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Birefringence Table for Identification of Minerals in Petrographic Section

Tabela de Birrefringência para Identificação de Minerais em Secção Petrográfica

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Abstract

The minerals have great importance through deposits, being widely used in the more traditional fields of geology (economic geology, prospecting, sedimentology, petrology / petrography). The aim of this research was the elaboration of a birefringence table, using only the optical properties, for a faster, safer, and more succinct identification of some important minerals in a petrographic section (0.03 mm), focusing on the most efficient characteristics and using the addition and subtraction colors related to birefringence, in which most of those analyzed are heavy minerals, as well as other very common minerals. The table prepared for this paper has two differential characteristics, which make it efficient. Updated values from birefringence in several minerals; plus, each combination color that could be visualized trough the accessory of 530 millimicron. Due to its ease and precision of use, it can be used by researchers, professionals and undergraduates. The table containing 42 common minerals, with the information on each of their character of optical signal, colors with quartz accessories, pleochroism, and the most relevant characteristic was chosen to facilitate the identification of such minerals.

Keywords: Colors; Millimicron; Optical character

Resumo

Os minerais têm grande importância através das jazidas, sendo amplamente utilizados nos campos mais tradicionais da geologia (geologia econômica, prospecção, sedimentologia, petrologia/petrografia). O objetivo desta pesquisa foi a elaboração de uma tabela de birrefringência, usando apenas as propriedades ópticas, para uma identificação mais rápida, segura e sucinta de alguns minerais importantes em uma lâmina petrográfica (0,03 mm), com foco nas características mais eficientes e utilizando as cores de adição e subtração relacionadas à birrefringência; no qual a maioria dos analisados são minerais pesados, bem como outros minerais muito comuns. A tabela elaborada para esta pesquisa possui duas características diferenciais, que a tornam eficiente: valores atualizados de birrefringência em vários minerais e cada combinação de cores que poderia ser visualizada através do acessório de 530 milimicra. Devido à sua facilidade e precisão de uso, pode ser utilizado por pesquisadores, profissionais e graduandos. A tabela contendo 42 minerais comuns, com as informações sobre cada um de seus caracters de sinal óptico, cores com acessórios de quartzo, pleocroísmo e a característica mais relevante foi criada para facilitar a identificação destes minerais.

Palavras-chave: Cores; Milimicra; Caráter óptico

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1 Introduction

Mineralogy, the study of minerals, is essential and a great foundation for several areas of geology, helping in the development of sciences and humanity. Studies involving the most common minerals present in the Earth's crust are recurrent (Klein and Dutrow 2012), of which a considerable part are heavy minerals. According to Suguio (1980), heavy minerals have a specific weight greater than the most common minerals in sedimentary rocks, such as feldspar and quartz, whose specific weight is 2.6 g/cm^3. The quantity of heavy minerals in a location depends on their abundance in the source area, their ability to resist weathering, abrasion, and their segregation due to differences in density, shape, and intensity of the transport process (Calliari et al. 1990) (Addad 2001). The usual identification methodology results from collecting samples and separating the minerals using bromoform, followed by classic petrographic characterization, using a prepared thin section with a thickness of 0.03 mm. A problem is in mineralogy books, which are often consulted for the purpose of identification and characterization, is the outdated values of some mineral birefringence. In the books, there are no addition and subtraction colors for each of the intervals and birefringence values at a thickness of 0.03 mm; this fact could save time and bring more precision to the identification, whether in thin section of igneous minerals or heavy minerals.

Heavy minerals are of interest for studies, as they can constitute economically exploitable deposits. They can serve as indicators of the nature of rocks and mineralizations and mineral occurrences located upstream of the collection point of a drainage sediment, the source area of a sediment or sedimentary rock, as well as providing direct information about mineralogical associations (present in sedimentary rocks) and paragenetic associations (in igneous and metamorphic rocks) contained in the most diverse lithotypes (Addad 2001) (Klein and Dutrow 2012). The study of heavy minerals has always been widely used in the more traditional fields of geology, such as economic geology, prospecting, sedimentology, petrology/petrography, and others. In economic geology and mineral prospecting, heavy minerals are used, directly or indirectly, by obtaining guide minerals, such as pyrope garnet, chromite, tourmaline, gahnite, and picroilmenite, in the search for mineral deposits. In sedimentology and stratigraphy, mineral chemistry studies carried out on certain heavy minerals are used to determine the areas of provenance. In petrology, for example, the characterization of the morphology of zircon populations is used for the purpose of classifying granite bodies (Krumbein and Pettijohn 1938) (Feo-Codecido 1956) (Krumbein and Sloss 1963) (Suguio 1980) (Deer et al. 2010). In nature, the concentration of heavy minerals occurs, above all, due to the loss of energy in the current produced by the transport agent (river, sea, wind), which will cause the deposition of these denser minerals in the most suitable places. They are used in the analysis of sedimentary basins and as indicators of environmental processes (Addad 2001).

To this study, a table was made containing the 42 most common minerals (in transmitted light) in the Earth's crust with a density greater than 2.50 g/cm^3, of which a considerable part are heavy minerals. To create the table of minerals, data relating to the 42 main minerals with a density greater than 2.50 g/cm^3 were used, focusing on specific characteristics that guarantee accurate and quick identification, both for researchers and professionals as well as for undergraduate and postgraduate students. The table prepared for this research has two differential characteristics, which make it unique and efficient. We used updated values of birefringence (using the most recent published value of double refraction) (Kerr 1987) (Nesse 2004) (Deer et al. 2010) (Frank 2018) (Schumann 2020) (Arem and Clark 2022); in addition, the table has all possible color combinations (addition and subtraction) for each birefringence interval of each mineral, using the quartz-gypsum accessory (the most common) that provides a delay of 530 millimicron; this information refers to the interference colors for each birefringence value of minerals not found in mineralogy books. The petrographic sections were made using grain minerals with a thickness of 0.03 mm. With this table it was possible to identify minerals in grains, if they have a thickness of 0.03 mm, in addition to being able to be used for minerals from igneous rocks, because it uses only optical properties. This methodology provides an easy and fast methodology.

2 Materials and Methods

Through the classic petrographic characterization of minerals, the identification of minerals using a polarized light microscope is based on optical and morphological properties, which uses 3 systems in the following sequence: polarized natural light, orthoscopic system, and conoscopic system. With the assistance of these tools, all the characteristics of a mineral in thin section are obtained. Through these 3 systems, some specific characteristics of each mineral were selected, which when combined provide faster and more efficient identification for heavy minerals. The first polarized light microscopy, is a non-destructive and robust technique for determining solid substances (crystalline or amorphous), has relatively high spatial resolution, and is also useful in studying mineral phases according to their texture (Flint 1965) (Fujimori and Ferreira 1987) (Nesse 2004) (Klein and Dutrow 2012). These devices allow the estimation of chemical compositions and also provide the necessary elements to understand the history of formation of the material, through the study of textural relationships (structure, weave, association and phase relationships, reaction textures). In this context, transmitted light microscopy cannot be replaced by other analysis methods that use ground samples for mineral phase identification by X-ray diffraction (XRD), or for whole rock chemical analysis by X-ray fluorescence (XRF) or Atomic Absorption Spectrometry (AAS) (Raith et al. 2014).

The second, the polarized natural light system, gives the observer some properties, such as color, pleochroism, absorption, relief, the index of refraction in relation to the medium (also known as the "Becker" line), cleavage and habit (Fujimori and Ferreira 1987) (Machado and Nardy 2016).

The orthoscopic light system uses crossed nicols (in parallel) and thus obtains characteristics when the light passes through the mineral. This vibrating polarized light, in this case, for example, in a north-south direction, falls on an anisotropic mineral placed on platinum and, when passing through it, unfolds into two rays that vibrate in planes perpendicular to each other. These two rays, in the most general case, have different propagation speeds Vx and Vz and respective refractive indices n2 and n1 and, when passing through the thick mineral e, they result in a difference in retardation path. The ray with the lowest speed constitutes the slow ray, and the one with the highest speed is the fast ray. Time delay exists between the two rays, fast and slow. Through this system, interference color, birefringence value, determination of the slow and fast radii of the mineral, types of extinction, twinning, and zoning are obtained (Zukov 1967) (Fujimori and Ferreira 1987) (Grimble and Hall 1992) (Machado and Nardy 2016).

The conoscopic system allows the observer to perceive the interference figures and these make it possible to determine isotropic and anisotropic character of the minerals, uniaxial and biaxial character, and positive and negative optical signal of minerals (Wahistrom 1969) (Fujimori and Ferreira 1987) (Nesse 2004) (Machado and Nardy 2016).

The table was made containing the 42 most common minerals (in transmitted light) with a density greater than 2.50 g/cm^3, of which a considerable part are heavy minerals. Some characteristics of the minerals were selected, such as character and optical signal, birefringence, and other specific features of minerals. The differential of this table is in the updating of birefringence data in several minerals (Kerr 1987) (Nesse 2004) (Frank 2018) (Schumann 2020) (Arem and Clark 2022) and we used the Michel Levy's color table to has all possible color combinations (addition and subtraction) for each birefringence interval of each mineral, using the quartz-gypsum accessory (the most common) that provides a delay of 530 millimicron; this information refers to the interference colors for each birefringence value of minerals not found in mineralogy books.

The table can be used in minerals in grains from petrographic sections and also in petrographic sections from igneous rocks; due to the exclusive use of optical data. The thickness of the material should be 0.03mm. The materials used for the use and testing of this table were under the above conditions.

3 Results and Discussions

Table 1 was made with the objective of more succinct and rapid identification of minerals in petrographic sections. It should be noted that there are many variables in the identification of minerals, such as: highly altered, fractured grains, with high absorption and difficulty for the observer in collecting and interpreting the characteristics of the mineral. When carrying out a quick and direct identification, some characteristics require greater caution, such as optical character and signal, birefringence, pleochroism, and cleavage. Birefringence is often underestimated and left as a supporting factor; however, when analyzing a mineral with a quartz accessory that provides a delay of 530 nm, it will present 3 colors (extinction, addition, and subtraction), this colors for each value from birefringence are not tabulated in books (Henrich 1965) (Zukov 1967) (Fujimori and Ferreira 1987) (Kerr 987) (Nesse 20004) (Machado and Nardy 2016) (Frank 2018), then that the analyzer must always check the birefringence value through the addition and subtraction tones.

Table 1, based on the direct identification of minerals (density greater than 2.50 g/cm^3) with a thickness of 0.03 mm, the optical character and sign (conoscopic system) were placed as the first identification step in the table, since when identifying and classifying minerals as uniaxial or biaxial (positive or negative), other analyzes are restricted to a very limited group of grains. A well-designed and interpreted interference figure guarantees excellent precision as part of the identification of a mineral and for this, the lower the absorption of the mineral in the polarized light system and the less zoned it is, the more the interference figure will be visible and, therefore, the interpretation will be more accurate. To identify the optical signal, the quartz accessory was used, which allows for a delay of 530 millimicron (Henrich 1965) (Wahistrom 1969) (Bloss 1999) (Nesse 2004).

Table 1 Birefringence table for identifying heavy minerals in thin sections.

Character and optical signal	Colors (quartz accessory)	Birefringence	Pleochroism	Most relevant characteristic	Mineral
Bi +	Vd - Am /Vd – Cz	0.025-0.037	Pleochroism: absent - weak (green)	Extinction: 15 ° to 20 ° (oblique)	Cummingtonite
Bi +	Vd – Am /Am - Alrj	0.020-0.022	Pleochroism: absent	Cleavage - perfect	Amblygonite
Bi +	Vd – Am /Am - Alrj	0.019-0.022	Pleochroism: weak	Cleavage - good	Brazilianite
Bi +	Vd – Am /Am – Alrj	0.024-0.032	Pleochroism: weak (green)	Extinction: 37 ° to 44 ° (oblique)	Diopside
Bi +	Rs – Lrj/ Am – Alrj	0.031-0.040	Pleochroism: strong (blue)	Cleavage: perfect	Lazulite
Bi +	Vd – Am/ Am – Alrj /Az – Cz / Azesv - Cz /Vd – Cz /Rs – Lrj /Vd – Vd	0.021-0.033	Pleochroism: weak	Extinction: 0 ° (straight)	Prehnite
Bi +	Vd – Am /Am – Alrj / Az – Cz/ Alrj – Cz /Rx – Cz /Azesv - Cz /Vd – Cz / Rs – Lrj	0.021-0.030	Pleochroism: absent - weak	Extinction: 22 °- 45 ° (oblique)	Pigeonite
Bi +	Rx – Cz /Az – Cz /Vd – Cz	0.019-0.024	Pleochroism: weak (blue)	Pleochroism: weak (blue)	Euclase
Bi +	Alrj – Cz /Rx – Cz/ Vd - CZ	0.013-0.028	Pleochroism: medium	Extinction: parallel in longitudinal sections	Anthophyllite
Bi +	Az – Am /Azesv - Cz	0.010-0.018	Pleochroism: medium (green to orange)	Extinction: Parallel	Enstatite
Bi +	Az – Am/ Am - Cz/ Az - Am	0.001-0.014	Pleochroism: absent	Extinction: 2 – 3 degrees (parallel)	Serpentine
Bi +	Am – Cz / Alrj - Cz	0.011-0.014	Pleochroism: weak (red)	Extinction: Low angle oblique	Rhodonite
Bi +	Am – Cz / Alrj - Cz	0.011-0.015	Pleochroism: strong	Extinction: parallel with the largest axis (usually)	Staurolite
Bi +	Az- Am / Am – Cz /Alrj - Cz	0.008-0.011	Pleochroism: weak - medium	Extinction: parallel or straight	Topaz
Bi +	Alrj – Cz/ Rx – Cz/ Vd - CZ	0.014-0.027	Pleochroism: strong	Extinction: 23 ° to 27 ° (oblique)	Spodumene
Bi +	Am – Cz / Alrj – Cz/ Vd - Az Azesv - Cz	0.012-0.020	Pleochroism: absent	EXTINCTION: 30 ° to 44 °	Jadeite
Bi +	Az- Am / Am – Cz /Alrj - Cz Vd - Az	0.008-0.014	Pleochroism: weak	Relief: High Positive	Chrysoberyl
Bi +/-	Az – Am /Am – Cz/ Alrj – Cz	0.005-0.014	Pleochroism: absent	Gemination Carls Bad/Baveno (K-Felspar; Negative Biaxial), Albite/ Pericline (Plagioclase; Positive/ Negative Biaxial)	Feldspars
Bi +/-	Rs – Lrj /Vd - Vd	0.033-0.045	Pleochroism: weak	Relief: High Positive	Olivine
Bi +/-	Rx – Cz /Az – Cz /Vd – Czcl / Vd – Cz/ Rs – Lrj	0.014-0.035	Pleochroism: weakness	Cleavage in two directions with angles of 56° and 124 degrees	Hornblende
Bi +/-	Vd – Am /Am – Alrj /Rs – Lrj / Rs - Rx	0.026-0.032	Pleochroism: medium	Extinction: 35 ° to 48 ° (oblique)	Augite
Bi -	Am - Az	0.008-0.010	Pleochroism: strong	Extinction: parallel in longitudinal sections	Andalusite
Bi -	Am - Az / Vd - Cz	0.010-0.012	Pleochroism: strong	EXTINCTION: Oblique in the cleavage and contour traces	Axinite
Bi -	Rs – Lrj /Rs - Rx /Vd – Vd / Vdcl – Alrj / Am – Rx / Rs – Az / Rs - Vd	0.033-0.059	Pleochroism: strong	EXTINCTION: Parallel to the cleavage direction	Biotite

Table 1 Cont.

Character and optical signal	Colors (quartz accessory)	Birefringence	Pleochroism	Most relevant characteristic	Mineral
Bi -	Alrj - Cz	0.0016-0.017	Pleochroism: strong (blue)	EXTINCTION: Oblique, 30º angle with the C crystallographic axis	Kyanite
Bi -	Az - Am	0.008	Pleochroism: weak	Relief: Moderate	Danburite
Bi -	Alrj – Cz /Rx – Cz /Az – Cz / Azesv - Cz /Vd – Cz / Vd – Am /Am – Alrj /Rs - Lrj	0.015-0.037	Pleochroism: strong	Extinction: Parallel	Dumortierite
Bi -	Alrj – Cz /Rx – Cz /Az – Cz / Azesv - Cz /Vd – Cz / Vd – Am /Am – Alrj /Rs – Lrj/ Rs - Rx /Vd – Vd	0.019-0.045	Pleochroism: strong	Extinction: parallel to the elongation	Epidote
Bi -	Vd – Am/ Vd – Cz / Vd – Am / Am – Alrj /Rs – Lrj/ Rs - Rx / Vd – Vd	0.028-0.045	Pleochroism: weak	Extinction: parallel to the cleavage, rarely with an angle of 5	Phlogopite
Bi -	Rs – Lrj /Rs - Rx /Vd – Vd / Vdcl – Alrj	0.033-0.043	Pleochroism: weak	2V angle: 70 ° to 90 °	Grunerite
Bi -	Vd – Cz /Vd- Czcl	0.026-0.028	Pleochroism: weak	Cleavage: in two directions, angles of 56º and 124º	Tremolite
Bi -	Vd - Czcl	0.027	Pleochroism: Absent	The maximum extinction angle is less than 30 °	Nephrite
Bi -	Rs – Lrj /Vd - Vd	0.035-0.042	Pleochroism: weak	EXTINCTION: Parallel to the cleavage direction	Muscovite
Uni -	Az - Am	0.002-0.008	Pleochroism: strong (blue), weak	Extinction: Parallel	Apatite
Uni -	Az – Am /Az,Vd – Cz	0.005-0.010	Pleochroism: weak	Extinction: parallel in longitudinal sections	Beryl
Uni -	Az,Vd – Cz	0.008-0.009	Pleochroism: Absent	Relief: High Positive	Corundum
Uni -	Az – Am / Az,Vd – Cz / Vd – Cz/ Vd - Czcl	0.001-0.025	Pleochroism: weak	Relief: High Positive	Idocrase
Uni -	Am – Az / Alrj – Cz /Rx – Cz / Az – Cz /Azesv - Cz /Vd – Cz / Vd – Am /Am – Alrj /Rs – Lrj /Rs - Rx /Vd – Vd / Vdcl – Alrj / Am – Rx / Rs – Az / Rs - Vd	0.008-0.080	Pleochroism: strong	Extinction: Parallel	Tourmaline
Uni +	Alrj – Cz	0.0017	Pleochroism: weak	Relief: High Positive	Phenakite
Uni +	Az,Azesvd – Am	0.008-0.010	Pleochroism: weak	Extinction: Parallel	Quartz
Uni +	Am – Cz / Alrj – Cz	0.014-0.016	Pleochroism: Medium (Yellow)	Relief: Very high positive	Scheelite
Uni +	Am – Az / Alrj – Cz /Rx – Cz / Az – Cz /Azesv - Cz /Vd – Cz / Vd – Am /Am – Alrj /Rs – Lrj /Rs - Rx /Vd – Vd / Vdcl – Alrj / Am – Rx / Rs – Az / Rs - Vd	0.002-0.062	Pleochroism: weak	Relief: Very high positive	Zircon

Subtitle: Alrj = Yellow orange; Am = Yellow; Amcl = Light yellow; Az = Blue; Azesv = Green Blue; Cz = Gray; Lrj = Orange; Rs = Pink; Rx = Purple; Vd = Green; Vdcl = Light Green.

Using the same accessory mentioned above, it is possible to determine the birefringence of the mineral (orthoscopic system) and thus what the addition and subtraction colors will be, what colors are not tabulated in the books, as well as what the purple hue that appears in all minerals when extinguished is; however, the latter was not used in the table, as all endangered grains will display this color when viewed with the accessory. By tabulating all the addition and subtraction colors of the main minerals, the analysis time is greatly reduced when the birefringence colors are combined with other selected characteristics present in the table (Table 1). Minerals such as corundum, which have a birefringence of 0.008, exhibit gray and yellow colors in slightly variable tones, as their double refraction very rarely deviates from this value. Some grains can display the same addition and subtraction colors such as zircon, corundum and topaz, but the optical character and signal are extremely useful in cases like this, and when these are not enough the other characteristics in the table can be used.

In order to ensure a more accurate and faster identification, the pleochroism of the minerals, and some very specific characteristics of the mineral, such as extinction angle, cleavages, etc., are also listed in the table. These characteristics are acquired in polarized light (without the nicols being crossed). The pleochroism of the specimens has been classified in the table as absent, weak, medium, or strong to make the identification of the grains even more certain. This classification is due to the degree of mineral absorption, in which the darker the color of the mineral, the greater the absorption (Zukov 1967) (Fujimori and Ferreira 1987) (Klein and Dutrow 2012). After evaluating the optical character and signal, colors of addition and subtraction of birefringence and pleochroism, a fourth characteristic was selected, which was preferably specific and easy to visualize in the mineral, such as extinction angle, number of cleavages and direction, relief, and angle 2V.

After completing this identification process using the aforementioned methodology, any chance of doubt regarding the identification of the mineral is eliminated. Therefore, the table facilitates the description of minerals. In addition to the aforementioned methodology having been used previously in a reduced version in the classroom in the optical mineralogy discipline, it is clearly very didactic and efficient, making the identification of the 42 most commons minerals faster and more reliable.

4 Conclusion

Through the analyzes and tests carried out, it was possible to develop a table that allows for the identification of minerals faster, more direct and efficient, by focusing on the most efficient characteristics and using the addition and subtraction colors related to the birefringence of minerals. The table consists of 42 most common minerals (density greater than 2.50 g/cm³) found, which are very relevant due to the importance attributed to their study and the interpretation of results in different segments related to economic geology, stratigraphy, sedimentology, and geochronology.

It is known that the presence of value, or the oscillation of the birefringence of minerals in books, is common practice. However, the colors they presented with the quartz accessory (530 millimicron) are not tabulated, what makes this table a differential. The compilation of this data allows for primary identification or for simpler questions about the identification of the mineral. Furthermore, the identification through this table is also more accurate as it has updated birefringence values of the various minerals. Due to its ease and precision of use, the table can be used by researchers, professionals, and students.

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Author contributions

Isaac Gomes de Oliveira: writing – original draft; funding acquisition; investigation; methodology; project administration; visualization; validation. **Marcelo Menezes Diniz Madruga:** software; writing - review and editing; corresponding author. **Isabelly Maria Maia Ferro:** software; writing - review and editing. **Lucilene dos Santos:** supervision; validation. **Tereza Falcão de Oliveira Neri:** supervision; validation.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature.

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