Volcano research flows from North Korea

An international team of scientists is studying Mount Paektu to understand its past activity and future hazards.

THE CALDERA LAKE AT THE SUMMIT OF MOUNT PAEKTU is about 5 km long and is roughly evenly split between North Korea (near side) and China.

"Enigma surrounds Mount Paektu's origins," says Clive Oppenheimer, a volcanologist at the University of Cambridge. The 2700-meter-tall volcano, which straddles the border between North Korea (officially the Democratic People's Republic of Korea) and China, is not near a tectonic plate boundary, he explains. "We don't understand why the volcano is where it is."

Mt. Paektu is important symbolically and culturally for Koreans—it is part of their founding myth and figures in the national anthems of both North and South Korea. It's a tourist hot spot, and is pictured on stamps, on calendars, and in official photos. The volcano's "millennium" eruption, around 946 CE, was one of the largest in history.

Oppenheimer is one of a handful of Western scientists who, with their counterparts in North Korea, are studying Mt. Paektu. The research has two thrusts: seismology, to look for molten rock beneath the volcano; and geology, to pry from rocks clues of the volcano's past. Overall, the scientists want to learn about the history of the volcano and assess risks of future activity. The scientific work is also breaking ground in terms of international cooperation.

"Amazing access"

Early last decade Mt. Paektu showed signs of activity. Scientists in the region observed an uptick in local earthquakes and measured changes in the gases emerging from the volcano's hot springs. On the Chinese side—where the volcano is called Changbaishan—GPS observations showed ground deformations. The volcano's activity made people in the area nervous about a potential eruption. Although the mountain had quieted down by 2010, North Korea reached out that year, via the nongovernmental organization (NGO) Pyongyang International Information Center of New Technology and Economy (PIINTEC), for help with studying the volcano.

On PIINTEC's behalf, Richard Stone, international news editor for *Science* who at the time was based in Beijing and had previously visited North Korea, invited Oppenheimer to help. He, in turn, brought in James Hammond of Birkbeck, University of London. In the summer of 2011, the trio, working with the Beijing-based international NGO Environmental Education Media Project, made their first visit to Mt. Paektu. During that first trip, visiting and North Korean researchers set scientific goals.

Out of that and subsequent trips has developed a collaboration made up of five or six Westerners—from the UK, the US, and France—and a couple dozen North Korean scientists. The Washington, DC–based Richard Lounsbery Foundation gave the collaboration about $200 000, which the team stretched to cover fieldwork, lab costs, and travel. The American Association for the Advancement of Science, publisher of *Science*, and the Royal Society helped with obtaining export licenses to send scientific instruments to North Korea.

Hammond arranged to borrow six seismometers through the UK's Natural Environment Research Council. They would be used for recording the passage of seismic waves from distant earthquakes to provide a window into Earth's interior. "We are trying to image the inside of the volcano and understand what's happening now," he says.

In 2013 the partners installed the seismometers in a line descending the volcano's slope and reaching out to 60 km away; the seismometers were retrieved and returned to the UK this past September. The North Koreans had built concrete structures to protect the seismometers from the weather, says Hammond. Three were sited in family gardens in distant villages. "To study the crust and magma, you also need to see the normal crust, far from the volcano," he explains. "We were taken into people's homes. It was humbling to get this amazing access."

Revealing rocks

The geological research at Mt. Paektu involves collecting and analyzing rocks. Kayla Iacovino, a former student of Oppenheimer's, traveled to Mt. Paektu in 2013. "We collected samples of pumice,

lava flows, ash beds—a lot of things that we can analyze to try to understand chemically," she says. She went home with about 10 kg of rocks and left roughly the same amount in Pyongyang. She continues to work on the project as an NSF postdoctoral fellow based at the US Geological Survey in Menlo Park, California.

"I am really interested in the millennium eruption," says Iacovino. Back in the lab, she looks for melt inclusions in the rocks. If magma traps liquid when it crystallizes, "that blob of liquid is frozen in time," she says. "You get a history of what happened during the last eruption. You can ask, How much gas was there? How much came out? And then big questions like, What impact did the eruption have on local and global climate?"

The simplest experiment is to crush the rocks and analyze the chemistry of the bulk, says Oppenheimer. More powerful experiments include remelting crushed rock at different temperatures and pressures. By re-creating rocks like the originals, the physical conditions of the volcanic eruption can be identified. "If you pick any piece of lava," says Oppenheimer, "the crystals will have very particular compositions and abundances, and those proportions are really sensitive to the conditions the magma experienced—what temperature, pressure, chemical activities, and water." The method, he says, allows the researchers to pinpoint a rock's origins to within 1 km in depth and 25 °C in temperature.

Building trust

The North Korean researchers know the mountain, and "they are well trained—they are better at math than most of our students," says Oppenheimer. But they lack sophisticated lab equipment, seldom attend international conferences, and have restricted internet access. "That's why they are reaching out to us to provide expertise. And we benefit from the opportunity to work on a very interesting volcano," he says.

The biggest challenges are communication and bringing equipment to North Korea. All communication is via PIINTEC translators. "You can't just shoot off an email," says Iacovino. PIINTEC—which also facilitates other logistics—passes messages to and from the North Korean scientists at the country's Earthquake Bureau. Still, Hammond says, communication has become easier "as our project has gone on and as we have established trust."

CLIVE OPPENHEIMER

KAYLA IACOVINO (wearing hat), translators from PIINTEC, and scientists from the North Korean Earthquake Bureau enjoy a picnic lunch during a rock-collecting expedition on Mt. Paektu.

Another restriction was triggered in the field: North Korea didn't let the Western scientists carry detailed maps or GPS. Instead, says Iacovino, the local partners "planned which sites they wanted to show us."

Equipment was restricted by international sanctions. "Getting that sorted out was a big challenge," says Hammond. He and his colleagues had originally hoped to measure Earth's conductivity with magnetotellurics. The method uses measurements of time-varying magnetic and electric fields to deduce the state of the subsurface, since molten rock conducts better than solid rock. But the UK government denied permission because the instruments are considered to be dual use—that is, to have military purposes. The team compensated by extending the period of seismological imaging. "We hope that will allow us to achieve our objectives with seismology alone, instead of with seismology and conductivity," Hammond says. Delays in obtaining the export license for the seismometers held up their installation by a year.

Given the differences in the cultures, Hammond says, "one of the most exciting outcomes was how much trust we have built up." He and Oppenheimer were helped by their previous experience in Eritrea. Hammond lists some guidelines for successful cross-cultural scientific collaborations, with the most important being to have clear and realistic scientific objectives. And, he says, open communication, enthusiasm, and flexibility in dealing with inevitable challenges and changes in plans are key to building trust. So far, Hammond has visited North Korea seven times, and last spring three members of the North Korean team spent several weeks in the UK participating in the analysis of the seismological data.

The collaboration's first publications were expected imminently as PHYSICS TODAY went to press; about a dozen North Koreans and a half dozen Westerners are coauthors. Now, says Hammond, "we are looking for funds to build on what was a relatively small project." The three intertwined objectives researchers still want to address, he says, are the history of the volcano, why it is where it is, and how hazardous it is.

In addition, says Oppenheimer, "James [Hammond] and I also work with Chinese scientists, and we'd like to facilitate the Chinese and North Koreans working together." Until now, research on Mt. Paektu on the North Korean side and research on the Chinese side have been largely disconnected.

Toni Feder