NZGW
New Zealand
Geothermal Workshop

45th New Zealand
GEOTHERMAL WORKSHOP

Handbook

15-17 November 2023

ISSN 2703-4275

Contents

Welcome

45th New Zealand Geothermal Workshop

Welcome to the 45th New Zealand Geothermal Workshop (NZGW).

The 45th NZGW is taking place during a pivotal period in geothermal research and development, education, industrial investment, and recognition and strong support from the government as New Zealand forges toward its net zero carbon emission target.

The first day of the 45th NZGW also marks the 65th anniversary of the geothermal power production at Wairakei.

The NZGW also provides the focal point for the annual general meeting of the New Zealand Association and the geothermal industry updates.

The 45th NZGW workshop also marks the closing of the academic year for our 18th Geothermal programme. The number of students has increased by 200% from last year, with a strong demand for geothermal energy education for the coming years.

We welcome our graduates to the geothermal community and wish them successful careers in this fascinating industry.

We want to thank all our sponsors for allowing us to run the workshop while keeping the registration fee as low as possible and subsidising the social functions.

We hope everyone has an enjoyable and fruitful time.

Conveners:

Sadiq J. Zarrouk
John O'Sullivan
Bridget Lynne
Mike O'Sullivan
Michael Gravatt

2023 Partners

MB Century

Triveni TURBINES REFURB

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2023 Sponsors

UNIVERSITY OF AUCKLAND Waipapa Taumata Rau NEW ZEALAND | ENGINEERING DEPARTMENT OF ENGINEERING SCIENCE AND BIOMEDICAL ENGINEERING

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ICELAND DRILLING

MARUBENI ITOCHU STEEL

Energy made Wonderful | Mercury

2023 Awards

New Zealand Geothermal Association

Best Overall Paper Award
Best Student Paper Award
Best Poster Award

Geothermal Institute

Best Geothermal Earth Sciences Award

General Information

The following information is provided as a guide to the Workshop. If you have any queries, please visit the registration desk.

Registration desk

For any questions, please visit the registration desk during Workshop hours.

If the registration desk is unattended, please call 027 287 5183.

Workshop catering

Lunches, morning, and afternoon teas will be served in the Level 4 Foyer of the Engineering building, University of Auckland.

Dietary requirements

Vegetarian options are provided with each meal break. Care has been taken to ensure all advised dietary requirements are catered to. If you specified your dietary requirements when registering, please make yourself known to the catering staff.

Mobile phones

During all presentations please switch off or turn your mobile phones to silent.

Presentations

As a courtesy to our presenters, please ensure you arrive at each session venue prior to the start of presentations.

Presenting authors

Presentation slots are 15 minutes long with 3 minutes scheduled for questions. Each session chair will be keeping strictly to time.

If you are scheduled to give a presentation, please ensure your PowerPoint is uploaded well in advance of your presentation time, preferably during the catering breaks or prior to the start of each day. Visit the registration desk for details on how to upload your presentation.

Cameras and electronic recording

No electronic recording of presentations is permitted in any form without the express written permission of Workshop organisers and speakers.

Urgent messages and lost property

Urgent messages for delegates and lost property can be directed to the registration desk.

Messages and lost property will be held there for collection until the conclusion of the Workshop.

Wi-Fi Access

Please use the UoA Guest Wifi network and login details below

Log in: nzgw2023@wifi.com

Password: NLPSYGTR

Social Events

There are a number of social events available to attendees. If you have not already arranged your tickets to these events, please visit the registration desk.

Workshop Reception

Tuesday, 14th November 2023, 5.30pm-7pm
Faculty of Engineering, 20 Symonds Street

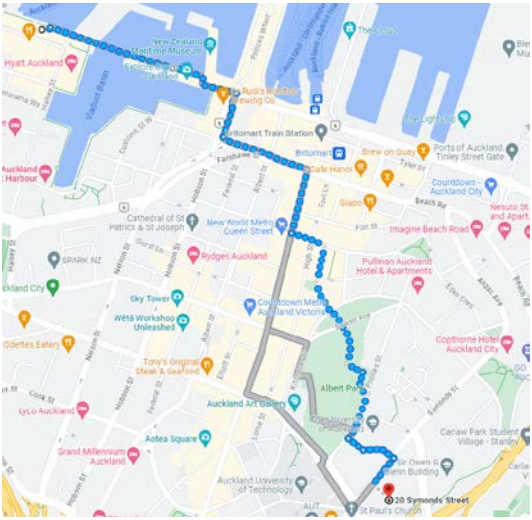
This will be a 'drinks and nibbles' event open to all registered Workshop delegates. No ticket required.

Workshop Dinner

Thursday 16th November 2022, 6:30pm – 10.30pm.

Wynyard Pavilion, 17 Jellicoe Street, Auckland CBD

Please note that transport to the workshop dinner venue is not provided. The venue is a 33-35 min walk from the workshop venue.



Auckland Information

The following information is provided as a guide to Auckland. If you have any queries, please visit the registration desk.

Emergencies, medical needs and illnesses

If you have an emergency you can contact the police, paramedics and fire department by calling 111 from any landline or mobile phone.

The workshop venue is:

Faculty of Engineering,
20 Symonds Street,
Waipapa Taumata Rau |
University of Auckland,
Auckland

If you require non-emergency medical attention during the workshop, please inform the registration desk.

Getting around

Taxis and airport shuttles
There are many taxi companies to choose from in Auckland. We suggest:

Blue Bubble Taxis 0800 228 296
www.bluebubbletaxi.co.nz

Auckland Co-op Taxis 00 300 3000
www.cooptaxi.co.nz

Super Shuttle 0800748 885 shared airport transfers direct to/from your accommodation
www.supershuttle.co.nz

SkyBus 24hrs a day, direct bus transfers to Auckland Airport from downtown Auckland
www.skybus.co.nz




Piha beach, (left), Wynyard Quarter (top right), Ferry Building (bottom left), Cornwall Park (bottom right).

Nearby Services

Pharmacy and Post Shop
Level 1 Kate Edgar Information Commons
Corner Alfred & Symonds Street

Eat & drink in Auckland

Where to start? Auckland has more great places to eat and drink than we could hope to recommend. For current reviews visit:

Metro Eats Auckland
www.metroeats.co.nz

Check the Top 50 Restaurants 2022, Cheap Eats and Best Bars lists.

The Urban List
www.theurbanlist.com/auckland

Places to Visit

Visit Waiheke Island for some of the best vineyards in New Zealand, including the University's own award winning Goldie vineyard.

Take a walk on one of Auckland's 50 volcanoes. For a quick trip, visit Mt Eden or One Tree Hill or for a day trip take the ferry out to Rangitoto Island.

View **www.aucklandnz.com** for more ideas.

Keynote Speakers

Bridget Ayling

Capability Lead for Reservoir Strategy, Contact Energy Ltd, New Zealand

Dr. Bridget Ayling is the capability lead for reservoir strategy at Contact Energy Ltd, based in Wairākei. She recently joined Contact after 7 years working in the western USA where she served as Director of the Great Basin Center for Geothermal Energy at the University of Nevada, Reno (UNR) and as an Associate Professor in the Nevada Bureau of Mines and Geology at UNR. In these roles, Dr. Ayling was responsible for developing research and education programs in the field of geothermal energy, leading research to understand the complexities of fluid flow in the upper crust and the implications of this for geothermal resource exploration and development, managing the public dissemination of geothermal datasets for the state of Nevada, and administering the National Geothermal Academy training program. Prior to joining UNR in 2016, she worked at Geoscience Australia, the Australian Government's geoscience agency, and the Energy and Geoscience Institute at the University of Utah. She has served on the Board of Directors for Geothermal Rising (formerly the Geothermal Resources Council) and the International Geothermal Association, and on the Earth Resources Standing Committee for the U.S. National Academies of Sciences, Engineering and Medicine. She is also a proud advocate and member of Women in Geothermal (WING). Dr. Ayling holds a B.Sc. with honors from Victoria University of Wellington, and a PhD in paleoclimate and environmental geochemistry from the Australian National University.

Recent advances in regional-scale geothermal exploration and resource evaluation to unlock hydrothermal potential in the Great Basin region, western USA and beyond.

The Great Basin region in the western USA is a world-class geothermal province, with ~1,200 MWe current installed geothermal capacity and an estimated hydrothermal resource potential of at least several GWe. One of the barriers associated with realizing this potential is the exploration risk associated with the discovery of new hidden and 'blind' geothermal systems. Additionally, hydrothermal systems in this region are typically structurally controlled, with relatively focused areas of permeability for fluid upflow and outflow that can make it challenging to accurately locate the 'sweet-spot' for successful production drilling. Research conducted at the Great Basin Center for Geothermal Energy at the University of Nevada-Reno over the last several years has aimed to address these exploration risks, through collaborative projects focused on: (1) Application of new technologies to reservoir characterization and mapping (e.g., hyperspectral core imaging); (2) Developing refined 3D and conceptual models of Great Basin geothermal systems; (3) Application of geothermal play fairway (PF) analysis to map regional potential (in the Great Basin and beyond, e.g., South America); (4) Integrating Machine Learning (ML) approaches into PF workflows; (5) Evaluating value-of-information (VOI) approaches to support drill targeting and exploration decision-making; (6) Regional data compilation and analysis, and (7) Developing integrated, comprehensive workflows for predictive resource mapping and evaluation to accelerate discoveries of new, commercially-viable geothermal systems (e.g., the INGENIOUS project). In this talk, I'll briefly review some of these projects and research highlights, and the opportunities for application to other regions.

Notes

Dr. Denis Voskov

Associate Professor, Department of Geoscience and Engineering, TU Delft, and Adjunct Professor, Department of Energy, Science and Engineering, Stanford University, The Netherlands

Dr. Denis Voskov is an Associate Professor at the Department of Geoscience and Engineering, TU Delft, and Adjunct Professor at the Department of Energy, Science and Engineering, Stanford University. He is leading a research group on the development of advanced simulation capability for energy transition applications which includes geothermal, CO_2 sequestration and hydrogen storage. Dr. Voskov is a co-author of more than 50 peer-reviewed journal publications and many conference papers on this topic. Before joining TU Delft, Denis was a Senior Researcher at the Department of Energy Recourses Engineering, Stanford University. His previous positions also include Chief Technology Officer of Rock Flow Dynamics Company (developer of t.Navigator), Chief Engineer at YUKOS EP company, and a leading specialist at the Institute for Problems in Mechanics, Russian Academy of Sciences. He holds a Ph.D. degree in applied mathematics from Gubkin's Russian State University of Oil and Gas. Dr. Voskov is an Associate Editor of the Society of Petroleum Engineers and Geoenergy Science and Engineering Journals.

Improving Geothermal Energy Production: Forward Modelling and Data Assimilation with Consideration of Uncertainty

In my talk, I will first introduce the DAPwell project, a living lab that will be a focal point of deep geothermal research and education at TU Delft. This project involves the drilling of a geothermal doublet designed for direct heat purposes. The production and multiple observation wells will be equipped with a wide range of advanced geophysical tools for monitoring and data acquisition. However, effective utilization of this data presents new challenges for forward modeling, data assimilation, and uncertainty quantification in geothermal energy production. During my talk, I will showcase the modeling technologies we have employed to accurately reproduce production and monitoring results while preserving and updating the geological model. Since the characterization of the reservoir entails uncertainties, it is crucial to perform accurate uncertainty quantification, which we can now achieve at a geological scale and fully support with distributed pressure, temperature, strain, and acoustic measurement inside the production well. Besides, additional information from electromagnetic sensing in the ultra-deep observation well will be integrated into the data-assimilation framework for the DAPwell project. To thoroughly evaluate potential hazards arising from hydraulic and thermal stresses, we have developed a fully coupled formulation with geomechanics. The modeling results can be linked with strain and acoustic sensing inside the production well and shallow observation wells around the doublets. To integrate all these forward and inverse modeling technologies, we have implemented them in our open-source modeling platform called the Delft Advanced Research Terra Simulator (DARTS). The combination of these modeling technologies and the DARTS platform empowers us to create an efficient and effective digital representation of the DAPwell project, enabling us to optimize energy production while ensuring its safety and sustainability.

Notes

Penny Doorman

Geothermal Programme Leader,
Bay of Plenty Regional Council, New Zealand

Penny Doorman is the Geothermal Programme Leader at the Bay of Plenty Regional Council. The Bay of Plenty Regional Council manages natural and physical resources in the Region, including 12 geothermal systems. Penny's role at Council is working closely with geothermal staff to ensure the geothermal workstreams within Council are coordinated and focused, including across planning, community engagement, science, resource consenting and compliance. Her current focus is the review of the regional planning framework for managing the Rotorua geothermal system. This work involves considerable engagement with the community, iwi and hapū and key stakeholders, as well distilling the technical inputs into policy development. Penny has a Master's in Environmental Science and Geography. She has worked in Local Government as a resource planner in various organisations for 30 years, initially focussing on heritage and biodiversity planning, more recently focussing on geothermal planning. She lives in Whakatane, on the East Coast of New Zealand's North Island.

Managing geothermal – a Local Government perspective on changing relationships and responsibilities

In Aotearoa New Zealand political, societal and cultural norms regarding management and use of geothermal have evolved over generations and continue to change as we enter a period of regulatory reform. While the relationship of tangata whenua with geothermal has been continuous, colonisation led to dramatic changes as successive Governments took control of management under various statutes. Most recently, in 1991 Central Government devolved responsibility for geothermal management to Regional Councils. Councils now manage geothermal under the Resource Management Act 1991 (RMA), and various policy documents that guide management.

Understandably, regional Councils are sometimes viewed only as a regulator. Their varied functions and responsibilities are not always well known, but include advocacy, education and outreach, relationship building, community engagement, research, and monitoring. These roles are delivered within a political structure that is open to public scrutiny, but due to requirements of the Local Government Act 2002 and the RMA, is not always as flexible or nimble as some might hope.

Particular challenges include balancing competing interests within the constraints of the law, while being accountable and responsive to our diverse communities. Our responsibilities under Te Tiriti o Waitangi are also at the forefront of our thinking, and the progression of Treaty Settlements means that management structures will continue to change.

As we transition to a new regulatory regime, Councils are mindful of the complex political, environmental and cultural climate, and of their contribution to the sustainable management of this unique taonga.

Notes

Jim Randle

Consultant, GT Management, Indonesia

Jim Randle is a self-employed mechanical engineer and freelance consultant based in Indonesia, specializing in geothermal project development and management. He has 40 years of experience in exploration, drilling, design, construction and operations (including procurement and project financing) and has been exposed to all engineering and geoscience disciplines.

Jim's early career was as an engineering officer in the British Royal Navy nuclear submarine service. After that he moved to New Zealand to work with the then New Zealand Electricity on the Ohaaki project. Following corporatization, he headed DesignPower NZ Ltd for a period before joining KRTA, followed by Kingston Morrison, and Sinclair Knight Merz. He then left New Zealand shores for Project Management roles in Nicaragua and Indonesia.

Jim has accumulated vast international experience having worked on geothermal projects in New Zealand, Philippines, Indonesia, Nicaragua, Kenya, Ethiopia, the Caribbean, Russia, and Chile. His employers and clients have included other international consultants, state owned power companies and geothermal companies, private sector geothermal developers and operators, and multilateral funding agencies. He is also a highly regarded guest trainer in the University of Auckland Geothermal Institute Project Management courses for geothermal professionals from Asia and East Africa.

The Role of Kiwis in the International Geothermal Industry

New Zealand has played a role in international geothermal development which is actually quite out of proportion to its relatively small population, and also to its own geothermal resources. Why is that?

Initial geothermal development in New Zealand started back in the 1950s at Wairakei. The initial driver was not electric power generation, but to provide a source of heavy water as a moderator for the UK nuclear reactor industry, however that nuclear option was dropped in favor of gas cooled reactors and someone had the bright idea of using all that hot water to generate electricity. Having built a successful modern geothermal project, the country started to look around for more opportunities. Domestically, continued exploration and drilling by government agencies (DSIR and the Ministry of Works) proved the subsurface potential at all of the geothermal projects that have been developed to date. The government also decided that it was good opportunity to build a Kiwi reputation by undertaking full scale projects in South East Asia. So, a very early push into the international market was thanks to some enlightened thinking at MFAT, where they found the budget to undertake a couple of complete projects, rather than just scratching around on the edges.

I believe that the industry was enhanced by the Kiwi "get up and go" and "we can make it work" attitudes, where people are prepared to get out into the field and get their hands and boots dirty. Hence, we saw people heading overseas to the Philippines, Indonesia and Kenya, where they learned about different resource systems and learned to share that knowledge across projects. The ability to work across disciplines was also an essential contribution to the early industry, as fostered by the Geothermal Institute. And all of this has contributed to a willingness to think and promote something new, rather than just following what was done before.

Notes

45th New Zealand Geothermal Workshop Programme

Tuesday 14 November			
3:00	Registration Open		
5:30	Welcome Reception | University of Auckland Engineering Building		
7:00			
Wednesday 15 November			
8:00	Registration Open		
8:30	Mihi whakatau		
8:40	Housekeeping: Sadiq J. Zarrouk		
8:45	Welcome and Opening: Richard Clarke, incoming Dean of Engneering, Sadiq J. Zarrouk and John O'Sullivan, Co-Directors, Geothermal Institute, The University of Auckland		
9:00	WORKSHOP AWARDS		
9:15	**KEYNOTE TITLE: Recent advances in regional-scale geothermal exploration and resource evaluation to unlock hydrothermal potential in the Great Basin region, western USA and beyond** Keynote Speaker | Dr Bridget Ayling, Capability Lead – Reservoir Strategy, Geothermal Generation and Trading Capability, Contact Energy, New Zealand		
10:00	Morning Tea		
	Session 1.1 – INDUSTRY UPDATES	Session 1.2 – RESERVOIR MODELLING 1	Session 1.3 – GEOTHERMAL GEOLOGY 1
	SESSION CHAIR | Mason Jackson	SESSION CHAIR | Ryan Tonkin	SESSION CHAIR | Sadiq Zarrouk
	Lecture Theatre 401.401	Lecture Theatre 401.439	Lecture Theatre 423.342
10:30	**ICELAND DRILLING | INDUSTRY UPDATE |** Sveinn Hannesson	46 | Equation of state modules for Waiwera including water, chloride and non-condensible gas – Adrian Croucher	13 | Fracture permeability in basement greywacke for supercritical drilling planning – Sarah Milicich
10:45	**AECOM NEW ZEALAND| INDUSTRY UPDATE |** Dennis Preston, June Chin	23 | Numerical model of the Tikitere geothermal system – Michael O'Sullivan	26 | 2012-2023 Comparative Ground Penetrating Radar and Temperature Survey at Orakei Korako, Taupō Volcanic Zone, New Zealand – Bridget Lynne

11:00	**MARUBENI-ITOCHU TUBULARS OCEANIA| INDUSTRY UPDATE |**	87 | Assessment of Enhanced Geothermal System (EGS) Methodology for Harnessing Geothermal Energy Potential in Depleted Gas Fields – Rohit Duggal	65 | Geologic Controls on Geothermal System Location and Type – Irene Wallis
11:15	**XCALIBUR MULTIPHYSICS| INDUSTRY UP-DATE |** Craig Annison	95 | Cloud computing for complex geothermal simulations using the parallel software Waiwera – Ken Dekkers	50 | Highlights of Borehole Imaging, Tauhara Geothermal Field Drilling, New Zealand – Sarah Milicich
11:30		73 | Fast-tracking numerical modelling projects using Volsung and Leapfrog Energy – Jonathon Clearwater	66 | Geologic Controls on Permeability Revealed by Borehole Imaging: Case Studies from Su-matra, Indonesia and the Taupō Volcanic Zone, New Zealand – Irene Wallis
11:45		94 | Greenfield resource assessment: maximis-ing early stage data to constrain uncertainty – Tia Jones, Claudia Saunders	102 | Updated Geological Structure and 3D Intrusion Model as Veritable Fracture Driver of Fracture Characterization in Wayang Windu Geothermal Field, Indonesia – Meiyanto Purnomo
12:00-1:30	Lunch and Poster Session:		
	57 | Insight into the Geothermal Structure in Tatun Volcano Group, Taiwan – Chi-Hsuan Chen		
	74 | The geothermal reservoir characteristics of metamorphic terrain, an initiative of geological and geophysical survey of Qingshui, Tuchang, and Renze, NE Taiwan – Gong-ruei Ho		
	79 | Geothermal characteristics of the Paolai Hot Spring area, Taiwan – Shao-Yi Huang		
	64 | Regional geothermal exploration in Dongpu Geothermal Field of Central Taiwan – Hsin-Yi Wen		
	86 | Exploring mildly acidic to neutral hot fluids through carbonate clumped isotope (Δ47) thermometer in the Liuhuangtzuping Area – Yi-Chia Lu		
	83 | A review of non-condensable gases (NCGs) reinjection within the geothermal industry and a comparison with other carbon capture and storage (CCS) technologies – Aston Carmichael		
	39 | Numerical Simulator for the Coupled Model of Wells and Fractured Reservoirs – Mitsuo Matsumoto		
	5 | Hydrothermal Alteration and Mineralogy Characterization at the Lake-Assal and the Hatchobaru Geothermal Fields – Holeh Mohamed Awaleh		
1:30	**MB CENTURY| INDUSTRY UPDATE |** Greg Thompson		
1:45	**NZGA Industry-led CO_2 emissions reductions project update |** Kennie Tsui		

	Session 2.1 – INDUSTRY UPDATES	Session 2.2 – PRODUCTION & MANAGEMENT 1	Session 2.3 – GEOPHYSICS
	SESSION CHAIR | Clare Baxter	SESSION CHAIR | Theo Renaud	SESSION CHAIR | Bridget Lynne
	Lecture Theatre 401.401	Lecture Theatre 401.439	Lecture Theatre 423.342
2:00	**WAIKATO REGIONAL COUNCIL | INDUSTRY UPDATE |** Katherine Luketina	82 | A process model for geothermal power generation – Anu Choudhary	47 | Towards a national temperature model for New Zealand – Alison Kirkby
2:15	**BAY OF PLENTY REGIONAL COUNCIL | INDUSTRY UPDATE** | Penny Doorman	43 | MakBan Drilling Campaign Offset Wells Monitoring and Post Drilling Production Evaluation – Edward Bermido	55 | Seismic reflection data acquisition in the Taupō Volcanic Zone: Reprocessing of Broadlands-Ohaaki 1984 seismic data – Callum Kennedy
2:30	**JRG ENERGY| INDUSTRY UPDATE |** John Gilliland	81 | Analysis of Heat Recovery Time Predictions for Multiple Periods of Temporary Reinjection in Geothermal Well Production at Lumut Balai Field – Erwandi Yanto, Aris Budiyanto	15 | Long Term Production in TVZ Geothermal Systems using a 2D Source to Surface Model – Warwick Kissling
2:45		85 | Detection and Diagnosis of Abnormal Conditions in the Feed Pumps of a Geothermal Binary Power Plant Using Feature-based Time-series Analytics – Paul Michael Abrasaldo	31 | Insights into the Waiotapu Geothermal Field using High Resolution SkyTEM Data – Robert Reeves
3:00		88| Reinjection Management Evaluation in Karaha Bodas Field 2022 – Kristina Emeralda Cici	
3:15	Afternoon Tea		
	Session 3.1 – INDUSTRY UPDATES		Session 3.3 – GEOCHEMISTRY
	SESSION CHAIR | Leighton Taylor		SESSION CHAIR | Claire Newton
	Lecture Theatre 401.401		Lecture Theatre 423.342
3:45	**MERCURY NEW ZEALAND| INDUSTRY UPDATE |** Stewart Hamilton		18 | REGEMP 2022: Waikato Regional Geothermal Monitoring Programme – Katherine Luketina
4:00	**EASTLAND GROUP | INDUSTRY UPDATE |** Alice Pettigrew		53 | Reversing Carbon Emissions in the Geothermal Energy Industry Project: A Geoscience Perspective – Eylem Kaya

4:15	**CONTACT ENERGY| INDUSTRY UPDATE |** Bridget Ayling		27 | The effect of CO2 reinjection on silica scaling in geothermal reservoirs – David Byrne
4:30	**WESTERN ENERGY| INDUSTRY UPDATE |** Marcus Prestney		33 | Rhyolite of the Tauhara Geothermal Field: insights and correlations from geochemistry – Mark Simpson
4:45	**WESTERN ENERGY | INDUSTRY UPDATE |** Abandoning Challenging Assets – Decommissioning a bunch of little annoying wells – Ben Drew		
5:00	**SEEQUENT | INDUSTRY UPDATE |** Jeremy O'Brien		
5:15	SEEQUENT sponsored drinks and nibbles		
Thursday 16 November			
8:45	Housekeeping		
9:00	**KEYNOTE TITLE: Improving Geothermal Energy Production: Forward Modelling and Data Assimilation with Consideration of Uncertainty** Keynote Speaker | Associate Professor Denis Voskov, TU Delft, The Netherlands		
9:45	**TRIVENI TURBINES| INDUSTRY UPDATE |** Shailesh K., Tushar SV		
10:00	Morning Tea		
	Session 4.1 – INDUSTRY UPDATES	Session 4.2 – DRILLING & WELL TESTING	Session 4.3 – ENVIRONMENTAL ASPECTS 1 / SOCIAL ASPECTS/ MĀTAURANGA MĀORI
	SESSION CHAIR | Jeremy O'Brien	SESSION CHAIR | Adrian Croucher	SESSION CHAIR | Ru Nicholson
	Lecture Theatre 401.401	Lecture Theatre 401.439	Lecture Theatre 423.342
10:30	**JACOBS| INDUSTRY UPDATE |** Jane Brotheridge	16 | Machine Learning Opportunities for Geothermal Drilling Operations: An Overview – Aira Aspiras	62 | Using Temperature Methods to Improve Geyser Monitoring at Rotorua, New Zealand – Brook Keats
10:45	**LFF NEW ZEALAND | INDUSTRY UPDATE |** Matt Goodin	70 | Geothermal Temperature and Pressure Transient Analyses of Well CHI-8A, El Salvador During Pressure Falloff – Jorge Alberto Rangel Arista	8 | Geothermal Systems of the Bay of Plenty Region, Aotearoa New Zealand – Inventory and Systems Extent – Mariana Zuquim

11:00	**MTL | INDUSTRY UPDATE |**	69| Collaborative and Holistic Applications Drive Record Drilling Performance in Mak-Ban Geothermal Field, 2020-2022 – Aira Aspiras	61 | Groundwater Modelling Assessment of Shallow and Deep Geothermal Aquifer Interactions Around Otumuheke Stream, Wairākei-Tauhara Geothermal Field – Jake Scherberg
11:15	**CASIL TECHNOLOGIES | INDUSTRY UPDATE |** Jim Johnston	19 | Cementing and Aerated Drilling Solutions for Curing Shallow Loss Circulation – Aira Aspiras	17 | State of the Environment Reporting using the DPSIR Model in the Waikato Region – Katherine Luketina
11:30	**ITALMATCH CHEMICALS GB LTD| INDUSTRY UPDATE** | Davide Parravicini	76 | Reducing Casing Heatup Rates in Geothermal Production Wells by using Coiled Tubing Gas Lift – Matthew Sophy	48 | Incorporating Māori world views in the Rotorua geothermal system management plan - Tamara Mutu
11:45		107 | Preliminary Analysis of Geothermal Drilling Results in Eastern Taiwan – Hsin Han Chen	
12:00	Lunch		
1:00	**KEYNOTE TITLE: Managing geothermal – a Local Government perspective on changing relationships and responsibilities** Keynote Speaker | Penny Dorman, Geothermal Programme Leader, Bay of Plenty Regional Council, New Zealand		
1:45	**ORMAT TECHNOLOGIES INC.| INDUSTRY UPDATE |** Rotem Ezer		
	Session 5.1 – INDUSTRY UPDATES	Session 5.2 – SCALING & CORROSION	Session 5.3 – RESERVOIR MODELLING 2
	SESSION CHAIR | Samatha Alcaraz	SESSION CHAIR |Wei Gao	SESSION CHAIR |John O'Sullivan
	Lecture Theatre 401.401	Lecture Theatre 401.439	Lecture Theatre 423.342
2:00	**GNS SCIENCE| INDUSTRY UPDATE |** Isabelle Chambefort	22 | Modelling Particle Tracking of Moisture Droplets in Geothermal Steam Pipeline – Kim Fong Chan	37 | Changes in geothermal reservoirs due to hydrothermal eruptions and fault reactivation – James Patterson
2:15	**GEOTHERMAL INSTITUTE| INDUSTRY UPDATE |** Sadiq J. Zarrouk, John O'Sullivan	56 | Laboratory HCl acid condensate testing of geothermal casing steels – Soroor Ghaziof	32 | Investigating Influences on Hydrothermal Fluid Flow in the Taupō Volcanic Zone with Numerical Models Constrained by Magnetotellurics – Sophie Pearson-Grant
2:30	**THORNDON COOK | INDUSTRY UPDATE |** Roger Hudson	38 | Update on the CaSil technology: economically solving global silica scaling, enabling low temperature direct heat extraction and electricity generation – Michael Schweig	78 | The influence of boundary conditions in a reservoir model on the accuracy of the simulation results – Bo Jin

2:45	**WING | INDUSTRY UPDATE |** Katherine Newman	41 | Development of a novel HT calcite scale inhibitor for geothermal applications – Davide Parravicini, Alessandro Guidetti	60 | Ensemble Methods for Geothermal Model Calibration – Alex de Beer
3:00	**DOBBIE CONSULTING | INDUSTRY UPDATE |**	42 | Case study: Silica Inhibitor Trial in Central America Plant – Alessandro Guidetti, Davide Parravicini	24 | Numerical modelling of tracer tests in the Ohaaki geothermal system – Michael O'Sullivan
3:15	Afternoon Tea		
	Session 6.1 – INDUSTRY UPDATES	Session 6.2 – DIRECT USE	Session 6.3 – ENVIRONMENTAL ASPECTS 2
	SESSION CHAIR | Mike Allen	SESSION CHAIR | Bart van Campen	SESSION CHAIR | Rony Nugraha
	Lecture Theatre 401.401	Lecture Theatre 401.439	Lecture Theatre 423.342
3:45	**NZTE – Indonesia | INDUSTRY UPDATE |** Putri Wuningsari	103 | Update of Direct Geothermal Energy Use Inventory and Management for New Zealand – Lucy Carson	49 | Vegetation in the Wairākei-Tauhara Geothermal System: History and Future Options – Christopher Bycroft
4:00	**NZTE – Philippines | INDUSTRY UPDATE |** Maricon Popanes-Lim	67 | Low-Temperature geothermal – a decarbonising solution for covered crop growers in New Zealand? – Anya Seward	44 | Geothermal vegetation of the Waikato Region: 2023 update – Sarah Beadel
4:15	**NZTE – Taiwan | INDUSTRY UPDATE |** Peg Tsai	63 | Assessing the potential of low to intermediate temperature geothermal resources for direct use – Maureen Nechesa Ambunya, Willis Ambuso	104 | Preliminary ESG Consideration for Geothermal Development in Indonesia: What Relevant Environmental, Social and Governance Aspects Need to be taken into Account? – Dewi Permatasari
4:30	**NZTE – Japan | INDUSTRY UPDATE |** Zea Rose	99 | Geothermal Direct Use Implementations and Its Potential Developments in North Sulawesi – Armando Ariakta Aloanis	
4:45 -5:45	NEW ZEALAND GEOTHERMAL ASSOCIATION ANNUAL GENERAL MEETING		
6:30	**NZGW Conference Dinner**		
10:30	**Wynyard Pavilion, 17 Jellicoe Street, Auckland CBD**		

Friday 17 November			
8:45	Housekeeping		
9:00	**KEYNOTE TITLE: The Role of Kiwis in the International Geothermal Industry** Keynote Speaker | Jim Randle, Consultant, GT Management, Indonesia		
9:45	Morning Tea		
	Session 7.1 – INDUSTRY UPDATES	**Session 7.2 – PRODUCTION & MANAGEMENT 2**	**Session 7.3 – HINDSIGHT & FORESIGHT**
	SESSION CHAIR | Fiona Miller	**SESSION CHAIR | Eylem Kaya**	**SESSION CHAIR | Michael Gravatt**
	Lecture Theatre 401.401	**Lecture Theatre 401.439**	**Lecture Theatre 423.342**
10:15	**UPFLOW| INDUSTRY UPDATE |** Andrew Marsh	89 | GeoEjector: Extracting geothermal fluid from a low-pressure geothermal well – Maria Gudjonsdottir	29 | 2022 Annual Aotearoa New Zealand Geothermal Review – Ted Montague
10:30		91 | Study & Design of Binary ORC Using Wet Cooling Tower (Existing) of Unit V & VI in Lahendong Geothermal Field, Indonesia – Adhiguna Satya Nugraha	9 | Integrated Real-Time Geothermal Operational Optimization and Improvement using a Robust Data Management, Visualization, and Diagnostic Analytics Platforms as a Digital Transformation – Fajar Khamim Mustofa, Muhammad Vito Hamza
10:45		10 | Double Energy Input IV, a proposal for a novel source of energy – Daniel Ramirez Ordas	72 | Impact of Project Variables on Tariffs Required for Economic Development of Geothermal Projects – Jim Randle
11:00		51 | Supercritical Well Performance Simulation using GFlow Wellbore Simulator: A Case Study of Ultra-hot IDDP Wells in Iceland – Julius Marvin Rivera	3 | Flexible geothermal application within the New Zealand electricity market – Andrew Marsh
11:15		21 | Comparison of Icelandic Supercritical Well Forecasts with Subcritical Geothermal Production Well Outputs – Julius Marvin Rivera	45 | Carbon Negative Geothermal: Theoretical Case Study for Biogenic CO2 Removal at Ngāwhā Power Station – Karan Titus

11:30			80 | Application of the United Nations Framework Classification for Geothermal Projects in the Waikato Region – Greg Ussher
11:45	Lunch		
12:45	WING Panel | Challenges and opportunities in building a resilient and diverse Geothermal workforce | Facilitator: Katherine Newman		
		Session 8.2 – RESERVOIR MODELLING 3	**Session 8.3 – GEOTHERMAL GEOLOGY 2**
		SESSION CHAIR | Mike O'Sullivan	**SESSION CHAIR | Bridget Lynne**
		Lecture Theatre 401.439	**Lecture Theatre 423.342**
1:45		12 | Understanding Mineralogical and Geochemical Evolution in Geothermal Reservoirs through Reactive Transport Modelling – Dale Emet Altar	59 | Regional geothermal exploration and potential assessment in the Taitung Hongye area, Eastern Taiwan – Pei-Shan Hsieh
2:00		105 | Kawah Kamojang Pilot Injection Test: Production Monitoring Evaluation and Numerical Reservoir Modelling Study to Support Kamojang Injection Optimization Program – Fathan Hamim Abdurachman	106 | The Impact of an Active Strike-slip Fault to The Principal Horizontal Stress Orientations and Fluid Flow in the Karaha Bodas Geothermal Field, Indonesia – Muhammad ikhwan
2:15		58 | Quantifying Geothermal Resource Potential and Uncertainty Analysis using a Natural State Model of Kotamobagu Geothermal Field in North Sulawesi, Indonesia – Bei Nagoro	28 | Combining geophysical, isotopes and geological studies toward geothermal models at Hongchailin for geothermal power generation in NE Taiwan – Jian-Cheng Lee
2:30		71 | Development module of a geothermal reservoir in sedimentary rocks in Taiwan – Bieng-zih Hsieh	
2:45		108 | An Integration Solution of Geomodelling Tools in a Geothermal Modelling Framework – Jeremy Rihet	
3:00	**Workshop close - Sadiq J. Zarrouk, John O'Sullivan**		

Abstracts

3 | Flexible geothermal application within the New Zealand electricity market

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***Keywords**: Flexible geothermal, intermittent, batteries, hydrogen, methanol, SAF*

Geothermal power production plays an important role as baseload in the New Zealand electricity market, supplying 18% of the total electricity production in the last calendar year. The proportion of gas peaker supply has decreased from 15% to 10%, while wind and solar have grown from 5% to 7% over the last five years and are set to grow rapidly over the coming decade.

The change in energy mix and a projected growth in demand pose significant challenges for system management. New Zealand is considering options to cover the risks posed by increasing variability of supply plus a shortfall of hydro storage during drier-than-average years. This is called the New Zealand Battery Project and preliminary studies have identified biomass, flexible geothermal energy, and hydrogen as alternatives to a large-scale pumped hydro scheme. Collectively, these alternatives have the most potential to store enough energy to help solve the "dry-year problem".

In geothermal systems with under utilised generating capacity due to resource depletion, it may be possible to redistribute electricity production across the year to when it is most needed. This lets the resource recharge when electricity demand is low, thus facilitating boosted output for limited durations when demand is high. However, this does not apply in New Zealand where geothermal resources are rarely the limiting factor and the underlying economics bias towards full utilisation of the capital-intensive plants and wells. Consequently, all geothermal in New Zealand has so far run as baseload.

This study models, using recent electricity market price data as a baseline, what conditions need to be present and to what extent it may be advantageous to vary output from geothermal power plants in the New Zealand context. Additionally, we consider the role of batteries, thermal energy storage and co-production of fuels, chemicals, and other value-adding products at geothermal sites: can they support flexible geothermal by providing an alternative utilisation path for renewable electricity while market prices are low?

Session 7.3

5 | Hydrothermal Alteration and Mineralogy Characterization at the Lake-Assal and the Hatchobaru Geothermal Fields

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Keywords: *Lake-Assal, Otake-Hatchobaru. XRD, XRF, Thin Section*

Twenty-one samples were collected from Lake-Assal and Otake-Hatchobaru fields. The samples were analysed by petrography and XRD to identify clay minerals, and XRF to identify to chemical constituents. In Addition, thin Section observation of two samples from Assal and one sample Otake-Hatchobaru. Results indicate that plagioclase, forsterite and fayalite, are the main primary minerals while chl/Sme, Illite/sme and hematite are the prominent secondary alterations. Advanced argilic surface alterations composed of alunite, cristobalite, and kaolin were also noted to have developed due to the alteration by steam-heated waters.

Poster Session

8 | Geothermal Systems of the Bay of Plenty Region, Aotearoa New Zealand – Inventory and Systems Extent

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Keywords*: geothermal systems extent, inventory, surface features, environmental management, regulatory framework.*

The Bay of Plenty Regional Council (BOPRC) is in the process of reviewing its inventory of natural geothermal resources of the region and their geographical extent. This work provides the science base-knowledge for identifying and mapping the systems for the sustainable management of the geothermal resources through its planning framework, as well as to inform work for other Council areas like Consents and Compliance. This work identifies the key sources of information publicly available and outlines the methodology developed to identify and propose the geothermal system' extent of the Bay of Plenty region. Two types of extents are suggested, tailored to the level of certainty around their geographical extent. Approximate extents are suggested when there is a reasonable level of certainty around its location, and inferred extents for when the level of certainty is moderate or low. Those different levels of certainty arise from variable levels of data availability, data quality and appropriateness of the data available for the purpose of this mahi. A high certainty is not considered achievable given the intrinsic complex hydrodynamics of geothermal systems and gradual lateral transition into cold groundwater systems, therefore none of the systems are proposed to be mapped with accurate extent. A distinction between geothermal systems and geothermal

occurrences is also proposed and recommended, as well as the inclusion, exclusion and merging of some of the geothermal systems identified in the planning framework of the Bay of Plenty Regional Natural Resources Plan and Regional Policy Statement. This paper also highlights that a significant heterogeneity in the level of knowledge and data availability exists across the various geothermal systems of the region. Geothermal systems with high commercial and scientific interest like Kawerau, Rotorua and Waimangu, for example, have been extensively studied over time, while a lower level of knowledge exists for some of the other systems, like the offshore Moutohorā Island (Whale Island), the low-temperature systems like the Tauranga-Mount Maunganui (Mauao)-Pāpāmoa-Maketū system and, to some extent, most systems with significant environmental constraints for development, like Tikitere.

Session 4.3

9 | Integrated Real-Time Geothermal Operational Optimization and Improvement using a Robust Data Management, Visualization, and Diagnostic Analytics Platforms as a Digital Transformation

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Keywords: *Digital Transformation, Operational Improvement, Asset Performance Management.*

Indonesia has substantial geothermal potential, and the country's government is committed to exploiting it, both for economic reasons and to meet its obligations as a signatory of the Paris Agreement on the climate change. A digital transformation is one of the main driver for optimizing the geothermal operational production. It has been deployed in Dieng and Patuha geothermal field by integrating steam field to power plant real-time operational data into a data management system platform, which is located on the Head Quarter office server.

A previous method for collecting the operational data in Dieng and Patuha fields was still using paper-based and non real-time data. By end of 2022, there was a digital initiative programme to transform it into a paperless system. By collecting the operational data, tagging from the OPC DA and Modbus Ethernet at both Dieng and Patuha fields, then it can be recorded into data management archive storage. After capturing all the operational data tagging, some formulae can be created in the asset framework environment and used to publishing these tags by utilizing a module in the database builder.

Operational data visualization also has been developed, displaying real-time steam field and power plant operational parameter trends. The advancement in technology like IoT, machine learning, advanced data analytics, and artificial intelligence could be applied to the geothermal operational data based on this platform. These technologies will offer substantial opportunities for technology advancement and cost reduction throughout the geothermal operational improvements. This paper describes some advanced data analytics, and visualization of trends from the steam field to power plant área that could help engineers to make a quick and concise operational improvements.

Session 7.3

10 | Double Energy Input IV, a proposal for a novel source of energy.

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Keywords: *DEI, Double Energy Input, High-Pressure System, Geothermal, Supercharging, novel source of electrical energy, New Zealand, Ring of Fire energy production, renewables, clean energy production.*

In order to slow down adverse global anthropogenic effects such as global climate change and the destruction of ecosystems, alternative energy sources that are clean, renewable, and efficient are needed to replace the existing energy sources.

Double Energy Input is a novel invention that gathers two renewable energy resources: hydro-electric and geothermal. This invention utilises the sea as a coolant, the geothermal heat to heat pressurised water and another chamber to run the steam power plant.

This model provides an alternative means for producing clean and renewable energy with two natural energy sources, heat and pressure.

Poster Session

12 | Understanding Mineralogical and Geochemical Evolution in Geothermal Reservoirs through Reactive Transport Modelling

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Keywords: *Reactive transport simulation, Fluid-rock interaction, Natural state reservoir model, TOUGHREACT™*

Reactive transport modelling plays a crucial role in unravelling the dynamics of geothermal reservoirs as they evolve over time. By utilising these models, we gain a deeper understanding of the temporal progression of mineral alteration and its influence on the reservoir's characteristics. This information empowers us to effectively manage and safeguard these valuable resources while offering critical insights into sustainable development.

This study was designed to understand the mineralogical and geochemical evolutionary process of conventional geothermal reservoirs. An idealised 3D large-scale numerical model was set up to comply with the prevailing conditions in a two-phase-liquid-dominated geothermal reservoir. The models were established to assess the long-term fluid and rock interaction in geothermal systems and gain insights into the hydrothermally altered rocks.

The results of our reactive transport modelling study provide information about the deep geochemical processes that occur during fluid circulation within the reservoir. The model captures the natural processes that alter the chemical composition of minerals in the reservoir over time, highlighting spatial mineral alteration patterns, their impact on porosity and permeability, and how these factors influence flow paths. Additionally, the study investigates

the mineralogical and geochemical changes induced by the influx of CO_2, H_2S and H_2. The model also explores the effects of fluid chemistry and geologic structures on underground fluid circulation.

Session 8.2

13 | Fracture permeability in basement greywacke for supercritical drilling planning

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Keywords: *greywacke, fractures, borehole image, resistivity.*

Supercritical geothermal resources have potential to decarbonise industry and power sustainable economic growth opportunities. It is inferred that fractured, low permeability metasedimentary basement rocks that underly much of the Taupō Volcanic Zone (TVZ), New Zealand, would host supercritical geothermal resources. These rocks have complex fracturing patterns resulting from a long history of deposition, burial, tectonism and hydrothermal activity. Therefore, the work described here is a first step to understand fracture distributions and fracture permeability in TVZ basement rocks. Fractures were characterised from a resistivity borehole image acquired from a >2 km-deep well in the Kawerau Geothermal Field; the deepest direct fracture dataset collected in the TVZ basement rocks. Basement greywacke comprises metasedimentary sandstones (greywacke) and mudstones (argillite) of the Waipapa Composite Terrane. Rock type through the imaged interval was split into dominantly sandstone, dominantly argillite, and an interbedded mixture of both lithologies.

Potentially permeable fractures (i.e., conductive, conductive fractures with resistive halo and micro-faults) have orientation consistent with current tectonics. Resistive fractures have moderate dip magnitude and no preferred strike orientation, consistent with them being mostly of metamorphic origin. Conductive fractures are interpreted as a combination of metamorphic and tectonic origins, with some likely to have been of metamorphic origin reactivated under current tectonics. Overall, there are more fractures in sandstone than argillite, but this is most pronounced for (mineralised) resistive fractures and (potentially permeable) resistive fractures with conductive halo than conductive fractures. Differences between lithologies are less pronounced when considering volumetric densities.

The lithological controls on fracturing differ amongst the three permeable zones. Two permeable zones occurred in a mixture of the three rock types while the third, major permeable zone was in dominantly sandstone and an interbedded mixture. Potentially permeable fractures of elevated thickness (>20 mm) are more common within the two minor feed zones than outside feed zones. Fracture density is higher in the major feed zone than outside feed zones. These results can be used as a baseline for fractures and fluid movement in basement rocks. This can be used to inform future reservoir models to explore supercritical resources and aid with planning future drilling.

Session 1.3

15 | Long Term Production in TVZ Geothermal Systems using a 2D Source to Surface Model

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Keywords: *Source-to-surface models, TVZ, mass and heat flow, geothermal systems, sustainability.*

A 2-D 'Source to Surface' regional-scale heat and fluid transport model of the central TVZ is described and used to investigate the nature of the high-temperature geothermal systems and long-term fluid production and reinjection from them. The model represents a 10 km-deep NW-SE cross-section across the TVZ with simplified geology including a 20 km wide 'rift'. At the base of the model a 'hotplate' heat source has a temperature of ca. 700oC and produces a heat flux of 0.7 Wm-2.

The (horizontal) permeability of the rifted basement is the key factor in the model. This is described as a function of depth, and the free parameters in this function allow a) the hotplate temperature to be set independently of the prescribed heat flux, b) sufficient shallow permeability to support widespread convection in the upper few km of the model, and c) control of the temperature distribution within the rift so that high-temperature geothermal systems form and temperature proxies for rift-scale geophysical constraints are satisfied. Another essential feature of the model is that the geological units outside of the rift must have low permeability (~10-16 m2) to prevent excessive cooling from cool fluid flowing into the rift.

The model suggests that the high-temperature geothermal systems in the TVZ are transient surface expressions of an unsteady rift-scale convective hydrothermal system. Temperatures in the geothermal systems can reach ca. 300oC at 2 km depth. The models respect constraints from geophysics, with the depth of the shallowest melt close to 10 km and the maximum depth of seismicity at 9 +/- 1 km.

The model describes the complete hydrothermal system underlying the geothermal systems and its principal geological controls. For this reason, it can be used to investigate the effects of fluid production and reinjection on timescales longer than the normal plant life of 30-50 years. We give some simple examples of this.

Session 2.3

16 | Machine Learning Opportunities for Geothermal Drilling Operations: An Overview

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Keywords: *Geothermal well drilling, MWD, Machine Learning, Geothermal drilling challenges*

Geothermal energy has been providing low carbon and reliable renewable resource for electricity generation since the 1950's; however, the total geothermal installed capacity comprises only 0.5% of total renewables-based capacity as of 2021, growing only ~3.5% annually. High upfront costs and resource risks associated with geothermal development proved a challenge for future investments and wide-scale adoption.

As heat is harnessed from the depths of the earth, drilling wells towards a viable resource is critical to the success of the project. Drilling has only ~83% success rate in the operation phase and accounts for 35-40% of the total capital expenditure of the project. Improving drilling performance by de-risking drilling operations will be a game-changer in pushing interest towards geothermal development.

With the recent advent of artificial intelligence (AI) technology, there is a renewed interest in looking at Machine Learning for optimising different drilling applications. Machine learning is a subfield of AI that automates the modelling of complex data sets for problem specific tasks. Combining these models with a problem specific decision model leads to AI. This paper summarises the challenges of geothermal drilling operations and gives an overview of machine learning applications in drilling operations.

Session 4.2

17 | State of the Environment Reporting using the DPSIR Model in the Waikato Region

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Keywords: *DPSIR, SOE Reporting, geothermal resources, sustainability.*

Waikato Regional Council (WRC) is responsible for sustainable management of the Regional Geothermal Resource, which encompasses approximately 70% of the nation's total. It comprises 15 high-temperature systems and about 30 low-temperature system. There are 9 geothermal power stations in the region, generating 800 MWe (Figures 1, 3). Under the Resource Management Act 1991 (RMA), WRC is required to monitor, keep records, and report on the state of the environment, including that of geothermal resources. In 2022 - 2023, WRC produced a set of State of the Environment reports, including one that examined the state and trends in nature, extent, and condition of the Regional Geothermal Resource (Luketina 2023), assessed against the internationally accepted DPSIR framework (Drivers, Pressures, State, Impact and Response model).

Degradation of geothermal surface resources through large-scale destruction of surface features and depletion of the geothermal resource by excessive extraction of the subsurface energy and fluid has effectively ceased since the RMA was enacted in 1991. Under the RMA the Waikato Regional Policy Statement (2016) and Waikato Regional Plan (2012) were developed, giving policies and rules to ensure sustainable management of natural and physical resources including geothermal resources.

However, ongoing small-scale destruction of geothermal features through inappropriate land use activities continues as a result of land use intensification. Ensuring that all uses of geothermal resources are sustainable is now more important than ever as we face increased pressure to use geothermal resources, for electricity generation and direct heat uses, and as intensification of land use and subdivision encroach upon rare and vulnerable geothermal ecosystems.

The adverse effects on geothermal resources of anthropogenic activity have been assessed for the four major cause-and-effect dynamics acting on the Regional Geothermal Resource:

1. Effects of geothermal energy development on surface features and their dependent ecosystems;

2. Effects of geothermal energy development on amount of energy and fluid available for future generations;
3. Effects of geothermal development on other uses of surrounding land and water; and
4. Effects of land uses on geothermal surface features and their dependent ecosystems.

Lack of funding for geothermal monitoring and research severely impairs the council's ability to identify and respond to threats.

Session 4.3

18 | REGEMP 2022: Waikato Regional Geothermal Monitoring Programme

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Keywords: *REGEMP, geochemistry, Waikato Region*

Waikato Regional Council collects and records monitoring data on geothermal features in the Waikato Region. Among other information, the database contains more than 2400 chemical analyses of geothermal features with variable analytical suites included, some dating back more than 100 years. Every few years more samples throughout the region are collected and analysed, and along with data from other sources, interpreted to determine regional temporal and spatial trends.

This paper presents an interpretation of the REGEMP dataset using classical geothermal classification based on major anions to indicate regional trends in geothermal geochemistry. The major anion plot distinguishes the types of geothermal processes that contribute to spring chemistry. In the REGEMP data the TVZ samples plot throughout the possible composition range on a major anion plot, whereas the North Waikato and Tongariro regions have a more restricted range of compositions. The North Waikato samples are concentrated along the Cl- HCO3 axis, possibly indicating that this area is depleted in S compared to Tongariro and TVZ area. This could indicate a systematic change in geothermal fluid composition in areas more distal from volcanism. Different geothermal fields also plot in relatively restricted, but overlapping, compositional fields on the major anion plot.

Summary recommendations include that major cation and anion ratios (as displayed in ternary diagrams) be used as the key tools to interpretation of the REGEMP dataset, and that alternative monitoring datasets such as satellite data or drone based thermal imaging should be considered.

Session 3.3

19 | Cementing and Aerated Drilling Solutions for Curing Shallow Loss Circulation

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***Keywords:** Geothermal well cementing, lost circulation, aerated drilling, shallow losses*

Performing cement plugs in the top-hole section due to shallow losses is expected in any geothermal drilling project. In fact, around 10-20% of the well's budget is allocated for this purpose. Many factors contribute to this high cost, but the most significant are the long turn-around time in between cementing jobs and the high number of plugs needed to seal the losses. This results in significant lost rig time and thus presents a big opportunity for cost reduction measures.

PGPC executed an 11-well campaign in known locations, with offset wells which showed that >20 plugs were required to be able to drill and case off the top-hole section. The primary objective of the team was to reduce the non-productive time associated with these losses. The initial approach was to develop a thick, viscous, fast-set cement plug with a lost circulation material (LCM) pre-flush to create a bridge near the wellbore to improve cement plug performance and also reduce waiting-on-cement (WOC) time. Further improvement led to a shift from an LCM-centric approach to cement gelation so the slurry would quickly gel up after pumping was stopped. At this point, the number of cement plugs was already reduced by 88% and the cement turn-around time decreased by 61%.

However, the team pushed further to eliminate shallow cement plugs by employing aerated drilling in the shallow sections. The cement plugs were successfully eliminated by the third well and the campaign was finished without any cement plug operations in the shallow loss zones.

Session 4.2

21 | Comparison of Icelandic Supercritical Well Forecasts with Subcritical Geothermal Production Well Outputs

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Keywords: *Supercritical Geothermal, Wellbore Production, Well Output, Geothermal: Next Generation, Iceland, New Zealand*

Possible energy production from supercritical geothermal reservoirs has been studied in Iceland for over twenty years with conceptual thinking and analysis performed as part of the Iceland Deep Drilling Project (IDDP). Icelandic works on well output simulations have been conducted seeking to estimate the possible production capacity of a supercritical well. The forecasting from this simulation work, together with NZ wellbore simulation undertaken by GNS Science, is compared to the output of subcritical geothermal production wells from six geothermal fields in the Taupo Volcanic Zone (TVZ).

The flow test measurements from the IDDP-1 well undertaken between 2010 and 2012 were analysed and the output from this superhot well has been summarised and compared to the production well dataset.

This comparative analysis is documented in this paper where thermal and exergetic power are computed and compared.

Session 7.2

22 | Modelling Particle Tracking of Moisture Droplets in Geothermal Steam Pipeline

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Keywords: *Steam quality, steam purity, water droplets, entrainment, deposition, system above ground, water wash, SPDOT.*

As the saying goes, "A persistent drop of water will wear away the hardest stone", very small water droplets in micro-scale in the steam can damage the turbine over time. Many studies on the steam quality found that although it is within the turbine manufacturer's limit and has 99.95% of dryness and above, the turbine still suffers from water impingement erosion and mineral scaling. The basis of water carryover from the separator and condensation in the steam line is adapted from the Steamfield Process Design and Optimisation Tool (SPDOT) by Umanzor & Zarrouk (2022). This work presents a comprehensive carryover analysis, water droplets interactions, and entrainment rate. This is to provide a better understanding of the system's moisture droplets and current equipment's limitations in capturing these water particles before entering the turbine.

Session 5.2

23 | Numerical model of the Tikitere geothermal system

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Keywords: *Tikitere, AUTOUGH2, Waiwera, ITOUGH2*

The Tikitere geothermal field is one of the 21 high-enthalpy geothermal fields in the Taupo Volcanic Zone (TVZ) in New Zealand. The field is renowned for the tourist attraction Hell's Gate, which consists of many natural geothermal surface features. Based on geoscientific data from the open-source literature, a conceptual model was set up in Leapfrog Geothermal.

A corresponding natural state reservoir model was then set up and calibrated using temperature and heat flux data from fourteen thermal areas. The calibrated numerical model matches the higher temperatures at the locations of some of the surface thermal features but does not match the estimated heat flows.

Session 1.2

24 | Numerical modelling of tracer tests in the Ohaaki geothermal system

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Keywords: *Waiwera, Ohaaki, Tracer tests.*

The Ohaaki geothermal field (OGF) is a gassy two-phase geothermal field in the volcanic and sedimentary accumulation basin at the eastern margin of the Taupo Volcanic Zone in the central North Island of New Zealand.

The long history of exploration and development of Ohaaki started with the drilling of the first well in 1965. Large-scale testing of the production wells was conducted from 1965 to mid-1971, and power production commenced in 1989.

Many tracer tests have been carried out at Ohaaki to better understand flow pathways between wells. The aim of the present study is to use modelling of these tracer tests to help in improving the calibration of a reservoir model.

First the available information about the historical tracer tests in Ohaaki was collected and reviewed. Three of the tracer tests were selected as the first group to be used for modelling using the parallel open-source simulator Waiwera and the latest Ohaaki model developed at the University of Auckland.

Good agreement is shown between the data and the model results for some wells. For other wells where agreement is not satisfactory the mismatch is used to decide on improvements that should be made to the permeability structure of the model.

Session 5.3

26 | 2012-2023 Comparative Ground Penetrating Radar and Temperature Survey at Orakei Korako, Taupō Volcanic Zone, New Zealand

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In 2012, a Ground Penetrating Radar (GPR) and downhole temperature measurement survey was undertaken around the boardwalk at Orakei Korako geothermal field, Taupō Volcanic Zone, New Zealand. In 2023, this survey was repeated to identify if and where changes in the subsurface had taken place over the last 11 years.

Nine 2012 downhole temperature measurement sites and ten surface temperature measurements sites were repeated for a direct comparison with our 2023 data. Downhole temperature measurements were taken where possible at depths of 0.5 m, 1.0 m and 1.5 m using a K-type digital temperature probe with a quick response tip. Surface temperature measurements were obtained at the start and end points of each GPR transects using a digital temperature probe with a K-type thermocouple.

Thirteen GPR sites were repeated in 2023, five 2012 GPR sites were not repeated due to inaccessibility to the site. GPR profiles from seven new sites were also collected during the 2023 survey. In 2012 we used a GSSI SIR-2000 GPR unit with a 200 MHz antenna. In 2023 a Leica DS2000 GPR unit fitted with dual frequency antennas of 250 MHz and 700 MHz was used. The 700 MHz antennae collected high resolution data from the shallow subsurface (0-3 m depth), while the 250 MHz antennae captured data from deeper layers (0-7 m) at a coarser resolution.

Our repeat survey identified areas that have heated up and cooled down, mapped migrating subsurface heat pathways, located ascending steam conduits, identified fractures, mapped zones of hydrothermal alteration, as well as imaged the thickness of the siliceous sinter terraces.

The combined techniques of GPR and temperature measurements offers an innovative method and new perspective for characterising changes that take place in the shallow subsurface over time.

Session 1.3

27 | The effect of CO_2 reinjection on silica scaling in geothermal reservoirs

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Keywords: *NCG reinjection, emissions, CO_2, reactive transport, geochemistry, scaling*

The capture and reinjection of the non-condensable gases (NCG) that are associated with geothermal brine production is a key technology to ensure that geothermal energy remains a sustainable part of Aotearoa's transition to a low carbon economy. Whilst several pilot schemes are underway to trial the viability of NCG reinjection, its potential effects on reservoir geochemistry are not well understood. Here, we present a combined experimental and modelling approach to investigate the effect of the incorporation of CO_2 (the primary component of the NCG fraction in NZ geothermal brines) into reinjected brines.

Four experimental reinjection simulations were performed in high-PT flow-through reactors under geochemical conditions relevant to New Zealand geothermal reservoirs, with varying levels of added CO_2. The empirical observations collected as part of these experiments were used to constrain the rate parameters of a reactive transport model built using PFLOTRAN that can accurately reproduce the geochemical behaviour of the experiments. This numerical model can then be used to extend our investigation to the relevant spatial and temporal scales required to understand the long-term reservoir response to NCG reinjection. We show that for acid-dosed brines, addition of CO_2 can significantly reduce the rate of silica scaling in reservoir. This has significant implications for reducing the injectivity decline of reinjection wells, which may help realise previously underappreciated cost savings achieved by NCG reinjection technologies. We demonstrate a framework whereby this combined experimental-modelling approach can be used to quantify the effect on silica scaling for any brine-reservoir rock combination, with the aim of helping to de-risk and accelerate the deployment of NCG reinjection technologies across the NZ geothermal sector.

Session 3.3

28 | Combining geophysical, isotopes and geological studies toward geothermal models at Hongchailin for geothermal power generation in NE Taiwan

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Keywords: *Geothermal geological model, Szeleng Sandstone, Hongchailin, Yilan, Taiwan.*

In this study, we conduct a multi-disciplinary study, including geophysics, geochemistry, and geology, to reconstruct a geothermal geological model at the shallow 3 km level, for a project of potential geothermal power generation at the Hongchailin site in the Yilan plain of northeastern Taiwan. Our geophysical techniques include seismic imaging from natural earthquakes as well as ambient noise. Three seismic arrays deployed at different time periods in the past decade were used. We also incorporate geophysical imaging results from previous studies, in particular a series of seismic reflection profiles. Three magnetotelluric (MT) surveys have been conducted in three different periods. Three test holes were drilled around the Hongchailin site in 2016-2019. Logging and on-site measurements were conducted at increment depths, including rock types, P/T measurements, fractures analyses, geochemical analyses.

Incorporating regional geological structures, geophysical subsurface imaging, we reconstruct geothermal geological models in line with detailed geological cross sections at the shallow 3 km level. We interpret a shallow geothermal reservoir within the massive quartz sandstone layers (Szeleng sandstone) at 1-2 km depth with the downhole temperature of 80-100°C. Geologically, the reservoir is located at the regional Songlo syncline and its south limb; and geophysically, it corresponds to a relatively low resistivity area. Isotope results show that the cool meteoric water came from nearby higher altitude mountain area, then flew through the Szeleng sandstone, which plunges 1-2 km depth below the Yilan plain. Hot fluid is interpreted to be derived from deeper heat source interpreted from seismicity data, which then upflows along a N-S trending vertical faults system. Drone-based thermal imagery confirmed the presence of hotter areas at surface. In addition, two E-W trending major faults, identified by the seismic reflection profiles, seem to act as hydrothermal fluid barriers to confine the hot fluid within the reservoir area.

Session 8.3

29 | 2022 Annual Aotearoa New Zealand Geothermal Review

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Keywords: *New Zealand, geothermal, Annual Review, 2022.*

During 2022 geothermal electricity generation increased by 1% to a new record of 8,060 GWh. This output supplied 18.5% of New Zealand's electricity. Due to the impact on hydro generation from favourable hydrologic conditions, total renewable generation increased to 87% of national electricity supply.

Net installed geothermal capacity remained steady at 1033 MWe for 20 stations on 8 fields. Over the next five years, geothermal electricity generation will likely increase by 24% to over 10 TWh per annum with the addition of new plants: Tauhara II (174 MWe), Te Huka 2 (50 MWe) and Nga Tamariki (37 MWe).

The industry's weighted average CO_2e emissions rate remained steady at 63 tonnes of CO_2e per MWh. In response to global imperatives to decarbonise and steadily increasing carbon prices (peak of NZ $88.5/tonne in November 2022), power producers progressed pilot schemes for reinjecting CO_2, CH4, and other non-condensable-gasses. These schemes at Nga Tamariki, Ngawha, and Te Huka power stations are able to reinject between 25% to 100% of emissions.

Although developers did not commission new high-temperature, direct-use facilities during the year, projects to increase heat use by (13 GWh) are in execution phase with commissioning expected in late 2023.

Operators drilled six deep conventional wells and five shallow wells during the year.

NZ Universities continued to support the industry. Enrolments at the NZ Geothermal Institute look set to bounce back from the COVID low of six in 2021.

Session 7.3

31 | Insights into the Waiotapu Geothermal Field using High Resolution SkyTEM Data

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Keywords: Waiotapu Geothermal Field, Reporoa Geothermal Field, ATEM, SkyTEM, resistivity

Airborne Transient ElectroMagnetic (ATEM) geophysical methods enable high densities of data to be collected over large areas in an efficient manner. Resistivity models derived from the ATEM data enable high-resolution geological and hydrological structures to be interpreted

in the near surface (approx. 400 m). We use ATEM data to interpret geological and hydrological features in the Waiotapu and Reporoa Geothermal Fields of New Zealand.

Selected cross-sections of resistivity models derived from ATEM data collected over the Waiotapu and Reporoa study areas are interpreted in terms of geology, hydrogeology and geothermal influences. Preliminary interpretations from the cross-sections show:

Good correlation between the ATEM data and the direct current resistivity maps of the spatial extent of low resistivity anomalies associated with the Waiotapu and Reporoa Geothermal Fields.

Good correlation between the locations of low resistivities and geothermal surface features.

A near-vertical low resistivity boundary on the western side of the Waiotapu Geothermal Field correlating with the mapped Ngapouri Fault. This implies a constrained permeable structure, or bounding structure.

Possible eastern extension of the Waiotapu Geothermal Field under the Kaingaroa Ignimbrite.

Correlation between some mapped active faults and
low resistivity anomalies, indicating that faults (and specifically, which parts of the fault) could support geothermal fluid flow.

Abrupt resistivity boundaries may indicate either possible unmapped faults and/or geological boundaries.

Potential geothermal flows to the surface can be inferred in areas where low resistivity anomalies from the deeper part of the system can be traced to the surface.

Session 2.3

32 | Investigating Influences on Hydrothermal Fluid Flow in the Taupō Volcanic Zone with Numerical Models Constrained by Magnetotellurics

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Keywords: *Taupō Volcanic Zone, TOUGH2, geothermal modelling, magnetotellurics, fluid flow.*

There are 23 high-temperature geothermal fields in the central Taupō Volcanic Zone (TVZ), discharging ~4200 GW of heat. Magnetotelluric (MT) surveys over large areas in the central TVZ have detected eight low-resistivity anomalies (i.e. plumes) in the brittle part of the crust. These plumes are interpreted as upwelling hot geothermal fluids with high conductivity compared to the surrounding cold-water-saturated meta-sedimentary basement rocks. The upper extents of these conductive plumes correspond well with the surface expressions of most geothermal fields, but not all.

We have used TOUGH2 numerical modelling software to explore regional influences on subsurface geothermal fluid circulation. We created simplified models with uniform geology and:

1. localised heat sources at 5 km depth as modelled from MT data.
2. surface elevation variations based on the water table (a muted reflection of topography).
3. a combination of influences 1 and 2.

We then compared resulting modelled zones of high temperature at 500 m depth with geothermal field boundaries as delineated by DC resistivity measurements.

Modelled upflow zones correspond extremely well with some of the known geothermal fields, such as Tikitere and Ngatamariki. In other areas, e.g. Waimangu and Rotokawa geothermal fields, modelled upflow zones are in the right geographic regions but have different lateral extents.

Beneath the Haroharo Volcanic Complex in the Okataina Volcanic Centre, a conductive plume and modelled upflow do not underlie any areas of hydrothermal activity at the surface. Here, we hypothesise that mapped or previously unidentified geological structures such as faults or volcanic domes may be influencing regional geothermal circulation. Some fields are not explained by MT anomalies or topographic effects, and these will be the subjects for future studies.

Session 5.3

33 | Rhyolite of the Tauhara Geothermal Field: insights and correlations from geochemistry

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Keywords: *Rhyolite, portable X-ray fluorescence, pXRF, geochemistry, Zr, Y, Ti, geothermal, Tauhara, Wairakei.*

Since 1965, numerous subsurface rhyolite lavas have been drilled at the Tauhara Geothermal Field, Taupō Volcanic Zone. These, and additional rhyolite lavas, were intercepted in 12 geothermal wells drilled from 2019–2022 for the Contact Energy Tauhara II (174 MWe) power development project. Some rhyolites had already been characterised and formally named (e.g., Racetrack Rhyolite), but others were only affiliated to broad groups based on phenocryst type and abundance. To validate stratigraphic correlations, portable X-ray fluorescence (pXRF) analysis was trialled during the drilling campaign to geochemically 'fingerprint' the rhyolites by their immobile element concentrations (i.e., elements unaffected by hydrothermal alteration). Of the elements robustly quantified by pXRF, only Zr, Y, and Ti were useful to distinguish the rhyolites. Since concentrations of Zr, Y, and Ti overlap it is typically not possible to identify a given unit exclusively based on chemistry with few exceptions (e.g., Tauhara Moana rhyolite). However, by evaluating pXRF geochemical data combined with spatial and stratigraphic information, plus mineralogy, this technique was able to confirm previous correlations for several rhyolites. It also distinguished rhyolite lavas that are not the same despite their spatial proximity and similar mineralogy (e.g., Racetrack and Kauri rhyolites) resulting in new correlations.

Session 3.3

37 | Changes in geothermal reservoirs due to hydrothermal eruptions and fault reactivation

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Keywords: *Geothermal Reservoir, Reservoir Modelling, Hydrothermal Eruption, Fault*

Geothermal reservoirs naturally change over time as hot upflows shift within the subsurface. The causes of such evolving flow paths are often speculated upon. Of the many possible mechanisms, large hydrothermal eruptions (focal depth > 100 m) and faulting (new or reactivation) may cause sudden changes in the pressure and flow field locally, leading to changes in temperature and pressure in the deeper subsurface. The extent and magnitude of such changes are poorly understood.

We employ a numerical reservoir simulator to investigate how fluid flow throughout the geothermal system is affected by a sizable hydrothermal eruption or permeable fault zone. By using simplified models, we identify scenarios in which these mechanisms have greatest impact and set bounds on the extent and magnitude of change. We show that the permeable zone created by a hydrothermal eruption has strong impacts on the pressure, temperature, and flow regime in the shallow reservoir (<1 km), but their effect on the deeper reservoir (>1 km) can be limited in the presence of deeper flow barriers (i.e., a deep clay cap). By contrast, fault development extending into the deeper reservoir and penetrating such flow barriers has the capacity to alter the system by slightly shifting where hot upflows move into the shallow system. Our findings can be applied to other reservoirs, providing a first-order assessment of whether hydrothermal eruptions and/or faulting could be responsible for the changes in the temperature, pressure, and hydrologic structure of the geothermal system.

Session 5.3

38 | Update on the CaSil technology: economically solving global silica scaling, enabling low temperature direct heat extraction and electricity generation

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Keywords: *Geothermal, silica scaling, calcium silicate hydrate, direct heat utilisation, process heat, enhanced energy extraction*

Silica scaling remains the world-wide largest unsolved problem in the full utilisation of geothermal resources. Dissolved silica becomes supersaturated during cooling and steam production leading to intractable scale that blocks pipework, heat exchangers and reinjection wells. This blockage can significantly lower the efficiency of heat exchangers which causes a direct decline in electricity production and sales over time. Regular and costly maintenance is required which necessitates plant downtime. Conventional silica scale mitigation methods are not wholly successful and come with drawbacks such as high cost or corrosion concerns.

The proprietary CaSil Technology utilises a disruptive approach of transforming dissolved silica entities into a novel calcium silicate (CaSil) product, forming discrete particles that remain suspended and do not adhere to metal surfaces.

Within seconds, the technology achieves a significant reduction in the silica saturation index to well below 1. The robust process is compatible with a wide range of brine compositions, irrespective of the initial silica concentration, ensuring reliable prevention of silica scaling. Furthermore, the CaSil Technology enables safe lowering of brine temperatures beyond current limits without inducing any silica scaling. This opens new business opportunities for additional process heat utilisation in for example greenhouses, aquaculture or milk powder production, thus supporting the decarbonisation of industry.

Successful trials on development plant scale across three different geothermal resources in New Zealand have been undertaken. The technology seamlessly integrates into existing geothermal operations or greenfield plants, offering a versatile solution.

This paper presents data from the trials and highlights the effectiveness of the technology to prevent silica scaling while unlocking the full potential of geothermal resources for enhanced heat extraction. By addressing the silica scaling challenge in a novel and disruptive way, CaSil Technologies paves the way for the sustainable and efficient utilisation of geothermal energy resources on a global scale.

Session 5.2

39 | Numerical Simulator for the Coupled Model of Wells and Fractured Reservoirs

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Keywords: *wellbore flow simulation, reservoir simulation, cycling wells*

This study presents a numerical simulator for the coupled model of wells and reservoirs, which is being developed. The simulator is capable of transient flows along directional wells and intersecting multiple planar structures based on the concept of discrete fracture network models. Comparisons with analytical and numerical solutions obtained using reference codes successfully validated the simulator of this study. An application to the hypothetical coupled problem of a directional production well intersecting multiple planar structures was demonstrated, in which a steam cap was generated at the top of the reservoir while producing for 300 days. The flowing enthalpy at the wellhead varied depending on the temporal variation in the flow rate in each feed zone. The simulator will be further extended and enhanced based on the requirements of specific problems and suggestions from scholars in open communities.

Poster Session

41 | Development of a novel HT calcite scale inhibitor for Geothermal applications

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Keywords: *calcite, scale, geothermal, scale inhibitor, high temperature*

Chemical treatment for preventing scale formation and deposition is now widely used in the geothermal industry. The high temperatures involved in the geothermal processes constitute one of the major challenges for most of the standard chemistries currently applied for scale inhibition. The chemical product may undergo a thermal degradation which cancel their scale inhibition effect and, in some cases, may generate additional scale due to by-product formation.

In this paper, the development of a novel, highly stable, chemical product is presented. Extensive lab work has been done with results and protocols described in detail. Compared to standard technologies, this new product has shown an exceptional thermal stability and excellent performance against calcite, which is one of the most common types of scale generally present in geothermal plants.

Following the good results obtained in the laboratory, an industrial trial was done in a 30MW plant in Turkey having high temperature reservoir (> 200°C) and severe silicate and calcite scaling issues. In the same plant, several different chemical products were applied with very bad results. The new product was applied for two months, and the performance were assessed by checking the amount of scale formed on scale coupons and by monitoring the geothermal brine composition in order to identify any variation in ions content that could be linked to scale precipitation.

At the end of the trial, the results confirmed the lab observation, by showing excellent performance in scale inhibition at such high temperature conditions.

Results presented in this paper represents a step forward in the development of new chemical product which can offer a more effective technology to geothermal operators aiming to improve their plants efficiency.

Session 5.2

42 | Case study: Silica Inhibitor Trial in Central America Plant

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***Keywords:** silica, scale, geothermal, scale inhibitor, Central America*

This paper provides a description of a field trial performed in a geothermal plant in Central America affected by severe silica scaling.

Silica is one of the most common and serious scale that geothermal operators have to face, and it typically deposits in the colder sections of the plant. Among all the different ways currently available for preventing silica deposition, the use of chemical inhibitors is considered one of the most promising and cost-effective approach.

The presence of highly charged cations such as Al3+ and Fe3+ in the geothermal brine increase the severity of conditions as those cations boost silica polymerization and precipitation also affecting the efficacy of scale inhibitors and dispersants. For this reason, it is crucial to select and correctly apply the best product able to provide good protection even under harsh conditions.

The trial started with two runs, as base lines, without the application of the scale inhibitor followed by a run where the scale inhibitor had been applied. All the trial runs had a duration of 30 days each and the plant operating condition were kept constant for the entire trial period. After each run, the system was cleaned up and scale coupons, placed in different area of the system, were extracted and analysed by measuring the scale weight and thickness together with a visual inspection of the pipelines.

The performance comparison showed very good results obtained during the run with the scale inhibitor which registered a reduction of scaling by 70 to 80%. Also, the visual inspections showed much cleaner pipelines conditions after the run with the product.

This work confirms how the use of a proper scale inhibitor, even at low dosage, could mitigate the negative effects of silica deposition, increasing the efficiency of the plant and the power recovery and eliminating the need of costly shutdowns for mechanical cleaning.

Session 5.2

43 | MakBan Drilling Campaign Offset Wells Monitoring and Post Drilling Production Evaluation

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***Keywords:** Mak-Ban Geothermal Field, Steam Production Enhancement Campaign, SPEC, offset wells monitoring, geochemical parameters, production evaluation*

A recently completed drilling campaign at the Mak-Ban Geothermal Field, Philippines (the 2021-2022 Mak-Ban Steam Production Enhancement Campaign – MB SPEC) targeted production from the deep reservoir to provide steam for the existing powerplants. The campaign included nine production wells and two injection wells, using existing active wellpads. The welltracks of the MB SPEC wells were in close proximity to active wells so there was a need for a proactive approach to monitor the drilling impact and mitigate the potential migration of drilling fluids and cement to the nearby offset wells. The Mak-Ban Resource Management Team developed

an offset wells monitoring plan as a guide for recommending whether to shut-in offset wells during the drilling operations and to minimize associated generation losses.

Aerated drilling fluid with bentonite and polymer were used during the drilling operations. As a general rule, when bentonite was used, all offset wells within a radius of 300 ft of the welltrack were proactively shut-in to mitigate the risk of plugging the permeable zones. When polymer was used or when the offset wells were within 300 to 800 ft, a reactive shut-in approach was implemented based on the geochemical parameters that would suggest possible interference. During cementing, all offset wells within 800 ft were proactively shut-in.

The original plan was to have the steam and condensate samples from the offset wells to be analyzed for total %NCG by Wet Test Meter (WTM), Normal Gas Analysis (NGA), Total Suspended Solids (TSS) and pH. For brine samples, pH, Cl and Mg were initially planned to be analyzed. However, the monitoring plan was simplified only for the parameters with the quickest analysis turnaround time which were total %NCG and Cl. Offset wells were shut-in when the parameters increased above threshold values.

The offset well monitoring plan was deemed successful as it was able to help prevent the potential breakthrough of drilling fluids and cement in offset wells. The equivalent of up to 24.5 MWe production from the offset wells was preserved after the end of the campaign and the preventive offset wells shut-in losses were reduced to 16 GWh actual from the planned 34 GWh.

Session 2.2

44 | Geothermal vegetation of the Waikato Region: 2023 update

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Keywords: *Geothermal vegetation, ecology, Waikato, inventory, extent, condition, ranking, ecosystems*

We present the findings from our 2022-2023 update to the inventory of geothermal habitats in the Waikato Region. This is an updated inventory of the current distribution, condition, and extent of geothermal vegetation and habitats in the Waikato Region, where almost 74% of New Zealand's geothermal systems occur. Forty-six sites with geothermal vegetation, within 14 Geothermal Systems were identified, mapped, described, and assessed for significance. For each site, the vegetation, site boundaries, and location relative to other sites were mapped. Changes in site condition, management actions, and threats were all considered. Since the last inventory study in 2014, an additional 142.8 hectares of geothermal vegetation has been mapped, however most of this area is the result of discovery of additional areas of existing habitat as the quality of aerial photography continues to improve. Real increase in vegetation extent was noted for two sites covering only relatively small areas. Overall, the extent of geothermal vegetation across the Waikato Region has been relatively stable in the last ten years. Minor reductions have occurred at some sites due to increases in pest plant cover and, in some cases, from herbicide use on site margins. The condition of many sites has improved as a result of ecological restoration effort. However, some sites are in poorer condition since the last survey, mainly as a result of the expansion of pest plant infestations. Many geothermal areas have been

fenced in the past 10+ years, but in many cases where no other restoration effort has taken place this has resulted in a significant increase in blackberry.

Session 6.3

45 | Carbon Negative Geothermal: Theoretical Case Study for Biogenic CO_2 Removal at Ngāwhā Power Station

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Keywords: *geothermal, biomass, CO_2, retrofit, economics*

Geothermal energy is a mature and base load source of low carbon electricity in New Zealand, and the only one that can facilitate onsite carbon dioxide removal (CDR). Here, we investigate the potential for bioenergy hybridisation and biogenic CDR using existing reinjection wells at Ngāwhā geothermal field. The proposed designs would produce increased electricity generation and negative CO_2 emissions.

Bioenergy hybridisation is achieved with biomass combustion that directly increases the enthalpy of production fluid before or after a separator. Mass-energy balance determines the optimal biomass burn rate to sustain turbine delivery enthalpy in the face of resource decline. We calculate the potential CO_2 emissions that can be sequestered via dissolution in the reinjection line. Finally, we estimate high-level economic indicators for this retrofit.

Our findings suggest that it is possible to increase plant capacity by 1 MWe through combustion of 24 kt/year of forestry residues. The cost of new electricity generation could be competitive with conventional geothermal projects at CDR investment prices as low as \$75/tCO_2. Conversely, the cost to remove biogenic CO_2 through this process could range between \$77-154/tCO_2 depending on the configuration, which is more cost effective than most direct and indirect atmospheric carbon removal schemes (Fasihi et al., 2019). Monetized on international markets, CDR revenues could reach USD \$3.9 million per year, which adequately covers anticipated biomass fuel costs of USD \$2.1 million per year.

Applications of CDR technologies in New Zealand can decarbonise hard to abate emissions from agriculture, steel and aviation. CDR via geothermal reinjection wells makes use of onsite infrastructure and mitigates CO_2 buoyancy risks, allowing for cost-effective and secure storage. In addition, hybridisation with bioenergy could alleviate or delay the need to drill more wells to maintain plant capacity. This can be important if fluid production is nearing a geothermal field's maximum allowable consent.

Session 7.3

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46 | Equation of state modules for Waiwera including water, chloride and non-condensible gas

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Keywords: *Reservoir models, numerical modelling, flow simulator, Waiwera, chloride, non-condensible gas*

In some geothermal systems there are high concentrations of chloride and some non-condensible gas (mainly CO_2). For reservoir modelling, equation of state (EOS) modules that can handle non-isothermal mixtures of water, chloride and NCGs are required. In the TOUGH2 simulator, EWASG provides a suitable EOS.

In this paper we describe a set of new EOS modules for modelling chloride-rich systems using the parallel, open-source geothermal flow simulator Waiwera. EOS modules for water & chloride, water, chloride & CO_2 and water, chloride & air are provided. Shared code is used to give consistency between results from different EOS modules. The main physical properties of chloride are computed using the updated thermodynamic formulation of Driesner (2007) which also removes the low-temperature limitations of EWASG. As in the pure water and water & NCG EOS modules for Waiwera, primary variable interpolation gives improved phase transition performance and hence faster convergence of natural state simulations.

Some results for theoretical test problems and real high- and low-temperature geothermal fields are presented.

Session 1.2

47 | Towards a national temperature model for New Zealand

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Keywords: *temperature, thermal conductivity, heat production, numerical modelling.*

Knowledge of crustal temperature is important in expanding geothermal energy use across New Zealand, including low temperature direct use applications. However, crustal temperature distribution across much of New Zealand is not well known, despite New Zealand's extended history of developing geothermal resources. We are developing a national temperature map using a 1D transient heat flow model. To support the model, we have established thermal properties measurement capability and are using measurements from this in conjunction with geochemical and mineralogical data to estimate thermal properties. Development of other model inputs is ongoing. In this paper we discuss the thermal regime in three locations to demonstrate the impact of different processes occurring across the relatively young and tectonically active landmass of New Zealand. The Taupō Volcanic Zone is well known for extremely high heat output but the temperature gradient is strongly variable in this region due to fluid convection. Here, a conductive heat flow model will not be applicable, and so an alternative approach may be required. On the Alpine Fault, our transient 1D heat flow model estimates that the surface heat flow is enhanced by a factor of three due to Quaternary uplift and erosion; there are likely to be additional topographic and fluid flow effects for which the model does not account. In Wanganui, western North Island, our model predicts that the near surface heat flow is depressed by 20 mW/m2 as a result of Plio–Pleistocene basin formation. In both regions, the effect of transient processes is present to depths of >20 km. Thus, Neogene processes leave a strong pervasive transient signal that extends to at least the mid crust.

Session 2.3

48 | Incorporating Māori world views in the Rotorua geothermal system management plan

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Keywords: *Rotorua, geothermal, Māori, mātauranga, mauri, Te Arawa, system management plan*

Tangata whenua, the indigenous people of New Zealand have a long, unique and intergenerational relationship with geothermal. In Rotorua, ngā wai ariki (geothermal) remains central to everyday life and the wellbeing of tangata whenua.

However, colonisation, following the signing of Te Tiriti o Waitangi, set in motion legislative and social changes that have altered the way that geothermal is used and managed. Key to this was the Crown taking control of the formal management of the geothermal

system, under various statutes. While customary practices continued, wider access to and use of geothermal was managed by the Crown, which compartmentalized and commodified the system.

In 1991 the Resource Management Act (RMA) signalled an intention to shift focus back towards sustainable management and the recognition of the relationship of Māori with geothermal. Since then, there has been 'fine tuning' of legislation, progress towards Treaty of Waitangi Settlements, building of case law on Māori rights and interests in geothermal, and growing awareness within central and local government of Te Ao Māori, a Māori world view.

The development of the Draft Rotorua Geothermal System Management Plan (SMP) by the Bay of Plenty Regional Council (Council) provides an opportunity to rethink the way the system is managed. The Draft SMP has been co-developed by the Council and tangata whenua, to embed the unique perspectives and mātauranga (knowledge) of tangata whenua; and to reflect the aspirations of tangata whenua. The opportunities are considerable, but this new approach also brings tensions and challenges for both Council and tangata whenua.

Session 4.3

49 | Vegetation in the Wairākei-Tauhara Geothermal System: History and Future Options

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Keywords: *Wairākei, Tauhara, geothermal system, electricity generation, geothermal vegetation, adaptive management*

The Wairākei-Tauhara Geothermal System (WTGS), contains c.164 hectares of discontinous geothermal vegetation and habitat that has a complex history of natural and anthropogenic change. A key feature is the extensive areas of geothermal kānuka-dominant vegetation on geothermally-heated ground. The WTGS supports populations of nine plant species classified as being either Threatened or At Risk. Changes to the patterns and dynamics of geothermal vegetation in the WTGS are linked to the effects of energy extraction. Energy extraction commenced in 1958 on the WTGS at Wairākei Power Station and since then has been subject to multiple modifications and expansions. The extraction has resulted in changes and losses to some steamy habitats (mostly alongside geothermal streams, springs, and geysers), reducing habitat for species that require steamy habitats. Between the 1950s and 1980s, there was a marked increase in geothermally-heated ground habitats, substantially increasing the extent of geothermal kānuka. Since the late 1980s geothermally-heated ground habitats have been slowly declining in size, although the extent of geothermal kānuka-dominant vegetation remains considerably larger than before energy extraction began. Monitoring and assessment of WTGS geothermal habitats has been undertaken regularly since the early 2000s. Here we present

findings of these assessments, including our identification of some recent changes at specific sites. We also present options for the future management of geothermal vegetation in the WTGS under two scenarios: continued use (though modified energy extraction), compared to the likely effects of no further energy extraction. We determined that continued extraction, at least in the short term can provide opportunities to invest in the protection of geothermal habitats and species. For steamy habitats this can sometimes be achieved through artificial creation of lost habitats. Careful restoration management of the highest quality remaining geothermal habitats in the WTGS is also recommended.

Session 6.3

50 | Highlights of Borehole Imaging, Tauhara Geothermal Field Drilling, New Zealand

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Keywords: *well targeting, conceptual model, borehole image, structural permeability, Tauhara Geothermal Field, New Zealand.*

Assessing fracture characteristics is key to robust assessment of the contribution of structural permeability to a well's capacity for production or injection. Contact Energy acquired eleven borehole images at the Tauhara Geothermal Field, New Zealand, during the 2011, 2019 and 2021-2022 drilling campaigns. Here, we present some key observations from borehole imaging at Tauhara. The borehole imaging technology adopted in the 2021-2022 Tauhara drilling program was the Acoustic Borehole Imager (ABI43) from ALT provided through HADES and MB Century in New Zealand. The ABI43 imaging sensor is rated to 170°C and the orientation sensor to 125°C. The ABI43 tool was run down into formation temperatures in the range of 200-300°C, with well quenching keeping temperatures generally <125°C. Borehole images provided measurements of: 1) fracture appearance, density, orientation, and apparent thickness, and 2) in-situ stress orientations. Borehole image interpretations were then combined with geological interpretation of drill cuttings and permeable (feed) zones delineated using downhole measurements of pressure, temperature and spinner velocity (PTS). The combined datasets were interpreted to evaluate the nature of permeability and characterise the fracture network including potential fault intersections in the boreholes. The data also aided interpreting hydrothermally altered lithology types and unit boundaries.

Reservoir-scale faults were interpreted from the images and major feed zones were often found associated with these reservoir-scale faults, or with fracture clusters. Minor feed zones were usually associated with fracture clusters or fractures spread out over a larger interval. In some minor feed zones, lack of fractures suggests that fluid flow is not clearly controlled by local fractures. Integration of borehole images with geological and reservoir measurements

revealed that permeability is heavily controlled by fractures at the new production and injection areas of Tauhara. This observation had implications for well targeting strategies during the drilling campaign and the geothermal system conceptual model.

Session 1.3

51 | Supercritical Well Performance Simulation using GFlow Wellbore Simulator: A Case Study of Ultra-hot IDDP Wells in Iceland

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Keywords: *Wellbore Modelling, Supercritical Geothermal, Wellbore Simulator, GFlow, IDDP*

Wellbore modelling was undertaken to forecast production output of wells with feeds accessing supercritical fluids and to characterize the fluid flow and energy at the wellhead. This paper exhibits the use of the GFlow wellbore simulator developed by GNS Science and GERD to demonstrate its supercritical capability, handling high temperature and pressure fluid, for data calibration and well output estimation.

Data from IDDP wells drilled in Iceland were used to conduct wellbore calibration and output forecasting. Well flow testing data from IDDP-1 undertaken between 2010 and 2012, and well IDDP-2 injection test carried out in 2017 were investigated to determine the productivity and potential well output at the given reservoir conditions. The resulting flow conditions at the wellhead are then presented and analysed.

Session 7.2

53 | Reversing Carbon Emissions in the Geothermal Energy Industry Project: A Geoscience Perspective

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Keywords: *NCG reinjection, CO_2 trapping, geothermal reservoirs, fluid-rock interaction, geochemical analysis*

This research aims to help reduce Green House Gas (GHG) emissions by creating processes that will enable trapping gases, especially CO_2, in solid form while boosting the fluid production from geothermal resources. This will require characterising the unique geochemical, geological, petrophysical, and fluid dynamic properties to investigate potential mechanisms for trapping GHGs, to allow negative-emission energy generation.

CO_2 entrapment is favoured when there are significant quantities of available cations for chemical and mineralogical reactions to take place. We will build a pressure chamber to conduct laboratory experiments on typical Taupo Volcanic Zone geothermal host rocks placed inside the chamber. The novel part of this programme involves an approach based on injecting chemical agents into the pressure chamber to increase the quantity of available cations, which will encourage permanent entrapment of GHG.

The availability of reactive surface areas is also an important control of chemical and mineralogical reactions. Rock characteristics, such as textures, voids, crystal size, and shape, all play a role in enhancing or inhibiting reactions. We will assess the suitability of various TVZ host rocks for GHG entrapment. The programme involves an innovative multi-step process designed to document the elemental composition, textural characteristics, and mineralogy of rocks pre-, during, and post-pressure chamber conditions. Laboratory analyses will include X-Ray Diffraction, Scanning Electron Microscopy, Energy Dispersive Spectroscopy, Computerised Tomography, and chamber fluid analyses. This will enable the most suitable TVZ Formations to be targeted for our field trials and determine the optimal chemical agents required for injection that will favour permanent GHG entrapment. The programme is further supported by modelling the predictive behaviour of chemical reactions based on our laboratory results and field trials. As our programme advances during field trials, we plan to monitor the GHG storage capability of various TVZ rock formations.

Session 3.3

55 | Seismic reflection data acquisition in the Taupō Volcanic Zone: Reprocessing of Broadlands-Ohaaki 1984 seismic data.

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Keywords: *Geophysics, Seismic reflection, Ohaaki,*

Reflection seismic data is used to provide a high-resolution image of the earth's crust by recording the response of elastic waves reflected by subsurface structure. It is used widely in the oil and gas industry but rarely used in geothermal areas. The Broadlands-Ohaaki seismic survey, acquired in 1984 (Henrys and Hochstein, 1990), is one of only a few reflection seismic surveys to have been acquired in the Taupō Volcanic Zone (TVZ) and where field data are still available. The OHAAKI-84 data used dynamite sources detonated in shallow holes and recorded on a rolling 48 receiver array spaced 20 m apart.

In 2023 we reprocessed seismic data from the OHAAKI-84 survey using modern imaging technologies to determine if the original processing could be improved upon and to help inform any future seismic reflection surveys in the TVZ for geothermal energy exploration or understanding of exiting fields. We recreated the shot and receiver geometry and applied a contemporary processing sequence that has improved on the continuity of the reflectors and provided more detailed P-wave velocity information.

The near-surface volcanic deposits in the TVZ provide a challenging environment for seismic acquisition but our reprocessing has highlighted the value of seismic reflection and we make a number of recommendations for new seismic reflection acquisition including using a modern vibroseis source with longer source to receiver offsets.

Session 2.3

56 | Laboratory HCl acid condensate testing of geothermal casing steels

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Keywords: *HCl Gas, Dew Point Corrosion, Geothermal, K55, Casing Steels, Linear Polarisation Resistance, Impedance Spectroscopy.*

The geothermal steam discharged from superheated geothermal wells can contain a range of corrosive gases: mainly hydrogen sulphide (H2S), carbon dioxide (CO_2) and ammonia. Occasionally hydrogen chloride (HCl) and boric acid may also be present. At the temperatures encountered in geothermal wells the superheated "dry" steam is rarely corrosive. However, dew point corrosion can be significant even with relatively low concentrations of HCl gas leading to corrosion

of steam pipelines, wellheads and at times well casings. HCl contaminated dry steam reaching the turbine can lead to corrosion as well as Stress Corrosion Cracking of the turbine components. This paper is aimed to the evaluation of the corrosion behavior of K55 and new casing steels in an acid steam condensate derived from high temperature HCl gas contaminated steam condensing at atmospheric pressure and a temperature of the order of 97 °C. A Steam Condensate Test rig was developed for testing of the comparative resistance of the casing steels. This work used a miniature probe design. A three electrode system was used with Electrochemical Impedance Spectroscopy (EIS) to compare the performance of K55 alloy and the new casing steels, 17Cr and Cr13U.

This paper will summarise the results from this study (a NEDO commissioned project) including measured corrosion rates and pH limits identified for examined casing steels in HCl contaminated steam condensate.

Session 5.2

57 | Insight into the Geothermal Structure in Tatun Volcano Group, Taiwan

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Keywords: *Geothermal Structure, Tatun Volcanic Group, 3D Inversion, Database, Conceptual Model.*

The Tatun Volcano Group (TVG) which is known as the highest temperature geothermal field in Taiwan. There are four geothermal potential areas named Beitou, Matsao, Shi-Huang-Ping and Chinshan. The government conducted exploration activities in the late 1960s focused on these areas. The highest drilling temperature encountered, nearly 290 º at the Matsao area at a depth of less than 2 km, implies there is a commercial temperature for power generation. However, the geothermal development has been suspended due to a high acid content and highly corrosive fluids. Last decade, some review and exploration activities raised the possibility of finding neutral brine and developing geothermal generation at TVG. This study integrates previous research studies and newly completed geological, geophysical and geochemical surveys to establish a geothermal conceptual model of the TVG. The deep hydrothermal fluid along the extensional fracture is one of the primary heat sources in TVG that meets the criteria of high temperature and neutral geothermal brine based on E208 drilling data. Based on the MT 3D resistivity model, a total of 5 low resistivity areas that could be the possible clay cap are proposed. The low-resistivity is located at the bottom of the volcanic rock body, and the resistivity, as low as 10 ohm-m, is consistent with the mineral character of smectite, illite, and chlorite. All the data mentioned above was transformed into digital form and combined with the TWD97 projection system. Finally, a digital 3D geothermal conceptual model based on Leapfrog geothermal was established.

There are some areas with high temperature and low acid fluid in the TVG area, from the perspective of the geochemistry view. However, the new proposed potential areas need further confirmation by the drilling of an exploration well.

Applying developed volcanic activity observation techniques to monitor environmental changes while conducting geothermal surveys can ensure the safety of future geothermal development efforts.

Poster Session

58 | Quantifying Geothermal Resource Potential and Uncertainty Analysis using a Natural State Model of Kotamobagu Geothermal Field in North Sulawesi, Indonesia

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Keywords: *Geothermal resource potential, uncertainty quantification, 3D natural state model, geothermal reservoir modelling*

Kotamobagu Geothermal field, located in North Sulawesi, Indonesia is expected to hold significant potential as a geothermal energy

resource. This study presents a calculation of its resource potential using an uncertainty analysis and a natural state model. Through the utilization of publicly available reports and data, a comprehensive 3D geological model of the field has been constructed. This process was followed by setting up a numerical model that was used to simulate the steady state of the geothermal system. Many sample models were run and conditioned against the limited data and this process was used to determine the reservoir potential.

The construction of the 3D geological model involved the integration of geology, geophysics, geochemical and spatial data using LEAPFROG Geothermal. Based on this, a numerical model was developed that is compatible with both AUTOUGH2 and Waiwera. The model was calibrated by adjusting the permeability and upflow to simulate the natural state of the geothermal reservoir. Next, 1000 samples of possible alternative models were generated based on the distribution of upflow and the rock permeabilities and simulated using high-performance computing facility. These samples were then filtered using the estimated temperature below the clay cap. Finally, the filtered samples were used to estimate the resource potential by applying a production algorithm.

The results show a range of reservoir temperature from 200-250°C with applying 109 kg/s upflow. The model estimates that the upflow of heat arises underneath Mt. Ambang and along the northeast-southwest trending faults. Additionally, the same family of faults at the east side of the volcano acts as a barrier preventing the fluid from seeping out. The filtering process resulted in 213 sample models which were used in the Approximate Bayesian Computation (ABC) to show that the P90, P50, and P10 estimates of power outputs are 70 MWe, 160 MWe, and 270 MWe, respectively, for the 25 years of simulated production.

Session 8.2

59 | Regional geothermal exploration and potential assessment in the Taitung Hongye area, Eastern Taiwan

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Keywords: *3D geothermal conceptual model, magnetotellurics, geochemistry, discrete fracture network analysis, geothermal potential assessment.*

This study compiles various geothermal exploration reports and academic papers since the 1980s, and conducts supplementary geological, geochemical, and magnetotelluric surveys and geothermal potential assessment. The three-dimensional geothermal conceptual model of the Taitung Hongye area shows that under plate compression, the rock uplift resulting in a high geothermal gradient may act as the heat source of the geothermal system. A deep circulation of meteoric water accompanied by some deep crustal hot water forms a bicarbonate-type hot water with temperatures possibly exceeding 150°C. It migrates upward from the fracture zones and after being blocked by a relatively intact rock mass in the shallow depth, the hot water then migrates laterally along the fracture zone. Some of it infiltrates through river channels to form hot springs.

The geothermal resource is the phenomenon of high-temperature and high-salinity hot water stored in fractured rock masses, which often shows that the resistivity is more than a hundred times lower than that of the intact rocks. In the three-dimensional resistivity model, a low-resistivity structures resembling mushroom shapes is recognized, with the hot water up-flow zone as the stem and the out-flow zone as the cap. The up-flow zone has the highest temperature and is ideal for the geothermal production wells. Based on these characteristics, this study has identified six potential geothermal structures. An 800-meter deep geological borehole commissioned by the Central Geological Survey was completed in the out-flow zone. The significant hot water feed zones are between 300-400 meters deep, with a maximum measured temperature of 142°C, which corresponds well to the interpreted depth range of the low-resistivity geothermal structure obtained from the magnetotelluric survey. A high correlation between the low-resistivity structure and the geothermal structure is confirmed. Preliminary estimation of the potential generating capacity using the Monte Carlo stored heat method ranges from 51 to 181 MWe.

Session 8.3

60 | Ensemble Methods for Geothermal Model Calibration

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Keywords: *reservoir modelling, model calibration, uncertainty quantification, ensemble methods.*

A typical geothermal model requires significant computational resources to simulate and can contain hundreds of unknown parameters. The process of estimating these parameters, often referred to as model calibration, is a difficult task; traditional methods such as Markov chain Monte Carlo generally require running a prohibitively large number of simulations to obtain accurate results. Ensemble methods form an alternative class of algorithms for approximating the solution to the calibration problem and have the potential to provide accurate results using considerably fewer simulations. Ensemble methods have been used successfully to calibrate large, complex models in areas including petroleum engineering, oceanography, and weather forecasting. There are, however, few examples of applications of these methods to geothermal reservoir modelling. In addition, the wide variety of ensemble methods that have been developed mean there is a need for numerical studies that examine their respective benefits and drawbacks when applied to specific problems. To support the effective use of ensemble methods for geothermal reservoir model calibration, we review two widely used ensemble methods and apply them to the problem of calibrating a synthetic reservoir model. We demonstrate that both methods are capable of generating accurate reconstructions of the model parameters, with appropriate characterisation of uncertainty.

Session 5.3

61 | Groundwater Modelling Assessment of Shallow and Deep Geothermal Aquifer Interactions Around Otumuheke Stream, Wairākei-Tauhara Geothermal Field

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Keywords: *Groundwater, Geothermal Energy, Tauhara Geothermal Field, Otumuheke Stream, Taupō Hot Springs.*

Williamson Water & Land Advisory has collaborated with Contact Energy in a hydrogeological modelling study of the shallow Tauhara Geothermal Field, focused on the Otumuheke Stream area. The stream, fed by geothermally heated groundwater and flowing into the Waikato awa approximately 1 km upstream of Huka Falls, holds significance to local Iwi and is a popular recreation site.

Flow and temperature changes have occurred in the Otumuheke stream since the 1960s in response to reservoir pressure trends. Since 2013, reservoir pressure near Otumuheke spring has increased due to nearby reinjection. Contemporaneously, ground subsidence has declined as has flow from the uppermost spring in the valley. The decline in stream flow has coincided with declining groundwater levels within the shallow aquifer that resides within the Taupō Pumice and Oruanui Formations.

Groundwater level declines are less evident with increasing distance from geothermal features and subsidence anomalies, indicating that declining groundwater levels and streamflow are not due to climate alone. The hypothesis was that the reinjected geothermal fluid partially submerged or quenched the steam zone at the base of the shallow aquifer, reducing the pressure buffer separating shallow groundwater from the deep geothermal reservoir and allowing increased downward vertical leakage.

For this study, a numerical modelling approach was applied to improve understanding of the mechanisms causing the observed changes in the shallow hydrogeological environment. A groundwater model was calibrated with groundwater monitoring data and Otumuheke Stream flows records. Results show that the model is suitable for simulating observed groundwater levels and streamflow, and thereby replicating the interaction between the shallow aquifer and geothermal reservoir.

Results indicate that vertical leakage losses currently range from approximately 15,000 to 24,000 m3/day (175 to 277 L/s), which is substantial relative to the median flow of the Otumuheke Stream (less than 100 L/s since 2014), though a small effect relative to the 130 Mm3 estimated for shallow aquifer water storage within the Otumuheke Catchment. The model is suitable for further investigating the shallow aquifer effects of a range of environmental variables and future power plant management options.

Session 4.3

62 | Using Temperature Methods to Improve Geyser Monitoring at Rotorua, New Zealand

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Keywords: *geyser, temperature, surface features, geothermal monitoring.*

Geothermal surface features in the Rotorua Geothermal System (RGS) hold significant cultural, economic, and environmental value to Bay of Plenty Regional Council (BOPRC) and local iwi groups. Activity at many of these surface features have been recovering since the bore closure program was instigated in 1986. The recovery has been variable however, and appropriate data to monitor these long-term trends has not always been available. BOPRC therefore partnered with Te Puia, New Zealand Māori Arts and Crafts Institute, and GNS Science to trial a temperature sensor based monitoring system at Geyser Flat, Te Puia in late 2022.

Five thermocouple temperature sensors were deployed around Pohutu and Te Tohu (Prince of Wales Feathers) Geysers, and one at the outlet of Te Horu overflow pool from October 2022 to July 2023. Observational datasets of eruptive activity at the site were also acquired and used to help develop an algorithm to translate the recorded temperature data into a record of eruptive activity.

A clear pattern was immediately evident in the data. Eruptive activity typically began at the Te Tohu Geyser vent, with eruptions at Pohutu following around 15-20 minutes later. Both geysers then continued erupting together for another 30-60 minutes, before ceasing activity simultaneously. This pattern is consistent with historic observations (e.g. Lloyd, 1975) where activity at Te Tohu precedes Pohutu.

While the data could be noisy, the algorithm appeared to work well throughout the trial period, with the flagged start and end of eruptions typically within 6 and 3 minutes of the observed eruption start and end, respectively. Recorded eruptive activity is very consistent, with 17 eruptions occurring each day on average, and more than 50% of each day spent in an eruptive state. Eruptions lasted an average of 37 and 54 minutes at Pohutu and Te Tohu respectively, notably higher than any previously reported values.

Session 4.3

63 | Assessing the potential of low to intermediate temperature geothermal resources for direct use.

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Keywords: *wellbore simulation, geothermal resources, low-to-medium enthalpy reservoirs*

Electricity generation by use of direct condensing conventional turbines or by organic Rankine binary systems remain the most viable options for exploiting geothermal resources. Wells used for the two power systems typically have adequate and consistent steam

flow rates at relatively high pressure. However, with the development of geothermal fields, some of the many drilled wells may not meet the required steam and heat flow rates at the required well head pressures. Such marginal wells will probably have intercepted low-to-intermediate temperature formations or poor permeability zones. These wells are typically used for either re-injection of waste brine/ blowdown or for monitoring temporal changes in reservoir conditions. With increased emphasis on green forms of energy, marginal wells have proved useful as source of heat, and their exploitation for direct use purposes. These uses are predominantly at local boiling conditions or below. However up-take of direct use at higher temperature above local boiling, and at large scale has been slow. Consequently, a need to design and develop direct use methodologies usable to applications that use intermediate temperature in the range, 1000C to 1400C. Temperatures in this range may be more usable for industrial applications leading to better utilization of geothermal resources. To justify the accompanying investment in the heat conveyance system from the source to the utilities, it is important to ensure a priori that the resources tapped by the wells can sustain production and usage of heat for long enough periods and at competitive costs compared to traditional sources of fuel. This paper looks at effect of the wellbore design on developing and exploitation of a geothermal resource at intermediate temperature for direct use. In addition, production sustenance through re-injection will need to be done differently from regular reservoirs. This paper addresses these aspects and proposes methods of assessing the energy potential of these reservoirs.

Session 6.2

64 | Regional geothermal exploration in Dongpu Geothermal Field of Central Taiwan

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***Keywords:** 3He/4He ratios, geothermal exploration, fluid geochemistry, Dongpu Geothermal Field*

Dongpu geothermal potential field is located in the shale belt of the Hsuehshan Range in Nantou County, central Taiwan. The key exploration area will cover an area of approximately 53 square kilometers, including the Dongpu Hot Spring and the Lele Hot Spring. The major interest of geothermal exploration is to understand the location of heat source and geological information. Geothermal fluids included thermal water and gas, which emitted from geothermal reservoir through faults and/or fissures. In general, geothermal fluids formed hot springs and fumarolic gas (or bubbling gas) at the Earth's surface, and in which the information of geothermal reservoir was preserved. Therefore, based on chemical and isotopic composition of fluids can provide the information of the origin and evaluation. In this study, we conducted fluid geochemical survey at geothermal fluids outcrops in the region of Dongpu Hot Spring and the Lele Hot Spring. We measured the fluid composition and also helium isotope composition of the sampled hot spring water and bubbling gas. Together with previous studies, we discussed the geochemical characterization, which may provide further insights on geothermal resource assessment.

Poster Session

65 | Geologic Controls on Geothermal System Location and Type

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***Keywords:** global review, structural controls, volcanic controls, system localization, The Great Basin, Ireland Rift System, Taupō Rift Zone, East African Rift System,*

We evaluate five productive geothermal regions to determine the district-scale geologic controls on the distribution of conventional geothermal resources that are suitable for development. The regions included are the East African Rift System, the Great Sumatra Fault in Indonesia, the Iceland Rift System, the Taupō Volcanic Zone in New Zealand, and the Great Basin in the USA.

This study expands our previous work that focused on the structural context by evaluating the distribution of volcanism. There is an unequivocal global- and district-scale relationship to volcanism that is reflected in both the type of geothermal system and their spatial distribution. However, our case studies highlight that the presence of recent volcanism does not guarantee localisation of a developable resource. A structural and tectonic setting that enables high-flux fluid flow is also required.

We propose a classification system for geothermal resources that expands the common categories of volcanic (arc and rift-type) and deep circulation (magmatic and amagmatic) by including the temporal and spatial distance to a volcanic heat source. The distance to heat source has implications for the temporal stability of the geothermal anomaly, as evidenced by the degree of mineral disequilibrium. This classification system improves analogue selection, provides a framework for comparative studies, and highlights the diverse range of geothermal resources that can be developed.

Session 1.3

66 | Geologic Controls on Permeability Revealed by Borehole Imaging: Case Studies from Sumatra, Indonesia and the Taupō Volcanic Zone, New Zealand

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Keywords: *Microresistivity borehole image, acoustic borehole image, feedzone, permeability*

We use borehole images, which provide a continuous, high-resolution record of the borehole wall, to evaluate wellbore-scale geologic controls on permeability. Typically, borehole imaging studies include one or more wells from a single reservoir. Ours is unique for its cross-comparative nature, with seven case study wells from four volcanic-hosted geothermal reservoirs, of which two are in Sumatra, Indonesia, and two are in the Taupō Volcanic Zone, New Zealand.

A quantitative well capacity (injectivity index) is included for each case study, which is also novel for a borehole image study. This enabled a key insight: wells with the largest capacity have fracture frequencies that are two to three times greater than lower capacity wells. As well as the influence of fracture frequency, our results reveal the impact of host rock properties and fracture arrangement, hydrothermal alteration, and stress rotation. We introduce a novel category of drilling induced damage that correlates with the distribution of feedzones.

Session 1.3

67 | Low-Temperature geothermal – a decarbonising solution for covered crop growers in New Zealand?

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Keywords: *Low-Temperature geothermal, greenhousing, horticulture, decarbonisation.*

Low-temperature geothermal energy can provide a low-carbon, energy efficient solution for low-temperature heat users in New Zealand. Many places in the world are already utilising their ambient and low-temperature geothermal resources for space heat and cooling, including residential and commercial buildings, district

heating systems, retirement villages, schools, swimming pools, and greenhouses.

The Netherlands is a standout example of converting their greenhouses from using natural gas to utilising their natural deep 80°C water resources (located at ~2-3km depths). The Netherland has set a target of 43% of greenhouse heating to be sources by geothermal by 2030, removing more that 30PJ of natural gas combustion on an annual basis.

Many covered crop growers in New Zealand, are seeking means to decarbonise their operations and are investigating the potential of utilising geothermal for their heating needs. GNS Science is working with New Zealand's horticulture industry to investigate the potential of low-medium temperature geothermal resources to meet heating demands for covered crop growers. Initial work will focus on understanding the potential of ambient groundwater systems. These cool groundwater temperatures remain stable throughout the year, providing an ideal heat source for ground-source heat pump systems to convert to an optimum space heating temperature to distribute through the soil and air within the glasshouse. Other sources of stable low-grade temperatures include the natural thermal gradient of the shallow sediments and rocks, and surface water (including seawater, lakes and rivers).

This paper discusses the opportunities of using geothermal resources in New Zealand, for decarbonizing the horticulture industry.

Session 6.2

69 | Collaborative and Holistic Applications Drive Record Drilling Performance in Mak-Ban Geothermal Field, 2020-2022

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Keywords: *Geothermal Drilling, Mak-Ban Geothermal Field, PGPC*

Philippines pioneered the geothermal development in Southeast Asia and consistently remained as one of the largest producers in the world since the birth of the industry in 1971. Philippine Geothermal Production Company, Inc. (PGPC) operates both Tiwi and Mak-Ban geothermal fields. With over 300 wells drilled since its exploration days, PGPC maintained its significant load share in the Luzon grid up to present.

In fields such as Mak-Ban, wells as deep as 3,000m. are drilled in order to tap this renewable resource. From 2020-2022, PGPC executed an 11-well drilling campaign comprising of 9 deep production wells and 2 multilateral injection wells, with all wells now in the system. Seven out of ten deepest wells (>3,000m) in Mak-Ban were drilled in this campaign. This campaign resulted to several records; fastest well drilled 3,611m in 23.9 days, fastest daily Rate of Penetration (ROP) of 523m per day, and lowest Non-Productive Time (NPT) of 3% despite of new well design challenges.

This paper aims to share the journey of PGPC Drilling Team in improving drilling performance by adapting a collaborative and holistic approach from well planning, operational alignment, design improvement and technology selection. Drilling performance metrics from recently concluded 9-well Mak-Ban drilling campaign and the previous 2002-2004 drilling campaign were compared to show the success and improvement. These metrics are: (1) Days drilled vs Actual Depth reached, (2) Rate of Penetration, (3) Target depth reached vs Planned depth, and lastly, (4) Drilling Non-productive time.

Session 4.2

70 | Geothermal Temperature and Pressure Transient Analyses of Well CHI-8A, El Salvador During Pressure Falloff

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Keywords: *Geothermal, Temperature transient analysis, Pressure transient analysis, Temperature derivative, Well testing.*

Temperature transient analysis (TTA) examines the transient temperature logs of a well during completion testing. Most of the studies encompass only oil and gas reservoirs. The capabilities of geothermal temperature transient analysis have not been thoroughly studied. This paper examines the geothermal well CHI-8A, El Salvador, during pressure falloff. Two approaches were considered; analysis of pressure response (PTA); examination of temperature and pressure responses (TTA-PTA). By matching temperature and pressure, our study shows that geothermal TTA improves the resolution of geothermal PTA. Geothermal TTA complements geothermal PTA and provides further insight.

Session 4.2

71 | Development module of a geothermal reservoir in sedimentary rocks in Taiwan

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Keywords: *Geothermal, Sedimentary rock, Horizontal well, Module, Sensitivity Analysis, Capacity.*

The purpose of this study is to build up a geothermal development module for the geothermal reservoir in sedimentary rocks in Taiwan. The sedimentary geothermal reservoir we targeted is a saline aquifer with a formation temperature above 147° in Taiwan's sedimentary basins. The geothermal gradient of the sedimentary basin in western Taiwan is above 3.5°/100m. This makes the formation temperature higher than 130° at a depth of 3500 meters.

The reservoir simulation method is used in this study. We build up a natural-state geothermal reservoir model and then give a specific well design by considering the well replacement, well completion, production and injection rates, and the total simulation time. The basic design of the geothermal development module is using two horizontal production wells and one horizontal injection well with a horizontal section length longer than 1000 meters. The injection well is placed in the middle between them. The numerical calculation is conducted by the simulator STARS developed by CMG.

The efficiency of the geothermal development module is analyzed based on the running capacity calculation. The spatial distribution of the reservoir pressure, fluid flow, and temperature are analyzed. We use the pressure front to define the effective volume of the geothermal development module with specific well replacement and well completion designs. The injected water front is used to analyze the recirculation efficiency of the geothermal fluid. The cold front is used to define the optimal distance between the injection and production wells within an operation time period.

Session 8.2

72 | Impact of Project Variables on Tariffs Required for Economic Development of Geothermal Projects

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Keywords: *Geothermal Tariffs, Cost Estimates, Financial Modelling.*

The author participated in 2015 in a World Bank/ ADB funded study of Indonesia's geothermal sector, aimed at advising on revised tariff setting procedures. The study identified a lack within the government sector of a definitive financial model to cater for the very wide variation in parameters that could potentially affect the tariff required for economic development. EBTKE subsequently requested assistance in the preparation of a suitable model to support development of a variable tariff system. This model was prepared by the author and colleagues, with initial inputs from Arup of UK, but subsequently by the NZ team alone. The model has been recognized as realistic by EBTKE, Ministry of Finance, INAGA and the World Bank, although the corresponding tariff system was not eventually adopted by the government, who preferred a fixed tariff system based on PLN's avoided generation costs. The model has subsequently been further developed and used to examine the impacts of technical,

subsidy and other potential regulatory changes.

The developers have now used the model to examine the impact on required tariffs of a number of project parameters, including resource quality, project size in terms of total MW capacity and generating unit configuration, costs of drilling to various depths, the use of slim hole exploration techniques, who is carrying exploration risk, development by SOEs or private sector etc. While the specific model was developed for Indonesia, the principles should be valid for all areas provided suitable input variables and financial factors are used. Although the actual derived tariffs will require the underlying cost database to be revised to reflect post-COVID costs, the ratio of the various required tariffs, as presented in this paper, is expected to remain relevant and will provide guidance to developers and regulators of the areas which need the most consideration in planning development.

Session 7.3

73 | Fast-tracking numerical modelling projects using Volsung and Leapfrog Energy

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Keywords: *modelling, reservoir model, reservoir simulation, geological model, conceptual model, Volsung, Leapfrog.*

The key input to a geothermal reservoir numerical model is a robust conceptual model, which is a concise representation of the primary structures and processes that determine a reservoir's characteristics and behaviours. These key elements are often modelled, updated and stored in Leapfrog Energy 3D models and presented graphically on cross sections or 3D scenes.

In this paper we present a workflow for quickly transferring model outputs from Leapfrog Energy to the Volsung flow simulation software to fast-track the development of the numerical reservoir model and ensure that it is based closely on sound geoscience. This workflow is based on using volumes and faults from the Leapfrog Energy model to define numerical model regions and adding qualitative conceptual model elements using geo-referenced cross section image files. Well track information can also be exported from Leapfrog Energy to Volsung. All data are represented and transferred independent of a particular explicit grid structure. Outputs from the numerical model simulation, such as the time-dependent spatial distribution of pressure and temperature, can be exported from Volsung and imported back into Leapfrog Energy to be visualized in conjunction with other multi-disciplinary geoscience data.

Any revision to the geological or conceptual model can easily be transferred to Volsung to update the associated reservoir numerical model, leading to a robust system for updating and maintaining models over the duration of a geothermal resource development.

This workflow is a practical and efficient methodology for fast-tracking the development of a numerical model. It reduces numerical model development time and enables teams of geoscientists to collaborate to produce better numerical models, leading to higher confidence in numerical model predictions and improved geothermal reservoir management.

Session 1.2

74 | The geothermal reservoir characteristics of metamorphic terrain, an initiative of geological and geophysical survey of Qingshui, Tuchang, and Renze, NE Taiwan

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Keywords: Metamorphic terrain, Ilan geothermal system, Taiwan

Tectonic investigation of northeast Taiwan using seismicity, structural mapping, and geochemistry supports that the rocks and fluids have experienced post-collisional extension. Active rifting and lateral spreading can be observed in this metamorphic terrain (e.g. slates, phyllites, metasandstones, and quartzites mapped with normal faults). GPS and palaeomagnetic observations also show about 45-50° clockwise rotation along the Lanyan River. Since the 1970s, the Ilan area has been the largest exploration and development area for geothermal exploitation in Taiwan, such as Qingshui (an experimental power plant from 1981, transferred to commercial in 2021), Tuchang, and Renze, where ~50 exploration wells have been drilled.

A synthesis of available data of magnetotellurics (MT), seismic profiles, drilling, and field measurements has resulted in interpretative geological cross sections along the Lanyang River at different depths, and here we document: (1) the geothermal pathway is confined by faults and secondary fractures near the surface. Mineral veins strike 320 and indicate the late-stage of extension of about 050; (2)

normal faults and reactive strike-slip faults may play an important role as the upflow zones at depth of ~2 km. (3) MT measurements suggest two electro-stratigraphic packages within 3 km, high resistivity caprock sitting on top of the geothermal reservoir; low resistivity hydrothermal fluids were recognized from high porosity sandstones and fault zones. (4) seismic tomography also observed two different heat sources from 10-15 km. (5) two geothermal systems are suggested at different depths: one with a deep upflow at ~2 km, entering a fractured zone at <200°C and generating ~5 MW of electricity; the second in rocks at 4-5 km close to the brittle-ductile transition where deep-seated fluids are probably produced, and present-day temperatures are in the range of 400-500°C.

Poster Session

76 | Reducing Casing Heatup Rates in Geothermal Production Wells by using Coiled Tubing Gas Lift

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***Keywords:** Vertical Discharge, Casing, Coiled Tubing.*

After drilling completion, geothermal production wells are allowed to heat up for some time, then discharge tested to remove drilling debris and determine well output characteristics. Vertical discharge is a practical and inexpensive method of conducting the initial flow test. However, in some cases this method can result in rapid, uncontrolled heating of the casing with increased potential for casing damage or failure.

While it is preferable to heat the casing slowly, this is not always possible and wells may be opened from zero to 100% flow in a few minutes with associated casing temperature changes in the order of 200°C. Some wells have static temperature conditions with up to 800 meters of <150°C above hot 300°C reservoir. The cold column of water can be difficult to heat to saturation temperature required for boiling and initiation of self discharge. To reduce the heating rate and have better control of the flow it is now common practice to initiate well discharge using coiled tubing with air or nitrogen gas lift.

Recently Contact Energy have used Western Energy's coiled tubing unit to initiate flow in several otherwise difficult-to-start wells. During two of these jobs a temperature-pressure gauge was attached to the bottom of the coiled tubing string to record actual downhole conditions while initiating flow.

This paper compares heatup rate between "traditional" uncontrolled well discharge and that measured during a coiled tubing airlift.

Session 4.2

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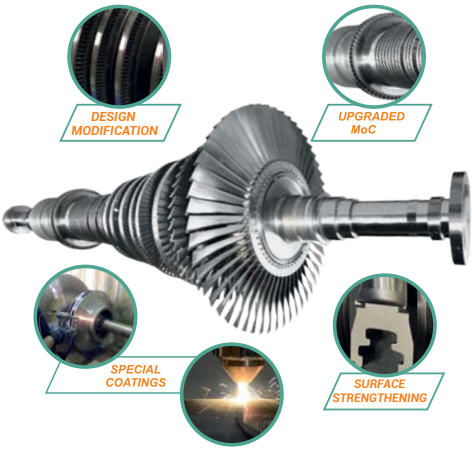

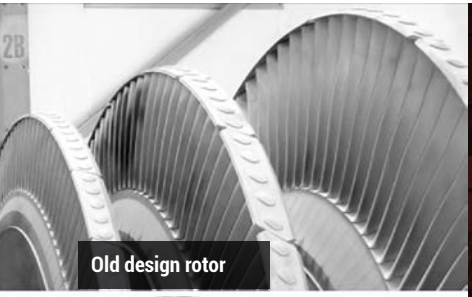

Old design rotor

New design rotor

CASE STUDY

Revitalize 16MW Turbine Geothermal Sector

Client Overview

Our client, a prominent player in the geothermal energy sector was running a turbine of Americas origin, was confronted with persistent challenges related to erosion and corrosion, and depleting life of rotor material significantly hampering the performance of their 16MW geothermal turbine.

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78 | The influence of boundary conditions in a reservoir model on the accuracy of the simulation results

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Keywords: *Boundary condition, cell volume, volume factor, upflow.*

A geothermal system could include multiple geothermal fields, and it is common to find later that such separate fields are associated. Therefore, when developing a reservoir model, it is a prudent strategy to include the entire geothermal system to leave the potential for further modifications in the future. However, acquiring the necessary data for all the fields or constructing the whole model from the beginning can be difficult.

In this research, the Domes field, a part of the Olkaria geothermal system in Kenya, is extracted from the entire model and used for detailed construction. This paper will introduce how the unsymmetrical block sizes on the borders of the model influence the fluid flow in the reservoir. It also discusses techniques for making modifications along with calibration strategies considering fluid inflow from neighboring fields.

Session 5.3

79 | Geothermal characteristics of the Paolai Hot Spring area, Taiwan

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Keywords: *Paolai, geothermal exploration, hydrological circulation, Taiwan*

In order to understand the geothermal potential of Paolai Hot Spring area, we conducted extensive geological surveys, collected seismic data, and analyzed geochemistry of hot springs in this region. Two hydrological circulation models are assessed here that are based on previous campaigns and studies: 1) the single fault (the reverse Chaozhou Fault) model and 2) a dual fault model considering the reverse Meilunshan Fault as an additional regional rupture zone. In the single fault model, the Chaozhou Fault serves as the controlling boundary with groundwater replenished from the eastern mountainous area and circulating downward into the subsurface and heated. The deeply circulated hot fluid would be directed upward along the highly ruptured, permeable zone within the fault system. In the dual fault model, the Chaozhou and Meilunshan Faults compartmentalize the hydrological circulation into two systems. To the east of the Meilunshan Fault, groundwater is replenished from the mountainous area, circulating downward, heated, and migrates to the surface along the open fissures on the hanging wall of the Meilunshan Fault to form hot springs. The western compartment would be controlled by the Chaozhou Fault. Our field results concur

the occurrence of the Meilunshan Fault while the seismic and geochemical data also suggest distinct characteristics across the fault. To better evaluate the geothermal potential in Paolai area, further investigation towards the complex structures in this region should be thoroughly considered.

Poster Session

80 | Application of the United Nations Framework Classification for Geothermal Projects in the Waikato Region

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Keywords: *geothermal, UNFC, Waikato Region*

This paper presents an energy assessment and classification of all geothermal projects in the Waikato Region, New Zealand, using the new Geothermal Specifications for the United Nations Framework Classification (United Nations, 2020). The assessment includes major potential projects and existing projects that generate electricity and heat within the region but excluding Protected Geothermal Systems and small Geothermal Systems. The work has been sponsored by the Waikato Regional Council as part of their obligations to report on the geothermal energy resources available within the region.

To evaluate each project, a standard template has been developed and populated with publicly available data and data provided by project owners, capturing a simplified description of the Project and Energy Source and the key factors that are needed to assess classification on the E-axis, F-axis, and to assess energy production with uncertainty represented on the G-axis. Furthermore, the assessed projects are categorized according to their status within the UNFC framework.

This assessment/classification is probably the most comprehensive application to date of the UNFC system to any geothermal region and provides a robust view of the present and near-future geothermal energy potential of the region. The present status of projects includes some already in long-term operation, in active development, undergoing major re-development with new plants, direct heat use projects, and undeveloped opportunities with no known development plan. As such, this represents a good example of how UNFC can be applied to all stages of development. Observations and suggestions regarding further application of UNFC to geothermal are provided. The major geothermal developer/operators in the region have participated in the work and are assessing how they may be engaged or use UNFC in future

Session 7.3

81 | Analysis of Heat Recovery Time Predictions for Multiple Periods of Temporary Reinjection in Geothermal Well Production of Lumut Balai Field

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Keywords: *Re-injection wells, Thermal recovery rate, Geothermal reservoir, Hot reinjection, Reservoir management strategies.*

In Lumut Balai geothermal projects, where suitable re-injection wells are lacking, the temporary reinjection of hot fluids into high-temperature wells becomes necessary, albeit risky. Initially designated as production wells, three wells have been temporarily repurposed as reinjection wells due to the urgent requirements for the commissioning of the Power Plant Operation. Over a reinjection period of approximately four years, the focus of concern has arisen, especially as the current project is in the process of developing Power Plant Unit 2, in which these three wells will revert to being production wells. A significant concern in this scenario is the duration required for the wells to return to their natural state. Our research approach encompasses several key steps: Developing a two-dimensional conceptual model of the geothermal reservoir, Simulating the temperature distribution under natural operating conditions, Assessing the effects of cold reinjection during three distinct periods: three months, six months, and one year, Conducting a comprehensive evaluation of the results, with a specific focus on the evolution of the well's temperature profile, the rate of thermal recovery, and associated risks, This research endeavor is aimed at deepening our understanding of the challenges posed by temporary hot reinjection in geothermal projects. Ultimately, it seeks to inform the development of best practices and effective reservoir and risk management strategies for addressing similar challenges in the future.

Session 2.2

82 | A process model for geothermal power generation

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Keywords: *Geothermal, energy, gases, organic Rankine cycle, process model, wells, geothermal fluid.*

Geothermal power plants utilize the heat from geothermal reservoirs to generate electricity. Geothermal fluid has some non-condensable gases brought to the surface during electricity generation. These gases mainly consist of carbon dioxide. There is an impact of these gases present in the geothermal fluid on the production well productivity, the heat transfer efficiency of heat exchangers, etc.

Process models are considered powerful tools for understanding the working of geothermal power plants. The process models prepared are based on the specific components and given details of a geothermal system. The process model developed for this paper is a coupled wellbore and subsurface model of a geothermal power plant. Firstly, the wellbore model was developed using WELLFLOW, a wellbore simulator, and then the sub-surface model was developed using DWSIM, an open-source process modeling software. Both WELLFLOW and DWSIM can use Python scripting, which was utilized, and both models were coupled.

The paper demonstrates a coupled process model calculating the fluid flow from the production well and the output from the geothermal power plant. The wellbore model provides the flow rate from the wellbore based on the wellhead pressure. The composition of the geothermal fluid is obtained from the reservoir data. The process model shows that for a given wellhead pressure, we can estimate the flow rate from the wellbore and the pentane required for an Organic Rankine cycle. The process model then provides us with the output from the turbine and the desired temperature for the reinjection fluid.

Session 2.2

83 | A review of non-condensable gases (NCGs) reinjection within the geothermal industry and a comparison with other carbon capture and storage (CCS) technologies

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Keywords: *Non-condensable gas, Reinjection, Geothermal field, Carbon capture and storage*

Greenhouse gases (GHGs), including carbon dioxide (CO_2), are the primary drivers of global warming and climate change. To combat this urgent issue, there have been global efforts to reduce GHG emissions from energy production through initiatives like the Paris Agreement and national carbon taxes. In the geothermal, oil and gas, and coal bed methane (CBM) industries, various strategies have been explored to mitigate emissions. This report reviews the current status of Non-Condensable Gas (NCG) reinjection within the geothermal industry and compares the techniques used with other carbon capture and storage (CCS) methods.

The geothermal industry has shown promise in reducing GHG emissions by reinjecting NCGs. Pilot projects in multiple countries have successfully demonstrated NCG reinjection, primarily through basaltic mineralization and residual trapping. However, further research is needed to assess the potential of NCG reinjection in different geothermal reservoir geologies.

In the oil and gas, and Coal Bed Methane (CBM) industries, various CCS methods have been investigated. These include CO_2-enhanced oil recovery (CO_2-EOR), CO_2-enhanced gas recovery (CO_2-EGR), CO_2-enhanced coal bed methane (CO_2-ECBM), and CO_2 storage in saline aquifers and depleted oil and gas fields. CO_2-EOR has extensive project experience but is primarily an enhanced oil recovery technique rather than a climate change mitigation method. CO_2-ECBM faces challenges such as coal swelling and decreased permeability. CO2-EGR is still in development and has limited project experience. Saline aquifers and depleted oil and gas fields are seen as long-term storage solutions, but uncertainties remain regarding modelling and cap rock integrity, and there is also a current lack of financial incentive for these methods.

In summary, these approaches contribute to global efforts to reduce GHG emissions. These methods differ significantly in their strategies. Further research and development are necessary to optimise these methods and address their limitations for effective climate change mitigation.

Poster Session

85 | Detection and Diagnosis of Abnormal Conditions in the Feed Pumps of a Geothermal Binary Power Plant Using Feature-based Time-series Analytics

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Keywords: *Geothermal binary plant, artificial intelligence, machine learning, feature engineering, time-series analysis, fault detection, condition monitoring.*

Industries worldwide have seen innovative growth fueled by volumes of data generated by inexpensive sensors deployed across critical points of various systems. These large datasets have led to artificial intelligence and machine learning applications in designing and operating energy systems. Furthermore, analytics-driven decision-making in industrial operations is a field of research that has benefitted from the confluence of developments in data storage, capture, and processing technologies.

This study investigates the application of time-series analytics in detecting and diagnosing abnormal operating conditions in circulating feed pumps operating in a geothermal binary power plant. Pump power and speed data have shown that the pumps experience episodes of cavitation that have led to reduced performance and reliability in the past. Operators have documented five cavitation events within one year, but operators believe there may have been

more events that were not recorded.

Systematic time-series feature engineering, supervised, and other machine learning methodologies were applied to detect and diagnose the drivers of the pump cavitation events. A fully-labelled dataset was used to develop predictive models to forecast the occurrence of the target events and diagnose the primary drivers that may have triggered such events in the past. The workflow deployed in this study can be used as a foundation for developing fit-for-purpose tools that can automatically detect abnormal operating conditions for different components and systems across other geothermal operations.

Session 2.2

86 | Exploring mildly acidic to neutral hot fluids through carbonate clumped isotope (Δ47) thermometer in the Liuhuangtzuping Area

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Keywords: *Tatun Volcano Group (TVG), carbonate clumped isotope (Δ47) thermometer, neutral hot fluids.*

The Liuhuangtzuping area, located in the northeastern part of the geothermally active Tatun Volcano Group (TVG), is situated adjacent to the She-Huang-Ping steaming ground(SHP) and Geng-Zi-Ping (GZP) steaming ground. Historically, SHP was deemed unsuitable for geothermal power generation due to its high corrosion potential with a pH value of hot springs ranging between 2-3. However, in recent years, Fabulous Power Co. has successfully drilled dry steam in SHP and is currently underway with the construction of a 1.4MW geothermal power plant. Liuhuangtzuping, in close proximity, presents an intriguing prospect for future Enhanced Geothermal Systems (EGS) development, featuring substantial layers of lava flows beneath.

In this study, we examined clumped isotope compositions for carbonates precipitating from near-neutral fluids in drilled cores of the Liuhuangtzuping area. The Δ47 values for five carbonate samples ranged from 0.434±0.012 ‰ to 0.512±0.020 ‰, corresponding to the estimated temperatures ranging from 184±6° to 114±7°. Overall, these results suggest the existence of a subsurface reservoir where fluids are neutral in pH and sufficiently hot (180-185°) for geothermal energy exploration.

Poster Session

87 | Assessment of Enhanced Geothermal System (EGS) Methodology for Harnessing Geothermal Energy Potential in Depleted Gas Fields

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Keywords: *Depleted gas fields, Enhanced geothermal system (EGS), Geothermal Energy, Integrated methodology, Reservoir simulation, Process model, Economic analysis.*

This study explores the potential of utilizing depleted gas fields for geothermal energy extraction, employing the Enhanced Geothermal System (EGS) methodology. Depleted gas fields, characterized by their permeable reservoir structures, offer promise for geothermal energy production. The prevailing approach involves injecting hot fluid from the surface, necessitating an assessment of energy consumption during pumping and energy extraction efficiency from the geothermal reservoir.

The study introduces a comprehensive framework for assessing geothermal potential in depleted gas fields. A coupled wellbore-reservoir-surface network model is utilized to analyze factors influencing energy production, considering heat loss in low-enthalpy systems. A history-matched model of the depleted gas field predicts reservoir behavior during energy extraction and fluid reinjection using pumps.

Economic feasibility is evaluated through a Levelized Cost-based model. Future research may consider evolving reservoir properties in mature oil and gas fields and their impact on energy extraction from mature gas fields.

This research advances the understanding of geothermal energy extraction from depleted gas fields, informing policymakers, industry experts, and sustainable energy researchers. Findings are relevant to New Zealand's energy landscape, supporting carbon-neutral goals and sustainability.

Session 1.2

88 | Reinjection Management Evaluation in Karaha Bodas Field 2022

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Keywords: *Karaha Bodas, Reinjection Management, injection well, inter-well connectivity*

The Karaha Bodas Field features a two-phase system with a vapor fraction ranging from 50% to 98%, which is tapped by five production wells. As of 2022, the field includes one injection well, namely KRH-1.A, with an injection flow rate of approximately 60-100 tph. Geochemical monitoring has indicated an increase in dryness in KRH-A.1, as well as in wells originating from the Talaga cluster (TLG-C.1 & TLG-C.2), due to the absence of reinjection fluid contributing to the production wells. This observation is further supported by the findings of the 4D microgravity monitoring study, which reveals areas with reduced mass around the production wells in the Karaha Bodas Field. This trend aligns with the limited occurrence of micro-earthquake events around production wells. The Karaha Bodas Field presents challenges owing to its relatively high decline rate, patchy structure, and low-to-

medium permeability. An inter-well connectivity study was conducted using the KRH-1.A injection well to confirm these indications. After six months of studies, it has become evident that there is no connectivity between the injection and production wells. The absence of reinjection fluid support for production wells has led to a decline in production by 9% annually. Tracer results also underline the absence of a structured path towards production wells or the presence of poor permeability due to the patchy structure, which is a contributing factor to the significant decline in output. To address this challenge, a modification in the injection strategy is imperative, involving the addition of the injection wells KRH-A.3 & KRH-B.3.

Session 2.2

89 | GeoEjector: Extracting geothermal fluid from a low-pressure geothermal well

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***Keywords:** Ejector, Geothermal energy, Power generation, CFD, Well productivity*

In the GeoEjector project, we investigate the potential to connect a low-pressure geothermal well to a nearby high-pressure well with an ejector system. The aim is to induce flow from the low-pressure well which cannot sustain high enough pressure for the operating conditions of the geothermal plant. A rudimentary ejector was tested in Theistareykir Geothermal Power Plant in Iceland in 2021. The results were promising, as the measurements showed entrained flow from the low-pressure well and subsequently increased fluid pressure up to 0.55 bar as it mixed with the stream coming from the high-pressure well. However, it was found that the existing design of the ejector cannot handle the real operating conditions of the wells for the plant, where higher back pressure is required. To address this challenge, an improved ejector design has been made and is planned to be tested in 2023. Also, a down-scaled laboratory ejector is being set up to collect measurements of combined low- and high-pressure water and steam flows. We have used an analytical model to improve the ejector's design and Computational Fluid Dynamics (CFD) models to simulate its flow. This paper will introduce this project and show the preliminary results.

Session 7.2

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Contact: mbcentury.com or Info-nz@mbcentury.com

91 | Study & Design of Binary ORC Using Wet Cooling Tower (Existing) of Unit V & VI in Lahendong Geothermal Field, Indonesia

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Keywords: *Indonesia, PT Pertamina Geothermal Energy, Lahendong, Tompaso, Binary ORC, Cooling Tower, Production, Operation, Engineering.*

Utilization of hot brine from production separator has a great potential to generate electricity as a secondary turbine in Lahendong and the other PT PGE fields. Currently, the separated water from separator will move directly into reinjection wells with gravity due differential elevation of about 60 meters.

In order to utilize hot brine from production separator, the existing line should be modified by making pipe branch 6" schedule 40 toward secondary turbine, from main line 16" schedule 40. The pressurized water from upstream (7.83 barg) has a pressure drop 0.13 barg and heat loss 0.019°C along 30 meters of new pipeline.

In this study, pentane was chosen as the best selection of binary working fluids due to had power output greater than others and the surface condenser with pressure 1.32 bara is connected to the existing wet cooling tower as the cooling system. The calculation using Scilab and CoolProp as numerical computation, with vaporizer pressure 8.63 bara or 7.70 barg resulting net power 1795.32 kW and SSI value 2.02, while using vaporizer pressure 18.7 bara resulting net power 626.1 kW with SSI value 0.99.

Session 7.2

94 | Greenfield resource assessment: maximising early stage data to constrain uncertainty

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Geothermal fields are a valuable resource in the energy sector. However, there is significant cost and risk involved in determining the viability of a field for production. We have, therefore, improved a method to assess the potential of a geothermal resource using numerical modelling and uncertainty quantification.

We have further conducted a study on the impact of different data types for resource assessment of a geothermal field. The research focuses on understanding the significance of each data type and its contribution to the accuracy of the resource estimations. A systematic methodology was developed to analyse and compare the effectiveness of various data types in assessing key parameters, including reservoir temperature, surface features, mass outflows, and clay cap formations. This was conducted by filtering models on the above parameters individually and in succession. These filtered models were then used in production simulation to gauge a representation of the predicted geothermal resource output.

Session1.2

95 | Cloud computing for complex geothermal simulations using the parallel software Waiwera

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Keywords: *Cloud Computing, High-Performance Computing, Waiwera, Uncertainty Quantification, Resource Assessment*

Numerical modelling of geothermal fields has been around for a few decades and has proven to be very insightful for sustainably managing geothermal projects. It is a great, cost-effective tool for evaluating various development plans using a realistic model of the field.

Simulating geothermal fields, however, is a time-consuming process, especially when the model become more complex and refined, and the simulation time increases. The geothermal simulator Waiwera, recently developed by the University of Auckland (UoA) in collaboration with GNS Science, has proven to be able to reduce simulation time drastically by using parallel computing on standard desktops, and even more so when using high-performance (cloud) computing. Simulation times reduce by a factor of 10-50 depending on the complexity and size of the model. Additionally, uncertainty quantification of a model, which requires running thousands of sample models, benefits hugely from high-performance cloud computing.

In this paper we explore three cloud computing platforms: NeSI (New Zealand eScience Infrastructure), AWS (Amazon Web Services) and Azure (Microsoft). Different options of user interaction with the cloud computing platforms will be discussed. Moreover, the simulation speed and costs will be compared for these three platforms.

Session 1.2

99 | Geothermal Direct Use Implementations and Its Potential Developments in North Sulawesi

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Keywords: *Geothermal, Direct Use, North Sulawesi*

Indonesia is located in the ring of fire area, granted by an enormous potential for geothermal resources, including North Sulawesi. The government is currently focusing on generating electrical power from geothermal resources. Lahendong geothermal power plant is the first geothermal project in the east of Indonesia, operated since 2001, generating 20 MWe. Currently, Lahendong is supplying 20 Mwe of each 6 unit for SULUT-GO (North Sulawesi and Gorontalo) electric network and developing small scale power plant using binary

cycle with a capacity of 0.5 MWe. In contrast , in many locations, North Sulawesi is also known for its Geotourism, such as Bukit Kasih, Danau Linauw, Bukit Pinus and other hot swimming pools. Geothermal fluid is also utilised by Yayasan Masarang in producing palm sugar. Another development is being carried out in drying agricultural foods. With the considerable potential for geothermal direct use to support tourism and agriculture, development needs to be conducted further

Session 6.2

102 | Updated Geological Structure and 3D Intrusion Model as Veritable Fracture Driver of Fracture Characterization in Wayang Windu Geothermal Field, Indonesia

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Keywords: *Wayang Windu, Fracture Driver, Fracture Characterization, Geological Structure, 3D Intrusion Model*

Wayang Windu is a two-phase geothermal field located in Indonesia with electricity generating capacity of 230 MW. Several make-up well drilling campaigns have been conducted since the field started commercial operation in 1999, with the most recent campaign resulting in a steam gain that significantly exceeded expectations.

As part of a continuous improvement process for selecting subsurface well targets, Star Energy Geothermal is applying a novel workflow to interpret permeability distributions, especially in relatively undrilled parts of the reservoir. The workflow is referred to as Fracture Characterization and Optimized Well Placement (FCOWP). FCOWP consists of two main processes. The first generates fracture orientations and intensity distributions, then the second models the range of fracture apertures and lengths and includes sensitivity and uncertainty analysis. This paper focuses on the creation of Discrete Fracture Network (DFN) realizations for Wayang Windu which is part of the first process.

The major initiatives related to creation of a DFN include an updated interpretation of geological structures and a model of rock intrusions. The Wayang Windu's FCOWP methodology depends on two fracture drivers. The first fracture driver is related to faults and associated stress, and the second fracture driver is related to intrusion geomechanics and thermal cooling. The input of the fracture drivers in Wayang Windu came from recently updated geological structures and a 3D intrusion model. Each fracture driver was validated by comparing fracture properties generated by the model (dip angle and dip azimuth) with fracture data observed in wells. Fractures from the well data are explained by a certain fracture driver if a fracture with the same properties is developed by that driver in the model. This validation process shows that up to 91% of fractures at Wayang Windu are explained by fracture drivers while the other 9% are not explained and can be dealt with stochastically.

Incorporating all fracture drivers results in a DFN where the fracture properties are comparable to fracture data from the wells. Thus, the updated structural model and 3D intrusion model are considered as reliable fracture drivers to predict permeability distributions in Wayang Windu to improve the selection of subsurface targets and well placement.

Session 1.3

103 | Update of Direct Geothermal Energy Use Inventory and Management for New Zealand

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Keywords: *Geothermal direct use, New Zealand, geothermal energy*

As New Zealand transitions away from fossil fuels, more emphasis is being placed on renewable energy solutions. The technological, economic and environmental benefits of direct geothermal use are well demonstrated globally. In New Zealand, direct geothermal use spans sectors (tourism, agriculture, aquaculture, residential, commercial and industrial) and includes a broad range of energy use technologies from high-temperature industrial processes to low-temperature small-scale installations. Access to reliable and accurate direct use data informs decision making on resource management, assisting with determining the appropriate balance between utilization and the protection of special natural features at the surface of geothermal systems.

As a means to monitor, promote and inform on the potential of utilizing New Zealand's natural

geothermal resources, GNS Science has been cataloguing geothermal direct energy use activities, through the development of an online tool. This paper summarises recent geothermal energy use in New Zealand, recent drivers for uptake, and showcases some new initiatives.

Session 6.2

104 | Preliminary ESG Consideration for Geothermal Development in Indonesia: What Relevant Environmental, Social and Governance Aspects Need to be taken into Account?

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Keywords: *Geothermal energy, Environmental, Social and Corporate Governance (ESG) factors, Sustainable Development Goals (SDGs)*

Indonesia's islands are abundant with geothermal energy, a sustainable and environmentally-friendly source of energy. Various research studies have supported the environmental advantages of geothermal energy and its potentials to support the global and national mission of carbon emission reduction to decelerate global warming. More specifically, geothermal energy's potentials can be harnessed in the Carbon Market Exchange, as well as to support the 17 pillars of sustainable development goals (SDGs), and the environmental, social and governance (ESG) business assessment. ESG is a parameter used to manage business operations risks, which are related to environmental and social impact management and corporate governance activities, all of which have currently become trending topics in various discourses about business development and investment.

This paper will attempt at presenting some preliminary discussions related to the potentials of geothermal energy development in Indonesia, related to the ESG aspect. This paper uses an empirical study, surveying about 250 respondents, involving both those who are familiar with the geothermal exploration and exploitation and those who are not.

Our survey result revealed that at least 32% of all respondents had already been familiar with the geothermal sector and the challenges of developing this sector in Indonesia, with only about 1.6% still unfamiliar with the term and had never heard of it. About 68.8% of the respondents understood the environmental concerns related to geothermal energy development, starting from greenhouse gas emission, biodiversity, the land borrow-to-use permit system, concerns about the stench and noise of energy projects, as well as concerns about the management of domestic waste as well as Hazardous and Toxic Waste. It is also important to take into account the implications that these projects will have on the social and corporate governance aspects.

Our survey results also revealed that on average, the respondents have the optimistic view that the development of geothermal energy in Indonesia can also contribute to the national renewable energy mix. The survey results also prove that it is highly important to factor ESG risks into the challenges related to geothermal energy development. The importance of understanding geothermal energy development from the ESG perspective then requires practitioners to boost their basic knowledge and awareness related to ESG, while at the same time requiring them to play an active role in

educating relevant stakeholders so the latter can have accurate perception about clean and renewable energy management.

Session 6.3

105 | Kawah Kamojang Pilot Injection Test: Production Monitoring Evaluation and Numerical Reservoir Modelling Study to Support Kamojang Injection Optimization Program

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Keywords: *Kamojang, Pilot Injection Test, Reservoir Management, Injection Optimization, Production Monitoring, Reservoir Numerical Modelling.*

Injection optimization strategy is an essential component of geothermal resource management, as it plays a pivotal role in ensuring the security of steam supply. Presently, Kamojang geothermal field continues to produce at full capacity at 235 MW from about 515 kg/s of steam production and giving an excess of 95 kg/s condensate to reinject. Condensate injection in the Kamojang field began in 1978, corresponding with the initiation of commercial production and to date the condensate injection strategy in the field is predominantly focused on the central area.

Superheat, as a potential threat to the security of Kamojang steam supply, is periodically monitored using surface superheat measurements. The monitoring program has observed a steady rise in superheat levels since 2017, with the most notable increase in superheat reaching up to 10º. This increase is particularly evident in wells located in the vicinity of Kawah Kamojang area in the northeastern part of Kamojang. Several initiatives are currently being undertaken to counter the propagation of superheat. One such initiative is the injection pilot test in Kawah Kamojang area. There are currently 6 production wells and 1 non-commercial well in Kawah Kamojang area. The sole inactive well, situated in the northernmost part of Kawah Kamojang was selected as the injector candidate where the pilot injection test was conducted over a duration of 2 months.

A surveillance program was established to monitor the production of wells and the surface superheat in order to observe the responses of the reservoir to the pilot injection test. The collected data is used to evaluate the impact of injection changes on the reservoir.

The numerical reservoir model of Kamojang was employed to demonstrate the substantial extension of the steam supply forecast following the pilot injection scenario and to help determine the next step in the Kamojang injection optimization program.

Session 8.2

106 | The Impact of an Active Strike-slip Fault to The Principal Horizontal Stress Orientations and Fluid Flow in the Karaha Bodas Geothermal Field, Indonesia

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Keywords: *Principal stress, geomechanics, structure, induced fracture, geothermal.*

The Karaha Bodas field is located in an active tectonic region which consists of complex volcano-stratigraphy and structural framework. To determine the best strategy for its development, we studied its tectonic setting and how it correlates with the productivity of a well using the geological evidence in a production well called WELL-A. The geological structure analysis from the image log data in WELL-A includes the identification of the maximum horizontal stress orientation along the well from the orientation of the drilling-induced fractures, including borehole breakout and drilling-induced tensile fractures or DITF. The maximum horizontal stress orientation is also determined from caliper data using the maximum and minimum size of the caliper to define the breakout or washout interval along the borehole. This image log analysis shows evidence of a rotation in the maximum horizontal stress in the reservoir rocks from N235°E to N200°E, which is strongly believed to be caused by the active NE-SW strike-slip Candramerta fault that was targeted by WELL-A. This active fault is also interpreted to contribute to production from the well as the response in the production log that is acquired in this well indicates a significant mass flow change at the fault. Overall, both the drilling-induced tensile fracture and caliper-breakout analysis capture the stress trend rotation and suggest the present-day principle horizontal stress orientation is directed NE to NNE. This is also similar to the regional stress data that suggest the maximum horizontal stress in West Java is oriented north-northeast.

Session 8.3

107 | Preliminary Analysis of Geothermal Drilling Results in Eastern Taiwan

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Keywords: *Geothermal Exploration, Geological Drilling, Well Testing, and Rock Core Testing*

Geothermal resource exploration represents the riskiest phase in geothermal development, and the results of geological drilling serve as the most crucial reference for risk assessment. These results enhance the reliability of geothermal information, reduce upfront investment risks in geothermal development, and attract as well as facilitate corporate investment.

This article presents the outcomes of a fully cored geological exploration well (referred to as CGS-YP01), drilled to a depth of 800 meters in the eastern region of Taiwan. The content includes drilling cores and logs, electric well logging, in-hole pressure and temperature measurements, rock mechanics testing, and thermal conductivity analysis.

Session 4.2

108 | An Integration Solution of Geomodelling Tools in a Geothermal Modelling Framework

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Keywords: *Modelling framework, Geothermal Reservoir Simulation, Waiwera, Python, JavaScript, Macros, SKUA-GOCAD, Abaqus.*

A new functionality in SKUA-GOCAD was developed, allowing it to create both the grid mesh and the deck file necessary for the Waiwera simulator. Through a combination of Python Scripts and JavaScript Macros, a user-friendly interface was created, simplifying the creation of Geothermal Simulation inputs. It is possible for any user to modify it on demand, making it an ideal candidate for integration in a modular geothermal modelling framework where flexibility is key. By construction, it can also be easily run in a batch mode, opening the door for sophisticated workflows like Assisted History Matching, Sensitivity Analysis, or Coupled Flow-Thermal-Geomechanical Simulations using third-party software. In addition to the advantages introduced by the new Macros, the existing advanced modelling functionality and the post-processing capabilities available in SKUA-GOCAD may also enhance the quality of the models produced.

Session 8.2

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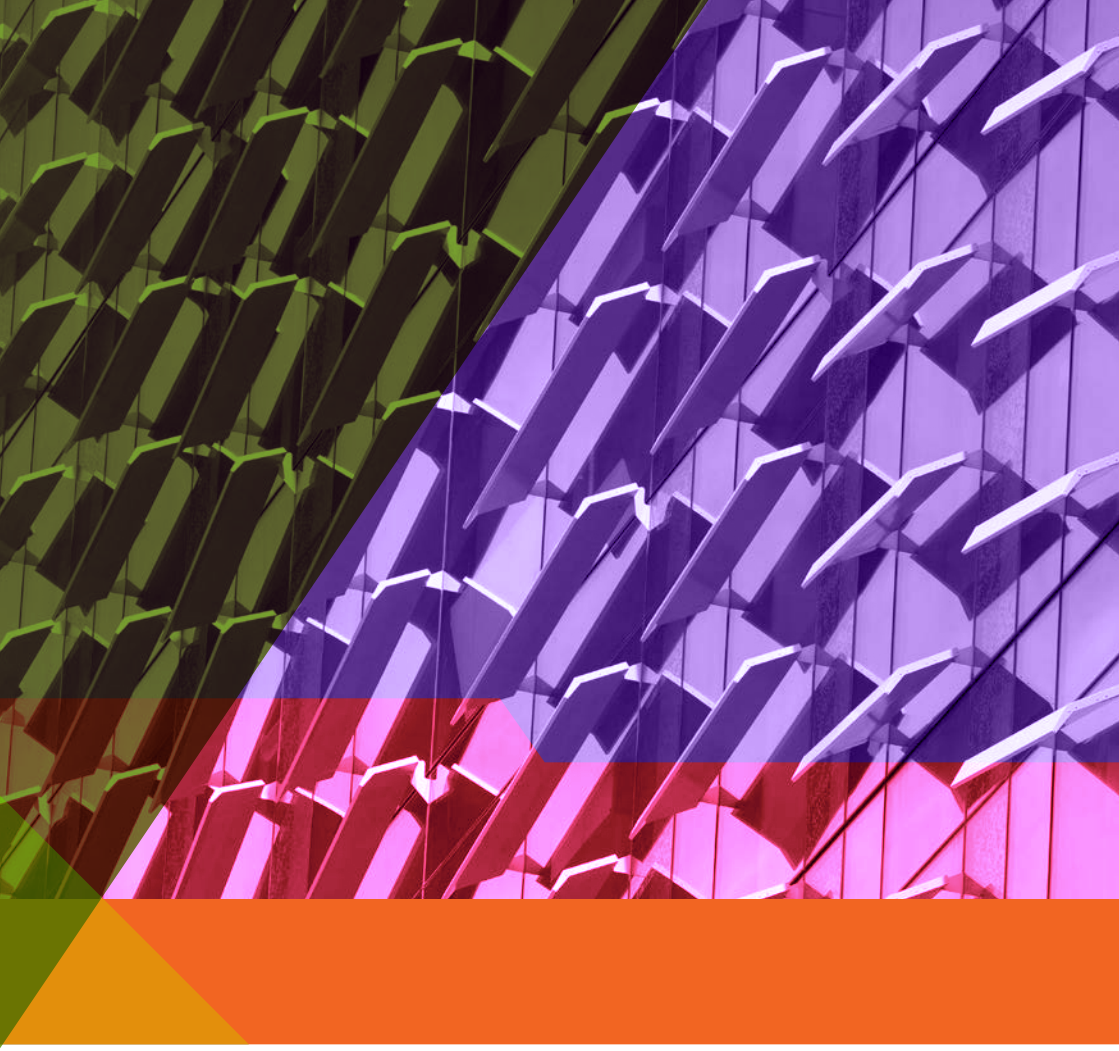

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