The Isthmus of Panama: Out of the Deep Earth

April 1 2014, by Kevin Krajick, The Earth Institute, Columbia University

On the remote Azuero peninsula of western Panama, geologists are hunting for rocks that may help tell the story of a pivotal event in earth's history: the formation of the slender land bridge joining the Americas. Centered on the isthmus of Panama, it changed not just the world map, but the course of evolution, climate and ocean circulation. But finding these rocks can be a strenuous task.

As dates in geologic history go, the formation of the slender land bridge that joins South America and North America is a red-letter one. More than once over the past 100 million years, the two great landmasses have been separated by deep ocean waters. The narrow section of Central America that now unites them–at its narrowest along the isthmus of Panama–changed not just the world map, but the circulation of oceans, the course of biologic evolution, and probably global climate. The tortured product of diverse forces, today's version of the isthmus was probably fashioned by volcanism and movements of tectonic plates somewhere between 15 million and 3 million years ago.

Cornelia Class, a geochemist at Columbia University's Lamont-Doherty Earth Observatory, and Esteban Gazel, a Lamont adjunct researcher now based at Virginia Polytechnic Institute, are looking into one of the most mysterious forces at work on this natural construction site: the Galápagos Plume.The plume is a long-lived hot upwelling of material from the deep earth that melts near the surface and has formed strings of volcanoes, both underwater and as ocean islands. Coming from earth's mantle, dozens of miles down, the still-active plume is similar to hotspots of magma that percolate under Hawaii and Yellowstone. It is believed to have started with huge outpourings of lava some 100 million years ago under what is now the Carribean, but due mainly to the movement of tectonic plates above, has since migrated far south and west into the Pacific, to its current active location under the Galápagos Islands, some 600 miles away. Gazel and Class are trying to help unravel its life story, and its role in creating the land bridge. Usually such rocks are buried far below the surface or lie deep on the ocean floor. Here, they are sitting on more or less dry land, offering an unusual window into the processes of the deep earth.

In fall 2012, Class and Gazel hunted for rocks created by the plume on Panama's Azuero peninsula, which juts into the Pacific Ocean. Gazel, who grew up in adjoining Costa Rica (where identical rocks exist), specializes in studying this region. Equally at home discussing melt fractionation chemistry or walking around with an 8-pound sledgehammer slung over his shoulder, he looks around for likely boulders to smash open. Class, a geochemist originally from Germany, is an expert in mantle chemistry; she has worked on rocks from east Africa, Antarctica and the bottom of the Atlantic Ocean. "People often try to understand faraway things, like how the stars are formed," says Class. "Actually, we should be looking much closer to home. Here, we're trying to understand what's underneath us. How did the earth itself develop?"

The largely unpeopled western part of the Azuero peninsula is tough on geologists. Its precipitous hills are swathed in thick red soil and humid forests and pastures; rocks are rarely seen, except in some creek beds or along the coast, where vigorous erosion has shorn off vegetation and dirt. Only recently was a single small paved road pushed partway along the coast, so working inland involves pushing through muddy tracks, fording creeks and getting stranded in the gigantic rainstorms that sweep in every afternoon during rainy season. Along the coast itself, the best research sites are sea cliffs, headlands, detached islets and rubble heaps that plunge directly into the dangerously churning sea. To get at these, Gazel and Class hire a local fisherman to motor his boat in as close as he dares. Then, they plunge over the side with the sledge hammer and other equipment, and swim for it through the surf. If they are lucky, there is a small beach to land on; if not, they must take care not to get dashed by waves against the rocks. After pounding off samples, they swim back to the boat, weighted down now with both their tools, and the rocks. Luckily, Gazel and Class are strong swimmers–and the sharks and crocodiles who sometimes haunt these waters don't seem to be around.

The rocks in this part of Panama are a complicated mélange, representing the complex history of the isthmus. From their heavily weathered exteriors, it is hard to tell one kind from another. It is only by breaking them open that Gazel and Class can tell if they have found their quarry. This is picrite–a type of igneous rock that crystallizes as magma from the mantle heads upward. Generally formed on the seafloor, it contains sparkly yellowish-green crystals of olivine, a typical mantle-derived mineral not seen in rocks formed nearer the surface. PIcking their way through heaps of rounded boulders like convicts on a prison rock pile, Gazel and his graduate student Jarek Trela swing the sledge at likely looking boulders, until an edge splits off. If they are lucky, the telltale crystals lie inside; then they smash the rock into smaller pieces. Class uses a smaller geologist's hammer to clean the weathered outer edges off the fist-size specimens, before bagging them.

Getting almost anywhere inland requires walking and, often, getting soaked. In the fog following an afternoon rain torrent, Gazel and co-investigator Cornelia Class of Lamont-Doherty Earth Observatory ford a swollen creek.

Geologists think the Galápagos plume became active more than 100 million years ago under what is now much of Central America. By about 75 million years ago–apex of the age of dinosaurs–giant outpourings of lava from the plume were helping form an earlier version of the land bridge. Tectonic plates were also shoving up against each other, pushing sections of seabed out of the water. At some point, the combined processes turned ocean into swamplands, then an archipelago–then, eventually, to dry land. The Americas were joined. Creatures once isolated on one continent or the other were able to migrate, and mix back and forth. The proof can be seen today in fossils showing the evolutionary trees of related dinosaurs, and early worms, snakes and mammals in sites as far apart as Utah and Argentina. But this first land bridge is believed to have broken up by around 50 million or 65 million years ago, as continuing tectonic movements at it. (The latter date roughly concurs with a giant meteorite that struck off Mexico that killed off the dinosaurs; but whether that was in any way related to the breakup is unknown.)

Some 15 million to 65 million years ago, the Galápagos plume was migrating westward into the Pacific, forming strings of volcanic islands and underwater volcanoes. At the same time, the Pacific tectonic plate above it was moving back eastward. As the plate moved, it carried remnants of the plume-derived volcanoes back to Central America. Here, the Pacific plate was slowly colliding with a separate plate moving in from what is now the Caribbean. As the opposing plates met, sections of them got scrunched upward, and a second land bridge started taking shape. Some plume-derived islands and seamounts riding on the Pacific plate got plastered onto the developing landmass, like cherries on a cupcake. It is the now-crumbling remains of these traveling volcanic mountains that make up many of the peninsula's hills and sea cliffs. The plume continues to erupt under the distant Galápagos islands (part of Ecuador, not Panama). Its exact shape and the dynamics of the current eruptions are still the subject of some mystery.

Back at the researchers' labs at Lamont-Doherty and Virginia Tech, chemical analyses of the Panamanian picrites will help reveal the timing, temperatures and other conditions under which the rocks formed. The researchers hope this will shed light not only on the formation of the isthmus, but on processes in the deep earth. Gazel and other colleagues have been working on the Galápagos plume for a while now. Among their initial findings: since dinosaurian times, the plume magmas seem to have cooled some 200 degrees F; also the size and rate of eruptions have tailed off. That may mean, says Gazel, that "mantle plumes may be like people; they get old, and die." But this one, he says, has a ways to go before it winks out–probably tens of millions of years.

Regarding the current land bridge, Gazel favors the current theory that it formed in fits and starts, starting like the earlier one, as a series of swamps, straits and islands, maybe 15 million years ago. By maybe 8 million years ago, the moving seamounts were rising from the ocean floor, and crashing into the coalescing masses of land. He thinks it was these mountains that finally fully closed the isthmus, making Panama and Costa Rica the hinge point of the Americas. "Without these, we would not have the land bridge," he says. The conventionally accepted date of full closure is about 3.5 million years ago, but Gazel thinks it could have happened a couple of million years earlier.

Whatever the exact sequence and timing, fossils show that creatures that had evolved in isolation for tens of millions of years in the separate Americas began to once again flow and evolve from north to south. Some of the first were ones that could swim well, or at least wade: southward-heading tapirs, peccaries and elephant-like Gomphotheres, and northward-heading giant sloths, or Megatherium, some as tall as 29 feet. As the land bridge filled in, the trickle of migrants became a flood. This culminated a few million years ago with the so-called Great American Biotic Interchange. At various times, flowing upward from South America came the ancestors of today's North American armadillos, porcupines and opossums, and now long-extinct predatory 9-foot high flightless birds. Heading down from North America came deer, mastodons, camels, raccoons, cats, dogs, and rodents of all kinds. For reasons unknown, the invasion from the north was much more successful than the one from the south. As a result, many southern species were replaced by the northern ones–the ancestors of today's jaguars, llamas and other characteristic South American fauna.

The isthmus united continents, but it divided oceans. Once the Atlantic and Pacific were separated, marine creatures such as mollusks on the shallow, warm Caribbean side took very different evolutionary paths from those on the colder, deeper Pacific side. The circulation of ocean water itself was completely changed, too; before the division, water flowed east to west, from Atlantic to Pacific, but the flow was now blocked. This created a permanent giant detour in the Atlantic–the Gulf Stream–which now pushes warm waters up from the tropics to the edge of the arctic. The transport of that warmth now gives northern Europe its habitably warm climate. And because warmth increases evaporation, it has also probably increased northerly precipitation in the form of snow. At various times in earth's orbital cycle, this has built up into glaciers, pushing the northern hemisphere into the series of great ice ages it has seen in the last several million years. On the Pacific side, weather patterns changed too, with deep waters along the western coasts of both continents continually welling up, and the domination of the cyclic El Niño pattern, in which the eastern ocean surface alternately warms and cools. El Niño now directly or indirectly drives rainfall, and thus agriculture, on scales of decades across much of Asia, and both Americas.

It is along the coast, with its constant tectonic uplift and violent erosion, where rocks are most exposed. But with lack of roads and other obstacles, few sites are accessible by land. This wind-torn islet was reachable at low tide after a hike through the woods. It was volcanic in origin, but turned out to contain no picrite.

"The rocks, our field of study, it's so narrow," says Gazel. "But it also helps us understand a lot about the biology and climate of the earth."

The Isthmus of Panama is not unique. Elsewhere, other land bridges have come and gone. The Bering Strait, which currently divides Alaska and Siberia, has periodically been the Bering land bridge, when ice ages locked much of earth's water into ice, lowering sea levels. It was perhaps the route by which humans and other creatures entered the Americas. At times of lower sea levels, other now-vanished bridges once connected Great Britain to mainland Europe; Sri Lanka to India; and parts of Indonesia or Australia to Asia. Egypt's Sinai Peninsula now links Africa and Eurasia, but it did not always; those continents were once separated, and may be again some day.

Panama remains a crossroad in all ways. When the Spaniards came in the early 1500s, they quickly pegged it as the narrow spot between two great oceans, and used it as the springboard to invade the western Americas. They talked about a canal as early as 1524, but never got around to it. Following the California gold strike of 1849, a railroad across the isthmus carried a flood migrants west. The French tried building a canal in the 1880s, but were halted by malaria and landslides. A takeover by the United States brought completion of the 45-mile-long Panama Canal in 1914–still a pivotal trade route. As the hinge point between the two great continents, Panama (as well as Costa Rica) maintains an outsize store of biodiversity: hundreds of species of reptiles and amphibians, at least 950 species of birds, and legendary yearly migrations of birds and sea turtles on the Azuero peninsula and surrounding areas.

Geology is deeply connected to biology. Formation of the isthmus allowed flora and fauna from South and North America to mix, and formed a rich corridor for current wildlife migrations. At a local fishing harbor, vultures hang out at low tide.

The Panama Canal was a boon for geologists, who gleaned many of their original insights into the region's history from rocks exposed by the excavations. Today, an even bigger canal is being dug alongside, and researchers are heading there again. For now, though, Gazel and Class prefer the wilder, more remote Azuero peninsula. "It's fundamental for us to come here to try and read the rocks, says Gazel. "I also enjoy the nature. There are not that many places left, where you can get away from civilization like this."

Provided by Columbia University

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