LITTLE THINGS CAN HAVE BIG EFFECTS

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In the North Atlantic ocean, a section of the mid-Atlantic Ridge 2,000 km long runs across a massive, 5-km-high topographic dome (Figure 1). So extreme is this feature that its summit rises above the surface of the ocean to form the island of Iceland, some 350 km in north-south extent. At this unique place, over 20 spreading segments and 35 active volcanoes lie above sea level, to the convenience of scientists but to the inconvenience, from time to time, of citizens who must live with the effects of the frequent volcanic eruptions.

The crust spreads at a rate of 2 cm/year, Iceland widens along the ridge, but is simultaneously eroded around its coast. The net effect of these opposing processes currently results in an island 450 km wide in east-west extent. Curiously, however, the oldest rocks exposed at the coasts are only 17 million years old. In that period of time, only 340 km of widening can have occurred. The excess ~ 110 km of crustal width must thus be older, and submerged beneath younger lava flows [Foulger, 2006]. This unexpected feature is unexplained, and is one of many geological enigmas that persist about Iceland, despite decades of intense research.

The spreading plate boundary does not cross Iceland in a simple fashion (Figure 2). The ridge comes onshore in the southwest as a highly oblique array of spreading segments that form the 80-km-long, east-west-striking Reykjanes Peninsula. At its eastern end the strike of the entire plate boundary changes by 80˚ and it continues north as the Western Volcanic Zone. About 100 km further east lies a parallel ridge section, the Eastern Volcanic Zone. Crustal spreading is shared between these two ridges.

In its centre, Iceland is divided into north and south by an east-west orientated zone of active volcanism that extends from the furthest western tip of the Snaefellsnes Peninsula across almost all Iceland. In the north, only a single strand of the plate boundary is currently active, the Northern Volcanic Zone, its counterpart in the west having recently become extinct. Every volcanic zone in Iceland is made up of many smaller units that typically contain a central volcano dissected by a swarm of fissures. Each erupts at intervals of a few decades to a few centuries and many contain economically valuable geothermal resources. In the sea to the north, the spreading ridge joins with the submarine Kolbeinsey Ridge via the complex Tjörnes Fracture Zone. Iceland lies where the strike of the marine spreading plate boundary changes from N 50˚ E on the Reykjanes Ridge south of Iceland to N 20˚ E on the Kolbeinsey Ridge north of Iceland, another unexplained enigma.

The pattern of volcanism and tectonics in Iceland is thus extraordinarily complex, deviating massively from the simple picture that scientists envisage for sea-floor spreading. Why is this? Iceland has been popularly attributed to a deep mantle plume, ever since the theory was originally proposed by Morgan [1971]. In this view, a column of hot rock rises through thermal buoyancy from the core-mantle boundary, at a depth of ~ 3,000 km in the Earth, and impinges on the base of the lithosphere near the surface. There, it melts and causes excess volcanism on the surface. This magmatism is not expected to alter significantly surface tectonics, but merely to add volcanism to independent processes related to plate tectonics. This theory falls short, however, of explaining the myriad of complexities observed, many of them unique to Iceland. As a result, the new Plate hypothesis, recently developed in response to perceived widespread inadequacies in the Plume hypothesis [Foulger and Natland, 2003, www.mantleplumes.org], has been extensively applied to Iceland [Foulger and Anderson, 2005; Lundin and Doré, 2005]. Iceland lies on the southernmost boundary of the Caledonian suture, a site of ancient subduction. The geochemical traces of such subduction are found in Icelandic lavas [Breddam, 2002; Chauvel and Hemond, 2000; Foulger *et al.*, 2005], and seismic tomography images suggest that the melt-extraction system beneath Iceland is confined to the shallowest mantle [Foulger *et al.*, 2000; Hung *et al.*, 2004; Ritsema *et al.*, 1999]. It has been tacitly assumed for several decades that the origin of Iceland was understood, but current research suggests that it may have been completely misunderstood.

During recent days and weeks, it has not been the fundamental origins of Icelandic volcanism that have been of paramount importance, but the ultimate fate of the products. There is typically an eruption somewhere in Iceland on average every 2-3 years. A recent spectacular eruption was the 1996 eruption of Gjálp, which melted a large hole in the Vatnajökull icecap (Figure 3). The meltwater formed a catastrophic glacial burst that flooded from the southern edge of the glacier and destroyed a large section of the coastal ring-road, bridges and power lines. Later eruptions occurred in Grímsvötn in 1998, Hekla in 2000 and again in Grímsvötn in 2004. These eruptions went largely unnoticed by the international community, but this is not the case with the present eruption.

The ongoing activity in Eyjafjallajökull (translated, Eyja-fjalla-jökull means "island-mountain-glacier") first became apparent when it was seen visually 20th March. Despite the fact that earthquakes and surface deformations had increased in the weeks before the eruption, the unrest was not significant enough that an eruption was expected and a warning issued. For the next several days, lava erupted from a fissure 500 m long, in a similar style to Hawaiian fissure eruptions. Since the fissure was lower down the mountain than the icecap, no ice melting occurred initially, and the eruption was benign–a mere tourist attraction to most people. Spectacular "lava falls" developed where the lava cascaded over cliffs and April 12th the eruption stopped.

Late in the evening of April 13th, however, intense earthquake activity and eruption tremor onset higher up in the mountain, and a new eruption commenced in the centre of the ice-capped volcano crater (Figure 4). This eruption grew rapidly and the volcano is currently producing a vigorous plume of volcanic ash and steam. Although the eruption is small compared with cases such as Mt. St. Helens, unfortunately the wind is blowing from the north and spreading the ash over Europe. This is not the first time that Iceland has made itself known in this way. In 1783 the great Laki eruption–the largest outpouring of magma known in historic times–produced ash and gas that resulted in the deaths of 30% of the inhabitants of Iceland, and drove another 30% to emigrate to Canada. Denmark, which governed Iceland then, debated whether the country was fundamentally uninhabitable and whether the entire remaining population should be evacuated to Denmark. Environmental contamination and climate cooling seriously affected food production throughout much of Europe and North America and resulted in many deaths there also. This history reminds us that, despite the inconvenience and economic damage being wrought by the present eruption, it could, and one day surely will, be worse.

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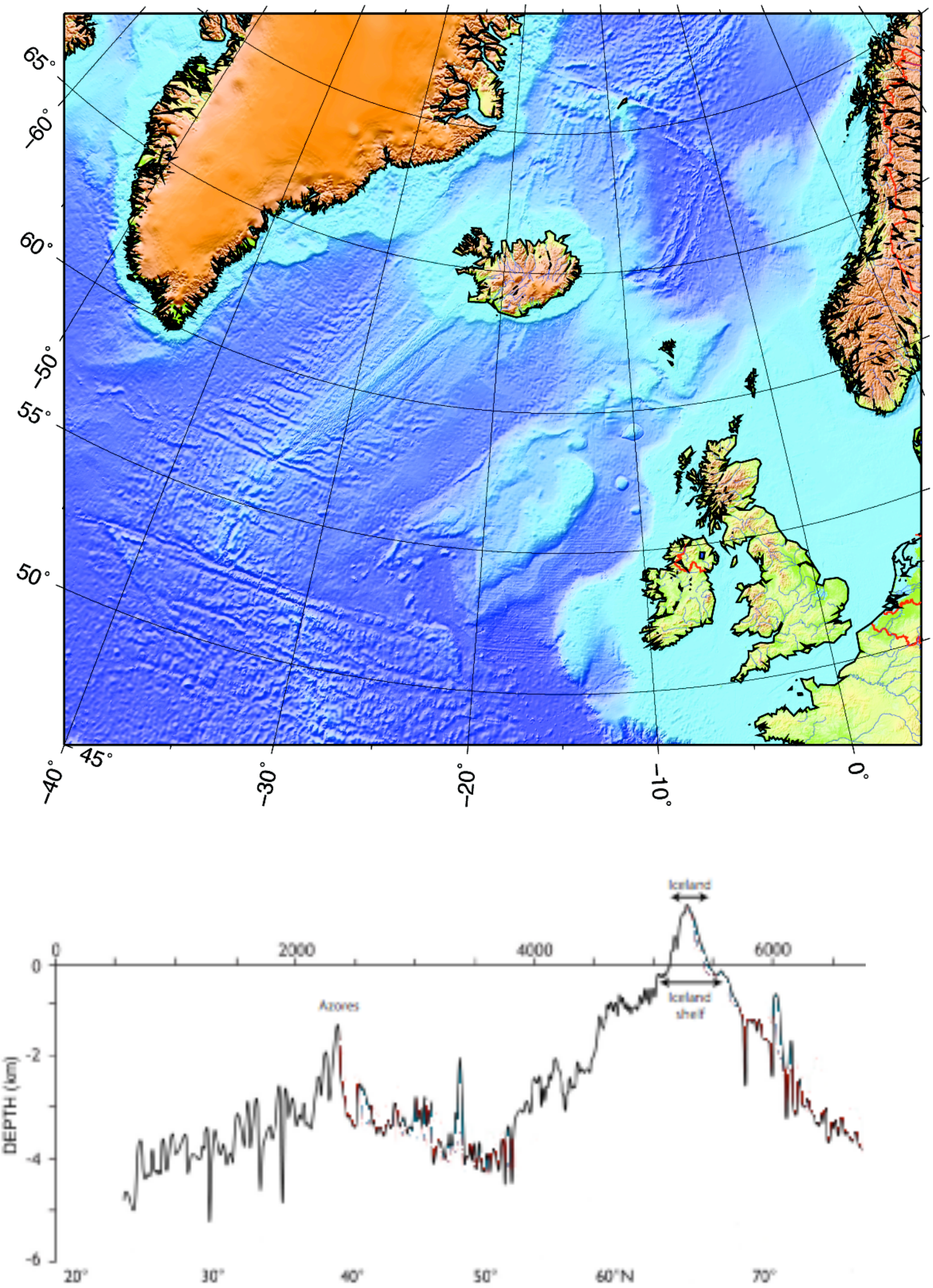

Figure 1: Bathymetry and topography of the Iceland region. IFR: Iceland-Faeroe Ridge. [basemap from *Smith and Sandwell*, 1997]. Inset shows bathymetry along a profile along the Mid-Atlantic Ridge. Iceland is not an isolated topographic anomaly but simply the summit of a vast bathymetric high ~ 3,000-km-wide that fills much of the North Atlantic [from *Vogt and Jung*, 2005].

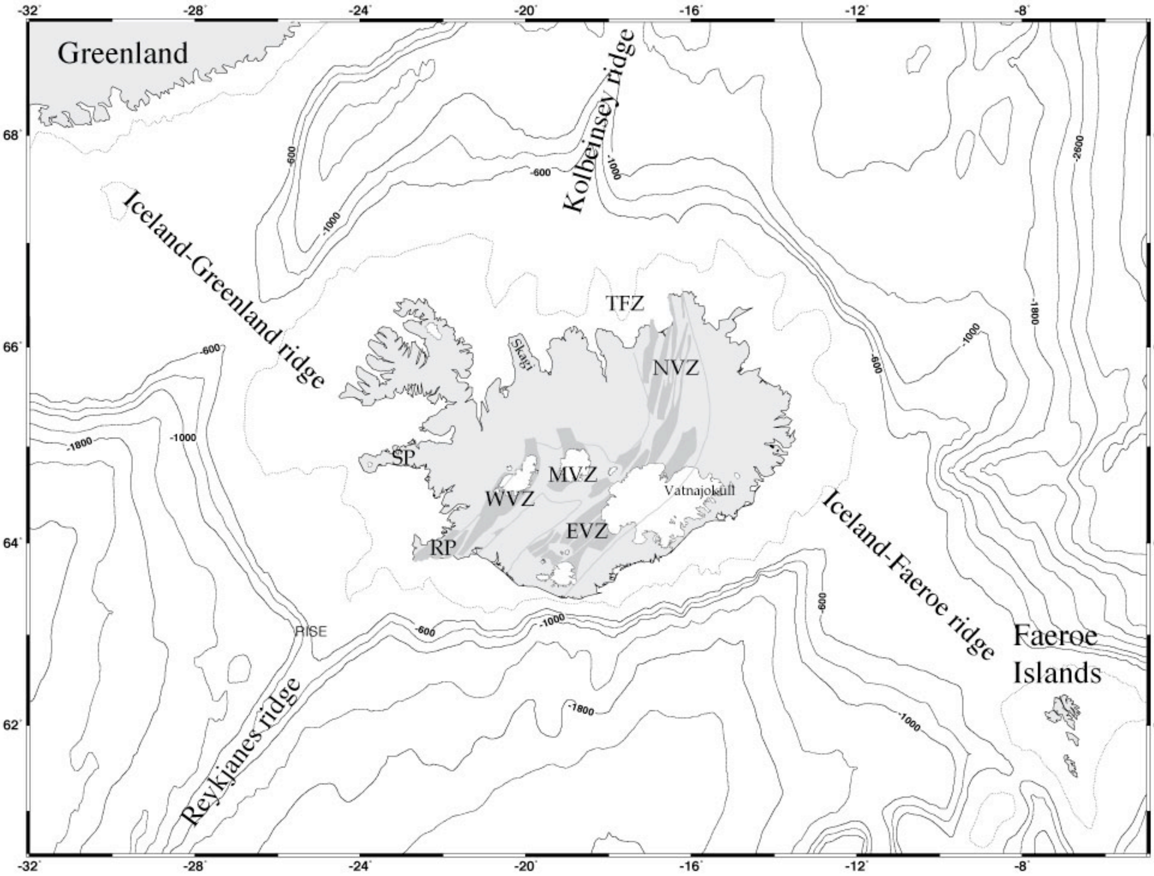

Figure 2: Map of the Icelandic transverse ridge showing bathymetric contours and tectonic features in Iceland. The neovolcanic zones are outlined. Spreading segments (volcanic systems) are shown in dark grey and glaciers in white. RP: Reykjanes Peninsula, WVZ: Western Volcanic Zone, EVZ: Eastern Volcanic Zone, SP: Snaefellsnes Peninsula, NVZ: Northern Volcanic Zone, MVZ: Middle Volcanic Zone, TFZ: Tjörnes Fracture Zone.

Figure 3: Eruption of Gjalp, in the Vatnajökull icecap, 1996.

Figure 4: Eruption of Eyjafjallajökull, April 17th, 2010, from http://www.swisseduc.ch/stromboli/perm/iceland/eyafallajokull_20100417-en.html.

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