

Satellites reveal melting of rocks under volcanic zone, deep in Earth's mantle

July 6 2017, by Simon Lamb And Timothy Stern



Mount Ngauruhoe, in the foreground, and Mount Ruapehu are two of the active volcanoes in the Taupo volcanic zone. Credit: Guillaume Piolle/Wikimedia Commons, CC BY-ND

Volcanoes erupt when magma rises through cracks in the Earth's crust, but the exact processes that lead to the melting of rocks in the Earth's mantle below are difficult to study.

In our [paper](#), published today in the journal *Nature*, we show how it is

possible to use [satellite measurements](#) of movements of the Earth's surface to observe the melting process deep below New Zealand's central North Island, one of the world's most active volcanic regions.

Rifting in the Taupo volcanic zone

The solid outer layer of the Earth is known as the crust, and this overlies the Earth's [mantle](#). But these layers are not fixed. They are broken up into [tectonic plates](#) that slowly move relative to each other.

It is along the boundaries of the tectonic plates that most of the geological action at the Earth's surface occurs, such as earthquakes, volcanic activity and mountain building. This makes New Zealand a particularly dynamic place, geologically speaking, because it straddles the boundary between the Australian and Pacific plates.

The central region of the North Island is known as the [Taupo volcanic zone](#), or TVZ. It is named after Lake Taupo, the flooded crater of the region's largest volcano, and it has been active for two million years. Several volcanoes continue to erupt regularly.

The TVZ is the southern tip of a zone of expansion, or rifting, in the Earth's crust that extends offshore for thousands of kilometres, all the way north in the Pacific Ocean to Tonga. Offshore, this takes place through sea floor spreading in the [Havre Trough](#), creating both new oceanic crust and a narrow sliver of a plate right along the edge of the Australian tectonic plate. Surprisingly, this spreading is going on at the same time as the adjacent Pacific tectonic plate is sliding beneath the Australian plate in a subduction zone, triggering some of the major earthquakes in the region.



Lake Taupo is the caldera of the region's largest volcano. Credit: NASA/Wikimedia Commons, CC BY-ND

Sea floor spreading results in melting of the Earth's mantle, but it is very difficult to observe this process directly in the deep ocean. However, sea floor spreading in the Havre Trough transitions abruptly onshore into the volcanic activity in the TVZ. This provides an opportunity to observe the melting in the Earth's mantle on land.

In general, volcanic activity happens whenever there is molten [rock](#) at depth, and therefore the volcanism in the North Island indicates vast volumes of molten rock beneath the surface. However, it has been a

tricky problem to understand exactly what is causing the melting in the first place, because the underlying rocks are buried by thick layers of volcanic material.

We have tackled this problem using data from Global Positioning System (GPS) sensors, some of which form part of New Zealand's [GeoNet network](#) and some that have been used in measurement campaigns since 1995. The sensors measure horizontal and vertical shifts in the Earth's surface to millimetre precision, and our research is based on data collected over the past two decades.

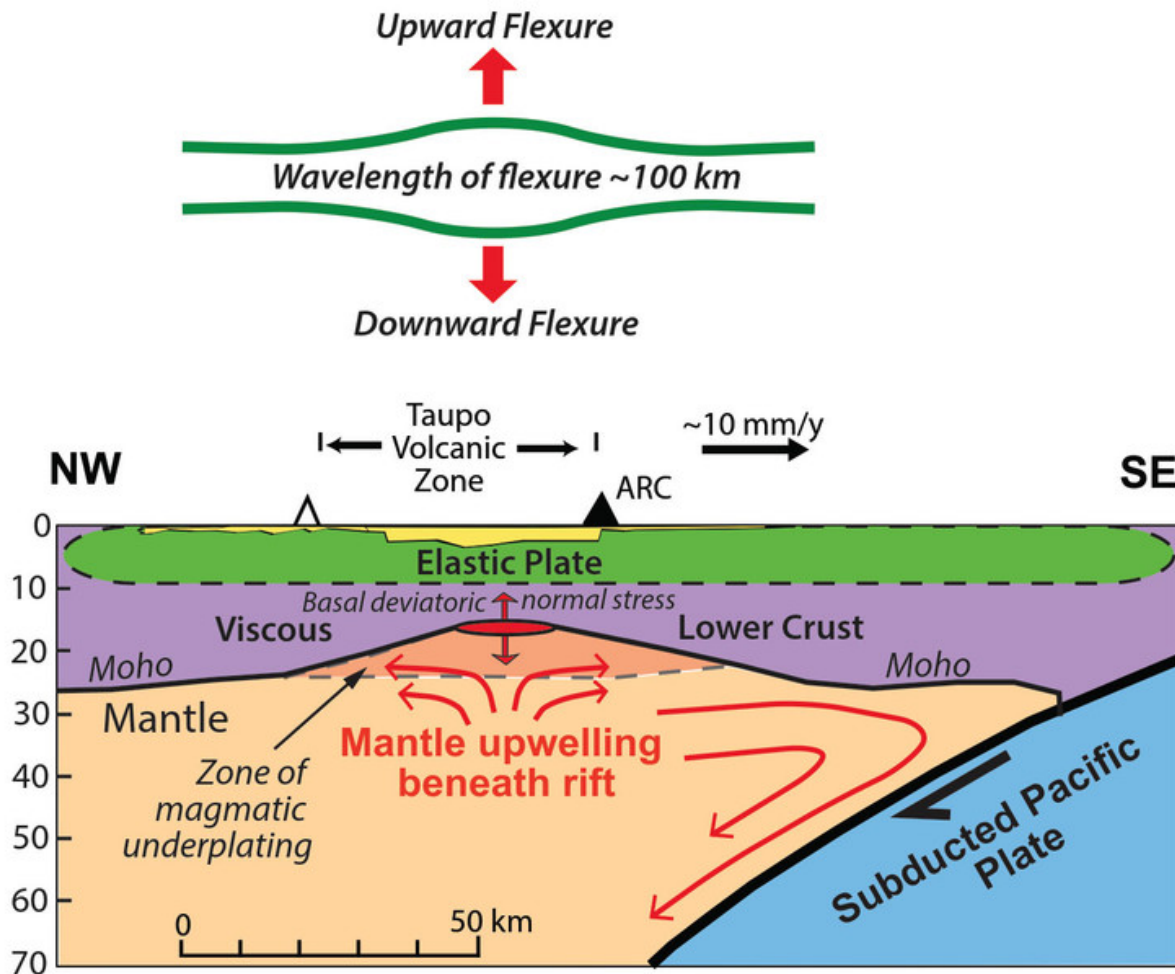
Bending of the earth's surface

The GPS measurements in the Taupo volcanic zone reveal that it is widening east-west at a rate of 6-15 millimetres per year - in other words, the region, overall, is expanding, as we anticipated from our previous geological understanding. But it was surprising to discover that, at least for the past 15 years, a roughly 70-kilometre stretch is undergoing strong horizontal contraction and is also rapidly subsiding, quite the opposite of what one might anticipate.

Also unexpectedly, the contracting zone is surrounded by regions that are expanding, but also uplifting. Trying to make sense of these observations turned out to be the key to our new insight into the process of melting beneath the TVZ.

We found that the pattern of contraction and subsidence, together with expansion and uplift, in the context of the overall rifting of the TVZ, could be explained by a simple model that involves the bending and curving of an elastic upper crust, pulled downwards or pushed upwards by an underlying vertical driving force. The size of the region that is behaving like this, extending for about 100 kilometres in width and 200 kilometres in length, requires this force to originate nearly 20 kilometres

underground, in the Earth's mantle.



This diagram illustrates a patch of suction stress along the axis of the underlying upwelling mantle flow beneath the Taupo volcanic zone. Credit: Simon Lamb, CC BY-ND

Melting the mantle

When tectonic plates drift apart on the [sea floor](#), the underlying mantle

rises up to fill the gap. This upwelling triggers melting, and the reason for this is that hot, but solid, mantle rocks undergo a reduction in pressure as they move upwards and closer to the Earth's surface. This drop in pressure, rather than a change in temperature, begins the melting of the mantle.

But there is another property of this upwelling mantle flow, because it also creates a suction force that pulls down the overlying crust. This force comes about because as part of the flow, the rocks have to effectively "turn a corner" near the surface from a predominantly vertical flow to a predominantly horizontal one.

It turns out that the strength of this force depends on how stiff or sticky the mantle rocks are, measured in terms of viscosity (it is difficult to drive the flow of highly viscous or sticky fluids, but easy in runny ones).

Experimental studies have shown that the viscosity of rocks deep in the Earth is very sensitive to how much molten material they contain, and we propose that changes in the amount of melt provide a powerful mechanism to change the viscosity of the upwelling mantle. If mantle rocks don't contain much melt, they will be much stickier, causing the overlying crust to be pulled down rapidly. If the rocks have just melted, then this makes the flow of the rocks runnier, allowing the overlying crust to spring back up again.

We also know that the movements that we observe at the surface with GPS must be relatively short lived, geologically speaking, lasting for no more than a few hundred or few thousand years. Otherwise they would result in profound changes to the landscape and we have no evidence for that.

Using GPS, we can not only measure the strength of the suction force, but we can "see" where, for how long, and by how much the underlying

mantle is melting. This melt will eventually rise up through the crust to feed the overlying volcanoes.

This research helps us to understand how volcanic systems work on a variety of time scales, from human to geological. In fact, it may be that the GPS measurements made over just the last two decades have captured a change in the amount of mantle melt at depth, which could herald the onset of increased [volcanic activity](#) and associated risk in the future. But we don't have measurements over a long enough time period yet to make any confident predictions.

The key point here is, nevertheless, that we have entered a new era whereby satellite measurements can be used to probe activity 20 kilometres beneath the Earth's surface.

More information: Simon Lamb et al. Episodic kinematics in continental rifts modulated by changes in mantle melt fraction, *Nature* (2017). [DOI: 10.1038/nature22962](https://doi.org/10.1038/nature22962)

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