

third speaker, delivered his talk for him. For 30 years, they noted, paleontologists have known that a crustal block now locked in the Andes north of Mendoza in far western Argentina, called the Precordillera, contains distinctively North American fossils of 540 million years ago. But Astini helped pin down the North American connection by drawing attention to similarities between the rock types and the sequence of strata in the Precordillera and the southeastern United States. "They are identical," says Hatcher. "It's amazing."

At an October workshop in Argentina, other geologists agreed that the Precordillera

of western Argentina broke away from the Gulf Coast about 500 million years ago, say Thomas and Hatcher. But younger fossils in the Precordillera imply that before it "docked" on the South American coast, the block of crust spent some time on its own, as an island. That suggests that Laurentia and South America "were not in contact," says Hatcher, "but they could easily have been within 1000 to 2000 kilometers of each other," given the timing of the transfer.

That Laurentia was near South America 500 million years ago rather than 4500 kilometers off Africa on the other side of

Gondwana is gratifying, says Dalziel, but he hasn't given up on the idea that they collided. Direct contact would eliminate any uncertainty about Laurentia's location, after all. Perhaps, instead of breaking all connections with North America before colliding, the Precordillera could have remained attached to it by a long, submarine plateau, much like the one that now connects the Falkland Islands to South America. North and South America might not have embraced during this dance of continents, but perhaps they stole a kiss.

—Richard A. Kerr

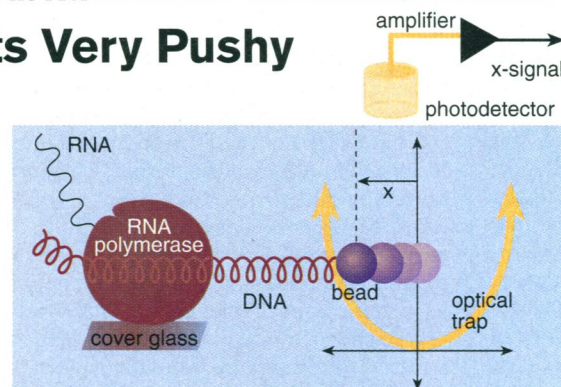
BIOCHEMISTRY

RNA Polymerase Gets Very Pushy

RNA polymerase doesn't appear to be an enzyme designed for hard work. Its main job is to slide along a DNA strand and splice free ribonucleotides into a messenger RNA chain based on the DNA template. But DNA is anything but a well-greased track: Somehow, the enzyme has to negotiate kinks and sticky spots. Motor enzymes, such as kinesin, are designed for such tough situations; they convert energy gained from other reactions into mechanical movement. RNA polymerase bears little resemblance to such molecules, however, and researchers have never thought of it as having a powerful motor. As it turns out, it has one of the biggest.

On page 1653 of this issue, investigators report that polymerase is not only more powerful than motor proteins like kinesin, but it uses fuel—pyrophosphates freed from ribonucleotides during RNA synthesis—just as efficiently. A consortium of three labs—headed by Jeff Gelles of Brandeis University in Waltham, Massachusetts; Steven Block of Princeton University in New Jersey; and Robert Landick of the University of Wisconsin, Madison—measured the force exerted by RNA polymerase as it pulled on a strand of DNA whose far end was caught in a laser-based trap called an "optical tweezers." The tug approached 14 piconewtons; other motor proteins pull at a strength of up to 6 piconewtons.

That combination of power and efficiency indicates why the enzyme can move along a DNA strand with apparent ease. Moreover, the technique gives scientists a whole new window on the interactions between the enzyme and the DNA substrate. Measuring force and displacement may allow them to analyze whether the enzyme moves one base at a time or in longer jumps, and how regulatory proteins such as transcription factors affect that movement. Other researchers are powerfully impressed. "It's one of the most elegant bits of biophysics that's been applied to transcription," says physical biochemist Peter von Hippel at the Univer-



Transcription tug of war. As RNA polymerase transcribes a DNA strand, it pulls a bead attached to its far end from a low-energy spot in an optical trap formed by a laser beam. When the energy of the beam equals the force exerted by the enzyme, the polymerase stalls; that force is indicated by the bead's displacement (x).

sity of Oregon. "This adds a whole new dimension to understanding how the enzyme articulates with the [DNA] strand."

The major obstacles RNA polymerase encounters on a DNA strand are so-called "supercoiled" structures where the DNA helix is further twisted around itself. The polymerase has to overcome these constraints to keep a continuous hold on one strand. That would seem to require a lot of motor power, yet nobody had determined how much drive the polymerase actually had.

The team made this measurement by first fixing the polymerase to a glass cover slip while preserving its transcription activity. The enzyme, held stationary and unable to move along a DNA strand as it normally does, instead pulls the strand toward itself. Then the researchers fastened the far end of the DNA strand to a polystyrene bead just 0.5 micrometers in diameter. The bead is held under the "optical tweezers," an interferometer developed by Block and several colleagues which traps the bead at a low-energy spot at the center of a laser beam.

Then, says Gelles, "you start transcription by adding ribonucleotides." The polymerase starts tugging at the DNA strand, pulling the bead toward areas of more energy and higher resistance. The enzyme stalls when the resis-

tance level of the beam matches the power of the enzyme's tug. A photodetector atop the apparatus measures the displacement of the bead, which is converted into a measurement of the enzyme's force.

Measuring "how much it takes to stall the enzyme is a completely new twist," says von Hippel. In addition to exhibiting the 14-piconewton force, RNA polymerase produces that force as efficiently as do "traditional" motor enzymes, converting about 10% to 20% of the free energy available from one cycle of ribonucleotide addition into mechanical energy. The polymerase, says Gelles, is the first member of what might be an unappreciated class of nucleic acid motor enzymes.

What excites Block about this work is the potential for getting a "blow-by-blow description of the polymerase in real time." Other experiments have indicated that RNA polymerase pauses and reverses at various points along the template, and may occasionally jump 10 bases at a time. Observing the changes in force exerted by the polymerase as it encounters different features of the substrate—individual DNA bases, or regulatory or suppressor proteins—should reveal which of those features are sending which signals. (For more on transcription and chromosomes, see the special section beginning on p. 1585.)

The present apparatus, however, can't measure much beyond overall stalling force. So the researchers are building a force-feedback clamp. Instead of maintaining a constant force on the bead, the clamp will change force to hold the bead steady as events at the polymerase end alter the tugs; researchers can then correlate the force changes with the transcription events. "This paper," says biophysicist Hermann Gaub of the University of Munich, Germany, "is opening up the field."

—Claire O'Brien

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