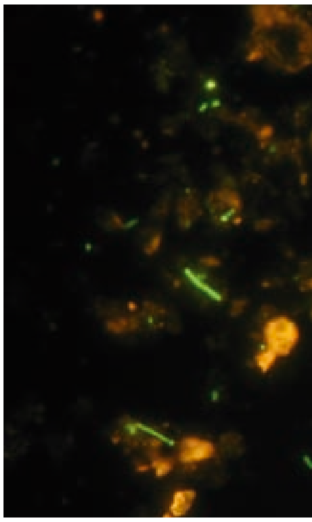
Deep **heat**

Scientists get into hot water in County Durham looking for a carbon neutral energy source and intra-terrestrial life. **Ian Head, David Manning** and **Paul Younger** explore life deep beneath the surface.



In the drive to discover environmentally benign forms of energy, NERC-sponsored researchers at Newcastle University have been getting into hot water.

We have been exploring the possibilities of harnessing geothermal energy from deep below the Earth. Our work has highlighted the potential of geothermal energy as an important part of the UK's energy economy. But is has also opened a window on the fascinating microbes thousands of metres under the Earth's surface.

Not just for Iceland and New Zealand

Some readers will be familiar with the 'Hot Dry Rock' experiments carried out in Cornwall in the 1980s. Engineers and geologists knew certain types of granite release heat when natural radioactive elements contained in the rocks decay.

Granites like this also lie beneath the North Pennines, the Lake District, the eastern Highlands of Scotland and the Mountains of Mourne in Northern Ireland.

The Cornish investigations used deep borehole technology and high-pressure techniques to create artificial permeability in rather blank granite. High permeability is an important factor in exploiting geothermal energy. Without it, it is difficult to abstract and circulate the hot water effectively: water-flow rates can't be maintained. Artificially fracturing the rocks to increase permeability adds to the cost making it a tricky economic proposition. But no one thought to look for natural permeability until now.

In Eastgate, a County Durham village near Weardale in the North Pennines, the geochemistry of certain mine waters suggested substantial natural permeability at depth. With funding from the Regional Development Agency, One NorthEast, a 1000m borehole was drilled to investigate this idea.

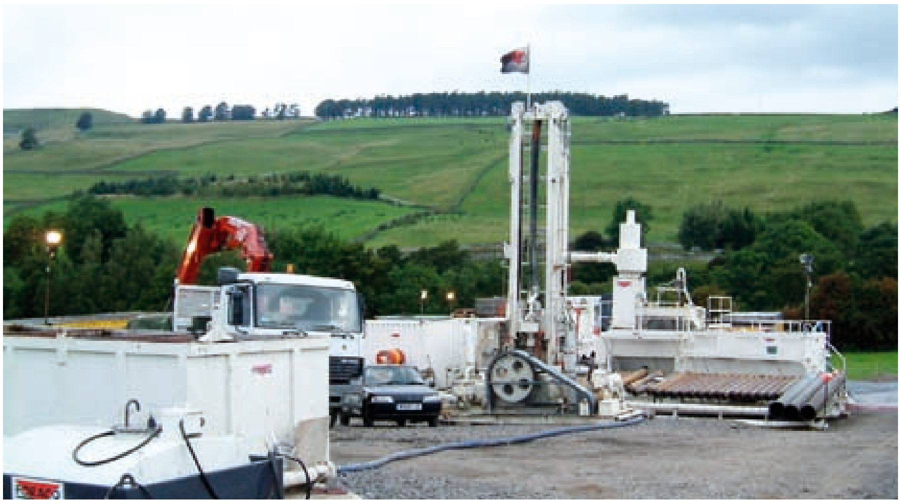
This proved highly successful, demonstrating what is believed to be the highest natural permeability ever found in granite anywhere in the world. The team also found that the granite's heat production rate was about 25 per cent higher than previous estimates. Given the rather widespread nature of these radiothermal granites, the Weardale experience suggests a fresh look at other possible prospects is justified.

A window on the deep biosphere

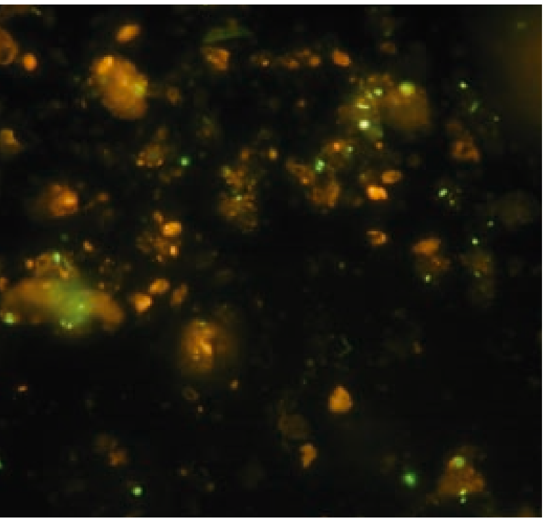
When we think of life on Earth it is usually surface-dwelling plants and animals that come to mind, or perhaps some of the microbes that are involved in recycling energy and matter in the planet's waters, soils and sediments.

But we have known for some years that life persists even in the deepest recesses of the Earth's crust. Some even believe that the microbes living in this vast underworld (bacteria and archaea) may harbour as much as half of the Earth's total carbon biomass – carbon in living organisms.

Despite this, the deep subsurface remains one of the least explored biological habitats on Earth. This is in part due to technical difficulties and great costs associated with getting to these places. So our Weardale borehole offered a rare opportunity to sample the microbiota that dwell deep below our feet. Funding from a NERC small grant allowed us to do some fundamental geobiology in the small window of opportunity prior to the borehole's commercial development.



In search of cheap energy and new life. Drilling the 1000m Weardale borehole in Durham.



Bacterial cells from a deep groundwater sample stained with a dye that binds to DNA and fluoresces green.

Damaged drill bit caused by drilling through granite and waters with high salinity.

Starvation diet

One of the great mysteries that continues to perplex microbial ecologists who work in deep subsurface environments is where does the energy come from to maintain the microbial populations that comprise the deep biosphere? The fact that the waters from the Weardale granite contain only around 10,000 microbes per cubic centimetre is evidence that microbes do not have an easy life – surface waters typically contain about a million cells per cubic centimetre, and sediments and soil may contain a billion cells per cubic centimetre.

The deep Weardale microbes most likely survive on a subsistence diet. The types of organisms we found – bacteria and archaea (single-celled organisms without nuclei) – provide some clues as to how they make a living.

Soon, it will not be just the microbes that are making a living from the deep.

Researchers have speculated that microbes in deep granite survive by oxidising hydrogen which might be produced by the reaction of radioisotopes (naturally-produced radioactive isotopes) in the rock with water. Microbes might force a reaction between hydrogen and carbon dioxide in the water to produce either methane or acetic acid (vinegar). Both chemicals are vital to much life above the surface.

Now we have the first part of a food web deep beneath the ground. Acetic acid produced in this way could feed other organisms in the ground water dependent on acetate for survival.

This theory is consistent with what we found in the Weardale granite. The archaea we identified are known as methanogens – they produce methane – and are most closely related to organisms identified previously in deep subsurface marine sediments and petroleum reservoirs. These belonged to a specific group of archaea that convert acetic acid to methane and carbon dioxide. Some can also convert hydrogen and carbon dioxide to methane. From this we reckon hydrogen and acetic acid are the most likely fuels for the Weardale deep biosphere.

The bacteria we found were related to bacteria that normally use sulfate as an alternative to oxygen for respiration, specifically a bacterium named *Desulfobulbus propionicus*. But what was odd was that the Weardale waters contained little sulfate. *Desulfobulbus propionicus* can grow without sulfate by fermentation of other organic acids to produce among other things acetic acid. We also found other bacteria that use acetate and still more that ferment sugars and produce organic acids which can be used by the putative sulfate reducers and methanogens.

So what we found was a complex food web in the waters from the Weardale granite driven by hydrogen and CO_2 produced from the reaction of radioisotopes with water.

But, as with life, things may be more complicated still. Analysis of the water suggests that it has come from surface waters which have percolated through many hundreds of metres of rock picking up minerals and giving it a characteristic salty composition.

Since the water has come from the surface it is likely that it has brought with it traces of organic matter from the soil which may also form a source of energy for the Weardale deep biosphere. So rather than being a completely isolated community that derives its energy from geochemical reactions not sunlight, it seems that the Weardale deep biosphere may operate on a mixed economy of geochemical energy and energy from photosynthetically derived organic carbon.

Where to with geothermal energy?

Soon, it will not be just the microbes that are making a living from the deep, hot waters of Weardale. The drilling of the 1000m borehole was the first step in the evolution of a concept for a renewable-energy model village, which will see the geothermal resources integrated in a novel way with hydropower, wind power (using less obtrusive vertical-axis turbines) and a biomass power plant.

As with the Weardale deep biosphere, the vision for the dale is one that is sustained through a mixed energy economy. This development, which has been led by a consortium of Wear Valley District Council, Durham County Council, One NorthEast and LaFarge Cement, is now in the late stages of planning. Future visitors to Weardale can look forward to basking in a brand-new hydrothermal spa, which will form the centrepiece of a new economic development zone providing carbon-neutral energy to the dale. ❖

MORE INFORMATION

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