METEORITE IMPACTS

Diamonds everywhere

Christian Koeberl

DIAMONDS have long caused excitement not only among the general public, which appreciates them mainly for their beauty and value, but also among geologists. The latter use diamonds in a not very glamorous way as probes of the properties of the Earth's mantle, which is otherwise rather inaccessible. On Earth, diamonds usually occur in rocks derived from the Earth's mantle — igneous rocks such as kimberlites, or metamorphic rocks of mantle origin — and are thought to have formed from fluids or melts in the upper mantle at immense pressures and temperatures.

Considering the copious information available on the 'common' mantle-derived diamonds, many may be surprised to find out that diamonds have also formed in nature directly on the Earth's surface. On page 41 of this issue, Hough *et al.*[1] add an important discovery to the small body of research on diamonds produced during meteorite impacts on Earth. In their studies of material from the 23-km-diameter Ries crater in Germany, they found minute quantities not only of cubic and hexagonal diamond (the latter is known as lonsdaleite), but also cubic diamond intergrown with silicon carbide. Never before have such composites of diamond and SiC been found in nature. What is more, the diamonds seem to have formed not through shock but from the vapour phase.

Although mantle-derived diamonds probably originated during several diamond-forming events early in the Earth's history, two other natural processes are capable of producing diamonds at any time. Meteoriticists have long been aware of the occurrence of diamonds in iron meteorites[2,3] and ureilites[4], but initially assumed that the diamonds originated at high gravitational pressures within meteorite parent bodies, as for kimberlitic diamonds on Earth. Later work[5] indicated that these meteoritic diamonds have formed not in an environment of steady high pressure, but by shock from graphite or amorphous carbon in a mere instant. However, with evidence that the shock event during which these diamonds formed was related to collision and breakup of the meteorite parent body, and not to the impact of the meteorite on the Earth, attention was diverted away from impact craters.

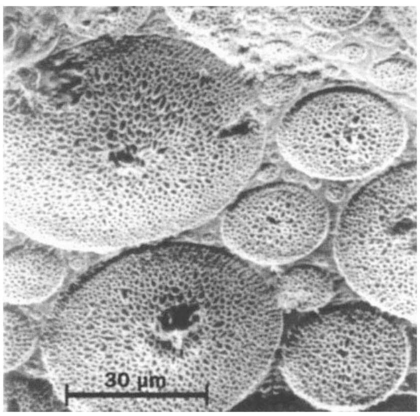
New attention was drawn to diamonds in meteorites when an elusive anomalous noble-gas bearing component in chondritic meteorites was identified as consisting of nanometre-sized diamonds[6]. Once meteoriticists started looking, they found such small diamond grains in surprisingly large quantities (up to several hundred parts per million) in a variety of meteorite types. What is more, the rare-gas composition of these minute diamond grains gave them away as being of interstellar (presolar) origin, having probably formed by vapour condensation in stellar atmospheres. The discovery of diamonds in clays marking the boundary between the Cretaceous and Tertiary periods (K/T boundary)[7], which contains fairly unambiguous evidence of a large-scale impact, provided the next surprise. The nanometre-sized diamond grains were first interpreted as being remnants of the original meteorite[7], but carbon and nitrogen isotopic data pointed to an origin during the impact or from within the fireball[8].

Speculation was rife about the origin of these clearly impact-associated diamonds. Here, earlier work by Soviet scientists (largely unknown outside the Soviet Union, as some aspects of this research were considered to be a state secret) gained importance. Polycrystalline diamonds of up to about 1 cm in size were discovered in impactites at a few Russian and Ukrainian impact structures[9]. These diamonds, which usually contain appreciable amounts of lonsdaleite, have crustal chemical and isotopic signatures[10] and pre-

The natural way to leave an impression

"Every now and then", said D'Arcy Thompson in 1917, "we come to deep-seated signs of symmetry which seem to lie beyond the reach of the ordinary physical forces". This statement came at the conclusion of an exposition on radiolarian skeletons, whose astonishingly symmetrical silica frameworks embellished several pages of Thompson's classic *On Growth and Form*. But Thompson's aim was to demonstrate that "it by no means follows that the forces in question are not essentially physical forces". Geoffrey Ozin and colleagues now seem to have shown the truth of that supposition experimentally on page 47 of this issue, where they report that intricately patterned inorganic materials like the one pictured here can be prepared by what one could justifiably call 'bucket chemistry'.

The formula sounds alarmingly simple: throw together phosphoric acid and pseudo-boehmite (a hydrated aluminium oxide) in tetraethylene glycol in the presence of an alkylamine; heat, dry and recrystallize. The millimetre-sized aluminophosphate spheres that are produced have surface patterns that resemble nothing so much as the silica



skeletons of radiolaria, patterned with arrays of disks, pores and bowls of micrometre dimensions.

Where do these patterns come from? Ozin *et al.* suppose that they are imprinted by vesicles formed by self-assembly of the alkylamine amphiphiles, whose close-packing on the surface of the growing aluminophosphate spheres leaves regularly spaced imprints. The mechanism remains speculative, but it is nothing more than the natural extension of templated patterning of inorganic materials on the molecular and nanometre scales. At the former scale there is the synthesis of microporous molecular sieves (synthetic zeolites) from the polymerization of silicate ions in the presence of quaternary ammonium ions, which act as templates for the material's ångström-scale cavities. The latter size regime pertains to the synthesis of ordered mesoporous solids (see *Nature* 359, 710; 1992), where the templates seem to be micelles.

Templating by amphiphilic vesicles would therefore extend this principle to the next rung of the hierarchical ladder, carrying the patterning to the micrometre scale. It might also provide a model system for investigating how radiolaria themselves perform their delicate handiwork. Pleasingly, this would not only broaden the emerging picture of pattern formation in materials via organic–inorganic interactions but could establish that D'Arcy Thompson, by proposing that "the peculiar form and character of these little skeletons are due to the moulding of [inorganic] material upon an underlying vesicular structure", was demonstrating another example of the prescience with which his book is filled. P. B.