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Chrysoprase – history and present

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Abstract

The authors present the history of chrysoprase discovery and the progress of knowledge about this material over the millennia, based on the extended review of world literature. Tracing the oldest archaeological artifacts from before 9,000 years, the lens of history turns on a stone that has not been properly identified mineralogically for centuries. In the 1830s, chrysoprase was finally included into the chalcedony group and its green color was associated, very correctly, with nickel compounds dispersed in its structure. After all, the most current mineralogy of chrysoprase is presented on the basis of the results of modern analytical studies. These data clearly indicate that chrysoprase is a mixture of several SiO_2 polymorphs with varying degrees of structural order (opal, chalcedony, moganite, quartz). This radically changes the previous taxonomy of chrysoprase and its position in current mineralogical and petrographic systematics.

Keywords: chrysoprase, history, mineralogy, terminology

1. History

According to American archaeologist J.M. Kenoyer, chrysoprase (*chrysophrase* or *chrysoprasus*) has probably been already known at the turn of the late 8th/early 7th millennia BC. This is evidenced by radiocarbon-dated archaeological artifacts found, among others, in the Mehrgarh settlement, in the Indus Valley, on the Kacchi Plateau, in the present-day Baluchistan (Pakistan) (Bouquillon, Poirot 1995; Kenoyer 2017). Lots of various objects (necklaces, pendants, headgears, bracelets, rings, and other ornaments as well as votive gifts) made of white and black steatite, calcite, turquoise, carnelian, lapis lazuli, serpentinite, and goethite were also found at that site. These are the relics of an ancient culture dated back to about 7,000 BC, older than the Egyptian and the Sumerian civilizations. Excavations in this area are still continued by Indian, English and American archaeologists (Singh 2008; Chakrabarti 2009; Kenoyer 2017). So far, the exact source of chrysoprase found there has not been identified (Pruthi 2004). Chrysoprase beads were also discovered in the Harappa area, located in the Sahiwal district of the Punjab State (India). The archaeological layers studied there date back to the time span 5,500-2,600 BC (Possehl 2002).

Similarly ancient chrysoprase artifacts came from the Western Asia, precisely, from the areas of present-day Syria, Arabian Peninsula, Egypt, and Mesopotamia. The most important city-state of southern Mesopotamia in the 4th millennium BC was Uruk. Before the World War II and then in the 1980s, it became the target of intensive archaeological excavations. Among numerous stone artifacts, single objects made of chrysoprase were found, as well (Finkbeiner 1991; Moorey 1999). Likewise, old Mesolithic artifacts were found in the Sudety Mts. in Poland (Přichystal 2013). Another example is a Neolithic bead made of chrysoprase, found during excavations in Syria, dated to the late 8th millennium BC (now in the collection of the Metropolitan Museum, in New York). On the other hand, chrysoprase beads and other ornaments made of carnelian, lapis lazuli, and turquoise from the Shakhr-i-Sokhta and the Tepe Hissar workshops (now Iran), discovered and studied in the early 20th century by Hungarian archaeologist Aurel Stein, were dated to the 3rd millennium BC. A group of Italian archaeologists led by Professor Maurizio Tosi also carried out excavations in that area. Their findings indicated that in the ancient times, chrysoprase was relatively rarely used for making ornaments, which explains only the single stone objects of that type found on the examined archaeological sites (Biscione et al. 1974).

Possible source of raw material for ancient sculptors may have been deposits located in the Jebel al-Ma'taradh massif, near the village of al-Ghail, in the territory of the Ra's al-Khaimah emirate (now the member of the United Arab Emirates), discovered by French archaeologists (Charpentier et al. 2017). An exceptionally valuable find was an axe handle made of chrysoprase from the Suhaila 3 site, with a doubly convex facing section and strongly sharpened edges. Chrysoprase artifacts were encountered as far as 300 km from the Jebel al-Ma'taradh. This is significant fact because so far, in the archaeological literature of the United Arab Emirates and the Oman Peninsula, no record has been encountered of chrysoprase and other silica varieties in the area, let alone the existence of the Jebel al-Ma'taradh deposit itself.

In ancient Egypt, from Predynastic times and later, in the Old, Middle and New Kingdoms until the Greco-Ptolemaic and Roman periods, precious and decorative stones were highly valued. Chrysoprase necklace beads from 5,300 BC, originated from very early stage of ancient Egyptian civilization, are some of the oldest archaeological items taken from unnamed tombs in the Upper Egypt (Rapp 2002). It seems that chrysoprase was not a common raw material for manufacturing of small stone artifacts in ancient Egypt due to the lack of local deposits (Aston et al. 2000). However, it was occasionally imported for making the scarabs, especially their specific sepulchral variety – the "heart scarabs". These items were symbols of rebirth after death, a sign of resurrection, therefore, these were placed near the heart of the deceased, under the rolls of bandages with which the mummy was wrapped (Śliwa 2003; Chudzik 2016).

In the surviving Theban manuscripts, dated to the end of the 3rd century AD (i.e., the end of the Ptolemaic-Roman period), in the second part of the so-called "*Stockholm Papyrus*", chrysoprase was mentioned among the 13 stone names given there, together with the recipe for its production: the matrix was the rock crystal, which, together with greater celandine (*Chelidonium majus L.*) and indigo as a dye, were all subjected to thermal treatment (Stawicki 1987). One can only doubt whether the name *chrysoprásios* referred to the green stone we know today. These doubts were expressed, among others, by James A. Harrell in his work on gemstones of ancient Egypt (Harell 2012), as well as by Aston et al. (2000). Such ambiguity regarding certain gems and ornamental stones applies to many other Greek and Roman authors until the modern era, when developments in science and technology allowed for their proper identification and nomenclature.

The most important legacy of ancient Greek literature on the issue of chrysoprase is the book of Theophrastus of Eresos (c. 372-282 BC) "*On the Stones*". This Greek scientist and philosopher was a scholar and friend of Aristotle (384-322 BC), one of the greatest thinkers of ancient Greece. In the heyday of Greek and Roman culture, science was seen as an access to secret knowledge aimed at spiritual and moral perfection, whereas mysticism was intertwined with philosophy and realism. The poetic treatise on stones (*Lapidarium*) by Theophrastus also fits this pattern. It is a unique writing in the Hellenistic period, compared to other such books, referred to by the common term *lithika* (gr. λίθος – stone). Theophrastus did not explicitly mention χρυσοπράσιον (*chrysoprásion*) although, according to Mottana and Napolitano (1997), one could conjecture that he used this term to describe the greenish variety of chalcedony (Greek χαλκηδών – *chalkēdṓn*). At this point, the authors refer the Reader to numerous translations of and commentaries on Theophrastus book (e.g. Meinecke 1805), which is one of the most famous works in the world scientific literature, on a par with *Historia Naturalis* by Pliny the Elder. According to Philipp Hedwig Külb, a respected translator and commentator on Pliny, chrysoprase (*chrysoprasus*) was identified with the golden prazion (*pazion, prasion, prasoides*) (Külb 1856), while according to David Edward Eichholz, it was identical with the plasmas (= praser or prase; *prasius*) (Eichholz 1962). Schönauer (1996), on the other hand, believed that Pliny described chrysoprase as a stone having the color of leek juice with a golden tinge (πράσω χλωρώ).

Since the times of Pliny the Elder (23-79 AD), the knowledge of this stone has been supplemented by new data about its physical (including optical) properties, origin, etc. (see e.g. Gliozzo 2019). In 1652, the first book in English: *A Lapidary on the History of Precious Stones* was published by Thomas Nicols. This author referred to many eminent figures, besides Theophrastus and Pliny, also Anselmus Boëtius de Boodt (1550-1632), Albert the Great (1205?-1280), Andrea Bacci (1524-1600), Girolamo Cardano (1501-1576), and others. All of them mentioned in their works a green, poorly transparent stone, in which it is not difficult to recognize the chrysoprase we know today. In the mineral systematics of Charles Linnaeus (1707-1778), included into *Systema Naturae* (1735), it appeared as a variety of *pseudo-smaragdus*. The author described chrysoprase in quite a detailed way, providing its physical parameters and difficulties in processing, and linked the color to the presence of Fe compounds. In his opinion, this stone occurred within serpentinites in Bohemia (near Turnov) and in the Silesian Principality of Ziębice (now Poland), in the area of Koźmice and Grochów.

A very significant progress in the knowledge of chrysoprase was made by the Swedish chemist Johan Gottschalk Wallerius (1709-1785). In *Systema mineralogicum* (1778), he included chrysoprase into the group of silicates, next to: agates, carnelian, onyx and chalcedony. He also mentioned Silesian chrysoprase (*chrysoprasium münsterbergensem in Silesia*) as a special, precious variety, identifying it with chrysoberyl. Apart from Wallerius, another Swedish chemist and mineralogist Axel Frederik Cronstedt (1722-1765) deserved particular attention. In the book *Versuch einer Mineralogie* (1770), he also classified chrysoprase among siliceous minerals, but included it into the varieties of topaz, together with chrysolite. The same position of chrysoprase was proposed by the Hungarian scientist Giovanni Antonio Scopoli (1721-1788) in his work *Principia mineralogiae systematicae et practicae* (1772) where he referred to Pliny, Agricola and Boetius.

The last decades of the 18th century were a breakthrough in knowledge about chrysoprase. Its chemical composition was finally determined and it was definitely included into the group of SiO_2 minerals. The knowledge about its Silesian origin became common. The green coloration of chrysoprase caused by nickel compounds was first discovered by the German apothecary Martin Heinrich Klaproth (1743-1817), called the "father of analytical chemistry". He was followed by another German mineralogist and chemist Friedrich August Cartheuser (1734-1796) as well as by the French mineralogist and chemist Balthasar-Georges Sage (1740-1824). Both scientists incorporated chrysoprase (*emerald prase, Smaragdpraser*) into the group of ornamental stones. They also provided information about the known deposits of this stone in Bohemia, Silesia and North America. Similarly, the German mineralogist Franz Ernst Brückmann (1697-1753) in his book *Gesammelte und eigene Beyträge zu seiner Abhandlung von Edelsteinen* (1783), described dark green prase (Greek *prason*, German *Prasem*) from Koźmice and Ząbkowice Śląskie areas in the Lower Silesia (Poland).

The systematics of chrysoprase most similar to the currently accepted was provided by Johann Friedrich Gmelin (1748-1804) in the academic textbook *Einleitung in die Mineralogie* (1780), and in his next work *Grundriss der Mineralogie* (1790). This author incorporated chrysoprase into the group of silicates, together with carnelian, onyx, opal, hydrophane, chalcedony and jasper, and placed it between chalcedony opal (*Opalchalcedony*) and prase (*Praser*). Following Klaproth, he also indicated nickel as responsible for the color of this stone. A similar systematics of chrysoprase was provided by the Swedish mineralogist and naturalist Torbern Olof Bergman (1735-1784) in his textbook *Sciagraphia regni mineralis* (1782) and by the Austrian mineralogist Karl Haidinger (1756-1797) in his original classification of minerals (1782), based on both the systematics of Cronstedt and Wallerius, and the latest developments in analytical chemistry of that time. The list of researchers of that period is completed by the Irish chemist and mineralogist Richard Kirwan (1733-1812), author of *Elements of Mineralogy* (1784), for whom chrysoprase belonged to silicates (*Siliceous Genus*), together with amethyst and lapis lazuli.

A new classification system, based on the theory of A.G. Werner, was presented by the German mineralogist Dietrich Ludwig Gustav Karsten (1768-1810) in his academic textbook *Tabellarische Übersicht der mineralogisch-einfachen Fossilien* (1791). The author challenged Richard Kirwan's systematics and grouped chrysoprase (*Krysopras*) with quartz (amethyst, rock crystal, common quartz, prase), chert, chalcedony (common chalcedony, carnelian), after heliotrope and before lydite.

Two well-known persons close the review of chrysoprase literature at the time: Abraham Gottlob Werner (1749-1817) and Johann Gottfried Schmeisser (1767-1837). A.G. Werner, a German scientist known as the "father of geology", created a canon for identifying and classifying minerals based on their external characteristics. He first presented these concepts in the book *Von den äuserlichen Kennzeichen der Foßilien* (Leipzig 1774), and then in an extended version, in the textbook *Oryktognosie oder Handbuch für Liebhaber der Mineralogie*, published in Leipzig, in 1792. After his death, Johann Carl Freiesleben prepared the final version of this systematics supplemented by Werner's notes as *Abraham Gottlob Werner's letztes Mineral-System* (1817). In this compilation, chrysoprase (*Krisopras*) had already found its permanent position in the class of earthy minerals (*Erdiche Foßilien*), in the silica genus (*Kiesel-Geschlecht*), and in the quartz family (*Sipschaft des Q*). J.G. Schmeisser, in turn, ranked chrysoprase as the most precious stone among siliceous minerals. He also developed his own systematics: *A system of mineralogy* (1794), based on Cronstedt's concept and Werner's description of the external features of minerals. Therefore, he placed chrysoprase in the class of earths and stones, as a type of silicate, after chalcedony, onyx, sardonyx, and before aventurine and jasper. Moreover, Schmeisser concluded that chrysoprase position was next to chalcedony, which it most closely resembles.

Ultimately, at the end of the 18th century, European mineralogists accepted without any reservations that chrysoprase is a variety of chalcedony colored with nickel and they also knew its Silesian origin.

2. Mineralogy, origin and accumulations

The name of chrysoprase is related to its color shades, which are a mixture of yellow and green (Greek *khrysos* – gold, *prasinos* – greenish). Based on the latest results of X-ray diffraction (PXRD) as well as infrared (FT-IR) and Raman (FT-RS) spectroscopy methods supported by polarization and electron microscopies, it was found that chrysoprase is not a monomineral material. Instead, it is a mixture (mineral assemblage) of low-temperature SiO_2 varieties: opal, chalcedony, moganite and quartz (for details see: Sachanbiński 1980; Barsanow, Yakovleva 1984; Heflik et al. 1989; Kinnunen, Malisa 1990; Plusnina, Szpila, 1990; Miehe, Graetsch 1992; Graetsch et al. 1994; Origlieri 1994; Gaweł et al. 1997; Göetze et al. 1998; Sachanbiński et al. 2001; Moxon, Rīos 2004; Sojka et al. 2004; Shigley et al. 2009; Graetsch 2011; Hatipoğlu et al. 2011; Jiang, Guo 2021; Jiang et al. 2021). According to Plusnina, Szpila (1990) and Gaweł et al. (1997), the transformation of low-temperature silica took place in several stages, in which gradual changes proceeded of its structure, recrystallization degree and crystal morphology. In such silica transformation process, the following succession can be distinguished:

1/ Opal A (amorphous) – opal CT (cristobalite-tridymite) series;
2/ Opal CT – chalcedony series;
3/ Chalcedony – opal CT series;
4/ Chalcedony series;
5/ Chalcedony – moganite – quartz series.

All these silica phases are found in chrysoprase, but in various proportions. Due to such a complex mineral composition of chrysoprase, its hardness should be replaced by the grading resistance (GR) parameter, as proposed by Hänni et al. (2021).

Chrysoprase shows varying degree of green color saturation (from light to dark green) (Fig. 1). After the years of research, it was found that the color of this stone is related to the dispersed nickel-bearing minerals of "kerolite-pimelite" series (Sachanbiński 1985; Heflik et al. 1989; Natkaniec-Nowak et al. 1989; Nagase et al. 1997; Sachanbiński et al. 2001; Sojka et al. 2004; Witkowski, Żabiński 2004; Čermakova et. al. 2017). In addition, the color of chrysoprase is also influenced by willemseite of the pyrophyllite-talc group (Vasconcelos, Singh 1996) and gaspéite – a nickel-rich variety of calcite (Henn, Milisenda 1997; Graetsch 2011). It turns out, however, that the concentrations of NiO in chrysoprase vary in particular deposits around the world: the highest contents (5.631 wt.%) were found in Australian chrysoprase (Jiang et al., 2021) whereas the lowest values (0.004-1.23 wt.%) were encountered in Polish stones from Szklary near Ząbkowice Śląskie, in Lower Silesia (Figs 1, 2). Comprehensive studies of Australian chrysoprase using many modern analytical methods, including transmission electron microscopy (TEM), X-ray fluorescence (XRF), UV-Vis spectroscopy, Raman spectroscopy (FT-RS) and colorimetric analysis showed that, in addition to nickel, the brightness and the shades of green color of these stones are influenced by the sum of chromium and iron. Chrysoprases with a low degree of crystallinity contain more Ni and their green color is more intense (Jiang, Guo 2021; Jiang et al. 2021). Moreover, it was found that the green color in chrysoprase appears already at the content of only about 0.05 wt.% NiO (Ostrowicki 1965). Interestingly, apart from nickel and the aforementioned chromium and iron, many other trace elements (e.g. Sr, Ba, Ag, As, Be, Co, Cu, Pb and others) and rare earths (e.g. Ce, Nd, Sm, Eu, Tb, Tm, Yb, Lu) may also be present in chrysoprases. This is indicated by the results of study on emerald-green chrysoprase from Haneti-Itiso (Tanzania) provided by Kinnunen and Malisa (1990).

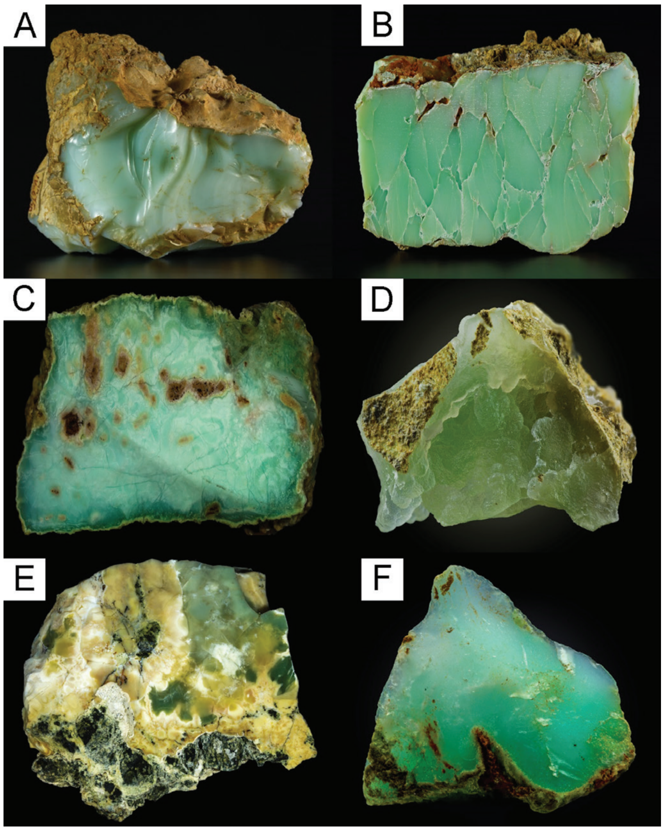

Figure 1. Different color varieties of chrysoprase from Lower Silesia (Poland): A – opal chrysoprase (prazopal), Szklary; B – light green chrysoprase, Szklary; C – matrix chrysoprase, Wiry; D – botryoidal chrysoprase, Szklary; E – matrix chrysoprase, Szklary; F – chalcedony chrysoprase, Szklary. Photos by P. Rachwał.

Jiang et al. (2021) conducted a color assessment of the analyzed Australian chrysoprases using the Munsel N9.5 background and fluorescent lamp (correlated color temperature of 6,504K) and a special affinity propagation (AP) clustering algorithm for processing the obtained measurement results. By determining the noticeable differences in the color of individual samples and the cluster centers (AP) they classified the chrysoprase colors into the five groups: Fancy Light, Fancy, Fancy Intense, Fancy Deep and Fancy Dark. Moreover, Jiang et al. (2021) proposed the application of this classification method also to other green stones, e.g. emerald, jade and tourmaline.

Chrysoprase is also translucent to various degrees, as is chalcedony, which explains why it has been classified for many years as a colorful variety of this mineral. The lack of transparency of chrysoprase is due to its microporosity (pore diameters from 0.03 to 10 µm),

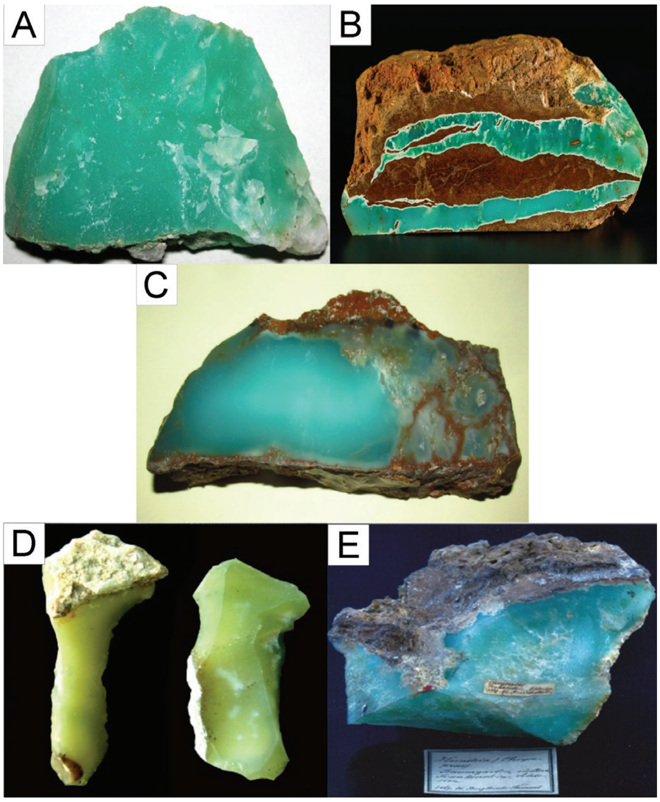

Figure 2. Chrysoprase from selected occurrences in the world: A – Australia. Photo by J. St. John, 2018, Wikimedia Commons; Creative Commons Attribution-Share Alike 4.0 International license; B – Tanzanian emerald green chrysoprase. Collection of the Mineralogical Museum of the University of Wrocław. Photo by P. Piotr Rachwał; C – Sarykul-Boldy, Kazakhstan. Collection of the Fersman Mineralogical Museum of Fersman in Moscow; D – Neolithic chrysoprase blade, Suhaila, Ras al Khaimah Emirate. Photo by V. Charpentier; E – The oldest specimen of chrysoprase from Braszowice, Lower Silesia, found in 1869. Mineralogical Museum of the University of Wrocław. Photo by P. Rachwał.

observed in SEM images, as well as to the presence of H_2O particles located in the internal defects (Jiang et al. 2021).

Chrysoprases derived from various deposits around the world reveal a wealth of mineral, structural and genetic varieties (Fig. 2). In weathering crusts developed on ultramafic rocks, chrysoprases were formed as a result of transformation of silica gel into minerals from the SiO_2 group. As previously mentioned, individual SiO_2 polymorphs are present in different proportions in chrysoprases and interpenetrate themselves. Moreover, these show very diverse microstructural forms, e.g. fibrous, radial-fibrous, spherulitic (globular), checkerboard-like, mosaic, rosette and mixed (Sachanbiński 1985). Such variable microstructural forms are accompanied by a diversity of habits and sizes of mineral individuals. Detailed recognition of the internal structure of chrysoprases requires the application of comprehensive mineralogical tests (e.g. PXRD, FT-IR, FT-RS – see Sachanbiński et al. 2001), mainly in order to find out the degree of crystallinity of individual components from the SiO_2 group (Plusnina, Szpila 1990; Gaweł et al. 1997). This allows us to distinguish a number of different structural varieties of chrysoprase, ranging from chalcedony chrysoprase to opal chrysoprase, called *prasopal* (Sachanbiński 1980, 1985). These varieties differ not only under the microscope but also macroscopically, showing, among others, different colors, fractures and glosses. Moreoever, chrysoprase color is more intense when: (i) the degree of structural order (crystallinity index) of the components is lower, (ii) the nickel content is higher and (iii) the specimens reveal higher microporosity and more structural defects. According to Graetsch (2011), the MN index (Murata-Norman 1976) for chrysoprase from Haneti (Tanzania) is 8.7, for the Silesian chrysoprase it is 9.7 and for the Australian stones the average MN value is 0.7.

From the gemological point of view, purity plays an important role in the qualitative assessment of any raw material, which considers both the quantity and the quality of mineral and organic intergrowths, and various types of internal defects (e.g. microcracks, pores, etc.). In the case of chrysoprase, the studies reported on various types of fluid inclusions, usually single and/or two-phase, syn- and epigenetic, and hosting solid, liquid, and/or gaseous phases (Kozłowski, Sachanbiński 1984). Predominant are mineral intergrowths, which play an important role in genetic considerations, being a specific proof of the environment of chrysoprase formation and the subsequent processes of their transformations. The most important are clay minerals mentioned above, which influence the color of chrysoprase. In turn, liquid and gas inclusions play a crucial role in thermobarometric tests, because on their basis the temperature of mineralizing processes can be determined. Studies of fluid inclusions together with stable isotope analyzes, especially for $\delta^{18}O$, have shown that chrysoprases could also be formed with the participation of hydrothermal solutions (Miljević et al. 1994; Skrzypek et al. 2003; Hatipoğlu, İlbeyli 2015).

As mentioned above, chrysoprase is genetically related to ultramafic rocks (peridotites, dunites) and transformed members of ophiolite complexes (serpentinites), where it forms interesting color varieties with opal (*prasopal*). In Europe, the earliest known sources were Polish chrysoprase deposits in Koźmice, Grochowa and Szklary near Ząbkowice Śląskie areas (Lower Silesia) (Fig. 3). The discoverer of Silesian chrysoprase was Johann Gottlob Lehmann (1719-1767), who personally visited the open-pit mines in the Koźmice area and described from there the four color varieties of this stone (Lehmann 1761). Ultimately, Lehmann introduced the term *chrysoprase* into the world scientific literature. It was not until the 19th century that chrysoprase deposits were discovered in India (Hindustan), and in the USA (California, Oregon). At the beginning of the 20th century, the new deposits were found in Australia (Marlborough Creek in Queensland and several sites in New South Wales, South Australia and Western Australia) and later on in Russia (Ural), Kazakhstan, Myanmar (Mandalay, Sagaing), Indonesia (Java, Celebes), Serbia and Kosovo (Glavica, Drevnica), Turkey (Biga-Çanakkale, İkizce-Bilecik, Sivrihisar-Eskişehir, Oltu-Erzurum, Savur-Mardin),

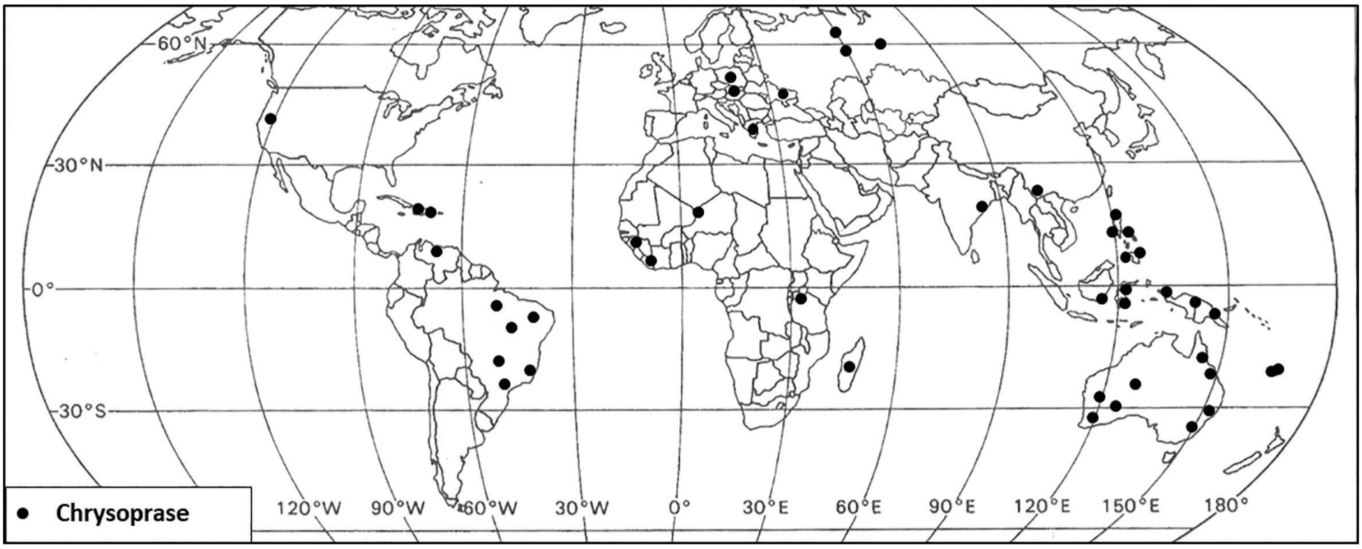

Figure 3. Map of chrysoprase occurrences in the world. Prepared by M. Sachanbiński.

Argentina (Andalgalá, Catamarca), Brazil (Central-West Region, Northeast Region, Pará), Peru (Ayacucho), South Africa, Tanzania, Namibia, Ethiopia and Madagascar. In the first decade of the 21st century, chrysoprase deposits were also discovered in the United Arab Emirates (Ras al-Khaimah), Portugal (Branca, Albergaria-a-Velha, Aveiro), Spain (Andalusia) and Bulgaria (Rhodope Mountains). In many of the above-mentioned locations, the green stone has already been known since the Antiquity but only now these occurrences have been properly described and studied.

3. Chrysoprase as a gemstone

The chrysoprase market has changed over the centuries, along with the discovery of more and more accumulations, the growing demand from craft workshops, the fashion trends, etc. A special advantage of this stone was and still is its color, which is alleged to have a positive effect on humans associated with the joy of life and the hope for a better future (alike the blue color). In color therapy, green is supposed to trigger positive emotions in human's mind, to soothe and to facilitate the relax. Homogeneous, intense, grass-green (emerald-green) or bluish-green shades of chrysoprase (*chrysoprásios*) were previously compared to the color of emerald (*smaragdos*), i.e., the noble variety of beryl (*béryllos*), already known in the Ptolemaic-Roman period of ancient Egypt (about 3rd century BC), as well as to turquoise and amazonite.

Currently, chrysoprase is a green stone of high decorative value, sought after on the jewelry market. Both the raw specimens and the cabochons are valued, the latter especially when crafted from pure, homogenous raw-material. Commonly, chrysoprase is also used to make various fancy forms, e.g. pears (*pendeloque*), hearts, drops, spindles (marquees), etc. Sometimes, chrysoprase cabochons are faceted, surrounding the edge of the stone with two or three rows of triangular facets, or covering with them the entire cabochon surface. Currently, a rosette and a chessboard patterns are in demand among the various types of faceted cabochon cuts. In the catalogs of various jewelry companies, one can find both the old and the contemporary, gold and silver pieces, in which chrysoprase is the only decorative element, or it is accompanied by other stones, e.g. green garnets or even by amber. Particularly high prices are achieved by the Art Nouveau and the modernist jewelry from the turn of the 19th and 20th centuries. Ancient gems (cameos, intaglio) carved in chrysoprase or chrome chalcedony (sometimes called Cr-onyx) very rarely appear on the antiquarian market. Although the prices of such pieces are very high, they always find willing buyers.

Chrysoprase was already used in the decorative arts of ancient Rome and medieval Europe (Sachanbiński 1980; Evangelista et al. 1992). Many chrysoprase artifacts discovered over the years during archaeological works are now in world museum collections as well as in the hands of private lovers and collectors of stones (Figs 2, 4). The ennoblement for the Silesian chrysoprase is placing it in the royal crown – a masterpiece of medieval goldsmithing, found in 1985, in so-called "treasure from Środa Śląska" (Poland) (e.g. Girulski, Sachanbiński 2018). Chrysoprase is used also as a luxury cladding and inlay stone in ebenistics, in Florentine (*pietra dura*) and Roman mosaics, as well as for the production of small stone accessories. Real masterpieces, made also of chrysoprase, came from the jewelry workshop of Peter Carl Fabergé (House of Fabergé), from the time of Russian Tsar Alexander III Romanov. These were made in the Genoese style of gold or silver jewelry, decorated with enamel and colored glass. In modern products, chrysoprase, most often surrounded by diamonds and set in white or yellow gold, platinum and silver, is used by world-famous manufacturers to make jewelry for heads of the states, business elites and movie stars. The most famous jewelry designers include Luis François Cartier (1819-1904) and Suzanne Belperron (1900-1983), Aldo Cipullo (1936-1984), Donald Claflin (1935-1979), Tony Duquette (1914-1999), Georg Jensen (1866-1935) and David Webb (1925-1975). Following the history of chrysoprase in various cultural circles over the centuries, one can also find its presence in

Figure 4. Chrysoprase in the world of art: A – element of the frame (left side) of the icon *Holy Trinity* by Andrei Rublev, irregular chrysoprase cabochon between the images of Blessed Sergey Radonezhsky and the martyr Georgyi. Trinity Lavra of St. Sergius in Sergiyev Posad, Russia; B – gothic female wedding crown (early XIVth c.) from the so-called "Środa Śląska Treasure" with 193 stones (almandines, pyropes, pearls, sapphires, emeralds, and chrysoprase) set on the rim made of gold-silver alloy with copper admixture. National Museum in Wrocław, Poland. Inv. No. V-2333; C – pair of bracelets set with stones (garnet, amethyst, emerald, pearls, chrysoprase) as well as glass and enamel from a gold treasure found in Olbia (Ukraine), late 2nd / 1st century BC (Greco-Roman period), 5.3 x 7.9 cm. Walters Art Museum, Baltimore. Inv. No. 57.375-6; D – brooch "Dragonfly-woman" (1897-98) (gold, chrysoprase, chalcedony, moonstones and diamonds, enamel). René Lalique collection. Calouste Gulbenkian Museum, Lisbon, Portugal. Photo Sailko / Wikimedia Commons; Licence: CC BY 3.0.

painting, sculpture and literature where that life-giving, green, mysterious and magic stone was depicted.

Each stone was associated with esoteric symbolism, often read on the pages of the Bible and, according to some scientists, also in the Torah. In the Septuagint, the first translation of the Old Testament, chrysoprase did not appear, although some experts found it in the prophecy of Ezechiel (27:16), as the *chodchod* (Hebrew: כדכד, *kdkd*), as it appeared in the Latin translation of the Bible, the Vulgate (Jerome 1884; Streeter 1898; Souvay 1913). In John's Revelation of the New Testament, it was clearly articulated as the 10th stone of the foundation of the New Jerusalem (Rev 21:20). Chrysoprase was referred to there as "the physician of men's hearts" and, above all, as a symbol of hope, and the mystery of God's mercy (Heflik et al. 2005; Harell 2011; Kobielus 2012). Ecclesiastically, it can also be read: *khrysos* (gold) as a symbol of God-Christ's love or *prasos* (green) as a symbol of hope and connection with the Holy Spirit. For centuries, both the biblical scientists and the experts in mineralogical and gemological literature have been in dispute about the place and the role of chrysoprase in biblical accounts (Manutchehr-Danai 2009).

4. Chrysoprase – a taxonomical problem

In this article, the authors often questioned the current classification of chrysoprase, in which this stone is still categorized as a color variety of chalcedony. However, the analytical data clearly shows that chrysoprase is not a mineral. Instead, it is an example of complex silica assemblage, in which the percentage of individual SiO_2 polymorphs determines its internal and external characteristics. Therefore, it seems necessary to modify the existing taxonomy and mineralogical-petrographic systematics of chrysoprase. Broda et al. (2022) described the larimar from Dominican Republic, which is an example of complex pectolite mineralization and provided also an example of agate which, alike chrysoprase, is composed of variable proportions of SiO_2 phases (see e.g. Dumańska-Słowik et al. 2008, 2013; Natkaniec-Nowak et al. 2016). Sometimes, SiO_2 polymorphs can generate unique optical properties of agates, previously attributed only to precious opal (Natkaniec-Nowak 2020). Moreover, Broda et al. (2022) used for the first time the term "polyminerals" to describe this type of complex mineral compounds. Thus, the authors intend to start a discussion among mineralogists and petrologists, not treating this term in an unambiguously binding manner, but rather as a proposal for the future nomenclature of many similar mineral compounds showing a complex internal structure.

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Conflict of interest

The authors declare no conflicts of interest.

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