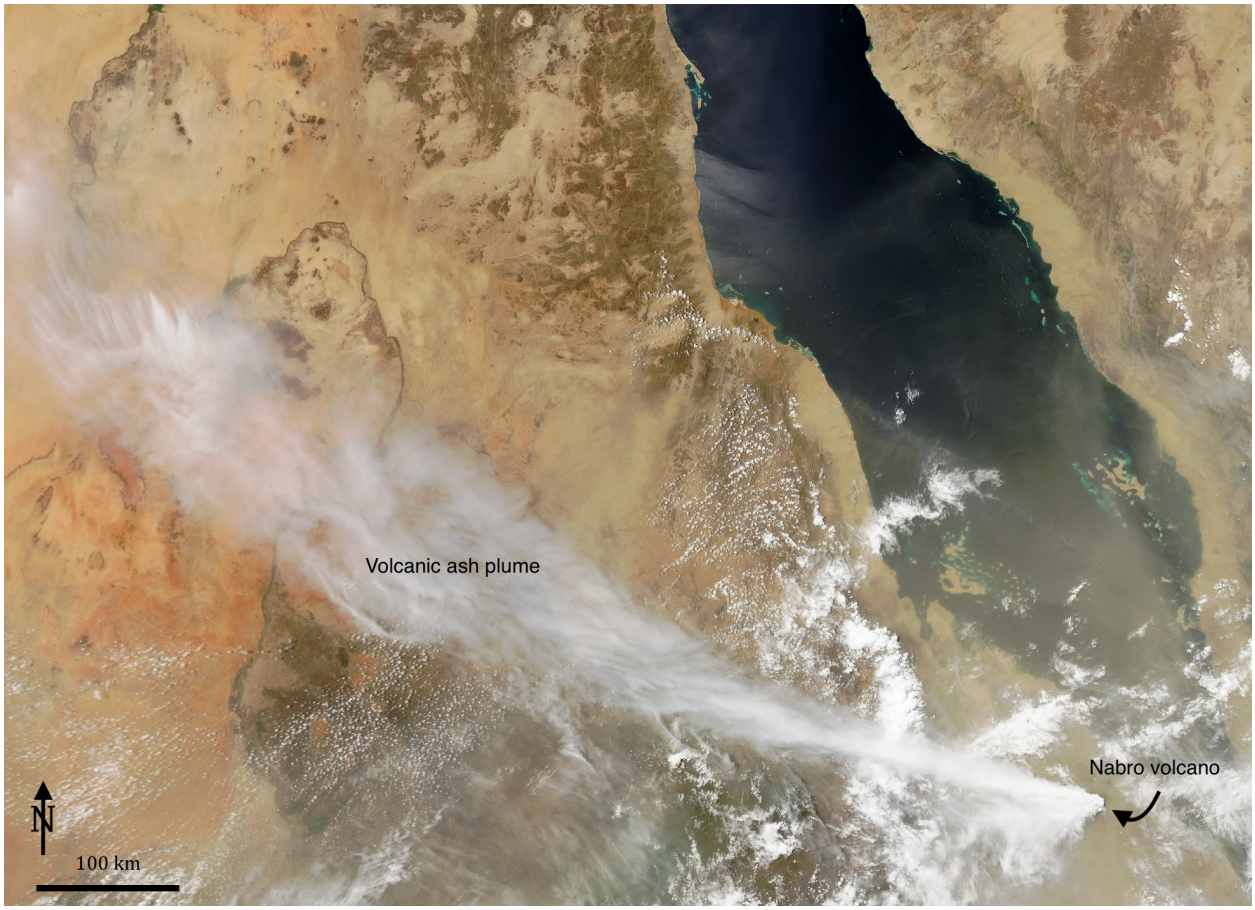
Teaching resource for Geography Southwest

Exploring volcanic hazards and risk in Ethiopia

Erin Martin-Jones, University of Cambridge



2011 eruption of the Nabro volcano, on the Eritrea-Ethiopia border. Image credit NASA

Erin worked on lake sediment records of past volcanism in the Ethiopian Rift as part of her NERC funded PhD at the Department of Geography & Earth Sciences, Aberystwyth University, and later as a researcher at the University of Cambridge Tephra Lab, within the Department of Geography.

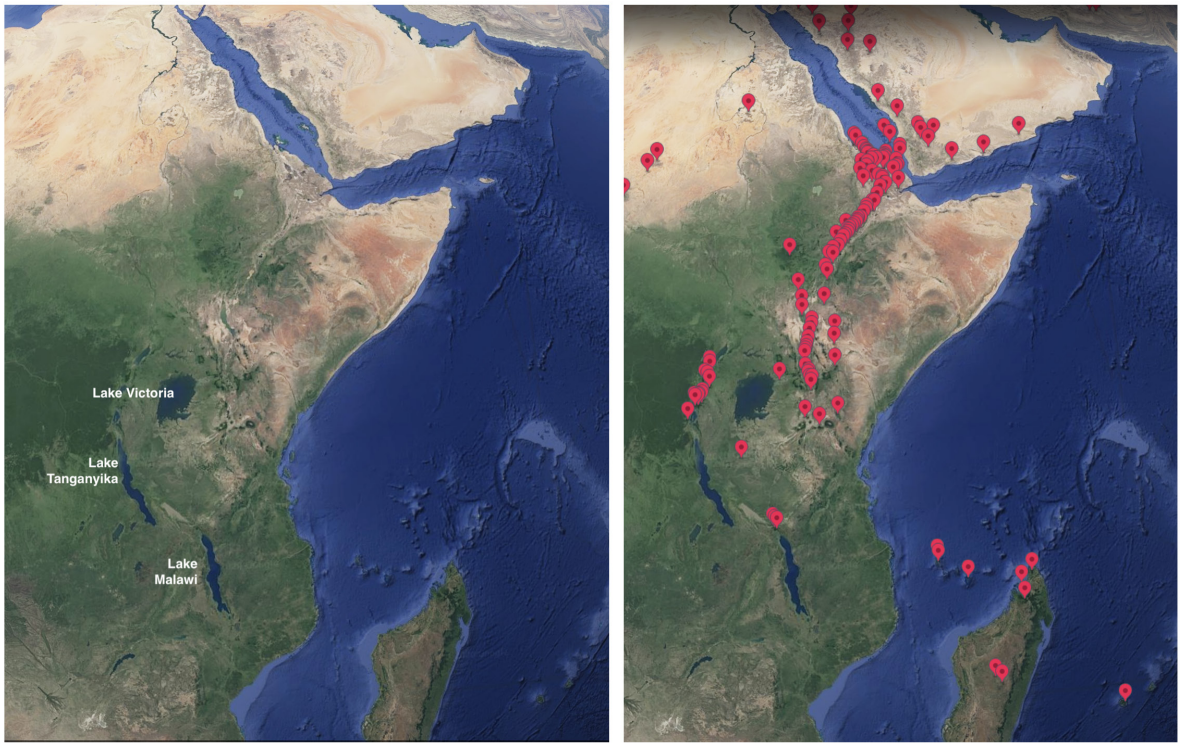
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The East African Rift

The East African Rift Valley is one of Earth's most iconic geological features. You can see it from space, stretching 6,000 km through Ethiopia, Kenya, Rwanda, Burundi, Zambia, Tanzania, Malawi and Mozambique. The Rift is a gigantic fracture in the Earth's crust; the point at which East Africa is splitting in two and new land is being created. The spread is slower than the rate our fingernails grow, but come back in a few million years and a new ocean may have formed.

A chain of lakes and volcanoes is found in this channel of subsiding land. Tanganyika (the second-deepest freshwater lake on Earth) Malawi and Kivu are just some of the lakes formed by rifting. The thinning crust allows magma to rise, some of it piercing through the surface to form volcanoes. There are more than 100 young volcanoes (those which have erupted over the last 10,000 years) along the length of the East African Rift.

Many of these volcanoes are currently dormant, but they could erupt in the future. Back in 2011 the Nabro volcano, on the Eritrean-Ethiopian border, erupted unexpectedly. At the time there was no permanent system for monitoring volcanoes in Eritrea or Ethiopia, so the eruption was only spotted on satellite images. Seven people were killed by the eruption



Maps showing the East African Rift, with the Great Lakes on the left and recent volcanoes on the right in pink. Images from Google Earth, using the '10000 years of volcanoes layer'

and 12,000 were left homeless. Flights were cancelled as the sulfur-rich ash cloud spread out over Sudan and Saudi Arabia.

Volcanic Hazards in East Africa

The East African Rift is home to a great variety of volcano types, from explosive stratovolcanoes and calderas like Nabro to effusive basaltic fissures that produce mainly lava. Some of the volcanoes here erupt less than once a millennium, whilst others erupt once every 200 years.



Longonot Caldera, in the Kenyan Rift. The caldera formed after a large explosive eruption about 20,000 years ago. Image credit: Orientalizing on Flickr (CC BY-NC-ND-2.0).



The Chyulu Hills volcanoes (Kenya). These small scoria cones typically erupt only once, and often produce extensive lava flows. Image credit: Peter Steward on Flickr (CC BY-NC-ND-2.0).

Many of East Africa's volcanoes are currently dormant, but it is likely that several of the large stratovolcanoes could erupt in the coming decades. Using a satellite-based method called InSAR, which measures changes in the shape of the Earth's surface (or geodesy), volcanologists have observed magma movement beneath eight Kenyan and Ethiopian volcanoes - suggesting future eruptions are likely (Biggs *et al.,* 2009; Biggs *et al.,* 2011).

We can tell that these stratovolcanoes have been active in the past. In the rocks surrounding these volcanoes are layers of volcanic ash and debris; deposits from explosive eruptions that occurred hundreds or even thousands of years ago.
Ash fall (or *tephra*; from the greek for ashes) is one of the more deadly hazards in a volcano's armoury, and can potentially have widespread impacts. Nearby the volcano, tephra can be several metres thick, causing buildings to collapse and blocking roads. Tephra can also fall hundreds of kilometres downwind of the volcano. Although deposits are often thinner here, just a few millimeters of tephra can shut down airports and result in damage to farmland.

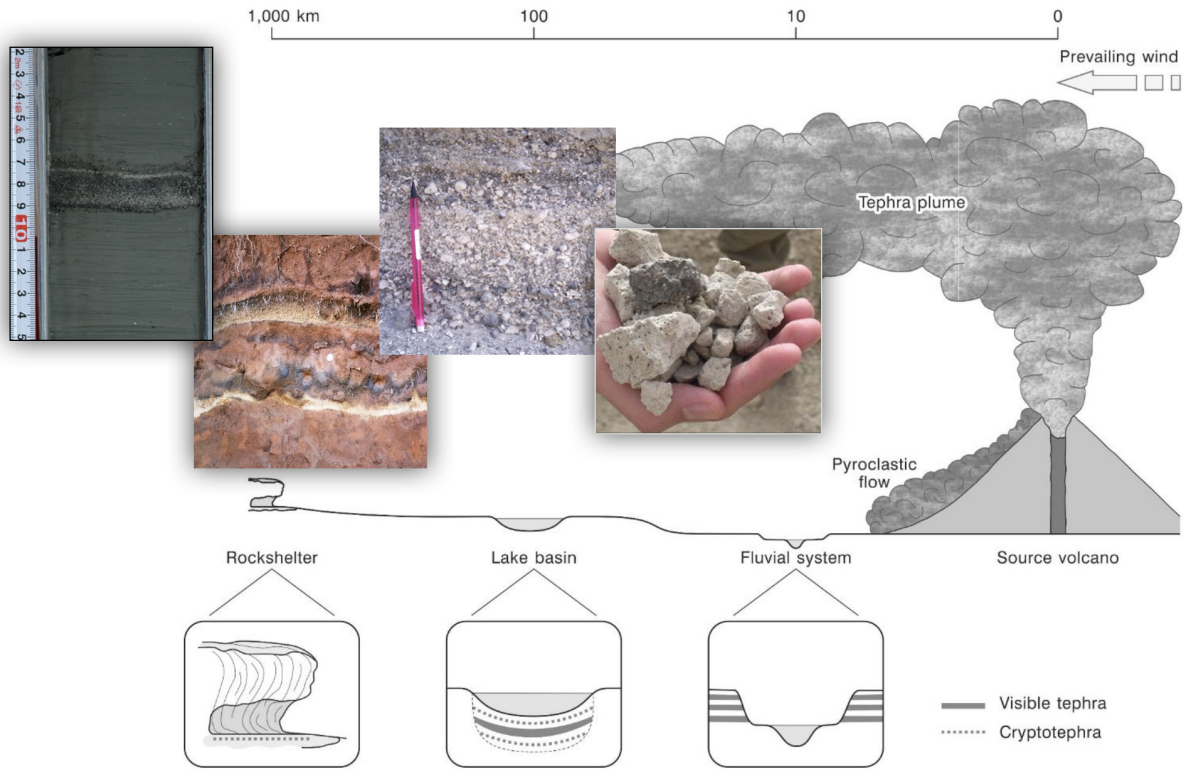
Tracking volcanic hazards

To prepare for volcanic eruptions and prevent damage to communities and infrastructure, volcanologists collect detailed information on each volcano. The aim is to get to know a volcano's personality - which means studying both its current and past behaviour.

Volcanologists check a volcano's 'vitals' by taking gas measurements and monitoring seismic activity. Changes in these indicators may suggest magma is rising, and warn of an impending eruption. But it helps to understand what is usual for a volcano - how often does it tend to erupt and how big are the eruptions? Patterns of past eruptions are unique to each volcano, but the behaviour tends to repeat.

Data on long term volcanic activity, extending back thousands of years, is stored in the geological record. Layers of tephra in road cuttings and gullies beside volcanoes provide a visual record of past eruptions. But often the evidence is hidden from view. When a volcano erupts, tephra sinks to the bottom of any nearby lakes and gets trapped in mud. By taking a core-sample of sediments from a lake, scientists can access layers of tephra going back thousands of years.

Volcanologists undertake detailed field work, and record the location and thickness of each tephra layer preserved in the geological record. Data on tephra thickness and dispersal can be turned into an isopach map, from which the eruption size can be calculated. Past volcanic eruptions in soil sequences and lake cores can also be dated, telling us how frequently eruptions occurred. Radiocarbon dating is commonly used, and works best on burnt vegetation (carbon) found in the tephra deposits.



Tephra deposits can be found in a variety of locations, including caves, lakes and river terraces. With distance from the volcano the tephra will become thinner, until hundreds or thousands of kilometres away it is a 'cryptotephra', which is only visible under the microscope. Image credit: Lane and Woodward (2016).

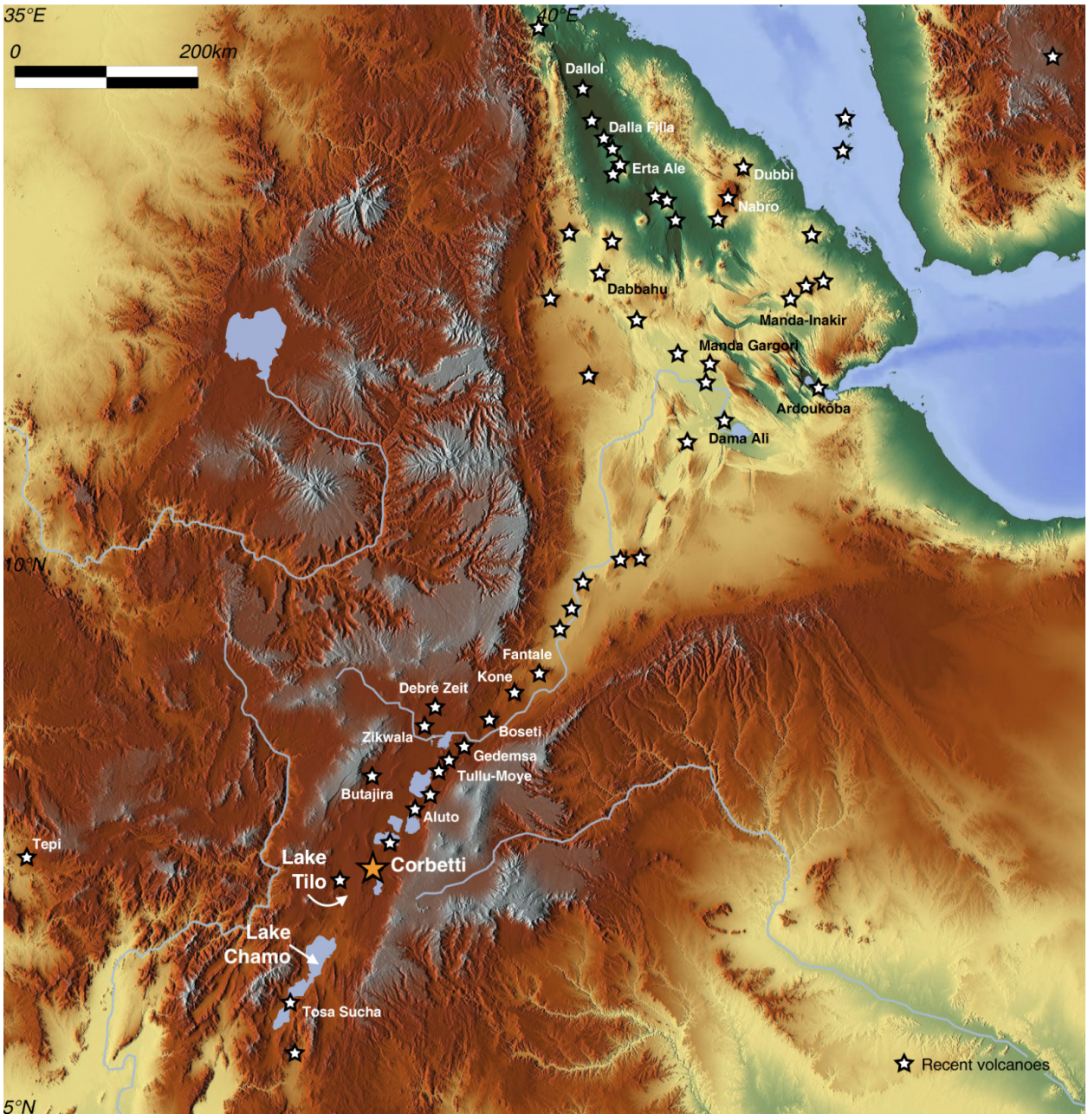
Volcanic hazard and risk in Ethiopia

In Ethiopia, where the majority of East Africa's volcanoes are found, understanding volcanic hazards is especially important. Ethiopia's population is currently 100 million and growing. Roughly half of the population live within 100 km of a volcano.

Until recently, not much was known about the Ethiopian volcanoes. There have been relatively few studies on Ethiopia's recent geological record, meaning that many past eruptions have been missed. In fact only 15 of Ethiopia's 65 volcanoes are known to have erupted in the past 10,000 years (GVP, 2013). In 2011, a report for the World Bank classified Ethiopia's volcanoes at the highest level of hazard uncertainty. With little data on the volcanoes, roughly half of the country's population were left exposed to an unquantified level of volcanic risk.

But over the two decades, our understanding of Ethiopia's volcanoes has been improved by projects such as the Afar Rift Consortium and RiftVolc. New geological data has shown that volcanoes like Corbetti and Aluto, in central Ethiopia (see below map), erupt on average one to four times every 1000 years (Martin-Jones *et al.*, 2017; Fontijn *et al.*, 2018; McNamara

et al., 2018). This means they are far more active than previously thought. The following report takes a closer look at the Corbetti volcano, and how data on its past can help us understand its future.



Map of the Ethiopian Rift, image credit Giacomo Corti.

When does a hazard become a risk?

A volcanic hazard is any volcanic process (e.g. lava, pyroclastic flows, tephra) that has the potential to cause physical damage.
Risk is the likelihood that damage or losses will occur to persons or property and infrastructure.
Risk depends on a number of physical and human factors, ranging from the size and type of eruption, to the proximity and vulnerability of assets and populations near to the volcano.

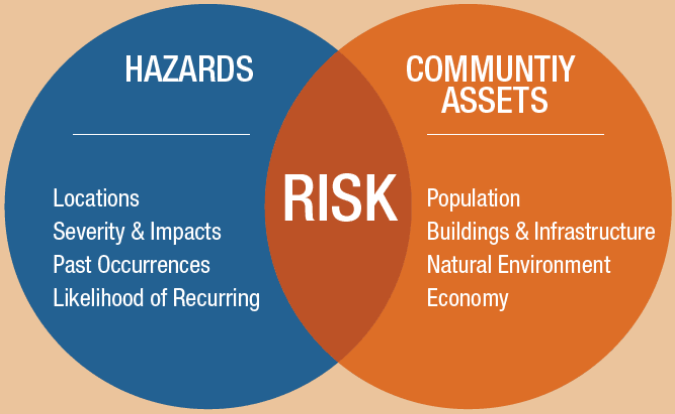


Image credit: Thurston Regional Planning

The Corbetti caldera

Corbetti is Ethiopia's southernmost large volcanic system. It has a 15-km wide caldera which formed some 200,000 years ago, layered onto the older (Pliocene) Awassa caldera. Lake Awassa now infills this older caldera. Corbetti has been described as having 'a youthful appearance': obsidian flows and pumice deposits from three young cones, Artu, Chabbi and Urji, inside the caldera are un-vegetated and fresh. Satellite imagery shows that Corbetti is one of the fastest deforming volcanoes on Earth (Lavayssière *et al.*, 2019). The steaming fumaroles inside the caldera are a testament to its continued activity; but its recent geological history has only recently been revealed.

The expanding population and infrastructure in this part of the Rift means greater exposure to volcanic hazards, and therefore risk is high. The main trunk road south through the Rift and into Kenya passes through Corbetti caldera, as well as several other large calderas to the North. The rapidly developing city, Hawassa, which is located inside Corbetti caldera and neighbouring Shashamene town are collectively home to roughly 260,000 people. Significant infrastructural investments have been made in Ethiopia as part of the Belt and Road Initiative. The Hawassa Industrial Park, built by Chinese contractors in 2017, is attracting global manufacturing firms and is expected to employ more than 100,000 locals. A new geothermal plant is currently under construction at Corbetti, marking a crucial step in meeting Ethiopia's growing need for reliable, clean energy.





The Corbetti Caldera, Ethiopia (left) with steam from active fumaroles inside the caldera. Image credit: both USAID Ethiopia on Flickr (CC BY-NC-2.0).

Piecing together Corbetti's explosive past

Evidence of a recent and explosive eruption

Piles of tephra, laid down by many repeated eruptions, can be found inside the Corbetti caldera. Some deposits are different colours, others are separated from one another by old soil horizons (*or palaeosols),* and many of the deposits contain characteristic minerals - all of which allow volcanologists to distinguish between different eruptions. An initial field study on Corbetti, by Rapprich et al. (2016), recognised a thick, and widespread pumice deposit. When the area was surveyed, they found the same layer 10 km away in Shashamene, where it was still 50 cm thick. Radiocarbon dates on the soil beneath the layer indicate the eruption occurred roughly 2,000 years ago.

The grey-white tephra deposited by the Wendo Koshe eruption can also be found at the bottom of nearby lakes (Martin-Jones *et al.,* 2017). A 20 cm-thick tephra from the eruption occurs near the top of a sediment core from the tiny, 1-km diameter crater Lake Tilo, 40 km West of Corbetti caldera. The same tephra layer was also found in Lake Chamo, roughly 170 km to the southwest of Corbetti caldera. At this distance from the volcano, the tephra was less than a millimetre thick and could only be identified with a microscope.



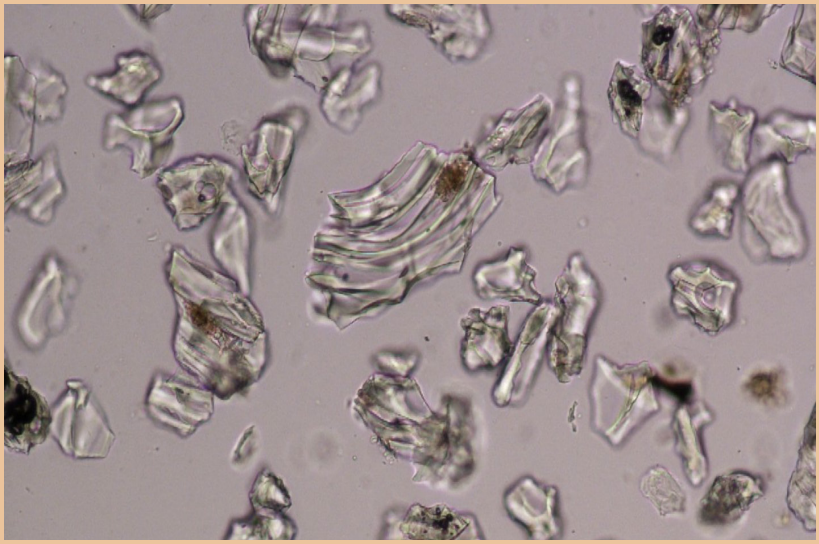
Right: grey tephra layers stand out from the darker Lake Tilo sediments.

This was an explosive eruption - we know this because of how widely the tephra has been distributed on the land. Mark up a map with the occurrences of the Wendo Koshe tephra and you will see the deposit spread over an area roughly the size of a thousand football pitches. Volcanologists used this same mapping method to work out the magnitude of the Wendo Koshe eruption. They calculated that the volume of rock released by the eruption exceeded >1.3 km3 (Martin-Jones *et al.,* 2017; Fontijn *et al.,* 2018). Put that on a scale of eruption magnitude, and the Wendo Koshe classifies as a VEI (volcanic explosivity index) 5 - that's approximately the same magnitude as the Mount St. Helens eruption of 1980.

Volcano forensics - tracing an eruption

When viewed under the microscope, tephra is made up of tiny pieces of glass, together with minerals and small rock fragments. These glass shards are often smaller than the width of a human hair. They were once molten magma that cooled rapidly and was shattered by the force of the eruption.

Volcanologists analyse the chemistry of this volcanic glass to establish the 'chemical barcode' of an eruption. This barcode is often unique for each volcano, and for each of its eruptions, allowing the tephra from a single eruption to be identified in locations hundreds of kilometres apart.



Forensic scientists use the same method. Fragments of glass on a burglar's clothing can be chemically compared to a broken window at the crime scene. Volcanologists are instead trying to identify the suspect volcano and the area over which the glass was distributed.

Up to 50 cm of tephra from the Wendo Koshe eruption is found underneath the highly populous town of Shashamene. If an eruption of this size occurred in the future, significant damage to communities and infrastructure would result. But how likely is another eruption? To work out the likelihood of this we need to understand how frequently Corbetti erupts.

Recurring eruptions

The Wendo Koshe wasn't Corbetti's only explosive eruption. Work by Martin-Jones *et al.,* (2017) revealed in total fourteen tephra layers occur in the core from Lake Tilo. Twelve have a chemical signature which matches Corbetti, whilst two come from Aluto, roughly 70 km North of Corbetti.

Radiocarbon dating of the core sediments was used to establish the age of each tephra layer. The oldest tephra found at Lake Tilo was erupted from Corbetti roughly 10,000 years ago. With Corbetti erupting eleven times since then, the recurrence of eruptions is somewhere between once every 800-900 years. The youngest tephra in the core was deposited around 900 years ago, a previously undocumented eruption lying above the Wendo Koshe. Based on the occurrence of past eruptions, there is a 35% chance of Corbetti erupting in a 500 year period.

Six tephra layers, including the Wendo Koshe pumice, in the Lake Tilo sediments are between 20 cm and 50 cm in thickness, indicating that at least six highly explosive eruptions have occurred from Corbetti caldera during the past 10,000 years. Several of these older eruptions have also been found in the rocks around Corbetti caldera (Fontijn *et al.,* 2018), but more mapping is required before their magnitude can be calculated.

The geological record shows that explosive eruptions are a recurring theme at Corbetti. From looking at past patterns, it also seems likely that Corbetti will erupt in the coming decades.

Balancing volcanic risk and reward

By looking at the past we know that Corbetti erupts explosively and at regular intervals, and there is a high likelihood eruptions will occur in the future. Satellite data also confirms that magma is rising beneath Corbetti. By identifying the most risky Ethiopian volcanoes, scientists and stakeholders can now begin to plan for future eruptions. Data on past eruptions can be used to make hazard maps, which show hazardous zones where planners may need to reinforce buildings or develop evacuation plans.

There are more benefits to understanding Ethiopia's volcanoes. Tourists flock to East Africa to see spectacular landforms, including the Rift volcanoes Mount Kilimanjaro and the Ngorongoro Crater.

The hot gases that rise from volcanoes can be used to generate geothermal power. This relatively clean and low carbon electricity is more reliable than solar, wind or even hydro; and is available year-round. Ethiopia has ambitious plans for geothermal energy generation, and is developing new plants at Corbetti and Aluto that together will have an estimated energy yield of 10,000 MW. Ethiopia follows in the steps of neighbouring Kenya, where in 2010 fewer than 20% of Kenyans had electricity. Now, thanks to geothermal

power, some 60% of the population do. As Ethiopia continues to industrialise and modernise, geothermal will fulfil the country's growing energy demands.



The Olkaria geothermal plant in Kenya, image credit: Geo Thermal on Flickr (CC-BY-NC-ND-2.0)

The steam emitted by volcanoes also offers opportunities for leisure and tourism, via the creation of spas and resorts. Volcanic materials, such as ash and pumice can be mixed into concrete and the clays formed from weathering of tephra can be used in ceramics.

Ethiopia's volcanoes and rift landscape are what make the landscape so remarkably varied. The remote Danakil Desert, in northern Ethiopia, is known for its alien landscape of sulfurous volcanic pools. Much of the desert is below sea level, and temperatures often top 40°C. Yet in the Bale Mountains on the eastern Rift shoulders, at an altitude of 3,000 m, temperatures hover at around 5°C. The Bale Mountains National Park is home to the highest incidence of endemic species on Earth, including the Ethiopian Red Fox.



Ethiopia is a land of contrasts: the Danakil Desert on the left (A.Savin (Wikimedia Commons) and on the right, the Bale Mountains National Park, image credit Nina R on Flickr (CC-BY 2.0)

It is in these dynamic surroundings that archaeologists have found the oldest skeletal evidence for anatomically modern humans. Some scientists think the variable topography and climate of the Rift played a part in human evolution, providing niche envirronments for shelter and hunting - and pushing our ancestors to develop new technologies and mix with other populations when their environs changed.

Ethiopians have been living alongside volcanoes for millions of years; they are part of the country's geoheritage. In the short-term, the socio-economic benefits of volcanic activity far outweigh the risk. But to continue to reap rewards of volcanic activity, sustainable development strategies should also consider how to reduce disaster risk.

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See RiftVolc for latest publications from the project.