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Editorial

Editorial for Special Issue "Colours in Minerals and Rocks"

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Colour is one of the most eye-catching properties of some minerals and rocks. A wavelength-dependable absorption coefficient is responsible for colours in minerals. Selective absorption of a certain light wavelength by a mineral usually relates to electronic processes, such as crystal field transitions within a chromophore element and charge transfer transitions between elements. The colour-bearing elements can be essential to the mineral composition (idiochromatic minerals) or they can just play an occasional role as impurities (allochromatic minerals), along with other sporadic sources of colour, such as colour centres associated with structural defects. Finally, in other cases colour is the result of processes at a higher dimensional scale as in the case of exsolutions or mineral and fluid inclusions.

Colour is a vast subject with conceivable intersection with almost any branch of mineralogy and its related sciences. The goal of a Special Issue devoted to this topic cannot pretend to group exhaustively all the possibilities of mineralogy-related research based on this vast subject. When the present issue was projected, we envisaged some of the possible research topics associated with the concept of colour, such as gems, pigments, coloured glazes and glasses, decorative building stones, mosaics, colourful rock formations, and, of course, particular colours and chromatic effects in minerals. It has been very exciting to confirm that the contributions that constitute the Special Issue deal with our anticipated topics, although some unexpected themes have also emerged.

Six papers within this Special Issue deal with colour classification connected to studies in the field of gemstones. These contributions reflect how colour is a crucial property within this field and that precise quantification is required to evaluate the quality of the gems. The paper by Chow and Reyes-Aldasoro [1] explores the use of several machine-learning algorithms based on training using images of different gems. The features that are extracted from the images were the colours (histograms of the colour coordinates of the pixels defined in a given colour space) and texture analyses operators. The authors worked with 68 different classes and achieved automatic gemstone classification with high accuracies (~70%), demonstrating superior rates of success compared to trained gemologist macroscopic classification and particularly providing faster classification. Artificial intelligence tools are becoming increasingly widespread and in the contribution by Jiang et al. [2] they were also used although in this case to undertake intra-class distinction instead of inter-class. The authors started from colourimetric measurements of different samples of green chrysoprase performed in different backgrounds. A clustering algorithm was used to classify the samples into automated colour grades determining also the most effective Munsell background for colour grading. Colourimetric measurements, using a spectrophotometer, appear to be the standard way to quantify the colour of gemstones and CIELAB the common colour space employed. This type of measurements was also applied in [3] to characterize several bluish-green polished serpentinites, and a colour appearance model was used to predict chromatic values under different conditions, this allows the selection of the best conditions to present and classify the different specimens of the gemstones. In addition to colourimetric measurements, colour data can be also acquired from a computer

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vision system, i.e., a camera that captures images such in [1]. In the contribution by Zhang and Guo [4], the authors compare the performance of a low-cost computer vision system (industrial camera) and that of the common colourimetric measurements to characterize 111 samples of jadeite-jade covering a wide range of colours. In both cases, the acquired data were expressed in CIELAB space and although the corresponding colour variables (L*, a*, b*) differed, they showed high values of coefficient of determination ($R^2 > 0.9$). Therefore, the authors established that computer vision can be used to predict colourimetric results with lower costs and operation constraints. Finally, another approach to colour characterization is to use it as an additional proxy along with other types of data. In the paper by Wang and Shi [5], macroscopic colour evaluation using the Munsell colour theory was correlated to chemical and mineralogical characterization to distinguish green nephrites (amphibole-based jade) from the Manas County (China) and Eastern Sayan (Russia). In the paper by Díaz-Acha et al. [6], colourimetric measurements of archaeological and geological samples of gemmy phosphates (variscite and turquoise) from the Neolithic mines of Gavà (Spain) supplemented other characterization proxies, a correlation between Cr^{3+} and gemmy variscite was suggested and the chromatic effect of intimate natural mixtures with other minerals was also established.

Particular chromatic effects are also a topic potentially covered by the present Special Issue. The paper by Qiu and Guo [7] explores the causes of the "alexandrite effect" in pyrope-spessartine garnets that change from green colour in the presence of daylight to purplish red under incandescent light. The main cause of the colour change is the presence of a UV-Vis spectra with two zones of transmittance in the red and blue-green regions divided by a zone of absorbance where appear the absorption bands of Cr^{3+} and V^{3+} (at around 574 nm). Colour matching functions were used to calculate the colour parameters influencing garnet colour-changing under different light sources. Daylight has a higher spectral energy distribution in the blue-green zone than incandescent light, which causes the garnet to appear green. In contrast, incandescent light has higher spectral energy distribution in the red zone, which causes the colour-changing garnet to appear purple-red. Another contribution [8] explores the causes of the green colour and gold hue of obsidian (natural volcanic glass) of Sierra de las Navajas (Mexico). As already previously hypothesized, green is possibly linked to presence of Fe^{2+}. However, differences in colour intensity cannot be attributed to the presence of microcrystals; they rather relate to the occurrence of vesicles of different size, shape, and orientation. Lighter green colours appear in highly vesiculated surfaces, whereas non-vesiculated samples are darker. Additionally, a high concentration of coarse vesicles provides a uniform golden hue.

Another field considerably represented in the Special Issue is colour characterization as part of archaeometric studies in archaeological and material heritage research. Along with the aforementioned contribution on the Neolithic variscite mines [6], six other contributions fit within this research domain. The archaeometric studies gathered in this Special Issue deal with colour studies on a variety of supports, including mineral, stone, glass, painted murals, and baked clay (pottery and bricks). In her contribution, Travé Allepuz [9] presents a study of biotite in pottery pastes. Forty greyware pottery samples from medieval Catalonia (Spain) were analysed focusing on the transformations in colour, texture, and optical properties of their biotitic inclusions for firing temperatures above 800 °C. She concluded that at temperatures between 800 and 850 °C, small biotite laths start separating as a result of interlayer K depletion and >900 °C or above, the effect is generalized to inclusions of all sizes along with a significant darkening and accompanied by a complete loss of pleochroism above 950 °C. In another contribution that relates to baked clay, Pérez-Montserrat et al. [10] characterize 16th century bricks from the city walls of Padova (Italy). The bricks exhibit beige, pale, and dark red colours and the authors demonstrate their correlation with compositional and textural features. Beige colour relates to Mg- and Ca- (carbonate)-rich illitic clays fired at temperatures of over 900 °C forming calcium-aluminosilicates and calcium/magnesium silicates (high-temperature phases), whilst reddish hues relate to illitic clays richer in Fe and fired at lower temperatures (850–900 °C) in such a way that free iron forms hematite. Colours related to other material supports are discussed by Casas et al. [11] in one example of the rare comprehensive studies of both stone and glass tesserae from a polychrome mosaic. Thirteen types of tesserae from the so-called Circus Mosaic (4th century AD, Barcelona, Spain) were studied using colourimetry and other analytical techniques. The authors show that stone tesserae (mainly limestones) were used for white, black, grey, red, brown, and yellow hues and the actual geological provenance of four stones could be unveiled. Only three types of tesserae were identified as glass, those bearing uncommon colours in natural rocks. Interestingly, the bluish were made with Sb-based opacifiers and dissolved Cu and Co were responsible for the colour, in contrast in the green glass tesserae Sn-based opacifiers were found and the colour was created by the mixture of blue (dissolved Co) and the yellow $PbSnO_3$ pigment. Another particular study that regards a stone material (marble) is included in the Special Issue, the contribution [12] deals with the *Forma Urbis Romae*, a monumental map of Rome (3rd century AD) carved into Proconnesian marble slabs, originally attached in the *Templum Pacis*, Rome. The map is currently incomplete and in a fragmentary condition. Its reconstruction is an archaeological challenge that the authors attempt using the variations of cathodoluminescence (CL) colour. This is the colour that appears after exciting the marble sample with an electron beam and it is worth to highlight the innovative use of CL to reconstruct a fragmented monument instead of its common application for provenance studies of heritage marbles. Finally, two more papers deal with pigments on painted murals. On the one hand, the paper by Moon et al. [13] tackles a standard pigment characterization using a number of analytical techniques. The authors determine that the ancient pigments that constitute the Afrasiab murals (a rare example of Sogdian art from mid-7th century AD, Uzbekistan) were lazurite (blue), cinnabar (red), and amorphous carbon (black), and these were applied on an undercoat made of gypsum plaster. On the other hand, another study [14] deals with the characterization of the impurities in Cu-based (green and blue) paint layers from three historical wall paintings (in Poland) situated in the vicinity of copper ore deposits. The authors hoped to find data to link the pigments to the ore deposits. However, they conclude that, with the presently available data, impurities are better used to group paintings than to trace the provenance of the pigment.

Pigments, are also tackled in the paper by Travé et al. [15] but here in a purely geological context. Karst fills of different colours (red, pink, orange, ochre, and greenish) were investigated in the onshore Penedès Basin and offshore València Trough (Spain). The different colours are attributed to fluctuations in the water table, which control the Eh/pH conditions in the karst system. The reddish colours (due to goethite) reflect low water table levels and oxidising episodes, and orange and ochre ones (related to Fe^{2+} contained in dolomite and clays) reflect high water table levels and more reducing episodes. The greenish colours of fills could be related to fluctuations in the Fe^{3+}/Fe^{2+} ratio.

All of these examples show that colour characterization is an important research topic in mineralogy with important implications, particularly within the fields of gemmology and archaeometry but also present in many other research fields. It is our hope that this Special Issue would be a valuable and significant resource for anyone interested in colour studies and that the papers that contain could serve as inspiring examples for further research on the topic.

Conflicts of Interest: The authors declare no conflict of interest.

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