American Mineralogist, Volume 106, pages 150–153, 2021

A comment on "An evolutionary system of mineralogy: Proposal for a classification of planetary materials based on natural kind clustering"

Frédéric Hatert[1,*], Stuart J. Mills[2], Frank C. Hawthorne[3], and Mike S. Rumsey[4]

[1]Laboratory of Mineralogy, University of Liège, Quartier Agora, Allée du six Août 14, B-4000 Liège, Belgium
[2]Geosciences, Museums Victoria, GPO Box 666, Melbourne, Victoria 3001, Australia
[3]Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada
[4]Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD, U.K.

Abstract

The classification and nomenclature of mineral species is regulated by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (IMA-CNMNC). This mineral species classification is necessary for Earth Sciences, as minerals constitute most planetary and interstellar materials. Hazen (2019) has proposed a classification of minerals and other Earth and planetary materials according to "natural clustering." Although this classification is complementary to the IMA-CNMNC mineral classification and is described as such, there are some unjustified criticisms and factual errors in the comparison of the two schemes. It is the intent of the present comment to (1) clarify the use of classification schemes for Earth and planetary materials, and (2) counter erroneous criticisms or statements about the current IMA-CNMNC system of approving proposals for new mineral species and classifications.

Keywords: Classification, nomenclature, mineral species, IMA-CNMNC, "mineral kinds"

Introduction

Hazen (2019) proposed setting up a classification "of condensed planetary materials into natural kinds based on the observed range of chemical and physical properties of any natural condensed phase—properties that reflect not only a substance's major element chemistry and crystal structure, but also its paragenetic mode." We make classifications to help us in our understanding of how natural processes work or how we may more efficiently deal with the objects under consideration. Multiple classifications pertaining to the same kingdom can coexist without conflict, being individually useful for the purposes for which they were developed. We also need to recognize that classifications are a human artifact, which we have progressively developed in all areas of Natural Science.

We recognize that Hazen (2019) has every right to develop a classification system specifically designed to characterize planetary evolution. However, we consider it unfortunate that Hazen (2019) chose to be ambivalent about the relationship between his ideas and the IMA-CNMNC classification. On the one hand, he recognized the important role of the IMA-CNMNC in defining minerals, a process without which we cannot deal with them in any scientific context. On the other hand, he took a confrontational approach to criticizing the IMA classification in terms of several areas where he feels it is not optimum in terms of studying planetary evolution. Why should the IMA-CNMNC classification be optimum for studying planetary evolution? It was not set up for this purpose. If Hazen (2019) wishes to set up a more suitable classification for planetary materials, this will not conflict in any way with the IMA-CNMNC classification, as it is done for a completely different purpose, in the same way that structure hierarchies of minerals or the gemological classification of diamonds do not conflict with the IMA-CNMNC classification of minerals. However, there are several factual errors and unjustified negative comments in the criticisms of Hazen (2019), and we consider it important to correct these so that they do not propagate throughout the Earth Sciences community.

Historic mineral classification

Mineral classification was created through name-giving (definition), which is based on description. It has progressed through both promotion and relevance of use, the classifications that were useful stuck around and were built upon or refined, and those that were not useful died out. At any one-time, mineral classifications can be seen as a representation of our collective level of general understanding of the mineral kingdom, the boundaries of the kingdom and as a guide for the methods in which scholars and scientists are working toward furthering that understanding.

"The first step in wisdom is to know the things themselves; this notion consists in having a true idea of the objects; objects are distinguished and known by classifying them methodically and giving them appropriate names. Therefore, classification and name giving will be the foundation of our science." (Linnaeus 1735, translation from Engel-Ledeboer and Engel 1964).

Prior to Linnaeus (1735), the classification of minerals has progressed from the largely descriptive works of Agricola (1546), the often cited "father of mineralogy" and de Boodt (1609). Within their classification boundaries are objects we now consider as rocks and fossils, which alongside minerals were described on the basis of a variety of properties, including additional "properties"

* E-mail: fhatert@ulg.ac.be

0003-004X/21/0001–150$05.00/DOI: https://doi.org/10.2138/am-2021-7590

such as purported use in medicine or physical attractiveness. Such additional "properties" have been progressively removed from mineral classifications initially through the prioritization of physical properties (e.g., Woodward 1695, 1728), then physical and chemical properties (e.g., Linnaeus 1735) progressing to almost exclusively chemical properties that significantly reset the boundaries of the mineral kingdom with the almost complete loss of rocks and fossils (e.g., Cronstedt 1758, 1770).

The final steps to an ancestor of our modern mineral classification were provided by de L'Isle (1783) and Werner (1774) who gave us quantitative ways of measuring relevant properties, allowing for repeatability, a common language when describing physical properties, and an alignment with a chemical classification (St. Clair 1966). J.D. Dana's *System of Mineralogy* (Dana 1837) is the first extensive compilation of minerals systematically arranged by their chemistry. The collective progression for 450+ years has been a movement from extrinsic to a specific set of intrinsic properties, from qualitative to quantitative measurement providing diagnostic characterization and classification. In modern mineralogy (end of 20th and 21st centuries), we have come to understand and characterize these intrinsic properties on an ever-increasing scale.

It is worth noting that in many early works on classification and description, all bodies dug from the ground were termed "fossils"; the word "mineral" took some time to develop in having consistent meaning in relation to what we now consider the mineral kingdom across different languages. *Le Grand Dictionnaire des arts et des sciences*, published by the M. de l'Académie Françoise (1695), has "Mineral" as an entry, and the English dictionary of the Arts and Sciences (Harris 1704) lists "Minerals" with a brief and similar definition but cross references the reader to the terms "Fossils" and "Stones" that go on to describe more items we now appreciate as minerals alongside other geological objects.

The IMA-CNMNC

Matters pertaining to the approval and naming of new mineral species, mineral nomenclature and mineral classification fall within the purview of the Commission on New Minerals Nomenclature and Classification of the International Mineralogical Association (Nickel and Grice 1998; Hatert et al. 2017).

Mineral definition

The approval of a new mineral species amounts to a definition of that mineral. It includes the measurement of a list of properties that are required to have the new mineral approved, which together show that the mineral be distinct from all other approved minerals (Nickel 1995; Nickel and Grice 1998; Mills et al. 2009; Hatert et al. 2013). The basic properties defining mineral species are their crystal structures and their major element chemistries; each species is designated by a unique name.

Mineral nomenclature

The assignment/approval of names for minerals attempts to follow a fairly consistent approach whereby many minerals have the same root name, and their differences are indicated via prefixes or suffixes indicating substitution of one or more ions in the root mineral by other ions to give rise to a different but related mineral of the same bond topology (Hatert et al. 2013). This was not always the case in Mineralogy, and prior to the establishment of the IMA Commission on New Minerals and Mineral Names (CNMMN) in 1959, there was no guiding principle that in formulating a name, the author should give clues to any specific property, and so species naming across the whole mineral kingdom was inconsistent. Of course, mineral nomenclature is also not independent of other areas of the Earth Sciences, particularly petrology, and both (1) frequency and period of use, and (2) use in rock nomenclature in conjunction with a historical lack of mineral-naming principles, prevent the retrospective alteration of names to a completely consistent scheme. Consequently, many non-systematic names are "grandfathered" into the nomenclature because they are too embedded in the literature or nomenclature of other disciplines and to be changed conveniently (Morimoto 1988; Hawthorne et al. 2012).

Mineral classification

The IMA has a mixed chemical/structural classification system for minerals based on sub-groups, groups, supergroups, sub-classes, classes, and families (Mills et al. 2009), which is essentially a continuation of the classical work of early mineralogists as outlined above. This allows us to present mineral data in an orderly and logical fashion and to teach Mineralogy in an effective manner. Most of the current IMA-CNMNC work on classification involves (relatively) small supergroups or groups of minerals that (1) serve to organize our knowledge of these minerals; (2) impart understanding to some aspects of the relation between chemical composition and crystal structure; and (3) provide Petrology with a well-defined set of minerals that may be used as a basis for the classification of rocks and for the investigation of their petrogenesis (Schertl et al. 2018).

Other classifications and the IMA-CNMNC

As noted above, we make classifications to help us in our understanding of how specific things work. For example, there has been a lot of work in the last 20 yr on structural hierarchies of minerals (summarized by Hawthorne 2014, see also Christy et al. 2016a), focused on organizing minerals on the basis of bond topology such that the classifications may be used to understand the sequential crystallization of complicated hydroxy-hydrated oxysalt minerals (e.g., Schindler and Hawthorne 2004, 2008; Christy et al. 2016b). In a different context, gemologists classify diamonds by the presence or absence of N impurities. This diamond classification has a major role in the assessment of completely natural, treated and synthetic diamonds (Breeding and Shigley 2009), aspects that have a major effect on their price. There are numerous other such classifications that inform specific aspects or uses of subsets of minerals. There is no conflict between the chemical classification used by the IMA and these other mineral classifications, and there have been no arguments in the literature as to the defects of one classification relative to the other. They have been set up for different reasons and purposes, and as such, there is no basis for criticism of one with respect to the other.

Natural kinds

Use of the term "natural kinds" in the context of minerals is problematic as there is significant controversy over the meaning of this term in the area of Philosophy. Moreover, Santana (2019) has made a persuasive case that minerals do not conform to the idea of natural kinds. Although Santana (2019) addressed his arguments to minerals as defined by IMA-CNMNC, some of his arguments also apply to the "natural kinds" described by Hazen (2019). However, the classification that Hazen (2019) proposes to create has no need to rely on the idea of natural kinds.

The IMA-CNMNC defines each mineral and the compositional limits of that mineral. However, no claim is made that different samples of a specific mineral species are identical; each has a wide variety of other properties (e.g., minor- and trace-element contents, isotopic compositions of each of its constituent elements, defect structures, and short-range order) and its environment (e.g., coexisting minerals, host-rock type, and coexisting bio-organisms), which may also serve as bases for any number of classification schemes. Thus, the classification of rocks is based on the IMA-CNMNC mineral classification plus additional properties, particularly coexisting minerals and conditions and environments of formation. The classification proposed by Hazen (2019) accords with these other classifications in that it relies on the mineral definitions and nomenclature of the IMA-CNMNC to define what might be called its "root minerals" and then develops additional classification criteria based on other properties of those minerals.

Non-crystalline and composite Earth materials

Hazen (2019) makes the point that "the definition of a mineral...arbitrarily excludes...volcanic glass, solidified silica gel, shungite, amber, coal..." and states that "the mineralogical requirement of crystallinity may lead to biases when attempting to understand deposits rich in amorphous and nanoscale materials." First, there is nothing arbitrary about the original exclusion of non-crystalline materials. Polarized-light microscopy was a major technique in characterizing minerals in the 18th and 19th centuries, and non-crystalline materials were resistant to detailed characterization by this method, and hence were excluded, just as rocks were excluded by Cronstedt, who predicted the inevitable repercussions and argued that *"if some objects are thrown out from mineral collections on account they do not belong to them, other collections will be augmented..."* (Cronstedt 1758, *translated* 1770). Second, consider the statement "the mineralogical requirement of crystallinity may lead to biases when attempting to understand deposits rich in amorphous and nanoscale materials" (Hazen 2019). Let us first consider volcanic glass and magmas: there is an enormous amount of highly sophisticated work on glass, both natural and synthetic, in the Earth Science and Material Science communities, work that has major implications with regard to natural hazards and commercial uses of glassy materials. We do not think anyone could claim that this work is "biased" by the "mineralogical requirement of crystallinity." Next, let us briefly consider coal: coal has been of commercial importance for centuries, and an immense amount of work has been done in terms of understanding its structure, chemical composition, and response to heating (burning). The amount of effort that has gone into attempts to reduce the impact of coal burning on levels of atmospheric CO_2 in recent years has been enormous. Again, we do not think anyone could claim that this work is "biased" by the "mineralogical requirement of crystallinity." The classification of coal, like diamond, is long-standing (with a history dating back to 1837; Speight 2016) and is fit for this purpose and does not conflict with the IMA-CNMNC.

Formally it is not correct to state that all amorphous materials "lie outside the purview of modern mineralogy" (Hazen 2019). Metamict minerals were regularly approved by the CNMNC, as, for example, gadolinite-(Ce) that, when unheated, "gave no X-ray diffraction pattern, due to its metamict state" (Segalstad and Larsen 1978). In the CNMNC guidelines, Nickel and Grice (1998) clearly stated that *"Amorphous substances are non-crystalline, and therefore do not meet the normal requirements for mineral species. However, some geologically derived substances such as gels, glasses, and bitumens are non-crystalline. The basis for accepting a naturally occurring amorphous phase as a mineral species could be a series of complete quantitative chemical analyses that are sufficient to reveal the homogeneous chemical composition of a substantial number of grains in the specimen, and physicochemical data (normally spectroscopic) that prove the uniqueness of the phase."* Since then, some amorphous minerals have been approved, e.g., santabarbarite, $Fe^{3+}_3(PO_4)_2(OH)_3(H_2O)_5$ (Pratesi et al. 2003). However, it also must be stated that the opportunity to describe amorphous materials as minerals has not been widely used by the mineralogical community.

Many amorphous or semi-amorphous Earth materials may be grouped under the general heading of **mineraloids**: naturally occurring mineral-like substances that are not (or only partly) crystalline (although the enigmatic phrase "mineral-like substances" needs to be defined more specifically). Mineraloids are commonly heterogeneous, and their chemical compositions vary beyond the rules outlined by Nickel and Grice (1998). Common examples are limonite, amber, obsidian, petroleum, tektite, chlorophaeite, and fulgurite. Although IMA regulations state that *"the basis of accepting a naturally occurring amorphous phase as a mineral species could be a series of complete quantitative chemical analyses that are sufficient to reveal the homogeneous chemical composition of a substantial number of grains in the specimen,"* it is apparent from the short list of mineraloids given above that this basis is not applicable to most mineraloids. The solution to this problem would be to set up a specific family of mineraloids and attempt to classify them not by the normal IMA-CNMNC rules for defining minerals, but by a different set of rules that work best for these types of Earth materials.

Implications

It is no accident that we date the prehistory of humanity by the materials with which our predecessors made their tools. One of our first scientific acts was to distinguish between different rocks and minerals and use them as tools according to their properties (Hawthorne 1993). From a historical perspective, as outlined above, the classification of minerals and rocks developed in an inductive manner and has continued to do so up until the present time.

The IMA-CNMNC process of mineral approval defines a mineral in terms of its crystal structure and range of compositional variation. The primary aim of this process is to define each mineral in terms of end-member chemical composition, range of chemical composition, and bond topology (atomic arrangement). Once defined, minerals can be further classified according to their other properties according to whatever scheme is appropriate for (1) studying the role of minerals in specific Earth and planetary processes; or (2) efficiently using specific groups of minerals in the economic and/or industrial sectors. The criticism of the IMA-CNMNC scheme of mineral approval and classification by Hazen (2019) is unfounded. There is no conflict between the IMA-CNMNC scheme of mineral approval and classification and Hazen's proposed classification of planetary materials. Hopefully, the present discussion will (1) clarify the use of classification schemes for earth and planetary materials, and (2) counter any erroneous criticisms or statements about the current IMA-CNMNC scheme of mineral approval and classification.

References cited

Agricola, G. (1556) De Re Metallica, 1st ed. Basel, Hieronymus Froben and Nicolaus Episcopus.

Breeding, C.M., and Shigley, J.E. (2009) The "type" classification system of diamonds and its importance in Gemology. Gems and Gemology, 45, 96–111.

Christy, A.G., Mills, S.J., and Kampf, A.R. (2016a) A review of the structural architecture of tellurium oxycompounds. Mineralogical Magazine, 80, 415–545.

Christy, A.G., Mills, S.J., Kampf, A.R., Housley, R.M., Thorne, B., and Marty, J. (2016b) The relationship between mineral composition, crystal structure and paragenetic sequence: the case of secondary Te mineralization at the Bird Nest drift, Mountain, California, USA. Mineralogical Magazine, 80, 291–310.

Cronstedt, A.F. (1758) An Essay towards a System of Mineralogy, by Axel Frederic Cronstedt. Translated from the Original Swedish, with Notes, by Gustav von Engestrom. To Which Is Added a Treatise on the Pocket-Laboratory, containing an Easy Method, used by the Author, for Trying Mineral Bodies, Written by the Translator. The Whole Revised and Corrected, with Some Additional Note, by Emanuel Mendes da Costa (1770).

——— (1770) An essay towards a system of mineralogy. Translated from the original Swedish by G. Engestrom. London.

Dana, J.D. (1837) A System of Mineralogy, including a treatrise on crystallography, with an appendix, containing the application of mathematics to crystallographic investigation, and a mineralogical bibliography. Durrie & Peck and Herrick & Noyes, New Haven.

de Boot, A.B. (1609) Gemmarum et lapidarum historia, qua non solus ortus, natura, vis & precium, sed etiam modus quo exiis olea, salia, tinctura, essentiae, arcana & magistera arte chymica confici possint, ostenditur. Claudium Mernium and Heredes Ioannis Aubrii, Hanouiae, Germany, 576 pp.

de L'Isle, R. (1783) Cristallographie. Imprimerie de Monsieur, Paris.

Harris, J. (1704) Lexicon Technicum or a Universal English Dictionary of Arts and Sciences explaining not only the terms of art but also the arts themselves.

Hatert, F., Mills, S.J., Pasero, M., and Williams, P.A. (2013) CNMNC guidelines for the use of suffixes and prefixes in mineral nomenclature, and for the preservation of historical names. European Journal of Mineralogy, 24, 113–115.

Hatert, F., Pasero, M., Mills, S.J., and Hålenius, U. (2017) How to define, redefine or discredit a mineral species? Elements, 13, 208.

Hawthorne, F.C. (1993) Minerals, mineralogy and mineralogists: past, present and future. Canadian Mineralogist, 31, 253–296.

——— (2014) The structure hierarchy hypothesis. Mineralogical Magazine, 78, 957–1027.

Hawthorne, F.C., Oberti, R., Harlow, G.E., Maresch, W.V., Martin, R.F., Schumacher, J.C., and Welch, M.D. (2012) Nomenclature of the amphibole supergroup. American Mineralogist, 97, 2031–2048.

Hazen, R.M. (2019) An evolutionary system of mineralogy: Proposal for a classification of planetary materials based on natural kind clustering. American Mineralogist, 104, 810–816.

Linnaeus, C. (1735) Systema Naturae, sive regna tria naturae systematice proposite per classes, ordines, genera & species. Translated in: Engel-Ledeboer, M.S.J., and Engel, H. (1964) Carl von Linné, Carolus Linnaeus systema naturae 1735; Facsimile of the First Edition. With an introduction and First English Translation of the "observationes", Dutch Classics on History of Science, No.8.

M. de L'Académie Françoise (1695) Le Grand Dictionnaire des arts et des sciences, Tome Quatrième M-Z.

Mills, S.J., Hatert, F., Nickel, E.H., and Ferraris, G. (2009) The standardisation of mineral group hierarchies: application to recent nomenclature proposals. European Journal of Mineralogy, 21, 1073–1080.

Morimoto, N. (1988) Nomenclature of pyroxenes. Mineralogy and Petrology, 39, 55–76.

Nickel, E.H. (1995) The definition of a mineral. Canadian Mineralogist, 33, 689–690.

Nickel, E.H., and Grice, J.D. (1998) The IMA Commission on New Minerals and Mineral Names: Procedures and guidelines on mineral nomenclature, 1998. Canadian Mineralogist, 36, 913–926.

Pratesi, G., Cipriani, C., Giuli, G., and Birch, W.D. (2003) Santabarbaraite, a new amorphous phosphate mineral. European Journal of Mineralogy, 15, 185–192.

Santana, C. (2019) Mineral misbehavior: why mineralogists don't deal in natural kinds. Foundations of Chemistry, 21, 333–343.

Schertl, H.-P., Mills, S.J., and Maresch, W.V. (2018) A compendium of IMA-approved mineral nomenclature. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 353 p.

Schindler, M., and Hawthorne, F.C. (2004) A bond-valence approach to the uranyl-oxide hydroxy-hydrate minerals: Chemical composition and occurrence. Canadian Mineralogist, 42, 1601–1627.

——— (2008) The stereochemistry and chemical composition of interstitial complexes in uranyl-oxysalt minerals. Canadian Mineralogist, 46, 467–501.

Segalstad, T.V., and Larsen, A.O. (1978) Gadolinite-(Ce) from Skien, southwestern Oslo region, Norway. American Mineralogist, 63, 188–195.

Speight, J.G. (2016) The Chemistry and Technology of Coal. CRC Press, Florida, 809 p.

St. Clair, C.S. (1966) The classification of minerals: some representative mineral systems from Agricola to Werner. Ph.D. thesis, University of Oklahoma.

Werner, A.G. (1774) Traité des caractères des minéraux. Translated from German to French by Picardet, Paris.

Woodward, J. (1695) An essay toward a Natural History of the Earth, and Terrestrial Bodyes, especially Minerals. Printed for R. Wilkin, London.

——— (1728) Fossils of all Kinds Digested into a Method. Printed for William Innys, London.

Manuscript received May 7, 2020
Manuscript accepted August 12, 2020
Manuscript handled by Edward Grew