Role of Geology in Targeting Permeability for Geothermal Resource Utilisation

Presentation Outline

Role of Geothermal Geologist

Mapping, Stratigraphy and Structure

Hydrothermal Alteration

Permeability

Exploration ➡ Development

Summary

Dr. Greg Bignall

Head of Department

Department of Geothermal Sciences

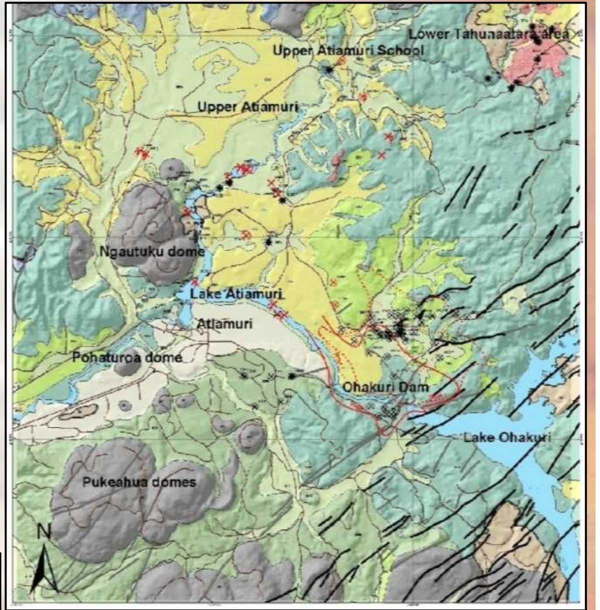
Wairakei Research Centre

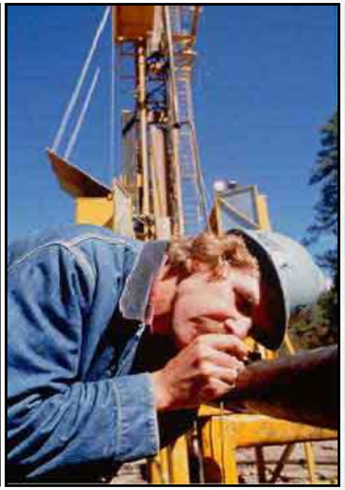
GNS Science, **NEW ZEALAND**

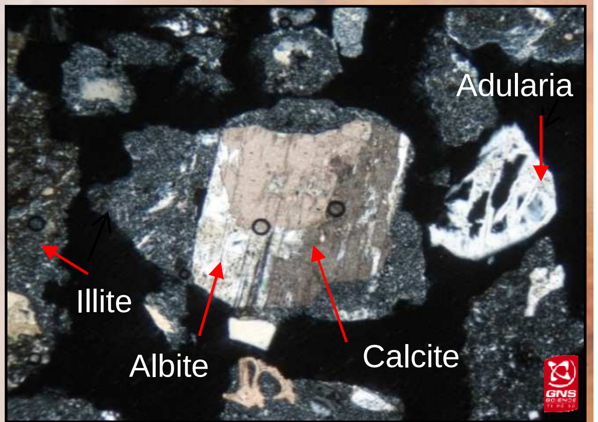
Role of Geothermal Geologist (1)

By observing minerals and rocks, the geologist learns about processes, and controls on hydrology.

- Rock types
- **Permeability controls**
- Fluid-rock interactions
- Heat source
- Age of the system
- Geohazards







Experience Matters !

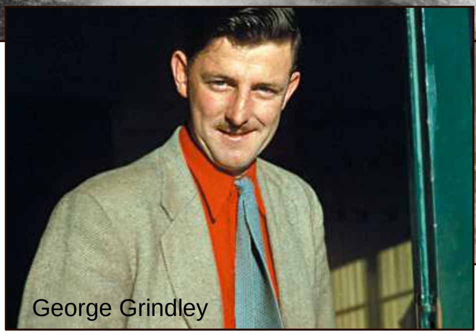
Pioneers of TVZ Geothermal Geology

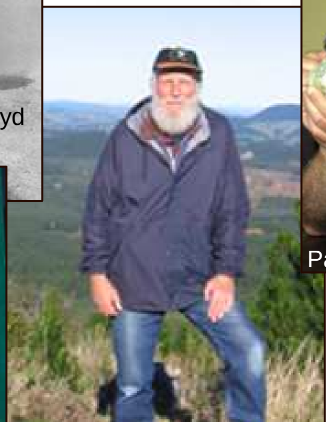
George Grindley, Jim Healy, Alfred Steiner, Don Rishworth, Bill Watters, Pat Browne, Peter Wood, Bruce Thompson, Ted Lloyd and others ….

New Zealand has long established geothermal research and consultancy expertise, acknowledged internationally.


Jim Healy

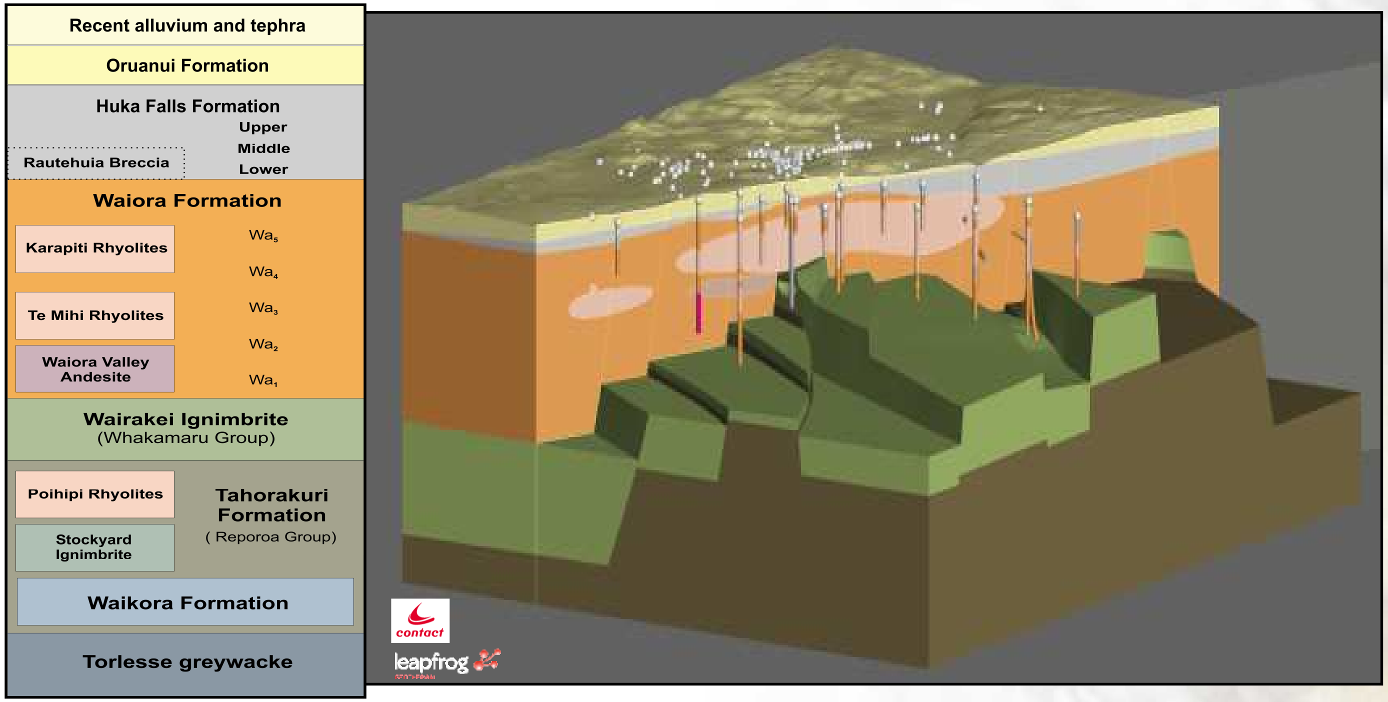

Ted Lloyd


George Grindley

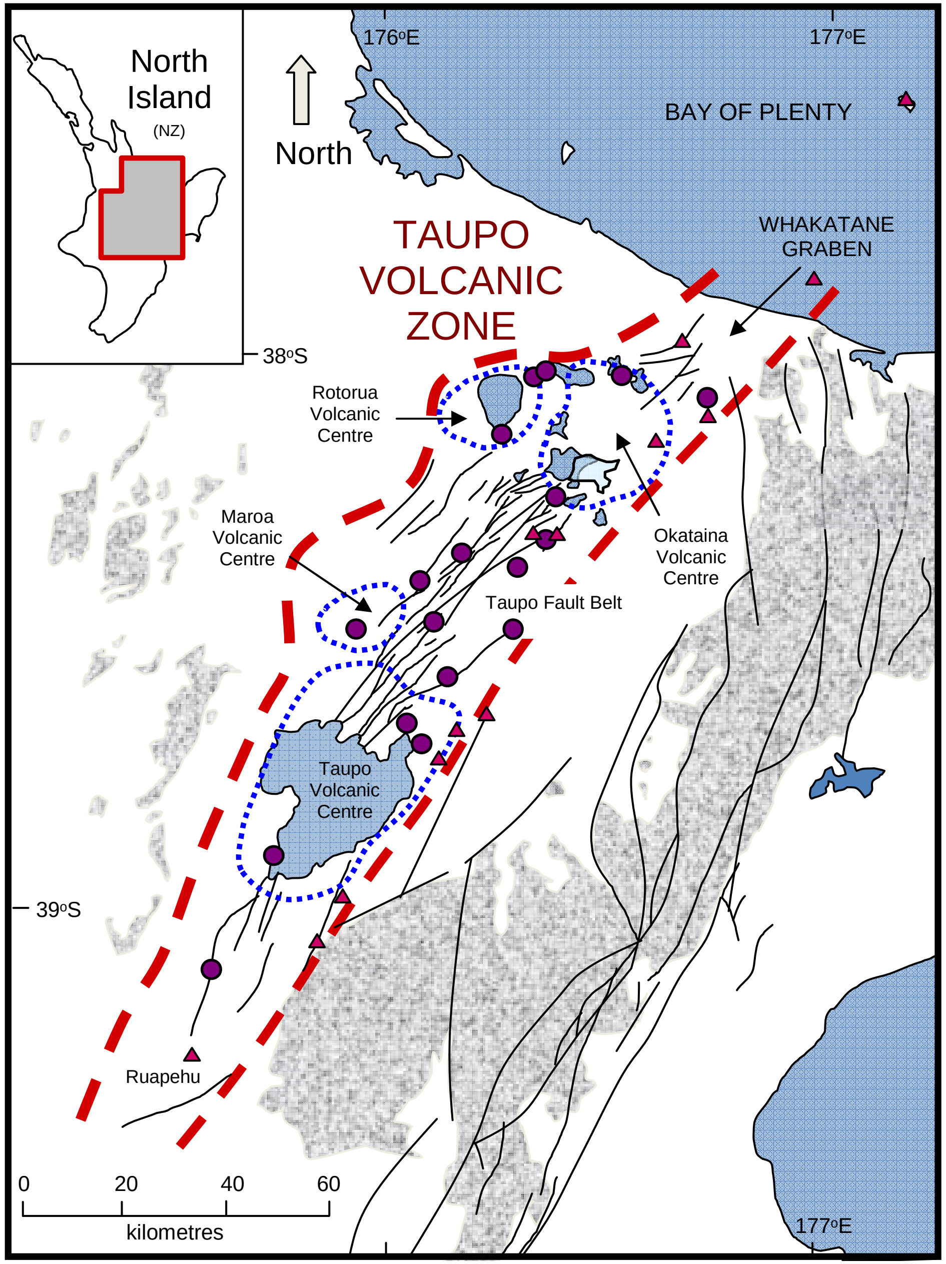

Peter Wood


Pat Browne

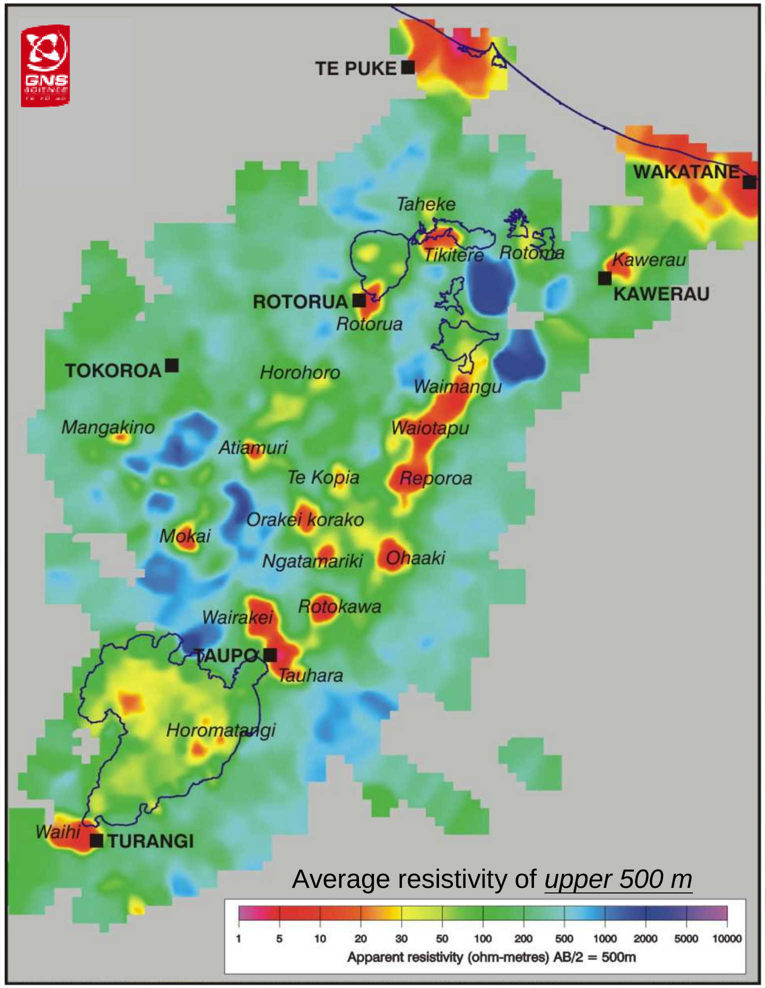

Alfred Steiner



Wairakei Geothermal Field



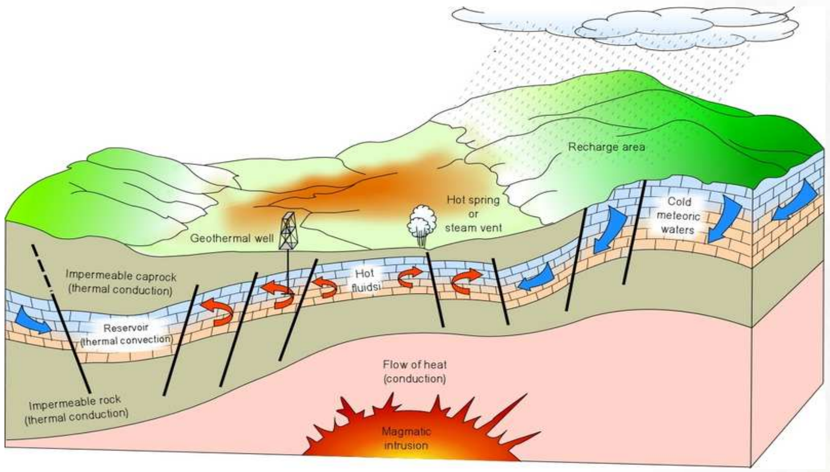
High temperature geothermal systems

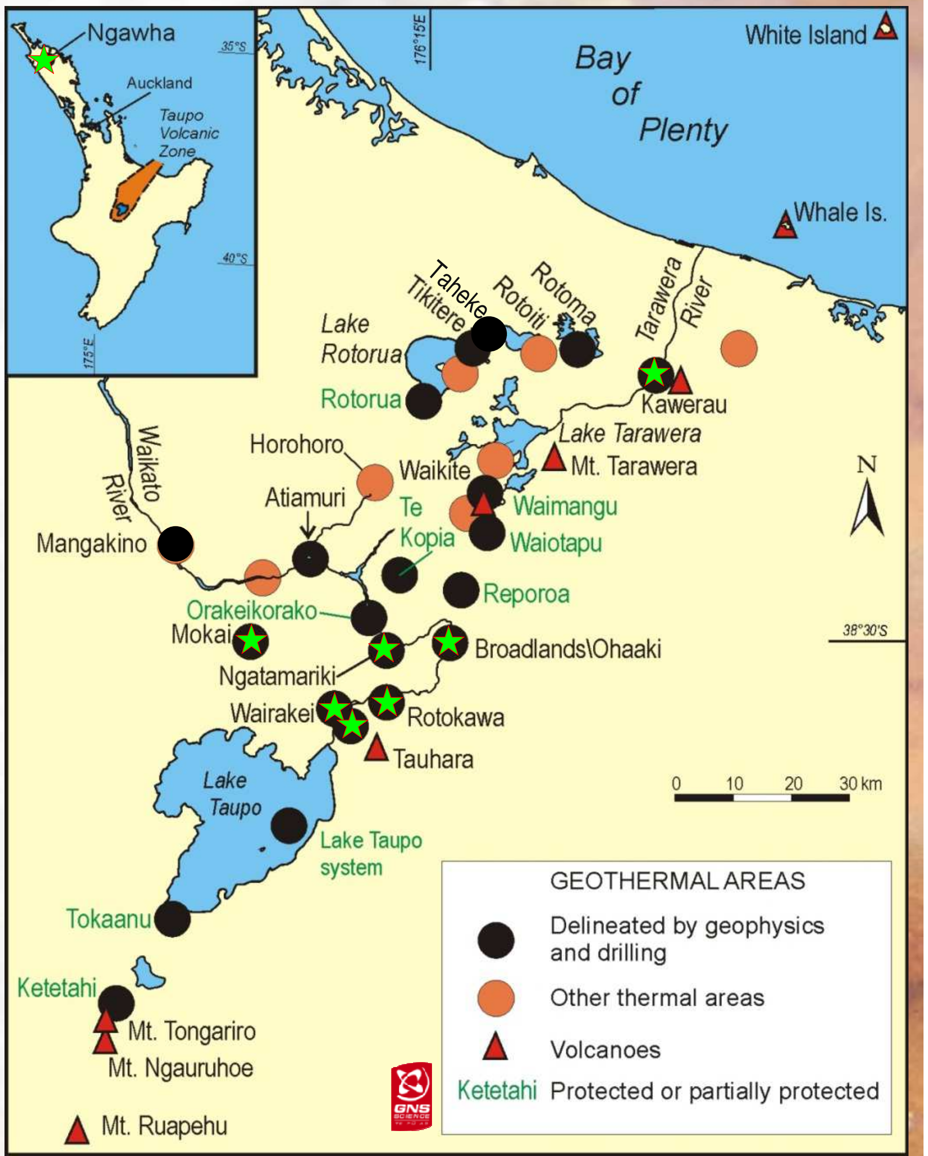


We've identified the "conventional" active, high-T geothermal systems in the TVZ – our challenge is to delineate the "deep-seated" (>4 km) resources (& low-enthalpy systems).

Recent TVZ Drilling Successes

- In the last 10 years, ~200 wells (for geothermal exploration, production, injection & T-P-X monitoring) drilled in N. Island.
- 10 fields (incl. Ngawha).
- Utilising dynamic targeting strategies, New Zealand has explored targets to -3000 mRSL



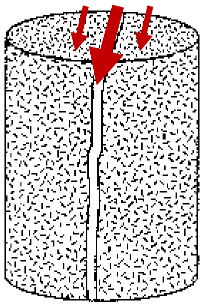


Permeability controls in TVZ systems

- In most TVZ systems, past drilling has targeted **structurally-controlled permeability**, associated with indurated rocks with low inherent permeability.

  e.g. reservoirs hosted by (andesitic) lava & meta-sediments (greywacke) at Kawerau/Rotokawa.

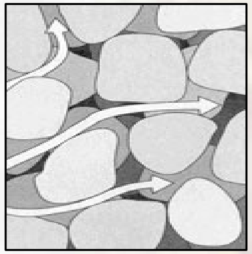
- In **ignimbrite-dominated** systems (e.g. Wairakei, Mokai), formation-hosted permeability may have greater importance in providing fluid pathways.



Formation Permeability

v

Fracture Permeability



Dominant control on fluid flow in TVZ systems ?

Drilling ignimbrite-hosted high temperature geotherrnal systems of the TVZ

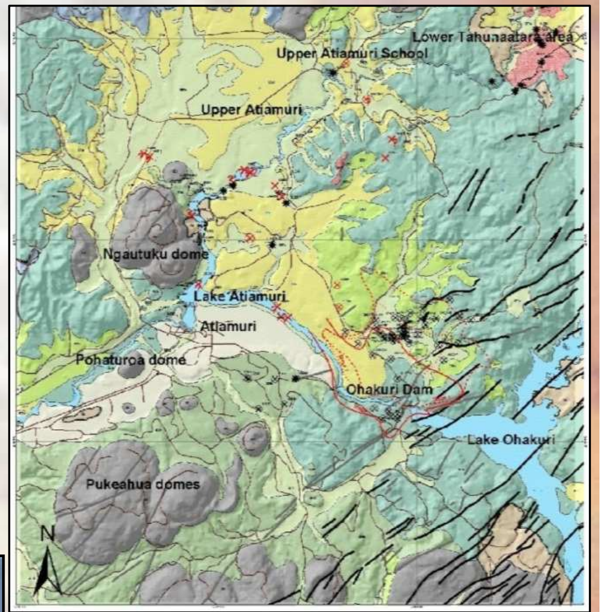
Role of Geothermal Geologist (2)

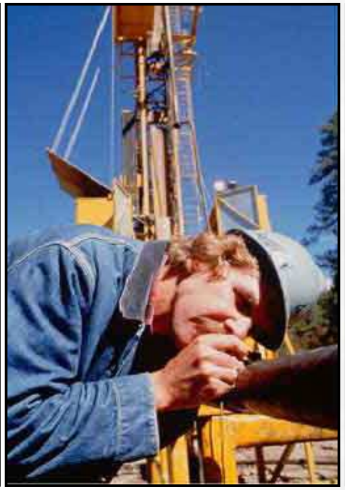
Geological activities divided into two parts:

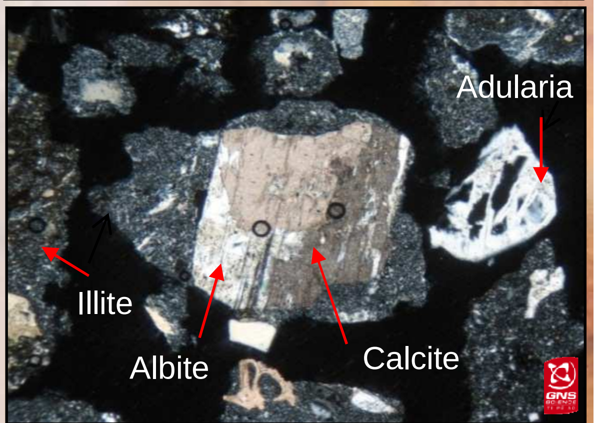
(i) Geology which takes place before drilling
(e.g. geological, alteration and surface feature mapping)

(ii) Geology undertaken during / after drilling

Geotechnical / geohazards geology important





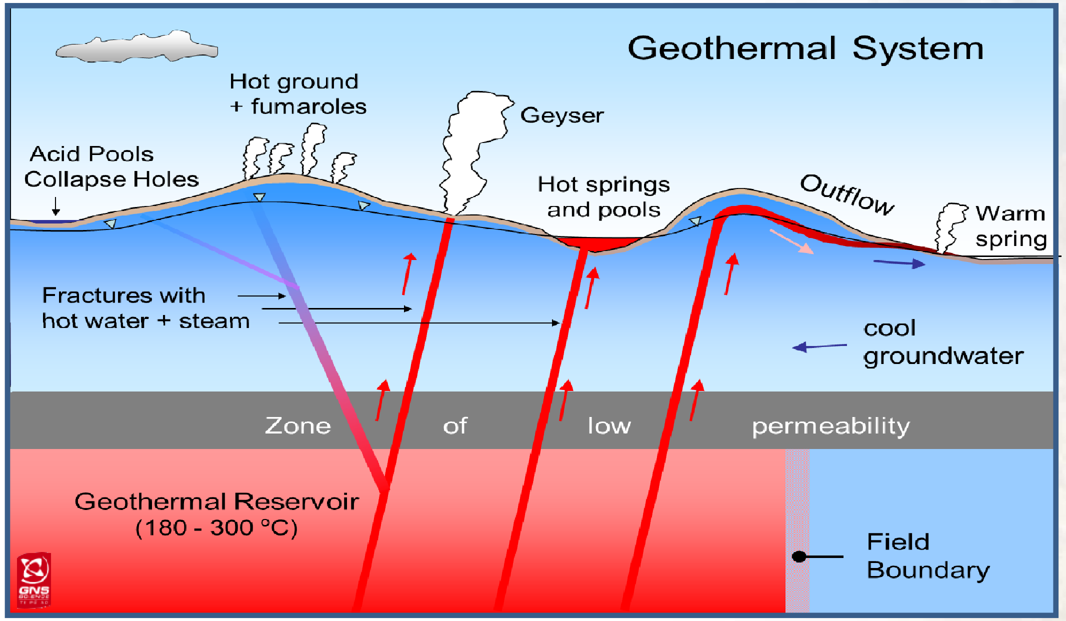


Surface Alteration Mapping

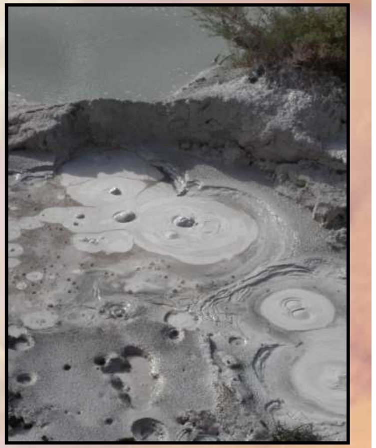
By understanding physical-chemical processes, and mineral stability ranges, the geologist can predict the nature of the reservoir fluids

Secondary minerals deposited in pores and fractures – replace existing minerals.

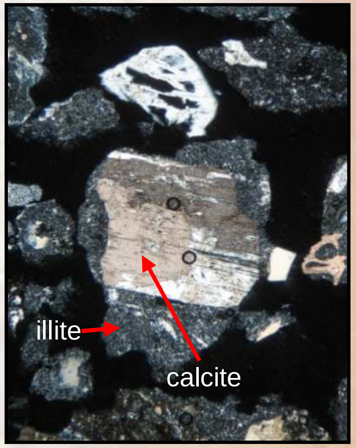
Distinguish degree (intensity) and nature (rank)



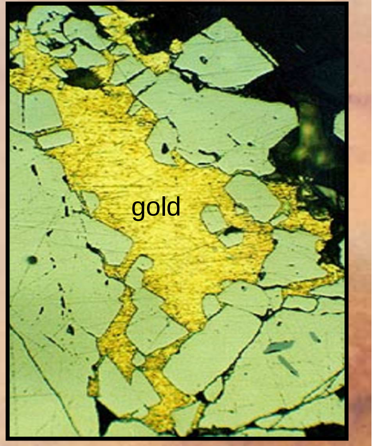
Silica sinter, Waiotapu



Mud pool, Rotorua



Calcite (illite overprint)



Mineral exploration

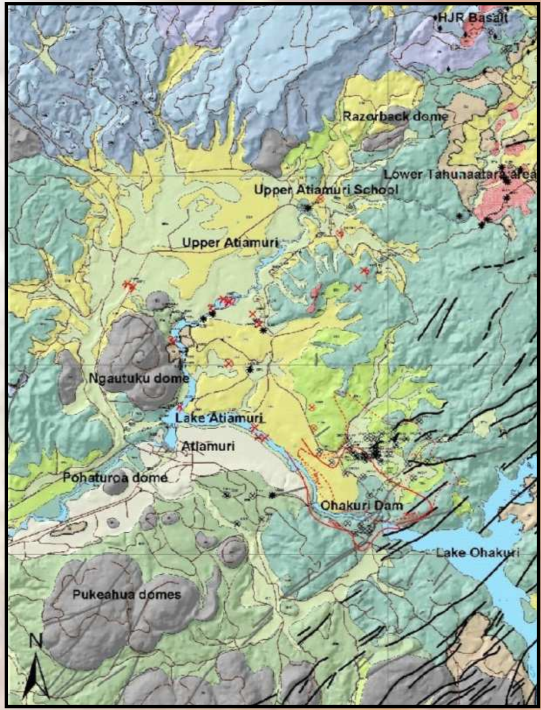
Surface Geological Mapping

Used to infer geothermal field geology

- Regional mapping
  - indicator of subsurface stratigraphy
  - analogy with other active volcanic areas

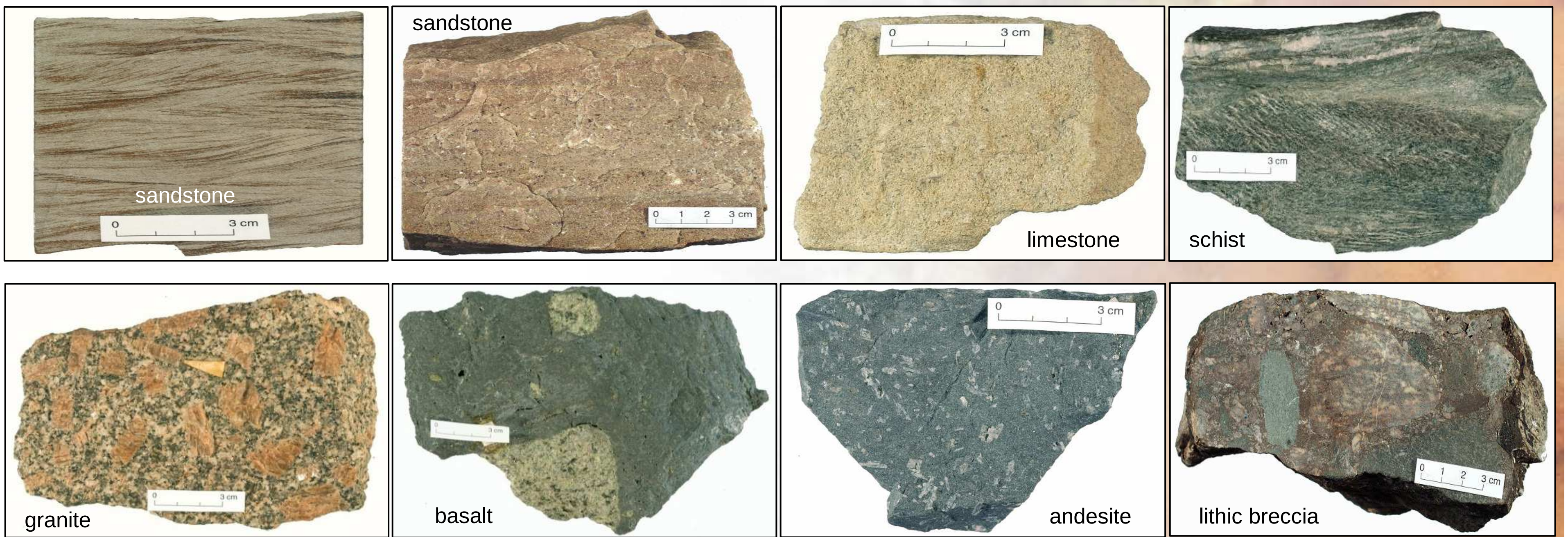
- Map thermal features/hydrothermal alteration

- Map stratigraphic relations to infer geological (eruptive/structural) history of the area
  - Units may not have been horizontally deposited
  - Units may have abrupt or irregular terminations
  - Cautious interpretation of age dating

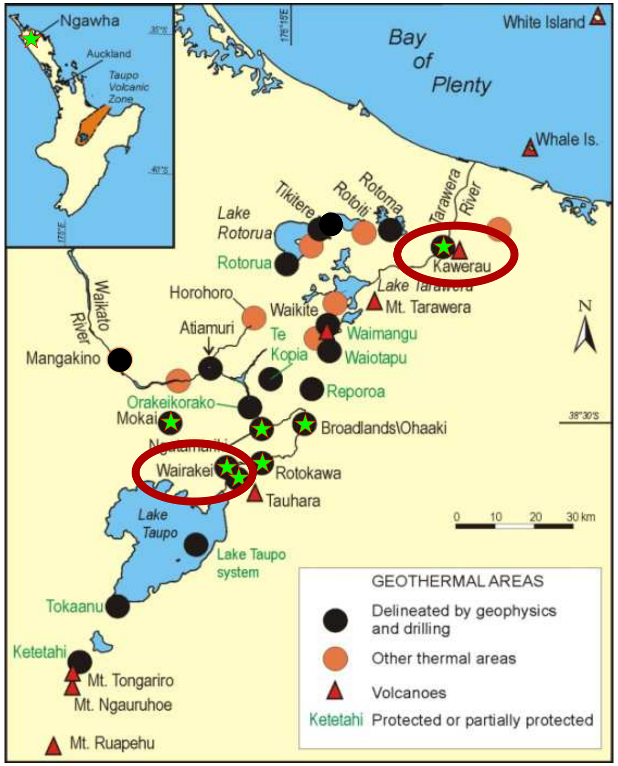


Typical Reservoir Rocks

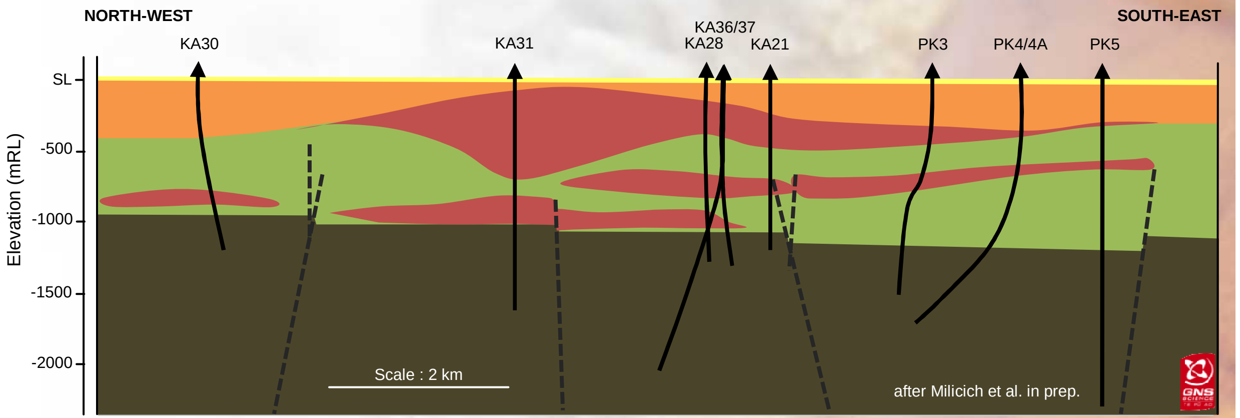
- Can be any type - most often volcanic or volcanogenic
- Easiest systems to develop are those with thick sequence of volcanic rocks
- Shallow, low-permeability basement: may not be favourable for production
- Carbonate rocks (e.g. limestones or marbles) may point to future problems



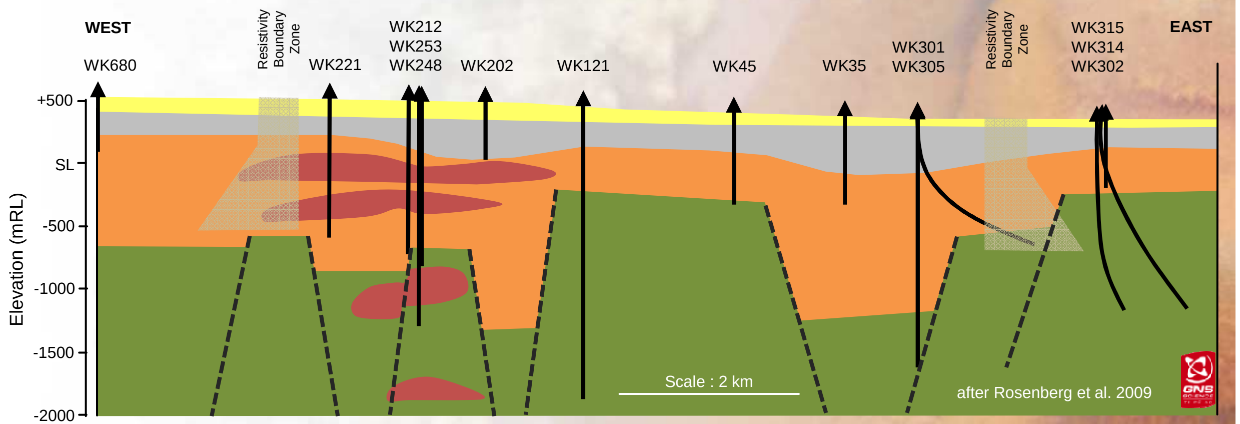
Field Stratigraphy



Surficial Deposits
Volcaniclastic Sediments
Volcanic Lavas and Intrusives
Post 250ka Pyroclastic Units
Pre 250ka Pyroclastic Units
Basement greywacke



Kawerau Geothermal Field



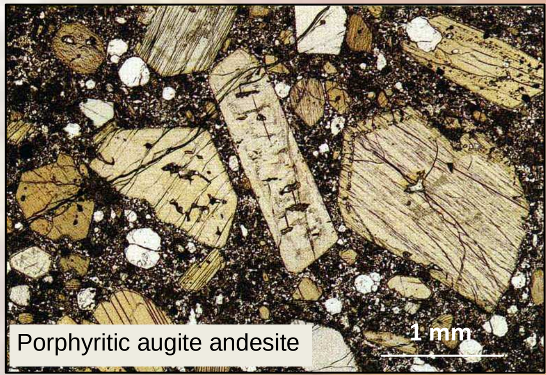
Wairakei Geothermal Field

Petrology

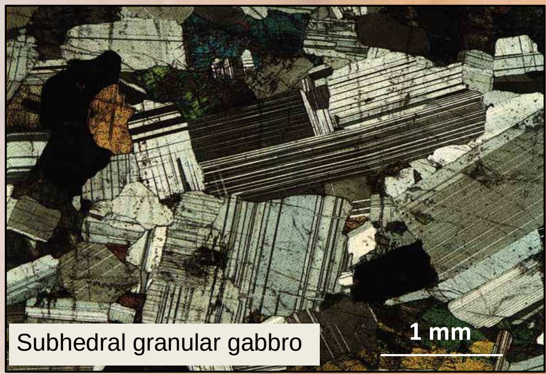
Objective of petrological work during exploration of geothermal systems is identification of :

- Primary Rock Types
  - assist structural interpretation
  - correlate/differentiate stratigraphic units
- Infer controls on permeability in the system
- Evidence for thermal (or chemical) change
- Help determine casing depths
- Hydrothermal Mineralogy

- infer fluid chemistry, reservoir temperature and system evolution



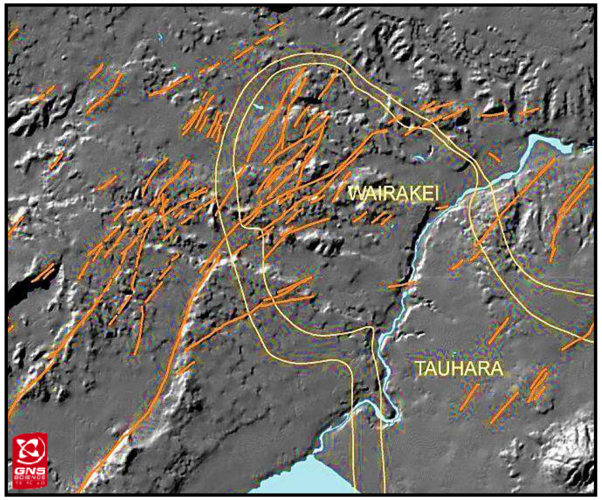
Porphyritic augite andesite



Subhedral granular gabbro

Structure

Silica sinter covered fault scarps, Orakei Korako



Active faults map, Wairakei-Tauhara

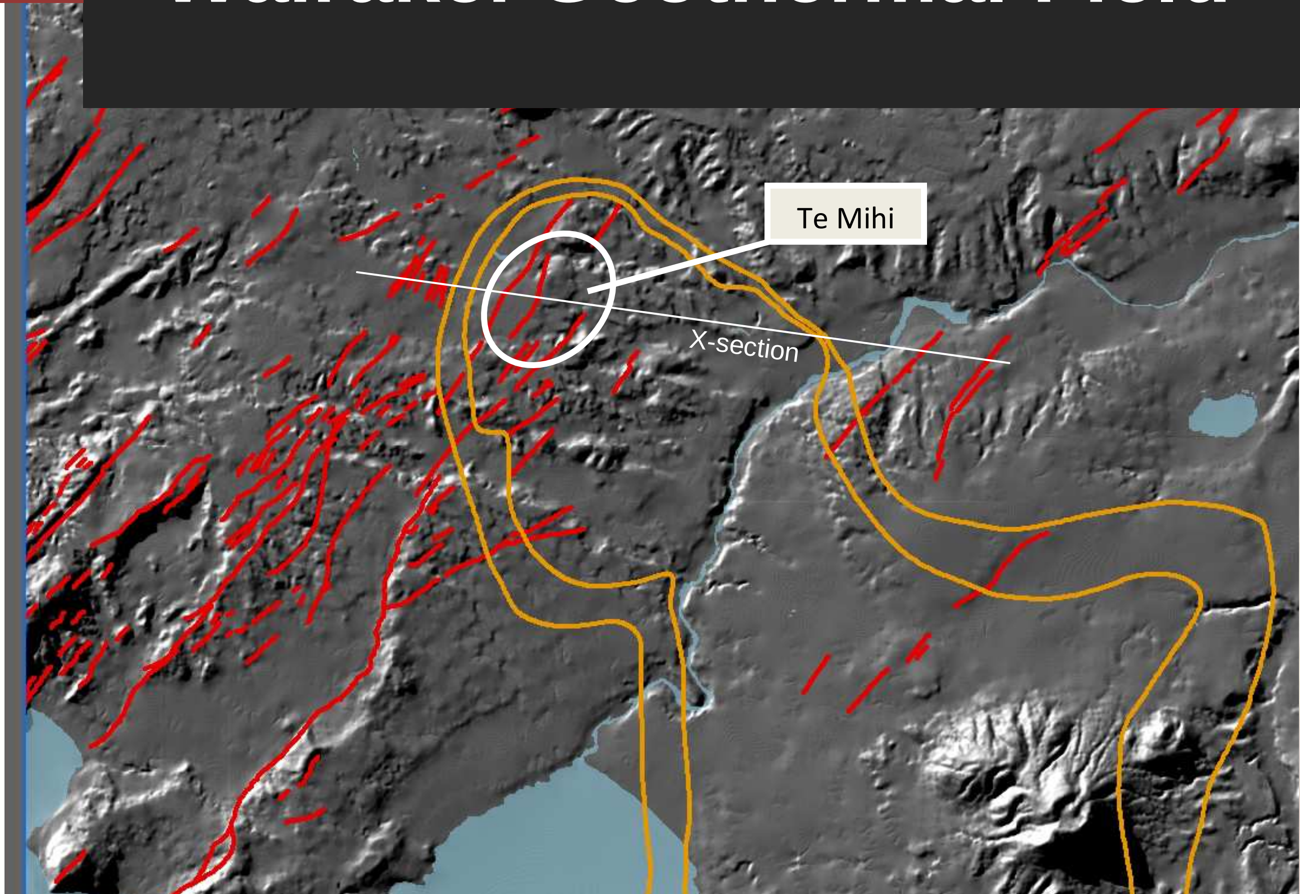
To predict permeability controls in the geothermal reservoir – particularly fracture permeability.

Consider:

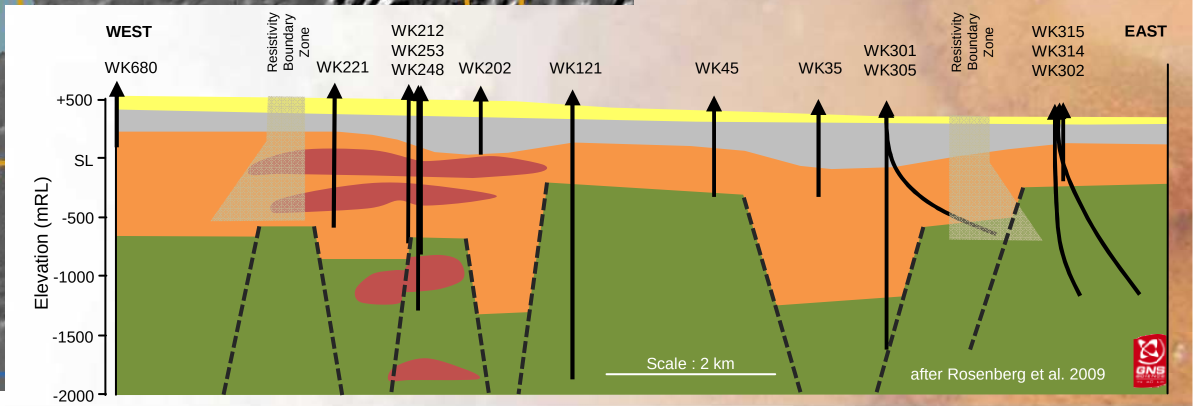
- Evidence of rejuvenated structural permeability
- Lateral outflows
- Detailed fracture and vein mapping
- Air photography – radar imagery
- Map structural lineations – thermal features

Within a sub-horizontal stratigraphy, the most productive zones are likely to coincide with wells that intersect steep dipping fractures.

Wairakei Geothermal Field



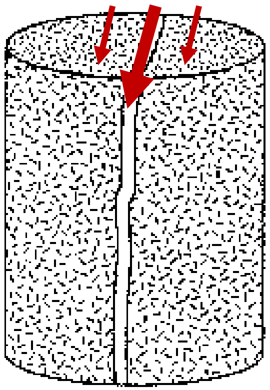
- Fault expressions eroded or obscured by recent volcanism
- Geodetic studies show NW-SE crustal extension in Taupo area of ~2-8 mm/yr
- Deformation provide fluid pathways along fault zones and diffusely through unconsolidated rock



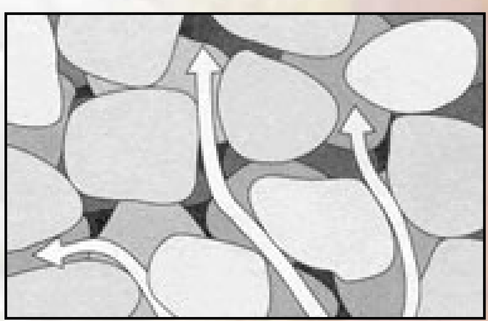
Permeability

"The state / quality of a material that causes it to allow liquids or gases to pass through it"

What is the dominant control on fluid flow in geothermal systems ?



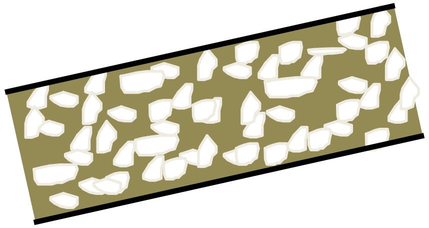
Fracture permeability (welded ignimbrite, andesite, greywacke)



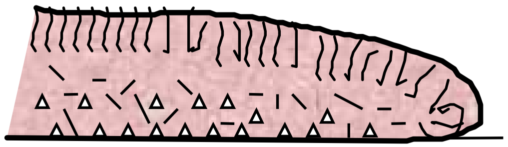
Bulk permeability (e.g. tuff, ignimbrite)

How does fluid move through rock?

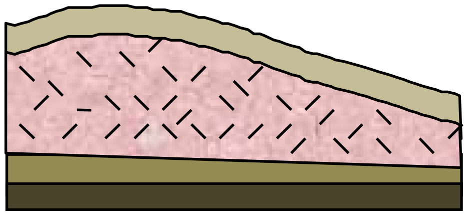
Primary Permeability



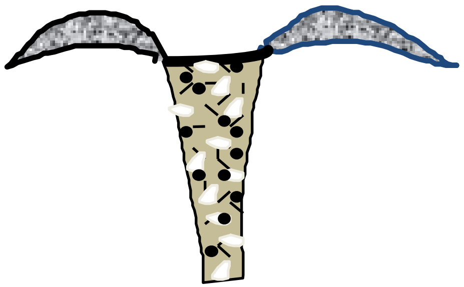
POROSITY
Distribution random, pores may not be interconnected



COOLING JOINTS & AUTOBRECCIATION
Lava Flows - random or sub-horizontal zones

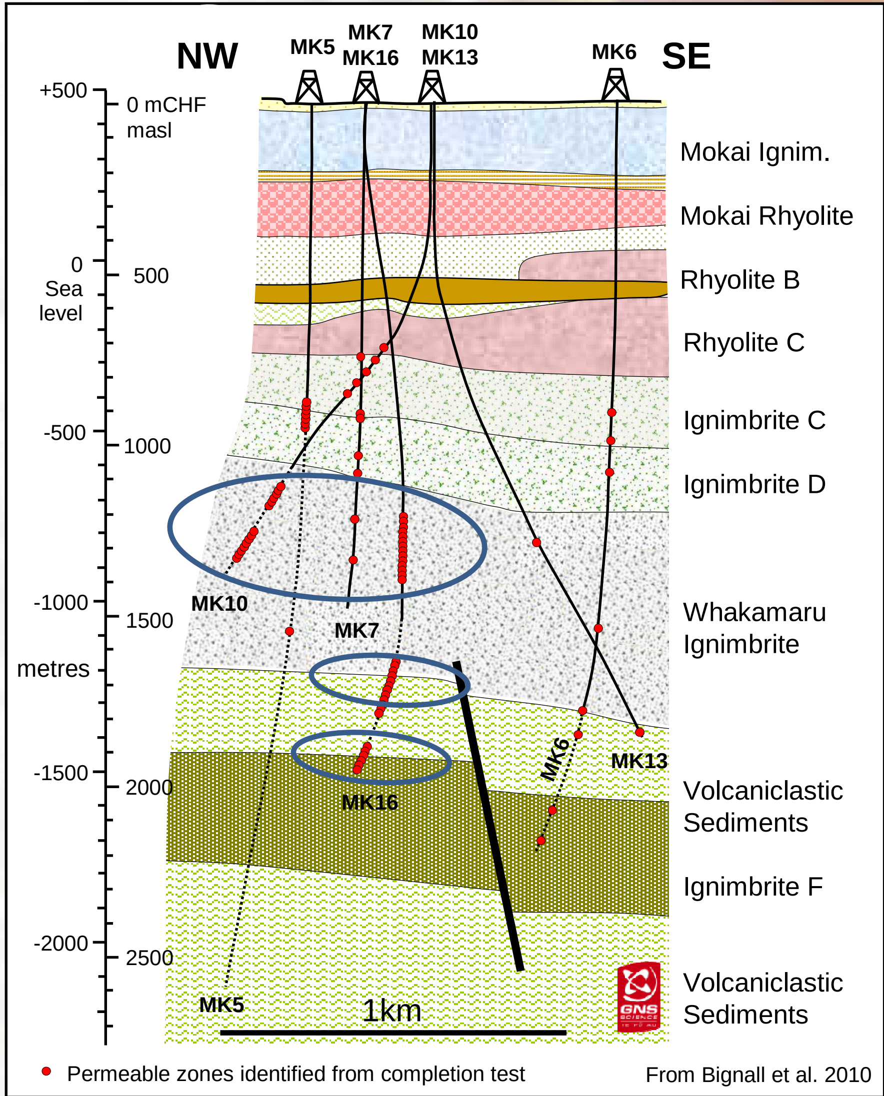


LITHOLOGICAL CONTACTS
sub-horizontal or low angles of dip



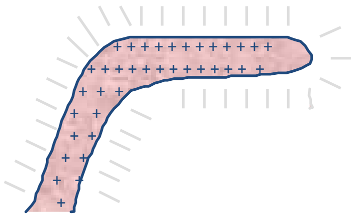
DIATREMES, VOLCANIC VENTS
Subvertical

after KML (1995)

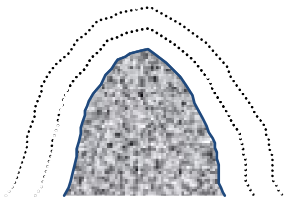


How does fluid move through rock?

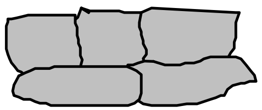
Secondary Permeability



FRACTURING
dyke injection - likely to be subvertical

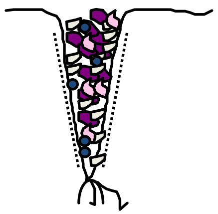


THERMAL CRACKING
Random distribution



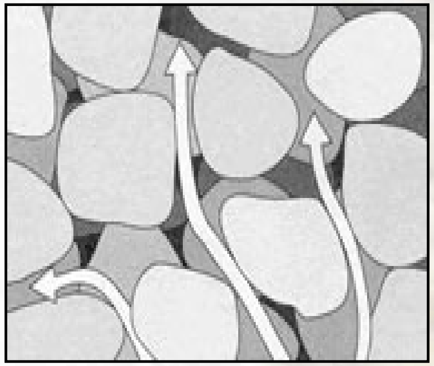
ROCK DISSOLUTION
Random distribution

FAULTING
Likely to be subvertical

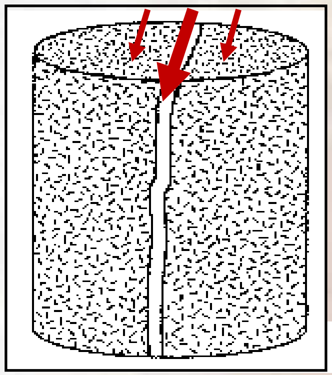


HYDROTHERMAL BRECCIATION
Likely to be subvertical

after KML (1995)

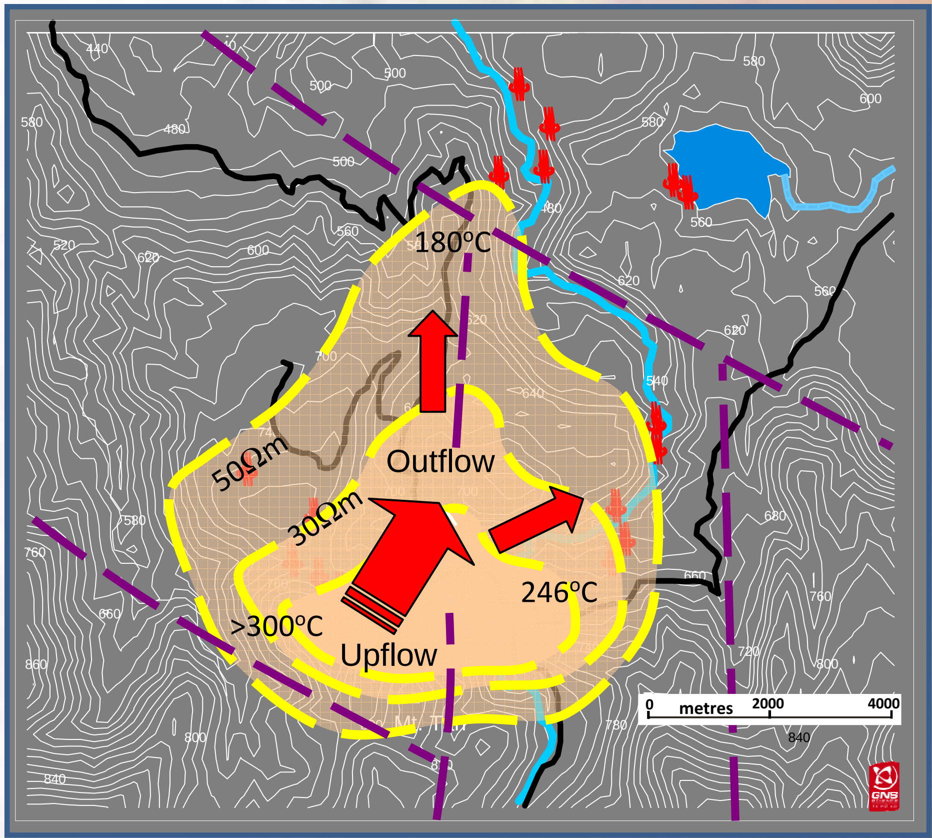


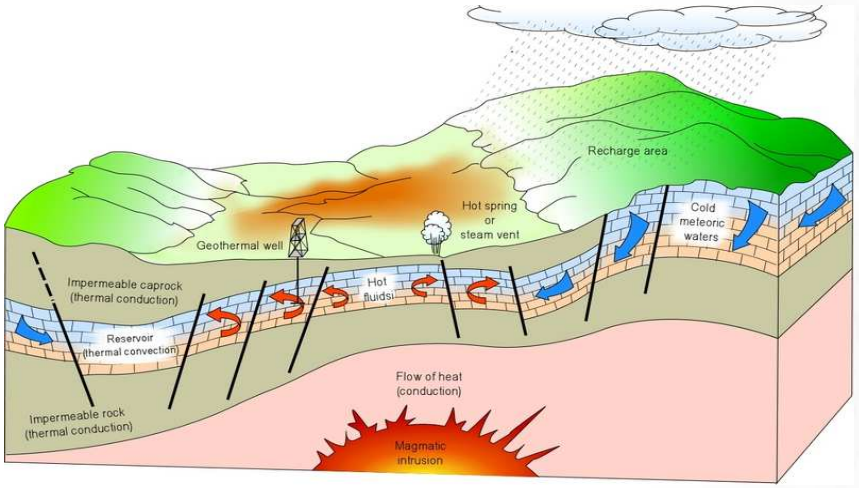
Formation v Fracture permeability



Conceptual (hydrological) Model

- Chemical / hydrological structure of the geothermal system
- Hydrological model evolves as more information comes available.
  - + geophysically-defined
  - + geological control on fluid flow
  - + chemical structure (e.g. reservoir conditions, flow path, temperature, acidic fluids ?)





Geological input to exploration drilling

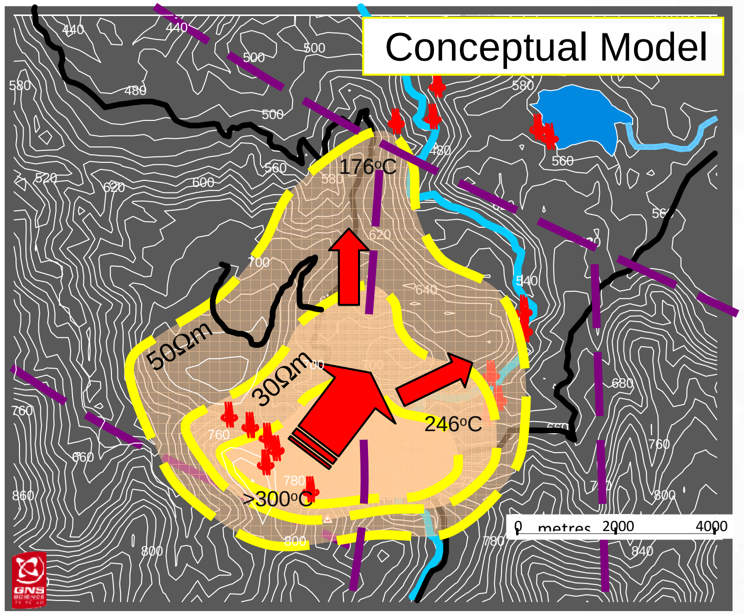
The exploration geologist has an important role, in combination with engineers and developers, to:

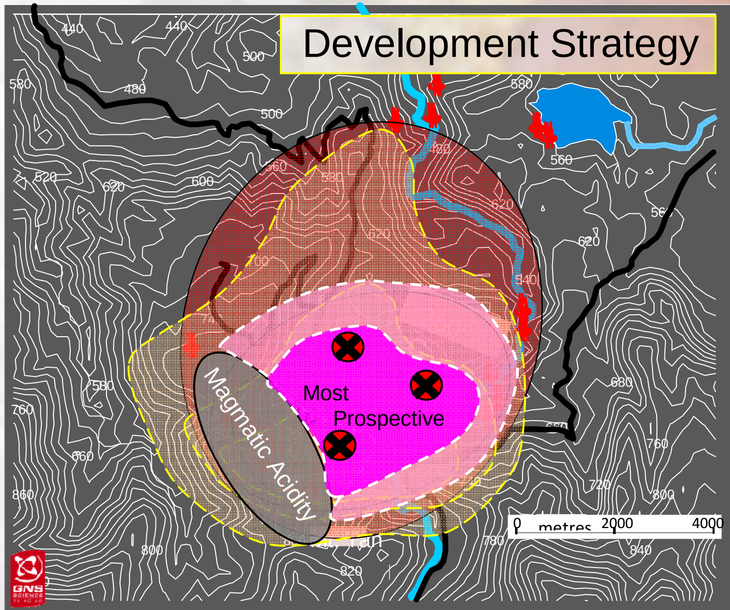
- design drilling strategy (define drill targets)
- achieve objectives of the drilling programme
- support interests of the developer/operator.

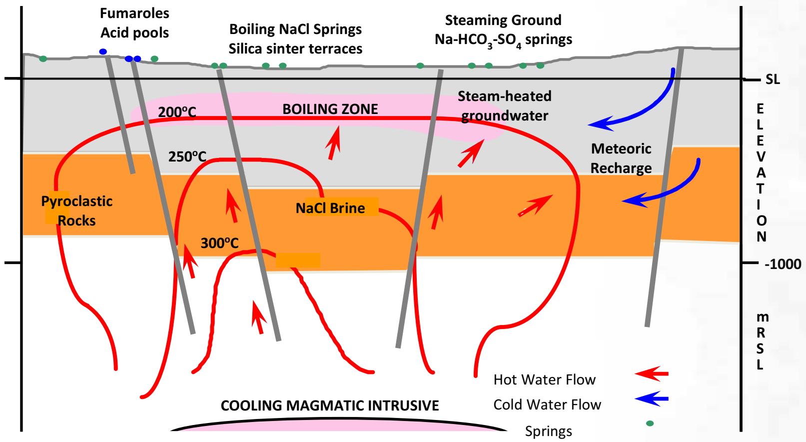
Goals of Exploration Drilling

- **Test hydrological (conceptual) model**
- Confirm commercial temperatures / permeability
- Refine capacity assessment
- Part of development scheme (commercially productive)
- Reasonable cost
- Provide project confidence

Well targeting at reduced risk (1)







Probable

Possible

Speculative

Drillhole

Well targeting at reduced risk (2)

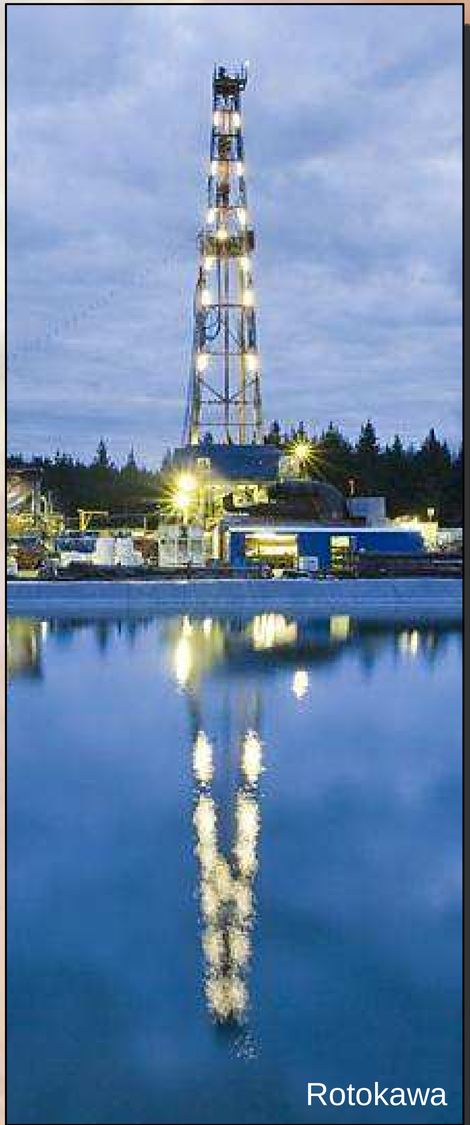
Conceptual model based on integrated geology, chemical and geophysical information

•Insights from conceptual hydrological model:

- upflow v outflow zones?
- fault/fracture permeability v formation permeability?
- expected reservoir temperatures?
- reservoir chemistry?
- geophysical information: resistivity-defined field boundary?

•“green-field” exploration: little subsurface knowledge:

- delineation drilling to test areal extent/resource potential

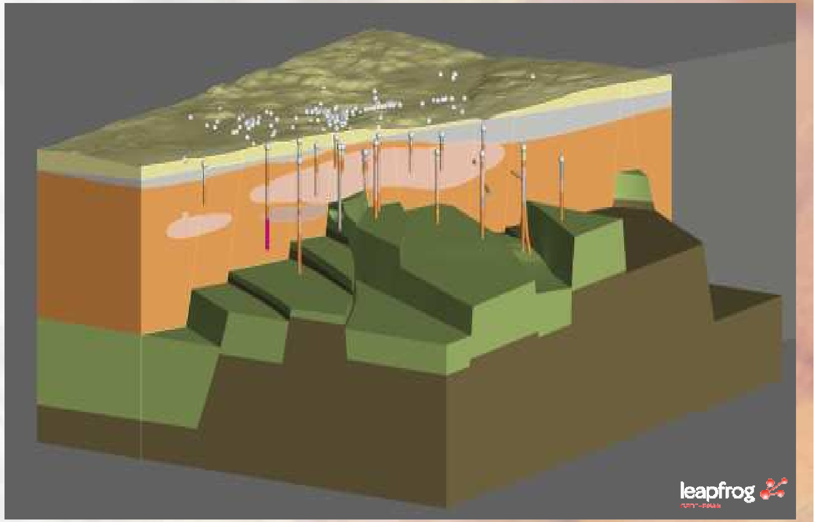

Rotokawa

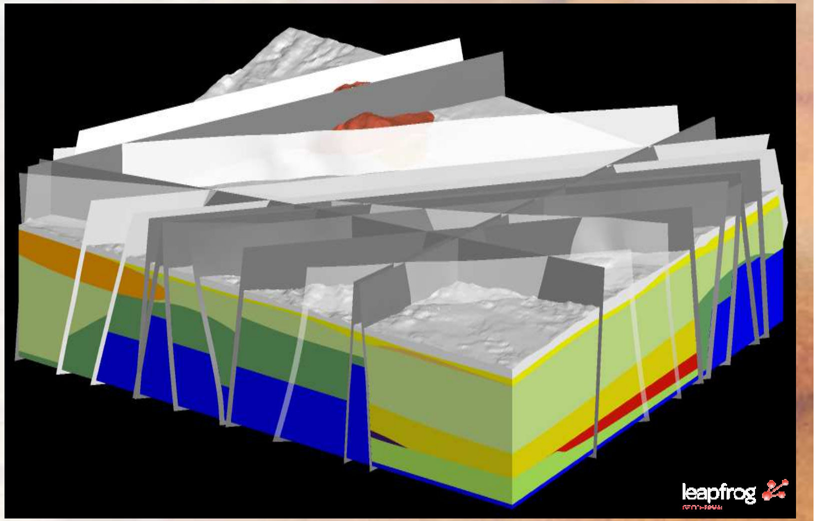
Role of Geothermal Rig Geologist

- Geologic prognoses:
  - stratigraphy and structure
  - permeable zones
  - temperature and pressure
- Recommend
  - depth of production casing shoe
  - coring depths
- Description of rocks
  - lithology
  - hydrothermal alteration
- Interpret
  - rock formations
  - stratigraphic context
  - fault structures
  - reservoir temperature
  - fluid chemistry
  - reservoir permeability
- Regular reporting
  - communication with on-site / office drilling staff
  - nature of formation (e.g. hardness, fracture permeability, acid zones, swelling clays, correlate drilling parameters with geology)
  - maintain geologic log / completion report

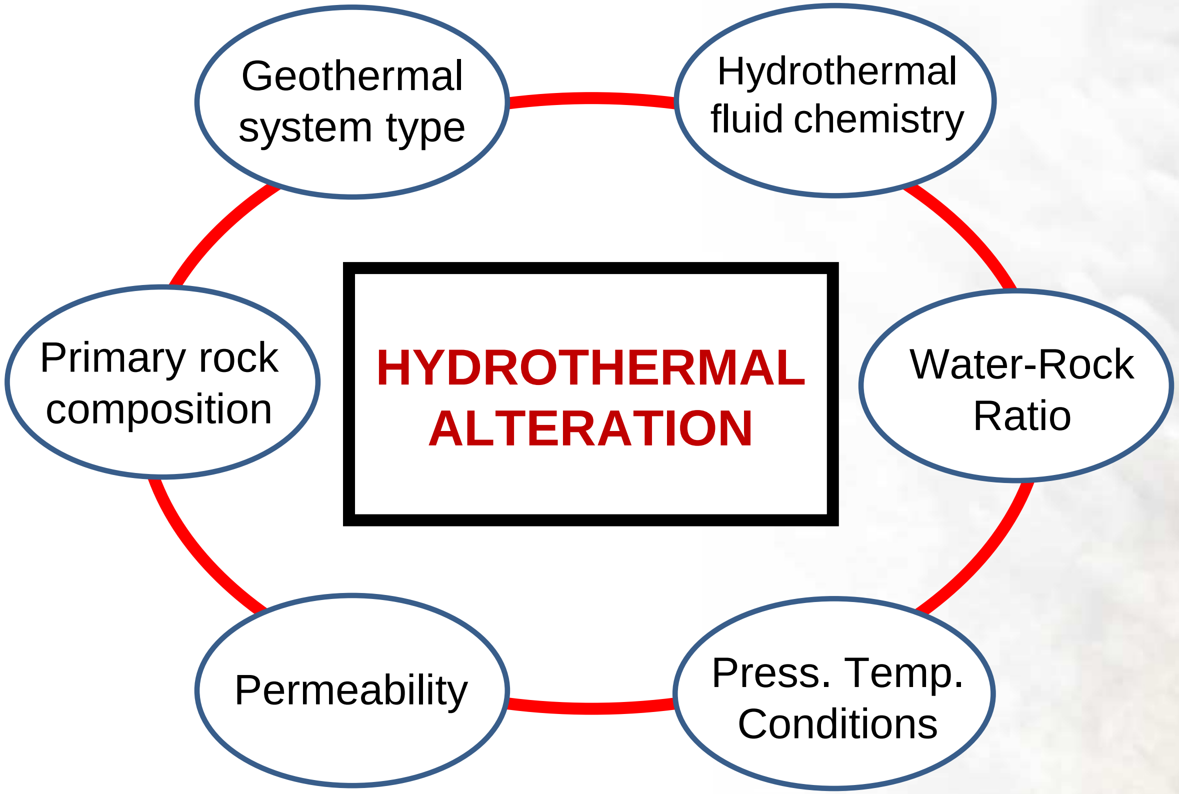
Geothermal 3D Modelling

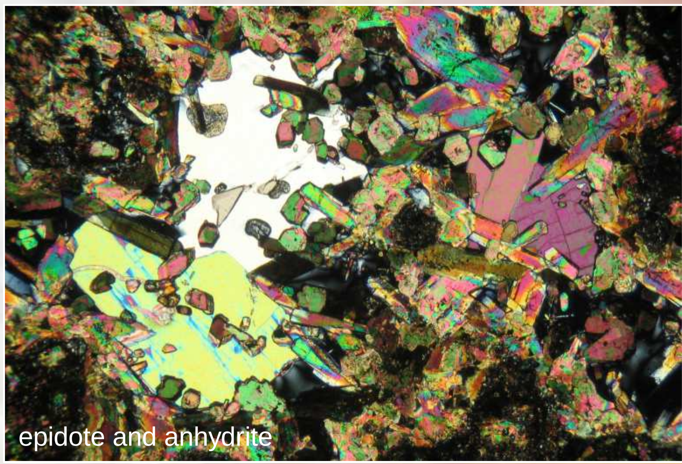
- 3D geological visualisation and modelling
- spatial integration of geoscientific data
  - geological, geochemical, geophysical data
  - DTM, air photos, maps
  - any x,y,z data
- only as good as the quality of input data
- conceptualisation of hydrological model
  - assist with future well targeting (geological prognoses)
  - reservoir management

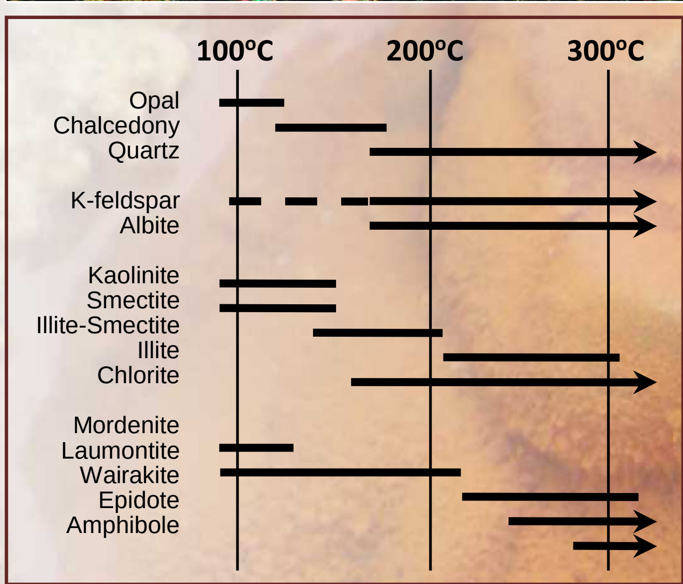




Hydrothermal Alteration







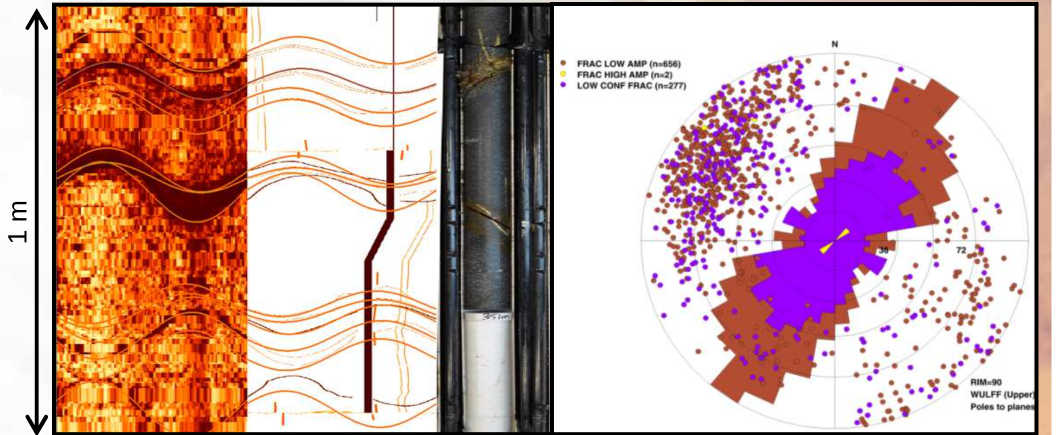
Look for evidence of thermal-chemical change in the geothermal system

Leading to revised hydrological model

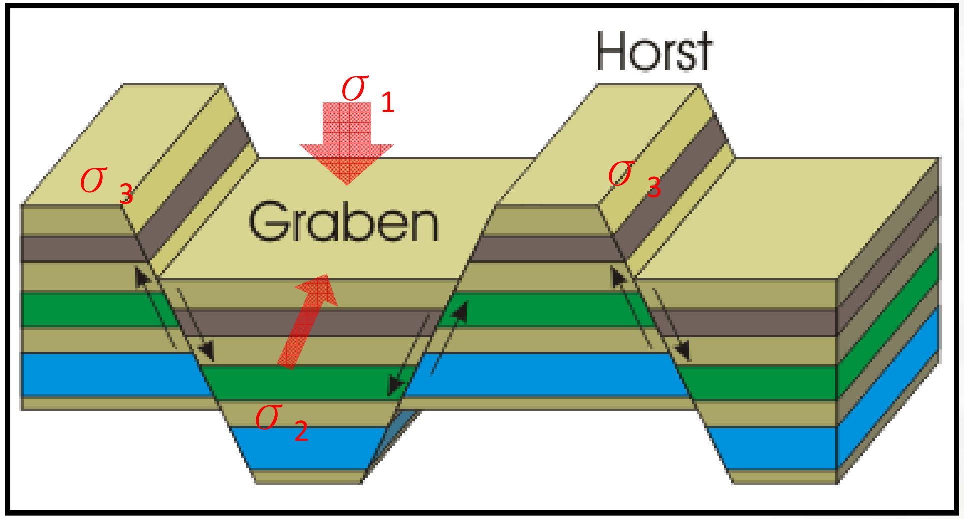
Fracture Imaging

High Temperature Acoustic Formation Imaging Technology (AFIT)

Acoustic Formation Imaging Technology



Fracture orientation, width & distribution

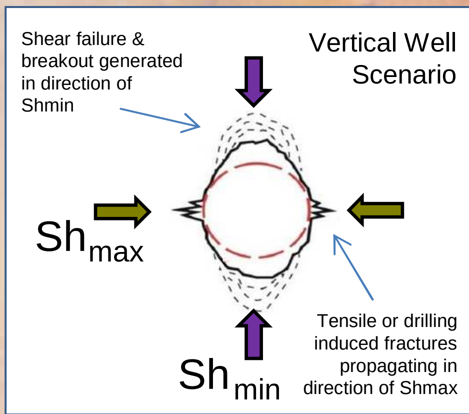


Characterise stress orientation

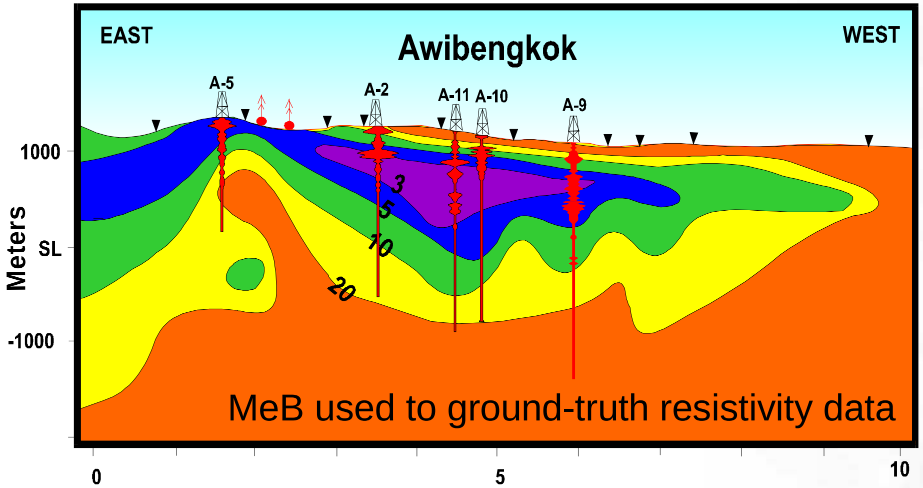
Extensional regime

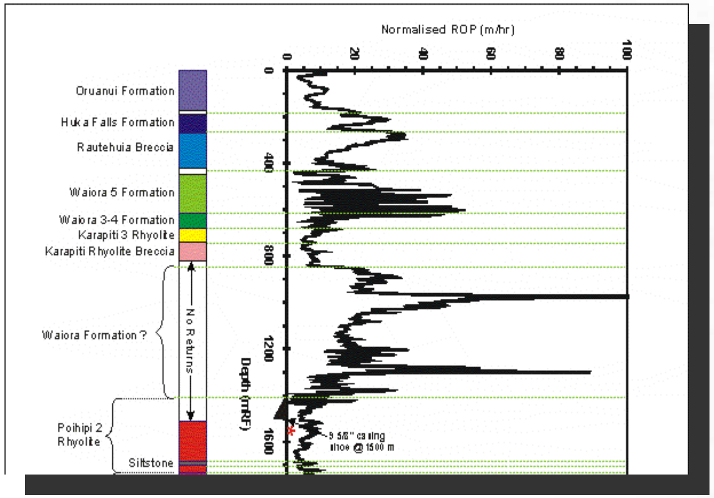
$S_V = \sigma_1$

Horizontal stresses are S_{hmin} (S_3, σ_3) & S_{Hmax} (S_2, σ_2)

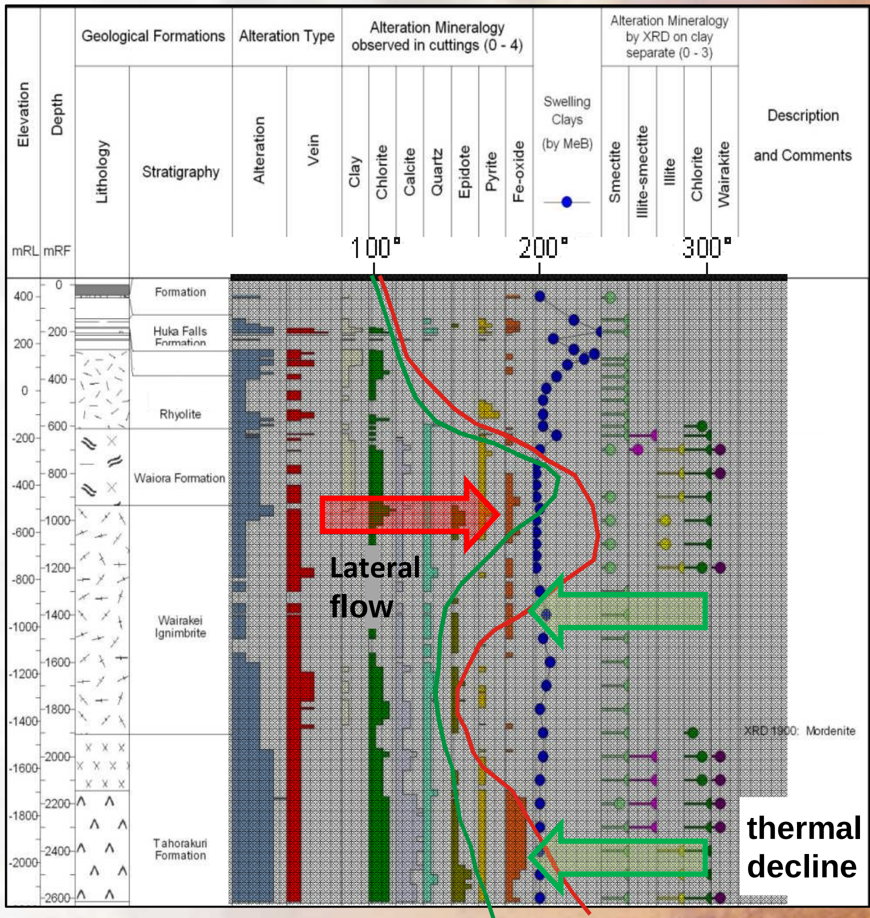


Infer Reservoir Geohydrology



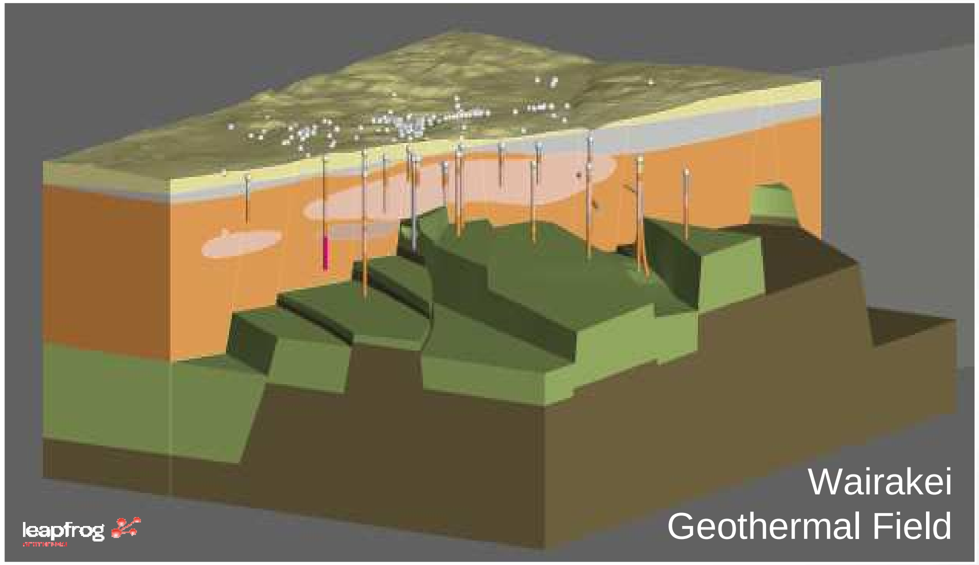


ROP: useful information in zones of blind drilling

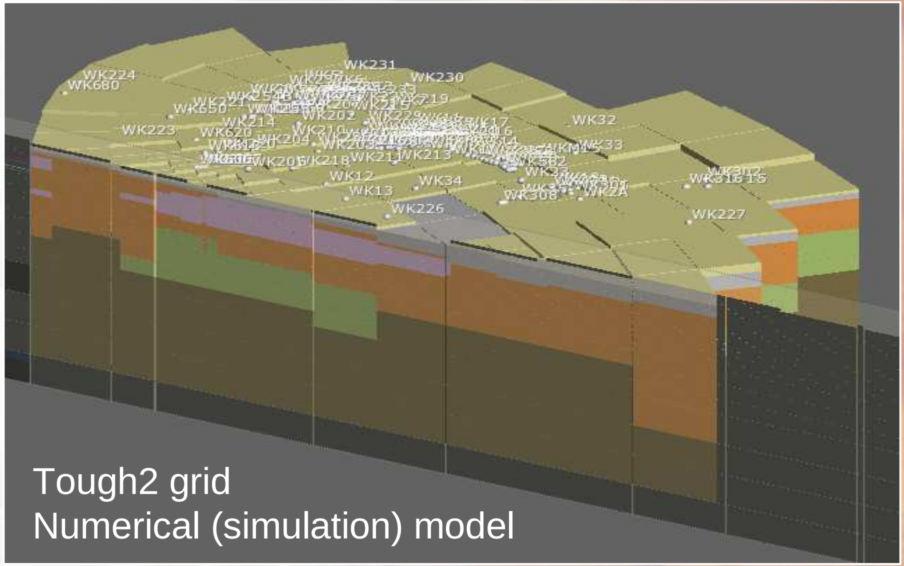


Infer upflow or outflow? / reservoir margin ? / thermal change ?

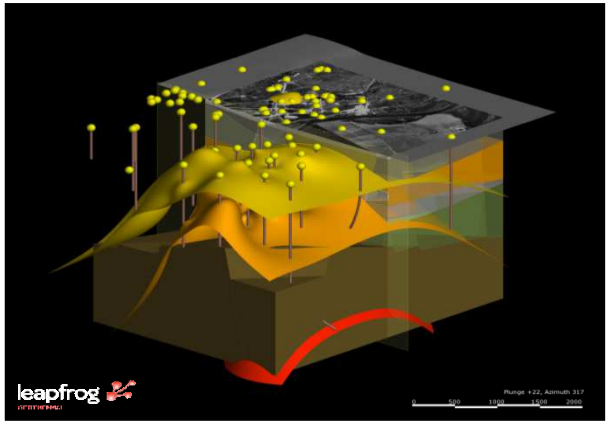
Revise Geological / Conceptual Model



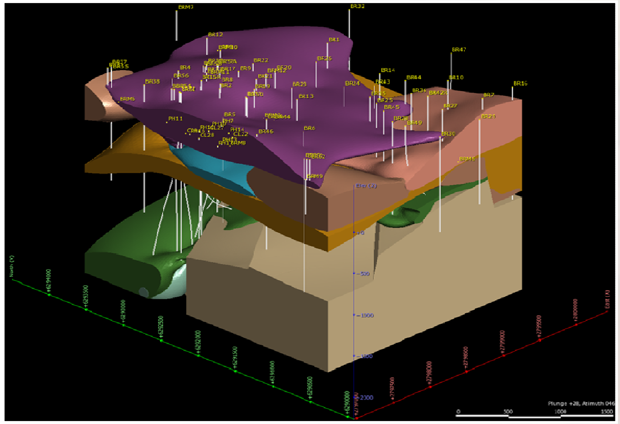
Wairakei
Geothermal Field



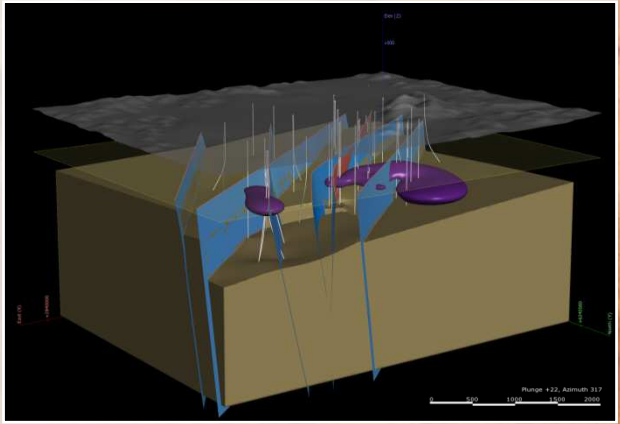
Tough2 grid
Numerical (simulation) model



Hydrothermal alteration



Stratigraphy



Structure

Engineered Geothermal Systems (EGS)

•Artificially create permeability via hydraulic and/or chemical stimulation of high temperature, low permeability rock mass.

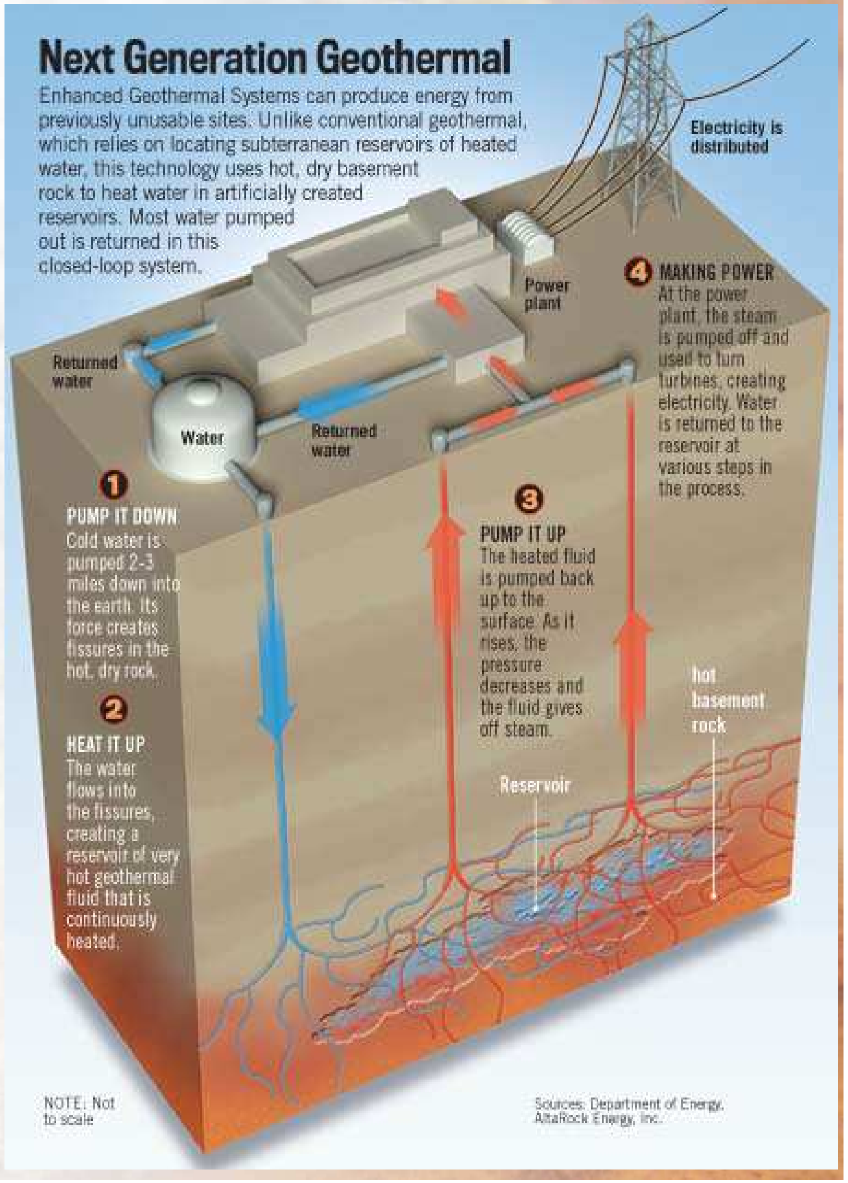
•Transfer heat to surface by circulating water (or other fluid) via a fracture network linking injection and production wells.

•Permeability is influenced by Thermal-Hydrological-Mechanical-Chemical effects

•Need to understand the effects, and their timing, in order to engineer the reservoir

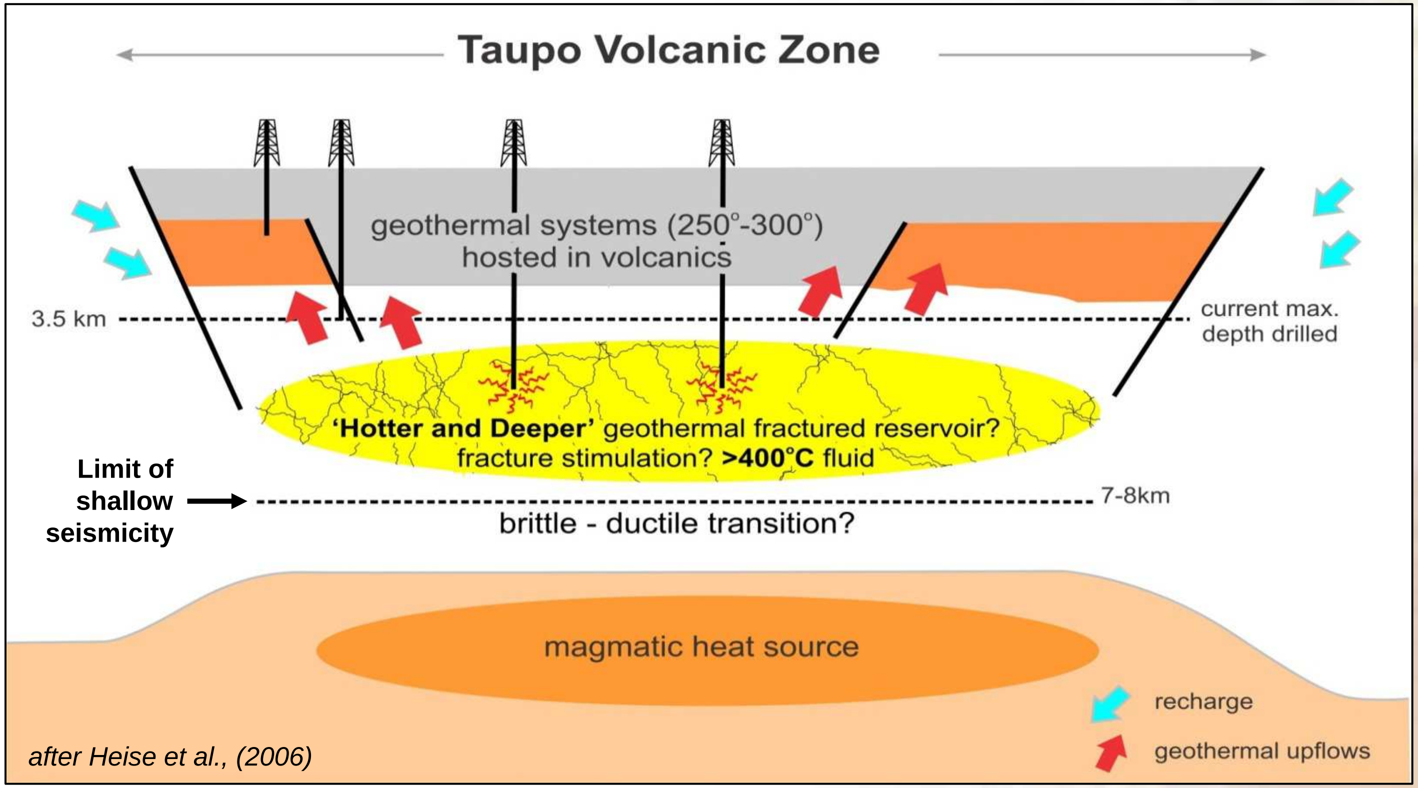
EGS Challenges :

•Resource characterisation
•Drilling Technologies (incl. cost)
•Reservoir Creation (stimulation)
•Longevity / Sustain reservoir
•Environmental Issues



Future Deep TVZ Drilling

The barrier to realising New Zealand's deep geothermal potential is the ability to identify permeability that can be tapped by drilling.



after Heise et al., (2006)

TVZ – deep science drilling project

Summary

1. Design geoscience strategy that aids decision making.
2. Geology input ongoing in field exploration, delineation and development stages.
3. Identification of positive resource attributes, and issues that could have a detrimental impact on resource development / use.
4. **Identifying / understanding controls on permeability is key !**
5. Sound geological advice early (and ongoing) has potential to save time, resources and money later …

Dr. Greg Bignall

GNS Science
Wairakei Research Centre
Taupo, NEW ZEALAND

http://www.gns.cri.nz

g.bignall@gns.cri.nz

THANK YOU