Proceedings World Geothermal Congress 2023
Beijing, China, October 2023

A Supercritical Geothermal Inventory for New Zealand ?

Brian Carey[1], Chris Bromley[1], John Burnell[2]

[1]GNS Science, Private Bag 2000, Taupō, 3352, New Zealand

[2]GNS Science, PO Box 30-368, Lower Hutt, 5040, New Zealand

b.carey@gns.cri.nz, c.bromley@gns.cri.nz, j.burnell@gns.cri.nz

Keywords: New Zealand, geothermal, supercritical, superhot, prospect inventory, national potential

ABSTRACT

As part of workstreams in the Geothermal the Next Generation (GNG) research programme there is an activity to develop an inventory of supercritical resource potential seeking to establish this at a national level for New Zealand.

The framework proposed to be adopted for developing this inventory is the United Nations Framework Classification for Resources Update 2019 (UNFC 2019) incorporating Supplementary Specifications for the Application of the classification framework to Geothermal Energy Resources (UNECE 2022). Within this framework projects are identified and assessed, with a methodology enabling an overall estimate of New Zealand's supercritical Geothermal Energy Resource potential to be developed by aggregation of assessed projects.

With limited ability to distinguish between the supercritical fluid state and other very hot geothermal fluid at depth the more general term superhot geothermal is used in this paper.

Geophysical techniques developed as part of the Explore workstream of the GNG research programme are proposed be used to identify discrete volumes of the subsurface that might be at superhot geothermal conditions, at depths shallower than ~8km. Energy assessments will be developed for each 'volume' identified and these will be aggregated to a total for the energy in the geophysics defined superhot project 'volumes' identified by the GNG programme. An assessment is to be made of the energy product produced at the surface over the life at each project site, using representative model simulations for a typical development scenario.

The paper also identifies methodologies developed in various nations, comparing and contrasting approaches, working to assist New Zealand researchers in identifying an appropriate energy product assessment methodology to implement in the New Zealand context.

The paper details the approach and process that the New Zealand GNG researchers are pursuing in developing the inventory. The energy product analysis will be undertaken subsequently and reported in a GNS Science report that will be available from the GNG website on completion.

1. INTRODUCTION

The hottest temperature measured in a geothermal well in New Zealand is in the Rotokawa Geothermal source in RK22 at a depth of ~2900m with a maximum measured temperature of 337 ºC (Sewell 2016). The highest enthalpy of fluid delivered from Taupō Volcanic Zone (TVZ) geothermal production wells is 2800 kJ/kg from shallow steam wells drilled into the Wairakei Geothermal source. The Geothermal the Next Generation (GNG) research programme is looking to access geothermal fluids at greater than 400 ºC with fluid enthalpies of 3000 to 3200 kJ/kg at depths of 3500 to 8000m, closer to magmatic conditions in the TVZ.

One of the Integrate workstreams in the GNG research programme is to develop an inventory of superhot resource potential seeking to establish this at a national level for New Zealand, to highlight the future significance of the expected resource potential in order to facilitate further exploration, regulatory and investment planning This paper outlines the approach that is being developed to establish that potential.

The United Nations Framework Classification for Resources Update 2019 (UNFC 2019) incorporating the Supplementary Specifications for the application to Geothermal Energy Resources (UNECE 2022) provides an internationally recognized methodology to classification and categorization. The framework, discussed in Section 2 of the paper, provides a systematic way of moving a superhot geothermal project from conceptual through to operational status. For a national assessment the framework envisages an aggregation of individual projects and project products. The UNECE (2022, p26) defines the term 'source' for the thermal energy under the ground, in the formations and fluid, and 'resource' for the sum of the geothermal energy products produced at the surface from the energy extracted from the source. The UNECE 'source' definition is different to the way the paper authors would use the term, with resource usually being used to refer to the geothermal energy under the ground. For consistency the paper seeks to use the UNECE definitions.

The methods for identification of superhot project locations and possible volumes in the TVZ of New Zealand using geophysical techniques are discussed in Section 3. International approaches to superhot project identification are discussed in Section 4 along with some commentary on the Icelandic work on superhot geothermal that they have been undertaking since the early 2000s. This section includes a summary of some of the results from the testing of IDDP1 undertaken in the 2010 to 2012 period.

Section 5 discusses the approach to computing individual project energy product assessments.

Section 6 discusses the extent of New Zealand's exclusive economic zone and the likely extensive undersea superhot volumes associated with the 30 plus volcanoes of the Kermadec arc and Section 7 briefly canvasses the applicable New Zealand regulatory framework that might apply to superhot geothermal and the influence that this might have on the inventory.

2. UNITED NATIONS FRAMEWORK CLASSIFICATION – UNFC-2019

The consideration in this paper is at the country level for New Zealand seeking to understand the application of UNFC-2019 to as yet unexplored superhot deeper geothermal energy below 3500m deep and possibly as deep as 8000m which ultimately may have potential to be developed and produce energy products.

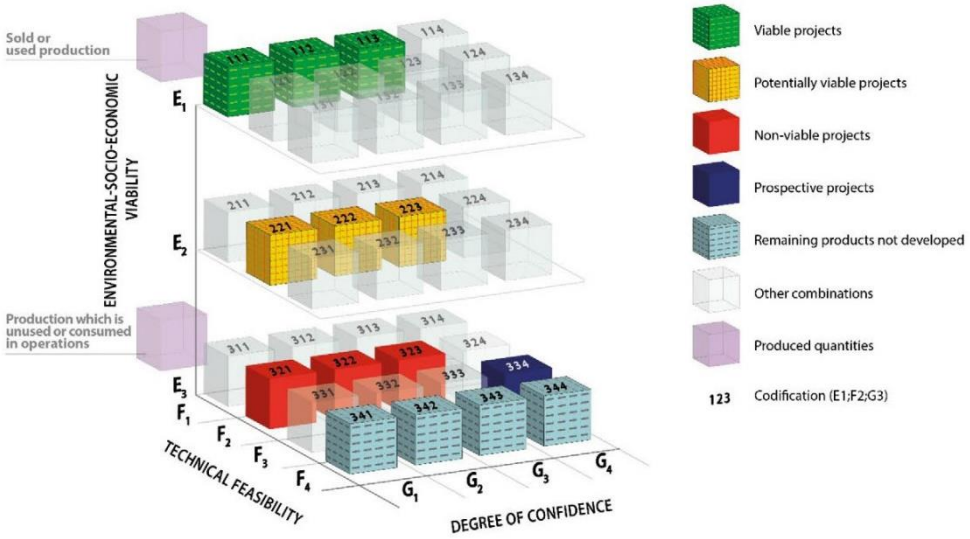

Figure 1: UNFC-2019 Categories and Examples of Classes (Diagram from UNFC-2019 p2)

The relevant documents are the United Nations Framework Classification for Resources Update 2019 (UNFC 2019) and the Supplementary Specifications for the application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resources (UNECE 2022).

With the inclusion of geothermal energy in the earlier UNFC-2009 (UNFC 2010, UNFC 2013) documents through UNECE (2016) there came the opportunity to standardize assessment and communication of geothermal sector activity as part of the broader energy sector, enabling non-renewable energy and renewable geothermal energy projects to be compared. This has been brought through into the UNFC (2019) and UNECE (2022) documents. The basis of the assessment is at a Project level using three fundamental criteria: economic and social viability, field project status and feasibility, and the degree of confidence in what is known. The three categories each have three or four levels: Economic and social viability (E1, E2, and E3), technical feasibility (F1, F2, F3 and F4), and Degree of Confidence in the estimate (G1, G2, G3 and G4). Category and sub-category definitions can be found in UNFC (2019) Annexes I and II. A three-dimensional matrix diagram is shown in Figure 1. **Fehler! Verweisquelle konnte nicht gefunden werden.**This common assessment framework can be used at project, company, country, region or possibly even world level.

A Project is a defined development or operation which provides the basis for environmental, social, economic and technical evaluation and decision-making. Mature Projects are able to be defined in significant detail whereas in the early stages of evaluation, including verification, a Project will be defined in conceptual terms. This is the case for the superhot geothermal projects being considered in this paper.

Where no development or operation can currently be defined, based on existing technology or technology currently under development, all quantities associated with that source (or part thereof) are classified in Category F4 (UNFC 2019 p17). Decision trees to aid the classification of geothermal projects are documented in Annex II UNECE (2022). The degree of confidence is covered for the G-axis decision tree in Annex II UNECE (2022) replicated here in Figure 2.

For the New Zealand superhot geothermal projects the classification is to the right of the dotted line in Figure 2 because there have been no exploratory wells drilled at any site confirming the existence or other wise of a superhot geothermal source; any project site therefore is prospective.

The G axis assessment is focused on estimates which will provide a G4.3 (relatively highest confidence) to G4.1 (relatively least confidence) rating. The decision boxes to the right of the dotted line in Figure 2 are either single estimates or probabilistic and deterministic estimates.

In order to further develop the G axis assessment of the energy potential two aspects need to be pursued:

- identification of possible project sites and
- an assessment of the energy product potential of each project

Another definition in the UNECE (2022) that has bearing on the classification is the Foreseeable Future, which in the geothermal context is a maximum of five years (UNECE (2022) p11). On the E axis this then categorizes New Zealand superhot geothermal at the time of writing this paper as E3, because development and operation are not expected to become economically viable within the next five years. The best fit subcategory is E3.3 (UNECE (2022) p17).

On the F axis the best fit subcategory is F4.2 which covers the position where the technology necessary to recover some, or all, of these quantities is currently being researched, but no successful pilot studies have yet been completed (UNECE (2022) p19).

To summarize, at the UNFC-2019 axis level, categorization of New Zealand super hot geothermal is rated E3:F4:G4 (344).

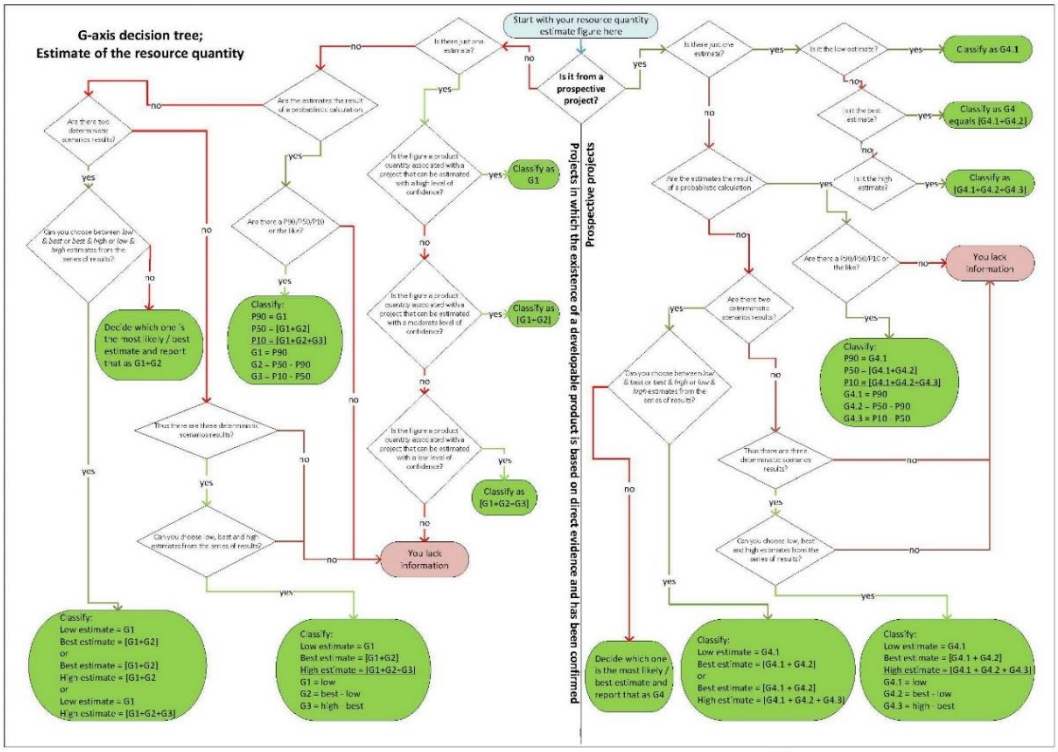

Figure 2: G Axis decision tree from UNECE 2022 p25

Energy Products

To make a New Zealand assessment under UNFC-2019 the identification of energy products (heat or electricity) needs to be made. Some of these energy products will be related to existing geothermal projects which are currently utilizing shallower geothermal sources, others will be separate and previously undefined as being a geothermal energy source.

With energy products identified, projects can be assigned and then the aggregation of the assessments associated with each of the projects becomes the national assessment. Projects under UNECE (2022) have a lifetime definition. In the first instance for the product assessments for the TVZ projects the lifetime is taken as 35 years which is the maximum take consent duration that can be granted under the Resource Management Act 1991. If, at the completion of this nominal project lifetime, the heat source is not yet depleted, then a new project can be defined at the same site.

The aspects of source identification and size are primarily based on geophysical evidence, with a depth cutoff related to the expected depth that might be drillable at a given time horizon. The ability of a deep well to flow under the estimated temperature, pressure and permeability conditions at depth is also considered.

The aspects of well depth for the TVZ circumstances have been considered in developing a well design for a 6000m deep well based on well prognoses at two different locations in the TVZ prepared by GNS Science and others (Carey et al 2021). Rivera and Carey (2023) document wellbore simulation modeling seeking to identify the ability to produce fluid and energy from 4500 to 6000m wells with temperature conditions in the 450 to 600 ^{o}C range. Fluid density encountered is an important consideration and, somewhat counter intuitively, a deeper 450 ^{o}C well may produce more than a 600 ^{o}C well because the cooler fluid is denser producing a greater hydrostatic reservoir pressure in support of well flow.

3. STATUS OF NEW ZEALAND SUPERHOT GEOPHYSICS

The application of geophysical techniques is seen as the way to identify volumes of the subsurface that might be at superhot conditions. The GNG research programme, led by GNS Science, has a not insignificant geophysical research component under the Explore workstream (Miller 2022). The focus of the Explore geophysical work is in the TVZ and within a depth of 10km from surface.

Three of the techniques and tasks in the GNG Explore work stream that are ordered from most-likely to least-likely relevant to assessing superhot sources deposits are the:

- Remodeling of existing magneto-telluric (MT) datasets, fine-tuned to identify magma and possibly the presence of geothermal fluid and associated rock alteration, with assistance from passive seismic data (earthquakes).
- Development of passive seismic tomography models to identify low velocity and amplitude attenuated regions associated with magma and fluid, possibly providing constraints on MT model interpretations, and
- Compilation of aeromagnetic data and the development of models to locate the depth to Curie Point, indicative of rock temperatures of ~580°C.

4. INTERNATIONAL IDENTIFICATION METHODOLOGIES

The International Energy Agency Technology Collaboration Programme (TCP) includes a TCP focused on geothermal energy. Working Group 12 of the Geothermal TCP works on collaborative activity associated with the deep roots of volcanic geothermal systems. Participating nations are working on methodologies appropriate to identification of superhot / supercritical geothermal sources, or to prioritization of prospect sites. Bromley and Carey (2023), written as part of Working Group 12 activity, documents these, identifying the following approaches by different authors. In Europe (specifically Iceland and Italy), favorable indicators for the presence of superhot energy sources include the likelihood of young magmatic intrusions in the shallow crust (Manzella et al, 2019). The most likely tectonic settings are subduction zones, mid-ocean spreading ridges, and volcanic rifts or extensional basins (zones of crustal thinning). Identifying prospective areas where superhot temperatures are likely to be encountered is assisted by constructing crustal thermal models. The main indicators are:

a) the depth to the 400 ºC isotherm (largely from extrapolating borehole temperature data but also, in places, from magnetic data revealing the Curie Point depth),
b) crustal thickness (largely from seismic data, indicating the depth of the MOHO discontinuity (boundary between the crust and the mantle)), and
c) earthquake event density which contributes to an estimated depth to the brittle-ductile transition.

In the USA, a probability approach has been used to assess the combined information from geophysics (especially resistivity from MT, density from gravity, magnetic susceptibility from magnetic surveys, and stress state from seismology), geology (especially petrology, geochronology and mapping of fault structures) and geochemistry (fluids, minerals and gases) to determine the best sites through a “play-fairway” approach.

In Mexico, researchers have found that modelling of the underlying magmatic plumbing structure (using petrology) helps resolve the likely depths and spatial relationships between different heat sources and their surrounds. Hence, we infer that the most favorable locations for significant sources of supercritical fluid could be the lateral margins as well as the overlying carapace of shallow intrusive bodies containing partially molten material.

In Japan, results of an ongoing supercritical geothermal assessment research project have been reported in a 2021/22 Special Issue of Geothermics Journal. Here, again, geophysics (especially MT resistivity and seismology) has played a major role in determining the likelihood of successfully encountering superhot sources. In addition, geochemical studies have addressed the issues of gas content in supercritical vapour and also the potential for silica deposition to provide a low permeability cap surrounding supercritical reservoirs.

Icelandic superhot geothermal activity

Icelandic activity in the superhot geothermal sector has been ongoing since the early 2000’s. This work includes the drilling and subsequent testing of IDDP1. The well was drilled to ~2100 m and encountered magma during drilling, ahead of terminating the drilling operation. The well was produced over an extended period in 2010 to 2012 (Ingason et al 2014) producing up to ~50 kg/sec of 3000 to 3200 kJ/kg fluid at wellhead pressures of 40 to 140 bar and wellhead temperatures of 300 to 450 ºC from a feed temperature of 470 ºC and feed pressure of 180 bar.

The Icelandic superhot geothermal work over the last two decades has been more focused on drilling and testing individual wells (IDDP1, IDDP2) rather than in developing approaches to assessing national potential, which for Iceland one would assume is extensive due to its geological setting with magma accessible in many places along the rift axis at quite shallow depths.

5. INDIVIDUAL PROJECT ENERGY ASSESSMENT METHODOLOGIES

The superhot geothermal prospects in New Zealand are at an early stage of assessment. Some geophysical assessment and interpretation is being completed as part of the GNG programme which is referred to in Section 3. No exploratory well drilling has been undertaken at the time of publication of this paper. The approach likely to be taken to the quantification of estimates will be to develop and compute energy estimates to a relatively low-confidence level using ‘volumes’ determined from the geophysical techniques and production assessments to enable the energy product at the surface to be assessed.

Simulations of performance of a representative superhot reservoir volume, under assumed future development scenarios, can contribute to the expectation of produced energy for a typical future project, but uncertainties typically remain large because of poor constraints on reservoir properties such as permeability and fluid recharge. However, simulations will become more important once exploratory drilling and testing is undertaken. As a simulation example, O’Sullivan et al (2020) describe a large scale 3D supercritical and subcritical reservoir model of all the TVZ geothermal systems, incorporating surface topography as well as deep roots to 7 km depth (using Equation of State EOS3sc in an improved TOUGH2 simulator) at an xyz grid resolution of 1km*1km*0.5km.

Currently, under the UNFC-2019 criteria, the level of confidence in the quantification estimates would be assigned G4.3 having the Flowest level of confidence, because of the lack of calibration data in the depth and temperature range of interest across the TVZ.

Grant (2015) reviewed stored heat assessment methodologies for shallower geothermal energy developments and EGS projects noting the over optimistic choice of values often used and the lack of rigor in the application of Monte Carlo probabilistic methods as these have been applied seeking to improve the quality of simpler assessment methodologies. This cautionary paper reminds us to be conservative in the choice of values (such as assumed recovery factor for the in-place stored energy) when undertaking superhot geothermal energy assessments.

As noted above, reservoir simulation could be used to provide project estimates, even in the absence of measured data. Ciriaco et al (2022), Power et al (2023), and DeBeer et al (2023) have outlined statistical methodologies that can assess production scenario uncertainties using numerical reservoir models. Some constraints on deep rock properties in the TVZ can also be inferred from large scale 2D modelling (Kissling 2023). The likely natural state evolution and migration of geothermal systems were modelled through millions of years, across the 20 km wide central part of the Taupo Volcanic Zone, above an inferred hot plate (700 ^{o}C partial melt at 10km depth, providing 700 mW/m^2 upward heat flux). For superhot geothermal prospects located underneath a conventional shallow geothermal project, calibration data can be obtained from the relevant project including shallow temperatures and pressures, heat flows and fluid chemistry. Through the development of a range of models that reproduce the observed conditions in the shallow reservoir, estimates (with uncertainties) of the underlying superhot project size and temperatures can be obtained.

6. CONTINENTAL ZEALANDIA (TE RIU-A-MĀUI)

New Zealand's extensive exclusive economic zone is shown in yellow outline in Figure 3 (Left). Also shown on the plan are the TVZ (red outline), Ngawha (orange) and the Kermadec arc offshore to the north (blue dashed line). The three areas noted are likely to be the locations that contain volumes of rock with superhot geothermal potential (within 8 km depth range from surface). The Kermadec arc has over 30 volcanoes in an extensional regime. At the Brothers Volcanoes black smokers on the seabed with temperatures measured at over 300 ^{o}C have been observed (de Ronde et al 2011).

Volcano count would point towards this Arc having quite significant superhot geothermal energy in place. Accessing and assessing in some detail the potential offshore projects will be more challenging than land-based endeavors. Different development approaches will be needed. Some of these superhot sources will reside in sub-seabed volcanic sequences with associated permeability. An offshore drilling operation would require lowering drill pipe to the seabed rather than having to drill through the overlying volcanic sequence to reach 300 ^{o}C plus.

Kissick et al (2021) identifies the regulatory regime in place for offshore New Zealand from 12 nautical miles beyond mean high-water mark to the outer limit of the Exclusive Economic Zone (EEZ). Activities contemplated are included in the regulations, others would need to be consented by the Environmental Protection Agency on application under the Exclusive Economic Zone Act. Exploratory geothermal drilling would require applications to be lodged, and possibly changes may be required to the existing regulations. The Act includes a requirement for decision makers that if the information available is uncertain or inadequate, caution and environmental protection must be prioritised. This would place a high burden of proof on an applicant with regard to the information presented in support of an application for geothermal exploratory drilling in the EEZ.

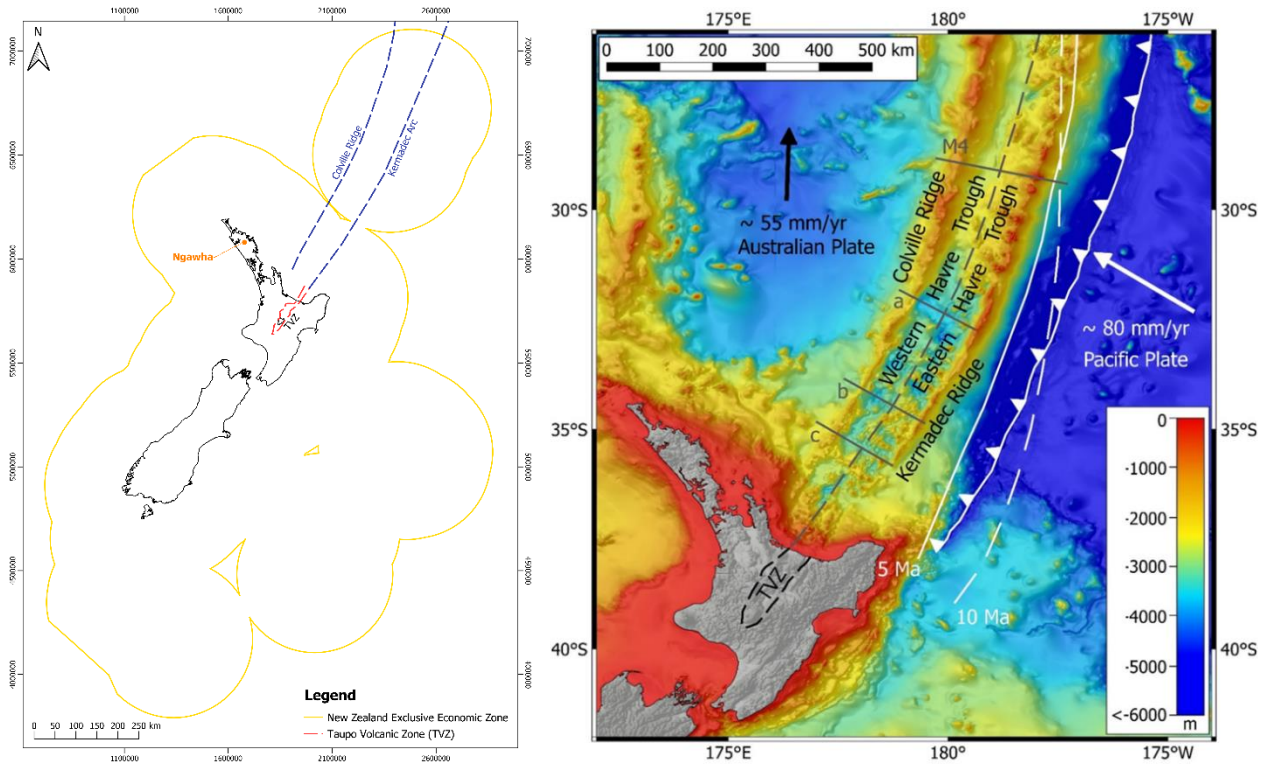

Figure 3: New Zealand's exclusive economic zone showing the Kermadec arc (left). Kermadec Arc and ocean water depth (m) shown in the right diagram (from Caratori-Tontini et al 2019).

7. REGULATORY PLANNING CONSTRAINTS

Regulatory planning requirements relating to geothermal and superhot geothermal source use in the Waikato and Bay of Plenty Regions have been summarized in Kissick et al (2023). Overall permits to access superhot geothermal sources should be able to be applied for and obtained. A significant proviso is that individual site specific aspects will influence the degree of complexity required to obtain permits or even if permits are able to be granted.

The ability to permit access at a site-specific location may change with time as the planning regulations develop and evolve. At the time of writing New Zealand is undergoing a round of significant reworking of the Resource Management law and regulations. In the future, this might influence the ease or otherwise with which resource consents can be obtained to access superhot geothermal at a particular site.

In developing a list of potential projects the key factor will be the energy potential obtained largely from geophysical data, supported by hypothetical energy extraction scenarios through modelling and representative reservoir simulations. At this early stage, a planning filter is not proposed to be applied before the energy assessment is undertaken.

CONCLUSION

Under the UNFC-2019 assessment, superhot geothermal in New Zealand is E3, F4, G4 rated. With the inclusion of the subcategories the classification is E3.3, F4.2, G4.1. This currently applies nationwide.

Geophysical techniques developed as part of the Explore workstream of the GNG research programme are to be used to identify discrete 'volumes' of the subsurface that might be at superhot geothermal conditions at depths shallower than ~8km. Energy assessments are proposed to be developed for each 'volume' identified. With the added benefit of representative simulation modelling, the outcome will be an energy product at surface for each of the identified superhot 'projects'. These will be aggregated to a total for the potential deliverable energy across the projects considered.

The coverage of the GNG Explore workstreams will limit the energy assessment to geophysical 'volumes' in the TVZ that have been identified. The TVZ data coverage is partial, so superhot 'volumes' that have not yet been identified in this area of New Zealand, or any assessment at Ngawha (Northland), or any assessment in the offshore Kermedec Arc will not be included in the initial aggregated superhot national energy inventory.

The process of establishing a preliminary inventory, by using the energy analysis approach described here, will be reported later in more detail in a GNS Science report that will be available from the GNG website on completion.

At the conclusion of the GNG project the superhot data coverage will be a partial assessment of New Zealand's potential with the methodology set up such that as geophysical data coverage is extended the potential will be able to be updated. At an individual project level the UNFC-2019 classification will be able to be revised as exploratory drilling and pilot studies are undertaken enlarging the knowledge of a specific superhot geothermal site. Many identified sites (as 'volumes') in New Zealand will remain at the E3.3, F4.2, G4.1 classification level until exploratory activity is undertaken on them.

ACKNOWLEDGEMENTS

The authors acknowledge funding from New Zealand's Ministry of Business, Innovation and Employment (MBIE, under contract C05X1904 to GNS Science) for the "Geothermal: The Next Generation" research programme.

REFERENCES

Bromley, C. J. and Carey, B., Ultra Hot - Supercritical Geothermal - IEA Geothermal Collaboration. Proceedings World Geothermal Congress 2023. Beijing, China, April 17 – 21, (2023)

Caratori-Tontini, F., Bassett, D., de Ronde, C.E.J., Timm, C., Wysoczanski, R. Early evolution of a young back-arc basin in the Havre Trough. Nature Geoscience, 12, pp. 856–862. (2019).

Carey, B., Rae, A., Bixley, P., Carson, L., Alcaraz, S. Prognoses for Two Supercritical Well Designs. GNS Science Report 2021/36 ISBN: 978-1-99-101304-0. (2021).

Ciriaco, A.E., Uribe, M.H., Zarrouk S.J., Downward, T., Omagbon, J.B., Austria, J.J.C., Yglopaz, D.M., Probabilistic geothermal resource assessment using experimental design and response surface methodology: The Leyte geothermal production field. Geothermics,Volume 103, 2022, 102426, ISSN 0375-6505, https://doi.org/10.1016/j.geothermics.2022.102426. (2022)

de Ronde C.E.J, Massoth G.J., Butterfield, D.A., Christenson, B.W., Ishibashi, J., Ditchburn, R.G., Hannington, M.D., Brathwaite, R.L., Lupton, J.E., Kamenetsky, V.S., Graham, I.J., Zellmer, G.F., Dziak, R.P., Embley, R.W., Dekov, V.M., Munnik, F., Lahr, J.. Evans, L.J., Takai, K., Submarine hydrothermal activity and gold-rich mineralization at Brothers Volcano, Kermadec Arc, New Zealand. Mineralium Deposita (2011) 46:541–584, DOI 10.1007/s00126-011-0345-8 (2011)

De Beer, A., M Gravatt, T. Renaud, A. Power, J. Popineau, R. Nicholson, O. Maclaren, K. Dekkers, J. O'Sullivan, M. O'Sullivan: Geologically Consistent Prior Parameter Distributions for Uncertainty Quantification of Geothermal Reservoirs. Proceedings 48th Stanford Geothermal Workshop (2023)

Grant, M. A., Resource Assessment, a Review, with Reference to the Australian Code, Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015. (2015)

Ingason, K., Kristjansson, V., Einarsson, K., Design and development of the discharge system of IDDP-1. Geothermics 49: 58-65. (2014)

Kissick, D., Carey, B., Alcaraz, S., Deep Geothermal Exploratory Drilling and Testing in the Taupō Volcanic Zone. Traverse Environmental Limited 2023. ISBN 978-0-473-66734-4. (2023).

Kissick, D., Carey, B., Climo, M. An Overview of New Zealand's Geothermal Planning and Regulatory Framework. Traverse Environmental Ltd. ISBN 978-0-473-59132-8 (2021).

Kissling W., Ellis S., Barker S., Caldwell G. Source-to-surface models of heat and fluid transport in the Taupo Volcanic Zone, New Zealand. Presentation at FiNZ, 'Fluids in New Zealand' workshop, Victoria University of Wellington, 15-17 February (2023). Abstract (p13) in https://sms.wgtn.ac.nz/foswiki/pub/Events/FiNZ2023/Programme/FiNZProgrammeFinal.pdf

Manzella, A., Botteghi, S., Flovenz, O., Gola, G., Hersir, G.P., Limberger, J., Liotta, L., Santilano, A., Trumpy, E., van Wees, J-D.: Mapping super-critical geothermal resources in Europe, *Proceedings* European Geothermal Conference (EGC), Den Haag, The Netherlands (2019).

Miller, C., International Association of the Properties of Water and Steam 2022 Explore Overview (and Video). https://www.geothermalnextgeneration.com/knowledge/gng-exploring-for-supercritical-resources-in-the-tvz (2022).

O'Sullivan, J., J. Newson, S. Alcaraz, S. Barton, R. Baraza, A. Croucher, S. Scott, M. O'Sullivan: A Robust Supercritical Geothermal Simulator. Proc. 42nd New Zealand Geothermal Workshop, Paper 137. ISSN 2703-4275. (2020).

Power, A. M. Gravatt, K.Dekkers, O.Maclaren, R.Nicholson, J. O'Sullivan, A. de Beer, M.O'Sullivan : Improved filtering for a new Resource Assessment Method. Proceedings 48th Stanford Geothermal Workshop (2023)

Rivera, J., and Carey, B. Comparative Geothermal Well Performance – Supercritical and Subcritical. GNS Science Report 2023/01. ISBN 978-1-99-105800-3, DOI: 10.21420/EKKW-D514 https://www.geothermalnextgeneration.com/updates/comparative-geothermal-well-performance-supercritical-and-subcritical (2023).

Sewell, S. M., Statement of Evidence of Steven Michael Sewell, In Rotokawa Joint Venture Evidence package to the Waikato Regional Council Hearing Rotokawa consent application hearing evidence (2016)

UNECE, United Nations Framework Classification for Resources Update 2019 (UNFC 2019) incorporating Supplementary Specifications for the Application of the classification framework to Geothermal Energy Resources. https://unece.org/sites/default/files/2022-12/UNFC_Geothermal_Specs_25October2022.pdf (2022)

UNECE, Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources (2016).

UNFC 2019, United Nations Framework Classification for Resources Update 2019. https://unece.org/DAM/energy/se/pdfs/UNFC/publ/UNFC_ES61_Update_2019.pdf (2019)

UNFC-2009, United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 incorporating Specifications for its Application, ECE Energy Series No. 42, United Nations, New York and Geneva, 2013, eISBN 978-92-1-056516-5 (2013).

UNFC-2009, United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009, ECE Energy series No. 39, United Nations Publication, ISSN 1014-7225, (2010).