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Modelling ground deformation patterns associated with volcanic processes at the Okataina Volcanic Centre

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ABSTRACT

The Okataina Volcanic Centre (OVC) is one of two large active rhyolite centres in the modern Taupo Volcanic Zone (TVZ) in the North Island of New Zealand. It is located in a complex section of the Taupo rift, a tectonically active section of the TVZ. The most recent volcanic unrest at the OVC includes the ~1315 CE Kaharoa and 1886 Tarawera eruptions. Current monitoring activity at the OVC includes the use of continuous GPS receivers (cGPS), lake levelling and seismographs. The ground deformation patterns preceding volcanic activity the OVC are poorly constrained and restricted to predictions from basic modelling and comparison to other volcanoes worldwide. A better understanding of the deformation patterns preceding renewed volcanic activity is essential to determine if observed deformation is related to volcanic, tectonic or hydrothermal processes. Such an understanding also means that the ability of the present day cGPS network to detect these deformation patterns can also be assessed. The research presented here uses the finite element (FE) modelling technique to investigate ground deformation patterns associated with magma accumulation and diking processes at the OVC in greater detail. A number of FE models are produced and tested using Pylith software and incorporate characteristics of the ~1315 CE Kaharoa and 1886 Tarawera eruptions, summarised from the existing body of research literature. The influence of a simple ring fault structure at the OVC on the modelled deformation is evaluated. The ability of the present-day continuous GPS (cGPS) GeoNet monitoring network to detect or observe the modelled deformation is also considered. The results show the modelled horizontal and vertical displacement fields have a number of key features, which include prominent lobe based regions extending northwest and southeast of the OVC. The results also show that the ring fault structure increases the magnitude of the displacements inside the caldera, in particular in the vicinity of the southern margin. As a result, some of the cGPS stations in the vicinity of the OVC are more important for measuring deformation related to volcanic processes than others. The results have important implications for how any future observed deformation at the OVC is observed and interpreted.

1. Introduction

Large calderas must be continually monitored for time-dependent ground deformation to estimate magma chamber pressurization and assess their eruption potential (Galgana et al., 2014). However, the very long repose periods between eruptions at large calderas mean that the opportunity to directly observe deformation preceding volcanic unrest is limited. This means that at present there is also a limited understanding of precursory geophysical signals leading to major events (Ellis et al., 2007). This restricts the ability to distinguish subtle precursory volcanic signals from local hydrothermal and regional tectonic signals (Cabral-Cano et al., 2008; Fournier and Chardot, 2012).

Numerical models can be used to forward model changes in the volcano system and simulate the resulting surface deformation field. For 'simple' sources, such as a magmatic dike or magma reservoir, analytical models, (e.g. Mogi, 1958; Okada, 1985, 1992; McTigue, 1987), can be used. However, many volcano systems (particularly large calderas) are typically, 1) located in complicated rift settings, 2) co-located with active and energetic hydrothermal systems, and 3) have complex three dimensional structure (e.g. fracture systems linked to caldera collapse or complex layered crustal rheology). As a result the deformation field may be affected in an unpredictable way (De Natale and Pingue, 1993; Bonaccorso et al., 2005) and differ from that modelled by analytical techniques. More flexible numerical techniques, such as the Finite Element (FE) technique are required to reflect this complexity.

Studies utilising the FE technique are diverse and include investigations of the influence of topography and heterogeneous rock properties on volcanic deformation (Trasatti et al., 2003; Bonaccorso et al., 2005; Manconi et al., 2007; Currenti et al., 2008, 2010; Long and Grosfils, 2009; Geyer and Gottsmann, 2010; Ronchin et al., 2013), the presence of caldera boundary discontinuities (De Natale et al., 1997; Beauducel

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et al., 2004; Folch and Gottsmann, 2006), the relationship between hydrothermal activity and deformation (Todesco, 2009; Rinaldi et al., 2010; Rinaldi et al., 2011; Fournier and Chardot, 2012) and thermo-mechanical modelling (Hickey et al., 2015), to list a few examples. By simulating ground deformation, the FE technique can also be used to assess the ability of any in-situ continuous GPS (cGPS) network to observe or detect various magma system changes, such as dike intrusion at depth or chamber pressurization. This is also important to develop a monitoring network with a spatial resolution that is capable of distinguishing natural and anthropocentric sources of surface deformation (Eff-Darwich et al., 2008). However, studies that have applied this concept to real world volcano-monitoring using cGPS networks and/or other geodetic techniques (e.g. Fernández et al., 1999; Yu et al., 2000; Charco et al., 2007) are limited.

The Okataina Volcanic Centre (OVC) is one of two large active rhyolite centres in the modern Taupo Volcanic Zone (TVZ) in the North Island of New Zealand. It is located in a complex section of the Taupo rift, a tectonically active section of the TVZ (see Fig. 1). Magma supply is considered plentiful in this part of the rift and has been linked to large-scale deformation patterns and variations in rift architecture (Rowland et al., 2010; Ellis et al., 2014; Hamling et al., 2015). The most recent volcanic unrest at the OVC includes the ~1315 CE Kaharoa and 1886 Tarawera eruptions, in which dike intrusion was a key eruption mechanism (Nairn and Cole, 1981; Sherburn and Nairn, 2001; Nairn et al., 2004; Nairn et al., 2005). The OVC is presently monitored using continuous GPS (cGPS), seismographs and lake levelling instrumentation. Surface deformation has been observed across the OVC (Scott, 1989; Hamling et al., 2015; Holden et al., 2015), however there is no clear evidence that it is linked to renewed volcanic unrest. Rather, studies indicate a relationship to large-scale magmatic and rifting processes (Ellis et al., 2014; Hamling et al., 2015; Holden et al., 2015).

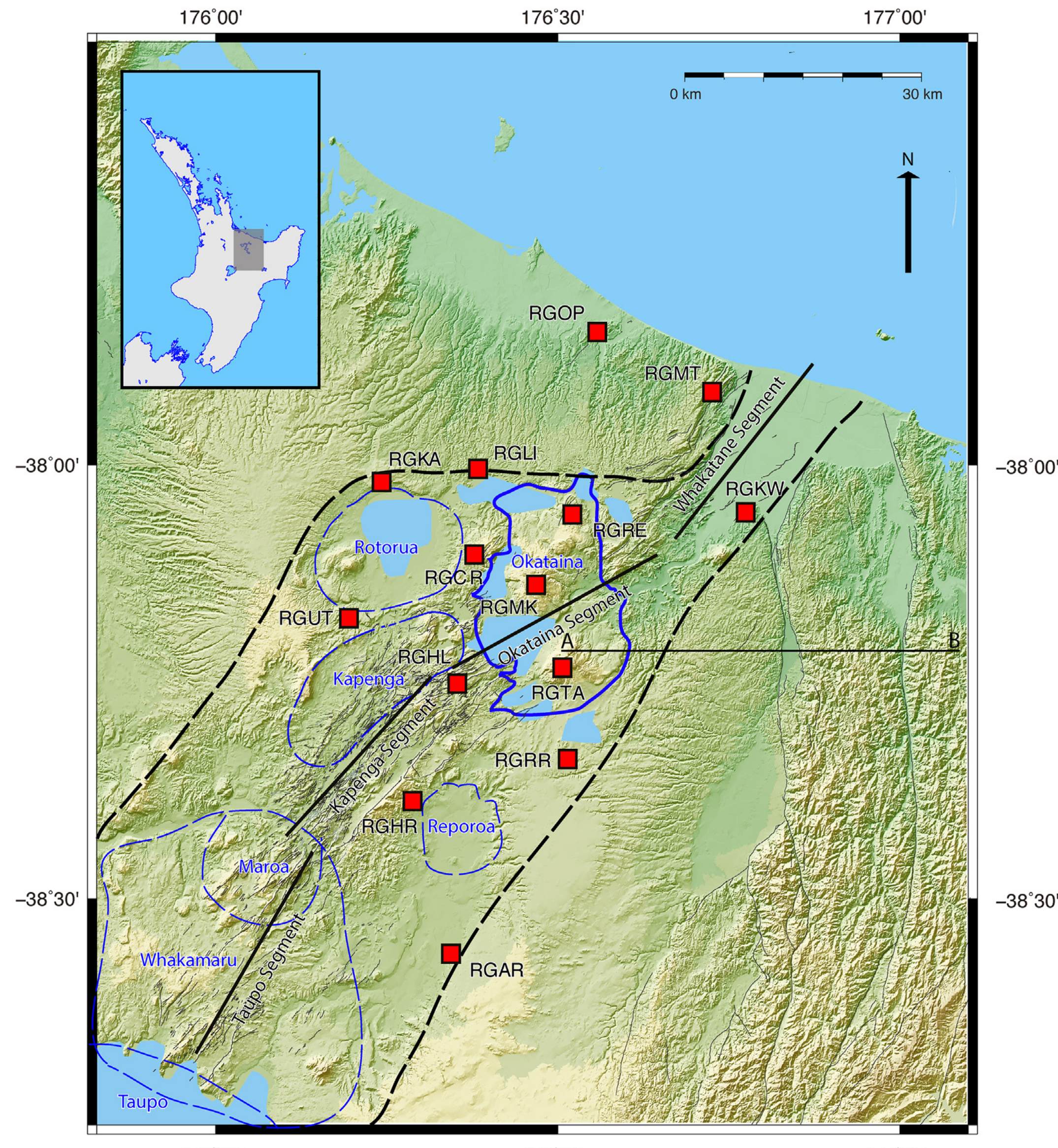

Fig. 1. Regional geological setting and location and distribution of all GPS stations used in this study. Locations of major TVZ calderas (from Spinks et al., 2005) are shown as blue dashed lines and their boundary locations are approximate. The Okataina Volcanic Centre (OVC) is shown as bold blue line. Modern TVZ boundaries are shown as dashed black lines from Cole (1990) and are approximate. GeoNet cGPS stations are shown as red squares. Rift segments are from Acocella et al. (2003) and shown approximately as solid black lines and labelled in the figure. The inset at the upper left shows the approximate location of the study area. The line A-B represents the profile used for later plots of modelled horizontal and vertical displacements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)