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Characterizing the subsurface structure and stress of New Zealand's geothermal fields using borehole images

David D. McNamara[a]*, Cécile Massiot[b], Sarah M. Milicich[b]

[a]*National University of Ireland Galway, University Road, Galway, Ireland*
[b]*GNS Science, 1 Fairway Drive, Lower Hutt, New Zealand*

Abstract

Borehole imaging captures geological information on lithology, structure, and stress in the Earth's subsurface. This paper synthesises currently analysed borehole imaging data acquired in geothermal fields in the Taupo Volcanic Zone. Structure and stress orientations agree with the tectonic trend, though display variation between and within geothermal fields. Structural variability is related to larger scale rift fault architecture, while stress orientation variations are related to active structures. Borehole images also provide information on structural fluid flow pathways in TVZ geothermal fields showing structures with NE-SW and E-W strike orientations and wide fractures occur within fluid flow zones.

Keywords: geothermal; New Zealand; Taupo Volcanic Zone; fluid flow; fractures; stress

1. Introduction

The Taupo Volcanic Zone (TVZ) contains much of New Zealand's high enthalpy geothermal resources, most of which are hosted within volcanic deposits and crystalline plutonic rocks, or indurated, metamorphic, greywacke basement. The permeability within these geothermal reservoirs is invariably dominated by faults and fractures, with only small contributions made by intrinsic, porosity type permeability [1,2,3]. As such, geological investigation that

* Corresponding author. Tel.: +353-9-149-3069.
E-mail address: david.d.mcnamara@nuigalway.ie

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reveals insights into the architecture of New Zealand's geothermal structural (fault and fracture) system, and the in-situ stress regime acting upon it, is vital for a resource's development.

In the TVZ more common techniques for characterizing the subsurface structure are not available. Seismic surveys reveal little about subsurface structures due to interference from high natural ground level noise and high attenuation [4]. Other geophysical methods commonly utilized for investigating subsurface architecture are limited to inferring the presence of larger scale crustal structures at depth [5,6,7]. Surface exposure of deeper lithostratigraphic units is limited, and active fault mapping and outcrop fracture measurements only reveal the structural characteristics of the uppermost lithostratigraphic layers of the TVZ volcaniclastic fill [8,9]. Three-dimensional structural modelling of TVZ geothermal fields and the basement structures of the entire TVZ are limited by the well density of individual fields and scale restrictions of geophysical data input [10].

Historically, borehole imaging technology had not been applied in wells drilled in the TVZ geothermal fields, despite geothermal boreholes being drilled since 1958. Temperatures encountered at drilling depths (up to ~350°C at depth of ~3.5km) are too high for traditional borehole image tool technology (which commonly caps at ~175°C). The development of a borehole televiewer (BHTV) tool by the HIgh Temperature Instruments for supercritical geothermal reservoir characterization and exploitation (HITI) project [11], first deployed in New Zealand in 2009, provided the first acoustic borehole images of the TVZ subsurface. Since then other logging practises (well quenching while logging) have been tested in some New Zealand geothermal fields to allow the acquisition of resistivity borehole images, though these are still rare [12]. To date approximately thirty wells in six TVZ geothermal fields have had an image log acquired which has provided the first direct measurements of sub-surface fracture properties and horizontal stress field orientations within TVZ geothermal reservoir lithologies. This paper highlights some of the key research and findings on structurally controlled fluid flow in New Zealand geothermal fields that have been produced from analyses of a selection of these new datasets and how this information can provide further insight into larger questions around the architecture of the TVZ itself.

1.1. Geological setting

The TVZ (~350 km long, ~60 km wide) is an extensional, back-arc rift structure located in the North Island of New Zealand, which formed as a result of westward subduction of the Pacific Plate (Fig. 1). The TVZ has experienced >4Ma, NW-SE (~137) directed extension most of which is accommodated by active rift faults, the modern expression of which is referred to as the Taupo Fault Belt (TFB) [13, 14]. The TFB is dominated by NE-SW striking faults which show strong spatial polarity in dip direction (NW or SE) that is used to define the approximate positions of the rift axis [15]. Offsets along this inferred rift axis are present and have been described as accommodation zones rooted in NW-SE oriented basement structures which are thought to play a crucial role in the spatial distribution of TVZ geothermal fields [16].

NNW-SSE and NW-SE striking, greywacke basement faults in the TVZ are not directly observed but are inferred from gravity and magnetic data, landsat data, aerial photos, second order residual gravity anomalies, and field mapping of exposed greywacke basement outside the rift [17]. N-S trending structures are also defined within the TFB by topographical mapping and seismic interpretation, and are inferred to be reactivated basement fabrics [18, 19], report NW-SE, N-S and E-W structural fabrics from measurements of fault traces and joints across the TVZ and TFB.

TFB faulting is pure normal to normal with a small strike-slip component [20, 21]. The dominant NE-SW fault strike orientation, and focal mechanisms define a vertical stress component (σ_1; S_v), a NE-SW oriented maximum horizontal stress component (σ_2; S_{Hmax}), and a horizontal minimum stress component (σ_3; S_{hmin}) aligned approximately NW-SE across the TVZ consistent with the extensional setting of the region. Evidence of strike-slip faulting is inferred from a number of sources a) steepness of fault dips, b) en echelon geometry of faults, c) horsetail splaying of major NE-SW trending faults and, d) the intersection of the North Island Dextral Fault Belt (NIDFB) [15, 22], though active fault scarps in the TVZ show geomorphic evidence of strike-slip displacement of surface morphological features [20].