NORTH AMERICA'S BROKEN HEART

A billion years ago, a huge rift nearly cleaved North America down the middle. And then it failed. Researchers may be getting close to finding out why.

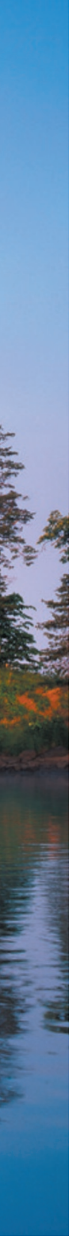
BY JESSICA MARSHALL

Basalt cliffs along the St Croix River are remnants of rifting 1.1 billion years ago.

On a bright October Saturday, the trees have reached their full autumn blaze at Interstate State Park on the border between Minnesota and Wisconsin in the US heartland. Crowds of people gawking at leaves thread their way along paths that wind through bulwarks of dark basalt, leading to views of the St Croix River. Along one of the walkways, a photographer directs a young couple in coordinating grey shirts to lean against the rocks as she snaps a romantic portrait.

If the two sweethearts are looking to commemorate their everlasting love, they should have picked a different backdrop. The fractured basalt that frames their faces is part of a great gash that opened up in the middle of North America and nearly split the continent 1.1 billion years ago — hardly a symbol of a happy union.

The volcanic rocks are remnants of what is called the Midcontinent Rift, and it is an enormous geological puzzle. Rifts are wounds in Earth's outer layer that can grow to eventually form new oceans. That is how the



MARVIN DEMBINSKY PHOTO ASSOCIATES/ALAMY

Atlantic Ocean got its start some 200 million years ago, and an active rift continues to widen that basin. But the Midcontinent Rift was different. It opened a 3,000-kilometre crack in North America and created a basin as big, perhaps, as the Red Sea — then the system shut down. The wound stopped growing and the continent remained intact.

"How that feature could just totally reorganize the crust of the Earth in the Lake Superior region and not manage to break the continent apart is fairly amazing," says G. Randy Keller, a geophysicist at the University of Oklahoma in Norman and director of the Oklahoma Geological Survey. "It's a spectacular failure." And a forgotten one, too. The rift is mostly buried under thick sediments, which makes it hard to study. And it lies far from the continent's attention-grabbing geological features, such as mountain belts and earthquake zones. "For a long time, the rift has been a very neglected thing," says Peter Hollings, a geochemist at Lakehead University in Thunder Bay, Canada.

That is now changing. Geologists have started to flock to the region to explore the enormous deposits of ore minerals left by volcanic activity during the creation of the rift: one area in northern Minnesota, for example, is the largest untapped copper–nickel deposit in the world. Another source of interest has come from the US National Science Foundation's EarthScope project and related programmes, which installed dozens of temporary seismometers across the rift to provide an unprecedented picture of Earth's crust and upper mantle there.

"It's a lot less mysterious than we used to think even a year ago."

Researchers are keen to test theories about why the rift began and failed — and to use the ancient wound to improve more general understanding of how plates move and break apart. What is more, because the lava flows in the rift are stuck in the middle of a continent, they have been left as they were 1 billion years ago, unmangled by the collisions that warp rocks at the edges of continents. The basalts therefore offer an unparalleled record of events on Earth at a time when the continental plates were assembling into a supercontinent dubbed Rodinia, not long after multicellular life evolved.

Among researchers, there is a sense that the rift's time has come. "There's a whole flood of interest on the part of geoscientists who really weren't interested before," says Keller.

LISTENING POSTS

Some 145 kilometres northeast of where the couple posed for its picture, Suzan van der Lee leans into her shovel, grey hair tucked under a bandana. About a metre below the forest floor, she uncovers a seismometer buried in a black plastic pipe. A geophysicist at Northwestern University in Evanston, Illinois, she is there with a graduate student, Emily Wolin, who squats in front of a laptop as she backs up data from the instrument.

The site is 50 kilometres south of Lake Superior, well off the main road amid a dense stand of aspen and oak saplings. Wolin selected the spot two-and-a-half years ago by touring the region, seeking places in or near the Midcontinent Rift that were far enough from roads to avoid vibrations from traffic.

Since then, Wolin has been monitoring the stations every six months. On her rounds, she has had to flee an angry dog, don skis after a late-spring snow and seek help from a bear hunter to rescue her car from mud. One of her stations was burned in a wildfire (it still worked, even though a cable had melted), and another recorded the vibrations of trees crashing down in a massive windstorm. At a different site, a hunter apparently used the solar panel that powered the instrument for target practice: Wolin found a bullet hole right through its centre.

Today the team is here to recover instruments that have weathered two winters while quietly logging seismic activity across the globe. The stations are part of an EarthScope accessory project known as SPREE, or the Superior Province Rifting EarthScope Experiment. The project aims to fill in details about the Midcontinent Rift by installing extra stations — 82 in total — tracing and transecting it. The seismometers provided what amounts to medical scans of the top 1,000 kilometres of crust and mantle near the rift. Van der Lee hopes to use that to better understand what is down there, learn how deep the rift extends and perhaps gather some clues as to what caused it.

Even though the researchers were careful to site the seismometers in quiet spots, the data coming back contain an inevitable amount of noise. The instruments are so sensitive that they detect not only earthquakes all over the world, but also noise from oceans and all kinds of other seismic background activity. The challenge is to pick that apart at each station and extract a real signal. The team is in the thick of that now and it will be months before it has a fuller picture of the subsurface structure.

But the picture that has emerged so far has been intriguing: the data show a significant amount of variation along the rift. "All the things that we're seeing suggest that we're dealing with a very complex structure," says van der Lee.

SECRETS OF THE DEEP

SPREE and other geophysical studies will be key to unlocking the rift's deepest secrets, because most of the structure is hidden. From magnetic and gravity surveys of the region over the past half-century, geophysicists have determined that the rift is shaped like a horseshoe, with two arms pointing south from Lake Superior (see 'Breaking up is hard to do'). Seismic studies in the 1980s revealed that the rift's basalt layers reach deep below ground, up to 30 kilometres below Lake Superior[1]. All told, the rift produced between 1 million and 2 million cubic kilometres of basalt, making it one of the world's largest deposits of that rock.

The sheer volume of erupted basalt has led many to suggest that the rift must have been fed by a mantle plume — a vertical stream of hot rock rising from the depths of the planet. Another widely held idea is that tectonic plates smashing into the continent from the east stopped the rift from growing.

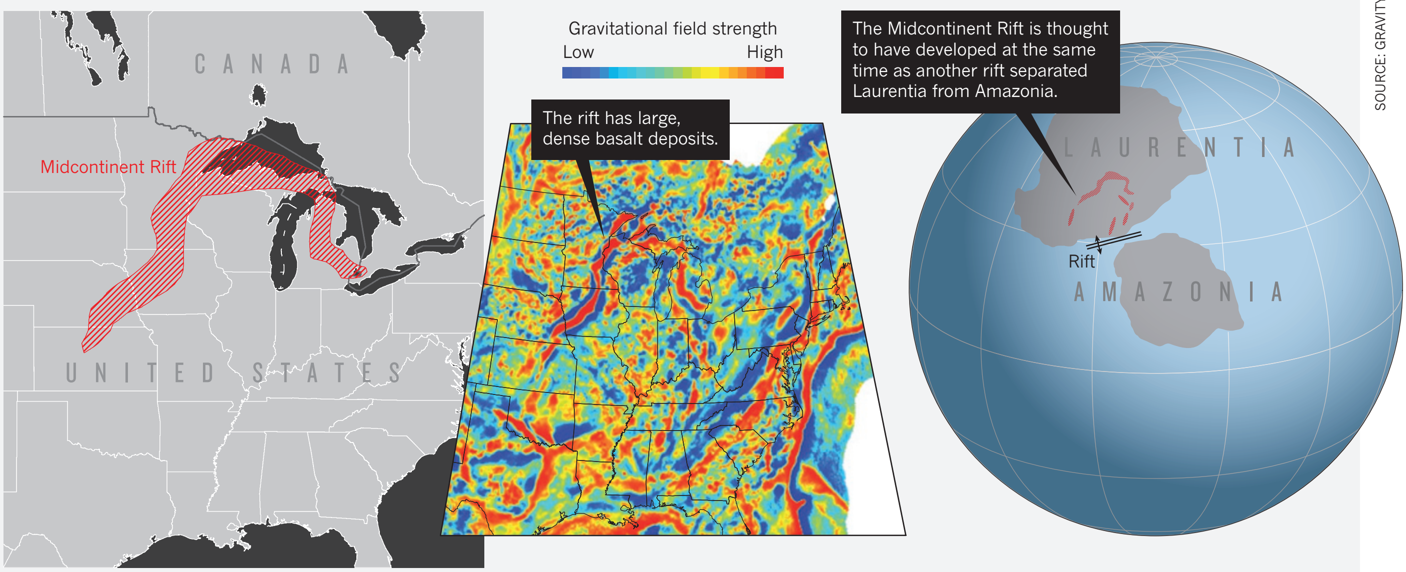
Researchers have used techniques in geochemistry, geophysics and other fields to test these ideas, with conflicting results. "There are problems with all of the models," says Hollings. "None of them really works perfectly." Still, he adds: "All the new work that's being done is allowing us to re-evaluate the models and look at different ways this could have happened."

Some researchers are starting to see the rift as part of a much bigger puzzle. Geophysicist Carol Stein of the University of Illinois at Chicago discussed this idea at a meeting of the Geological Society of America (GSA) in Denver, Colorado, in October. Working with Keller and others, she suggests that the Midcontinent Rift was not isolated, but in fact was connected to other rifts that caused large changes in Earth's tectonic plates at the time — all related to the assembly of Rodinia. The hypothesis is based on previous work[2] by Keller, who has proposed that gravity maps show the arms of the rift extending much farther to the south than was thought, towards the edge of Laurentia, the precursor to the North American continent. Other studies have suggested that Laurentia and Amazonia, the precursor to part of the South American continent, were in contact more than 1 billion years ago, and that they began to separate around the time that the Midcontinent Rift became active[3]. Stein proposes a three-armed rift system, formed of the Midcontinent Rift and the two arms that split Laurentia and Amazonia.

"In a lot of locations, when the continents break apart you seem to have three arms where one arm will fail and together the two arms make a new ocean," she says. "It's a lot less mysterious than we used to think even a year ago. We used to think of the Midcontinent Rift as this kind of weird feature that started and died in the middle of a continent." But

BREAKING UP IS HARD TO DO

Just over 1 billion years ago, North America started to split, opening a rift that filled with volcanic rocks. The wound healed, but left a horseshoe-shaped scar of dense rocks (left) that shows up on a gravity map of the central United States (centre). One theory proposes that the rifting was connected to the separation of Amazonia, now part of South America, from Laurentia, part of modern North America (right).



SOURCE: GRAVITY MAP, G. R. KELLER; GLOBE, C. STEIN

considered in connection with the rifts at the edge of Laurentia, it makes sense, she says. Stein likens the ancient system to what is happening on the eastern edge of Africa today. Two rift arms in the Gulf of Aden and the Red Sea are pushing the Arabian peninsula away from Africa, and another is starting within Africa. If that East African Rift fails to grow and eventually dies, it will end up looking like North America's Midcontinent Rift, she says.

Stein's hypothesis has piqued the interest of other experts. "It's a very reasonable idea," says Stephen Marshak, a geologist at the University of Illinois at Urbana-Champaign, although he feels that more testing must be done. He and others agree that understanding the Midcontinent Rift will provide insight into the East African Rift — what is driving it and how it might propagate in the future. "They are both informing each other," he adds.

HOT ROCKS

Apart from trying to understand the rift, researchers are also interested in using the feature as a window on the past. Protected in the stable centre of North America, the rift's lava flows have remained undisturbed for 1 billion years — a rarity for rocks that old. In some places, ripples that formed as the lava cooled are still visible on the basalt. "It's gorgeous," says Nicholas Swanson-Hysell, a geologist at the University of California, Berkeley. "How well these flows are preserved is pretty amazing. You could go to a lava field in Hawaii that erupted in 1950 and the surface would look similar to this 1.1-billion-year-old surface."

Just this kind of preservation is on display at Mamainse Point on the eastern shores of Lake Superior, where Swanson-Hysell has sampled 95 lava flows along 10 kilometres of shoreline. The individual flows, which range from a few metres to 20 metres thick, are part of a 4.5-kilometre-thick formation of rock created during the most active 15 million years of the rift's 30-million-year lifetime.

Magnetic grains in these rocks captured the orientation of Earth's magnetic field at the time the lava cooled. The readings from these minute frozen compasses can be used to track how Laurentia wandered around the globe during the span of the rifting. When Swanson-Hysell constructed a magnetic record from the Mamainse flows, he found signs that Laurentia may have been moving faster than any other plate is known to have travelled[4]. His latest estimates, presented at the GSA meeting, put its velocity between 16 centimetres and 45 centimetres per year. For comparison, the next-fastest known plate movement is India's 18-centimetre-per-year rush towards Asia between 50 million and 60 million years ago. "This velocity is considered to be very fast and near the maximum rate possible for continental motion," says Swanson-Hysell. Most plates today move only around 4–9 centimetres per year. The range Swanson-Hysell has calculated for Laurentia is broad, but he aims to narrow it in the future.

Knowing how fast the continent moved gives researchers important information to help them to reconstruct the motion of all of Earth's landmasses at the time the rift formed. Swanson-Hysell says it is possible that the extraordinary velocities recorded there reflect more than just Laurentia's movement. Some of the motion could have been caused by a phenomenon called true polar wander, in which the whole crust and mantle rotate together around the core. This would happen if an extra-dense blob of material in the mantle were migrating towards the equator, taking the crust and mantle with it.

If there was true polar wander, it would be a sign of "something big happening in the interior of Earth", says Swanson-Hysell. Even if there was not, he adds, the high speed of Laurentia could provide insight into what was driving the motion of the tectonic plates at the time. The truth could be a combination of the two. To test this, Swanson-Hysell wants to construct similar records for sets of rocks on other continents. If they show the same fast motion, it would demonstrate that all the plates were moving together, pointing to true polar wander. But it is no easy task to find such well-preserved rocks from so long ago.

Back at Interstate State Park, it begins to drizzle, and the crowds head back to their cars. The raindrops darken the basalt, momentarily giving it the look of a fresh lava flow. Soon the site will empty and only the rocks will remain, full of history that geologists are just starting to unravel. ■

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