Why is India drilling a 6-km deep hole in Maharashtra?

The Borehole Geophysics Research Laboratory (BGRL) in Karad, Maharashtra, is a specialised institute mandated to execute India's scientific deep-drilling programme. Under BGRL, the aim is to drill the earth's crust and conduct scientific observations to help expand our understanding of reservoir-triggered earthquakes in the Koyna-Warna region

DEEP DIVE: At the deep drilling site in Koyna region, Maharashtra, the towering drilling rig is seen surrounded by associated equipment, an onsite mud logging unit, gas analysis lab, and a geological studies lab. MOES-BGRL

Bhavya Khanna
Sukanta Roy
M. Ravichandran

Scientists don't yet have a way to predict when and where an earthquake will occur. We know powerful earthquakes at the boundaries of tectonic plates, which measure more than 7.5 on the Richter scale, are almost certainly associated with a severe loss of infrastructure and life. In the ocean, these geological events trigger tsunamis. However, more minor earthquakes that occur in a plate's interior are more challenging to predict because they occur at the least expected sites and could strike densely populated habitats. This is why scientific deep drilling is an indispensable tool for progress in the earth sciences.

What is scientific deep drilling?

Scientific deep-drilling is the enterprise of strategically digging boreholes to analyse deeper parts of the earth's crust. It offers opportunities and access to study earthquakes and expands our understanding of the planet's history, rock types, energy resources, life forms, climate change patterns, and more.

The Borehole Geophysics Research Laboratory (BGRL) in Karad, Maharashtra, is a specialised institute under the Ministry of Earth Sciences mandated to execute India's sole scientific deep-drilling programme. Under BGRL, the aim is to drill the earth's crust to a depth of 6 km and conduct studies to help expand the understanding of reservoir-triggered earthquakes in the Koyna-Warna region of Maharashtra.

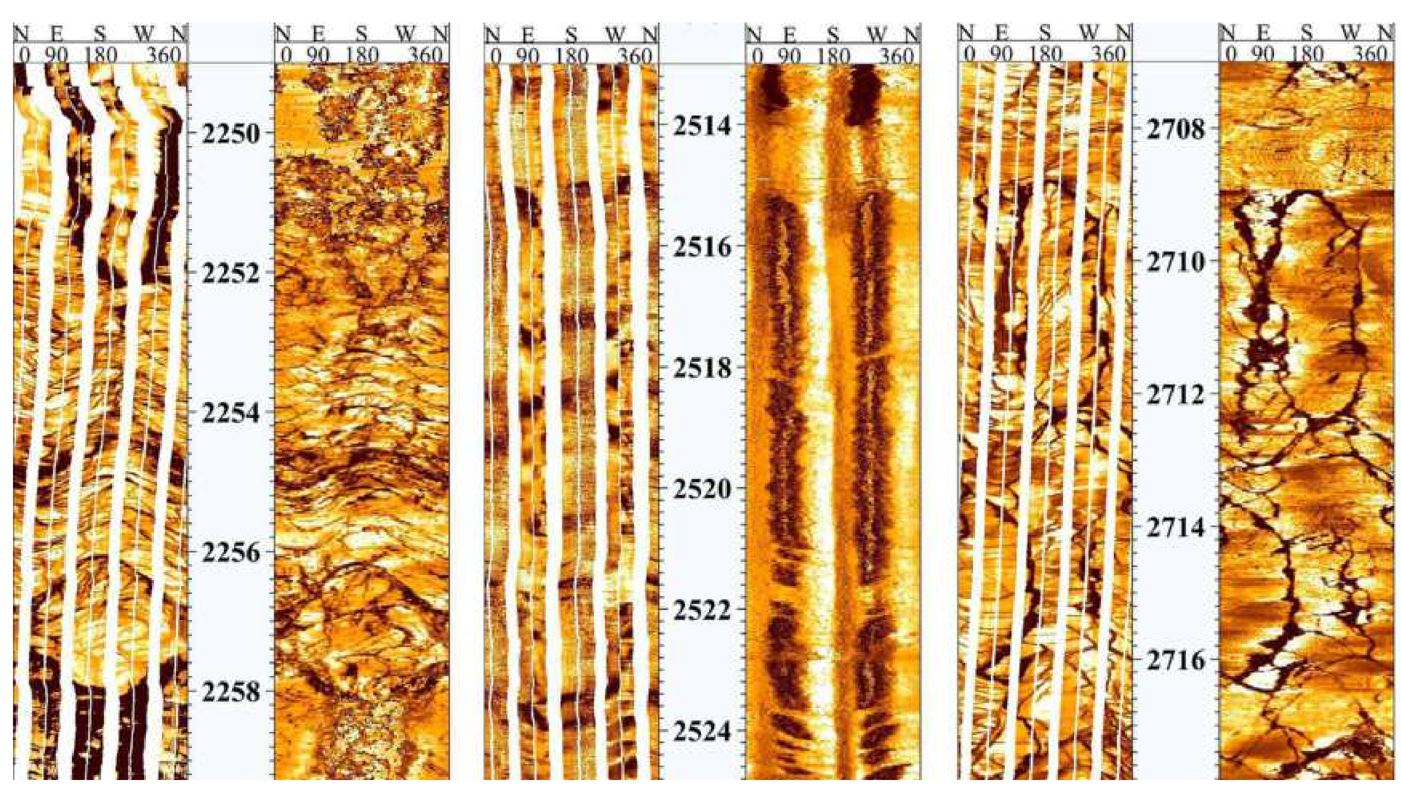
This region has been experiencing frequent earthquakes since the Shivaji Sagar Lake, or the Koyna Dam, was impounded in 1962. BGRL's 3-km-deep pilot borehole in Koyna is complete; the Ministry of Earth Sciences is committed to reaching a depth of 6 km.

Benefits of a deep-drilling mission

Earthquakes are challenging to study. Surface-level observations can't make complete sense of them. The recurrent earthquakes in Koyna are synchronous with the dam's loading and unloading during the monsoon and post-monsoon periods, offering an opportunity to widen our understanding of earthquakes.

However, making observations inside the earth is a different ball game. Scientifically drilled boreholes can be a hub of direct, unique *in situ* experiments and observations and monitor a region's fault lines and seismic behaviour. They also provide exact and fundamental knowledge of the composition of the earth's crust, structure, and processes, and help validate models based on surface studies. Thus, it can inform a range of societal problems related to geohazards and geo-resources.

Investing in scientific deep-drilling can also help expand scientific know-how and technological innovation, especially in seismology (the study of earthquakes). It can also spur the development of tools and equipment for drilling, observation, data analysis, sensors, etc.



High-resolution images (electrical and acoustic) of the borehole wall at a depth of 2,248-2,718 m in the Koyna pilot borehole showing the presence of fault-fracture zones and rock deformation features in detail. MOES-BGRL

Challenges of scientific deep drilling

Scientific deep drilling is the best tool to study the earth's interior. Other ways include geophysical measurements of seismic wave speed, gravitational and magnetic fields, and electrical conductivity from the near surface. Scientists can also examine crust fragments brought from deep underground to the surface.

But scientific deep-drilling remains the most reliable method because it helps get direct (*in situ*) and near-source measurements. Researchers can also capture rock and sediment cores aligned with the earth's timeline from within the borehole. It is also labour- and capital-intensive. The earth's interior is a hot, dark, high-pressure region that hinders long and continuous operations.

Even with these challenges, however, scientific pursuits are important. Expanding earth-science research, especially of solid earth, is crucial. Aside from earthquakes, this is because many surface phenomena – the composition of water and air, their availability, and the resulting interactions with climate-affected phenomena – are linked to what happens inside the earth's crust.

What is the drilling technique?

The Koyna pilot borehole is about 0.45 m wide (at the surface) and roughly 3 km deep. It employs a unique drilling strategy – a hybrid of mud rotary drilling and air hammering.

In rotary drilling, a rotating drilling rod made of steel is attached to a diamond-embedded drill bit at the bottom. As it penetrates the crust, it generates considerable heat due to friction, so drilling mud is flushed through the rod into the borehole to cool the drill bit. In addition to being a coolant and a lubricant, the drilling mud helps bring rock cuttings up from the borehole.

A ring-shaped space separates the drilling rod and borehole wall. The debris moves out from the space due to the pressure of the drilling mud pumped from the top through the drilling rod. The deeper the borehole, the more pressure is required to bring up the debris from this space.

Air hammering pushes highly compressed air through the drilling rod to deepen the borehole and flush the cuttings out.

Deep-drilling operations at Koyna use a rig capable of both techniques. The decision to use each technique at a particular point is based on the rock type, presence of highly fractured rock, water inflow zones, and the need to collect core samples, among others.

Decisions of this kind are dynamic. Operators used the mud rotary technique to acquire cores because it allowed us to capture long, intact cylindrical sections. Where operators used air-hammering, the team collected rock chips for studies of rock properties.

The operators also have to circulate the drilling mud while making downhole measurements of physical and chemical properties of the borehole environment using temperature, density, electrical conductivity, sonic velocity, rock porosity, and radioactivity probes – while installing steel pipes to secure the borehole's sides.

When the borehole depth increases beyond 3 km and strikes for 6 km, the entire rig will have to be updated with exponentially enhanced capacity. In addition, increasing the depth to 6 km heightens the complexities of drilling through fractured rocks in the Koyna seismic zone and the possibility of drill rods and sensors getting stuck.

Troubleshooting also becomes more complicated because of limited access to equipment deeper down the hole. Rocks at these depths are softer so drilling mud is lost. Further, a 4-in-wide and 9-metre-long granite core can weigh up to 200 kg, and lifting it up by more than 3 km is technically exacting. Operators will also encounter fault lines and fracture zones more often, through which water could enter the borehole and stall drilling.

If any of the above situations arise and troubleshooting fails, we may have to abandon the borehole. Another challenge is to steer the borehole at the desired inclination from the top, using vertically controlled actions. This requires drill motors, imaging tools, and monitoring devices that can be 'tuned' every minute. The planning and execution of deep-drilling are thus dynamic and must be foolproof. Human resources are also a challenge. The process needs highly skilled technical personnel for continuous on-site engagement for 6-8 months at a time in harsh weather; this was the case for the 3 km pilot borehole. For a 6 km borehole, continuous drilling will last at least 12-14 months.

What have scientists found?

The pilot drilling mission was a success and has yielded significant new information about the subsurface geological environment. For one, it revealed 1.2-km thick, 65 million-year-old Deccan trap lava flows, and below them 2,500-2,700-million-year-old granitic basement rocks. Downhole measurements of core samples and conditions from a depth of 3 km have also provided new information about the physical and mechanical properties of rocks, the chemical and isotopic composition of formation fluids and gases, temperature and stress regimes, and fracture orientations.

We also captured high-resolution images of the borehole wall using acoustic and micro-resistivity techniques. They can be used to validate data extracted from other cores worldwide. The team at Koyna also conducted hydraulic fracturing experiments to directly measure the rocks' stress regimes. We expect data from these experiments to be useful for many years, especially to understand the reasons for recurrent earthquakes in specific geographies. By integrating various datasets and using advanced analysis, the team could also detect buried fault zones and study their properties. One significant finding was the presence of water down to 3 km! It was found to be meteoric or rain-fed, implying deep percolation and circulation are possible. Another key finding was that the Koyna region is critically stressed: even small stress perturbations could cause the rock to fail and potentially trigger frequent, small-magnitude earthquakes in the region.

> Earthquakes that occur in a plate's interior are challenging to predict because they occur at the least expected sites and could strike densely populated habitats

What next?

The pilot data will inform future drilling. Modelling experiments suggest the temperature at 6 km could be 110-130 degrees C. Drilling equipment, downhole data acquisition systems, and sensors for long-term placement at depth need to be designed accordingly. The Koyna data and samples will also facilitate new experiments. More than 20 research groups nationwide are already studying the Koyna samples. One is examining the gouge from fault zones to understand the frictional properties of rocks in quake-prone regions. Another is characterising microbes on these rocks to understand life forms that thrive in hot, dark, nutrient-poor environments. Their findings could potentially yield new molecules and clues to improve industrial processes.

Members of the international geological research community have also sought access to core samples for projects in emerging fields such as carbon capture and storage in the deep Deccan traps. In sum, the Koyna exercise is establishing a firm footing in scientific deep-drilling for India. Its lessons will inform future deep-drilling experiments and expand academic knowledge in multiple ways.

(Bhavya Khanna is a Scientist D, communication in science, at the Ministry of Earth Sciences (MoES); Sukanta Roy is a Scientist G and Head of Borehole Geophysics Research Laboratory, Karad, under MoES; and M. Ravichandran is the Secretary to the Government of India, MoES.)

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