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Why is it so hard to drill off Earth?

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NASA's Curiosity rover raised robotic arm with drill pointed skyward while exploring Vera Rubin Ridge at the base of Mount Sharp inside Gale Crater—backdropped by distant crater rim. This navcam camera mosaic was stitched from raw images taken on Sol 1833, Oct. 2, 2017, and colorized. Credit: NASA/JPL/Ken Kremer/kenkremer.com/Marco Di Lorenzo

Humans have been digging underground for millennia—on the Earth. It's where we extract some of our most valuable resources that have moved society forward. For example, there wouldn't have been a Bronze Age without tin and copper—both of which are primarily found under the ground. But when digging under the ground on celestial bodies, we've had a much rougher time. That is going to have to change if we ever hope to utilize the potential resources that are available under the surface. A paper from Dariusz Knez and Mitra Kahlilidermani of the

University of Krakow looks at why it's so hard to drill in space—and what we might do about it.

In their 2021 paper, published in the journal *Energies*, the authors detail two major categories of difficulties when drilling off-world—environmental challenges and technological challenges. Let's dive into the environmental challenges first.

One obvious difference between Earth and most other rocky bodies that we would potentially want to drill holes into is the lack of an atmosphere. There are some exceptions—such as Venus and Titan, but even Mars has a thin enough atmosphere that it can't support one fundamental material used for drilling here on Earth—fluids.

If you've ever tried drilling a hole in metal, you've probably used some cooling fluid. If you don't, there is a good chance either your drill bit or your workpiece will heat up and deform to a point where you can no longer drill. To alleviate that problem, most machinists simply spray some lubricant into the drill hole and keep pressing through. A larger scale version of this happens when construction companies drill into the ground, especially into bedrock—they use liquids to cool the spots where they're drilling.

That isn't possible on a celestial body with no atmosphere. At least not using traditional drilling technologies. Any liquid exposed to the lack of atmosphere would immediately sublimate away, providing little to no cooling effect to the work area. And given that many drilling operations occur autonomously, the drill itself—typically attached to a rover or lander—has to know when to back off on its drilling process before the bits melt. That's an added layer of complexity and not one that many designs have yet come up with a solution.

A similar fluid problem has limited the adoption of a ubiquitous drill technology used on Earth—hydraulics. Extreme temperature swings, such as those seen on the moon during the day/night cycle, make it extremely difficult to provide a liquid for use in a hydraulic system that doesn't freeze during cold nights or evaporate during scorching days. As such, hydraulic systems used in almost every large drilling rig on Earth are extremely limited when used in space.

Other problems like abrasive or clingy regolith can also crop up, such as a lack of magnetic field when orienting the drill. Ultimately, these environmental challenges can be overcome with the same things humans always use to overcome them, no matter what planetary body they're on—technology.

There are plenty of technological challenges for drilling off-world as well, though. The most obvious is the weight constraint, a crucial consideration for doing anything in space. Large drilling rigs use heavy materials, such as steel casings, to support the boreholes they drill, but these would be prohibitively expensive using current launch technologies.

Additionally, the size of the drilling system itself is the limiting factor of the force of the drill—as stated in the paper, "the maximum force transmitted to the bit cannot exceed the weight of the whole drilling system." This problem is exacerbated by the fact that typical rover drills are leveraged out on a robotic arm rather than placed directly underneath where the maximum amount of weight can be applied. This force limitation also limits the type of material the drill can get through—it will be hard-pressed to drill through any significant boulder, for example. While redesigning rovers with drill location in mind could be helpful, again, the launch weight limitation comes into play here.

Another technological problem is the lack of power. Hydrocarbon-fueled engines power most large drilling rigs on Earth. That isn't feasible off of

Earth, so the system must be powered by solar cells and the batteries they provide. These systems also suffer from the same tyranny of the rocket equation, so they are typically relatively limited in size, making it difficult for drilling systems to take advantage of some of the benefits of entirely electric systems over hydrocarbon-powered ones—such as higher torque.

No matter the difficulties these drilling systems face, they will be vital for the success of any future exploration program, including crewed ones. If we ever want to create lava cave cities on the moon or get through Enceladeus' ice sheet to the ocean within, we will need better drilling technologies and techniques. Luckily, there are plenty of design efforts to come up with them.

The paper details four different categories of drill designs:

- Surface drills—less than 10 cm depth
- Shallow-depth drills—less than 1m depth
- Medium-depth drills—between 1m and 10m depth
- Large-depth drills—greater than 10m depth

For each category, the paper lists several designs at various completeness stages. Many of them have novel ideas about how to go about drilling, such as using an "inchworm" system or using ultrasonics.

But for now, drilling off-world, and especially on asteroids and comets, which have their own gravitational challenges, remains a difficult but necessary task. As humanity becomes more experienced at it, we will undoubtedly get better at it. Given how important this process is for the grand plans of space explorers everywhere, the time when we can drill effectively into any rocky or icy body in the solar system can't come soon enough.

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