SIGN OF LIFE?
Organisms’ effects on terrain aren’t all that easy to perceive
BY SID PERKINS

Imagine our planet unmarred by humans: no buildings, no highways, no farms, no dams, no open-pit mines. Now, imagine the world suddenly swept clean of all life whatsoever: no plants, no animals, not a single microbe. Would the newly vacant landscape retain unmistakable evidence that life had ever existed?

And would that topography be noticeably different if life had never evolved at all? For instance, would Earth’s mountains be craggier, or the courses of its rivers less sinuous, if life had always been absent?

These are the sorts of questions pondered by geomorphologists, the scientists who study the landscape and the processes that sculpt it. For these scientists, contemplating life’s effect on topography isn’t just an academic exercise. Learning how to identify the topographical signs of life on Earth could enable researchers to recognize the same signals on other worlds. It may also help scientists better understand how to restore ecosystems that have been disrupted by natural disasters or human activity.

At scales smaller than a meter, topographical signs of life such as gopher holes and anthills are abundant. However, if viewed at a larger scale—as seen from space, for example—few if any natural landforms on Earth bear the unmistakable mark of life.

“Life’s effects on topography are subtle,” says J. Taylor Perron, a geomorphologist at Harvard University. They don’t reveal themselves in dramatic signatures or single features. Instead, signs of life show up only in the large-scale patterns and general proportions of landscapes, he and his University of California, Berkeley colleague William E. Dietrich proposed in the Jan. 26, 2006 Nature.

Now, a flurry of new research is bolstering that contention.

BREAKDOWN
Without a doubt, life has a powerful effect on the landscape. The chemicals that microbes produce as they colonize rock surfaces pulverize minerals in the rock (SN: 11/15/03, p. 355). Plant roots squeeze into cracks smaller than a human hair and then exert pressures sufficient to split pristine bedrock as they grow. Over time, as the detritus from such erosion blows or washes downhill, sharp, rocky ridges become smooth, rounded hills.

Yet rounded hills aren’t necessarily a sign of life, says Perron. Wind, naturally acidic rain, and physical processes such as freeze-thaw cycles also break down rock. Field geologists can find rounded hills even in the Atacama Desert of South America, a wasteland so arid in some sites that even microbes can’t grow, says Perron. There, soil forms as particles of salt waft in from the nearby Pacific and chemically attack rocks. Images beamed to Earth from rovers on Mars also show rounded hills. The landscape on the Red Planet—which has never seen life larger than a microbe, if that—is probably sculpted by freeze-thaw cycles, says Perron.

Even though vegetation can break apart rock, scientists have considered it an erosion suppressor. Foliage prevents precipitation from striking the ground beneath a plant as forcefully as it would if the soil were unprotected, and a plant’s root system holds the soil in place. Severe erosion has been regarded as a sign of a foliage-free landscape.

However, this traditional view ignores the influence that plants have on the landscape at large scales, new research suggests. By keeping erosion in check at some spots, plants can dramatically boost erosion at bare locales nearby, says Stijn Temmerman, a geomorphologist at the University of Antwerp in Belgium. He and his colleagues analyzed how erosion processes have evolved on a tidal flat in southwestern portions of the Netherlands.

In 1989, this broad stretch of shoreline had only small, isolated patches of Spartina anglica, a salt-tolerant plant known as common cordgrass. As is the case on most barren beaches, water running off the land during ebb tides carved small channels into the sand. Incoming waves largely erased the channels during the next high tide. So, the channels often formed and re-formed at various places along the shore, says Temmerman.

Over time, individual tussocks of grass expanded and coalesced into large, irregular patches of vegetation. Erosion within those patches of grass was minimal—which wasn’t surprising, says Temmerman, because the root systems of the plants stabilized the sand. What was surprising, he and his colleagues note in the July Geology, was the extent to which erosion accelerated in areas of the tidal flat that remained bare.

The patches of vegetation increasingly funneled the water flow to plantfree areas of the tidal flat and boosted erosion there. By 1996, some of the channels were permanent features that measured as much as 10 meters wide and 1.5 m deep, says Temmerman.

After studying a computer simulation of channel patterns generated by tidal flow across a partially vegetated landscape, the team
suggests that the more densely the vegetation grows, the larger the number of erosion channels that will develop in any particular area and the more erosion there will be overall. "That's counterintuitive, because dense vegetation is traditionally considered to decrease overall erosion," says Temmerman.

What's more, he notes, the channels that form in simulations by the team that include vegetation are stable. Unlike channels made by erosion of a bare tidal flat, they don't form and then disappear.

**RAMBLING RIVER** In the lab, scientists are studying how vegetation affects the formation and evolution of meandering rivers, one of the most common features of many landscapes.

Earth's rivers typically flow in single channels that include few islands and follow sinuous courses. In the laboratory, however, scientists have found it difficult to recreate and study scale models of such waterways. In these experimental rivers—reproduced in flat-bottom flumes in which scientists can control the flow of water and soil—channels devoid of vegetation tend to widen, subdivide, and weave back and forth together. This forms a braided pattern that includes many islands, rather than the simpler form that nature takes on Earth.

Recently, geomorphologists Michal Tal and Chris Paola of the University of Minnesota in Minneapolis created a single-channel river by cultivating plants in their scale model. In so doing, they discovered—as Temmerman and his team had on the Netherlands tidal flat—that vegetation tends to stifle erosion in some places but boost it in others. They also found that, on a broad scale, plants can significantly modify the form of a river.

Tal and Paola conducted their simulations in a slightly tilted flume about 16 m long and 2 m wide. For soil, they used sand with a grain size of about 0.5 millimeter, which would represent 20-mm gravel in a full-size river. At any given time, water flowed at one of two rates: a trickle of 0.4 liter per second, which was too little to move any sand, and a flood of 2.1 liter per second, which easily eroded some of the material.

In one experiment, which ran continuously for 119 days, a flood was allowed to occur for 1 hour every 3 days. In another trial, which ran 138 days, a flood happened every 6 days. The researchers began both sets of trials with a scale model of a braided-river system. Just after each flood, they sprinkled alfalfa seeds across the sand—about one seed every square centimeter.

Results of experiments at both flood intervals were similar, Tal and Paola noted in the April *Geology*. In areas where alfalfa sprouted, the plants stabilized the sand. As the vegetation matured, it slowed water flow in the small, shallow channels of the braided layout. This change meant that the channels trapped more and more sand and seeds coming from upstream. Once those seeds germinated and gained a foothold, plants corrallled flood-stage flows into one or two channels with well-defined banks. These channels grew until they were just large enough in total volume to contain the model's flow during flood periods. During periods of trickling water, the large channels still had enough water flow to prevent any more seeds from becoming established.

In the later stages of the simulations, the scale-model rivers began to erode their banks in some areas and to meander, depositing eroded sand in other areas downstream, just as their full-size counterparts do.

These experiments demonstrate how the presence of plants and variations in water flow interact to create single-channel rivers, says Tal. Nevertheless, she notes, the link between floodplain vegetation and a river's structure is complicated. Vegetation doesn't always convert a braided river into one with a single channel, especially when flow volume in the river is consistently low. Also, meandering streams can form in the absence of vegetation. A sinuous, single-channel river on another planet wouldn't necessarily be a sign of life.

Indeed, meandering flows appear in many vegetation-free environments. On Earth, sinuous, single-channel streams carve their way through some permafrost landscapes, says Harvard's Perron. Moreover, deep, riverlike canyons snake across the ocean floor (*SN: 1/1/05, p. 9*). Similar features have even been spotted on Mars and on Titan, he notes. Erosion resistance in all these environments "probably stems from a certain degree of cohesion in the sediments," says Perron.

**SCULPTED BY WIND** In many arid locales, most erosion results from wind-driven material that literally sandblasts the terrain. In such environments, the wind scatters rock dander ranging from dust grains to small pebbles, all of which accumulates in features as small as sand ripples and as large as 100-m-tall dunes. Researchers are just starting to understand the signatures that plant life—or the lack of it—imprints on Earth and other planets.

In desert regions that have no vegetation, the size, shape, and pattern of such dunes depends largely on wind speed, wind direction, and the availability of sand, says Andreas C.W. Baas, an earth scientist at King's College London. Various teams of scientists have developed computer programs that can predict the dunes that will form in bare-sand areas under different scenarios. Now, Baas and Joanna M. Nield, also of King's College, have modified one of those simulations to include the effects of vegetation, something that previous experiments haven't featured.

In the enhanced model, vegetation not only decreases the likelihood that loose sand will be picked up by the wind but also slows down the air, which in turn drops more of the sand it's carrying. Researchers using the simulation can add to their landscapes various combinations of grasses, slow-growing shrubs such as creeping willow, and fast-growing shrubs such as mesquite. Each type of plant has a different effect on the erosion and deposition of sediment, says Baas.

He and Nield ran more than 1,200 computer simulations, each of which tracked the evolution of dunes in vegetated landscapes over a period lasting up to 50 years. Simulations varied only in the peak growth rate of the plants incorporated, but that change was enough to represent the effect of various plant species, says Baas. At the beginning of each simulation, the landscape was fully vegetated except for a 5-m-by-5-m patch of bare sand from which dunes could originate. The researchers described their findings in the March 28 *Geophysical Research Letters*.

Despite the variety of scenarios that the team analyzed, only eight types of cyberdunes resulted, each of which could be matched to a type actually seen in coastal environments on Earth. Some of the model's dunes were long, bare ridges of sand, like those commonly seen parallel to a beach, and others were lumpy mounds with wisps of sand trailing downwind. Simulations representing landscapes dominated by dense, fast-growing vegetation produced dunes that quickly became locked in place, says Baas.
Results of the simulations indicate that U-shaped dunes form only when two types of vegetation are present: a fast-growing grass that stabilizes the bulk of the dune and a shrub that locks down the wispy piles of sand extending from each end of the dune. In this, too, the model seems to duplicate reality, says Baas. Scientists have recorded such "parabolic dunes" only in places on Earth where sand supports discernible vegetation.

Is a U-shaped geological feature the topographical sign of life that researchers should look for on other planets? Not necessarily, Baas notes. Not all arid regions of Earth have been surveyed for dune types, so parabolic dunes might be out there in grass-and shrub-bare areas. Also, he notes, in the alien environments of other planets, some unknown chemical or physical processes could mimic the dune-freezing action of vegetation. In an effort to find more parabolic dunes on our planet, Baas says, "I spend a lot of time on Google Earth looking for U-shaped dunes."

LOOKING FOR LIFE The true topographic signs of life appear to be subtle. Although U-shaped dunes and single-channel rivers may not require vegetation to form, they probably appear more frequently in landscapes where life exists than they do in barren ones, says Perron. Therefore, differences in the overall pattern of features, not the features themselves, may be the key to detecting life from a distance.

One finding in Baas and Nield’s study bolsters this notion. Simulated landscapes populated only by mesquite produced dunes with a consistent size and spacing. In vegetation-free regions of deserts, Baas notes, dunes often form in a wide variety of sizes with inconsistent spacing. So the size of dunes—in particular, a size that typically falls within a small range—may be a sign of life, says Baas.

However, Perron notes, landscapes without soil-stabilizing plants can have features of a consistent size as well. The size and spacing of ripples that form in barren sand that’s below shallow, flowing water is just one example. Nevertheless, the sort of research conducted by Baas and Nield is “a good start to understanding where biotas are important,” says Perron. “Scientists don’t have a good handle on the feedbacks and interactions” between life and geological processes such as erosion, he notes.

As simulations improve, they’ll incorporate better calculations of the complex physics involved in most geological processes, says Perron. In principle, he adds, “we [geomorphologists] would like to be able to do what climate modelers do.” Rather than predict the evolution of climate, though, geomorphologists could predict the long-term topographic consequences of human activities such as suburban sprawl, or assess the likely outcome of environmental-restoration projects, such as removing a dam from a river.

Such models could also enable scientists to evaluate the effect of climate change on various landscapes, says Baas. Dunes that are now stabilized by vegetation could be reactivated if precipitation decreases below what’s needed to nourish the plants. Conversely, an increase in nitrogen-bearing substances deposited from the atmosphere could fertilize vegetation that might immobilize once-barren, shifting dunes.

One hurdle for creating accurate models is a lack of detailed data from other—and presumably lifeless—planets, says Perron. “We don’t have meter-scale topographical data for anywhere but Earth,” Perron notes. However, Mars Express, a European Space Agency probe that began orbiting the Red Planet late in 2003, will map the entire planet at a scale of 10 m. Detailed images of some swaths of the planet will enable scientists on Earth to detect Martian features as small as 2 m across, he adds.

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