GEOTHERMAL THE NEXT GENERATION

Supercritical (Super-hot) Geothermal Learnings from international collaboration and an approach to a National Inventory

Chris Bromley and Brian Carey

IAPWS Symposium Rotorua

30 November 2022

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IEA Geothermal

Outline

- Collaboration through IEA Geothermal TCP WG 12 (Deep Roots of Volcanic Geothermal Systems) & WG13 (Emerging Technologies, Task D on induced seismicity and Task E on corrosion and scaling and highT tracers) with respect to super-hot or supercritical resources
- Key technical issues and messages for our communities
- Innovation & collaboration opportunities
- Supercritical national resource inventory and assessment

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International Partnership for Geothermal Technology

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Supercritical Geothermal - IEA Geothermal Collaboration

- International Energy Agency - Geothermal Technology Collaboration Program (IEA-Geothermal TCP)
- Sharing of Knowledge & Joint Research into the deep, high-temperature roots of geothermal systems, which potentially host ‘supercritical’ or ‘super-hot’ fluids.
- Focus on delineation and identification of locations of ‘super-hot’ geothermal resources that are prospective and accessible (the large amount of energy in place in these ‘deep roots’ is undisputed).
- Advance novel technology to enable evaluation and reliable energy production from such high temperature prospects. (Also, help inform interested parties, and direct future enquiry).
- Develop appropriate regulatory regimes that provide adequate certainty to support the investment needed.
- Improve knowledge of the geochemical and physical conditions in these super-hot settings through experiments in fluid-rock interactions, tracer tests and corrosion/scaling mitigation studies and advanced simulation models.

Geothermal areas where super-hot temperatures (> 374 °C) have been recorded

- Promote cooperation, coordination, collaboration between existing projects
- Identify challenges and solutions
- Stimulate innovation opportunities

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Past and Current Projects

Iceland (IDDP1 Krafla, IDDP2 Reykjanes, IDDP3 Hengill?)

Italy (DESCRAMBLE, Larderello, Venelle-2)

Mexico/EU (GEMex, Los Humeros)

New Zealand (GNG: supercritical water-rock lab studies, community engagement, geophysics of high T/P roots, supercritical modelling, supported by international advisory panel.

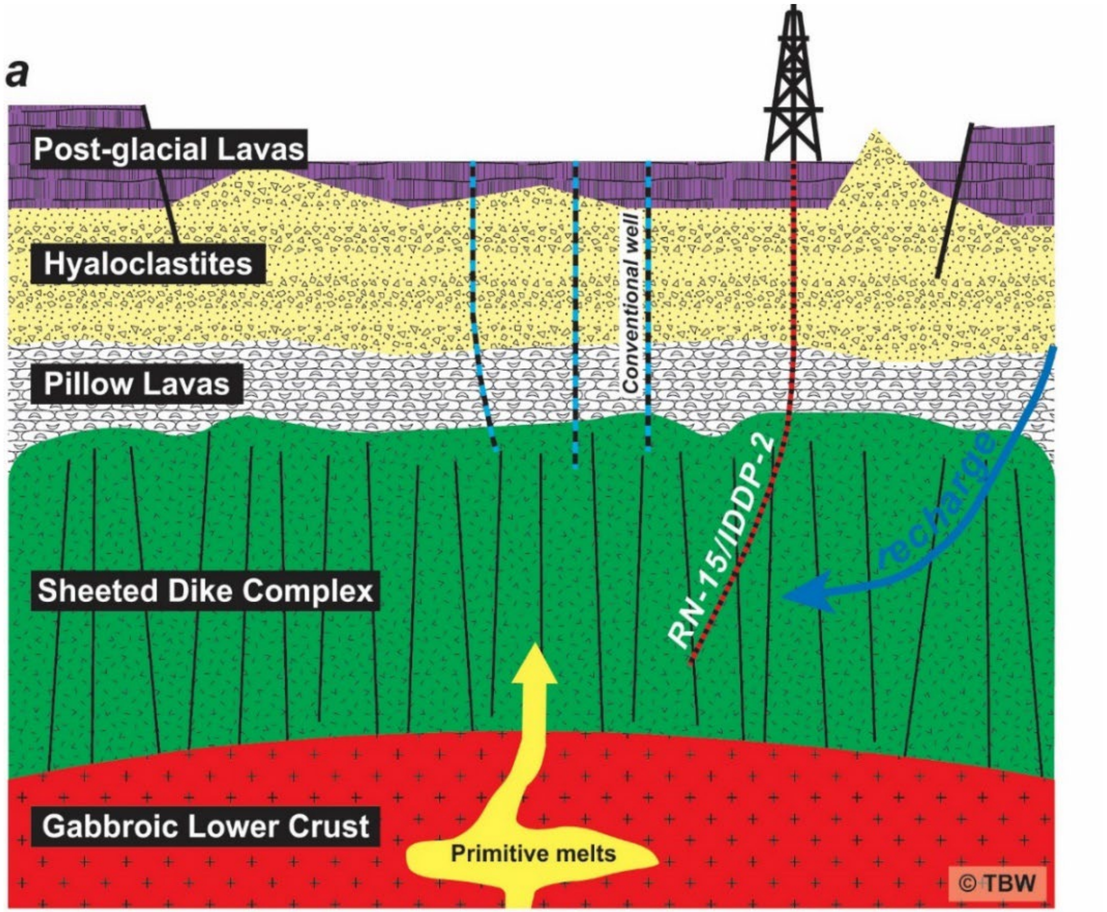
Japan (Supercritical) Geothermics Special Issue (resources, novel tools and geochemical challenges)

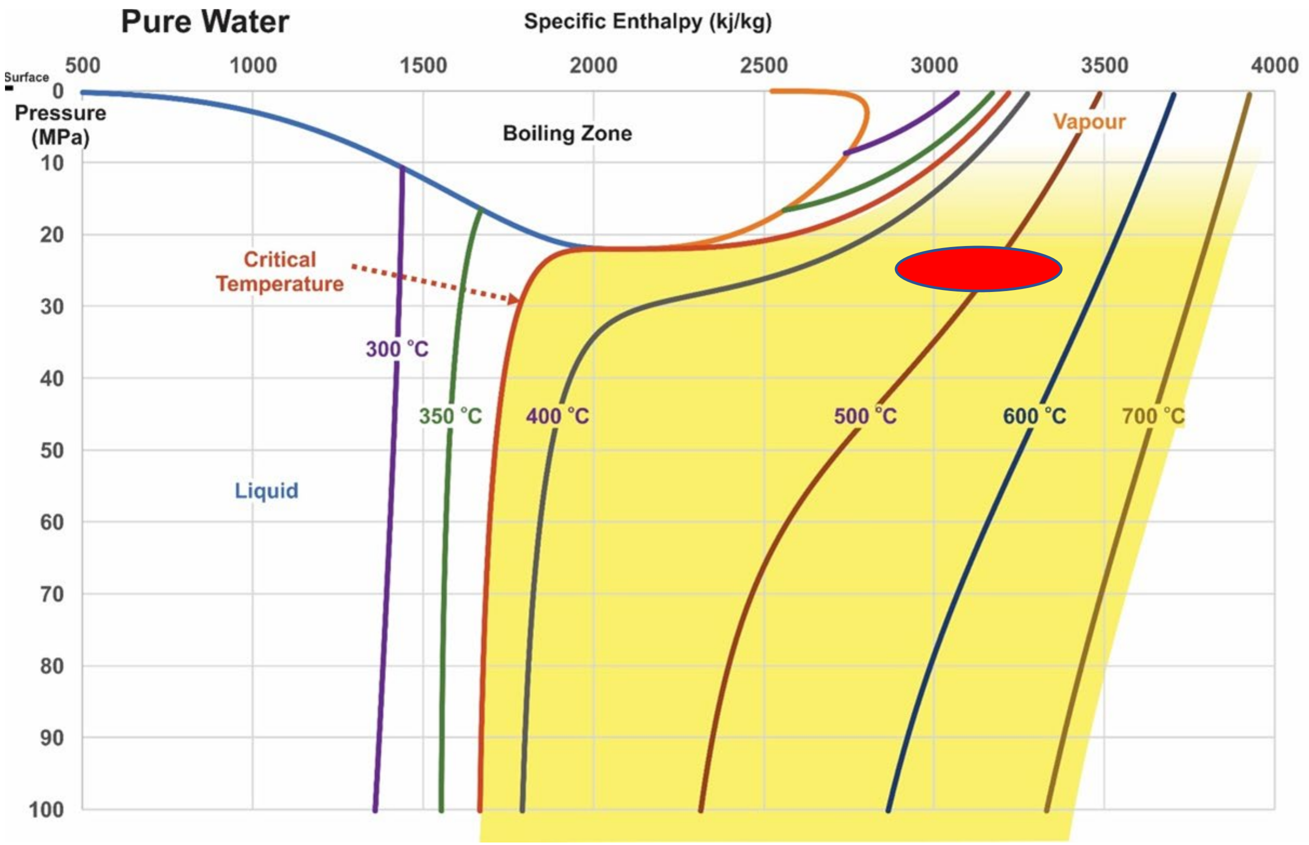
USA and EU: DEEPEN Geothermica 2021-2024
https://www.or.is/en/about-or/innovation/deepen/
(The Geysers, Puna, Newberry, etc)

IEA Geothermal

“Investigate unconventional, very high-temperature geothermal systems“

Iceland IDDP





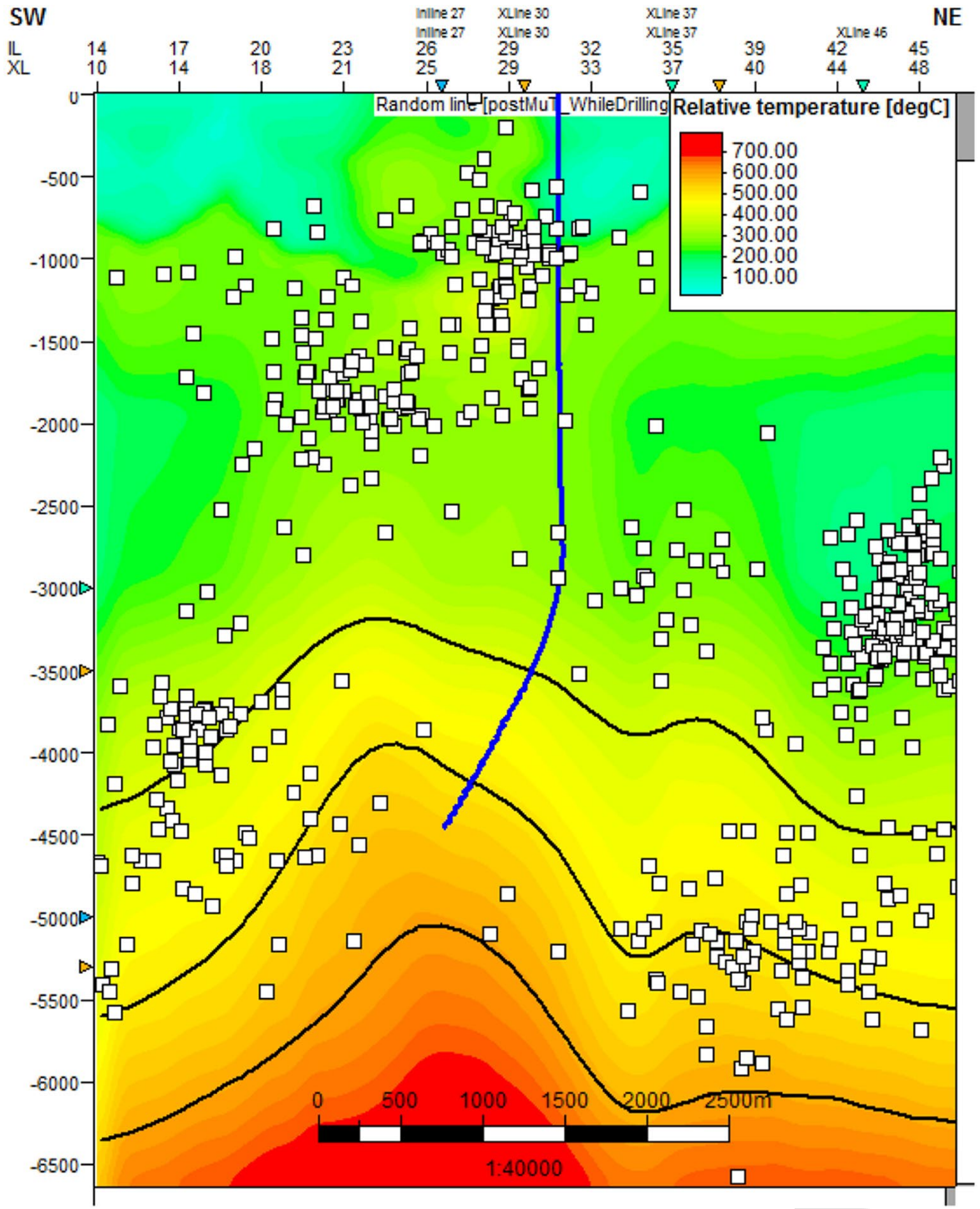
	Conventional dry-steam well	IDDP well
Downhole temperature	235°C	430-550°C
Downhole pressure	30 bar	230-260 bar
Volumetric rate of inflow	0.67 m^3/s	0.67 m^3/s
Electrical power output	~5 MW_e	~50 MW_e

Fridleifsson et al, 2014, 2017

Issues:

Where is the brittle-ductile transition zone?
How deep and how thick is it?
What is most favorable setting ?
geology? stress & strain state? fluid salinity?
gas content? depth, temperature & pressure ?

IDDP1 discharge, Krafla



IDDP2 supercritical target, Reykjanes

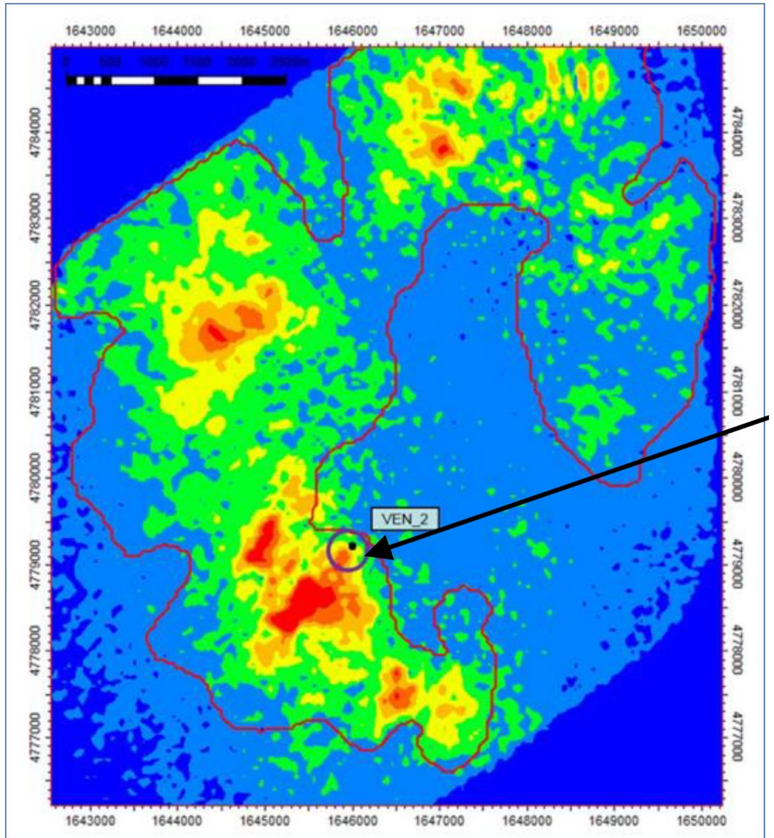
Hokstad (2017), Friðleifsson et al. (2018)

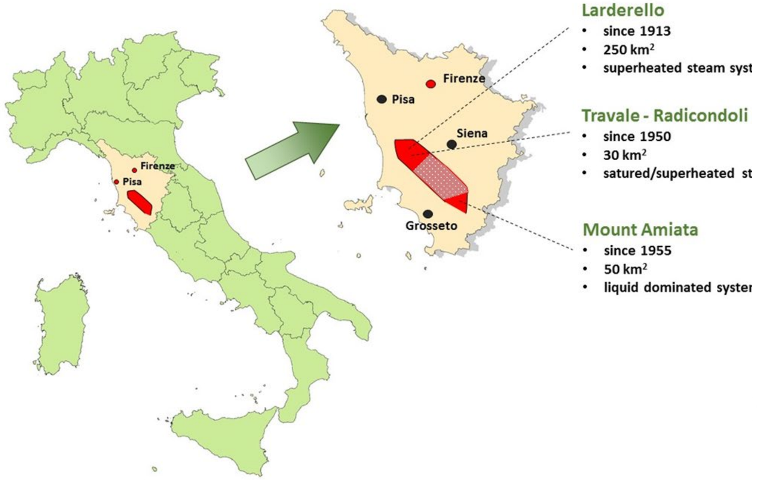
DESCRAMBLE, Larderello, Italy

Manzella et al (Image, 2017)
Bertani et al (Stanford, 2018)
Final Conference March 2018

Main achievements (2015-2018):

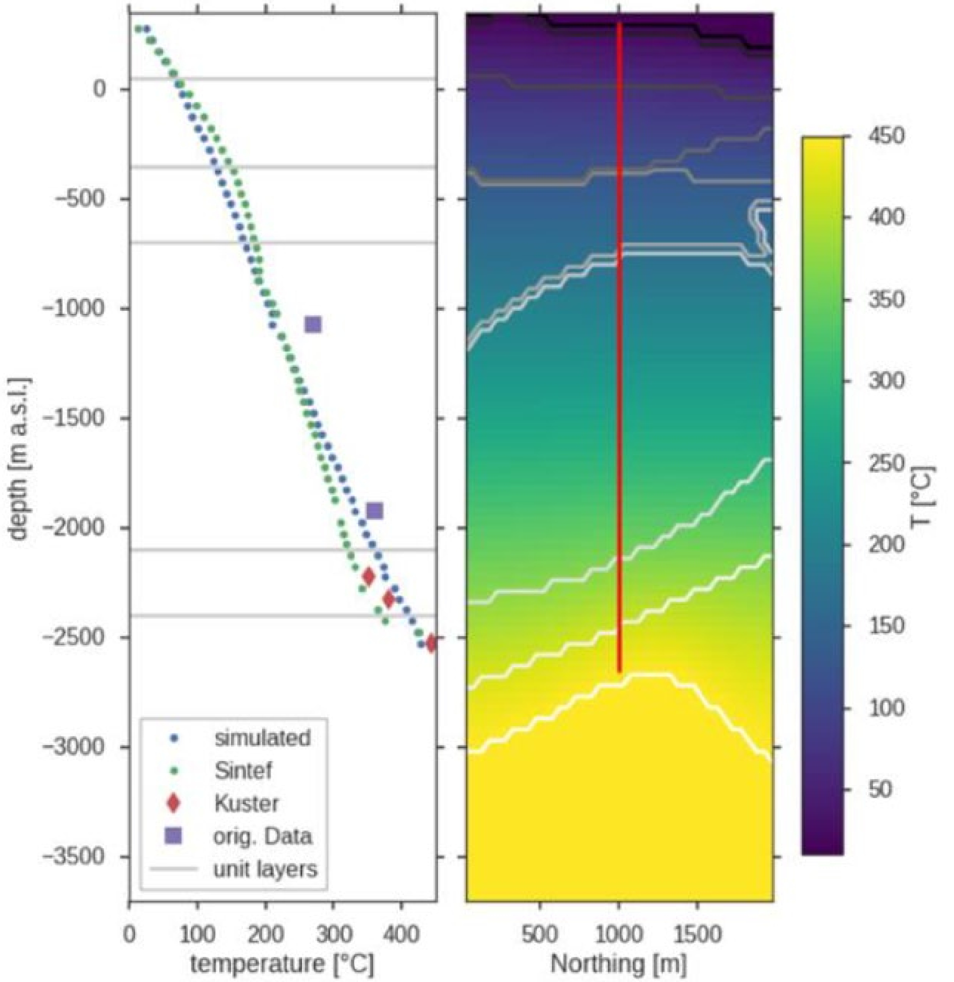
- Explored seismic k-horizon, magmatic hydrothermal systems at top of granite intrusions
- Deepened Venelle-2 from 2.2 to 3 km; >500 °C (higher than expected)
- Novel drilling techniques; proof of concept to reach supercritical
- Control of gas emissions & knowledge of high T/P chemical-ph conditions





Amplitude anomalies within Seismic k-horizon

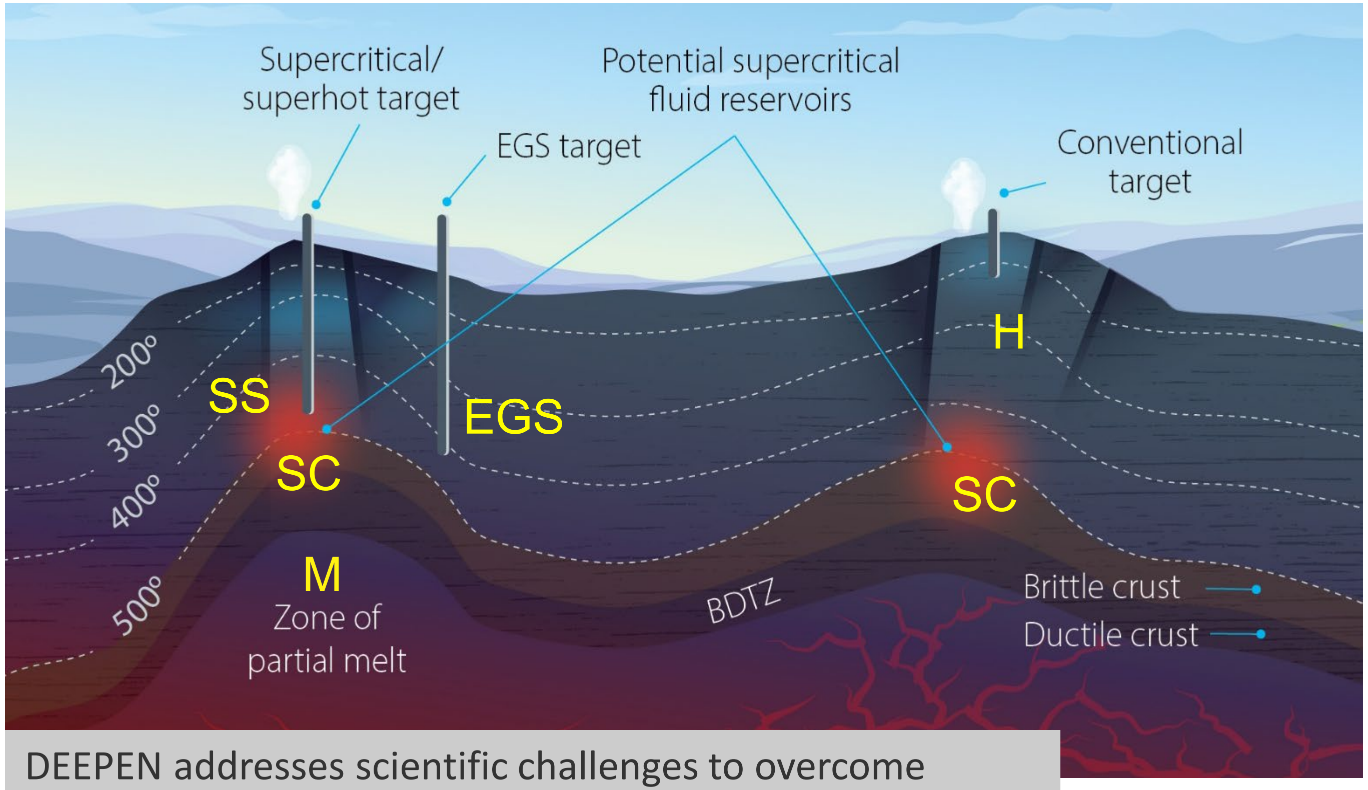
Bottom Hole Temperature >500 C
Synthetic fluid inclusion
Mechanical Kuster Tool
Sintef logging tool



DEEPEN: "DE-risking Exploration of geothermal Plays in magmatic ENvironments"

Geothermica project 2021-2024

- Adapting Play Fairway Analysis approach to exploration for multiple plays in magmatic, hydrothermal, supercritical/superhot and EGS systems (M, H, SC/SS, EGS)
- Developing innovative exploration methodologies informed by robust THMC modeling of processes in the "deep roots zone" of hydrothermal systems
- Application at demonstration sites in Iceland and US



DEEPEN addresses scientific challenges to overcome before supercritical fluids can become a viable geothermal energy source

Consortium members:
Iceland: ***Reykjavik Energy (lead)***, Iceland Geosurvey (ISOR), University of Iceland (UofI)
USA: National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory
Norway: Equinor, Norsar
Germany: German Research Centre for Geosciences (GFZ)
Switzerland: Eidgenössische Technische Hochschule (ETHZ)
France: IFP Energies Nouvelles (IFPEN)

Contacts: Amanda Kolkar NREL, Pat Dobson LBNL
Vala Hjörleifsdóttir ISOR

https://www.or.is/en/about-or/innovation/deepen/

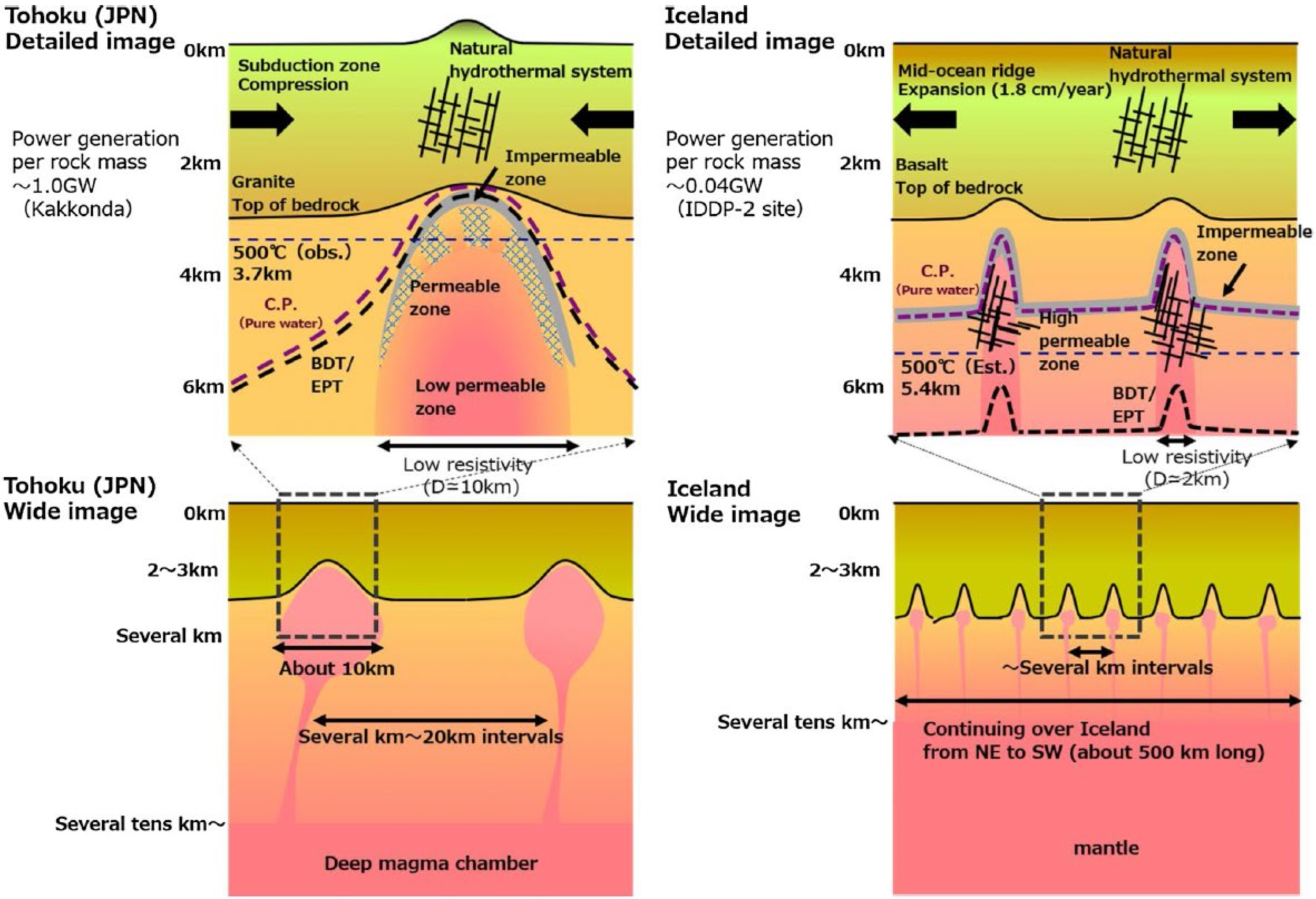
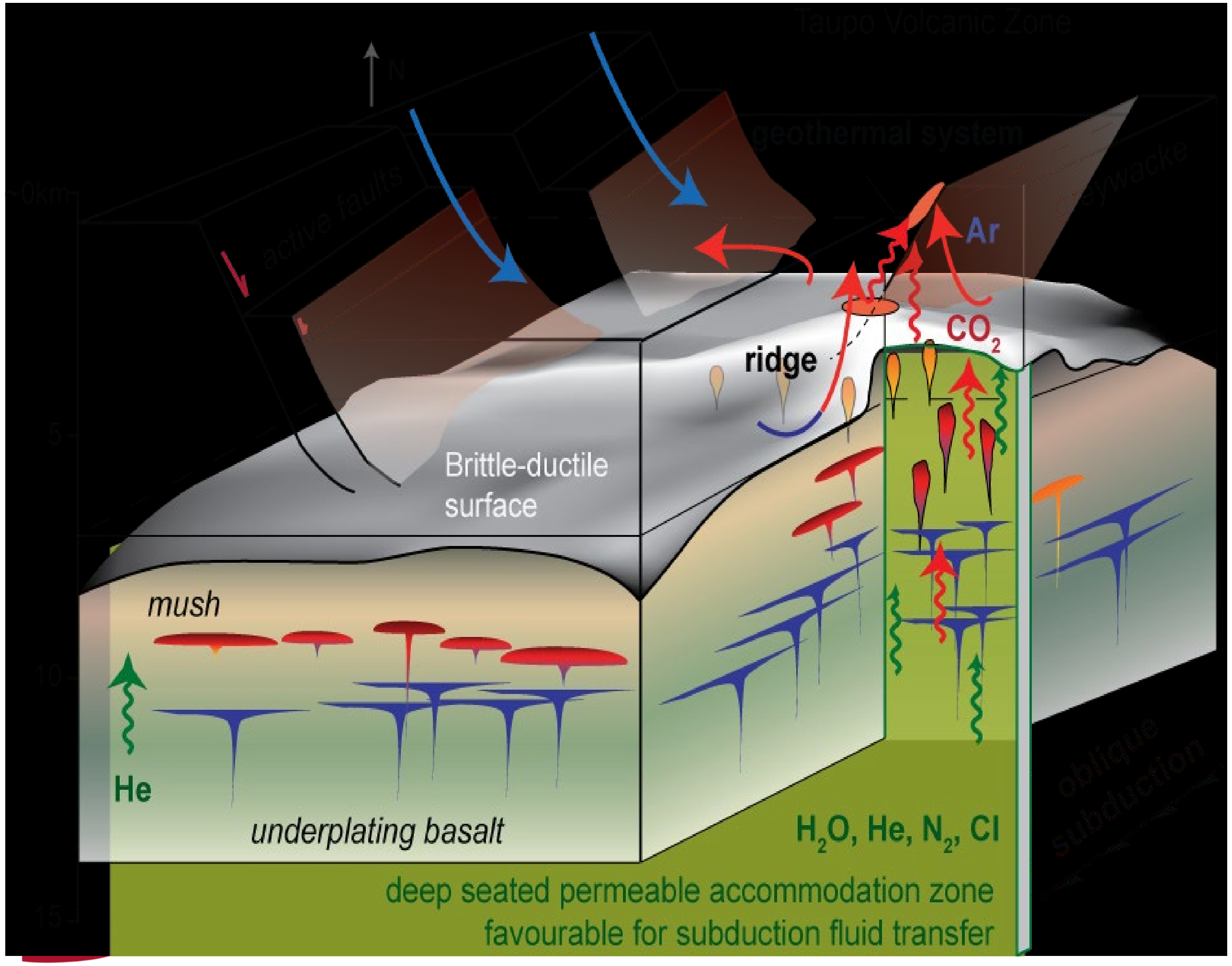
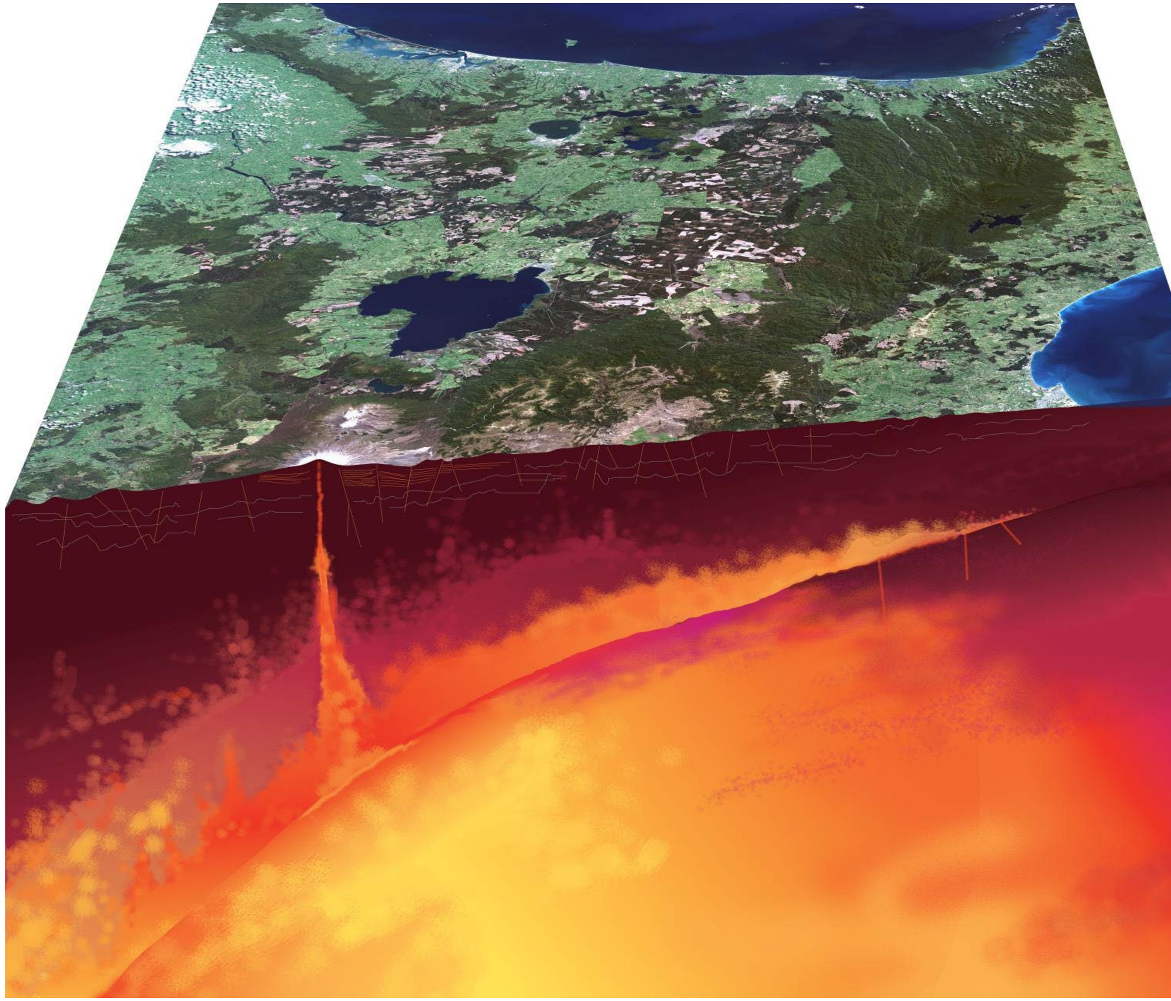


Fig. 9. Differences between reservoirs of the Tohoku (the left two panels) and Iceland (the right two panels) areas. The upper and lower rows show local and regional views, respectively.

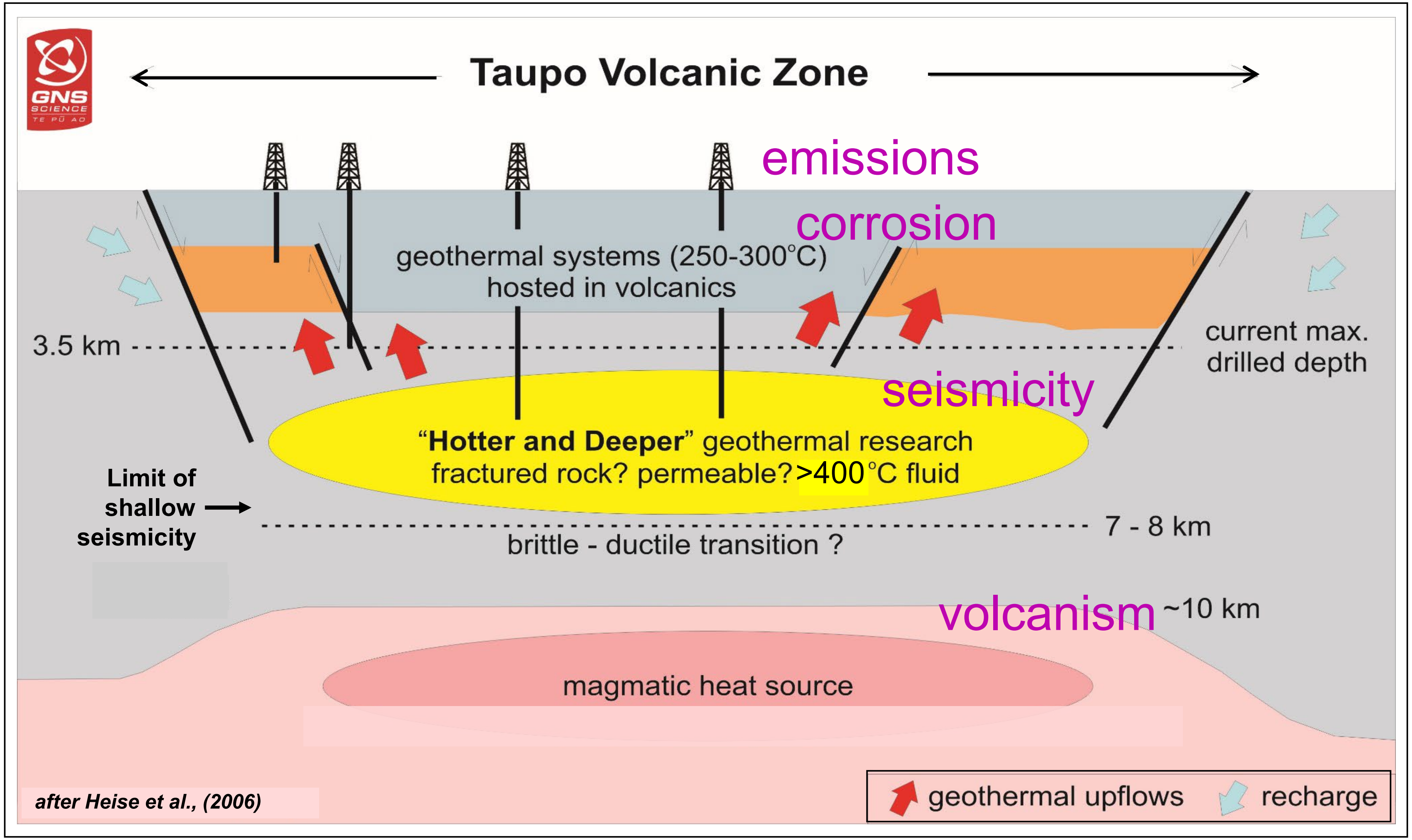
Japan comparison of Tohoku and Iceland superhot reservoir concepts. (Okamoto, Geothermics 2019). Also Special Issue 2021-2022

New Zealand Supercritical Research : Conceptual models of TVZ heat sources magma and gas upflow and fluid convection cells

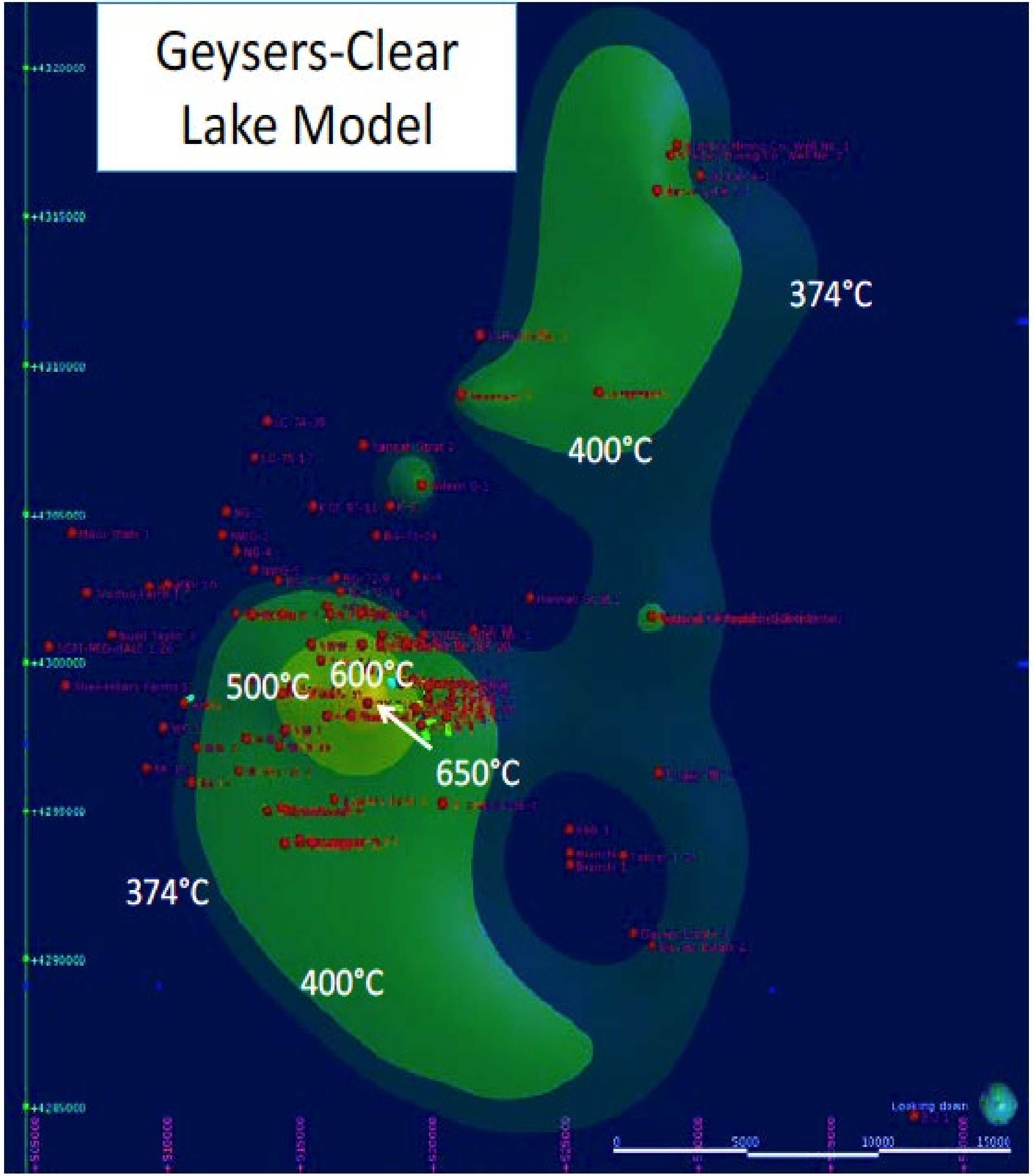




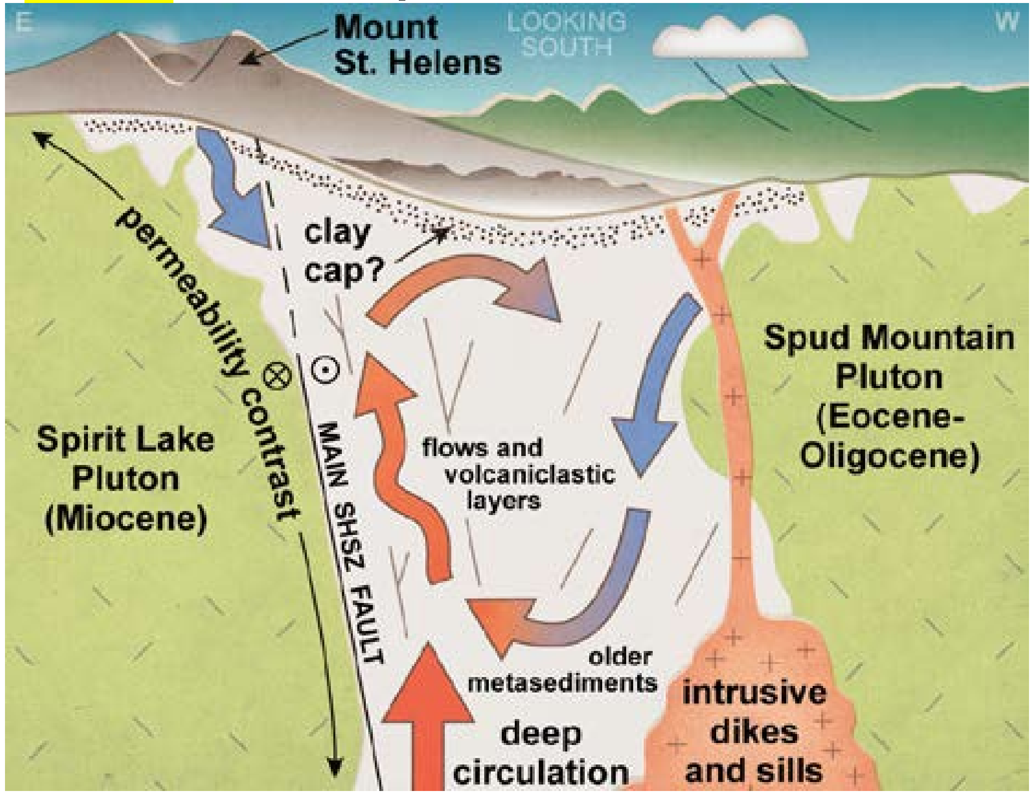
TVZ: 3-7 km depth, 5-10 GWe for ~1000 years?



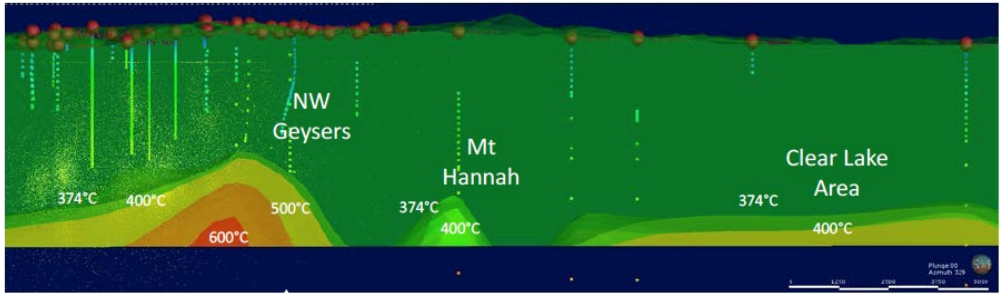
SUPERCRITICAL Realizing NZ's deep geothermal potential involves developing the ability to identify or create deep fractures (migrating towards ductile zone), and mitigating risks



USA conceptual models

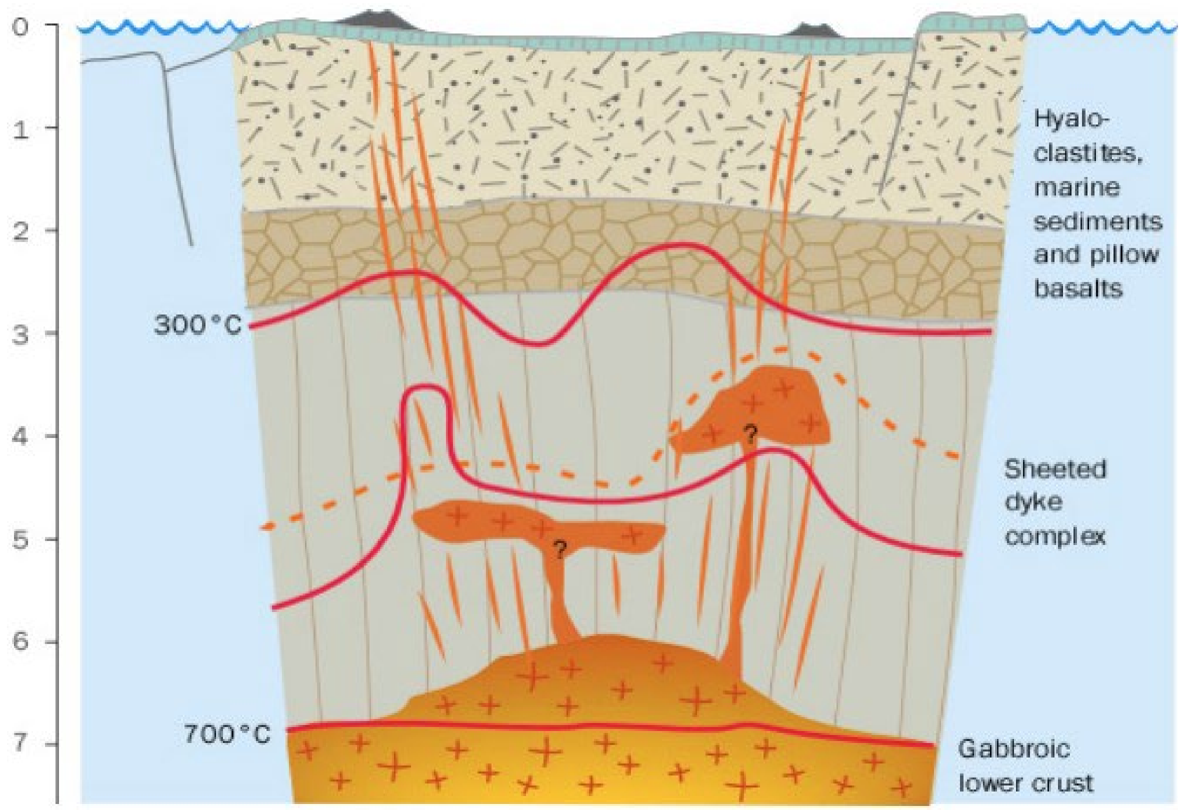


Mt St Helens (Forson et al 2017)
Oblique upflow (western offset of heat source)

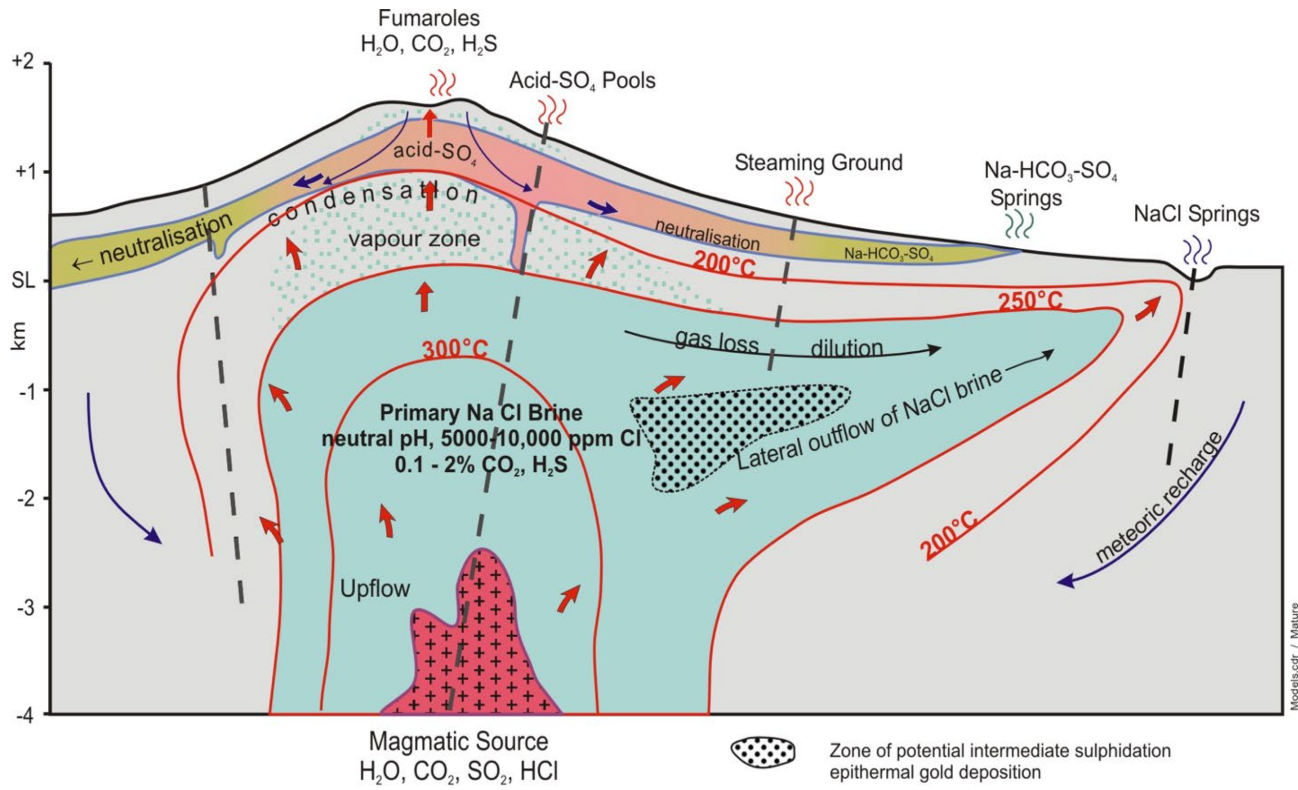


NW Geysers hot plutons (Stimac et al 2017)

More Conceptual Models: (collected by Pat Dobson)



Reykjanes (Iceland) basaltic , Nielsson et al 2021

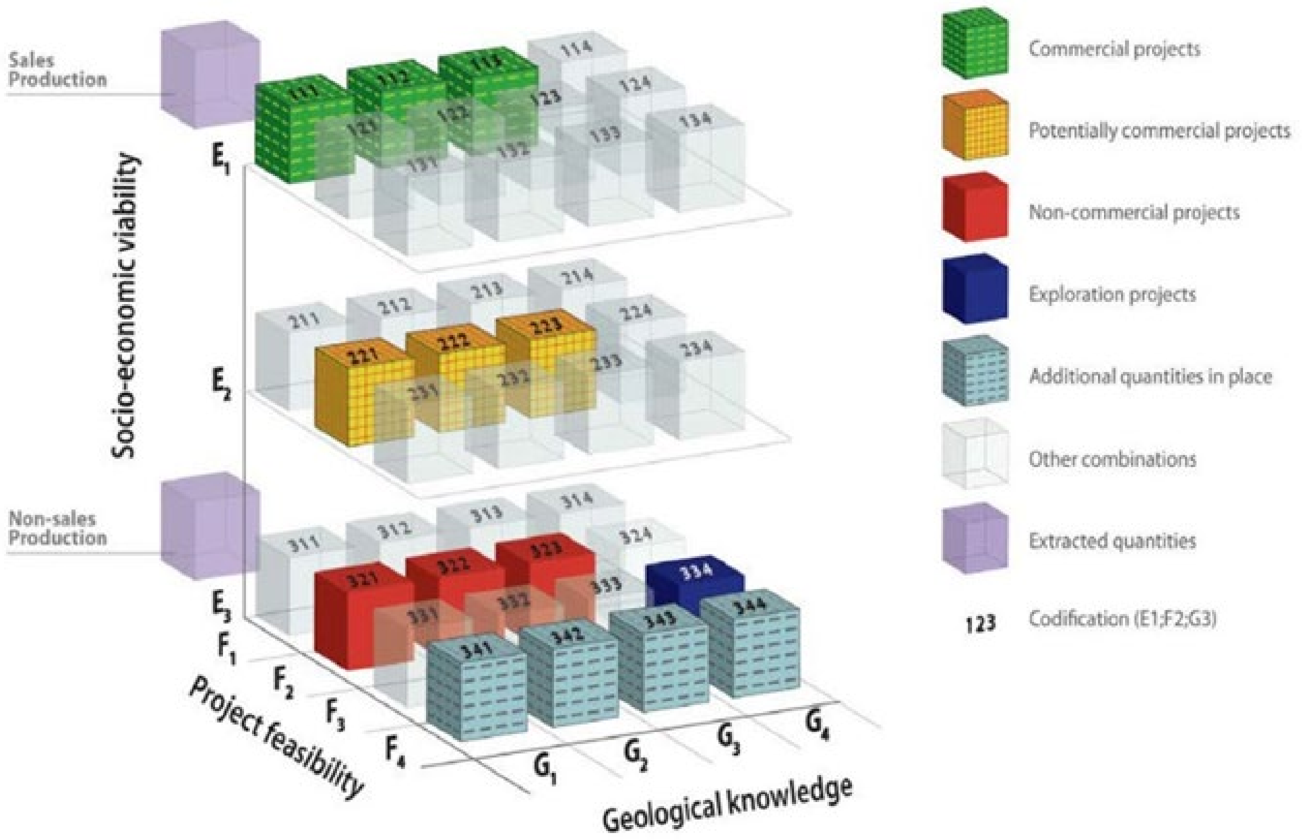


Strato-volcano (andesite) setting, Bogie et al 2006

Resource Assessment Methods and National Inventories

UNFC-2009 classification of identifiable geothermal resources: 3 axes for ranking projects

- E – Socio Economic viability
  - 3 layers
- F – Project Feasibility
  - 4 planes
- G - Geoscientific Knowledge
  - 4 planes
  - Matrix is E x F x G



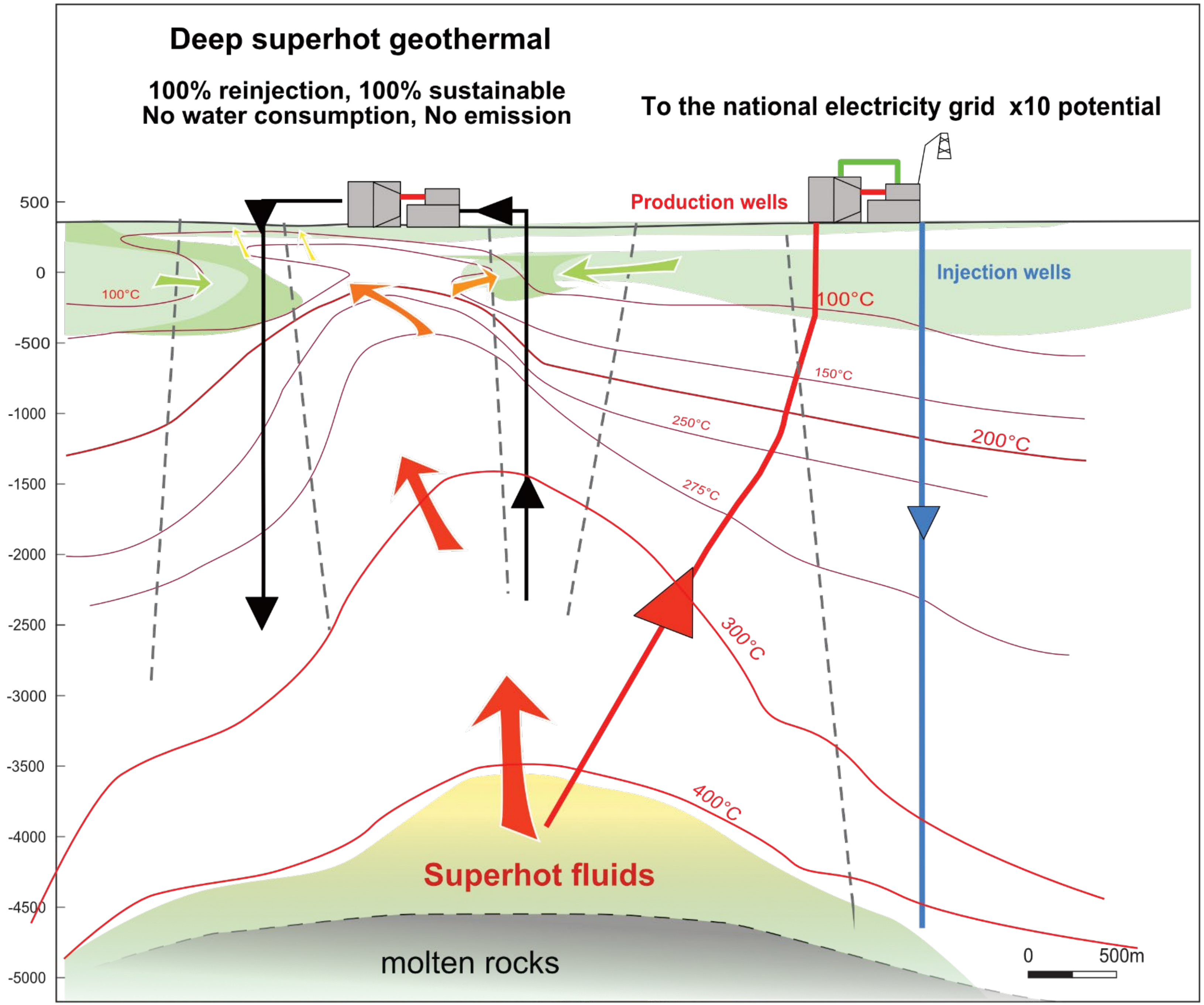
- Starting point is G (geo-science), identifying projects
- Only move up the E axis if the development will be producing a financially viable product in the foreseeable future (i.e. within maximum of 5 years).
- NZ Supercritical will be on level E3 (base level) for a while yet

International workshop planned in December 2022 to discuss SC volumetric resource identification, delineation and assessment methods (mostly using geophysics)

Concepts of supercritical development strategy…

to enable :

- community engagement;
- improved understanding of sustainable options;
- staged expansion to manage risk;
- adaptive reinjection strategy



CONCLUSIONS

The key challenges to address before significant advances can occur in use of supercritical geothermal resources :

- Solve drilling problems at extremely high temperatures and pressures (casing, drill-string, cement and mud fluids)
- Find or stimulate, and maintain, sufficient permeability to sustain production from a supercritical reservoir
- Reliably predict the competing effects of water-rock interaction (deposition, dissolution) and thermal stimulation (tensile fractures)
- Demonstrate mitigation methods for handling aggressive fluids (vapour, salt, magmatic gases, and acid condensates)

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Thanks

Chris Bromley

Geothermal : The Next Generation “Integrate”
IEA- Geothermal WG1,WG12, & WG13 Task D leader
IPGT: “Induced seismicity”