

EARTH SCIENCE

On the evolution of minerals

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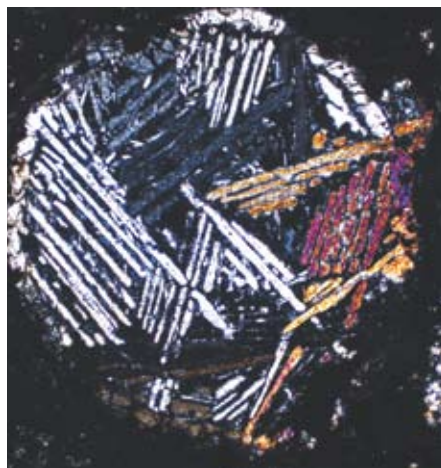
The variety of mineral species has increased since the birth of the Solar System and the development of terrestrial planets. A refreshing view likens the steady rise in mineral diversity to biological evolution.

The 94 naturally occurring chemical elements can combine into an endless number of compounds. In nature, however, such compounds come as a few thousand mineral species¹, each with its own eclectic selection of atoms systematically organized in crystal lattices. Geologists have long used the concepts of ‘primitive’ and ‘evolved’ rocks to describe the observation that planets such as Earth started out as more or less homogeneous systems, which over time segregated into chemically distinct reservoirs — on Earth, the continents, the oceans and the atmosphere, for example. The rocks that differ most markedly from the initial average planetary composition are ‘evolved’, and those

that never travelled far from their starting composition are ‘primitive’. The planets were constructed from building blocks similar to the meteorites that fall to Earth from time to time. The meteorites, in turn, are composed of grains that condensed out of the solar nebula or formed from melt droplets that circled the early Sun. The transition from primary dust to full-scale worlds was followed by a steady increase in mineral species diversity.

Writing in *American Mineralogist*, Hazen *et al.*² cast the progressive diversification of the mineral inventory of the Solar System and Earth (and presumably of the terrestrial planets in general) in terms of mineral evolution. They

Box 1 | A mineral selection



Shown here are just three examples from the wide world of mineralogy — from left to right, olivine, zircon and aragonite.

● Olivine — a magnesium-iron silicate — was one of the first minerals to form in the solar nebula, and is abundant in Earth's mantle and crust. This photomicrograph shows olivine crystals from the Allende meteorite; the crystals formed during quenching of a millimetre-sized droplet that originally circled



the newborn Sun. The colours are not true, but result from optical interference seen under polarized light in the microscope.

● Zircon is especially robust and is the oldest mineral found in Earth's crust. It consists of zirconium silicate, and typically forms small, clear prisms such as these 0.1-millimetre-long crystals from Greenland. When zircons crystallize during the cooling of granite magma, they incorporate



small amounts of uranium. Over time, some of the radioactive uranium decays to lead, which remains locked in the crystal. By comparing the amount of uranium remaining to the amount of new lead formed, zircon crystals can be dated with great precision and accuracy, making zircon one of the most valuable minerals for geochronology.

● The mother-of-pearl lining in the shells of some molluscs — such as these virgin paua — is

a highly systematic arrangement of aragonite crystals, the size and shape of which are controlled by the animal that forms the shell. Aragonite is one of the calcium carbonate minerals often grown by organisms. Another is calcite, which forms the hard parts of, for instance, echinoderms, and the shells of several types of plankton. These shells eventually become limestone — a type of rock that constitutes some 10% of sedimentary deposits. **M.T.R.**

M. T. ROSING; M. T. ROSING; C. MONTEATH/PHOTOLIBRARY.COM

review the extensive literature on the mineralogy of geological materials formed through Earth's history. That history starts with cosmic dust and meteorites, and with the earliest rocks that formed from magmas. Then came rocks formed by metamorphic reactions in the heat of the deep crust, and rocks that formed at low temperatures in Earth's surface environments, and finally those minerals that are produced through the activities of living organisms. This analysis allows the division of Solar System history into three eras and ten 'mineral evolution stages', each being characterized by the emergence of domains with new physico-chemical conditions that are expressed in the form of progressively more diverse mineral assemblages.

All of the processes that combine the chemical elements into minerals are governed by a simple set of thermodynamic principles. New minerals form if energy can be released by recombination of their constituent elements from previous hosts. Minerals can only accommodate elements with specific chemical characteristics in their crystal lattices. The chemical dissimilarity between the elements becomes less pronounced with increasing temperature, so the early hot Earth had only a few minerals such as olivine (Box 1), pyroxene and feldspar. As the planet cooled, the elements found homes in more and more picky mineral structures, such as clay minerals and the zeolites we use in washing powder. As Hazen *et al.* suggest, this cause of mineral species diversification must be a general feature of

Earth-like planets.

On Earth itself, the emergence of life gave rise to new opportunities in the mineral world. Living organisms can construct chemical compounds that are not favoured by thermodynamic equilibrium in the ambient environment and that would not have formed spontaneously without the intervention of life. These compounds — for example aragonite in some animal skeletons — provide advantages for an organism that make it worthwhile to expend energy acquired from other life processes to synthesize them. The intervention of life in Earth's geochemical cycles therefore greatly expanded the range of mineral species in Earth's surface environments, and added minerals such as the sulphate mineral gypsum that we use in drywall panels and the haematite used in red paint. This process coupled mineral evolution to biological evolution in that some of the diversification of mineral species was caused by diversification of biological species.

It may seem problematic to use the concept of evolution in connection with the non-living world of minerals. Hazen *et al.* discuss this issue at some length and show that it is semantically and etymologically permissible to use 'evolution' to describe the change in any parameter as a function of time. This may cause unnecessary animosity towards the concept that they propose, however, which could have been avoided by using a more neutral term such as diversification or differentiation. On the other hand, the scene for this type of analogy between the

living and non-living world was set many years ago by N. L. Bowen in his book *The Evolution of the Igneous Rocks*³.

Hazen and colleagues² provide an excellent review of the mineral inventory of Earth and the Solar System. In addition, they provide a good sense of the evolution of the environments that permitted new minerals to form. However, their paper also includes a discussion on whether minerals can become extinct: they suggest that, as planets evolve, some minerals that were present in the early stages are succeeded by newer ones, never to recur on the scene, and that this is akin to biological extinction. But the concept of mineral extinction is unsatisfactory because, unlike living species, mineral species do not depend on the transfer of information. As a result, identical minerals will emerge on the mineralogical scene repeatedly, as long as the physical and chemical boundary conditions can be re-established, so mineral species never become universally extinct.

Finally, the authors propose that the concept of mineral evolution should be used as a framework for teaching mineralogy rather than the classic, crystallography-based system that currently forms the basis of most mineralogy instruction. I find this suggestion undesirable: the stringent systematic features of crystallography and mineral chemistry are characteristics of the physical world that help separate life from its environment.

So I have reservations about some of the ideas associated with the principle of mineral

evolution. But otherwise I think it is an exciting concept that will do much to stimulate debate and enliven thinking in the usually staid field of mineralogy. ■

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1. Johnsen, O. *Minerals of the World* (Princeton Univ. Press, 2002).
2. Hazen, R. M. *et al. Am. Mineral.* **93**, 1693–1720 (2008).
3. Bowen, N. L. *The Evolution of the Igneous Rocks* (Princeton Univ. Press, 1928).