

# A DEEP (5 km?) GEOTHERMAL SCIENCE DRILLING PROJECT FOR THE TAUPO VOLCANIC ZONE – WHO WANTS IN ?

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## ABSTRACT

The Taupo Volcanic Zone (TVZ, New Zealand) is an active continental volcanic arc / back-arc and fault-controlled extensional basin, produced by westward subduction of the Pacific Plate beneath the Australian-Indian Plate. The TVZ is a vast natural heat engine, and hosts several geothermal systems that are developed for electric power generation. New Zealand's geothermal resources are utilised to ~3 km and temperatures up to ~340°C. Current geothermal generation is ~730 MWe (~13% of New Zealand's total electricity generation). The theoretical deep (>4 km depth) energy potential in the TVZ is massive, but are the resources realizable, and therefore a realistic part of New Zealand's energy future?

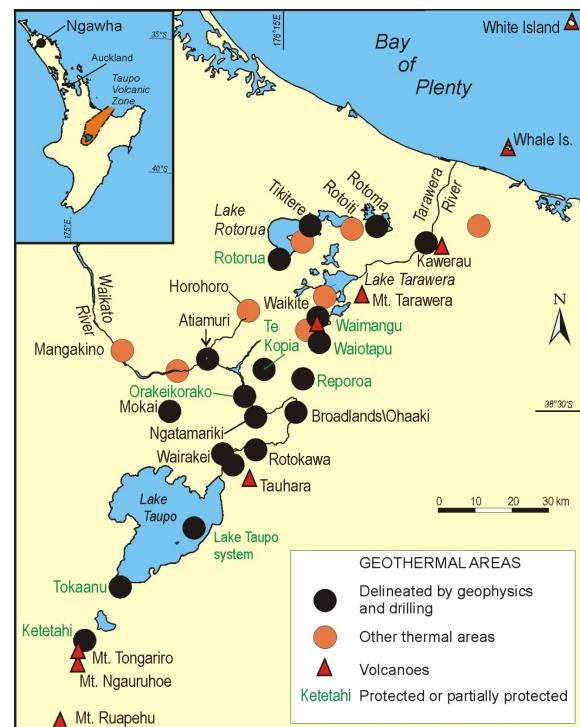
Since 2009, New Zealand Government-funded research has examined the nature of deep geothermal activity in the southern TVZ. Planning is now underway for an ambitious and technically challenging science drilling project, to successfully drill, sample (fluid and host rock) and assess the permeability structure of deep-seated TVZ geothermal activity. Scientific and engineering know-how obtained will help overcome barriers that restrict deep geothermal resource utilisation, whilst providing previously unobtainable insights into the chemistry, structure and evolution of TVZ geothermal systems. Drilling is aligned with international research objectives involving International Continental Science Drilling Program (ICDP) and International Partnership for Geothermal Technology (IPGT) relationships. The New Zealand geothermal industry is motivated to maximise the potential of their resources, and their involvement in the TVZ science drilling project is essential. As planning moves forward, we will identify those interested in planning the next stage of the programme; understand current research results; and ask who wishes to assist in funding the project, planning project goals and well targets, and coordinating research objectives.

## 1. INTRODUCTION

New Zealand is endowed with resources of “conventional” geothermal energy, from 1 to 3 km deep, >240°C reservoirs (Figure 1). Geothermal energy makes a major contribution to New Zealand's electricity supply, although increased utilisation is needed to help meet future demand. This fact has prompted the New Zealand geothermal industry and research community to consider the potential of untapped, deeper, hotter geothermal resources in the Taupo Volcanic Zone (TVZ) – i.e. within the interval marked by current maximum drilling (~3.5 km depth) and inferred depth to the brittle-ductile transition (~7 km depth) in the southern TVZ, as indicated by the apparent cessation of shallow-sourced earthquake loci in the area; Heise et al. (2007), Figure 2.

Whilst temperatures increase with depth, ease of extraction decreases, as rocks at high pressures and temperatures become less porous, thus reducing fluid flow. Whilst a number of technical issues need to be addressed, there is recognition of the resource potential of deep-seated geothermal systems in the TVZ, since conversion of even a small percentage of these natural energy resources could assure New Zealand's energy security.

A barrier to development of deep geothermal resources in the TVZ is the ability to identify, delineate and target zones of enhanced permeability, in order to obtain a sustainable supply of high-temperature fluid for electricity generation. Collaborative research is underway, led by GNS Science, and involving specialists at the University of Auckland, Victoria University of Wellington, and Industrial Research Ltd., in a New Zealand Government-supported project (previously administered by the Foundation for Research, Science and Technology (FRST), “Harnessing New Zealand's Geothermal Resources: Hotter and Deeper”; Bignall, 2010) that is an integral component of the GNS Science Core Science Area (CSA) Geothermal Research



**Figure 1: Taupo Volcanic Zone, showing major geothermal fields explored by drilling and geophysics, and locations of geothermal plants developed for electricity generation (green stars).**

programme. Our work aims to provide New Zealand's geothermal industry with a high level of confidence to proceed with deep geothermal exploration. The project addresses: (i) the deep structure and dynamics of the southern TVZ, New Zealand's most intense area of deep-seated geothermal manifestations; and (ii) the physical and chemical nature of the deep fluids and controls on their flow pathways.

By the conclusion of our research programme in 2012, we will have greatly extended our knowledge of the deep hydrology and structure of TVZ geothermal systems, such that an industry-research consortium will be well placed to target a deep geoscience hole (prospectively to >4-5 km depth) to assess the structure, controls on permeability and chemistry of New Zealand's deep geothermal resources. The findings of Taupo Volcanic Zone – Deep Geothermal Drilling Project (TVZ-DGDP), and the drilling / engineering experience gained, will be invaluable to the international EGS research and development community, and provide a vehicle to establish a range of initiatives to establish with collaboration with IPGT (International Partnership for Geothermal Technology) partners.

## 2. TAUPO VOLCANIC ZONE

The TVZ is an active continental volcanic arc / back-arc basin. It is an extensional basin (~8 mm/y), with numerous, predominantly normal (>60° dip) faults. The TVZ is divided into three sectors: north (Whakatane Graben) and south (Tongariro Volcanic Centre), where andesitic volcanism predominates, and a central part characterised by volumetrically dominant rhyolitic volcanism that is expressed as major caldera complexes (Houghton et al, 1995). Caldera-forming silicic volcanism in the TVZ began at c. 1.6 Ma, and at least thirty-four caldera-forming eruptions have occurred since that time (Wilson et al.,

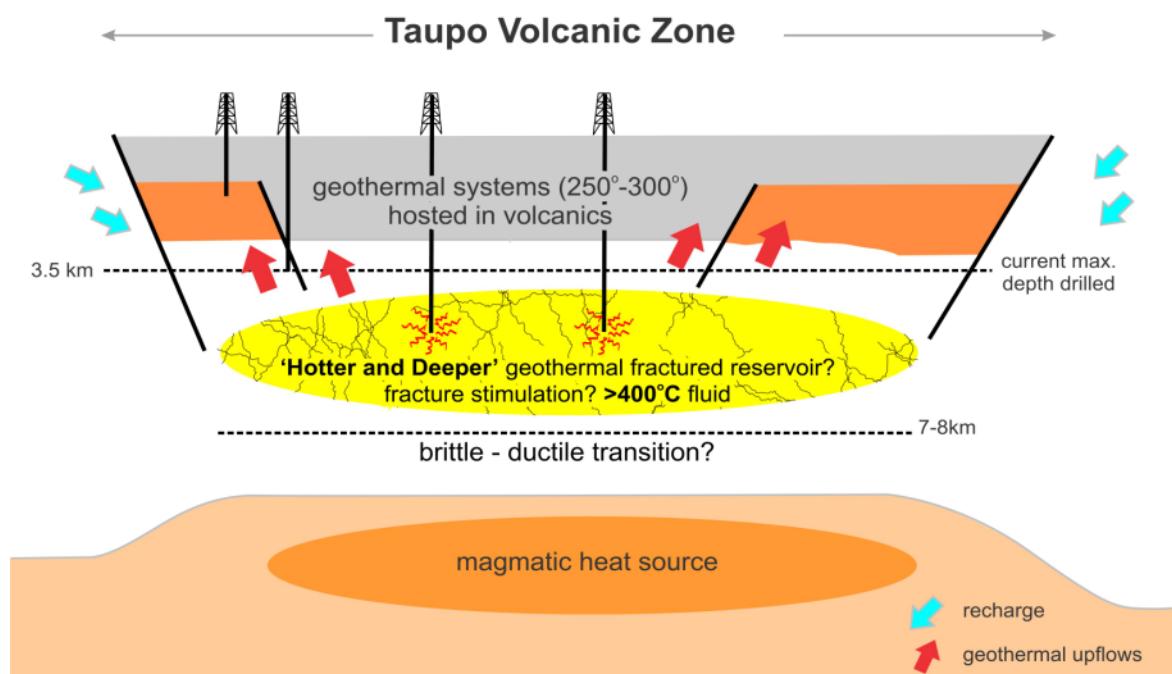
1995). Six of the calderas in the central TVZ have formed in the last 350 ka. These comprise both multiple event caldera complexes (Okataina, Taupo, Whakamaru) and single event calderas (Reporoa, Ohakuri, Rotorua). Geothermal activity, and the location of thermal centres and their evolution, are intimately associated with volcanism in the area, which are inferred to provide the heat energy to drive the hydrothermal convective systems.

## 3. NEW ZEALAND'S DEEP GEOTHERMAL RESEARCH PROGRAMME

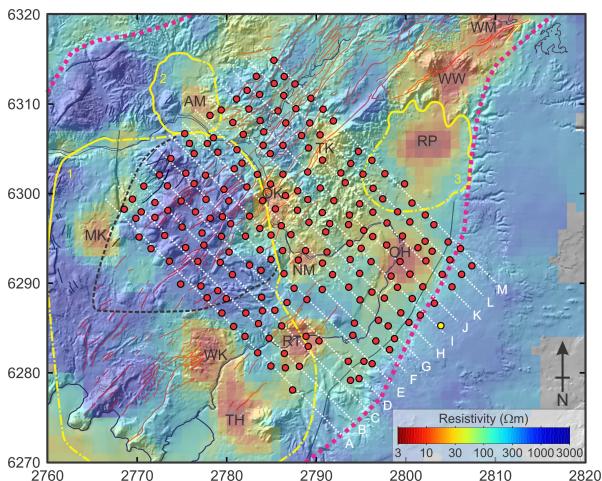
Our research programme investigates the character of deep geothermal resources in the Taupo Volcanic Zone, with the aim of providing developers with a high level of confidence and reduced exploration risk, and is a first step towards exploration drilling of New Zealand's deep resources.

Improved scientific knowledge will help quantify the deep resources and overcome barriers to development. The programme aims to "Improve understanding of the deep structure and dynamics of the Taupo-Reporoa Basin, through geological and geophysical mapping, and greater understanding of the chemical nature of the deep fluids and their flow paths ....", via :

1. a combined magnetotelluric and seismic model of TVZ mid-crustal structure (Bertrand et al., 2011; Figure 3), to identify deep permeability and fluid flow - development of a 3D image of the electrical resistivity structure of the basin to 3 to 7 km depth.
2. an understanding of the geological structure and stratigraphy of the Taupo-Reporoa Basin (e.g. Alcaraz et al., 2011; Figure 4), with a time-series reconstruction of basin evolution, and a model for the modern strain distribution across the basin.



**Figure 2. Schematic representation of the Taupo Volcanic Zone (after Heise et al., 2007), showing the current maximum depth of geothermal drilling and inferred brittle-ductile transition zone (below which the host rock is not expected to support fracture permeability), which bounds the region that might be explored in the future by deep drilling.**



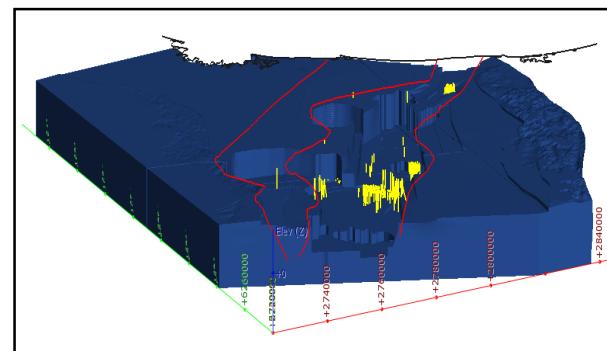
**Figure 3: Map of MT array in the southern TVZ, from Bertrand et al., 2011 (these proceedings), from “Hotter and Deeper” Research Programme. Red circles are MT sites. The yellow circle is the remote reference. Profiles used in 2-D modeling (described by Bertrand et al., 2011) are shown as white dashed lines. TH Tauhara, WK Wairakei, RT Rotokawa, MK Mokai, NM Ngatamariki, OK Orakeikorako, OH Ohaaki, TK Te Kopia, AM Atiamuri, RP Reporoa, WW Waiotapu-Waikiti, WM Waimangu. Yellow lines show caldera boundaries (1. Whakamaru, 2. Ohakuri, 3. Reporoa), with solid lines constrained by topography and dashed lines inferred structural collapse faults from Wilson and Leonard (2008). Black dashed line outlines the Maroa Volcanic Centre. The pink dashed lines show the approximate boundaries of the TVZ after Wilson et al., 1995. Active faults are shown as orange lines.**

3. development of numerical fracture models for the TVZ setting, including continuum mechanics of fracture formation by artificial means, and flow of water and steam in deep fracture-hosted rock networks.
4. determination of fluid-rock interactions at near-critical and super-critical pressure and temperature conditions, using custom-designed fluid-rock interaction apparatus (Mountain et al., 2011), to assess the effect of rock properties on porosity, fracture permeability and well productivity.
5. Development of a deep reservoir model (incl. fracture character and fluid flow), with equations of state (i.e. mixtures of water, salts and gases at high temperatures).

#### 4. TAUPO VOLCANIC ZONE – DEEP GEOTHERMAL DRILLING PROJECT (TVZ-DGDP)

We have now begun discussing with potential New Zealand and international consortium industry and research partners (c.f., strategy, financial issues) the rationale for deep geothermal drilling in the TVZ.

The proposed TVZ-DGDP project would build on the New Zealand Government-funded research (previously described), which aims to improve scientific knowledge of the TVZ - thus providing the New Zealand geothermal industry with a high level of confidence, at reduced risk, to support deep exploration drilling.



**Figure 4: 3D Basement model of the Taupo Volcanic Zone (looking to the NNE), from Alcaraz et al., 2011 (these proceedings).**

At the forefront of our interests, are a series of *research* questions related to magmatic-hydrothermal systems at mid-crustal levels in the TVZ, and their utilisation, including:

1. What are the physical and hydrothermal-chemical (fluid) conditions, and character of fluid-rock interactions in the TVZ, at >4-5 km depth?
2. What are the controls on permeability, and rheology of TVZ geothermal reservoir rocks, at mid-crustal depths? Will the TVZ-DGDP hole intersect the transition from brittle to ductile rheology – how will this impact drilling progress?
3. What stresses occur that influence fracture permeability, fracture initiation and propagation, and longevity, that might impact deep well productivity? What information can be gained concerning the healing of fracture permeability at, and below, the brittle to ductile transition?
4. Will deep drilling confirm our combined geophysical (MT - seismic), geological and numerical models of the TVZ below >4km depth? How will information gained from deep drilling change our thinking about the evolution of the TVZ, the location of magmatic heat sources and development of its hydrothermal systems?
5. What is the potential for sustainable, deep geothermal resource utilisation in the TVZ?

The goals of any prospective deep drilling project, as well as practical drilling/engineering issues (e.g. casing design, BHA design, drilling practices, costs etc), will concern geothermal industry partners, who will ultimately be the primary financial contributors (and benefactors) of the project. Some of the issues of concern to industry are now being discussed with prospective partners, but there are many aspects that need to be considered, including:

1. What are the key scientific questions related to the delineation of deep-seated geothermal systems, controls on deep permeability, and potential for utilisation of deep resources in the TVZ.
2. Is deep drilling the right approach, and capable of answering these questions? Are the drilling risks acceptable, given the value of information that may be gained?

3. Where will the drilling be undertaken (no preferred well location has yet been proposed)? What land access, permitting and environmental management issues need to be considered?
4. What agreements need to be established concerning IP and information exchange between industry and research partners, particularly if the prospective deep exploration/science hole is located (or drilled into) a field currently managed by one or more existing operator/owners?
5. Is deep drilling in/near existing active TVZ geothermal systems feasible? What type of fluids and conditions are likely to be encountered at 4-5 km depth, and could these fluids be utilised for power generation or other applications?
6. What preparatory research is still required?
7. How much is it going to cost? (preliminary costings have already been established for 4, 5 and 6 km-deep drillholes). How will the project be funded?, i.e. financial commitment for *drilling*, from New Zealand geothermal industry, New Zealand Government(?) and International agencies(?) and institutional funding for proposed *research* initiatives
8. How will the geoscience and engineering research programme (and teams) be structured, and who should lead the project? At some stage, confirmation of core research team (including international involvement) will be required, with establishment of peer-review / advisory panel.

#### 4.1 TVZ-DGDP Action Plan

Preliminary discussions with New Zealand geothermal developers have realised enthusiasm for deep exploration geothermal drilling in the Taupo Volcanic Zone – either as a dedicated science hole (possibly with co-ICDP funding for drilling activities, possibly supporting an intensive coring programme); or, for geoscience and engineering research to accompany the deepening of a conventionally drilled, “standard” production hole in a developed field.

As part of the plan to promote deep TVZ geothermal exploration, GNS Science hosted the “**Hotter And Deeper Exploration Science (HADES)** Geothermal Logging and Interpretation Workshop” on 25-26 May 2011 in Taupo. Keynote speakers at the workshop were Dr. Ragnar Asmundsson (ISOR-Icelandic Geosurvey, coordinator of the European Hiti project “High Temperature Instruments for supercritical geothermal reservoir characterisation and exploitation”, and member of IPGT high temperature tools working group) and Dr. Wilfred Elders (Principle Investigator of the Icelandic Deep Drilling Project and Professor of Geology at the University of California).

Dr. Asmundsson’s visit to New Zealand was sponsored by an “International Mobility Fund” (Royal Society of New Zealand) grant to Dr. Bignall (GNS Science), with additional funding to Dr. Bignall and Ms. Cecile Massiot from the Ministry of Science and Innovation, to support international travel of US participants.

As well as ongoing discussion with prospective industry partners, the next step in advancing the TVZ-DGDP is the organization of a *locally-funded TVZ-DGDP strategy*

*meeting, which we suggest may be held as* an adjunct to the Annual New Zealand Geothermal Workshop (in which the above issues could be discussed).

We anticipate 12–15 New Zealand researchers could be joined by a representative of the ICDP Operational Support Group, and researchers from other ICDP-supported projects, and representatives from international EGS drilling projects.

#### **ICDP Workshop, Application January 2012**

We intend to hold a 3–4-day international workshop in mid-2012, which we will bring together domestic and international expertise, to discuss existing knowledge (i.e. research outputs of the current “Hotter and Deeper” geothermal research programme) and the TVZ-DGDP drilling strategy and project goals.

The application for ICDP funding, to hold a sponsored international workshop MUST be submitted by 15 January, 2012. It is envisaged that one of the outcomes from the locally funded TVZ-DGDP strategy meeting will be the establishment of a steering committee who will be tasked with preparing the ICDP Workshop funding application, as well as advancing discussion and negotiations with industry partners and funding agencies, and addressing logistical aspects of the proposed deep drilling.

The outcome of the ICDP workshop will be the formulation of an international geoscience team of GNS Science and international researchers, and New Zealand geothermal industry representatives, who will prepare a full ICDP science drilling proposal, to be submitted to ICDP in January 2013.

A key question that will be addressed at the ICDP workshop is which international research organisations should be invited to participate in an ICDP-funded TVZ-DGDP Workshop, proposed for 2012, and during drilling of the TVZ-DGDP drillhole.

Looking towards 2013-14, we realise that the drilling programme envisaged for the TVZ-DGDP project is ambitious, and will be an expensive undertaking, necessitating significant (several NZ \$M’s) industry commitment. The TVZ-DGDP drilling phase is unlikely to happen soon, and the project will need to address a range of engineering issues – consequently, the TVZ-DGDP team will be operating at the cutting edge of current geothermal drilling technology.

#### **5 VALUE OF DEEP TVZ GEOTHERMAL DRILLING**

Deep science drilling in the Taupo Volcanic Zone has long been mooted, but for one (several) reason or another has not occurred. However, there are several positives reasons for the international community to support deep geothermal science drilling in the Taupo Volcanic Zone:

1. A long history of geothermal exploration and development science and engineering drilling experience, with >90% success rate by the New Zealand geothermal community in standard well completion (last ~10 years).
2. Strong geoscience research (institutional) and industry relationships. New Zealand has recently joined the International Partnership for Geothermal Technology (IPGT), and therefore will be a direct benefactor of

EGS insights from collaborating with US, Australian, Icelandic and Swiss researchers and engineers.

3. TVZ-DGDP builds on the last ~10 years of New Zealand Government-funded research to GNS Science, and its predecessor organisation (Institute of Geological and Nuclear Sciences Ltd.), and other universities – consequently, a wealth of geophysical and geological knowledge (at least to 2.5 km depth) already exists for the TVZ magmatic system, and for geothermal fields within the TVZ.
4. A supportive regulatory and consenting authority in which to undertake onshore drilling. Political support at a Government level, for renewable energy (and “geothermal”, in particular) to be a major energy contributor to the country.
5. A globally-credible scientist team at GNS Science (core research team), supplemented by specialist expertise at The University of Auckland, Victoria University of Wellington, Industrial Research Limited, and Canterbury University, with well-established international connections, and secure science funding.
6. A geothermal setting (access, topography etc) conducive for relatively straight-forward (by international standards) deep (>4km depth) drilling operations, with supporting infrastructure.

## 6. CONCLUSIONS

- Since 2009, New Zealand Government-funded research has examined the nature of deep geothermal activity in the southern Taupo Volcanic Zone.
- Preliminary planning is now underway for an ambitious and technically challenging deep (prospectively to >4 to 5 km depth) science drilling project, to successfully drill, sample (fluid and host rock) and assess the permeability structure of deep-seated geothermal activity in the Taupo Volcanic Zone.
- Scientific and engineering know-how obtained will help overcome barriers that could restrict deep geothermal resource utilisation, whilst providing previously unobtainable insights into the chemistry, structure and evolution of geothermal systems in the Taupo Volcanic Zone.
- Drilling is aligned with international research objectives involving International Partnership for Geothermal Technology (IPGT) relationships, to which New Zealand has recently joined, and science drilling objectives of the International Continental Science Drilling Program (ICDP).
- The New Zealand geothermal industry is motivated to maximise the potential of their resources. Their involvement in the TVZ science drilling project is essential for it to proceed, and to succeed in meeting its science and engineering objectives.

As planning moves forward, we aim to identify those interested in planning the next stage of the programme; understand current research results; and ask who wishes to assist in funding the project, planning project goals and well targets, and coordinating research objectives.

## ACKNOWLEDGEMENTS

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