Rock turns into soil at a ‘shockingly fast’ pace

Posted by Hannah Hickey-UW January 17th, 2014

Geologic time is shorthand for slow-paced. But new measurements from steep mountaintops in New Zealand show that rock can transform into soil more than twice as fast as previously believed possible.

“Some previous work had argued that there were limits to soil production,” says first author Isaac Larsen, who did the work as part of his doctoral research in Earth sciences at the University of Washington. “But no one had made the measurements.”

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The findings are more than just a new speed record, researchers say. Although they occupy just a few percent of the Earth’s surface, rapidly eroding mountain ranges account for at least half of the total amount of the planet’s weathering and sediment production.

So the soil production at the mountaintops has implications for the entire carbon cycle by which the Earth’s crust pushes up to form mountains, crumbles, washes with rivers and rainwater to the sea, and eventually settles to the bottom to form new rock.

“This work takes the trend between soil production rates and chemical weathering rates and extends it to much higher values than had ever been previously observed,” says Larsen, now a postdoctoral researcher at California Institute of Technology (Caltech).

The study site in New Zealand’s Southern Alps is “an extremely rugged mountain range,” with rainfall of 10 meters (33 feet) per year and slopes of about 35 degrees.

20 pounds of soil

To collect samples Larsen and co-author André Eger, then a graduate student at Lincoln University in New Zealand, were dropped from a helicopter onto remote mountaintops above the tree line. They would hike down to an appropriate test site and collect 20 pounds of dirt apiece, and then trek the samples back up to their base camp. The pair stayed at each of the mountaintop sites for about three days.

"I've worked in a lot of places," Larsen says. "This was the most challenging fieldwork I've done."

Researchers then brought soil samples back and measured the amount of beryllium-10, an isotope that forms only at the Earth's surface by exposure to cosmic rays. Those measurements showed soil production rates on the ridge tops ranging from 0.1 to 2.5 millimeters (1/10 of an inch) per year, and decrease exponentially with increasing soil thickness.

The peak rate is more than twice the proposed speed limit for soil production, in which geologists wondered if in places where soil is lost very quickly, the soil production just can't keep up. In earlier work Larsen had noticed vegetation on very steep slopes and so he proposed this project to measure soil production rates at some of the steepest, wettest locations on the planet.

Years, not centuries

The new results show that soil production and weathering rates continue to increase as the landscape gets steeper and erodes faster, and suggest that other very steep locations such as the Himalayas and the mountains in Taiwan may also have very fast soil formation.

"A couple millimeters a year sounds pretty slow to anybody but a geologist," says co-author David Montgomery, professor of Earth and space sciences. "Isaac measured two millimeters of soil production a year, so it would take just a dozen years to make an inch of soil. That’s shockingly fast for a geologist, because the conventional wisdom is it takes centuries.”

The researchers believe plant roots may be responsible here. The mountain landscape was covered with low, dense vegetation. The roots of those plants reach into cracks in the rocks, helping break them apart and expose them to rainwater and chemical weathering.

“This opens up new questions about how soil production might happen in other locations, climates, and environments,” Larsen says.

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Root fungi turn rock into soil

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Scots Pine seedling growing along a biotite (Bt) flake.

Trees help to break down barren rocks into soil, but how does that work exactly? It turns out that tiny fungi living on the trees' roots do most of the heavy work.

The fungi first bend the structure of certain minerals, weaken their crystals and then remove any useful chemical elements to pass on to their host tree. During the process, the rocks change their chemistry, lose their strength and in the long-run become soil.

These hard-working fungi are called mycorrhiza and cover the roots of trees like gloves. They are extremely small and thin, but they are everywhere: 'it is estimated that every kilogram of soil contains at least 200 km of fungi strands,' says Dr Steeve Bonneville, from the University of Leeds.

Bonneville explains: 'Mycorrhiza have a perfect business relationship with plants and especially trees.' They help the plant to get nutrients from the soil and in return they receive part of the carbon produced during photosynthesis.

About 90 per cent of tree roots in boreal forests have this symbiotic association with mycorrhiza.

Mycorrhiza play a major role in soil formation, but how do they do it? 'We created the first experiment that closely copies a natural system to find out how mycorrhiza help to break down minerals,' says Professor Liane G. Benning, the Leeds principal investigator of the project.

Together with colleagues at Sheffield the team planted a Scots pine seedling with the fungi Paxillus involutus, a mycorrhiza species. 'This is a very common tree-fungi association that occurs naturally in boreal forests,' says Bonneville. The tree and fungi were allowed to grow together for about 10 weeks and were then placed in a transparent pot with flakes of biotite, a common rock-forming mineral rich in potassium, iron and magnesium.

The seedling's roots became covered with fungi, which soon attached to the biotite. After three months, the scientists removed the biotite from the experiment and sampled the crystal along a single strand of fungi-covered root from the tip, middle and close to the root.

Bend first, steal later<\b>

'The first change we observed in the biotite, at the tip of the mycorrhiza, was mechanical stress,' says Benning. The fungi can apply a pressure onto the minerals that can be as high as the pressure in an average car tyre. This pressure value is 'very high', for a tiny organism, but unsurprising to Bonneville: 'these fungi evolved to penetrate minerals and rocks and some species are capable of even higher pressures.'

As a consequence of the pressure at the tip, the biotite starts to bend and to lose its strength. 'Once the crystal structure is weakened, the chemical changes start,' explains Benning. The mycorrhiza then proceeds to remove the potassium and other useful nutrients from the biotite, passing them on to the roots and ultimately the tree. Without potassium, the biotite breaks down into vermiculite and ferrihydrate, two minerals common in soils.

The mechanism - bend the structure first, steal nutrients later - is an efficient way for the fungi to breakdown minerals and at the same time gather essential nutrients for its host tree, write the authors on the report, published in July's edition of the journal Geology.

'This is a significant advance on previous simplistic ideas of mineral breakdown,' says Benning.

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S. Bonneville, M.M. Smits, A. Brown, J. Harrington, J.R. Leake, R. Brydson and L.G. Benning. Plant-driven fungal weathering: Early stages of mineral alteration at the nanometer scale Geology July 2009, v. 37, p. 615-618, doi:10.1130/G25699A.1

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