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Future Developments in Geothermal Energy

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Geothermal Energy

Strengths

- Clean, renewable energy
- Base load resource/generation
- Inexpensive (once going)
- Reliable

Weaknesses

- Long lead time: concept to production
- Large entry barriers
  - high upfront costs
  - high upfront risk
  - pre-drilling feasibility absent
- Location controlled by geology

Wairakei

First well drilled 1950

Power station commissioned 1958

50 years continuous base load operation (>140 MWe)

Renewable, Sustainable, Low Greenhouse Gas Emissions

Future Developments in Geothermal Energy

Discovery of new (blind) high temperature resources at <3 km depth

Enhanced or engineered geothermal systems (EGS)

Exploitation of deep hydrothermal resources at >3 km depth

Geopressured resources (e.g. abandoned oil-gas fields)

Utilization of ground sourced heat pumps (heating, air conditioning)

Improved efficiency in steam gathering systems

Advances in drilling and well logging methods

Novel power cycles (e.g. Kalina cycle)

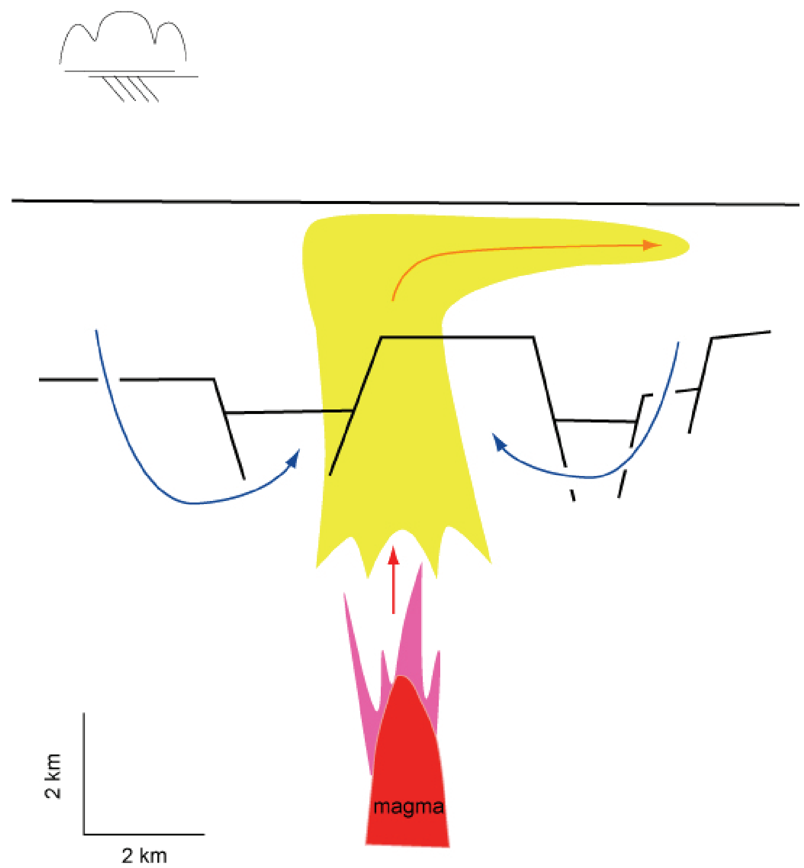
Mineral recovery (precious & base metals)

Topics Covered in this Presentation

New exploration methods: high temperature resources at <3 km depth

Enhanced or engineered geothermal systems (EGS)

Exploitation of deep hydrothermal resources at >3 km depth



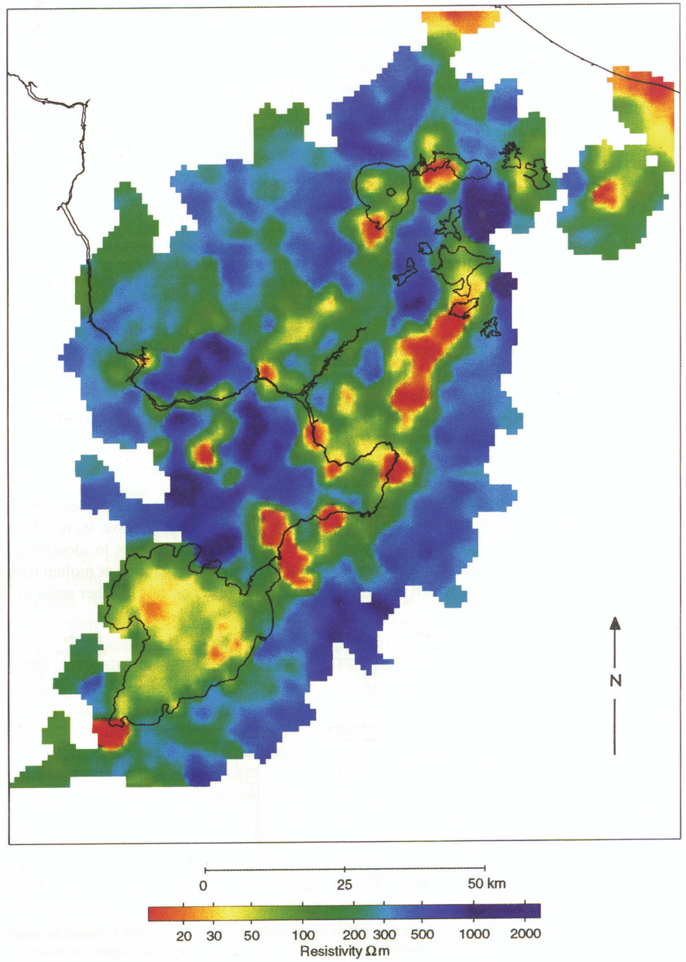
Essential ingredients for sustainable heat transfer

Permeability structure (i.e. faults, fractures, interconnected pore space)

Anomalous temperature gradient

Fluid supply (heat carrier)

Conventional Exploration Methods



Central TVZ: DC apparent resistivity
(Stagpoole and Bibby, 1998-GNS Science)

Joint Geophysical Imaging (University of Auckland*)

Combination of electrical and seismic geophysics methods

Dense array of geophones (surface & shallow borehole)

Dense array of magneto-telluric coils (surface)

Image active fluid flow-fracture networks

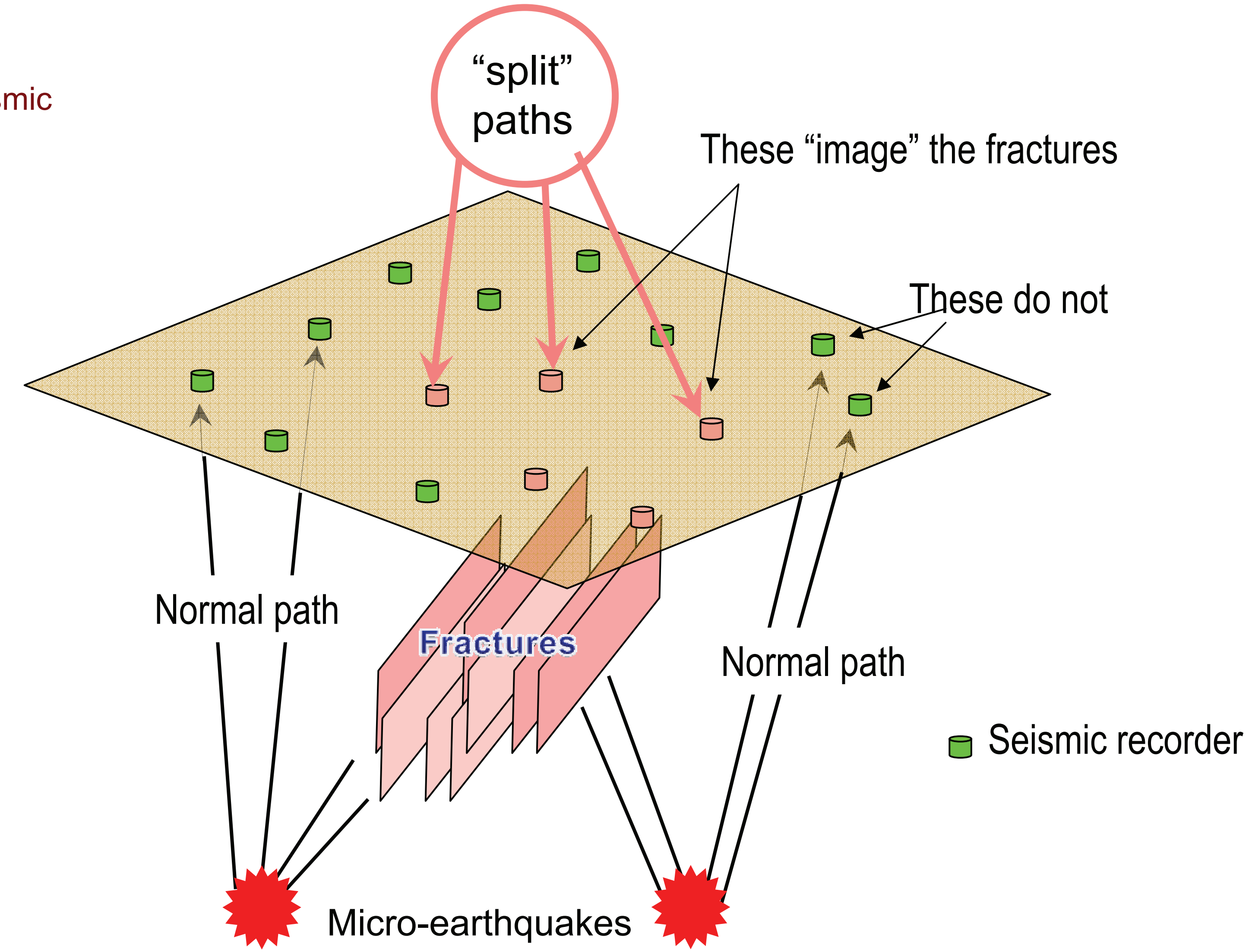
Identify drill targets

Enhance well production

Examples: Olkaria, Kenya & Krafla, Iceland

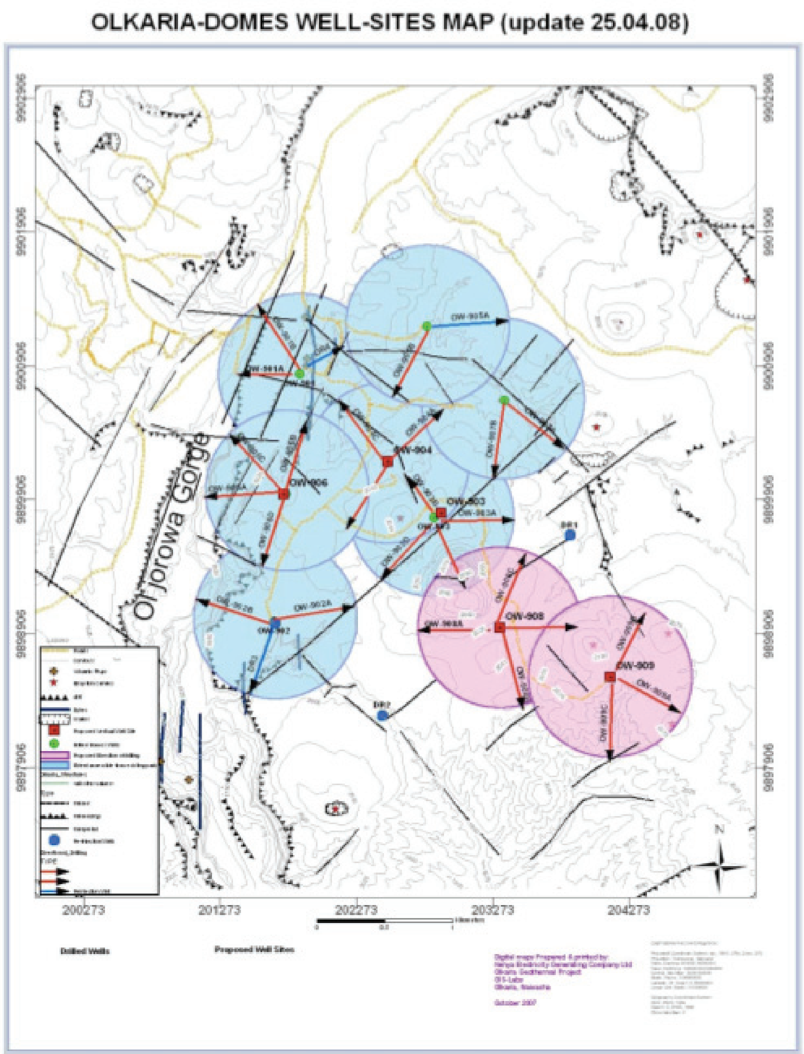
Peter Malin (p.malin@auckland.ac.nz), Stephen Onacha (s.onacha@auckland.ac.nz), Gary Putt (gary.putt@auckland.ac.nz)

Micro-seismic



Olkaria - Domes

- $2.75M investment by UNEP, World Bank & KenGen
- Average well productivity increased from 2MW → 5MW
- Developer doubled plans from a 70MW plant to 2x70MW for 140MW
- "$75M" in savings



http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=553&ArticleID=6017&l=en

Engineered Geothermal Systems (EGS)

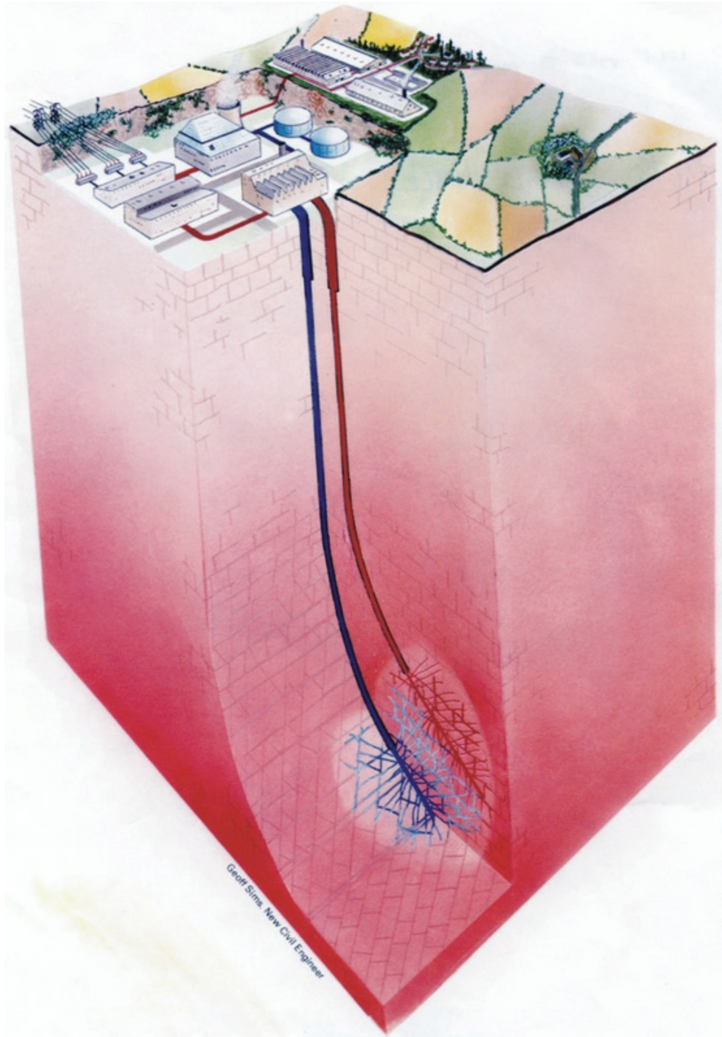
Deep hot rock

Induce fracture permeability (stimulation)

Inject fluid to advect thermal energy to surface

35 years of R&D (USA, Japan, Europe, Australia)

New investment in resource development

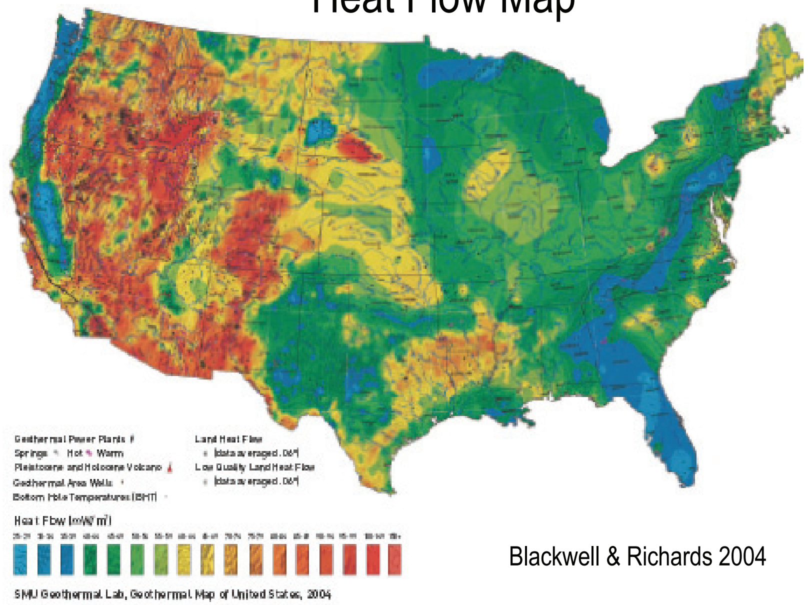


USA Resource Potential

Stored thermal energy 3-10 km depth	14.0×10^6 EJ
2% Recovery	0.28×10^6 EJ
Total consumption (2005)	100 EJ

EJ=10^{18} joules

Heat Flow Map

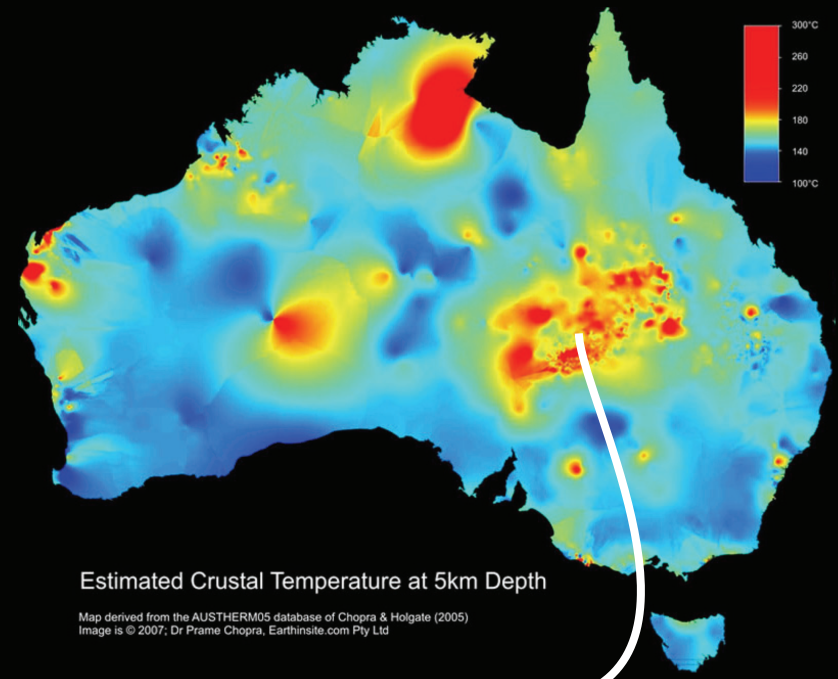


Blackwell & Richards 2004

*the Future of Geothermal Energy: Impact of Enhanced Geothermal Systems on the United States in the 21st Century, Tester et al. 2006

EGS Sites

Fenton Hill (USA)
Rosemanowes (UK)
Hijiori-Ogachi (Japan)
Soults-sous-Forêts (France)
Basel (Switzerland)
Cooper Basin (Australia)



Cooper Basin, Australia

Prospect area 2000 km^2

Hot granite beneath 4 km sedimentary rk

3 wells: >4 km depth, whp 350 bar, >240°C

Temperature gradient: ~60°C/km

Horizontal compression: Flat fracture system-connectivity between wells

1 MW power plant to be constructed

Steam flow Habanero 3 (March, 2008; Geodynamiics Annual Report 2008)

Soults-sous-Forêts (France)

Upper Rhine Graben (border w/Germany)

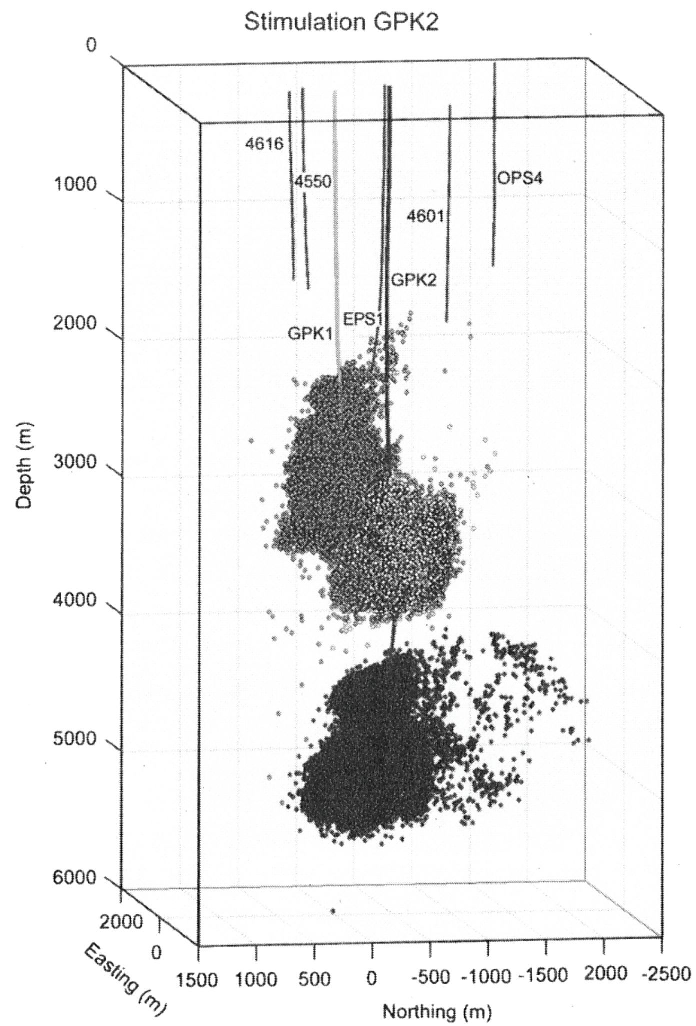
4 wells: 2 to 5 km depth, ~200°C

Temperature gradient: 40°C/km

Extensional tectonics: fracture connectivity restricted in granite basement (>1400 m depth)

Induced seismicity from fracture stimulation causes delays

1.5 MW power plant commissioned 2008



Majer et al. 2007 Geothermics

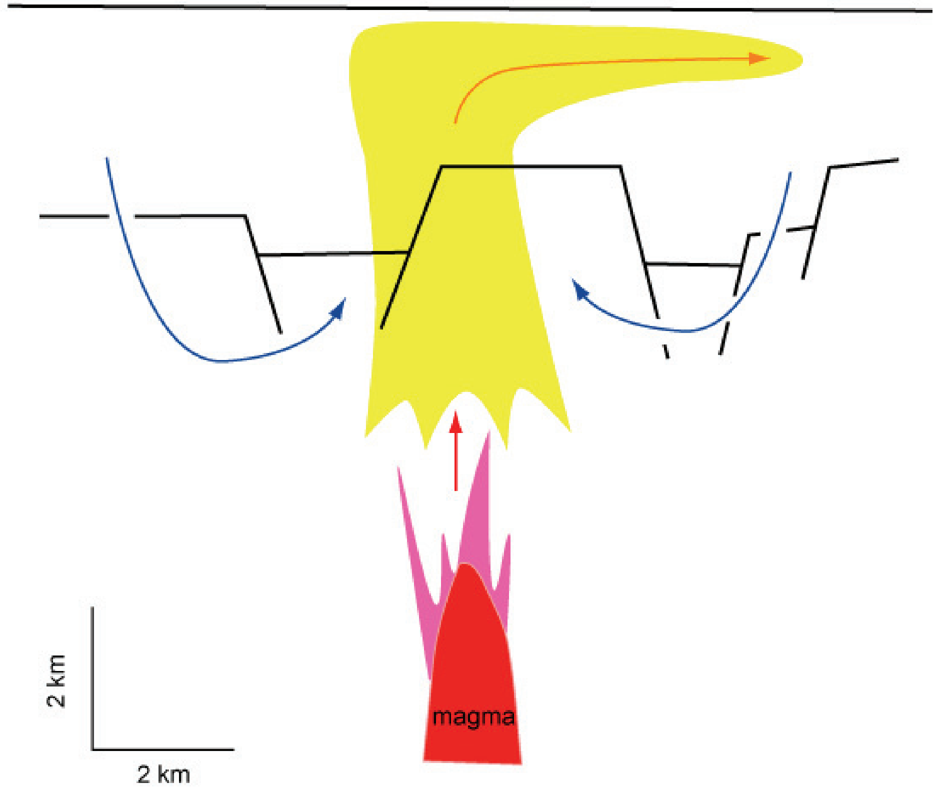
Deep Geothermal Resources

Deep drilling to near super critical conditions

Significantly increased power output per unit fluid mass (high enthalpy)

Uncertainties regarding permeability and production of deep fluid

Example: Krafla, Iceland



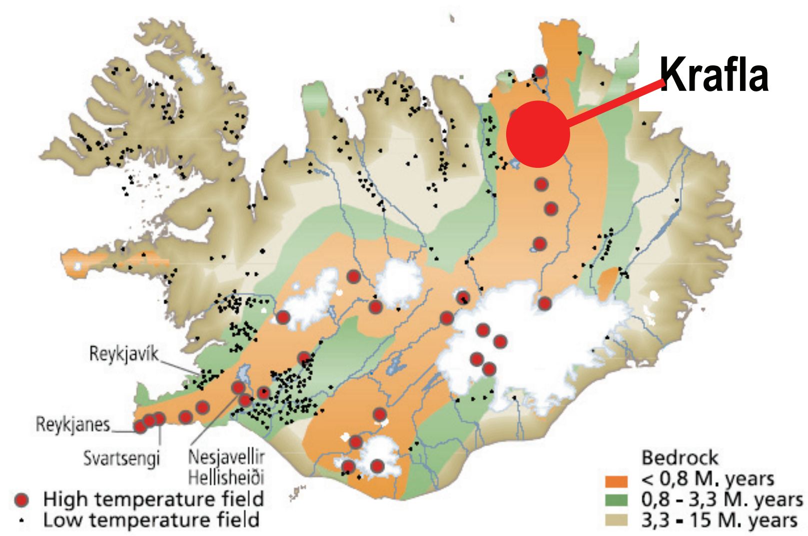
Krafla, Iceland

60 MWe production from existing steam field

New well 3.5 to 5 km depth, >450° C

Drill within seismogenic zone where brittle fracturing could enhance permeability

Rift setting: Deep tectonic fracturing influences magma emplacement & fluid flow



Map: Icelandic National Energy Authority & Ministries of Industry & Commerce, 2006

Krafla, Iceland

volcanic eruption 1975-1984

intruded volume: 1 m wide
9 km long
7 km deep

erupted volume: 100×10^6 m^3

temperature: >1100° C

Krafla, Iceland

Drilling began late 2008

After winter break, drilling recommenced March, 2009

Late April to Late June, 2009, drilling problems encountered

24 June, 2009, fresh magma intrudes into hole; further drilling suspended

Krafla IDDP Site (photo: http://www.iddp.is/)

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Summary of Main Issues

Diversity of R & D investment required: science & engineering

Challenges: permeability structure
sustained heat transfer

EGS most promising global resource
Conventional hydrothermal resources restricted