sodes when increased surface winds boosted marine productivity. These increases, he says, coincide with the four most recent Heinrich events of the North Atlantic.

Just how all these far-flung climate signals—ice sheet collapses, simultaneous warmings and coolings in high northern and southern latitudes, and changes in continental moisture and tropical winds—might be linked is anyone's guess, but paleoclimatologists are willing to speculate. One candidate mechanism dates from when researchers thought the mystery was limited to Dansgaard-Oeschger events in Greenland. Those swings, researchers speculated, could be explained by a climate "master switch" in the currents of the northern North Atlantic. Cold, salty, and therefore dense water sinks into the deep sea at high latitudes, forming a crucial turning point in a globe-girdling "conveyor belt" of currents that bring heat into the North Atlantic via the Gulf Stream. Natural oscillations in the conveyor belt, it seemed, might account for the climate oscillations seen in Greenland.

Another candidate mechanism came to the fore when the Heinrich icebergs showed up: the ice sheet itself. In a scenario proposed by ice-sheet modeler Douglas MacAyeal of the University of Chicago, North America's ice sheet underwent a natural cycle of thickening and collapse. Over thousands of years, it grew until it trapped enough heat flowing up from Earth's interior to melt its base, forming a lubricating layer that caused the ice to slip away in a Heinrich event. The melting icebergs would have put a lid of relatively fresh and therefore less dense water on the far northern Atlantic, temporarily shutting down the conveyor and intensifying the sharp cooling that accompanies Heinrich events.

Some paleoclimatologists think either of those North Atlantic switches might be capable of altering climate worldwide. The conveyor belt itself might carry a North Atlantic climate signal around the globe, notes Scott Lehman of the Woods Hole Oceanographic Institution, because it connects the hemispheres, passing southward through the deep North Atlantic into the South Atlantic and rising near Antarctica. Any variation in the flow of the conveyor—whether the result of an internal oscillation or an ice sheet collapse—could ultimately modulate the amount of sea ice around Antarctica and thus alter southern climate.

Some researchers argue, however, that the trigger for global climate oscillations may lie not in the North Atlantic, but in the tropics. Bond suggested a candidate. Tropical climate, he noted, is especially sensitive to orbital variations, in particular the changing orientation of Earth's axis, which can drive climate change by affecting the distribution of sunlight over the surface of the planet. In the tropics, the cyclical wobble of the axis can produce climate cycles of about 10,000 years. That might explain some of the strongest Dansgaard-Oeschger events, says Bond, and even some Heinrich events, which take place on a schedule of roughly 10,000 years.

But Bond admits that orbital changes are just one possible cause of the global climate spasms. In fact, there may well be multiple, interacting causes for geo-physicians to sort out. The key will be retrieving new records of the patient's past condition in all its far-flung parts.

–Richard A. Kerr

MATERIALS SCIENCE

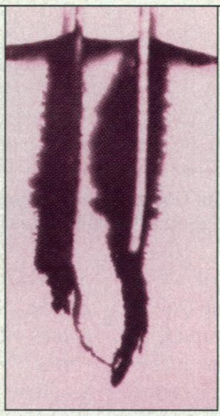
Wiring for a Very Small World

In the world of electronics, sometimes the smaller an advance, the bigger the breakthrough. For example, as circuits for computer chips have become more complex, they have tended to grow in one direction—sideways. Wider chips mean longer processing times and more energy costs, and scientists, looking for complexity without the costs, have been searching for ways to keep circuit size down. One potential solution is to extend that circuit's height, adding another dimension to hold additional circuitry but keep it in a compact form. Now a small step in that direction has been taken by a team from the University of California, San Diego (UCSD), led by chemist Michael Sailor.

On p. 2014 of this issue, Sailor's group describes a chemical process that grows multi-branched molecular wires the size of human hairs, using special conducting polymers that could become complex and compact three-dimensional circuits. This is one of the first fabrication techniques with this potential, says chemist Ralph Nuzzo of the University of Illinois, Urbana-Champaign. "This is still a simple demonstration," says Nuzzo. "But I think it's a really clever idea. It could become very interesting."

The conducting polymer used by the UCSD group is made of organic molecules called 3-methylthiophene (3MT). When monomers of 3MT bond together into a polymer, it can conduct electricity because its electrons are not tightly bound; they can jump from molecule to molecule and carry a current. This also means that the polymer will easily accept or give up electrons and—depending on how many electrons it has at any one time—the polymer can vary from conducting to insulating.

The researchers took advantage of these properties to grow a circuit with little more than some tinkering with an applied voltage. Sailor's group put molecules of 3MT into solution in a beaker and placed a pair of platinum electrodes, with opposite charges, into the solution. A current flowed toward the positive electrode, which began to leach electrons out of the 3MT molecules. These electron-poor molecules then attached themselves to electrons orbiting their neighbors, resulting in shared electrons and tight bonds as the monomers linked up to form a polymer chain. One end of the chain was anchored on the positive electrode, and the other end branched out like a bush as new monomers were added on randomly.



RITCHIE

Molecular connector. This polymer wire grew molecule by molecule.

After the chain grew for 30 seconds, the researchers reversed the voltage on the two electrodes. The newly negative electrode began injecting electrons back into the polymer chain, squelching its reactivity and growth. On the other side of the beaker, the newly positive electrode began to grow its own chain. As the voltage shifted back and forth, the two molecular bushes grew toward each other until two of the branches finally met up in the middle. The whole process took 30 to 45 minutes.

The wire looks more like a molecular tangle, but the connection does conduct electricity. More important, Sailor says, additional platinum electrodes can grow additional wires to come from above and below and join at the initial electrodes. In fact, there should be no limit to how many wires come out of each electrode, allowing the creation of a vast array of multidimensional connections. Such connections could form the basis for a neural network that processes signals much like your brain does, says Sailor, although so far his group has made only a three-sided circuit. "Your brain operates so much better than a computer," says Sailor, "since one neuron can talk to thousands of others, simultaneously."

Before he grows a neural network in a beaker, however, Sailor has a couple of problems to overcome. One is that current now passes through these wires in both directions, and circuits on computer chips require devices with one-directional flow. But if he can solve this and some other minor hurdles, the impact of these little wires could be very big indeed.

–Karen Fox