flow of materials (ions, proteins and water) to and from the sites where the crystals are formed. Another problem is how to grow a series of crystals in almost perfect alignment.

Members of the UC Santa Barbara Materials Research Center have now thrown light on both these questions. Tilman Schaffer and colleagues[1] studied demineralized pieces of 'flat pearl'; nacre deposited by the red abalone (a gastropod mollusc) on a glass coverslip introduced between the shell and the adjacent layer of living cells called the mantle. They show that many pores are present in the matrix sheets, through which ions and presumably also proteins can flow. The crystals can thus grow far away from the cells of the mantle, which supply the raw materials for growth.

Schaffer *et al.* used an atomic force microscope, combined with the new technique of scanning ion conductance microscopy. In that technique, a thin tip containing one of the electrodes is vibrated and scanned over the matrix sheets under water. Areas of low and high ion conductance were monitored, proving that the sheets are transparent to ions. The authors also suggest that some of the pores allow crystals to grow from one layer to the next without interruption (Fig. 3). A new nucleation event would thus not be required for every crystal in a stack. The growth through mineral bridges, as suggested, may ensure perfect alignment of the crystal axes along a stack without disrupting the basic brick and mortar alternation which provides the material with elasticity and increased resistance to fracture.

Mollusc nacre has always been at the vanguard of biomineralization studies, probably because of its elusively simple geometry. In 1847 Carpenter described its layered structure[5], and in 1924 Schmidt established the presence of discontinuous organic material[6]. By 1930, Bøggild in his classic study of mollusc-shell architectures, described nacre as "so well known, that it may be treated here briefly"[2]. Yet to this day it is the subject of many investigations.

The modern-day pioneer of the study of mollusc-shell formation, Charles Gregoire, discovered holes in the matrix using transmission electron microscopy, and noted that they had different shapes in different species[7]. In the abalone, the observed pore density was approximately 100 μm^{-2}, with an average diameter of 43–49 nm. The later study of abalone matrix by Nakahara and colleagues revealed a core 10 nm thick that is electron-lucent (relatively transparent to electrons), sandwiched between two 40-nm-thick electron-dense layers[8].

All these measurements are in remarkable agreement with those of Schaffer *et al.*[1]. On the interlamellar sheets they see rounded features separated by pits, with a pit density of 97 μm^{-2}. Partial digestion with proteolytic enzymes reveals pores 5–50 nm in diameter, and fibre-like structures about 10 nm thick. The fundamental difference from the previous measurements, which makes these data so reliable and convincing, is the use of atomic force microscopy. The specimen is observed unstained and still hydrated, avoiding the well-known artefacts that electron microscopy can introduce.

Schaffer and colleagues are very timely in solving this piece of the puzzle, because other pieces are also falling into place. For example, a biochemical study has shown that an important component of mollusc nacre is a protein similar to silk[9]. Perhaps the largest

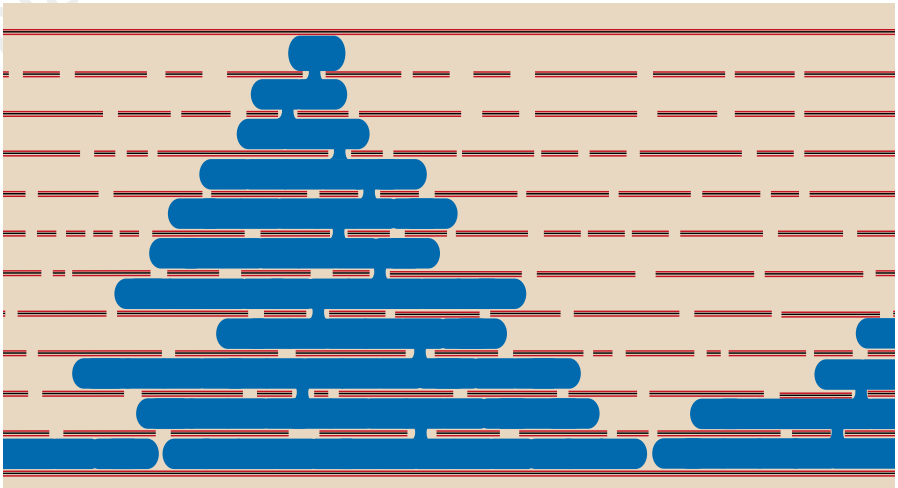

Figure 3 **Crystals of mollusc nacre growing between pre-deposited matrix sheets. The sheets have a central layer of core fibres (black), covered by protein layers (red), and are pierced by small pores that allow materials to be supplied to the growing aragonite crystals (blue), as well as keeping the layers crystallographically aligned via mineral bridges. (Adapted from a transmission electron micrograph[8].)**

Galaxy evolution

Smashed into shape

Collisions of galaxies are usually spectacular, but the latest images of a nearby cosmic pile-up do more than impress the eye.

This colour image from the Hubble Space Telescope (B. Whitmore, STScI) shows the impact region of two merging spirals, the Antennae galaxies. The region is outlined on the ground-based black-and-white image.

Star formation, induced by the collision, is clearly traced by the blue light from young, hot stars. Surprisingly, many compact young clusters of stars are seen in this and other recent observations of colliding galaxies. Previously, stellar groups of this size and shape, such as the globular clusters of our own Galaxy, were thought only to contain much older stars.

The clusters may also be useful as cosmic chronometers: by using the ages of the member stars to tell when a collision took place, it may be possible to investigate how interacting galaxies evolve, perhaps from spiral to elliptical shapes.

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