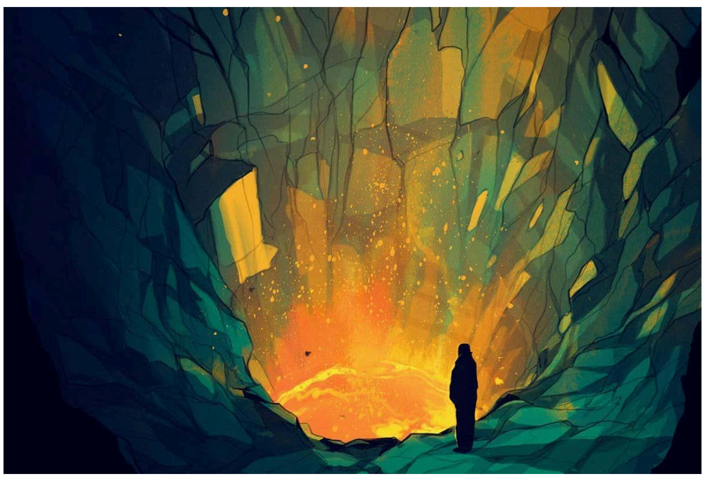
World's first tunnel to a magma chamber could unleash unlimited energy

In Iceland, scientists are planning to drill two boreholes to a reservoir of liquid rock. One will give us our first direct measurements of magma – the other could supercharge geothermal power

By Graham Lawton on January 3, 2024



Simon Prades

ICELAND is one of the most boring countries in the world. That is meant as a compliment, not an insult. The island nation is dotted with thousands of boreholes drilled deep into the rock to extract geothermal energy. They will soon be joined by another, which will be anything but boring. “We are going to drill into a magma chamber,” says Hjalti Páll Ingólfsson at the Geothermal Research Cluster (GEORG) in Reykjavík. “It’s the first journey to the centre of the Earth,” says his colleague Björn Þór Guðmundsson.

Well, not quite the centre. Some magma chambers – underground reservoirs of molten rock – lie just a few kilometres below Earth’s surface, putting them within reach of modern drills. They occasionally leak magma to the surface, where it spews out as lava. That is exactly what was starting to happen, to spectacular and devastating effect, around the town of Grindavík in southern Iceland, as this story went to press. The trouble is, we don’t normally know where magma chambers lie. “No geophysical technique has been shown to satisfactorily locate magma reservoirs,” says John Eichelberger at the University of Alaska Fairbanks.

Now, though, Ingólfsson and his colleagues have struck it lucky. They have stumbled across a magma chamber and have advanced plans to do the unthinkable and deliberately drill into it. The project will do no less than make scientific history, providing our first direct opportunity to study the hidden liquid rock that Earth uses to build its continents. Along the way, it may also discover a path to supply the world with unlimited cheap and clean energy.

Until recently, nobody had tried to drill into a magma chamber, not only because we generally don't know where they are but also because of the obvious risks. "You could never really propose to drill into magma," says Eichelberger, who has researched volcanoes for decades. "People would laugh at you and say, you'll start an eruption. And besides, you can't find it." But in 2009, that changed, dramatically and unexpectedly, at a volcano called Krafla in north-east Iceland.

It is one of the world's most active volcanoes, sitting right on top of the mid-Atlantic ridge at a point where the Eurasian and North American tectonic plates are pulling apart, and it has blown its top 29 times since Iceland was settled in the 9th century. The most recent activity was between 1975 and 1984, when it erupted nine times, an episode known as the Krafla fires.

Those events were studied intensely by earth scientists, including volcanologists Katia and Maurice Krafft, who tragically died a few years later during an eruption in Japan, a story told in the 2022 film *Fire of Love*. The work at Krafla led to the discovery of a potential magma chamber around 3 to 7 kilometres beneath the volcano. Páll Einarsson at the University of Iceland mapped seismic waves emanating from tectonic activity associated with the eruptions and found two "shadows" – spots where the waves were significantly weaker or missing altogether. This can be caused by a liquid – possibly magma – absorbing them, though there are other explanations. At the very least, it was a hint that there was something interesting down there.

When the borehole at Krafla in Iceland overheated, the result was a vast cloud of smoke billowing over the landscape. Krafla Magma Testbed/YouTube

In 2000, the Icelandic Deep Drilling Project (IDDP), an industry-government consortium, decided to bore into the volcano to explore the possibility of tapping extremely hot and pressurised "supercritical" water for geothermal power. They picked a spot where a recent geophysical survey had suggested that the magma chamber – if it existed – was at least 4.5 kilometres down. In 2008, Iceland's main power company Landsvirkjun, which runs a geothermal plant at Krafla, started drilling.

The plan was to go down to 4000 metres in order to get close enough to the magma but still remain at a safe distance. Work went smoothly until early 2009. Then, at a depth of around 2000 metres, the drill started inexplicably struggling. At 2104 metres, it suddenly plunged down like a hot knife through butter and then abruptly stopped. The engineers withdrew it 13 metres and tried to lower it again, but it refused to budge. Days later, samples from the borehole showed that it had been gummed up by a type of ultra-hard volcanic glass called obsidian. The only explanation was that the drill had penetrated a magma chamber and molten rock had flooded in as it was withdrawn, plugging up the opening. "When we drilled into magma, it was totally unexpected," says Bjarni Pálsson at Landsvirkjun, who was the project manager.

"I and some other scientists who deal with volcanoes were just amazed that somebody had actually drilled in the magma, and got samples of magma," says Eichelberger. It later transpired that similar accidental encounters had happened twice before, once in the Menengai caldera in Kenya and also at a volcano called Kīlauea in Hawaii. This was proof that it was both possible and safe to drill into magma without causing an eruption.

Landsvirkjun used the Krafla borehole for nine months to generate electricity. But the wellhead at the surface eventually overheated to 450°C – a world record, apparently – and the firm had to cool it down using cold water, with explosive results. Dramatic footage from the time shows vast clouds of black smoke billowing from the borehole. This wasn't a volcanic eruption, but the cremated remains of the drill and its steel casing as it was being obliterated by the magma, says Ingólfsson. It soon stopped and turned into an invisible haze of super-hot steam. "That basically destroyed the well," says Eichelberger.

The Krafla Magma Testbed

But if life gives you magma, make magma-ade. Pálsson and his team decided to exploit the fact that the magma chamber was so accessible to realise a long-standing goal among geoscientists to explore one. In 2014, they set up the Krafla Magma Testbed (KMT) project. A decade on, they are almost ready to start drilling.

The closest encounters geoscientists have had with molten rock up to now came from a series of expeditions in Hawaii run by the US Department of Energy. In 1959, the Kīlauea volcano erupted, filling its crater with lava to a depth of 130 metres. Over the next 30 years, the department took samples from the lava lake as it gradually solidified. "We cored into that, and it was quite amazing that you could core into liquid rock," says Eichelberger, who cut his teeth on the project. But that was as far as it went. The next step was supposed to involve finding and drilling into a magma chamber, but the researchers failed to locate one.

Yet now the quest for magma is back on. “This is what we’d been dreaming about,” says Eichelberger. “I had given up that we would ever succeed in this. But there it was.”

The first goal of KMT is to drill into the magma and make scientific discoveries. Starting in 2026, the project will break ground close to the original borehole and drill towards the chamber. It will take around two months to get there, progressing laboriously through the volcanic rocks until the drill hits pay dirt. First and foremost, the researchers want to build their fundamental understanding of magma and the chambers that hold it. “We don’t have any direct knowledge of what magma chambers look like, which is crucial in understanding volcanoes of course,” says Paolo Papale at Italy’s National Institute of Geophysics and Volcanology in Pisa. The little we do know largely comes from studying lava. But lava and magma aren’t the same. A lot of gas is released as molten rock comes to the surface and is then exposed to the atmosphere as lava, both of which change its chemical composition. “Being able to go into the crust and sample magma would give us huge knowledge,” says Ingólfsson.

As well as doing this, the researchers want to drop scientific instruments into the magma. At a bare minimum, that means temperature sensors. They would also like to take pressure readings, but that is more challenging, says IngÓlfsson: developing sensors, as well as drilling equipment that can withstand the intense heat, pressure and acidity, will take more time – hence the 2026 start date.

The plan is to drop instruments into the magma and leave them there for as long as they survive. The drill will cool the magma as it goes in, solidifying it to obsidian that will entomb the sensors. But the scientists will then allow it to heat up and melt again, releasing the sensors into liquid magma. “We hope to be able to have a direct measurement at least of temperature, which has never been done before,” says Ingólfsson. The borehole will stay open, allowing further monitoring and experiments to take place over many years. KMT describes it as the world’s first magma observatory. “It’s the Large Hadron Collider of earth science,” says Papale.

The team will also measure the temperature gradient as the solid rock transitions into magma. One of the big surprises of the earlier, unexpected encounter between drill and magma chamber at the site was how rapidly that occurs. “The theory was that you would go through solid rock and into what is called the brittle-ductile boundary, where the rock would be starting to get a little bit softer and more elastic because of the heat,” says Ingólfsson. That was expected to occur over hundreds of metres, but, with Krafla, it was just a few.

The caldera of Krafla volcano. Some 2 kilometres beneath it lies a magma chamber. Jarrod Ryan Jooste/Shutterstock

The nature of Krafla's magma is also of great interest. Most volcanoes spew out basaltic lava, which solidifies to form the volcanic rock basalt. Iceland is basically a colossal lump of porous basalt. But the samples taken in 2009 show that Krafla also holds rhyolitic magma, which contains more silica, is much more viscous, tends not to erupt and solidifies into the more durable rocks granite and rhyolite. These are the substrates for continent building, but the process isn't well understood, says Eichelberger. "This is a chance to understand how our planet makes continental crust," he says.

A second goal is to improve eruption forecasting. At present, that is largely done using seismometers and other instruments on the surface, but it is a very inexact science. "When something happens at a volcano, when the ground starts to move, we call it volcanic unrest," says Papale. "It means something is happening, but we're lacking direct information on what. We need to relate our surface measurements to dynamics occurring down there."

To further that goal, the project aims to prod the magmatic wasps nest and see what happens at the surface. For example, the scientists might inject fluids into the chamber to alter the pressure and temperature and then measure the results. "We can do real experiments on a real volcanic system and volcanic unrest, so we understand the meaning of the signals that we record at other volcanoes," says Papale.

Such knowledge could have provided more advanced warning of the eruption at Grindavík and will be useful in other places in danger. One example is Campi Flegrei caldera, which is similar to Krafla but lies in a densely populated part of Italy. "This has big consequences for active volcanoes and the risks associated with them," says Papale. "We have millions and millions of people at risk of their life, big infrastructure, industrial buildings and so on." The experiments may also improve the detection of unknown magma chambers. "When we intersect it on purpose, we can learn how to recognise the presence of magma at shallow level," says Papale.

Geothermal energy

The final goal is to make a quantum leap in geothermal energy production. Once the scientific well is under way, the researchers will start on a second one to use as a test bed for a new energy source that could supply the world with vast amounts of clean electricity for next to no cost.

Iceland and many other volcanically active countries, notably Kenya and the US, already tap hot geothermal fluids to drive turbines and generate electricity. But, at the moment, this captures only a fraction of the available energy. A fossil fuel plant uses steam at about 450°C, but standard geothermal fluids are at about 250°C. “It’s quite inefficient at those low temperatures,” says Eichelberger. “So there’s an interest in trying to develop super-hot geothermal.”

Before it got mired in magma in 2009, the Krafla borehole hit geothermal fluids at around 900°C and a pressure roughly 500 times that of the atmosphere. This generated around 10 times as much power as a standard borehole. The technical know-how developed by KMT, and the improved ability to discover magma chambers, might lead to a new energy technology called near-magma geothermal, where wells are drilled into the brittle-ductile zone and tap extremely hot, highly pressurised water to drive turbines. You might think that these wells would inevitably have to be dug much deeper than normal geothermal wells, and therefore they would be pricier. But that isn’t so. Standard geothermal plants in Iceland, which cost about $5 million upfront, have wells that descend about 2.5 kilometres, which is actually deeper than the Krafla magma chamber. For context, these existing geothermal plants produce electricity that costs 4.3 US cents per kilowatt-hour, about a sixth of the cost of electricity in the UK.

Many places on Earth have the potential to exploit this nascent near-magma geothermal method, not least the mid-Atlantic ridge in the Atlantic Ocean, a place where Earth’s crust is being ripped apart naturally. “Think about all the rift zones in the oceans,” says Ingólfsson. “We could use the experience and knowledge of advanced offshore drilling platforms from oil and gas and couple it with knowledge of getting energy directly from magma.” He foresees great platforms all around the ocean, harvesting energy from magma holes and using it to produce low-carbon synthetic fuels that could be shipped to shore.

That is for the future. But KMT could make it a reality. “There are endless opportunities,” says Ingólfsson. “The only thing we need to do is to learn how to tame this monster.” Well, that and a lot more boring.

Graham Lawton is a features writer at New Scientist