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Too hot to handle

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Too **HOT** to handle

The scientific community greeted the first results of the Iceland Hotspot Project with shock, denial, ridicule and delight. Gillian Foulger explains what it is like to turn considered wisdom on its head.

The Grimsvatnagos eruption 2004, Vatnajokull ice cap, Iceland.

If a scientific experiment goes exactly according to plan, it is likely to be at best no better than a small step forward towards a greater goal. It is experiments that turn up something completely unexpected that produce the Great Leaps Forward. This is the story of a really successful scientific experiment—one that produced results that were completely different from what we expected at the outset.

We set up the Iceland Hotspot Project to look at one of the most interesting and exciting problems in Earth science – the origin of the vast quantities of lava that erupt onto the Earth's surface at so-called 'hot spots'. These hot spots are places on Earth where volcanic activity is unusually intense. Well known examples are Hawaii, Yellowstone National Park in the United States, and Iceland. Scientists thought they could be explained by so-called 'mantle plumes' – great columns of rock warmed by the Earth's hot core that rise

to the surface, fuelling the volcanoes above. Our objective was simple – to produce a three-dimensional picture of the mantle plume beneath Iceland using seismic 'cat-scanning', known in the trade as seismic tomography.

Why Iceland, one might reasonably ask, rather than, say, Hawaii, which might be more, er, suitable? The reason we chose to brave the elements as far north as Iceland was because of its size. At 450 by 350 kilometres it represented the broadest hot spot target on Earth. This was important because the depth to which seismic tomography can 'see' is roughly equal to the width of the instrument array installed. Since the depth to the Earth's core, from where mantle plumes are expected to come, is about 3000km, it was important to probe as deeply as possible.

Your next question might be, hadn't this been done before? The answer to this one is yes, but only in a crude way. The

Iceland Hotspot Project used an entirely new kind of instrument that is revolutionising study of the deep interior of the Earth—broadband seismometers. These new instruments are small, easily portable, and capable of recording seismic waves throughout an unprecedented range of frequencies. In the field of earthquake seismology they represent a step forward comparable to the introduction of satellite imagery into geographical mapping. We planned to install a network of the new instruments that was bigger and denser than any previous broadband network, and to sort out once and for all what mantle plumes look like.

So much for the theory. In practice, the experiment was, to say the least, challenging. Iceland is an island about the size of Ireland, but its interior is an uninhabited wasteland of arctic conditions. For much of the year that interior is inaccessible even with four-

wheel-drive vehicles. Some regions are only snow-free for six weeks of the year. Others are permanently covered with ice caps. We needed to cover the whole island uniformly with instruments and to visit them every three months to retrieve data and recharge batteries. Something like this had never been done before, but I was convinced that this was because no one had ever tried.

We started work in early spring 1996. Three field parties spent a month installing stations around the coast where they could be sited near to roads with access to mains electricity. This was the easy part.

We had to site the interior stations with care. Of primary importance was the safety of the field maintenance crews, who would visit these stations every three months for the next two years, winter and summer. Fierce, unpredictable blizzards rage across Iceland's interior in winter. In such circumstances anyone who has ventured out must seek refuge in one of the mountain rescue refuges or sheep-roundup huts that are scattered throughout the interior. For this reason we installed our interior stations in these mountain huts. There was no electricity and so instead of small mains adaptors, we installed a quarter of a ton of marine deep-cycle batteries and banks of solar panels. Instead of a convenient concrete-floored basement to house the seismometer, we had to dig deep, back-breaking trenches. What had been a couple of hours' work for a party of two in the inhabited coastal strip became three days of hard labour for four at each station.

We installed six stations in this way, including one on Vatnajökull, the largest icecap in Europe. The data from this station were later to be the subject of articles in the media when, a month after we had installed it, a volcano erupted just five kilometres away. This eruption melted a huge hole in the icecap and caused a devastating flood on the plains to the south.

So what came out of the experiment? With our large array stretching the length and breadth of Iceland we could see down to around 400 kilometres. Not quite



Gillian Foulger preparing a trench for one of the interior seismometer stations.

down to the core, but further than anyone had seen before. The snapshot emerging from the instruments was nothing like what we had expected. Instead of a tall column reaching up through the mantle to the surface, its deepest parts were flat and looked like a vast slab, standing on edge and running from north to south beneath the island. Why should a mantle plume look like this? This kind of shape is what we expect towards the bottom of a hot upwelling, not at its top. Did the plume, then, come from a source shallower than the Earth's core? How was that possible, when a hot source is not expected at such shallow depths? Were plumes different from what we had thought? Frantic debate and seemingly endless discussion followed, with late nights spent rummaging through any published paper that might cast light on the meaning of this unexpected new discovery.

Then came the stunning revelation, so simple, elegant and obvious but at the same time so lusciously outrageous and unthinkable. It wasn't a mantle plume at all – there wasn't one there. Suddenly everything we hadn't understood before fell into place: the lack of evidence for unusually hot lavas; the persistence of volcanic activity in the centre of the Atlantic ocean, when the plume hypothesis predicted the volcanic activity should have migrated to Iceland; the odd

coincidence that Iceland started erupting just as the Eurasian supercontinent tore apart 50 million years ago to create the new Atlantic ocean. Suddenly we didn't have to keep trying to force a square peg into a round hole any more.

Along with the euphoria that came with this new dawning, came the realisation that this was, in fact, just the beginning of our work. This was mind-boggling, considering that some 15 person-years of work had gone into getting the image of Iceland's source. However, such is the nature of science – the really good results mark the beginnings of new research projects, not their ends. Thus, the Iceland Hotspot Project sparked off a global debate as to whether mantle plumes exist, not just beneath Iceland, but anywhere in the Earth. It has been described as the hottest topic in Earth science today.

Mantle plume theory was deeply entrenched in Earth science, and questioning it has been greeted variously with shock, denial, ridicule, reservation, welcome enthusiasm and delight. It has inspired dedicated international conferences and special sessions, new research projects, PhD theses, revision of undergraduate courses and textbooks, films, and magazine and newspaper articles. The primary question is, if not plumes, then what causes the amazing volcanism in Iceland and at Hawaii, Yellowstone and a plethora of other volcanoes that seemingly 'shouldn't be there'? A whole new generation of theories is erupting and tests for them are being devised, invigorating Earth science in a way that has seldom, if ever, happened since the advent of plate tectonics, 30 years ago.

The Iceland Hotspot Project was run by a consortium of scientists from Durham University, Princeton University, USA, the US Geological Survey and the Meteorological Office of Iceland. Professor Foulger was awarded the 2005 Price Medal of the Royal Astronomical Society for raising serious doubts about the nature of the hot spots beneath volcanic centres such as Iceland, Hawaii and Yellowstone. For the latest on the hot spot debate, visit www.mantleplumes.org