Application of Geoscience for Geothermal Resource Evaluation and Mitigation of Development Risks

Presentation Outline

Successful Low Risk Development
Geothermal Resource Evaluation
Geology – Chemistry – Geophysics
Hydrologic Models
Resource Parameters
Geothermal Risk Assessment

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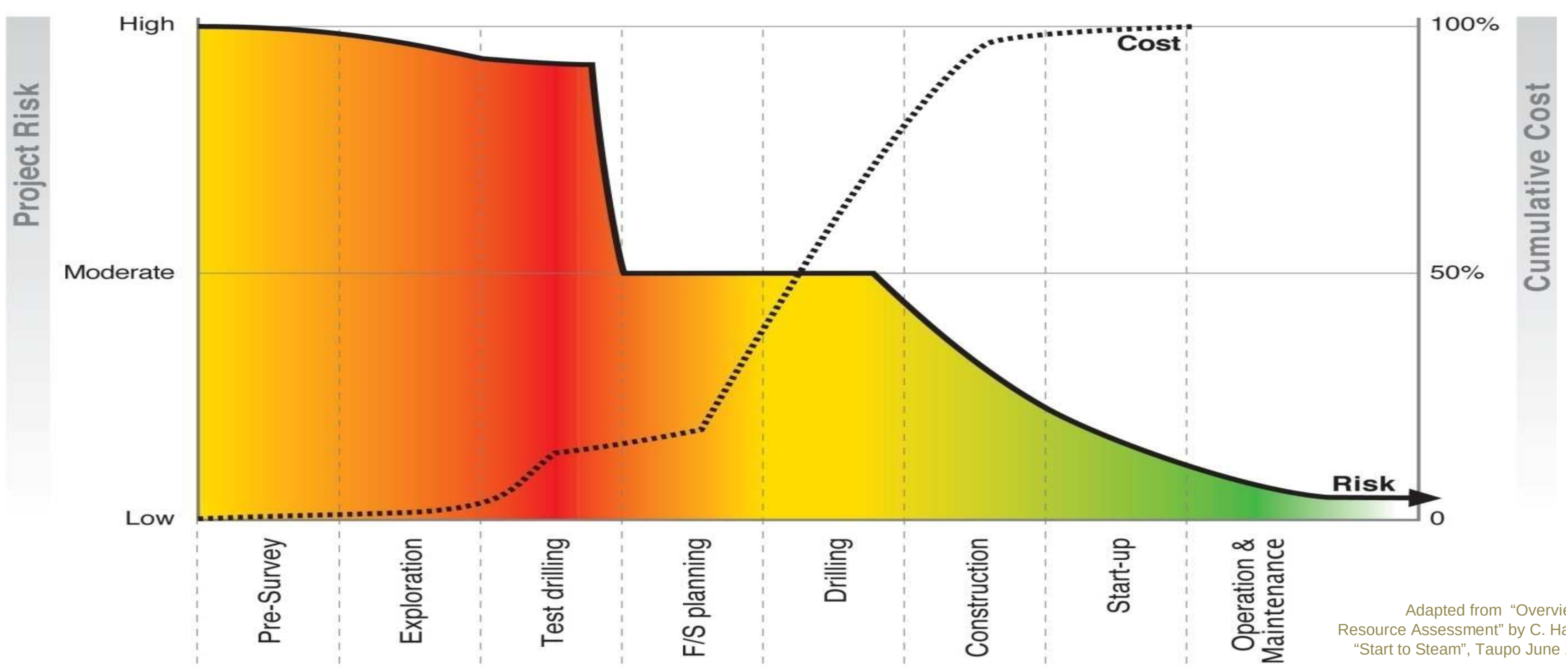
Outline of the presentation

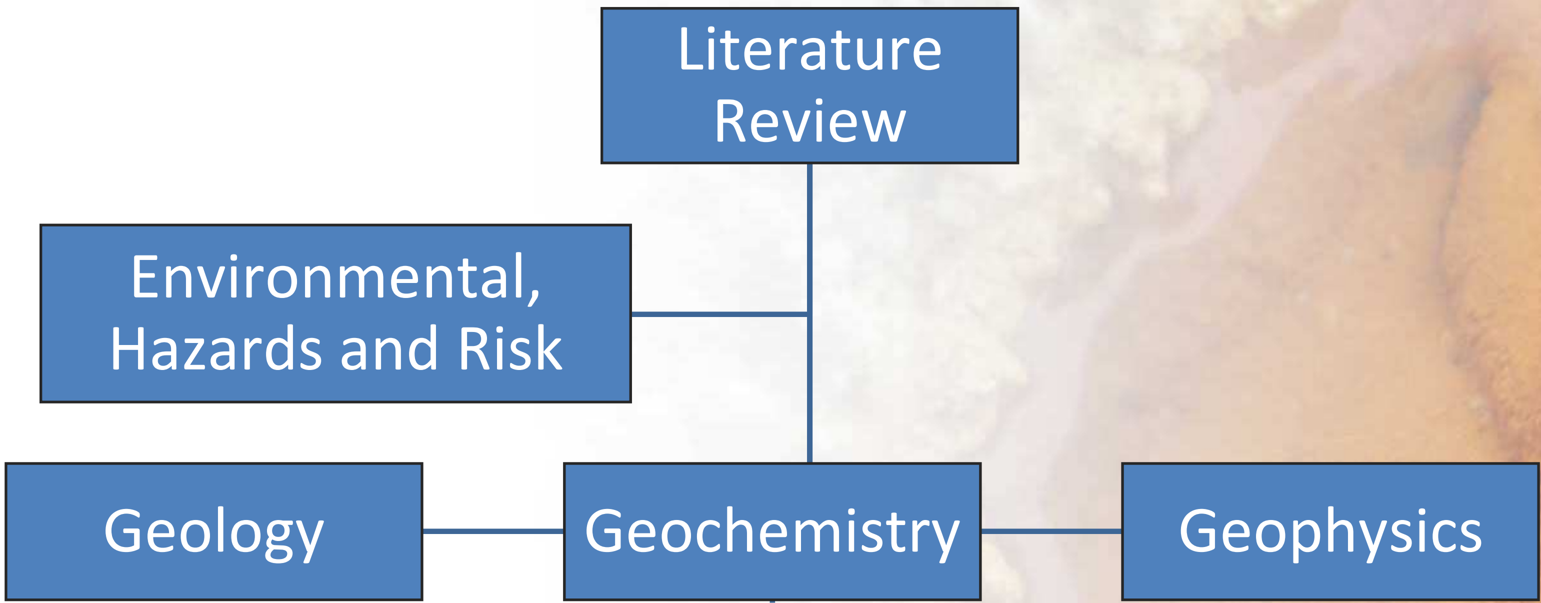
- This presentation reviews geoscientific disciplines used in exploration stages of geothermal project development, and assessment of risk.
- Highlights exploration techniques used for resource characterisation.
- Stresses the value of integrating all geoscience disciplines as the key to successful development of geothermal resources.



Adapted from "Overview of Resource Assessment" by C. Harvey "Start to Steam", Taupo June 2012

Key to Successful Low Risk Development

- Rigorous scientific studies at reconnaissance and exploration stages
- Integration of data from all disciplines (geology, geochemistry, geophysics)
- Recognition of hazards or barriers to development
- Conceptual models to be tested and refined by more detailed work



New Zealand Geothermal Scene

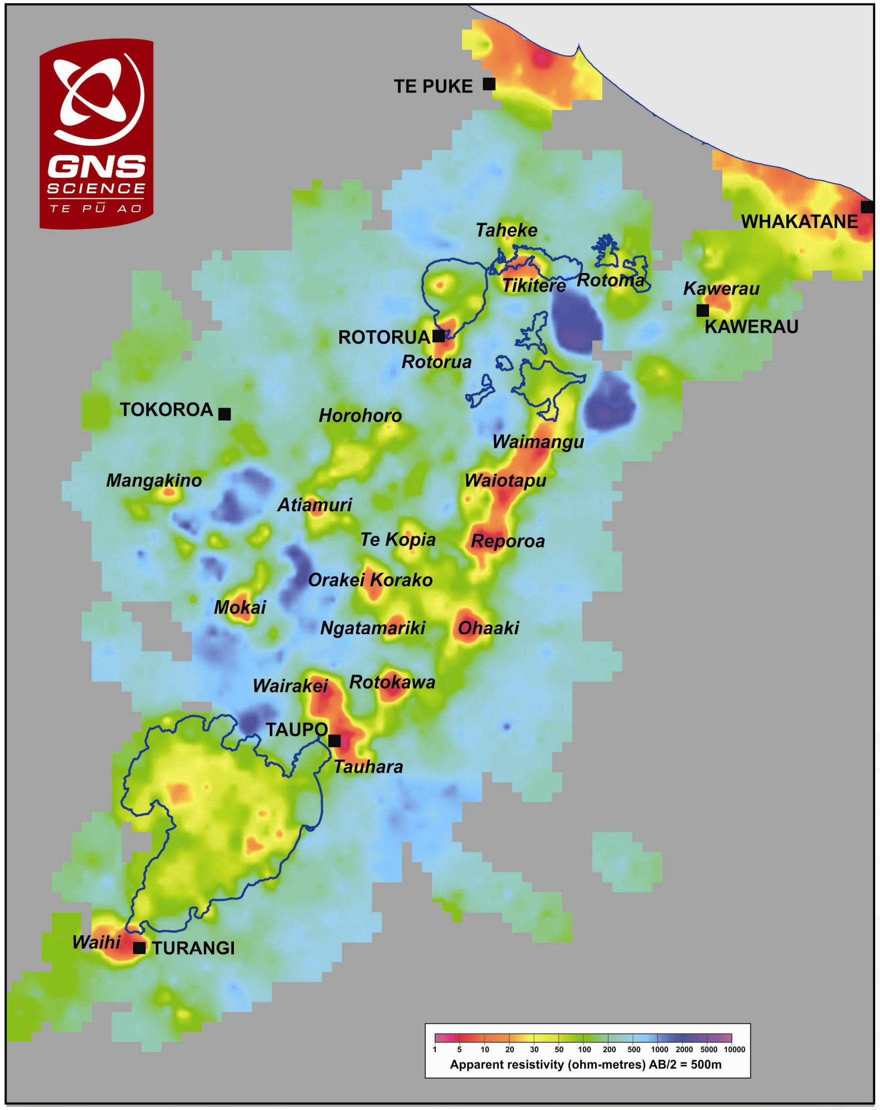
- Government dedicated to greater use of renewable energy resources

- **~830 MWe** base load electricity generation; **~15%** of generation

  Sixth for installed geothermal electricity generation capacity

- Increasing uptake of direct heat use – esp. GSHP

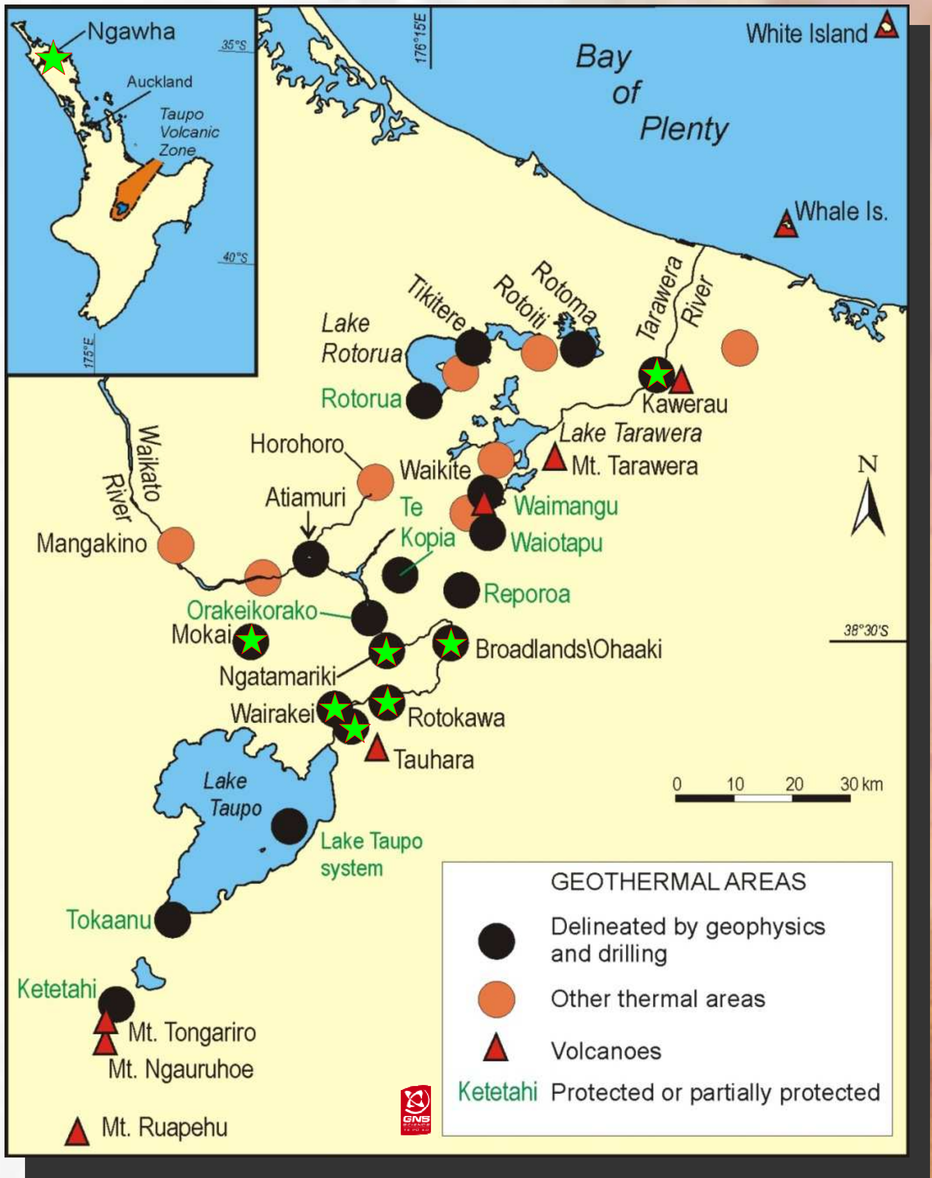
TVZ Geothermal Systems



Geothermal Energy, New Zealand

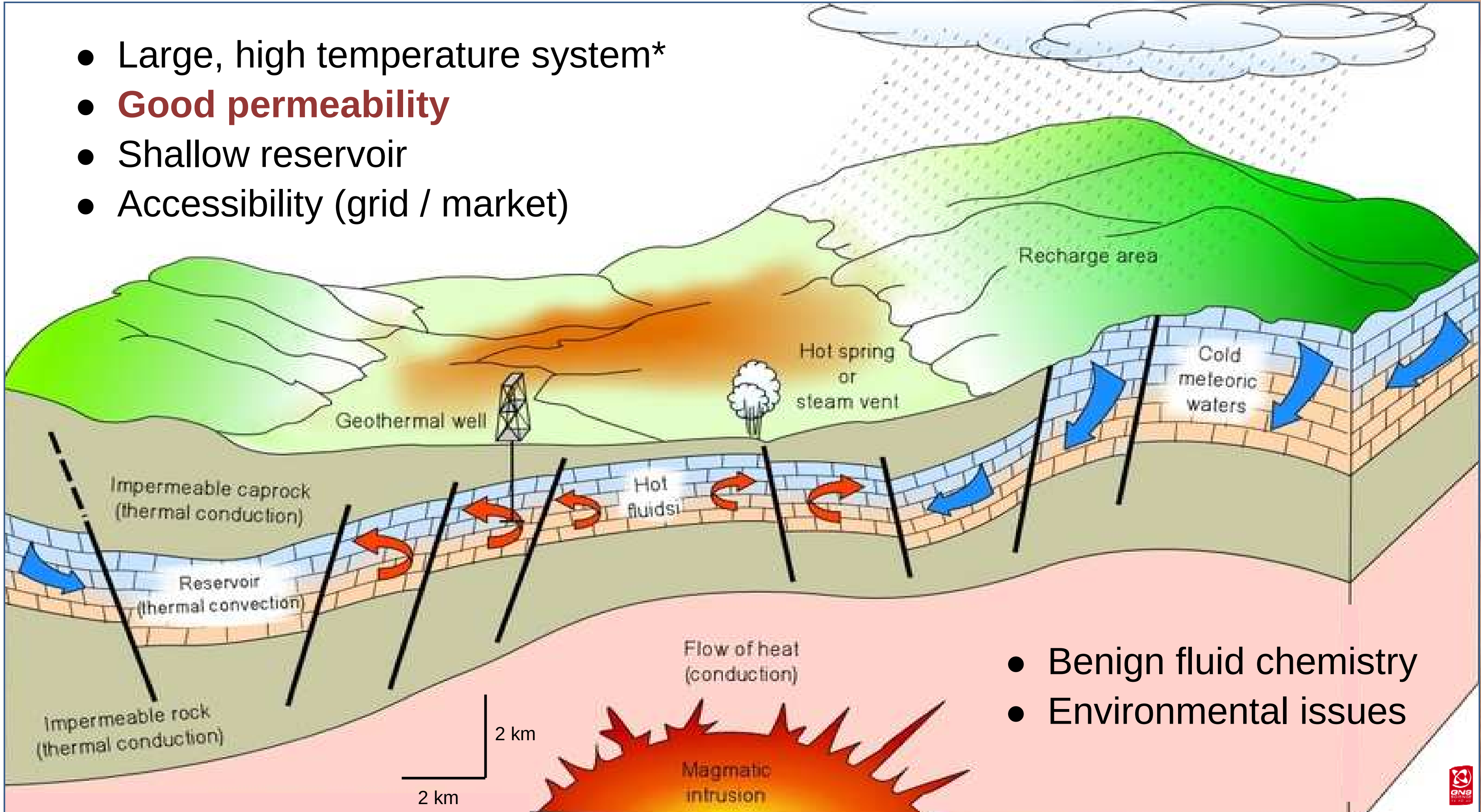
~ 1200 MWe available

~ 1600 MWe protected



Anatomy of TVZ Geothermal Systems

- Large, high temperature system*
- **Good permeability**
- Shallow reservoir
- Accessibility (grid / market)

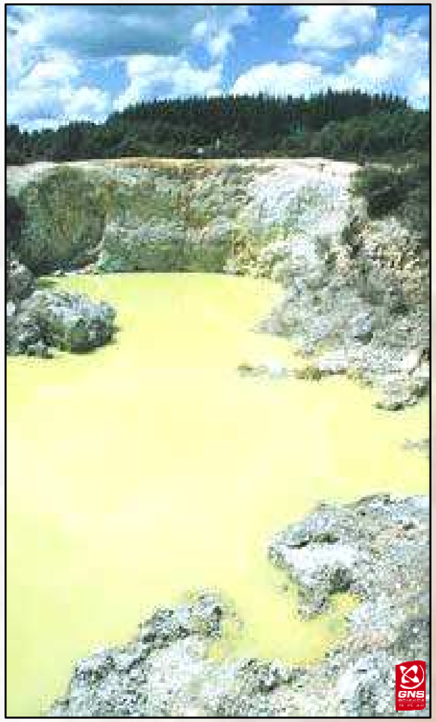


- Benign fluid chemistry
- Environmental issues

Geothermal System : A transfer of heat energy to the earth's surface.
Geothermal Energy : A resource utilised for heating or other direct uses (residential, industrial) or electricity generation.

No geothermal resources are identical

All geothermal systems have features that make for easy development, and other features that are a disadvantage



Integrate all resource data, to understand the system

Establish geoscience strategy that aids decision making

Does the area have geological, geochemical and geophysical characteristics consistent with a prospective geothermal system?

Sustainable Geothermal Development

Primary considerations :

1. **sustainability** of the geothermal reservoir…., avoiding detrimental impacts by maintaining the reservoir and surface character of the field

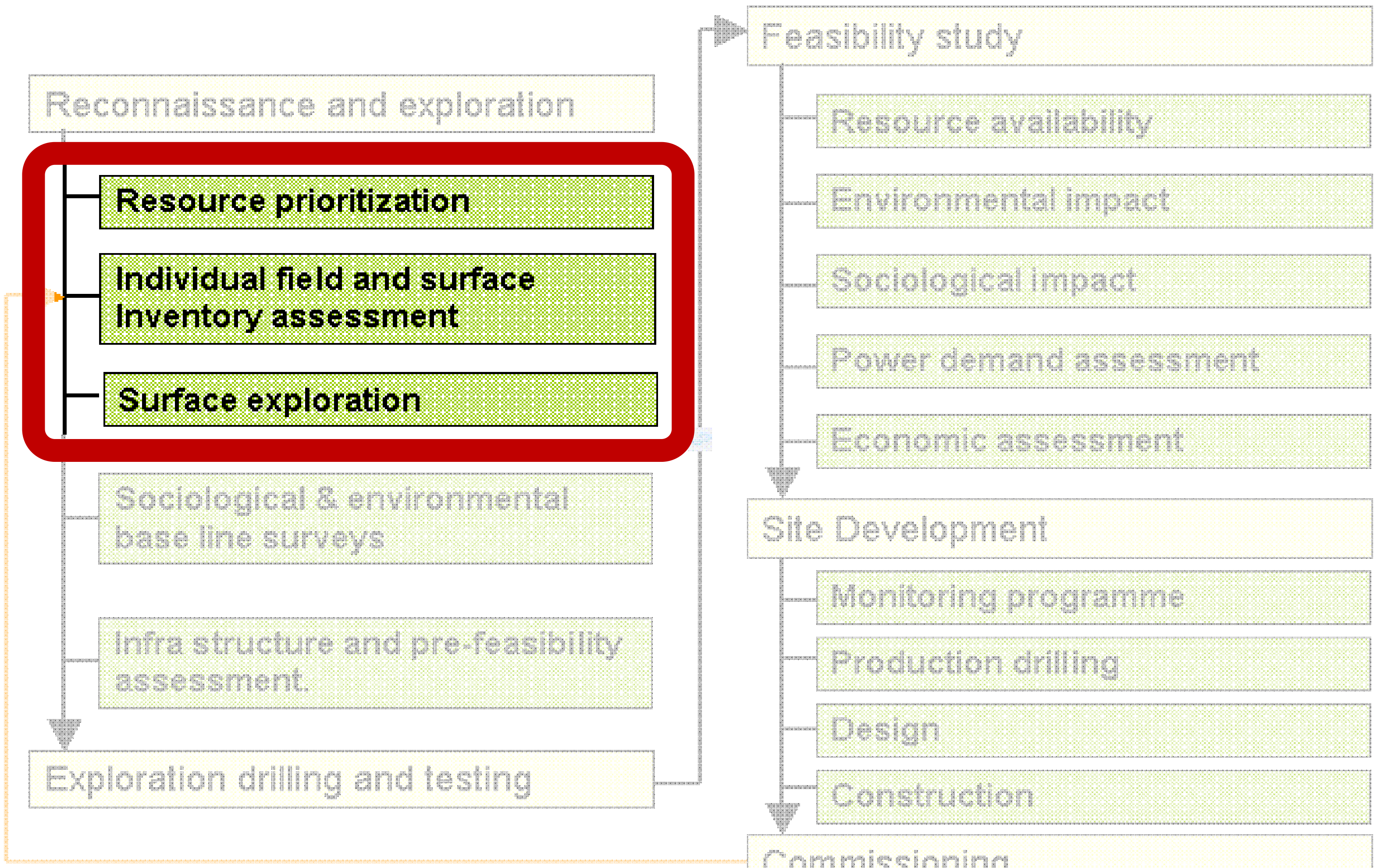

Wairakei Geothermal Field

and

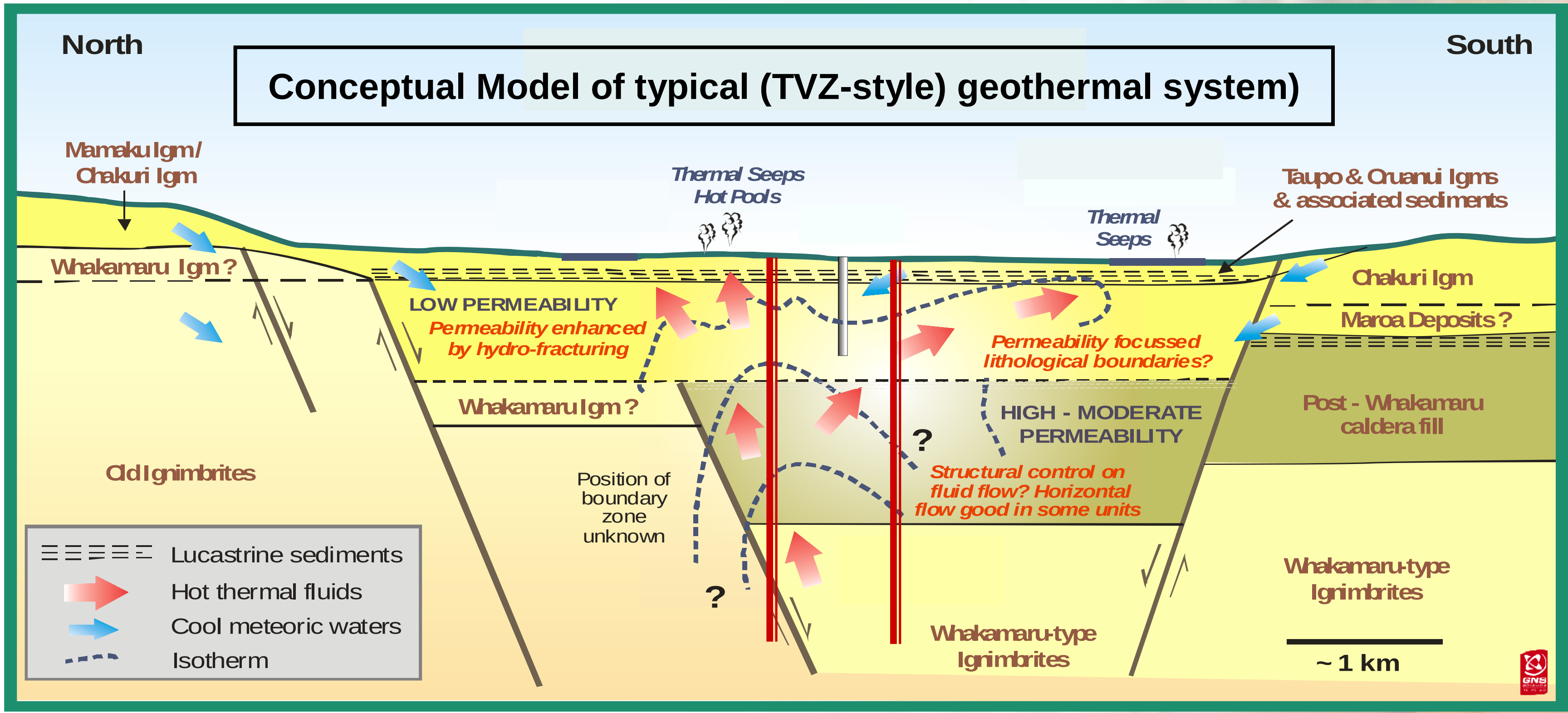
2. **maximising the use** of the geothermal energy, whilst **minimising risk** factors

   (generating the highest possible income at the lowest operation and maintenance cost to the developer).

Geothermal Development Flow Chart



(after Gislason & Arnason, 2005)



By **combining** geological, chemical and geophysical survey data, the geoscience team able to establish a conceptual hydrological model, which is updated through exploration and field development stages.

Exploration drilling is the final step to prove economic temperature and permeability, and resolve the deep stratigraphy and reservoir chemistry.

1. Chemical Surveys

Geochemical data important to help define system boundaries and identify possible up-flow zones

- Mapping thermal features (geodiversity)
- Characterise the fluid & gas chemistry (fluid sources)
- Obtain baseline data on non-thermal fluids
- CO_2 flux and ongoing monitoring surveys
- Identify development-limiting chemical components (scaling? corrosion?)

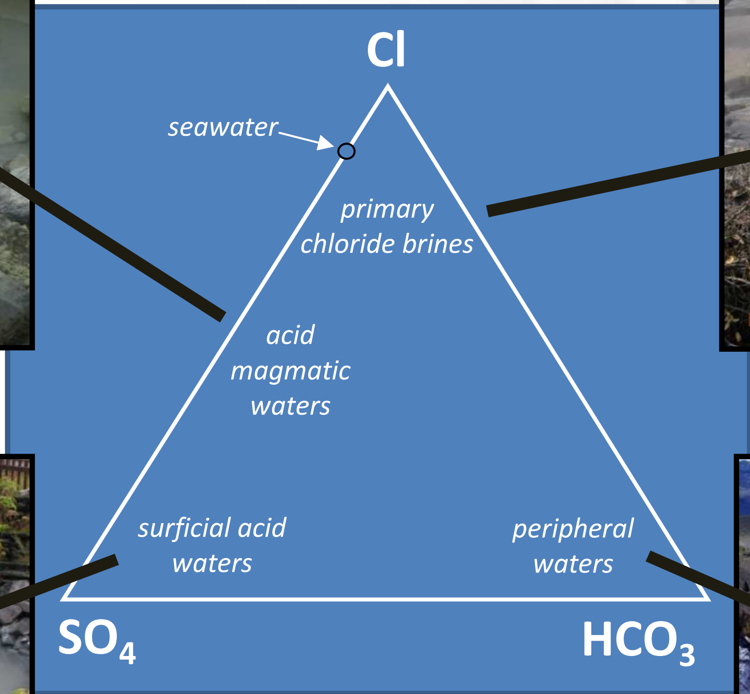
Obtain first temperature estimates of the resource (c.f. geothermometry)

Build hydrological model of the system

Fluid Types – Surface Manifestations

Interpretations of water chemistry requires an understanding of end-member types, and methods by which they were formed

Sulphur deposition & superheated fumaroles, may imply SO_2 / magmatic (acid) fluid conditions at depth



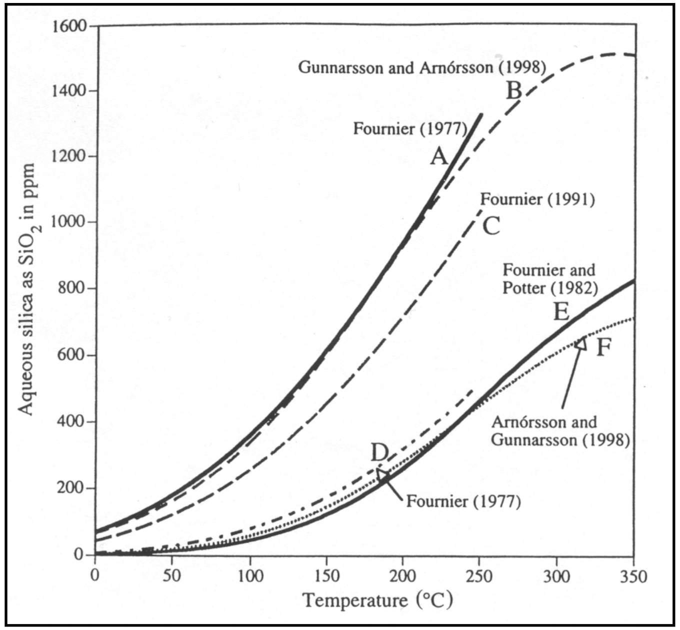
Silica sinter deposited by boiling, neutral, alkali-Cl waters, SiO_2 >350 mg/kg, >200ºC source fluids.

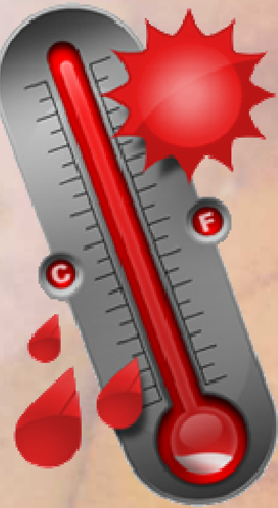
Turbid, grey acid-SO_4 pools, near-surface processes

Travertine – CO_2-rich, Na-HCO_3 springs, moderate to high gas contents?

Geothermometry

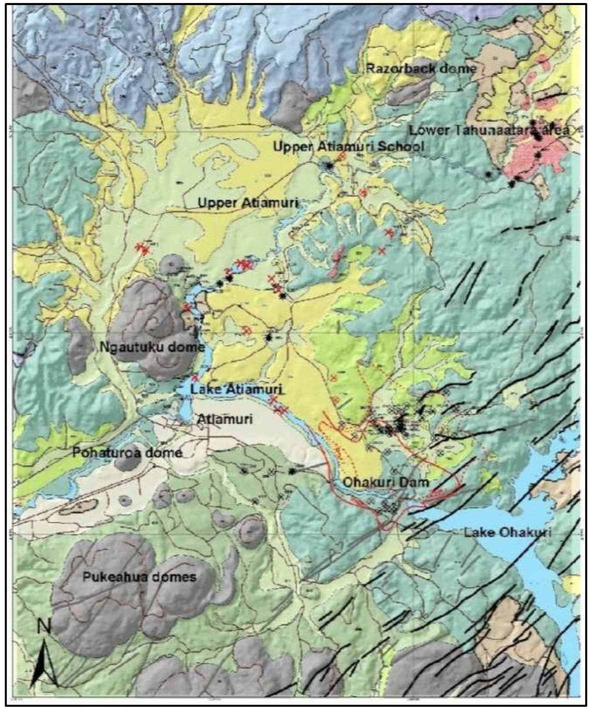
- Estimate reservoir temperature using water / gas chemistry data
- Based on field-observed correlations and theoretical data
- Each geothermometer has limitations
- Used to monitor changes in developed geothermal fields





- Solute - Quartz (T_{Qz})
  - Na/K ($T_{Na/K}$)
  - Na/K/Ca ($T_{Na/K/Ca}$)
  - Na/Li ($T_{Na/Li}$)
- Gas - Fischer-Tropsch (methane breakdown)
  - H-Ar geothermometer

2. Geothermal Geology

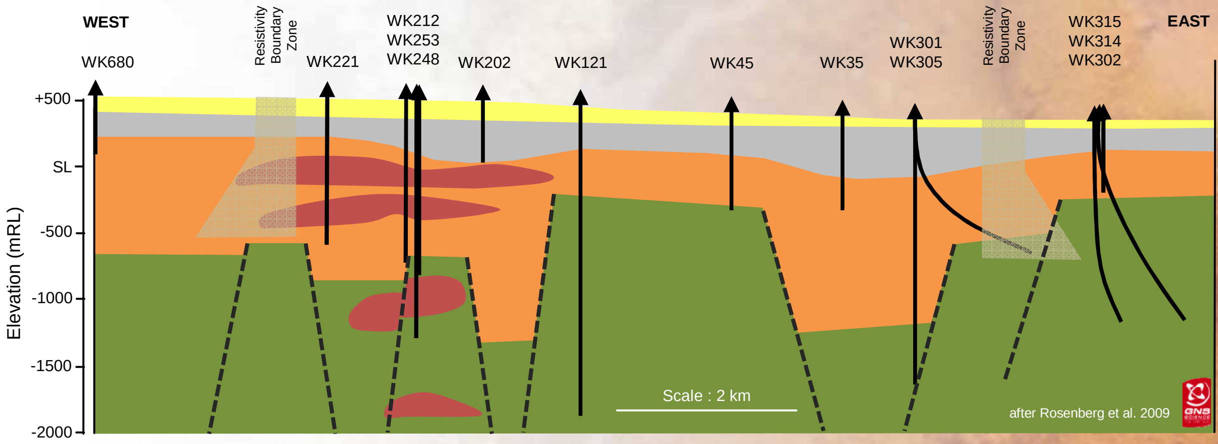


Geological activities divided into two parts:

(i)Geology which takes place before drilling
(e.g. map geology / stratigraphic relationships, surface hydrothermal alteration and manifestations)

(ii) Geology undertaken during / after drilling

Identify geotechnical issues / geohazards



Structure – Fracture Imaging

To predict permeability controls in the geothermal reservoir

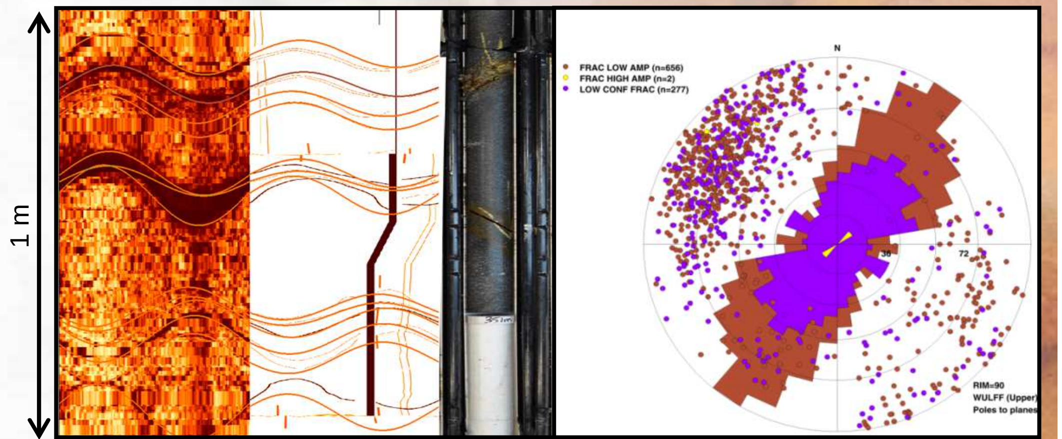
Silica sinter covered fault scarps, Orakei Korako

Evidence of rejuvenated structural permeability

- Lateral outflows
- Air photography – radar imagery – fracture mapping
- Map structural lineations – thermal features

Within the sub-horizontal (TVZ) stratigraphy, the most productive zones coincide with wells that intersect steep dipping fractures.

Acoustic Formation Imaging Technology



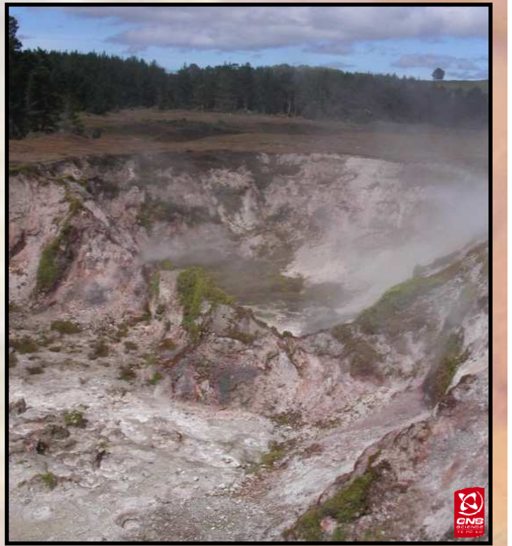
Fracture orientation, width & distribution

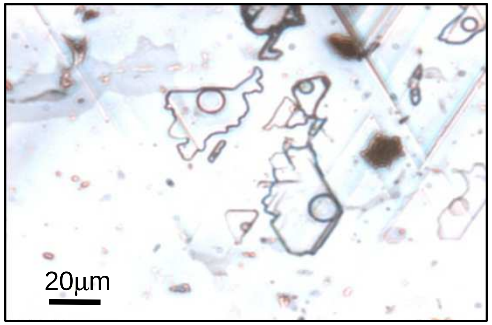
Evidence for system change

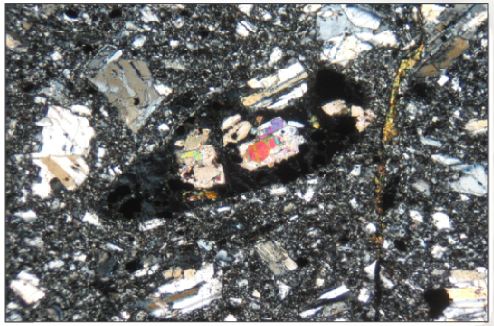
- Change in surface thermal activity (time and space)

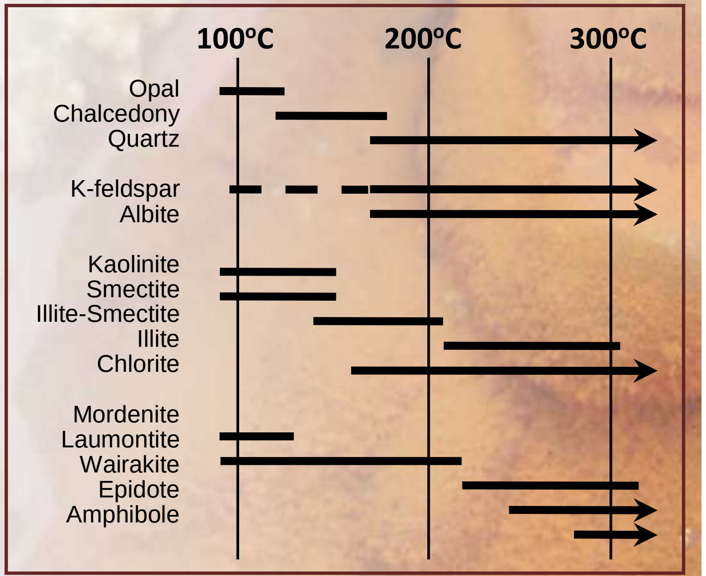
(e.g. surficial features that are not in equilibrium with current fluids)

- Record in hydrothermal alteration mineralogy
- Changes in fluid inclusion data with time (e.g. salinity and temperature - depth of erosion, fault displacement *etc*)
- Alteration minerals out of step with current T-X conditions









Leading to revised hydrological model

3. Geophysical Investigations

- Mainly to assess the dimension (extent, thickness) of reservoir
- Likely to postdate initial chemistry / geology surveys
- May provide information on:

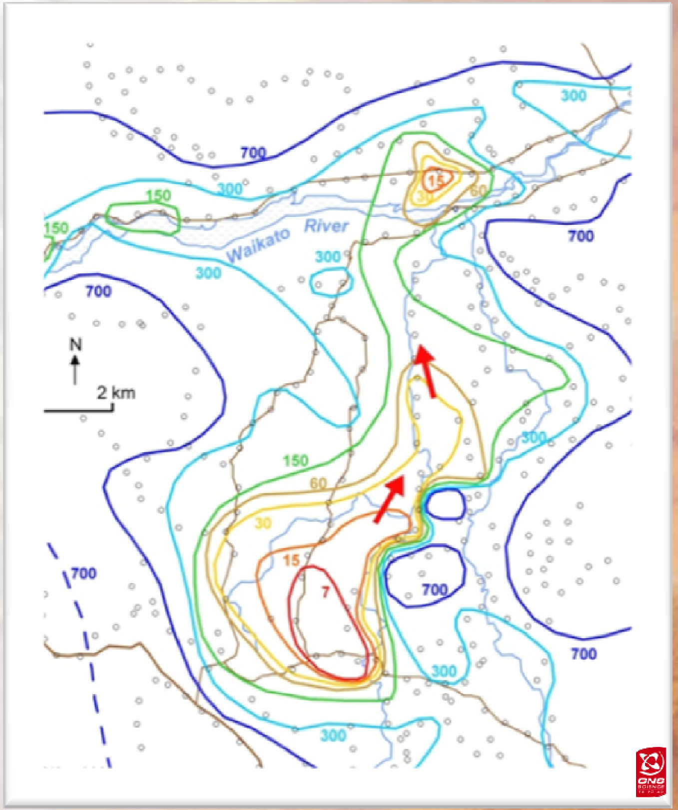
  - reservoir structure (shallow or deep, upflow zones, lateral outflows)

  - likely location of productive zones

  - natural heat balance

and, in a more regional sense…,

  - the geological setting of the system



Schlumberger apparent resistivity
Mokai geothermal system, AB/2=500m

Geophysical Methods

- **Heat flow surveys**
- Remote sensing
- Gravity
- Magnetics
- Resistivity
- Magneto-tellurics
- Seismic surveys
- Borehole geophysics

Understanding heat balance of the system

Measure heat discharges (convective, conductive, evaporative) from active manifestations

The success of any geophysical investigation depends on applying the best combination of techniques in the correct sequence to explore a prospect

Geophysical Methods

- Heat flow surveys
- **Remote sensing**
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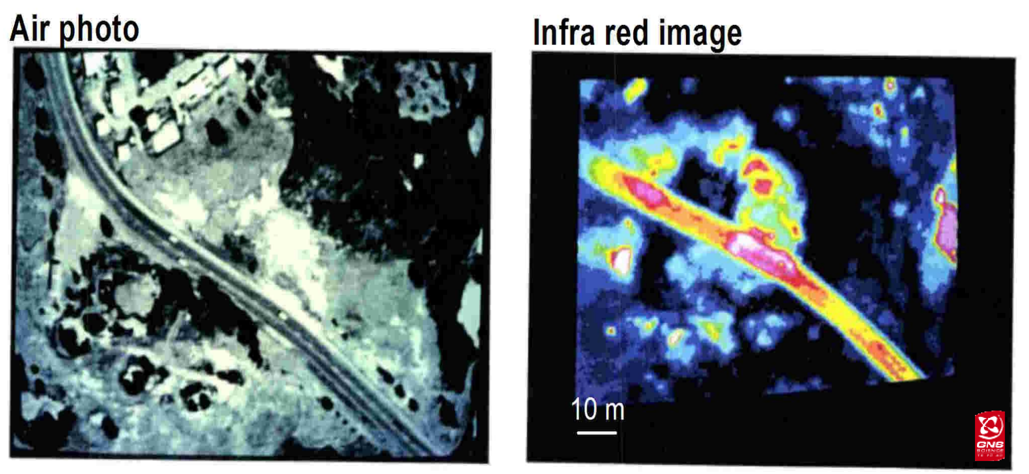
Distribution of surface/shallow temperatures
Geological setting and structures (local/regional)



IR imagery (satellite data, aerial surveys), Satellite and aerial photos, Spectral imaging, Radar altimeter, LIDAR

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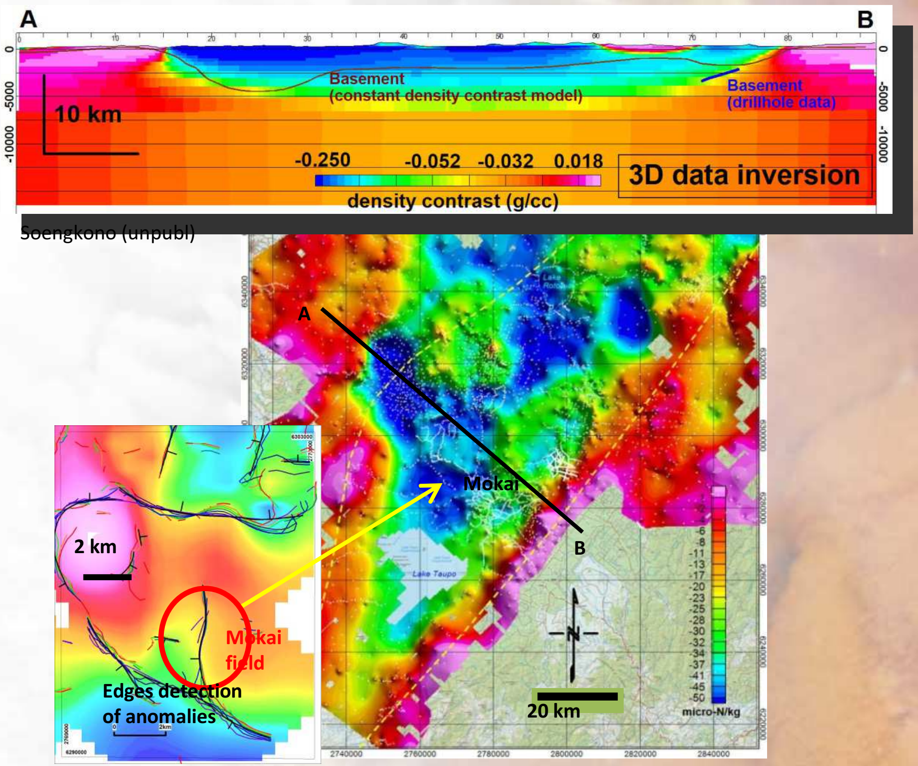

Small variations in the earth gravitational field

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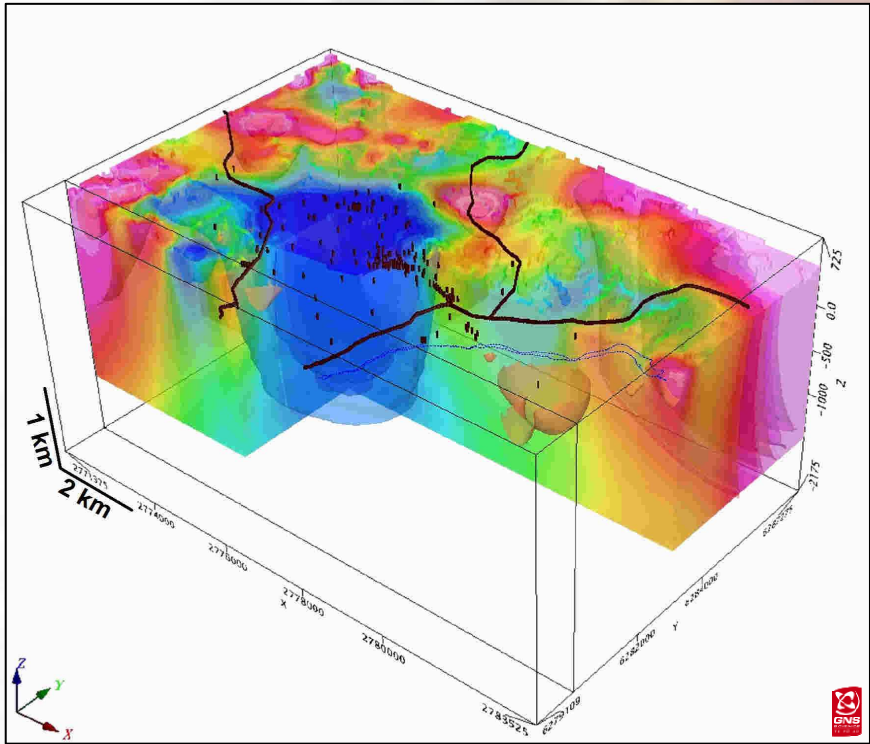

Mapping local disturbance of geomagnetic field

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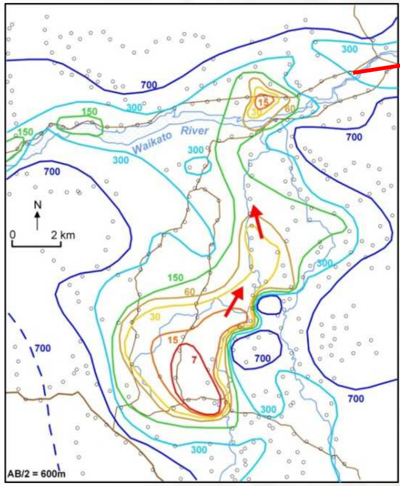
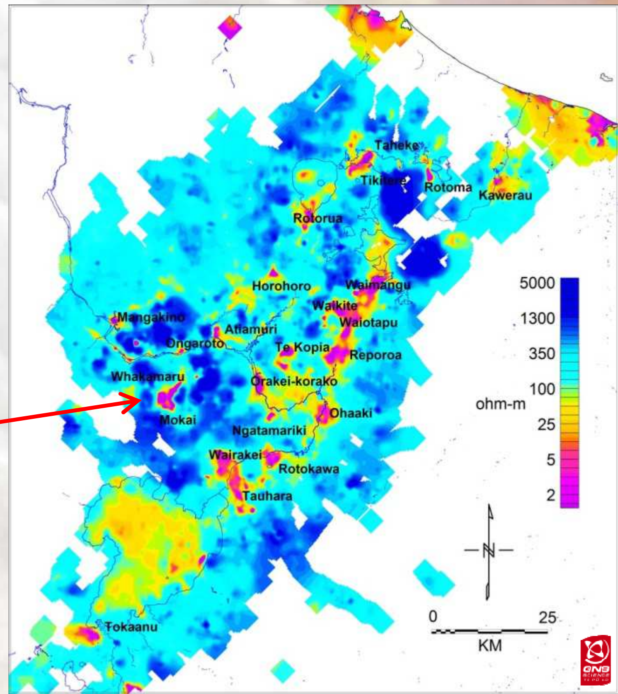
Mokai Geothermal Field





TVZ Schlumberger apparent resistivity
AB/2=500m (GNS data)

The success of any geophysical investigation depends on applying the best combination of techniques in the correct sequence to explore a prospect

Geophysical Methods

- Heat flow surveys
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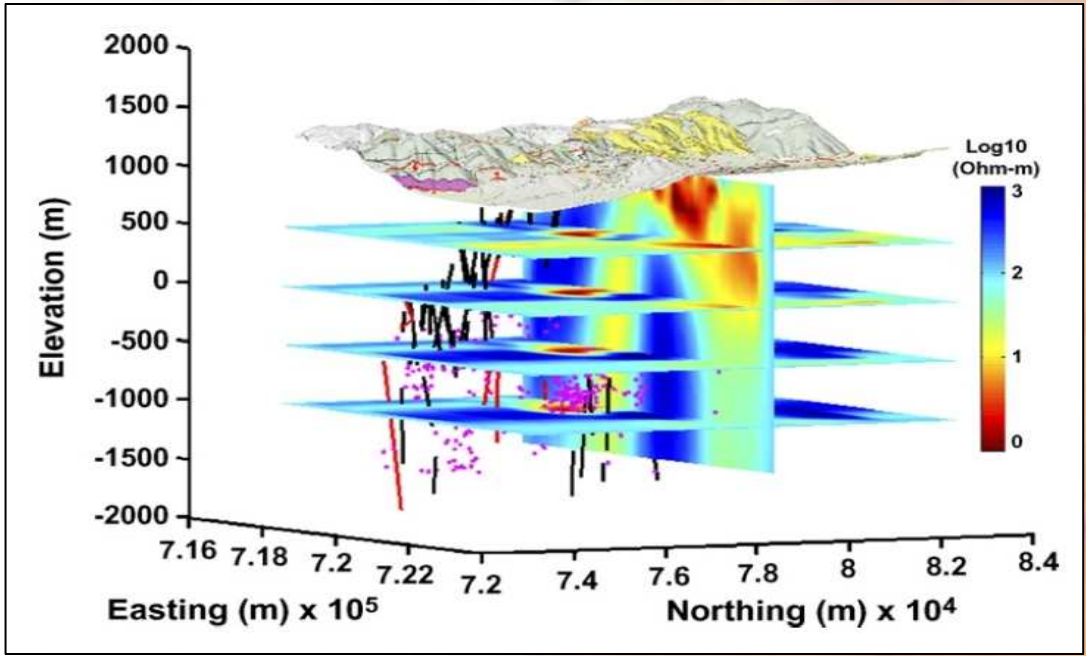
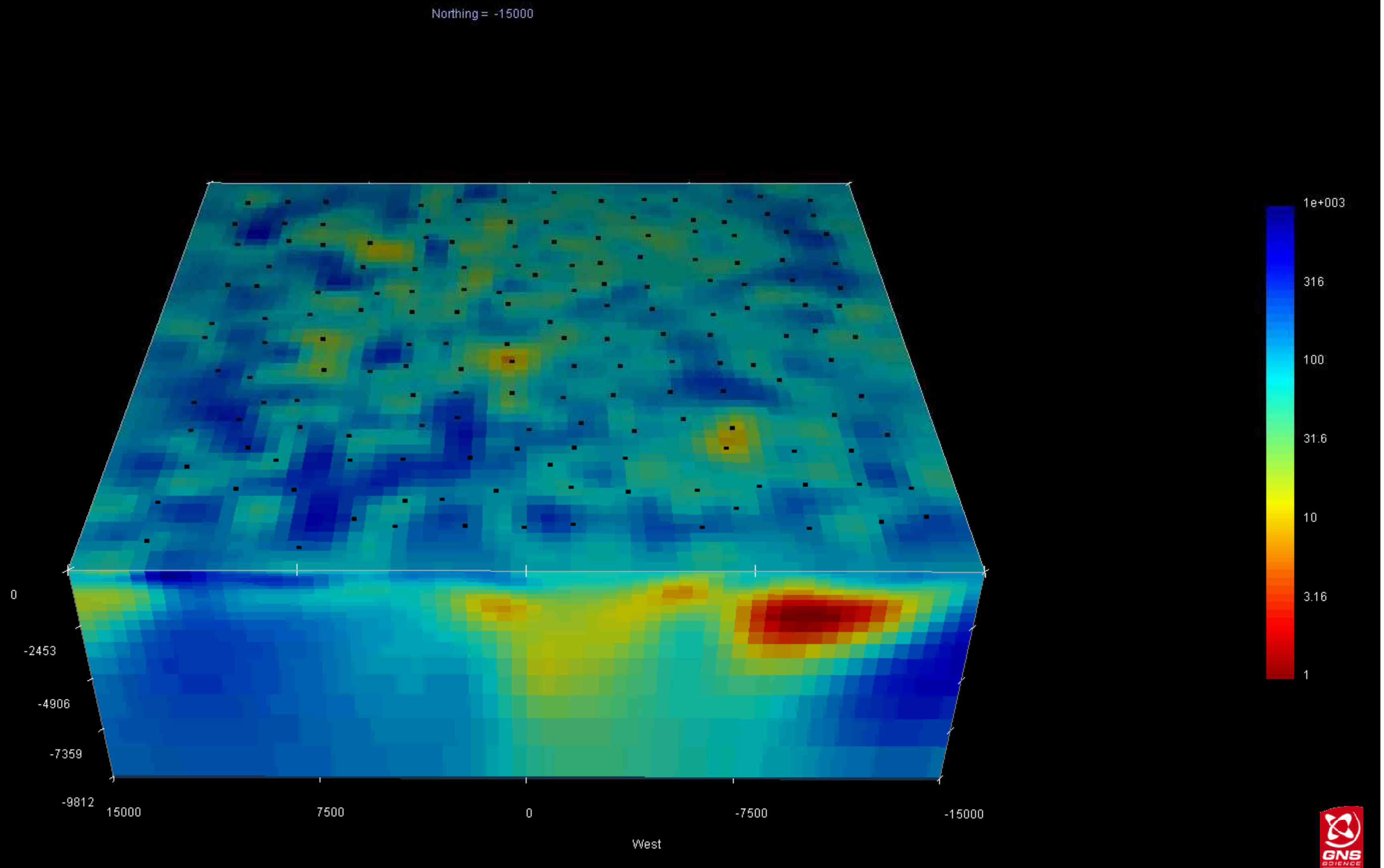
Recording natural electromagnetic waves at ground surface over a wide range of frequency



3D MT model, Coso Geothermal Field (Newman et al., 2008)

The success of any geophysical investigation depends on applying the best combination of techniques in the correct sequence to explore a prospect

3D MT Inversion Model of Southern TVZ



Geophysical Methods

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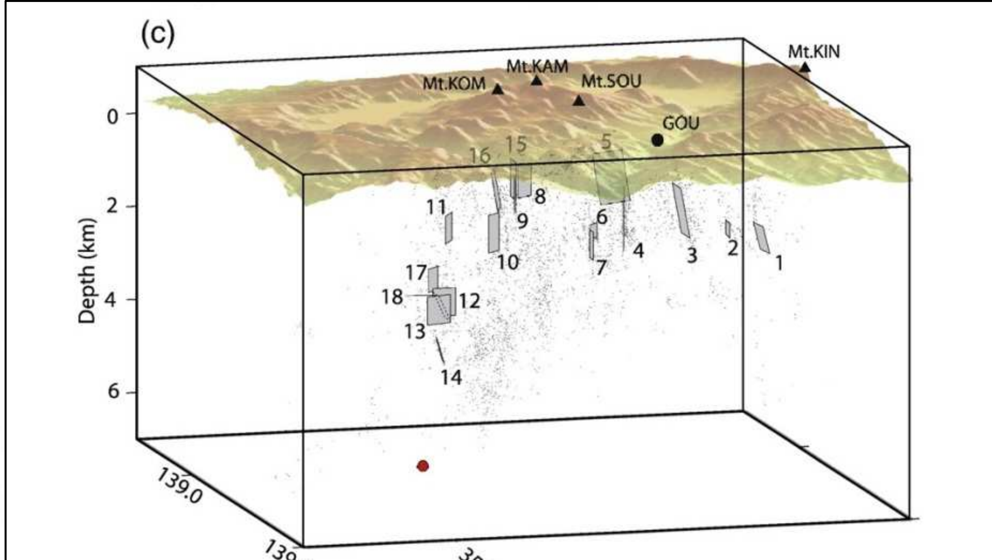


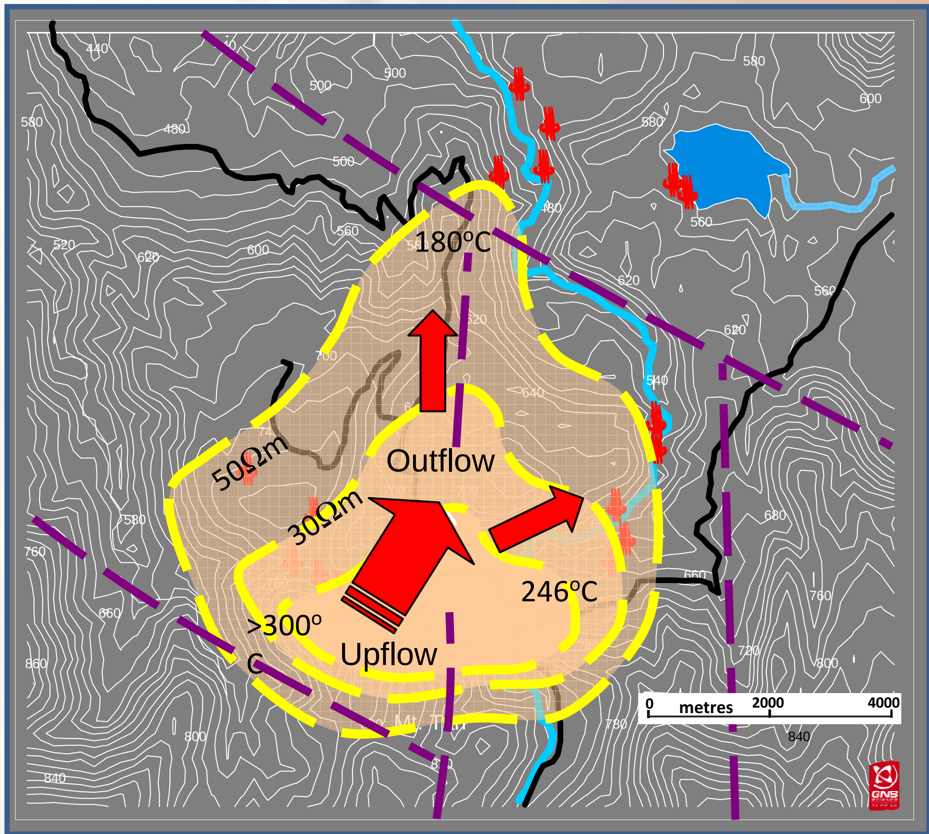
From Yukutake et al. (2008)

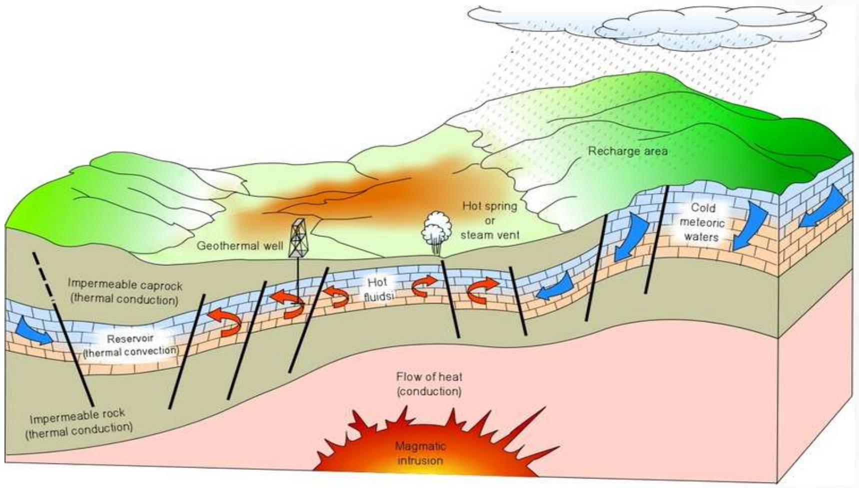
"Active seismic" (shot point) - "Passive seismic" (natural seismic signal) surveys - micro-earthquake surveys.

The success of any geophysical investigation depends on applying the best combination of techniques in the correct sequence to explore a prospect

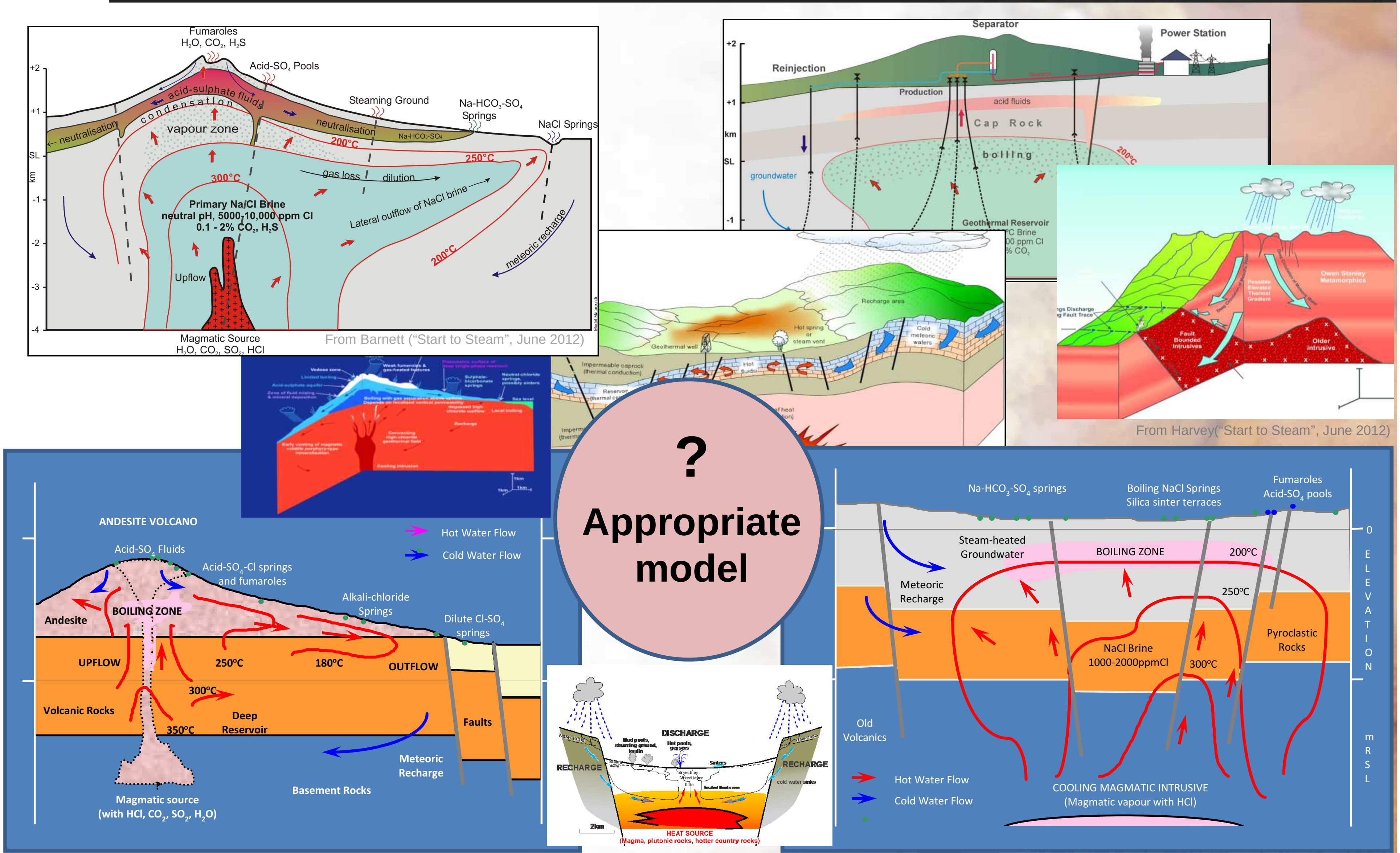
Conceptual (hydrological) Model

- 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, magmatic fluids)





Which Hydrological Model ?



Resource Capacity Assessment

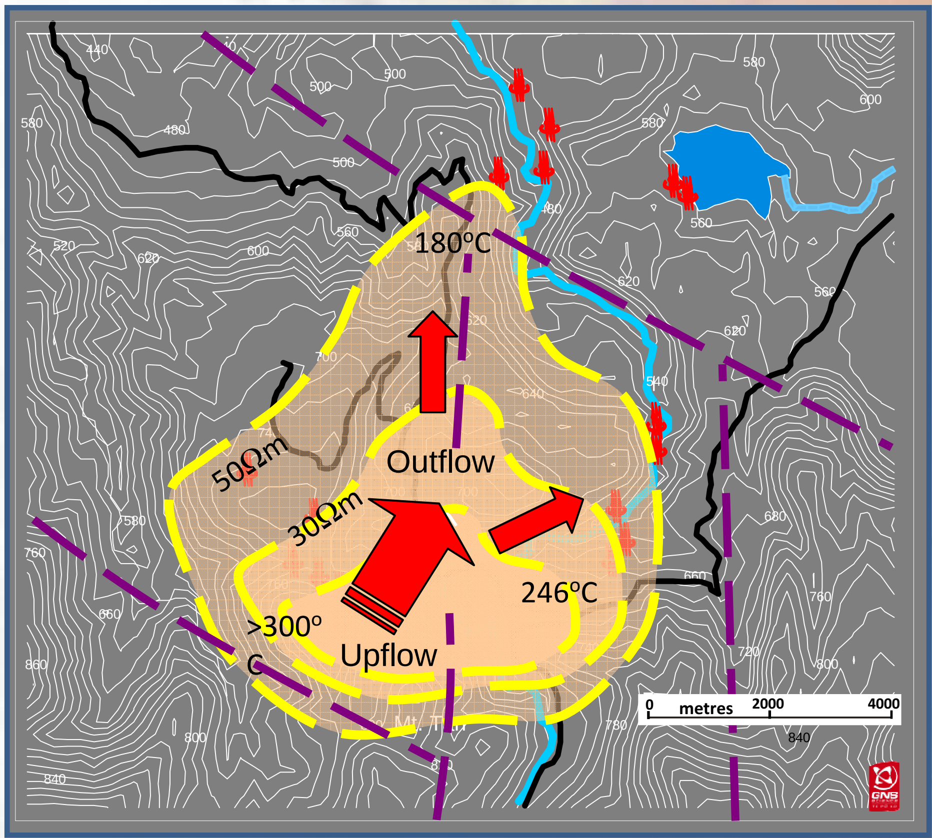
Resource Area

Surface Heat Flow

Resource Temperature

Controls on Fluid Flow

Reservoir Chemistry



Estimate total resource capacity

•Heat Flux Method

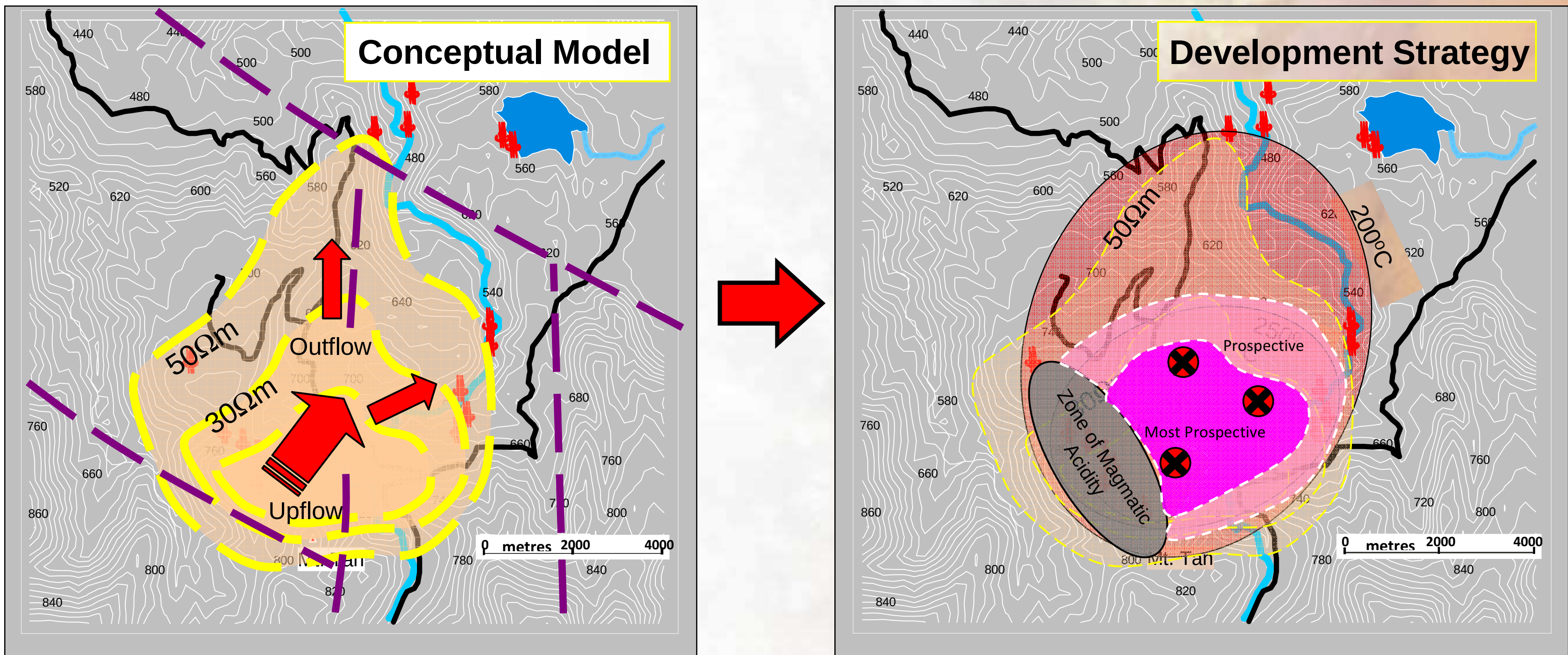
Natural heat flux of the system, derived from physical estimates

•Areal Method

Estimate development size from areal extent, multiplied by power density factor (8-10 MW/km^2)

Geothermal Risk Assessment

- Assess / mitigate risks that could threaten viability of development
- **Consequences** of some risks, may prove fatal to development(s).
- As exploration progresses, level of confidence in resource increases
- How probable that a constraint will apply during project lifetime?



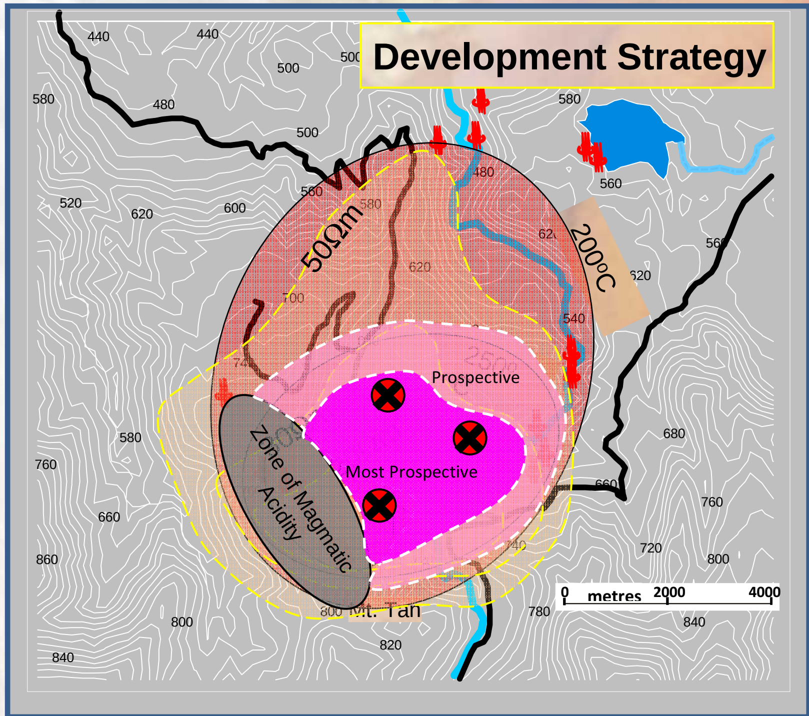
Exploration Drilling Programme

- Test surface exploration model - confirmation of resource extent and potential, at reasonable cost (ideally commercially productive).

- First well sited on basis of hydrological model, with clear objectives (e.g. test high temperature zone, permeability structure of the field)

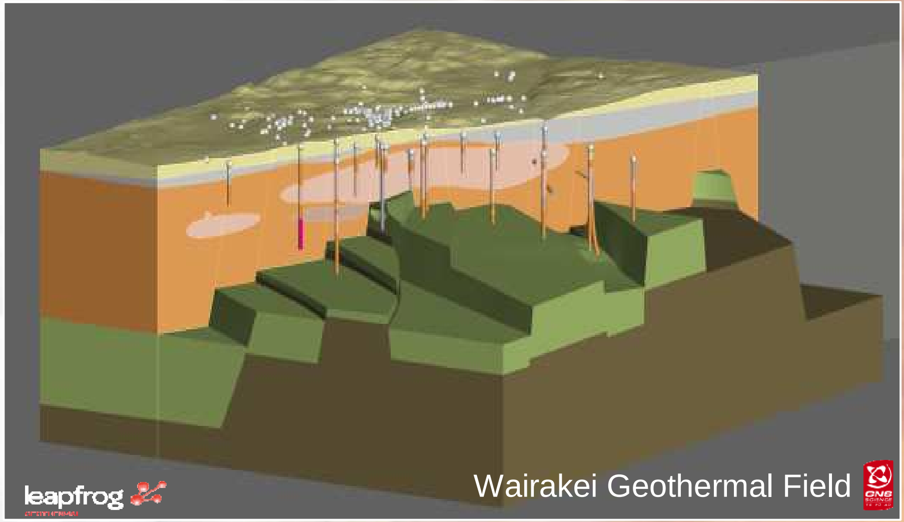
- Outcomes / drilling strategy assessed
  (a) drill second / third well as planned
  (b) change strategy of next well,
  (c) postpone / abandon project.

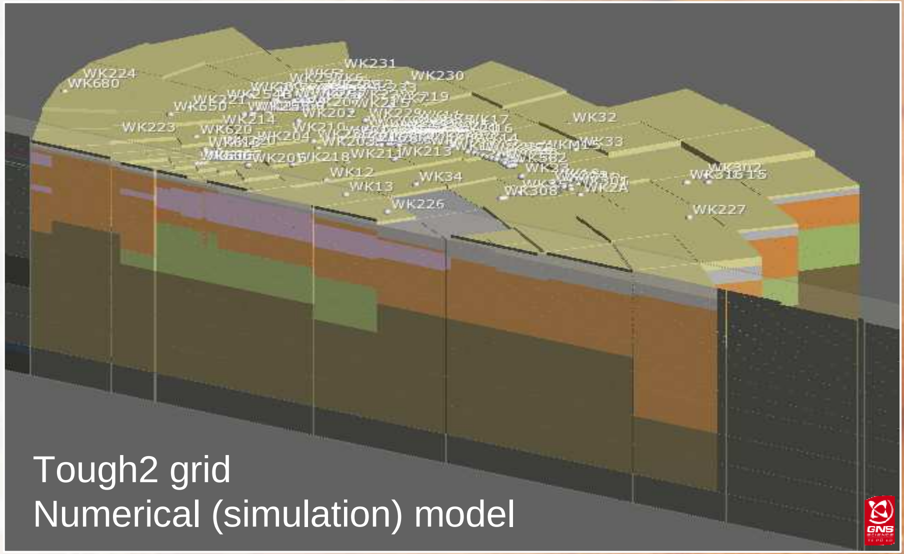
- Drilling costs reduced by drilling :
  (a) shallow ("temperature gradient") holes
  (b) slimholes (later drill full diameter wells)



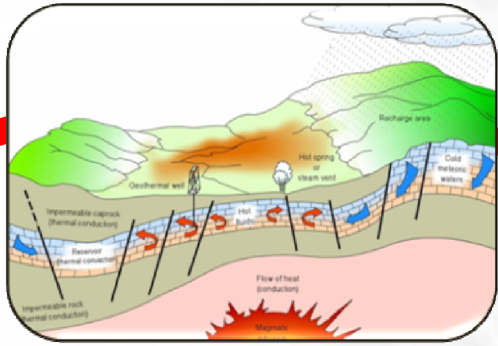
Resource Evaluation Outputs

- Conceptual (hydrological, and geological framework) Model
- Assessment of Energy Reserve and Sustainable Resource Capacity.
- Steady State Model (if possible, based on well data).
- Models for various development scenarios (include effect of resource use on existing field activities and surface features).





Resource Characterisation



Environmental Effects
Low Enthalpy Systems

Geothermal Resources of New Zealand

Sustainable Development

Geomicrobiology

NZ$4.4M/annum

Progamme Leader: Greg Bignall

Summary

1. Design geoscience strategy that aids decision making.

2. Geoscience 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 geoscience advice early (and ongoing) has potential to save time, resources and money later ….

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THANK YOU