AN INTEGRATED APPROACH TO GEOLOGICAL AND FLUID FLOW MODELLING: FROM A 3D GEOLOGICAL MODEL TO TOUGH2

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ABSTRACT

Various attempts have been made to understand geothermal fluid circulation in the Taupo Volcanic Zone (TVZ), focusing on the locations of the convective plumes over which the active geothermal systems lie. Additional studies have considered the effects of permeability and fault structures on convection through investigation of generic circulation models. These studies usually overlook the geological complexity of an area by simplifying the permeability models to two units consisting of undifferentiated volcanic layers, overlying the TVZ greywacke basement, therefore missing any variability in the rock properties of the different volcanic strata. A 3D Leapfrog Geothermal geological model is built to be incorporated into a TOUGH2 reservoir model to represent more realistic geology and hence permeability input data into the simulation.

This paper presents a 3D geological model through the central TVZ, extending from Waiotapu in the north to Ngatamariki in the south. The model will be used to create a TOUGH2 reservoir model of this area that investigates structural controls and recharge effects on fluid flow on a regional scale. The geology and structure of the area has been simplified to reflect the end use in a TOUGH2 flow model. The geology units have been simplified into hydrogeological groups based on similar age and groundwater flow characteristics (e.g., pore and fracture permeability, porosity). The fault structures used in the model have also been simplified to focus on large-scale faults (e.g., Paeroa Fault, Reporoa Caldera collapse fault) or those with significant fluid pathways (e.g. Ngapuru Fault, major upflow zones and associated springs). A combination of borehole data, surface geology and structures were used to generate representative geological formations at depth.

1. INTRODUCTION

This paper follows the development of a Leapfrog Geothermal 3D regional geological model (henceforth called the 3D regional model) extending from Waiotapu in the north to Ngatamariki in the south. The area of interest of the model (Fig. 1) covers several geothermal fields and was selected to include regions of geological complexity and variable surface groundwater recharge. This model will be used to export the geology into a gridded TOUGH2 model for investigating the structural controls and recharge effects on geothermal fluid flow on a regional scale. The geology and structure of the area has been simplified to reflect the end use in a TOUGH2 flow model. The geology has been simplified into hydrogeological groupings and the fault structures have been simplified to large scale faults.

A combination of borehole data, surface geology and structures were used to generate these representative geological formations at depth. The formations and faults have been selected based on the factual data available and modelling capabilities of the software. The software used for modelling the geology is Leapfrog Geothermal 2.8.1.

The model covers an area of 874 km^2 (Fig. 1) and is delimited at the ground surface by a 40 m resolution DTM (created by GNS Science). The resolution of the model is set to 100 m.

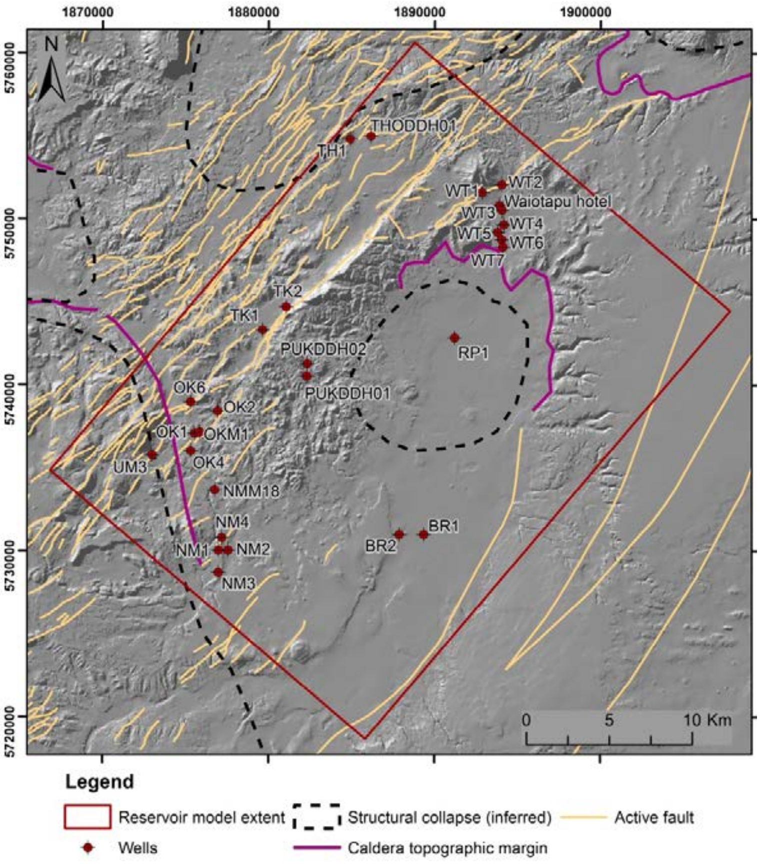

Figure 1. Map presenting the model extent and major caldera structures sourced from 1:250,000 QMAP Rotorua sheet (Leonard et al., 2010). The active faults are from the GNS Active Fault Database (Langridge et al., 2015). Wells used for subsurface information are shown.

2. MODEL INPUTS

The geological database used to create this model contains 10 simplified and grouped hydrogeological units. These groupings were selected to reflect the similarity of the hydrological properties of the constituent geological formations. Following is a description of the datasets incorporated into the 3D regional model.

2.1. QMAP

The hydrogeological groupings have primarily been defined by a simplification of the QMAP data from Leonard et al., (2010). The QMAP GIS polygons representing the surface geology from Leonard et al. (2010) have been grouped and merged into simplified geological units.

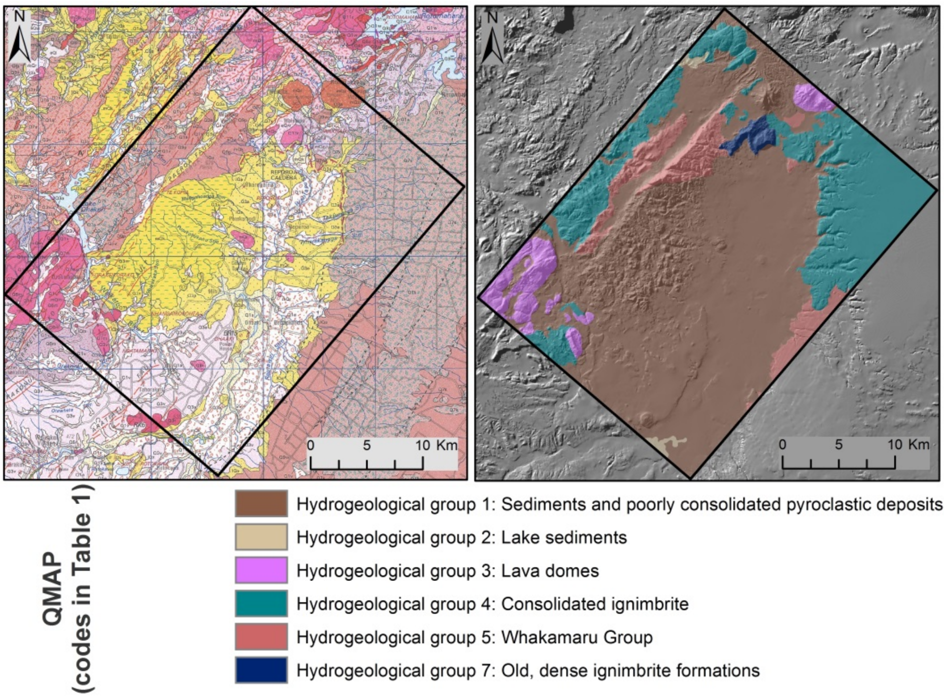

Figure 2. Simplification of surface QMAP geology to hydrogeological groupings used in the 3D regional model. The full legend for QMAP can be found in Leonard et al., (2010).

2.2. Well data

Leapfrog Geothermal allows the importing of borehole data from a Microsoft Access database. The tabulated borehole dataset includes three main data sets: collar information, survey data and geological descriptions. Publically available data from 28 wells drilled for exploration and development of geothermal fields are included in this database (Healy, 1955; Grindley, 1963; Steiner, 1977; Alder and Sharp, 1988; Fransen, 1988; Fransen and Sharp, 1988; Bignall, 1994; Wood, 1994; Brotheridge, 1995; Glass Earth (NZ) Ltd. 2009; O'Brien, 2010; Bosley et al., 2012). The same groupings applied to the QMAP data have been used to group the downhole data.

2.3. Cross sections

Published geological cross sections provided additional information for construction of the subsurface distribution of formations. Published cross sections of the Ohaaki (Rae et al., 2007; Rissman et al., 2001), Ngatamariki (Bosley et al., 2012; Chambefort et al., 2014) and Rotokawa (McNamara et al., 2015) areas are valuable where the well information is not publically available. In addition, cross sections from QMAP (Leonard et al., 2010) and Wilson and Rowland (2015) cross through the area.

2.4. Stratigraphic sequence

The hydrogeological groups reflect geological units of similar age and groundwater flow characteristics. A summary of the hydrogeological groupings and their hydraulic characteristics is given in Table 1. Table 1 and Figure 2 present the QMAP units which have been combined as hydrogeological groups used to build the model.

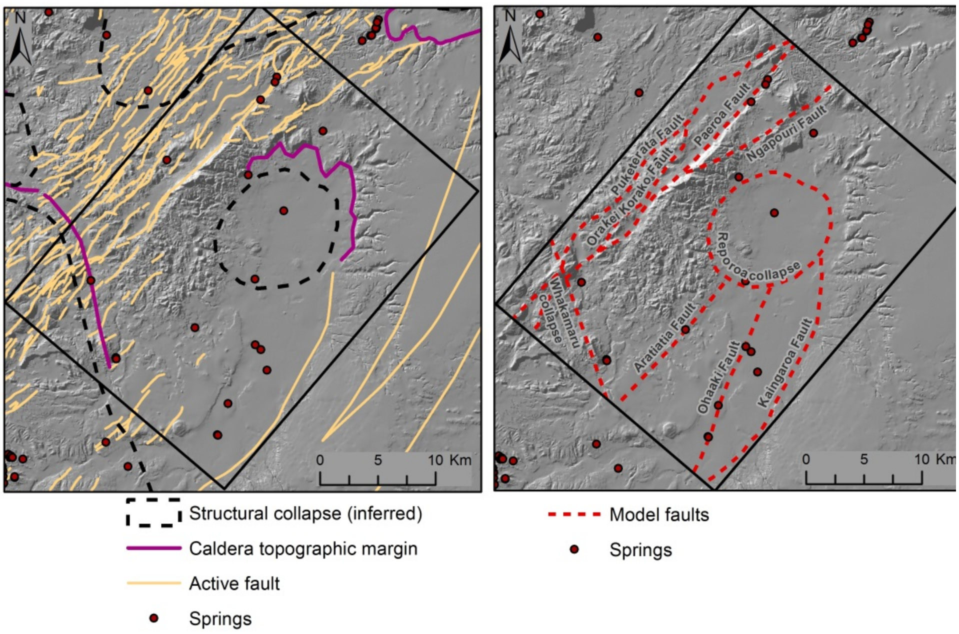

Figure 3. Major structures and their translation into the simplified structures used in the 3D regional model. The structural collapse and caldera margins are sourced from 1:250,000 QMAP Rotorua sheet (Leonard et al., 2010) and the active faults are from the GNS Science Active Fault Database (Langridge et al., 2015).

Table 1. Formation groupings used in the 3-D interface used as input to build a hydrogeological model. Geological map units and formation names are from Leonard et al. (2010).

Grouping for 3D hydrogeological model	Geological map unit code	Geological map stratigraphic unit names	Sequence	Hydraulic characteristics
Hydrogeological group 1: sediments and poorly consolidated pyroclastic deposits	lQaf	Alluvial fan	Tauranga Group	Medium to high hydraulic conductivity, porous flow
	Q1af	Alluvial fan	Tauranga Group	
	Q1al	Quaternary alluvium	Tauranga Group	
	Q1ta	Taupo Pumice Formation	Taupo Group	
	Q3ah	Hinuera Formation	Tauranga Group	
	Q3or	Oruanui Formation (in the area of Earthquake Flat Formation)	Taupo Group	
	Q4eq	Earthquake Flat Fm.	Okataina Group	
Hydrogeological group 2: Lake sediments	mQlk	Lake sediments	Tauranga group	Low conductivity, localised fracture flow
	Huka Group sediments from drilling (do not crop out at surface)			
Hydrogeological group 3: lava domes	Q5vmr	Rhyolite 0.068 to 0.125	Maroa Group	Low to medium hydraulic conductivity, fracture flow in interior and porous flow at margins
	Q6vmr	Rhyolite 0.133 to 0.168	Maroa Group	
	Q7vmr	Rhyolite 0.189 to 0.251	Maroa Group	
	lQvmr	Rhyolite 0 to 0.128	Maroa Group	
	mQvbt	Basalt 0.128 to 0.524	Maroa Group	
	Q3vb	Basalt 0.03 to 0.045	Maroa Group	
	mQvd	Dacite 0.128 to 0.524	Okataina Group	
Hydrogeological group 4: Consolidated ignimbrite	Q8orl	Orakonui Formation	Maroa Group	Low to medium hydraulic conductivity, fracture flow in welded, porous flow in unwelded (dominant)
	Q7kiu	Kaingaroa Formation	Reporoa Group	
	Q8ma	Matahina Formation	Okataina Group	
	Q7oh	Ohakuri Formation	Rotorua-Kapenga	
	Q7vp		Okataina Group	
Hydrogeological group 5: Whakamaru Group	Q9w		Whakamaru Group	Low to medium hydraulic conductivity, fracture flow in welded (dominant), porous flow in unwelded
	Q9wp	Paeroa Formation	Paeroa Subgroup	
		Tuffs (reported in Waiotapu wells)		
		Te Weta and Te Kopia ignimbrites (in drillholes)	Paeroa Subgroup	
Hydrogeological group 6: Old, consolidated ignimbrite	No outcrop	Pre-Whakamaru Group ignimbrite, not welded		Low hydraulic conductivity, localised fracture flow, porous flow
Hydrogeological group 7: Old, dense ignimbrite formations	eQwi	Waiotapu Formation	Including Akatarewa Ignimbrite (in drillholes)	Low conductivity, fracture flow
Hydrogeological group 8: Subsurface domes	No outcrop	Subsurface domes (rhyolite, dacite, andesite)		Low to medium hydraulic conductivity, fracture flow in interior and porous flow at margins
Hydrogeological group 9: Basement	No outcrop	Greywacke		Very low conductivity, fracture flow
Hydrogeological group 10: Intrusion	No outcrop			Low conductivity, fracture flow

Examples of the groupings are for instance, gravels, sediment and many poorly consolidated pumiceous tuffs, which have a high hydraulic conductivity and homogenous flow. For this reason all shallow coarse-grained sediments, reworked tuffs and young unconsolidated tuffs have been treated as one hydrogeological grouping (hydrogeological group 1 in Table 1 and Fig. 2). In contrast, welded ignimbrites have low conductivity, but sustain fracture permeability and have preferential flow paths (hydrogeological group 7 in Table 1 and Fig. 2).

2.5. Structures

The major structures (inferred structural collapses, caldera topographic margins and active faults) have been simplified in the area of the 3D regional model (Fig. 3). The simplified fault network has been chosen to best represent major offsets in geology (particularly at depth, e.g. greywacke basement offsets) and faults that have a major influence on the regional hydrology, e.g., the Paeroa Fault which represents a major fluid pathway, with numerous springs along its length (Fig. 3).

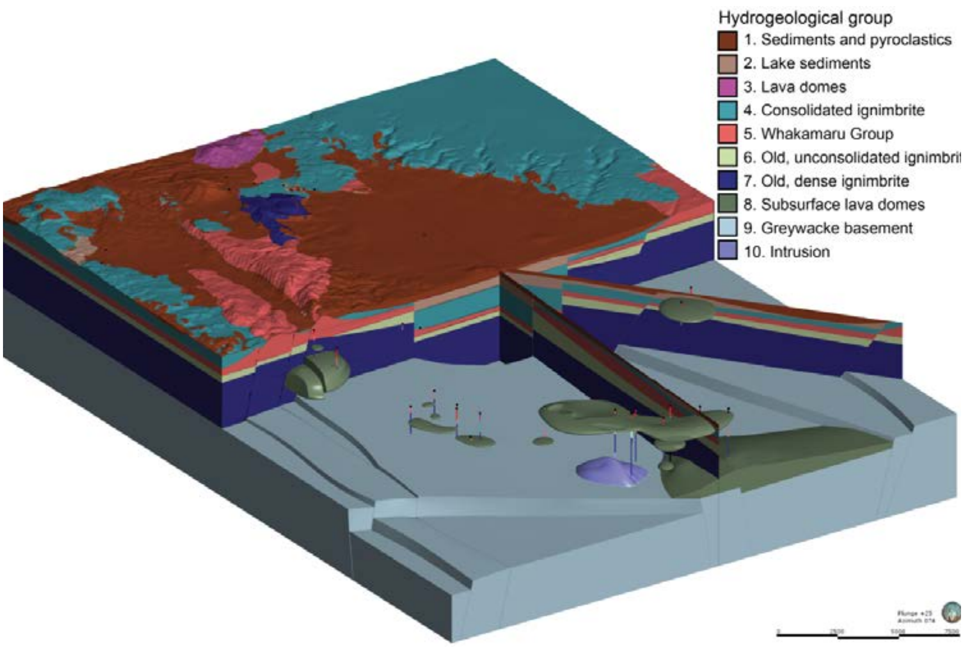

Figure 4. 3D geological visualisation of hydrogeological groupings and structural influences within the area of interest.

3. GEOLOGICAL MODEL

Using the described model inputs we have created a geological model in Leapfrog Geothermal. This model includes 10 hydrogeological units and 9 large-scale and simplified faults (Fig. 4).

4. TOUGH2 MODEL OUTPUT

Future work will involve creating a TOUGH2 simulation of the area based on the geological model presented in this paper. Using Leapfrog's built-in capability, the rock type parameter of the TOUGH2 grid will be automatically populated from the geological model. The rock types will then be assigned bulk permeabilities and porosities based on Table 1. By comparing this to a model based on highly simplified geology, and also by varying recharge rates, the effects of geological structures and recharge rates on geothermal fluid flow will be explored. These results can be compared with flow distributions and reservoir temperatures observed in real life to determine how much of a control they are. An example of the geology rendered in a TOUGH2 grid for this purpose is shown in Figure 5.

The full visualisation capabilities of the software will be used to facilitate the calibration of the numerical model and visualisation of the outputs of the simulations.

5. SUMMARY

We have created a geological model that encompasses several geothermal fields in the Taupo Volcanic Zone. We have grouped the geology into 10 hydrologically-based stratigraphic units simplified from QMAP, well data and cross sections. Large-scale faults that are thought to affect fluid flow were also modeled. This geological model will form the basis for a multi-field model of the TVZ that looks at how much of an effect geological structure and groundwater recharge has on geothermal fluid flow.

By creating the initial geological model in Leapfrog Geothermal, and using it as the input to define the various rock types of the TOUGH2 numerical model, we are taking into consideration the natural geological complexity of the area to look at more detailed and realistic fluid flow simulations. Combining TOUGH2 software with 3D modelling software like Leapfrog Geothermal allows inputs to be more easily visualised, and outputs to be compared with both the original model and any other datasets like well temperature, lithology or surface features. This helps to create more accurate models and to vastly improve the way that model results can be visualised and shared. This not only makes

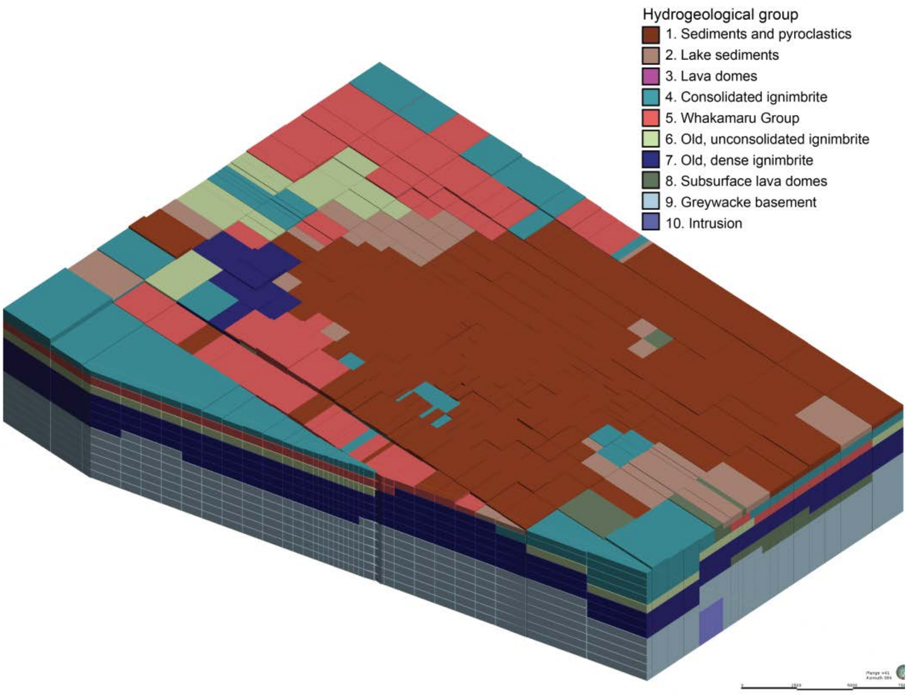

Figure 5. Example of a 3D geological grid output to be used as input into a TOUGH2 simulation of the study area.

the modeling process easier, but also helps when disseminating TOUGH2 models to a non-specialist audience.

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