International Mineralogical Association

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NEW MINERALS: PAST, PRESENT AND FUTURE (INTRODUCING THE IMA "MINERAL OF THE YEAR" INITIATIVE)

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In the 170 years since the publication of the second edition of Dana's *System of Mineralogy* (1844), in which the now-familiar principles of mineral classification were first laid out, the number of mineral species has grown twelve-fold. In less than a century, the typical mineral description has evolved from an exhaustive account of crystal morphology and a partial chemical analysis, to an impressively scrupulous synthesis of hundreds of data acquired with state-of-the-art instrumentation and, to a layperson, reading like "rocket science." Compare, for example, the description of clinozoisite in Weinschenk (1896) with the recently published report on its lead–manganese analogue, piemontite-(Pb) (Chukanov et al. 2012), which comes complete with several dozen electron-probe analyses, an IR spectrum, an X-ray pattern, a single-crystal structure refinement, and synchrotron XANES data.

As new minerals become harder to find and more challenging to work with, mineralogists have expanded their search for previously unknown combinations of elements and structure types beyond the Earth's crust and learned to operate on micron and smaller scales. For example, the most talked-about new species of 2014, bridgmanite, is the principal component of the lower mantle but was actually described from the Tenham meteorite (1879, Australia), where submicrometer-sized grains of this Mg-silicate "perovskite" occur in shock-generated veins (Tschauner et al. 2014; Fig. 1). Clearly, without this and similar discoveries, our understanding of the terrestrial planets and their evolution would be far from complete. The study of new minerals is also of great practical significance: the bewildering structural complexity of some of these minerals is a source of inspiration for materials scientists (Fig. 2).

The approval and naming of new species, as well as matters of mineral classification, are now handled by the IMA Commission on New Minerals, Nomenclature and Classification (CNMNC, http://ima-cnmnc.nrm.se/). Although there is a steadily growing interest in this area of research, with 55 new proposals approved by the Commission in 2004 and 2.5 times as many in 2013, it has not precipitated a proportional increase in the amount of available financial support. The funding situation echoes, perhaps, the skepticism voiced on some discussion forums with regard to the future of "mineral hunting" and the role of the CNMNC in streamlining mineral nomenclature.

To help the mineralogical community better appreciate the efforts of researchers involved in these activities, the IMA is introducing a new initiative: "Mineral of the Year". Beginning in 2015, this recognition will be awarded annually to one new mineral species whose description was published in a reputable international journal in the year preceding the award. The Mineral of the Year will be chosen by a specially appointed selection panel on the basis of the quality of its description and on its importance to society, science, and/or technology.

We would like to launch this initiative with the present article, where several well-known "mineral hunters" from around the world share their thoughts on the significance of their work and make some projections for the future. My interviewees are Anthony R. Kampf (ARK; curator emeritus at the Natural History Museum of Los Angeles, USA), Ulf Hålenius (UH; CNMNC chairman and professor of mineralogy at the Swedish Museum of Natural History), Igor V. Pekov (IVP; professor at Moscow State University, Russia), Frédéric Hatert (FH; professor at the University of Liège, Belgium), and Satoshi Matsubara (SM; curator emeritus at the National Science Museum in Tokyo, Japan). I cannot think of a better way of introducing these researchers than by saying that, collectively, they are responsible for 7% of all mineral species known to date, and each have had minerals named in their honor: kampfite [$Ba_{12}(Si_{11}Al_5)O_{31}(CO_3)_8Cl_5$], håleniusite-(La) (LaOF), pekovite ($SrB_2Si_2O_8$), hatertite [$Na_2(Ca,Na)(Fe,Cu)_2(AsO_4)_3$], and matsubaraite [$Sr_4Ti_5(Si_2O_7)_2O_8$].

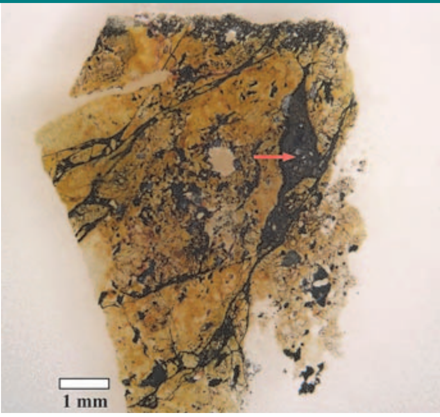

Figure 1 Shock-induced glass vein in the Tenham L6 meteorite (red arrow), containing minute crystals of the high-pressure phases bridgmanite and akimotoite (ilmenite-like $MgSiO_3$). Image courtesy of Chi Ma (Caltech) and Oliver Tschauner (University of Nevada, Las Vegas).

ARC: My first question is, naturally, "Why?"

ARK: Every new species adds something to our understanding of the natural world and the conditions under which minerals form and exist. In some cases, they can help us decipher geological processes that we cannot otherwise observe (e.g. new minerals in Ca–Al-rich inclusions in chondrite meteorites). Occasionally, they have structural features that have never been seen before, even in synthetic phases; such discoveries can lead to the development of new materials with important uses. It's like going out into the rainforest and collecting strange plants in search of a new wonder drug. You never know what's going to come out of a new discovery.

UH: Minerals are the fundamental building elements of our planet and, as such, provide a framework for the existence of life. Minerals are also fundamental sources for materials that are used in the development of infrastructure and new technologies. Consequently, knowledge of the properties of minerals, their stability fields and modes of formation, is critically important to society.

IVP: New mineral research satisfies the human hunger for knowledge. Any new mineral, even the rarest and smallest, is another building block in our understanding of Nature. These discoveries enrich not only mineralogy and geology, but also other disciplines. From a cultural viewpoint, the diversity of the Mineral Kingdom is equally as remarkable as that of the Animal Kingdom, and deserves as much attention. No synthetic analogues are known for ~50% of minerals, which underscores the practical importance of our work. Among the ~100 species discovered every year, dozens have previously unknown structure types, which could be of interest to technology as prototypes for molecular sieves, ion exchangers and other advanced materials.

FH: The description of new mineral species is extremely important to society because minerals that have formed through long geological processes in Nature constitute a fantastic reservoir of new structure types. Due to the extreme variety of geological environments, minerals may show exotic chemical compositions and structures which are difficult to obtain in the laboratory. A good understanding of these complex structures is of prime interest to solid-state scientists, for whom minerals constitute a source of inspiration for the development of valuable high-tech materials. A good example is triphylite, a lithium–iron phosphate. This mineral is often oxidized, which had been observed under the microscope by mineralogists back in 1937. Sixty years later, chemists

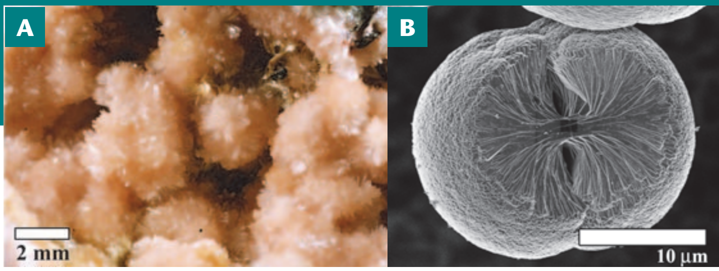

FIGURE 2 (**A**) Spherulites of the Na titanosilicate zorite, discovered in the Yubileinaya pegmatite body in the Lovozero Mountains, Kola, Russia (**B**) Spherulite of synthetic titanosilicate ETS-4, based on the zorite structure and used in a wide array of industrial applications, from gas separation to waste treatment. IMAGE A COURTESY OF I.V. PEKOV. IMAGE B COURTESY OF B. YILMAZ, J. WARZYWODA AND A. SACCO (YILMAZ ET AL. 2004).

discovered the exceptional electrochemical properties of this phase, which is nowadays used in lithium batteries found in electric cars and bicycles! The moral: always listen to what mineralogists have to say…

SM: The behavior of elements in minerals provides clues to Earth's history. For this purpose, the information gleaned from new minerals is very useful because they contain new combinations of elements, or concentrations of rare elements, not previously seen.

ARC: What attracted you to this area of research?

ARK: For the most part, I do it because I enjoy the challenge of putting together everything that is needed to define a new mineral and relish the sense of discovery that I get, especially when the crystal structure turns out to be unique or reveals an unusual new feature.

UH: Having been born and raised in an area with important ore deposits, exploration geology was the door opener for my interest in Earth sciences. With time, my interest in ore geology, in combination with a fascination for chemistry, led me to the field of mineralogy. In particular, I am intrigued by the fact that mineral colors, often of breathtaking beauty, can provide detailed information on the short-range structure of minerals.

IVP: (1) Scientific inquiry: an aspiration to find and examine previously unknown natural objects; (2) not knowing what to expect, because many new minerals are full of surprises and show intriguing structural or chemical characteristics requiring a customized approach to their investigation; (3) some new minerals broaden, or even break, stereotypical views on the behavior of chemical elements in nature; such was our recent discovery of modulated hydroxide-sulfides with Mo-for-Nb substitution.

FH: Owing to their perfect shapes and vivid colors, minerals are extremely attractive; for that reason, I became, at the age of 10, fascinated by them. I started collecting minerals and searched actively for quartz crystals close to my family home in the Ardennes Mountains of Belgium. This fascination is still there today! Even if the phosphate minerals that I generally work on can look dull, I see their beauty through the scientific questions that they bring to my mind.

SM: My first supervisor in the National Science Museum in Tokyo was Akira Kato, who was secretary of the Japanese Commission on New Minerals. I was interested in new minerals and the processes of their formation. I felt that the discovery of a new natural substance would be both important and exciting and that I could experience this excitement only in the field of mineralogy.

ARC: Do you have a favorite mineral deposit or a geological process that is particularly fecund for new minerals?

ARK: I got my start working on pegmatite phosphates, and these still hold a special place in my heart, but my horizons have expanded greatly to include all oxysalts. In general, secondary minerals formed at low temperatures under oxidizing conditions, such as those from the oxidized zones of ore deposits, are now of greatest interest.

UH: Chemical complexities, heterogeneity and a long history of recurrent thermal events have made some mineral deposits highly attractive for systematic mineral research. My favorite one is the Långban deposit in Sweden. Some 300 different species have been identified from this deposit and still more are in the pipeline. A wide variety of chemically diverse minerals have been described from this deposit, and some of these are endemic to Långban.

IVP: My favorites are: First, late mineral assemblages related to highly alkaline, initially agpaitic rocks; Second, "live" hot fumaroles on active volcanoes; Third, oxidation zones of complex chalcogenide ores.

FH: You can find new mineral species everywhere, in any type of geological environment. Some deposits of exotic geochemistry, or rocks affected by extreme geological processes, generally constitute a fertile ground for new species. Personally, I very much enjoy working on Mn-rich low-grade metamorphic rocks, like those in the Ardennes Mountains, and on granitic pegmatites, where many new phosphate minerals are described every year.

SM: I like metamorphic environments because I enjoy figuring out what the original materials were and how elements moved during metamorphism, in addition to characterizing new minerals from these rocks.

ARC: Where do you see this field of research in 50 years?

ARK: I wouldn't be surprised to see the number of minerals double. Our instrumentation will improve and we will be able to more readily identify and characterize minerals occurring in very small crystals. Given the ever increasing realization that the biological realm plays a critical role in mineral formation, given the difficulty in drawing the line between purely and partially biogenic processes in nature, and given that the distinction actually creates an awkward and rather artificial dichotomy between compounds that are, most importantly, naturally formed, I think eventually the definition of a mineral will be modified to include crystalline solids formed by purely biogenic processes.

UH: As information on short-range structures of minerals becomes more important, the application of synchrotron-based X-ray spectroscopies and high-resolution electron-microscope techniques will be increasingly important for new mineral characterization.

IVP: Further improvements of diffraction techniques could be a major progress-driving factor in our field. Access to ion microprobes also seems important, particularly for analyzing light elements that are undetectable by electron microprobes. EXAFS/XANES will become routine for the determination of element oxidation states.

FH: Analytical capabilities are constantly improving, so the number of new mineral species will increase exponentially. However, I am convinced that we will soon reach the peak in the number of new mineral proposals, because fewer and fewer scientists are interested in this field. Our next challenge will be to attract young people, and to do that we have to show them the pure beauty of minerals.

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