsolution and topotaxial growth (BURIVAL, 2018).*
*Fonte: Autores (2024).*

Plagioclases are mostly low-pressure crystals, with the calcic members being less stable than the sodium ones and, therefore, will present mono- or triclinic symmetry.

A summary of their properties that will allow comparison with the so-called alkaline feldspars can be seen in figure 7.

## 5. Gemological feldspar crystals

Anderson (2005) published that only the moonstone variety was frequently used in jewelry. However, many properties of feldspars began to be observed and appreciated (optical effects) and a series of varieties have been used in jewelry. Among the best known are sunstone, moonstone and labradorite.

Opaque, milky specimens or those with very saturated colors are generally cut in round or elliptical shapes, using the cabochon cutting technique (READ, 2005).

The varieties can be colorless or with shades of black (black moonstone), red (sunstone), bluish (blue moonstone), green (amazonite), yellow (moonstone) and orange (sunstone), as can be seen in figure 7.

In feldspars, exsolution is a common phenomenon and causes many of the optical effects found. Lamellae can vary in dimensions, spacing, directions, and continuity (Figures 6A and 6B). Figure 6C shows that several phenomena can occur superimposed on the same crystal.

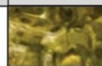
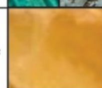
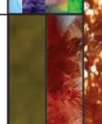
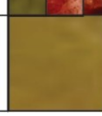
| Group | Minerals | Illustrations | Gemological varieties. Locations and possible colors reported | Optical effects developed | | | | | | | Crystallographic and physical data | | | | Optical data (biaxial crystals) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | Índices de refração n | | |
| | | | | ADU | CE | AST* | LAB | AVE | IRI | CG | Twinning | Cleavages | d | D | Signal | α | β | γ |
| Alkaline | Sanidine |  | Occurrences in Germany, USA (Idaho, Colorado and New Mexico), Russia, Italy and Madagascar. Transparent, colorless to yellow gemstones. It can also present shades of light brown, light gray and smoky. | - | X | X | - | - | X** | X | Carlsbad. | {001} perfect; {010} good | 2,56-2,62 | 6-6,5 | (-) | 1,518-1,525 | 1,523-1,530 | 1,525-1,523 |
| | Orthoclase |  | Occurrences in Madagascar, Myanmar, Sri Lanka, the Swiss Alps (especially in Adular, the locality where the variety is named), Czechoslovakia, Italy, Russia, USA (New Mexico, Robinson, Colorado, Goodsprings, Nevada, Pennsylvania), Brazil, Greenland. Adularia or moonstone; "Rainbow lattice sunstone" or "Rainbow lattice sunstone"; **yellow orthoclase. They can be colorless, champagne to yellow, pink, orange, light blue, light green, brown or gray. | X | X | X | - | - | X** | X | Carlsbad; Baveno e Manebach. | {001} perfect; {010} good; {110} imperfect | 2,57 | | (-) | 1,518 | 1,524 | 1,526 |
| | Microcline |  | Occurrences in Italy, Norway, Madagascar, Namibia, Zimbabwe, India, Russia, Brazil, Australia, Canada and the USA. Amazonite occurs in the USA, Canada, Brazil, India, Kenya, Tanzania, Madagascar, Namibia and South Africa, Russia, Afghanistan and Australia. Green microcline is reported in several locations in Brazil. Perthitic microcline; Graphic feldspar; Amazonite. It can be white, light yellow, salmon or green. | - | X | X | - | - | X** | X | Characteristic: Tartan twinning - Albite law, twinning plane {010} and Pericline law, twinning axis {010}; May occur: Orthoclase Law; Carlsbad; Baveno and Manebach (rare). | {001} perfect; {010} good | 2,54-2,57 | | (-) | 1,522 | 1,526 | 1,53 |
| | Anorthoclase |  | Some locations for well-formed material include: Italy; Norway; Germany; Democratic People's Republic of Korea; Antarctica; Mexico; USA; Republic of Somalia; Australia and New Zealand. It can be colorless, white, light cream yellow, green, red or pink. | - | X | X | - | - | X** | X | *Carlsbad; Baveno e Manebach. | *{001} perfect; {010} good | 2,58 | | (-) | *1,519-1,529 | *1,524-1,534 | *1,527-1,536 |
| Plagioclase | Albite |  | It occurs worldwide, with major locations in the Alps, Urals, Harz Mountains, France, Norway, Madagascar and the USA. It can be white, colorless, with light shades of blue, green, pink-orange, reddish or brown. Moonstone variety (Peristerite). | - | X | X | - | - | X** | X | Polysynthetic {010}; Carlsbad; Baveno and Manebach | {001} perfect; {010} good | 2,62 | | (+) | 1,527 | 1,532 | 1,538 |
| | Oligoclase |  | Some locations are: Sri Lanka; USA – Oregon Sunstone (locations in New York, Maine, New Mexico); Brazil; Kenya, Russia; Sweden, Norway and Canada, as well as Moonstone and Sunstone. Sunstone (reflective inclusions of hematite or goethite). It can occur in shades of white, gray, light green, blue, yellow and brown. | - | X | X | - | X | X** | X | | | 2,65 | | (-) | *1,533-1,545 | *1,536-1,548 | *1,542-1,552 |
| | Andesine |  | Locations include Greenland, the Andes Mountains (hence the name Andesine), Norway, the USA (California; pale yellow to colorless andesine is found in Idaho), China (red and green stones - occasionally called 'sunstone') and the Democratic Republic of the Congo (red stones), Japan, India, South Africa, Argentina, France, Italy, and Germany. This material has a wide range of properties and chemical composition that spans the Andesine-Labradorite boundary. Sunstone; Lavanite (similar to Sunstone, without the aventurescence). It can also have shades of white, gray, red, orange-red, green, yellow-red or with irregular color distribution. | - | X | X | - | - | X** | X | | | 2,69 | | (+)/(-) | *1,543-1,556 | *1,547-1,559 | *1,552-1,563 |
| | Labradorite |  | It is found in Canada (Tabor Island, Nain area of Labrador), Madagascar, Tanzania; Mexico, Russia, Brazil and USA (Oregon), Ukraine, Russia. Labradorite; Sunstone; "Rainbow Moonstone" or "Rainbow" moonstone; Black moonstone; Lynx's eye; Opaline feldspar; Bull's eye; Spectrolite. It can be colorless, white, grayish, faint yellow, bluish gray or greenish, often showing labradorescence (usually blue and green, but can be yellow, gold, red and purple). | - | X | X | X | - | X** | X*** | | | 2,71 | | (+) | *1,554-1,565 | *1,558-1,569 | *1,562-1,573 |
| | Bytownite |  | Locations include Canada; USA (Oregon); Mexico; India and South Africa. It is important to note that compositional variation can occur within any calcium-rich plagioclase source, so that intermediates can range from andesine through labradorite to bytownite. Sunstone. They can occur in shades of white, gray or colorless or they can have light shades of other colors or light pastel yellow. | - | - | - | - | - | X** | - | | | 2,74 | | (-) | *1,563-1,573 | *1,568-1,580 | *1,573-1,585 |
| | Anortite |  | Locations include the USA; Italy; Finland; Sweden; India and Japan (very rare transparent red crystals have been cut as gemstones). The gemstones are rare and usually cut only for collectors. They can occur in shades of white, grey, colorless or reddish, and may have light shades of other colors. | - | - | - | - | - | X** | - | | | 2,76 | | (-) | 1,577 | 1,585 | 1,59 |

*Figure 7 – Gemological varieties of the feldspar group and their properties. Key to table: ADU – Adularesence; CE – Cat's Eye; LAB – Labradorescence; AVE – Aventurescence; IRI – Iridescence; CG – Color Change. Source: Compiled and translated from O'Donoghue (2006, our translation) and HE Museum (2024).*

## 6. Optical effects in gemstones of the feldspar group

The previous chapters dealt with the composition of minerals in the feldspar group, whose compositions change as the crystallization temperature changes. The limitations of these reactions highlight specific structures that are fundamental for understanding the optical effects of feldspars (Figure 8).

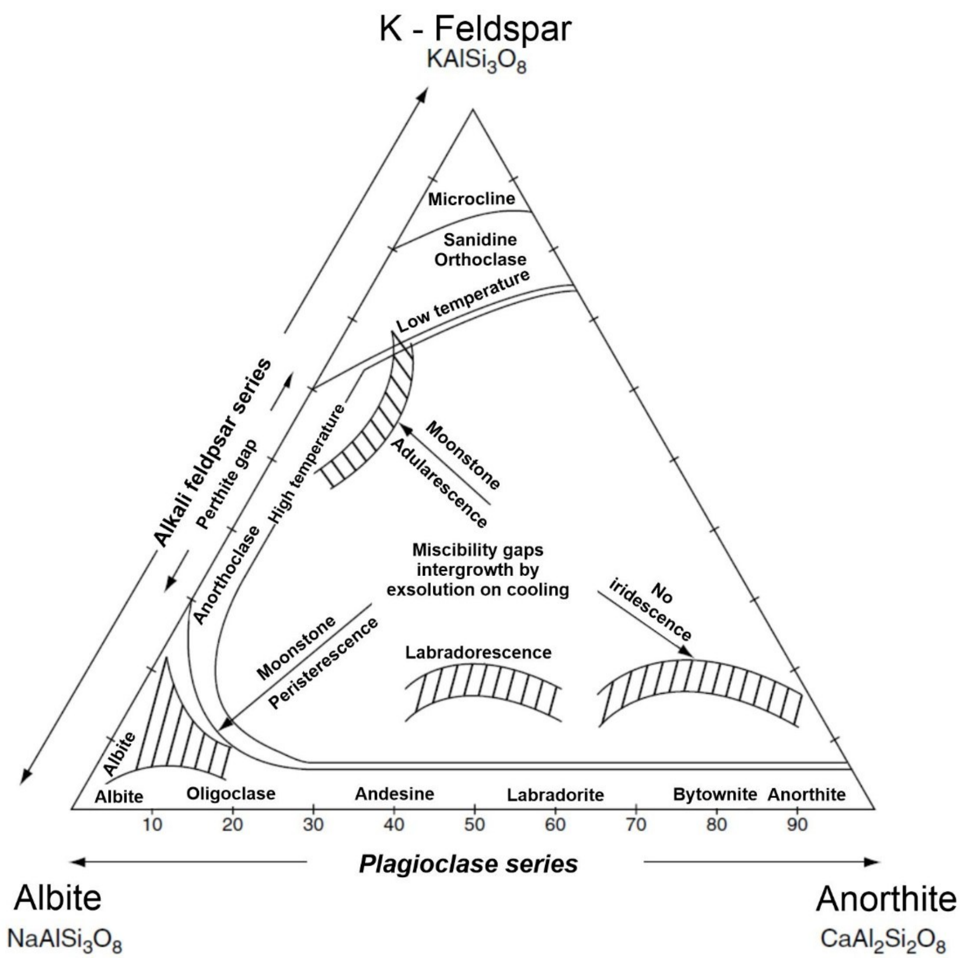



*Figure 8 – Isomorphic Substitution, Solid Solution and Exsolution.*
*Source: O'Donoghue (2006).*

Manutchehr-Danai (2005) describes gems with optical effects as "phenomenal gems" because they present some special occurrence of optical phenomenon that is observed or becomes visible.

Gems with optical effects are defined and grouped according to the cause for the effects:

"Special optical effects caused by the interaction of the gem with light, which can be of three types: structural (play of colors, labradorescence, iridescence and adularescence), caused by inclusions (chatoyancy, asterism and aventurescence) and color change (ABNT, 2016)".

Of these, those occurring in feldspars are shown in figure 07 and throughout the text.

When considering the presence and orientation of "structure(s)" in the context of cutting, understanding how optical effects relate, especially with the cabochon technique, is important because some crystals can develop more than one optical effect simultaneously.

In the following example, the same potassium feldspar crystal (Figure 9A) develops both the chatoyancy (Figure 9B) and the adularescence of moonstone (Figure 9C) simply by varying the degree of convexity of the cabochon during cutting; two effects and the same cause, the exsolution in thin albite lamellae (Figure 9D).

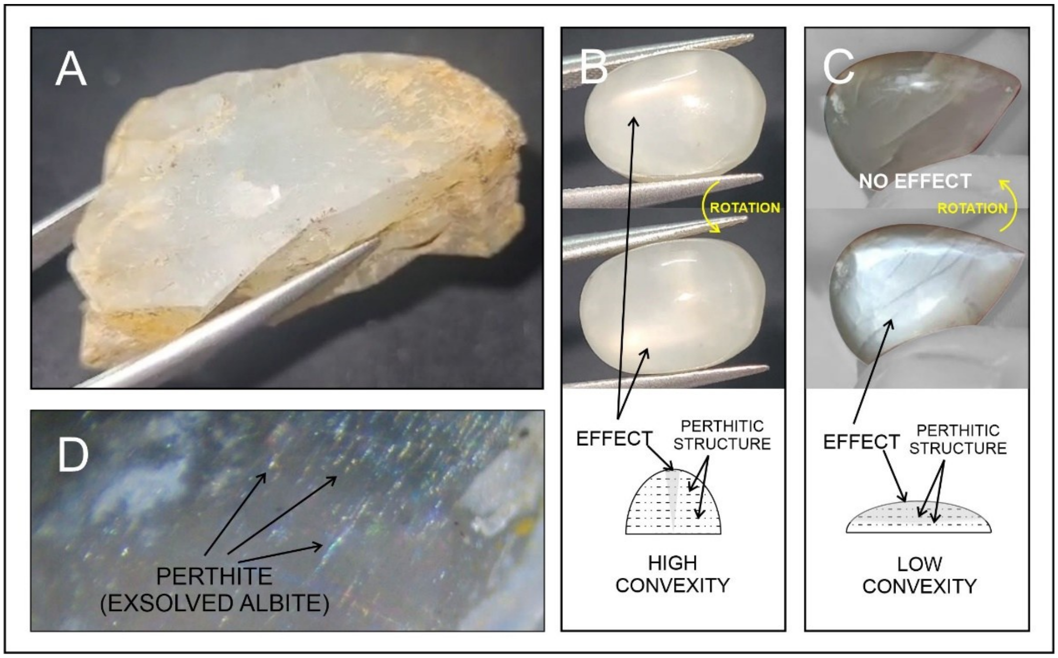



*Figure 9 – Example of change in effect from the cutting of crystal "A". Key to table: A – Crystal in its raw state; B – Single cabochon with elliptical base, with high profile; C - Double cabochon with drop shape, with low profile; D – Cause of the effects (PACÍFICO and BOLONINI, 2023), in transmitted light, magnification 2000x.*
*Source: Authors (2024).*

It is important to remember that exsolved lamellae vary in size and distribution, affecting the definition of optical effects in cut gemstones, and that proper orientation is crucial to avoid asymmetries (Figure 10).

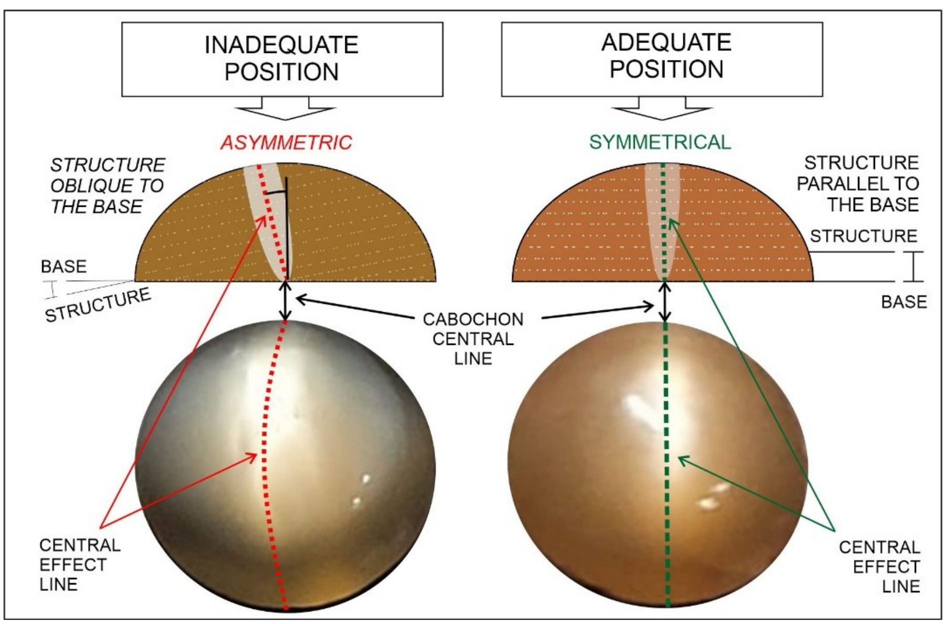



*Figure 10 – Variety of moonstone cut in cabochon, with cat's eye, in a round shape.*
*Source: Authors (2024).*

Moonstone can reflect different colors of light (silver, blue, white, gray, light brown, among others) and these reflections were attributed to adularia (RAO et al., 2013) and, therefore, the effect became known as adularescence. Figure 9C shows the silvery adularescence and figure 11 depicts the bluish adularescence typical of moonstone.


*Figure 11 – Example of bluish adularescence.*
*Source: Authors (2024).*

Adularescence is defined as:

"Optical phenomenon characterized by a white or bluish, diffuse and fluctuating glow, observed in a variety of feldspar (moonstone/adularia) (ABNT, 2016)".

The term "adularescence" does not apply only to adularia feldspar (a variety of orthoclase), as other feldspars also develop this optical effect and several studies show that moonstone varieties are composed of a mixture of perthites presenting themselves in various formats (GIA, 2024b; IAMSUPA et al., 2016; RAO et al., 2013; RAMAN et al., 1950; STONE-SUNDBERG, 2019; TATEKAWA, 1972). However, orthoclase crystals from Dong Nai Province in Vietnam, which also develop both adularescence and chatoyancy, were described by Le (2021) with optical effects caused by fluid inclusions, showing that research related to the causes of adularescence and chatoyancy effects in feldspar crystals needs to continue advancing so that, in addition to the origins of the effects, more and more tools can be used to facilitate their correct orientation during faceting.

Studies on cut beryl crystals have shown that the orientation of the bundles of structural tiny hollow tubes affects optical effects such as chatoyancy and asterism. The position of the center of the star in asterism and of the bands in chatoyancy varied according to the rotation of the cabochon (SCHMETZER, KIEFERT, HÄNNI, 2004). Therefore, the correct orientation of the structure in relation to the base is crucial to obtain the desired effect.

Chatoyancy and asterism are defined as:

"Chatoyancy or cat's eye - Optical effect characterized by a narrow, shiny band on the surface of a cabochon-cut gemstone, caused by the reflection of light in parallel inclusions. (ABNT, 2016)"

"Asterism - Optical effect characterized by two or more narrow bright bands that intersect on the surface of a cabochon-cut gemstone, caused by the reflection of light in inclusions arranged parallel to two or more crystallographic orientations. (ABNT, Op. Cit.)"

In these cases, the effects depend on the presence of some structure or pattern of repetition and orientation in one or more crystallographic directions, as these, combined with the shape given by the faceting, generate the different optical effects. Figure 12 shows a relationship between the quantity of structures present, angles and positions in relation to the shapes and planes of the cabochon bases.

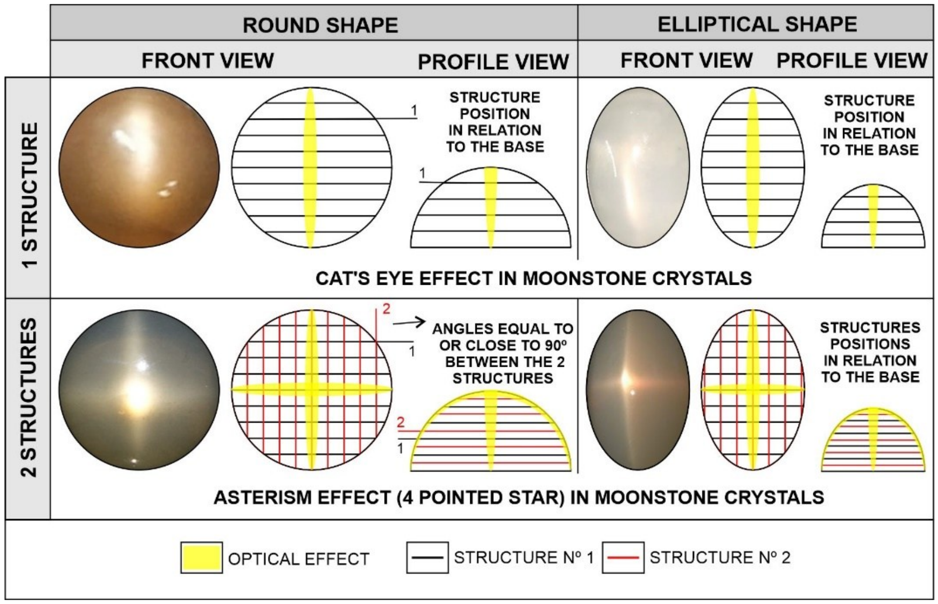



*Figure 12 – Examples of orientation of structures in gemological materials.*
*Source: Authors (2024).*

The cut profile of the cabochon represents the convexity it presents and, in the case of gemstones with optical effects, the decision to cut the cabochon with a high or low profile may make it impossible to produce the desired optical effect (Figures 12, 13 and 14).

When considering cutting, it is important to be aware that there are, therefore, optical effects that are dependent on the structuring or internal organization of inclusions, exsolution lamellae, among other physical discontinuities (Figure 13).

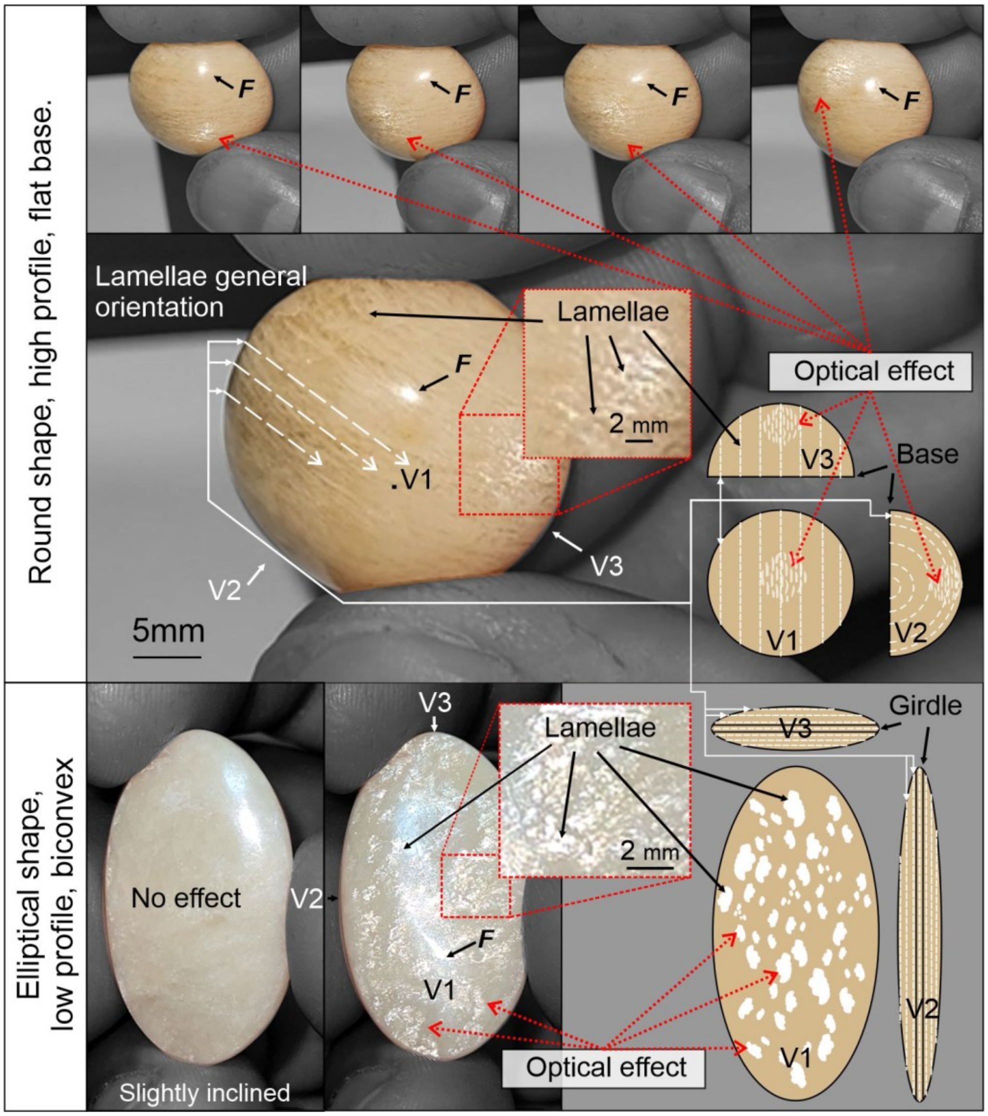



*Figure 13 – Influence of structure orientation and cut shape on the optical effect. Key to table: F - Camera flash; V – View; Dashed lines represent lamellae organized in planes.*
*Source: Authors (2024).*

Still regarding moonstone and its adularescence, it is important to know that the so-called "rainbow" moonstone should not be confused with moonstones composed of potassium feldspar and exsolved albite, as it is, in fact, transparent labradorite, with shine in a variety of iridescent colors (GIA, 2024b; JOHNSON and KOIVULA, 1997).

Labradorite is known for its vibrant colors (Figure 17) and the optical effect that causes these varied colors, called labradorescence, only occurs in labradorite and is defined as:

"Optical effect of reflection and interference of light, seen in certain labradorites, producing colors visible only in a given direction of observation ABNT (2016)".

Read (2005) describes labradorescence as a particular form of iridescence due to fine feldspar flakes resulting from lamellar twinning.

Studies show that the structures responsible for labradorescence are related to the Bøggild intergrowth region (JIN and XU, 2017a and 2017b; JIN et al., 2021; KALNING et al., 1997), forming a structure where two twinnings (albite and pericline) intersect orthogonally and, interspersed with the albite twinnings, there is a matrix with alternating Ca-rich and Ca-poor lamellae, with different thicknesses, parallel to the labradorescence plane, that is, it is responsible for its generation

(GOTZ, KLEEB, KOLB, 2022). Therefore, for the effect to be maximized, the correct orientation of the planes of this structure in relation to its base is necessary (Figure 14).

When comparing figure 14C with figure 14D, it can be seen that the development of the optical effect occurs on flat or convex surfaces, but it is necessary to observe the labradorescence in the raw sample, imagine/project an approximate plane for this surface and produce the base of the cabochon parallel to it so that the effect is maximized (Figure 14E).

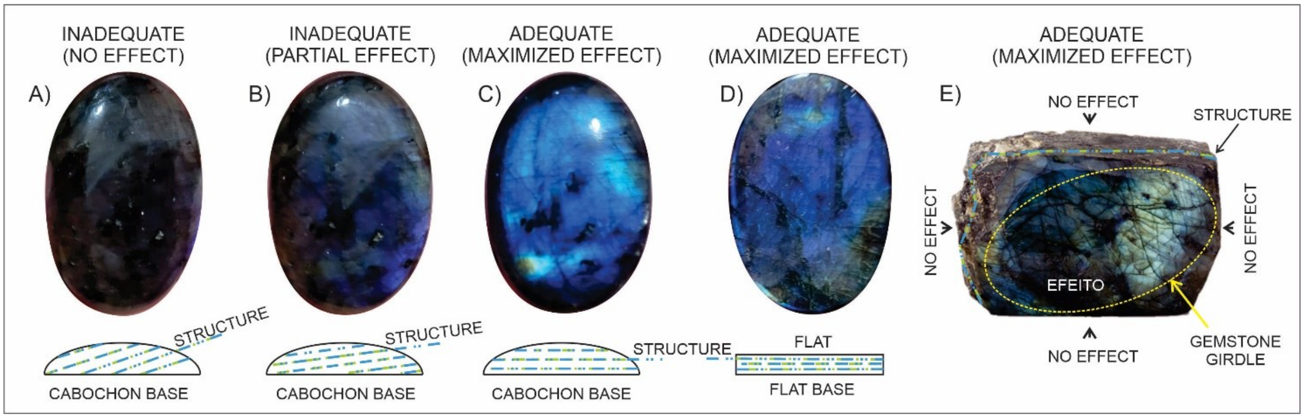



*Figure 14 – Positioning of the labradorescence planes in the cutting. Key to table: A) Oblique or incongruous structure, high angle; B) Slightly oblique incongruous structure; C and D) Structure parallel (congruous) to the base. A, B and C convex top and D flat top.*
*Source: A, B, C and D – Authors (2024); E - Adapted from HINKLEY (2012).*

Labradorescence only occurs in labradorite crystals, but not all labradorite exhibits the effect. Gemological quality crystals from Oregon, for example, are appreciated for their red, orange and green colors, as well as for the phenomenon of aventurescence which, according to Koivula (2016), is caused by copper exsolution platelets, normally a yellow-green color.

Aventurescence is defined as:

"Optical effect, observed when rotating the gem, characterized by bright or strongly colored reflections, originating from tiny inclusions in the form of platelets or flakes. ABNT (2016)".

Sunstone (Figure 15) is a variety where inclusions of hematite or goethite produce a specular reflectance. The term was originally applied to oligoclase crystals in which interference of light on these inclusions resulted in green or blue colors in the crystals. Over time, plagioclase crystals with aventurescence and other inclusions were discovered, as well as hematite and goethite. Even so, all feldspars with aventurescence came to be called sunstone (READ, 2005).

These gems have varieties of both potassium feldspar and plagioclase crystals and therefore the name refers to the appearance of the gem and not its chemical composition (GIA, 2024a).

Given the variability of crystal sources, there are diverse characteristics and properties for sunstone and not all sunstones exhibit aventurescence.

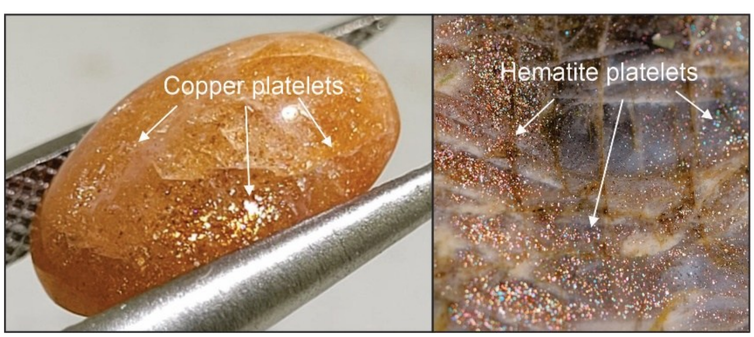



*Figure 15 – Sun stone (aventurescence). Key to table: Left, gem with 10 mm major axis; Right, another specimen with aventurescence with hematite platelets.*
*Source: Left, authors (2024); Right, Milshina (2021).*

Hofmeister and Rossman (1985) report that the sizes of platelets in inclusions depend on the Cu content and the temperature of their exsolution. Abduriyim and Pogson (2011) point out that copper platelets are better known in Oregon labradorites, tending to be larger than those in Tibetan samples.

Another very common effect in structures or discontinuities such as fractures or in so-called thin films inside and on the surface of gemological materials, which can occur on any scale, is iridescence (Figure 16).

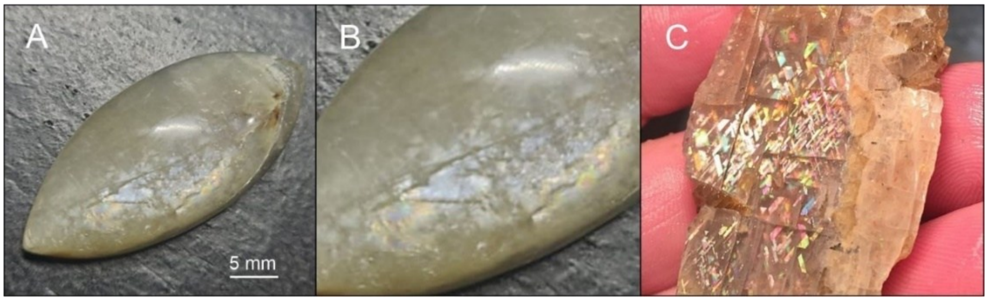



*Figure 16 – Cabochon in shuttle shape: iridescence in cleavage planes. A – Gem with 30 mm major axis; B – Enlargement of A; C - Iridescent network: sunstone.*
*Source: A and B, authors (2024); C - Wikmediacommons (2024).*

NBR -10630:2016 defines iridescence as:

"Optical effect characterized by the presence of colors similar to those of the rainbow, due to the reflection and interference of light in thin layers on the surface or inside the gem (ABNT, 2016)".

In Figure 16C it is possible to see a network pattern in a "Rainbow Lattice Sunstone"; commercial name given to orthoclase that exhibits iridescence from hexagonal hematite platelets producing a crossed network of colors, in addition to also presenting adularescence. According to Read (2005) and Stone-Sundberg (2019), the rare gemological material comes from northern Australia.

It is yet another example of the interdependence between the identification and orientation of the structure in the cutting process, considering that Branstrator (2023) states that crystals that present this iridescent network pattern also sometimes present characteristics of moonstone; adularescence. The author adds that magnetite inclusions (the iridescent, altered ones and the unaltered ones, which are black with a metallic sheen) form thin sheets at different levels of planes and are oriented to create the characteristic network pattern; and that hematite is seen in small platelets (yellow to orange) with hexagonal shapes, with a general orientation in parallel planes causing aventurescence. Therefore, crystals can present aventurescence, iridescence and adularescence simultaneously.

Certain gemological materials, however, only present an optical effect when the illumination source or light stimulus has its color pattern modified (references of illuminant patterns for the wavelengths where they are D65 – Daylight and A – Incandescent light: CIE, 2024), as they have optical effects that do not depend on the presence of the ordering of structures such as those mentioned above to occur.

This effect is known as the color change phenomenon or "Alexandrite Effect", as it is a characteristic of the mineral. However, other gemological materials may present such an effect, such as monazite, fluorite, garnets, corundum, spinel and kyanite (GUBELIN and SCHMETZER, 1982) and zircon (KRZEMNICKI, ZHOU, MAIZLAN, 2013).

NBR -10630:2016 defines the color change effect as:

"Optical effect perceived in certain gemstones that change color when observed under different types of lighting (incandescent light and natural light or equivalent) ABNT (2016)".

Schmetzer, Bank and Glibelin, (1980) point out $V^{3+}$ and $Cr^{3+}$ as favoring color changes with changes in light stimulus in corundum and some types of pyrope-spessartine garnets and Farrell and Newnham (1965) $Cr^{3+}$ in chrysoberyl/alexandrite crystals.

Krzemnicki (2004) described milky green labradorites from the Democratic Republic of Congo that turned red under incandescent light. O'Donoghue (2006) cited andesine/labradorite crystals from the Democratic Republic of Congo (showing alternating colors depending on the light source), from China (green material $An_{44}Ab_{54}Or_2$, showing a similar effect becoming red under natural light and losing transparency under incandescent light) and from Oregon, USA, at the Ponderosa mine, with the color change related to the effect of large copper colloids seen in incident light. In figure 17 an example of this optical effect in feldspars can be seen.

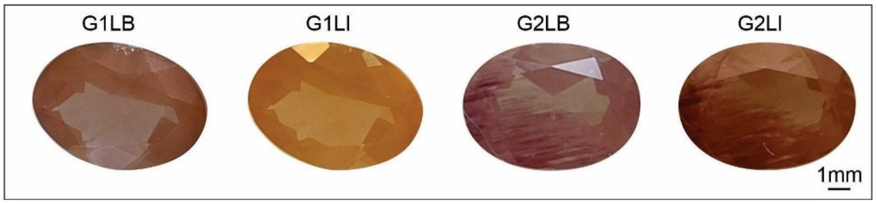



*Figure 17 – Gems G1 and G2 (visible inclusions) of potassium feldspar showing color change. Key to table: LB - White light; LI - Incandescent light;*
*Source: Authors (2024).*

## 7. Final considerations

This research sought to compile scientifically relevant publications to explain the optical phenomena that occur in gemological feldspar crystals and assist in their identification, in addition to providing guidelines for maximizing the gem's potential in cutting with the appropriate positioning of the structures. Feldspars are classified into alkali feldspars and plagioclase feldspars based on compositional variations (Or, Ab, An). Notable gemstone varieties such as moonstone, labradorite, and sunstone, known for their optical effects (adularescence, labradorescence, aventurescence), were discussed, emphasizing the role of mineral intergrowth for their development. Key findings include the importance of structural features and correct crystal orientation during cutting to achieve desired optical effects. It is concluded that continued research on the optical properties of feldspar can further refine gem processing techniques and improve the understanding of mineralogical phenomena.

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