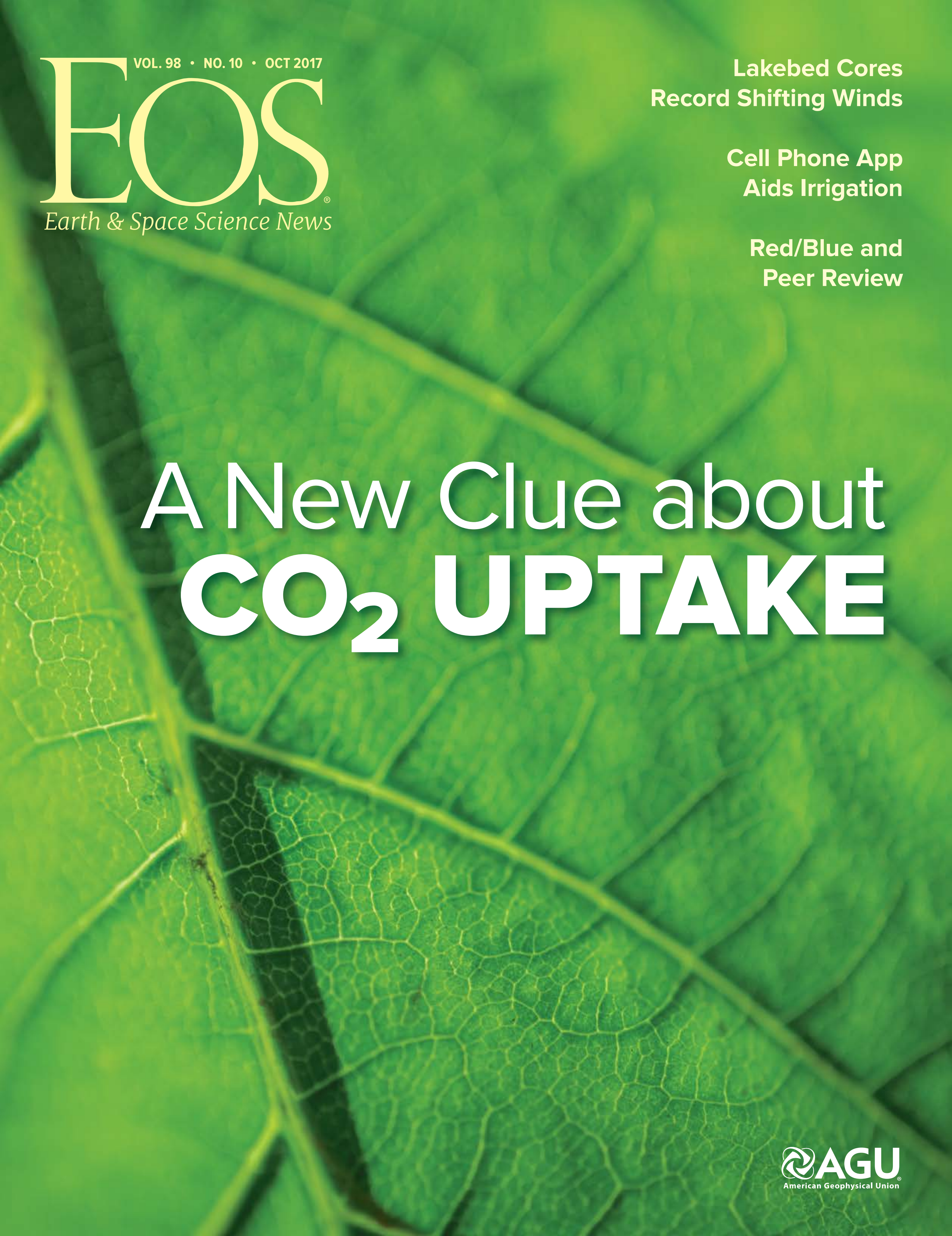

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rupted in a similar way because they're located in a natural depression in the cave, Rubin said. "They're packed down and they're protected."

The research team reported its findings in July in *Nature Communications* (http://bit.ly/nat-comms-paper).

Far from Constant

Rubin and his team showed that the time span between successive tsunamis is far from constant. Although 10 intervals within 4,500 years breaks down to an average of 450 years between the events, the researchers found evidence of one 2,000-year period free of tsunamis and also a single century that saw four tsunamis. "This study provides new evidence that tsunami recurrence can be highly variable," said Katrin Monecke, a geoscientist at Wellesley College in Wellesley, Mass.

The researchers, who included earthquake scientists, hypothesized that the thickness of each sand layer reflects the magnitude of the tsunami-causing earthquake because a larger earthquake would produce a larger tsunami and therefore plausibly transport more sand into the cave. According to this theory, the thickest sand layer, measuring roughly 25 centimeters, should correspond to the strongest earthquake that occurred within the nearly 5,000 years of history recorded in the cave.

The scientists inferred that no tsunamis occurred for more than 2,100 years after this thickest layer of sand was laid down. This extremely long interseismic gap is consistent with a period of reduced stress along faults—and therefore of a lower probability of another quake—after a massive temblor released a large amount of energy, the team suggests. Conversely, the researchers found that the four sand layers corresponding to the four tsunamis that occurred within 100 years of each other were all thin (fewer than 10 centimeters), which makes sense, they argued in their paper, because short interseismic periods are consistent with weaker earthquakes.

Rubin said he and his colleagues hope to find additional caves containing evidence of past subduction zone earthquakes. Although other complementary techniques exist for determining that tsunamis occurred in the past, for example, oral histories and chemical analysis, Rubin and his team are excited to literally dig into the past. "The only way to get at tsunami[s] older than historical records is with geology," Rubin said.

By **Katherine Kornei** (email: hobbies4kk@gmail.com; @katherinekornei), Freelance Science Journalist

Satellite Observations Could Help Forecast an Eruption's End

Lava flowing from Kīlauea volcano destroyed a road on the island of Hawai'i in 2010. A new study uses satellite observations to help predict how long such outpours of lava will last. Credit: U.S. Geological Survey Hawaiian Volcano Observatory

A method for predicting when a volcano will erupt has long remained out of reach. Less studied, but also important for public safety, is forecasting when eruptions will end, a feat that has proven equally elusive.

Now researchers are using satellite data to test a 1981 theory that lava flow–forming eruptions follow a predictable pattern, and they have confirmed the pattern in many cases. What's more, they find that by using the theoretical model and observations from space as their guides, they can predict with considerable accuracy when those pattern-fitting eruptions will stop.

"I actually didn't think it would work at all," said Estelle Bonny, a Ph.D. candidate at the University of Hawai'i at Mānoa who is affiliated with the Hawai'i Institute of Geophysics and Planetology (HIGP) and is the lead author of a recent paper about the findings. She said that she had suspected the model was too simple for a complex natural process, but "I was happily surprised that it made sense and could be used."

Effusive eruptions, characterized by lava flows, can go on and on. "It might only be a couple of days, but it can also be a year," Bonny said. "For people who live nearby, knowing when it will end can be important to knowing if they have to evacuate and, if they do evacuate, when they will be able to go back home."

"Wadge Curve"

British volcanologist Geoff Wadge came up with the 1981 theory that the rate of flow in an effusive eruption would follow an asymmetrical curve: an early cascade of lava, followed by a gradual decline.

Back then, measuring the rate of discharge involved difficult and dangerous fieldwork, and scientists might get only one or two measurements per eruption. However, since 2000, instruments aboard NASA's Terra and Aqua satellites have taken infrared thermal measurements of active volcanoes four times a day. From this, researchers readily calculate discharge rates. "Now we're lucky to have way more data sets than he had," Bonny said. "We wanted to use this [abundance] of data to see if the theory still makes sense."

In a paper published online in June in the *Bulletin of Volcanology* (http://bit.ly/end-lava-paper), she and her adviser, Robert Wright, associate director of HIGP, looked at 104 effusive eruptions that took place at 34 different volcanoes over the past 15 years. Of these, 32 eruptions followed the asymmetrical "Wadge curve," with an early peak and gradually slowing flow. Eight more were "double-pulse" eruptions: two initial bursts, followed by the same slow decline. Thirteen others she described as "half Wadge": an early peak, followed by a slow flow that continues for a long time.

The remaining 51 eruptions followed no pattern at all. "It's not perfect," Bonny said. "Sometimes it doesn't show the trend, but sometimes it does."

More Data Mean Better Forecasts

For eruptions that did follow the model, the scientists found that they could use satellite data to forecast in retrospect when eruptions would end.

It took 3 days' worth of observations to predict that the December 2005 eruption of Piton de la Fournaise on Reunion Island in the Indian Ocean would last for 9 days—it ended up stopping on the tenth day.

The model also worked for longer volcanic activity, like the eruption of the Kizimen volcano in Kamchatka, Russia, that began in March 2011. Bonny found that the longer she observed the volcano, the more accurate her prediction became. After 102 days of observations, the model predicted that the eruption would end after 210 days, just 2 days shy of the actual duration of 212 days. "About halfway through the eruption you could have a good prediction," she said. The prediction didn't change significantly after the halfway point.

What about eruptions that don't fit the pattern? The team didn't look at explosive eruptions. Those blasts generally offer little mystery about when they will end; most of the action typically ceases after that first, powerful bang.

"About halfway through the eruption you could have a good prediction."

Among the remaining lava-exuding eruptions the team investigated, Bonny found that the model could still predict double-pulse eruptions simply by resetting the curve at the second peak of the eruption.

However, she and Wright found that the model could predict endings for neither the half Wadge nor random-pattern eruptions. Nonetheless, Bonny said that applying the model to satellite measurements of such eruptions can still yield valuable insights. In about the same amount of time it would take to forecast an eruption's duration, observers can figure out what type of eruption they're dealing with, she noted.

Public Safety Applications

Ben Kennedy, a volcanologist at the University of Canterbury in Christchurch, New Zealand, said that the Hawaii team took the kind of space-based observing, data analysis, and modeling that represents "the future of volcanology" and applied those tools to a practical, public safety problem.

"This paper is answering the right questions," Kennedy said. "Hazard managers need to know what are the likely impacts of the event. A massive part of the impact is the duration of the [eruption]; this affects all sorts of critical hazard management decisions."

Although the study reaffirmed that every eruption is different, it also made significant steps toward classifying effusive eruptions, Kennedy said. "It seems about 50% are behaving in a predictable way. And about 30% are behaving in a way that will allow accurate predictions during the eruption of when it might end."

For Bonny, that's the next step. So far, she has produced only retrospective predictions, but she is now making plans to test the model on volcanic eruptions in real time—maybe on a volcano close to home. Bonny said that a future eruption of the island of Hawai'i's Kīlauea volcano, which has threatened nearby towns with lava flows in the past, would be a good case study for the modeling method.

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