Rinderer bases his number on morphometrics, the measurement of 25 physical features known to differ between African and European bees, such as wing length, leg length, and the angles between some veins in the wings. These traits are genetically determined, he says, and so serve as independent genetic markers. And the bees he has analyzed look like a 50-50 mix of European and African traits.

But even the person who developed the morphometric system, entomologist Howell Daly of the University of California at Berkeley, is skeptical about Rinderer's use of the technique. "I'm not so sure we can interpret what we see morphometrically as evidence of hybridization," Daly told *Science*. One problem: morphometric characteristics are not determined purely by genetics. Environmental influences such as climate and diet can change a bee's proportions. And even when morphometric changes do reflect genetic changes, hybridization between strains may not be the reason, Daly says. It may be that the bee that founded a given population was itself a genetic variant. Or it could be that the variant genetic traits have been selected for because of some adaptive value, he adds.

Both camps do agree on one thing: that the bees' tendency to hybridize will change when they reach the temperate United States. But exactly how readily they will hybridize and how fast and far they will spread their traits through the U.S. bee population is uncertain. Taylor predicts that they will form a "hybrid zone" in which hybrid offspring will be favored over pure African bees because of the adaptive value of European traits in temperate climates. Hall agrees that increased hybridization is likely, but he points out that there may be biological mechanisms unrelated to climate that will diminish the survival of hybrids. Funding to address such questions has been unavailable, Hall says, perhaps due to the USDA's conviction that the bees have been hybridizing all along. ■ MARCIA BARINAGA

Materials Tips from Sea Urchins

The spines of a sea urchin are marvels of molecular engineering. Each tough, fracture-resistant spear is actually a single crystal of calcite—normally a very brittle material but somehow strengthened and toughened by the urchin. Materials scientists would love to learn how the creatures do it, in hopes of picking up ideas for strengthening other single crystals, such as the brittle silicon blocks that form the bases for integrated circuits.

Now researchers from the Weizmann Institute of Science in Rehovot, Israel, and Brookhaven National Laboratory in Upton, New York, believe they have uncovered an important clue to the spines' toughness. On page 664, they report that the key may be how the distribution of protein molecules throughout the calcite spines modifies the microstructure of the crystal.

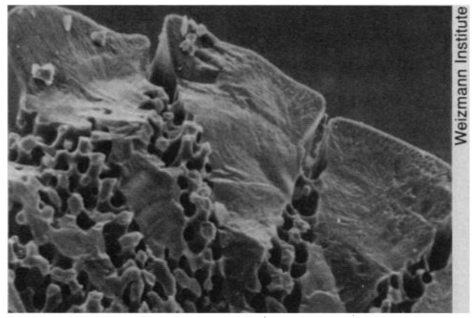
Scientists have long known that an urchin incorporates protein into the calcite crystals that compose its spines and, in 1988, Amir Berman, Lia Addadi, and Stephen Weiner of the Weizmann Institute showed that this protein affects how the spines fracture. They compared inorganic calcite (a chalk-like mineral consisting of calcium carbonate crystallized in hexagonal form) with crystals of calcite grown in the presence of proteins extracted from urchin skeletons (basically the same proteins as from the spines). The synthetic crystals fractured much as sea urchin spines do—they were much more difficult to crack than pure calcite crystals and, instead of cleaving neatly along flat planes as inorganic calcite does, they broke into irregularly shaped pieces like broken glass.

At the same time, the Weizmann researchers found the first hint of how the proteins change the fracturing behavior of the calcite. They discovered that as a crystal is being grown from a protein-bearing solution, the proteins are incorporated into the crystal on planes that lie at an angle to the cleavage planes (the planes along which cracks form). The proteins, which make up about 0.02% of the crystal by weight, apparently act like the fibers that materials scientists put into ceramic composites to prevent cracking, Weiner says. "The trick is not to prevent a crack from forming, but to stop its propagation," he adds. But although the synthetic crystals made with proteins from the sea urchins were stronger than pure calcite, they weren't as tough as the real thing. Something was missing.

Now Berman, Addadi, and Weiner, working with Leslie Leiserowitz at Weizmann and Åke Kvick and Mitch Nelson at Brookhaven, think they know what the missing piece of the puzzle is. At the National Synchrotron Light Source at Brookhaven, they performed x-ray diffraction studies of pure calcite crystals, synthetic calcite crystals made with proteins from sea urchin skeletons, and natural sea urchin spines. The powerful synchrotron radiation allowed them to detect very small variations in the crystalline textures of the various samples and revealed a telling difference.

No crystal is perfect in the purest sense of the word, Weiner notes, and the single crystals the researchers studied were actually mosaics of tiny near-perfect crystalline regions so closely aligned with one another that their x-ray diffraction patterns look like those of single crystals. But the high resolving power of the synchrotron radiation revealed variations in the arrangement of the individual regions, or domains, in the samples.

The pure crystals consisted of domains that were an average of about 500 nanometers across and that were misaligned by no more than about 0.004°. The synthetic



Broken spine. *Irregular break distinguishes urchin's spine from natural calcite crystal.*

crystals were very similar to the pure calcite crystals in the size of the domains, but the range of misalignments was about 0.03°. The domains in the sea urchin spines were smaller—only about 150 nanometers across—and were offset from one another by as much as 0.15°.

With this data, the Weizmann group is beginning to piece together exactly how the proteins are toughening the calcite spines. They suggest that the proteins are located along the boundaries of the individual domains, where they act to inhibit the spread of cracks in at least two ways. First, as their previous work indicated, the protein molecules are oblique to the cleavage planes and seem to act as barriers to any fractures along these planes. And second, because the domains in the spines are smaller and less perfectly aligned, a nascent crack will run into the boundary of a domain more quickly and will be less likely to jump to the next domain. The pure calcite crystals, with larger, almost perfectly aligned domains, are very brittle, and the synthetic crystals, with larger but less well aligned domains, are tougher than the pure crystals but more brittle than the spines. If this proves to be a general principle, the researchers say, the sea urchin may have pointed the way to making stronger crystals. Now the challenge will be to replicate the process in the laboratory.

■ ROBERT POOL