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CURRENT AND FUTURE GEOTHERMAL RESEARCH IN NEW ZEALAND

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ABSTRACT

Research programs by Crown Research Institutes (Geological & Nuclear Sciences Ltd. and Industrial Research Ltd.), university departments (Auckland, Massey and Victoria), power companies and private consultancies aim to obtain a better understanding of currently producing geothermal fields in New Zealand, and of deep geothermal systems which might have potential for future resource development. Research is also being directed at industrial and environmental issues related to exploitation, water-rock alteration processes, changes in shallow geothermal systems with time, and mineralisation as it relates to epithermal ore formation.

The chemical and physical environment of geothermal reservoirs in the Taupo Volcanic Zone (e.g. Thames, Kawerau, Ohaaki, Ngatamariki, Wairakei, Tongariro, Tauhara and Tokaanu-Waihi) is being quantified with the aim of developing a suite of magma to ambient production scenarios using numerical, reactive transport models. A variety of geological, geochemical and geophysical techniques including fluid inclusion geothermometry, stable isotope analysis, electromegnetic, micro-seismic and magnetotelluric analysis is providing high quality input data.

Through experimentation and computer modelling, criteria for assessing the optimal depths for re-injection of production effluents are being developed, and related problems such as silica and calcite scaling, pipeline insulation and chemical corrosion investigated. Paths, flow mechanisms and flow rates of re-injection plumes are being modelled using electrical resistivity, micro-gravity and radioisotope tracer methods.

Environmental affects related to testing and development, presently causing concern amongst local authorities and the public, are being quantitatively assessed, and recommendations made to mitigate them. The mechanical and petrological properties of rocks in shallow aquifers undergoing ground subsidence are being determined, and the extent and style of ground deformation investigated. Changes in surface heat flow and carbon dioxide flux are also being determined and the data obtained modelled to assess the use of shallow re-injection to resolve environmental problems.

1. INTRODUCTION

Geothermal power is a major energy source in New Zealand, estimated at more than 20,000 TJ (Allis and Speden, 1991). Recent deregulation of the electricity supply industry has resulted in a renewed focus on geothermal resources. The geothermal industry is currently active in assessing new developments, and there is increasing interest from developers, regulators, and communities in improving efficiency while reducing risk and environmental impact through appropriately targeted scientific programs.

Current and planned research by the Crown Research Institutes GNS (Institute of Geological & Nuclear Sciences) and IRL (Industrial Research Ltd.), Auckland, Massey and Victoria Universities, power companies and private consultancies is aimed at obtaining a better understanding of currently producing fields, on exploring deep geothermal systems which might have potential for future development, and on industrial and environmental issues related to exploitation and re-injection. Most current research deals with high-temperature volcanic-hosted systems, rather than low-temperature systems for immediate use.

Government funding for geothermal research amounts to some NZ$1.7M per year from the Public Good Science Fund (administered by the Foundation for Research Science & Technology, FRST), and an additional, much smaller amount, from input funding to Universities and from the Royal Society administered Marsden Fund. This funded research is targeted according to priorities and strategies devised by the New Zealand Science Ministry (MoRST) in consultation with the geothermal industry. All other research is funded by geothermal power companies both within New Zealand and overseas. Much of this is in the form of technological development to solve immediate problems, and may not be fully covered here.

2. GNS

Research programs based at Wairakei Research Centre and Gracefield, Lower Hutt focus on two main areas: (i) characterisation of deep geothermal reservoirs within Taupo Volcanic Zone (TVZ) and (ii), environmental effects of geothermal exploitation.

2.1 Understanding deep geothermal systems

The lack of deep (>3km) drilling in TVZ geothermal systems has, to some extent, hampered research in this area (deep drilling is very expensive @ >NZ$1M per km and therefore risky, so the reluctance of geothermal developers to explore greater depths is understandable). However, through a combination of field, laboratory, and theoretical studies, GNS research projects aim to provide both conceptual and numerical models which developers can use to evaluate deep production scenarios. Three major lines of research are currently being pursued:

Chemical and physical environment of magmatic heat source regions: This is being determined through detailed study of past "arc-type" magmatic events, and through characterisation of present-day fluid discharges. Data and conceptual understanding derived from this are being used to constrain numerical models of convective heat and chemical transfer processes (collaboratively with IRL).

Characterisation of arc-type magma-ambient environments as possible production reservoirs involves petrographic (including fluid inclusion geothermometry), geochronological (principally $^{40}Ar/^{39}Ar$ dating), chemical and stable isotope analysis of minerals associated with past magmatic events in the Ngatamariki, Kawerau, and Thames systems. Careful study of the alteration products from these events allows evaluation of pressure, temperature and compositional constraints as well as helping to unravel their individual chronologies. This information is being fed directly into reaction path (CHILLER, REACT) and reactive transport (CHEMTOUGH) models (White and Christenson, 1998) which are being used to identify key reservoir processes and to develop chemical exploration tools for recognising magmatic heat sources.

Studies of production fluids at Ohaaki are being extended to Kawerau and Wairakei, expanding on the observations of Giggenbach (1995) who recognised a strong magmatic signature in the Ohaaki field. In collaboration with Lawrence Berkeley and Lawrence Livermore National Laboratories (USA), and the Geological Survey of Japan, comprehensive analysis of fluid discharges from across the fields is being undertaken. This includes identification of major liquid and gas species, trace and ultra-trace metal compositions, and isotopic signatures of C, O, H, S, B, Cl, I, He, Ne, Ar, Kr and Xe. The data are being assessed in terms of established systematics for magmatic geo-indicators, and revised hydrologic models are being developed which address the origins and nature of the fluids.

Geophysical analysis of deep geothermal reservoirs and their boundary regions: A resistivity model for the upper 3 km of the NE Wairakei field boundary is being generated from time domain electromagnetic (TDEM) data. Combined TDEM and magnetotelluric (MT) data are being used to determine the deep (2-4 km) resistivity structure of the boundary region of the Ngatamariki field. These results will be combined with deep resistivity data from Kawerau and Ohaaki to determine common factors between these widely separated, but structurally comparable, systems. At the same time, old (>330 ka) TVZ volcanic units are being studied to determine whether they make viable production/re-injection aquifers. These units, which are presently under-utilised for production, are being assessed for their overall geothermal characteristics (degree of alteration, permeability, etc.) and suitability as production (ie. drilling) targets. This work interfaces with resistivity and microseismicity research conducted elsewhere within the volcanological programs at GNS to assess the effect of large scale geothermal convection on the rheology and seismicity of the crust beneath TVZ.

Understanding the Tongariro and Tokaanu-Waihi geothermal systems: Delineation of the resistivity boundary of the Tokaanu-Waihi system using the newly developed 50 Hz tensor method (Risk et al., 1997) (Fig.1) is being extended to the Tongariro system. MT survey data is being analysed and interpreted, and an aeromagnetic survey carried out. Geochemical analysis of the two systems is aimed at determining whether there is a single parent fluid feeding them. The data is currently being synthesized into a single working model.

2.2 Environmental impacts of geothermal development

The Resource Management Act requires sustainable exploitation of New Zealand's geothermal resources through re-injection of waste geothermal fluid for all new and existing geothermal developments. Environmental research at GNS is aimed at improving re-injection technology through analysis of silica scaling, determination of re-injection plume flow-paths, and assessment of the related issues of land subsidence and reduction of thermal features such as geysers and hot pools.

Silica scaling: The effectiveness of re-injection technologies is limited by silica deposition, which can quickly reduce the permeability of host formations. In collaboration with IRL, experiments are being conducted to determine how quickly geothermal fluid in equilibrium with amorphous silica re-equilibrates with respect to quartz. This will enable prediction of how much and where most of the silica deposition occurs after re-injection into a geothermal aquifer. Further experiments using more complex, and realistic packed and fluidised beds are planned to determine whether trace elements affect the scaling rates of complex brines. When these are completed, results will be combined with hydrodynamic data on colloidal silica to obtain a conceptual model for silica deposition from complex brines, backed by numerical simulation. Following this, comprehensive field testing will be undertaken by re-injecting silica-saturated brines and measuring fluid chemistry at monitor wells, to verify the experimental and modelling, results and thus improve re-injection efficiency in commercial operations.

Flow path tracing: Electrical resistivity and microgravity techniques are being refined and applied to determine flow paths of re-injected fluids in selected TVZ geothermal systems. CSAMT, gradient resistivity, and self-potential measurements are being made at 30 sites within 300m of re-injection well BR41 at Ohaaki. Standard 2-D resistivity modelling software has been adapted to incorporate time-changes, and is being used to map the direction, extent, and rate of movement of the re-injection plume from this well. A series of microgravity surveys at Wairakei is aimed at determining the changes in density with time associated with invasion (re-saturation) of the two-phase zone of the reservoir after large-scale re-injection. The changes in the relative positions of re-saturation regions will be analyzed to monitor the rate of advance of the re-injection plume. At the same time, a series of tracer tests, using both short- and long-half-life radioisotopes is being conducted to determine initial break-through locations and transport rates. Later, numerical simulation modelling will be carried out, integrating both sets of independent data to establish the relative rates of movement of fluid through the fractures and pores.

Land subsidence: At present, waste fluid is typically re-injected deep (>1km) into the periphery of geothermal reservoirs. Previous research (Allis et al, 1997) suggests that re-injection at shallow depth (<300m) may minimise reservoir pressure draw down and reduce exploitation-induced ground subsidence, a significant environmental problem in New Zealand. The mechanical properties of shallow rock formations are being measured at various temperatures in the laboratory, and petrographic examination undertaken to determine the role of secondary alteration in reducing permeability and enhancing the likelihood of formation compaction. These data will be integrated with other rock property measurements and the viability of shallow re-injection tested by numerical simulation modeling. Synthetic Aperture Radar (SAR) will be used together with traditional survey results, to map ground deformation at Wairakei and other geothermal systems in the TVZ so that, together with field measurements and numerical simulation modelling, full assessment of the use of shallow re-injection to mitigate exploitation-induced subsidence can be made.

Thermal features: New Zealand leads Task I: Environmental Impacts of Geothermal Development of the 5-year IEA GRTI agreement. The core of New Zealand's participation in the program is the study of impacts of exploitation on natural thermal features, the best-documented examples of which are at Wairakei. Variations in reservoir pressure, outflow rate, fluid temperature and chemistry are being quantitatively modelled, with special emphasis on determining the sensitivity of these parameters to different development scenarios and identifying trigger points to be used in monitoring. Geothermal development often causes localised but significant changes in surface heat flow which result in changes to thermal features and vegetation. Airborne thermal infrared surveys (TIR) are being used to map lateral variations in heat flow. A test area in the Wairakei-Tauhara field has been selected, in which shallow ground temperature measurements have been made, shallow depth (<1m) cores obtained for thermal conductivity measurements, and CO_2 flux measured. The data are being synthesized with results of further TIR surveys to relate temperatures to heat flow and CO_2 flux, establish repeatability, and determine quantitative limits for the TIR method.

3. IRL

Research programmes at IRL and its subsidiary company, MPT (Materials Performance Technologies Ltd.) focus on two main areas: (i) determining material performance and the down hole kinetics in geothermal bores, and (ii) modelling heat transport, source geometry and fluid transport in deep geothermal systems.

3.1 Corrosion in acid geothermal wells

Corrosion research, in collaboration with Tohoku National Industrial Research Institute (TNIRI, Japan) and various geothermal developers in The Philippines and New Zealand, is being conducted under the umbrella of an IEA Deep Geothermal Initiative Subtask on Materials.

The primary thrust has been to measure and model acid fluid well bore chemistry, and apply the results thermodynamically to predict down hole corrosion kinetics. Such models are being used to determine where corrosion control chemicals should be injected in geothermal wells. Research on White Island, based on previous research there by TNIRI and others, is assessing the importance of pH for controlling corrosion of acidic geothermal fluids. Difficulties in conducting this work in the field have prompted simulation of key parameters in laboratory pressure vessels. A series of trials, with and without H_2S added to mixed acids at a range of pH and temperatures up to 150°C, have been undertaken by MPT, and are currently being assessed.

Inhibitors with the potential for controlling corrosion are also being considered, as the use of NaOH for pH adjustment poses a real risk of scaling. Several generic inhibitors are being evaluated in the laboratory, using a spinning disc electrode with mixed acids at temperatures up to 95° C.

3.2 Reactive chemical transport modelling

Research into deep geothermal resources focuses on conceptualisation and computation of heat and mass transport within TVZ geothermal systems using numercial simulators such as TOUGH2. There are currently several areas of particular interest:

Silica deposition This research (jointly with GNS) involves modelling of geothermal brine in a re-injection aquifer. The rate at which injectivity changes when injecting silica saturated brine into an aquifer where the temperature is below the amorphous silica saturation temperature of the brine can thus be quantified.

Reservoir chemistry: Chemical conditions in a geothermal reservoir, and how these change with production are now being modelled with some certainty (Fig.2). This greatly increases the amount of data available for model verification and also allows predictions of mineral deposition and the likelihood of scaling or corrosion in well bores.

Deep geothermal sources: The reactive transport simulator, CHEM-TOUGH2 (White, 1995) is being used to simulate fluid flow adjacent to a shallow, degassing magmatic intrusion, a problem highly relevant to the evolution of TVZ geothermal systems. Model parameters are being derived in part from the paleo-magmatic heat-source environment in the Ngatamariki system. Cooling of geothermal reservoirs by groundwater in the upper 8km is also being modelled.

4. NEW ZEALAND UNIVERSITIES

4.1 Auckland University

A wide range of research projects is being undertaken by staff and students of the Geothermal Institute and Geology Department at Auckland University, including:

(i) An experimental study of silica scaling in a controlled environment (Fig.3) where hydro-dynamic conditions and silica colloid size are controlled. This work (jointly with Contact Energy), is developing a better understanding of what causes silica to deposit in certain locations, and the possible manufacture of silica sols.

(ii) Investigation of the best methods for insulating steam pipes, including a re-evaluation of earlier two-phase flow studies of pipes and fittings.

(iii) Analysis of trace metals co-precipitated with geothermal silica in the presence and absence of thermophilic bacteria.

(iv) Investigation of the links between the Ohaaki geothermal system and low-sulphidation epithermal ore deposits, including the genesis, significance and composition of hydrothermal clays and feldspars.

(v) Analysis of silica sinters, specifically the mineralogical and morphological changes they undergo as they age, and their environmental associations and signatures.

(vi) Determination of subsurface structures in TVZ geothermal systems using air borne and ground magnetic surveys.

(vii) Examination of natural convection in geothermal reservoirs, and pressure fluctuations in well bores.

(viii) Focused studies of various TVZ geothermal systems, including an analysis of fumeroles at Wairakei (jointly with GNS), computer modelling of the Ngawha system (high gas–low water discharge) and an analysis of geysering wells at Te Aroha.

(ix) Mineralogical and chemical studies of thermalised areas along, and W of, the Paeroa Fault to determine the way geothermal systems evolve.

(x) Determination of the characteristics of clay minerals in the Te Kopia and Orakeikorako thermal areas (jointly with Nanjing University).

(xi) Development of a ‘hot plate’ model for TVZ geothermal systems.

In addition, the Engineering Science Department has maintained a long-standing focus on numerical modeling of geothermal reservoirs to provide a better understanding of reservoir physical characteristics and evolution. Current research is concentrated on Ohaaki, Wairakei-Tauhara, and Kakkonda (Japan).

4.2 Victoria & Massey Universities

Research at Massey University involves mathematical modelling of hydrothermal eruptions. At Victoria University, the characteristrics of heat pipes are being investigated .

5. OTHER RESEARCH GROUPS

Private consultancies and power generation companies are involved in a range of research which tends to be more field or site specific, and technology focused than that of GNS, IRL or university departments:

(i) Century Drilling (formerly Downer Energy Services Ltd.) is undertaking research into calcite scaling at Kawerau, improved pipeline, injection tubing and casing mechanics, and improved P-T-F logging and monitoring techniques.

(ii) Glover Geothermal Chemistry maintains a strong interest in the Wairakei field, in particular the chemical changes in well discharges with time.

(iii) Kingston Morrison is undertaking research into tracer-dilution methods for measuring mass flow in pipelines, silica inhibition and new exploration techniques based on mineral deposit concepts.

(iv) Contact Energy is investigating re-injection into low-temperature loss zones.

(v) PB Power (GENZL Division) is undertaking a wide range of research including geothermal development in volcanic terranes, design and planning for geothermal power projects, water-rock-mineral interactions in geothermal systems, data management, and the use of geophysical techniques to delineate geothermal fields.

(vi) The Tuaropaki Trust is investigating Maori development issues, and the effects of geothermal development on Maori-owned land.

(vii) Geokem is undertaking research on problems associated with silica deposition, the occurrence of metals in geothermal systems and issues connected with the environmental consequences of geothermal development.

6. SUMMARY AND CONCLUSIONS

Geothermal research in New Zealand is wide-ranging, with a particular emphasis on delineating shallow producing fields, understanding deep systems, improving efficiency and life-times of power generating plants, and determining the environmental effects of exploitation to assist in mitigation.

Extensive use of numerical simulation modelling, backed up by cutting-edge geochemical and geophysical techniques are key components of the larger research programs. The advent of deep drilling in the TVZ will provide a further mechanism to refine models, and encourage future development.

A Geothermal Workshop is held in Auckland every November where members of the New Zealand geothermal community report their latest results. It is usually attended by 150-180 New Zealand and overseas geothermalists, and continues to provide an excellent forum for dissemination of ideas and healthy debate on current issues.

ACKNOWLEDGEMENTS

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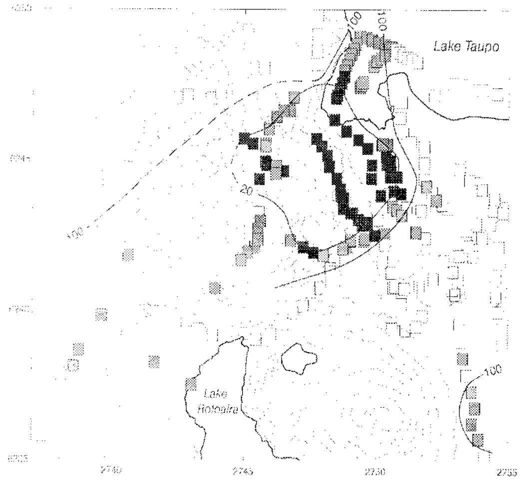
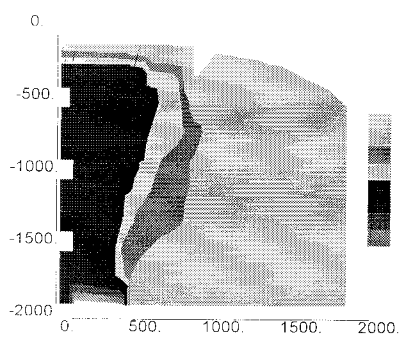


Fig. 1: Combined plot of apparent resistivities (in Ωm) in the Tokaanu-Waihi field measured with the Weiner, Schlumberger (AB/2 = 500 m), 50 Hz MT and waterborne methods. Resistivity values are shown in four bands: black < 20 Ωm, grey 20-50 Ωm, hatched 50-100 Ωm, clear >100 Ωm (Risk et al., 1998; Fig. 4).



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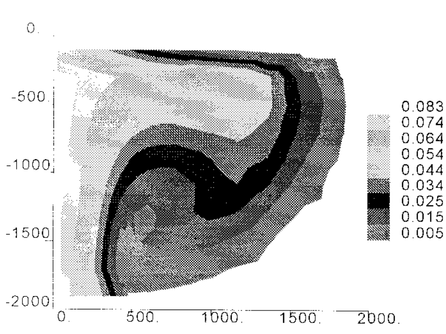
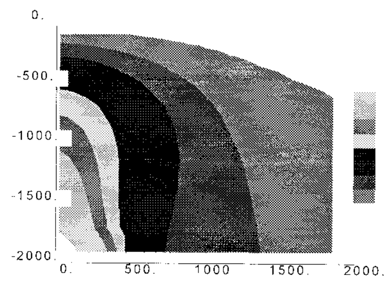
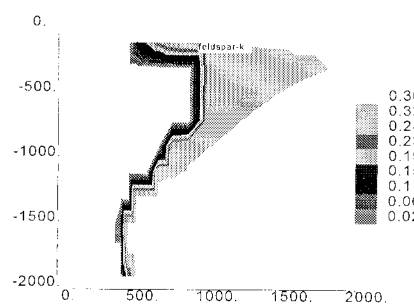


chloride



temperature



K-feldspar

Fig. 2: Final state of the reservoir 8000 years after a pulse of magmatic vapour has been injected (pH, chloride, temperature, K-feldspar patterns shown). Aqueous concentrations are in moles/kg and solid concentrations in moles/litre of fluid. All distances (both axes) are in metres (after White and Christenson, 1998; Fig. 3).

Fig. 3: Silica scaling experiments at Wairakei.