lective molecular filters, says Harvard University chemist George Whitesides. But the Toronto researchers currently have their eyes on other possible applications, such as designing strong yet flexible materials by grading the size of voids from large to small in sheets of their material.

Still, in practical terms, the technique used by Mann and his Bath University colleague Dominic Walsh may be closer to the mark, as it produces porous spheres about 1 micrometer in diameter. The British researchers, who reported their results in the 28 September issue of *Nature*, start by dissolving inorganic calcium carbonate and gaseous carbon dioxide in water. The carbon dioxide converts some of the calcium carbonate into calcium bicarbonate, a more soluble form. The researchers then add oil and a surfactant to ensure a uniform mixture. When the researchers spread this mixture into a thin film and remove some surfactant, two things happen. First, the oil forms droplets in the film, which pack next to one another, forcing the inorganic solution into a meshlike structure surrounding the droplets. Second, this mesh solidifies because the surface-to-volume ratio of the liquid has increased dramatically, causing the CO_2 to quickly diffuse out of solution. As a result, the calcium bicarbonate is converted back into calcium carbonate, which crystallizes out of solution, creating a subnanoscopic crystallization pattern that represents the first layer of the organizational hierarchy.

As this crystallization continues, the calcium carbonate grows to form 15- to 40-nanometer-thick walls surrounding the oil droplets, creating the second level of organization. The Bath team then spread the emulsion over polymer beads 1 micrometer in diameter. When the oil is washed away and the polymer bead is burned out, what remains is the highest level of organization: a branched spherical structure resembling the skeletons of marine algae known as *Thoracosphaera*. And because the holes in these structures are larger than those in conventional zeolites, that may make them useful as filters for large particles such as viruses, says Mann. The overall spherical shape, he adds, may be useful in packing such filters into a chemical separation column.

The final step in the Bath process, of course, isn't quite self-assembly. Although the technique produces porous inorganic spheres all of the same size, such precision is only possible because the researchers layer their emulsion over the plastic beads. So next up for both groups will be to see if they can encourage these systems to take on large uniform shapes without outside help. They're still a long way from self-made silicon chips, but they're getting closer, one pattern at a time.

–Robert F. Service

MEETING BRIEFS

Geologists Debate Ancient Life and Fractured Crust

At the annual meeting of the Geological Society of America (GSA) in New Orleans earlier this month, the juxtaposition of disparate research so typical of earth science gatherings was much in evidence. One day geologists were arguing over how crust under tension could, contrary to theory, break like a layer cake. Two days later paleontologists and developmental biologists were discussing how to disentangle the roots of the animals' family tree, before the first large animal fossils appeared in the record.

Embryos Give Clues to Early Animal Evolution

The Cambrian explosion 530 million years ago raised the curtain on a panoply of different animal forms. Paleontologists, intrigued to know how this dazzling performance was produced, have been trying to peer backstage: They have been searching the fossil record of even earlier times for solid evidence of the key evolutionary steps that led to the debut in the Cambrian Period of animal body plans ranging from arthropods to mollusks. At the GSA meeting, however, developmental biologists had some bad news: The hoped-for solid evidence won't be found.

"It doesn't look good for the traditional paleontologist," says Kevin Peterson of the University of California, Los Angeles (UCLA). "Fossils are not going to help you understand the relationships among the phyla"—the large groups of animals distinguished by their body plans. The reason, he says, is that well before the first fossils were preserved, the diversification took place in "squishy little larvalike things" that would never have been tough enough to show up in the fossil record.


DAVIDSON ET AL.

Rosetta stone? How larvae like this infant sea urchin develop may hold clues to the earliest branchings of the animals' family tree.

The key innovation leading to the current bewildering array of basic body types, say Peterson and his colleagues, was a new scheme of development that allowed microscopic animals to grow beyond a few thousand cells and sculpt themselves in many different ways. The researchers say that those evolutionary steps probably first took place in animals that looked rather like the larvae of modern marine animals: glassy assemblages of cells perhaps less than a millimeter long, which might have lived hundreds of millions of years before the first sizable animal fossils appear in the record.

At the meeting and in a paper on page 1319 of this issue of *Science*, Eric Davidson of the California Institute of Technology (Caltech), Peterson, and R. Andrew Cameron of Caltech argue from work in developmental biology and paleontology that early animals had to overcome a developmental barrier before the many body plans already evident in the Cambrian explosion could evolve. These earliest multicellular animals, the group contends, were limited in size and complexity because their fertilized eggs couldn't divide more than about 10 times before the repeated division hit some limit inherent in the way the embryo controls its development.

The solution to this growth limitation, Davidson and his colleagues say, was the invention of groups of cells, seen in certain kinds of embryos today, that were not immediately committed to developing into a particular type of tissue. These "set-aside cells" could later multiply indefinitely to produce macroscopic animals. To regulate the multiplication and specialization of these cells, the organisms would have had to evolve a complex hierarchy of genetic controls. Evolution, acting on those genetic control mechanisms, could then have produced the variety of body plans that now distinguish one phylum from another.

All this genetic groundwork had to have been laid down in the embryos of larvalike animals that evolved perhaps hundreds of millions of years before the Cambrian explosion. That would put them even earlier than the first fossils of macroscopic animals, the Ediacaran fauna, which appeared by 560 million years ago (*Science*, 27 October, pp. 580 and 598), say Davidson and his colleagues. If so, the first products of pivotal innovations will not be found in the fossil record. "There's very little chance you'll be able to find these pre-Ediacaran, larval-type organisms," says Peterson. For paleontologists, commented Peterson's colleague Charles Marshall of UCLA, a paleontologist himself, "that's just unfortunate."

Instead, Davidson and his colleagues argue that the key to understanding the relations among different animal phyla lies in embryonic development. The question evolutionary biologists should be asking is "How do you generate the patterns [in body forms] that we see?" comments Marshall. "What are the cellular and developmental processes necessary to define a front end from a back end or dorsal from ventral? How do you tell cells to organize so there's a septum that differentiates one part of the structure from another?"

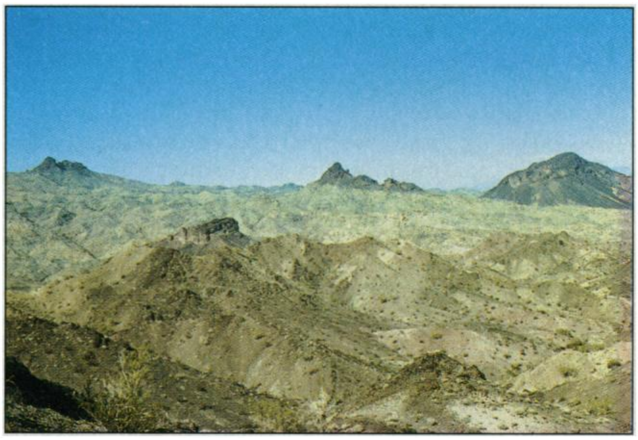
The answers to such questions—and clues to how the phyla of animals diversified—are to be found in the structure of embryos and larvae of living animals, says Peterson. The currently popular alternative of comparing the sequence of nucleotides in the so-called 18S ribosomal RNA molecules of different living animals produces a different evolutionary tree, but Peterson isn't worried. "That doesn't mean my tree is wrong," he says. There are real doubts, he says, about whether 18S trees can reach back to the origins of phyla.

In spite of the developmental method's implications for fossil hunters, "I really like this approach," says paleontologist David Jablonski of the University of Chicago. And he points out that it still leaves a complementary role for paleontologists. There may be no fossil record of primordial body plans awaiting discovery, but tracks and trails left in the mud just before the Cambrian explosion could give some hints, he says. Later fossil forms could also provide clues to the evolutionary tree: for example, the appearance of features, such as light-sensitive cells, that imply a distinctive pattern of embryonic development.

But Jablonski also sees some dangers in the developmental approach: "You have to be careful that attempts to apply it to organisms where you can't watch the embryology don't lead you into trouble." Trying to figure out what is happening behind a closed curtain is always risky.

Faults Stretch Rocks—and Theorists' Imaginations

The faults themselves may be in question, but there was no argument about the fault line in earth science that was exposed at the meeting. In a special GSA session, field geologists who spend their summers in the rugged deserts of southern California and southwestern Arizona faced off against a geophysicist who spends his time in an office, theorizing about how rocks can break. Years of mapping in the American Southwest, where tectonic forces have stretched the crust, have convinced geologists that rocks there have been pulled apart along great, gently sloping faults. But to rock mechanicists, such low-angle extension simply can't happen. The faults must be due to some other process that the field geologists have overlooked.


G. DAVIS/USC

Always so gentle? Erosion in southeastern California's Whipple Mountains has exposed what is now a gently inclined fault along which dark *(upper layer)* and light rock have slid.

At issue in the session, which was called to air these differences, were both the nature of the processes by which crust in the region has stretched and a broader question: the proper role of theory in geology. "Our job as field geologists is to define and defend what we think we see," says Gregory Davis of the University of Southern California, "and to let the theorists tell us how it can work." Rock mechanicist Roger Buck of Columbia University's Lamont-Doherty Earth Observatory was equally adamant, suggesting that field geologists need to revise their interpretation in light of theory. "Do you want a simple interpretation of the observations or a simple mechanism?" he asked. "I'm going to argue to keep simplicity of mechanisms."

Theoretical resistance to low-angle faulting has deep roots. "No one has ever come up with a viable explanation of how pristine rock could break at [an angle] lower than 45 degrees" during crustal extension, says Buck. Producing the faults at their current angles of less than 30 degrees would be something like tugging on the sides of a sheet cake and having it break into two layers along a nearly horizontal "fault." And just as intuition calls for the cake to break nearer the vertical, rock mechanics theory predicts that stretched crust should break at steep angles of between 45 and 70 degrees.

On the other hand, Buck and his fellow theorists have no problem with low-angle thrust faults, formed when one crustal layer is pushed over another. If some process weakens or lubricates the fault—forming a layer of slippery "icing"—and the assemblage is stretched later on, the rock layers could slide apart later in low-angle extensional faulting. The classic though now controversial example of that process lies beneath the Sevier Desert of Utah (*Science*, 12 November 1993, p. 992). And if that explanation doesn't hold up, say Buck and others, perhaps the low-angle faults were formed at a much steeper angle, then rotated into their current orientation.

Davis and other field geologists speaking at the meeting don't believe the geologic evidence supports either scenario. Instead, they see a wealth of evidence that the faults really did form when strained crust broke at a low angle. For example, sediments that had to have been laid down in horizontal layers are still lying nearly horizontally on top of some faults. And the orientation of traces of Earth's magnetic field locked into rock when it solidified near several faults indicates that it has rotated little since the faults formed.

Davis and his colleagues also reported calculating a fault's original slope by geometrical deduction. From the point where the fault broke the surface, they followed it to its intersection with a layer of rock deformed before the fault cut it. From the nature of the deformation, now exposed at the surface by erosion, they calculated the rock's temperature and thus its original depth. The result—a depth of 12 to 16 kilometers—gives an original fault slope of less than 30 degrees.

"Roger, I think, is ignoring a lot of geological evidence that he doesn't feel comfortable with," says Davis. "He's a fine rock mechanicist, but he's not a field geologist. As an observationalist, I'm biased, but I think that such disputes come down more often than not on the side of the observationalists rather than the theoreticians, who say 'We can't explain this theoretically; therefore the phenomenon doesn't exist.' "

"I wouldn't say I'm doing that," says Buck. "I'm speaking for a lot of geophysicists who think about mechanics [when I say] we're going to be very skeptical of these interpretations. I'm always going to err on the side of skepticism, particularly since I don't have a mechanism for starting these [faults]." So the standoff will continue, presumably until the evidence becomes so overwhelming on one side or the other that someone cries uncle. Back to the field and the desktop.

–Richard A. Kerr