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DEEP HYDROGEN

By David Tenenbaum - Jun 16, 2008

Crushing rock samples in a stainless steel chamber (center) releases the stored hydrogen molecules measured by the hydrogen detector (left).
Credit: *Ipek Kulahci*

Hydrogen is the simplest, lightest, and most common element in the universe. Although the hydrogen molecule (H2) is highly reactive, and therefore rare in Earth's atmosphere, it is usually found at parts per million levels in deep drill holes.

That hydrogen might be a mere curiosity – or it might be relevant to the hot conditions where life seems to have originated. In 2005, Kenneth Nealson of the University of Southern California suggested that sub-surface microbial communities can get energy from hydrogen without needing any products of photosynthesis. And in 2006, Norman Pace of the University of Colorado reported that most of the microbes in Yellowstone National Park's hot springs get their energy from hydrogen, rather than from sulfur, as had been assumed.

If hydrogen is the energy source at the base of the food chain in those extremophile-rich locations, then it may have played the same role when the early ancestors of these bacteria first appeared on Earth – and perhaps elsewhere.

But what is the source of the molecular hydrogen in deep rocks? And if it indeed is the sole source of energy for deep geologic bacteria, is it still being produced?

The accepted hydrogen-generating processes cannot produce all of the molecular hydrogen that has been found in so many deep drill holes, says Friedemann Freund, a principal investigator at the SETI Institute and a NASA Ames Associate.

Just as some microbes consume hydrogen, other species produce it. But hydrogen is also found in igneous rocks that have just cooled down from magmatic temperatures, where it is too hot for microbes to survive. That hydrogen had to have formed abiotically.

Hydrogen is liberated in chemical reactions that occur when water touches freshly fractured surfaces of rocks bearing iron and other elements, but the reaction quickly

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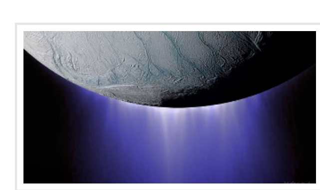

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ceases, and Freund argues that not enough deep rocks are being fractured to account for the amount of hydrogen that has been found. Hydrogen is also made by the process of serpentinization, which occurs when rocks called peridotite, containing the mineral olivine, rise from the mantle and contact superhot water, but serpentinization "cannot occur in stable parts of the continents because no peridotite is being brought up from the depths" there, says Freund.

Rocks from different geological ages are expected to contain different amounts of hydrogen. This Archaean rock, collected in Pilbara, Australia, which is more than 2 billion years old is expected to contain low levels of hydrogen.
Credit: *Ipek Kulahci*

So what did make the traces of hydrogen found in most or all deep drill holes, even three to five kilometers deep? And why does hydrogen seep for hundreds of hours when common rocks are crushed – even if their surfaces are dry, and thus could not be producing hydrogen by the well-known processes?

Freund dates his explanation to the 1960s, when he studied how water becomes incorporated into minerals. "The water molecules do not survive," he says. "They are ripped apart, forming OH-, hydroxyl ions." Freund found the results puzzling — some hydroxyls that should have been present were missing – until he recognized that the missing hydroxyls were producing molecular hydrogen: "The proton in the hydroxyl ion and the oxygen atom get into a domestic fight over an electron… and the proton rips away an electron from the oxygen and becomes a hydrogen atom," which contains one proton and one electron.

And two of these "domestic brawls," Freund says, would produce one molecule of hydrogen. This reaction, Freund says, seems to occur during the cooling of both igneous and metamorphic rocks.

Since rocks usually pick up some water when they crystallize from magma, Freund adds, "this led to the idea that maybe all rocks would contain molecular hydrogen." And to the extent that this cooling is still taking place, hydrogen generation inside rocks may also be an ongoing process.

In 2002, Freund and colleagues reported that they detected hydrogen molecules after crushing three types of the most common igneous rocks, and that the hydrogen stream was still gaining strength when they stopped measuring 200 hours later. Apparently, Freund says, the hydrogen within the mineral grains continued to seep out through the freshly created fracture surfaces.

According to his calculations, one cubic meter of rock could produce 5 liters of hydrogen (at standard pressure and temperature). That is not a flood of hydrogen, but it is a slow, steady outflow that seems to be regulated – in nature – by liquid water films that fill the narrow space between mineral grains. Water can only contain a certain amount of hydrogen. Once it became saturated with hydrogen, the outflow would stop, leaving the hydrogen molecules trapped between the rock grains. But if the hydrogen level were dropping – as it would if microbes entered the system after the rock cooled and were consuming hydrogen – then more hydrogen would get released from the rock.

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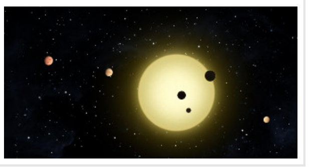

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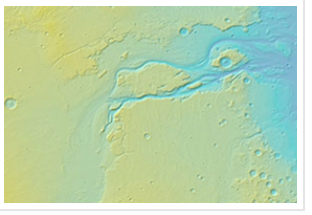

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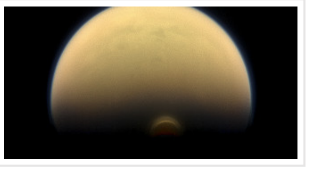

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Dr. Friedmann Freund of the SETI Institute and NASA Ames Research Center.

In early experiments, he says, hydrogen has appeared as expected. “In the moment of crushing, molecular hydrogen rushes out from inside the mineral grains simply because we created a fresh surface. After that, hydrogen molecules that are close to the fracture surface migrate slowly through the crystal structure and are released. The process works from the inside out. There is no need to add water to react with the fracture surfaces,” because the hydrogen already exists between the rock grains.

The flow also persists, he adds. “We place the powders into other containers and wait for weeks, measuring whether hydrogen will continue to be released. It works, we see the hydrogen coming out.”

Because hydrogen is formed inside the mineral grains in the rocks whenever molten rock cools below 600 degrees centigrade, Freund adds, “It’s my assertion that in all these large volumes of igneous and metamorphic rock that form Earth’s continents, every mineral grain is a potential source of hydrogen. It’s not very much hydrogen per unit volume rock, but very large in total mass.”

The hypothesis is still viewed with skepticism, admits Freund, a professor of physics at San Jose State University in California, and his physics-oriented approach has had trouble getting accepted among geologists, but it is “undisputed that hydrogen is available throughout the rock column. Whether you sink a drill 3 to 5 kilometers down in the Canadian Shield, or near the San Andreas fault, or in Hawaii, you will find hydrogen everywhere. The hydrogen is so common that nobody reports it, yet we have it everywhere. So nobody has gotten serious, and asked, where does this hydrogen come from?”

A NASA exobiology/evolutionary biology grant will enable Freund to pursue this research by quantifying the flow of hydrogen more precisely. “We now have set up a station where we can bust rocks,” says Freund. “We will take a piece of dry rock the size of your thumb and crush it between two tungsten carbide plates, with a pressure of 30 tons, to produce a fine powder.”

If rock-generated hydrogen is supplying the energy for microbes deep in the rock column on Earth, the same could have happened on Mars in the past — or could even be happening in the present, Freund says.

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