Development of Deep Unconventional Geothermal Resources (DUGR's) in Iceland and their Potential Application Elsewhere in Europe

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"Exploring High-temperature Reservoirs: New Challenges for Geothermal Energy".

Engine Workshop 2, 1-4 April 2007, Volterra, Italy

9 March, 2007, EU Commitment on Climate Change

"Reduce CO_2 Emissions by 20% from 1990 Levels by 2020 !"

Air Emissions Kg per megawatt hour	**Carbon Dioxide**	**Sulfur Dioxide**	**Nitrogen Oxides**	**Particulate Matter**
Coal (average existing facility)	996	4.7	2	1
Oil	760	5.5	1.8	Not available
Natural Gas	551	0.1	1.3	0.06
Average of all U.S. Power Plants	623	2.8	1.3	Not available
Geothermal (Flashed Steam)	27	12.3	0	0
Geothermal (Binary)	0	0	0	0

(Data from Kagel, Bates, and Gawell, 2005)

The World Energy Authority's Estimate of the Technical Availability of "Renewable" Energy Resources (WEA, 2004)

Energy Source	EJ/a
Hydropower	50
Biomass	276
Solar	1575
Wind	640
Geothermal	5000
Total	**7600**

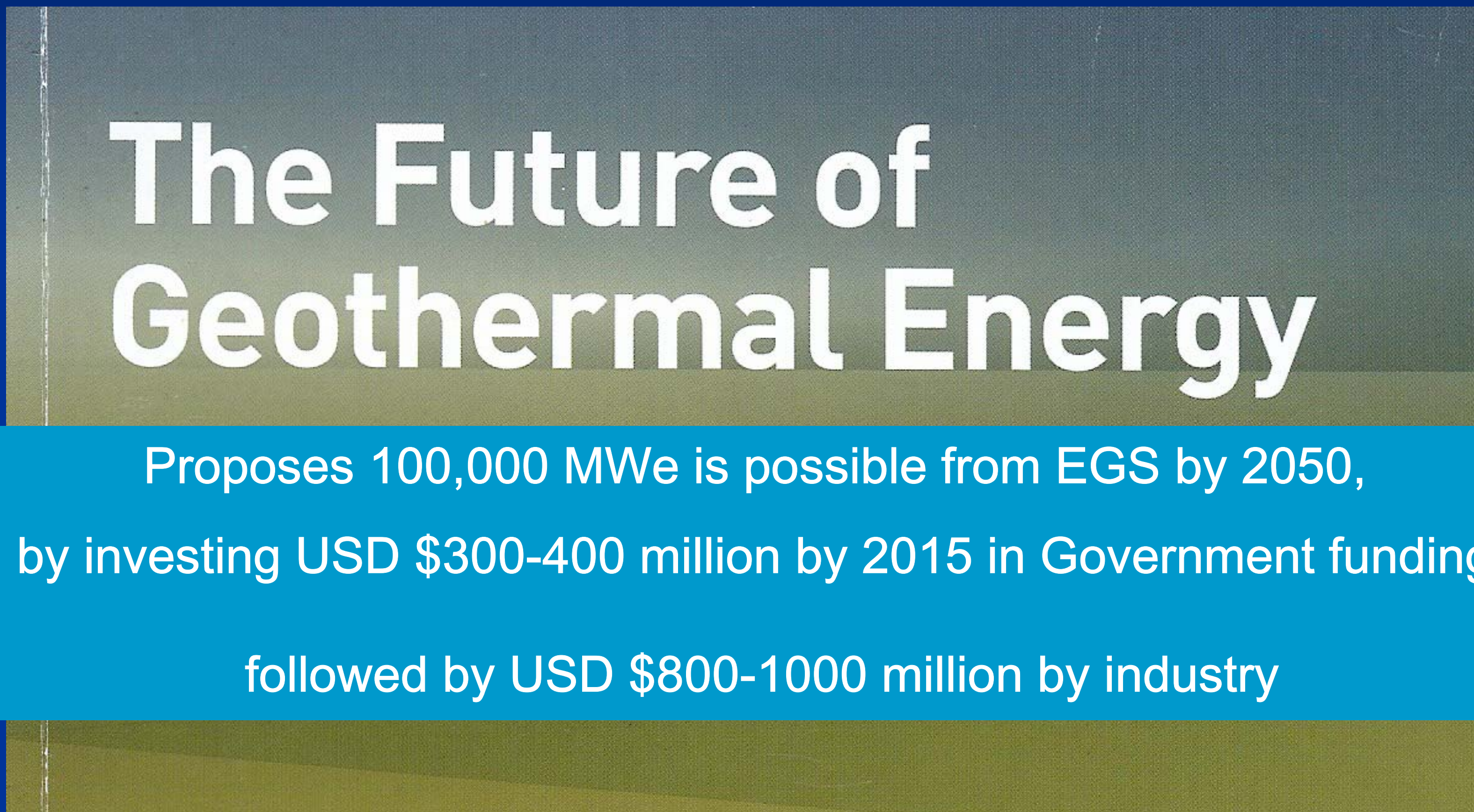
(www.iea.org)

DOE Geothermal Resource Estimate for the USA, February 2007 (NREL/TP-840-40665)

	Estimated Accessible Resource (MWe)	2006 (Actual MWe)	Estimated Developable Resource* 2015 (MWe)	2025 (MWe)	2050 (MWe)
Shallow Hydrothermal[1] (Identified) >90°C/194°F	30,000	2,800	10,000	20,000	30,000
Shallow Hydrothermal[1] (Unidentified) >150°C/302°F	120,000		TBD	TBD	TBD
Co-Produced & Geopressured[2]	>100,000	2[3]	10,000 to 15,000	70,000	>100,000
Deep Geothermal[4]	1,300,000 to 13,000,000	0	1000	10,000	130,000
Thermal Uses	(MWt)	(MWt)	(MWt)	(MWt)	
Direct Uses[5]	>60,000	620	1600	4,200	45,000
Geothermal Heat Pumps[6]	>1,000,000	7,385	18,400	66,400	>1,000,000
GHP[6] Avoided Power	120,000	880	2,100	8,000	120,000

*TABLE 1. * Please note that these resource estimates represent a consensus of a group of experts who considered existing resource assessments (referenced on next page). There is considerable uncertainty in the estimates as many resources are hidden and exploration to date has been relatively limited. The figures shown above are not a resource assessment, but, even with uncertainty, clearly show that the U.S. geothermal resource is a very large and important domestic energy source.*

Tester, et al., 2006



Proposes 100,000 MWe is possible from EGS by 2050,

by investing USD $300-400 million by 2015 in Government funding,

followed by USD $800-1000 million by industry

Tester's EGS Resource Estimates for USA

Table 1.1 Estimated U.S. geothermal resource base to 10 km depth by category.

Category of Resource	Thermal Energy, in Exajoules (1EJ = 10^{18}J)	Reference
Conduction-dominated EGS		
Sedimentary rock formations	100,000	This study
Crystalline basement rock formations	13,300,000	This study
Supercritical Volcanic EGS*	74,100	USGS Circular 790
Hydrothermal	2,400 – 9,600	USGS Circulars 726 and 790
Coproduced fluids	0.0944 – 0.4510	McKenna, et al. (2005)
Geopressured systems	71,000 – 170,000**	USGS Circulars 726 and 790

* Excludes Yellowstone National Park and Hawaii

** Includes methane content

Exploring high temperature reservoirs: ~~new~~ OLD challenges for geothermal energy

- 1. Adequate Enthalpy ←
- 2. Adequate Permeability and Porosity
- 3. Adequate Fluid Saturation

In an EGS at least one of the last two must be Engineered or Enhanced

Hence the need to emphasize High Enthalpy !

Availability Diagram for Water (Tester et al., 2006)

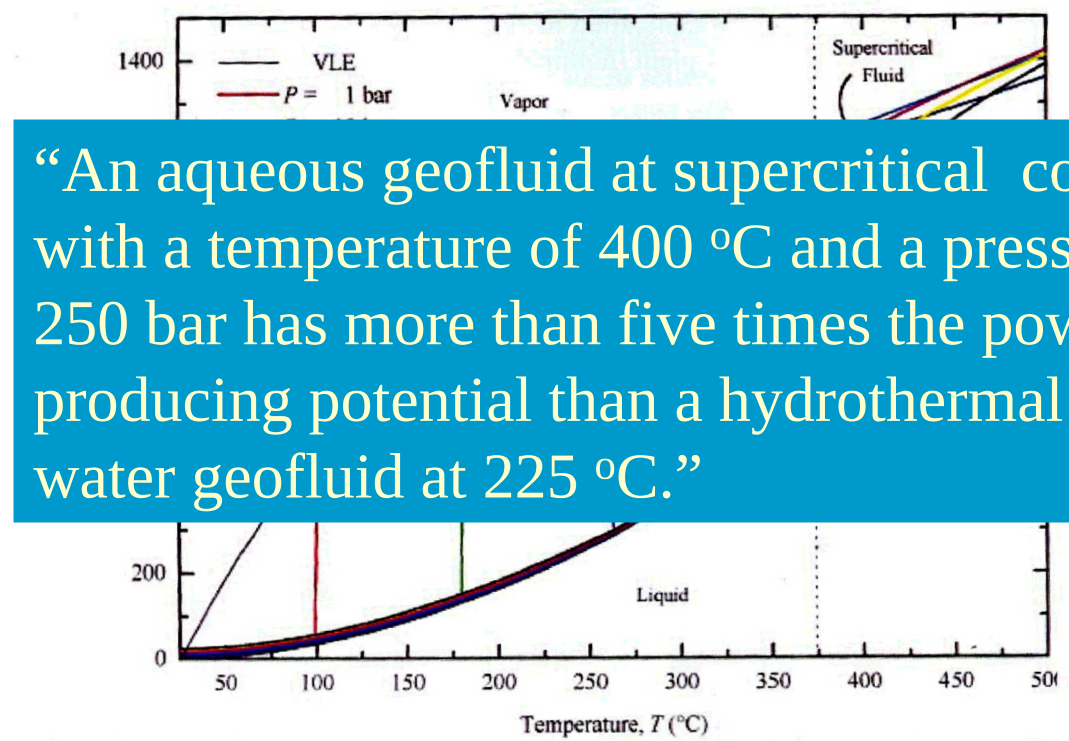
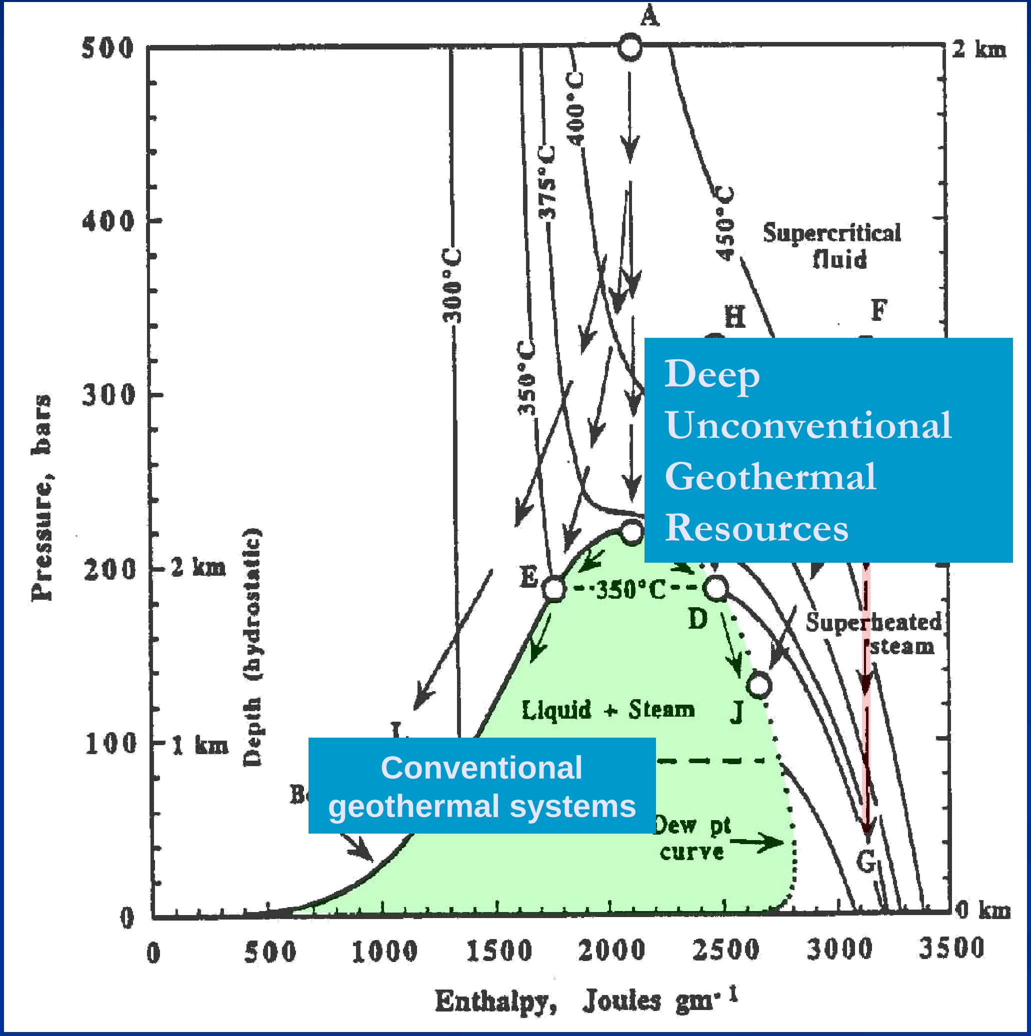


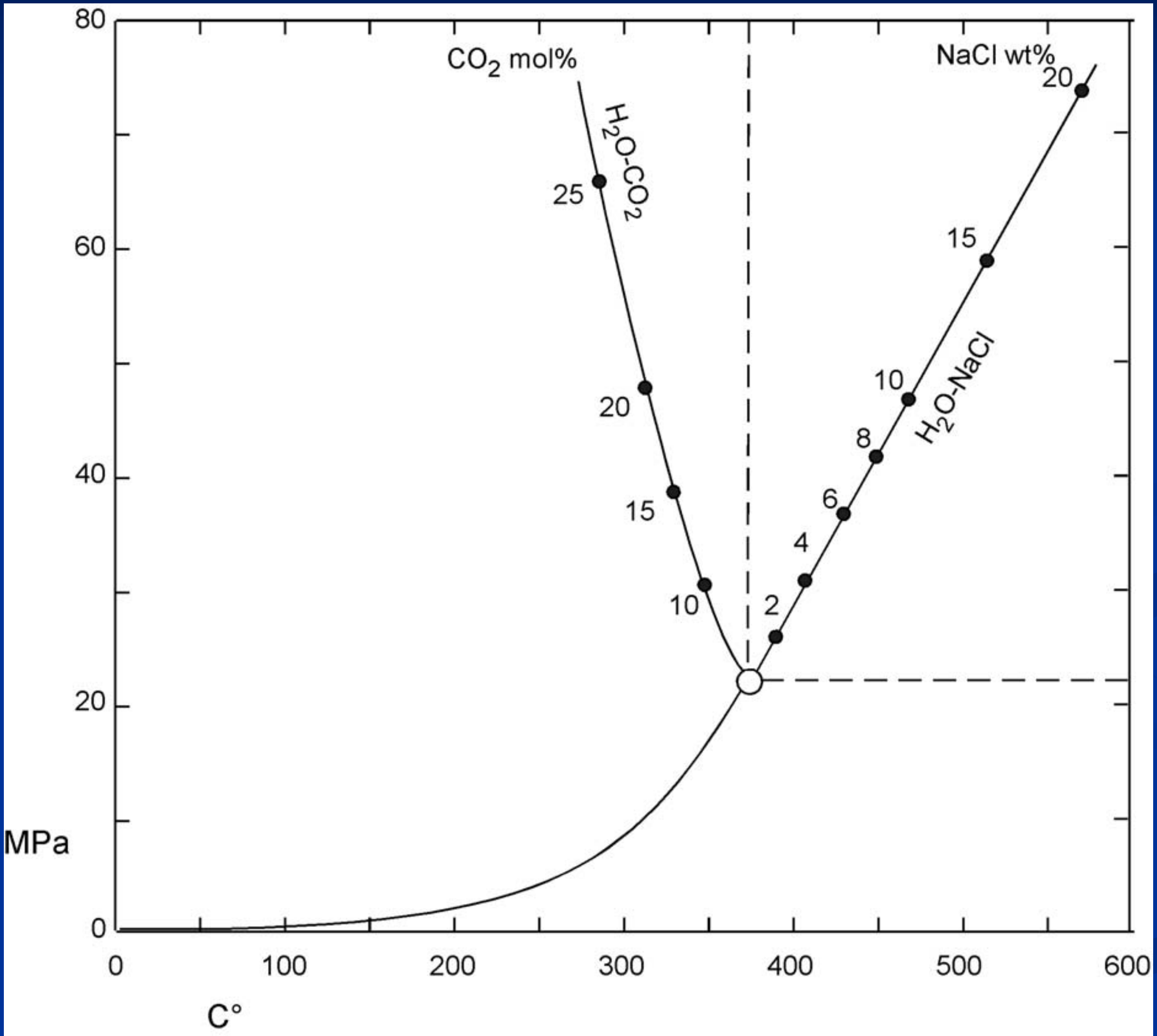
Figure 1.10 **Availability diagram for water. The magnitude of the availability is a direct measure of the maximum electrical work- or power-producing potential of aqueous-produced geofluid at specific-state conditions of temperature and pressure.**

"An aqueous geofluid at supercritical conditions with a temperature of 400 °C and a pressure of 250 bar has more than five times the power producing potential than a hydrothermal liquid water geofluid at 225 °C."

Fournier 1999

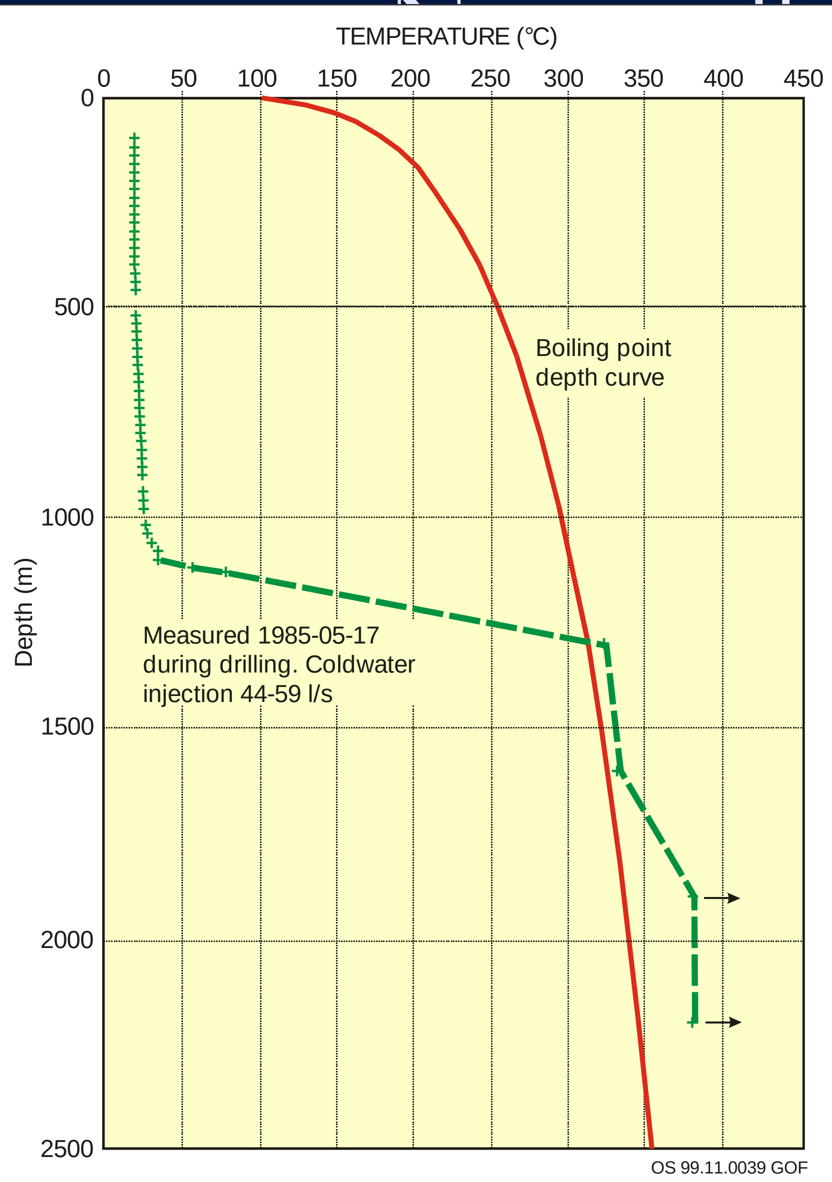


Effect of salt and gas on the critical P-T



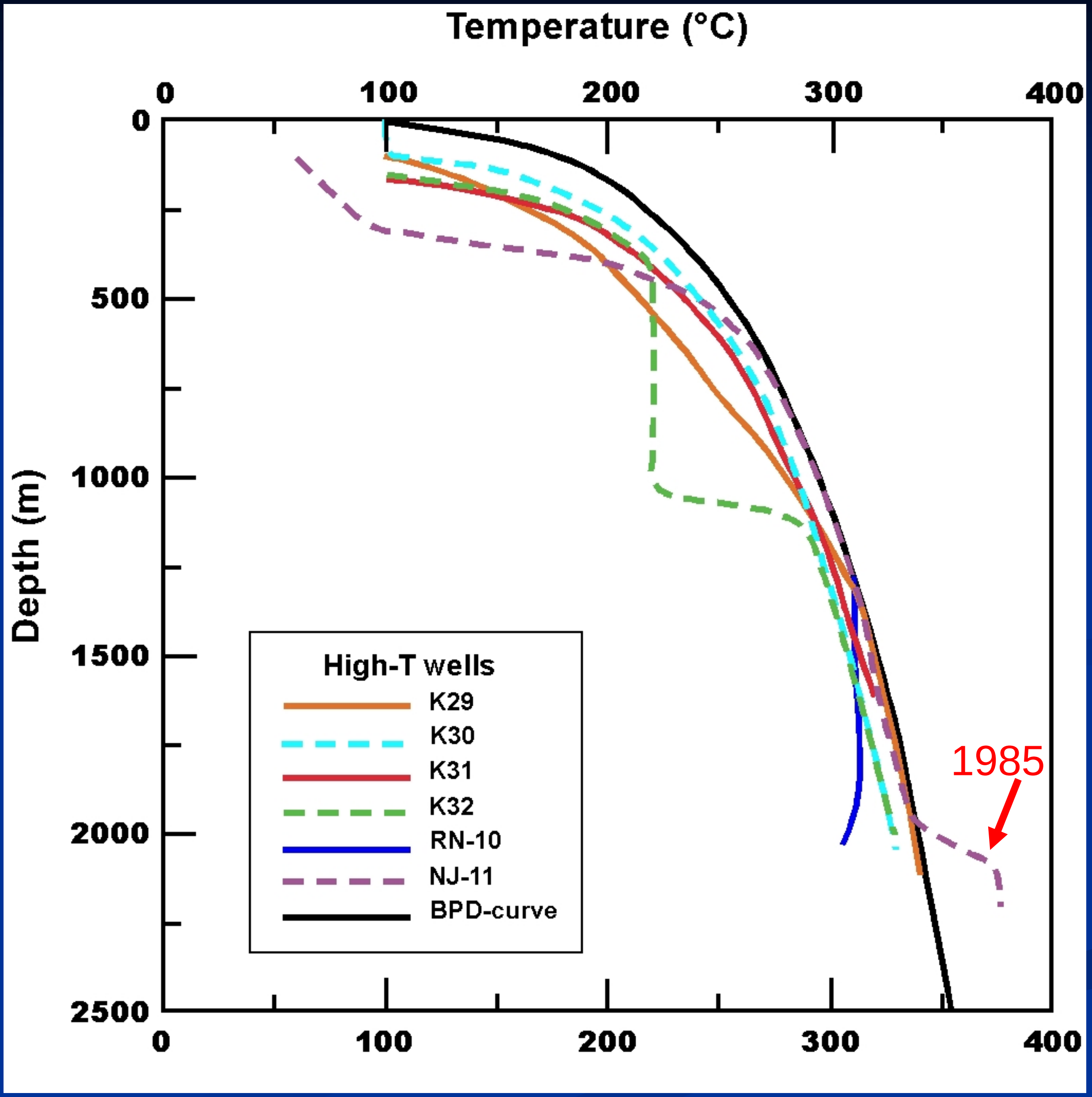
Tsuchiya, et al., 2006

…r, Iceland 1985



Temperatures in many high-T wells in ICELAND follow the BPD-curve with increasing depth

Examples from:
Krafla (K)
Nesjavellir (NJ)
Reykjanes (RN)



The Icelandic Energy Consortium:

HITAVEITA SUÐURNESJA HF.

Landsvirkjun

Orkuveita Reykjavíkur

OS ORKUSTOFNUN

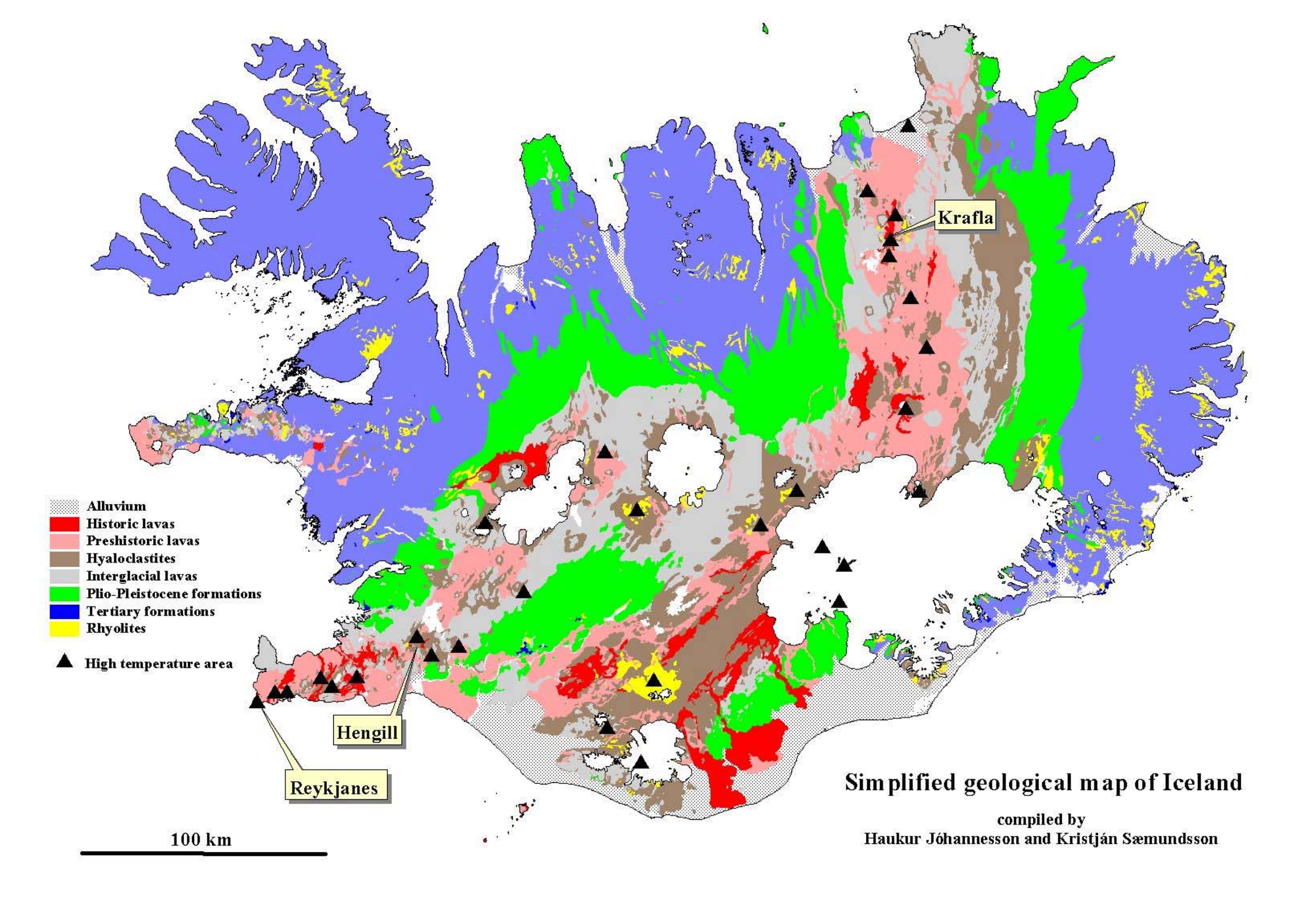
(National Energy Authority)

Advantages of the Industry/Government/Science Collaboration

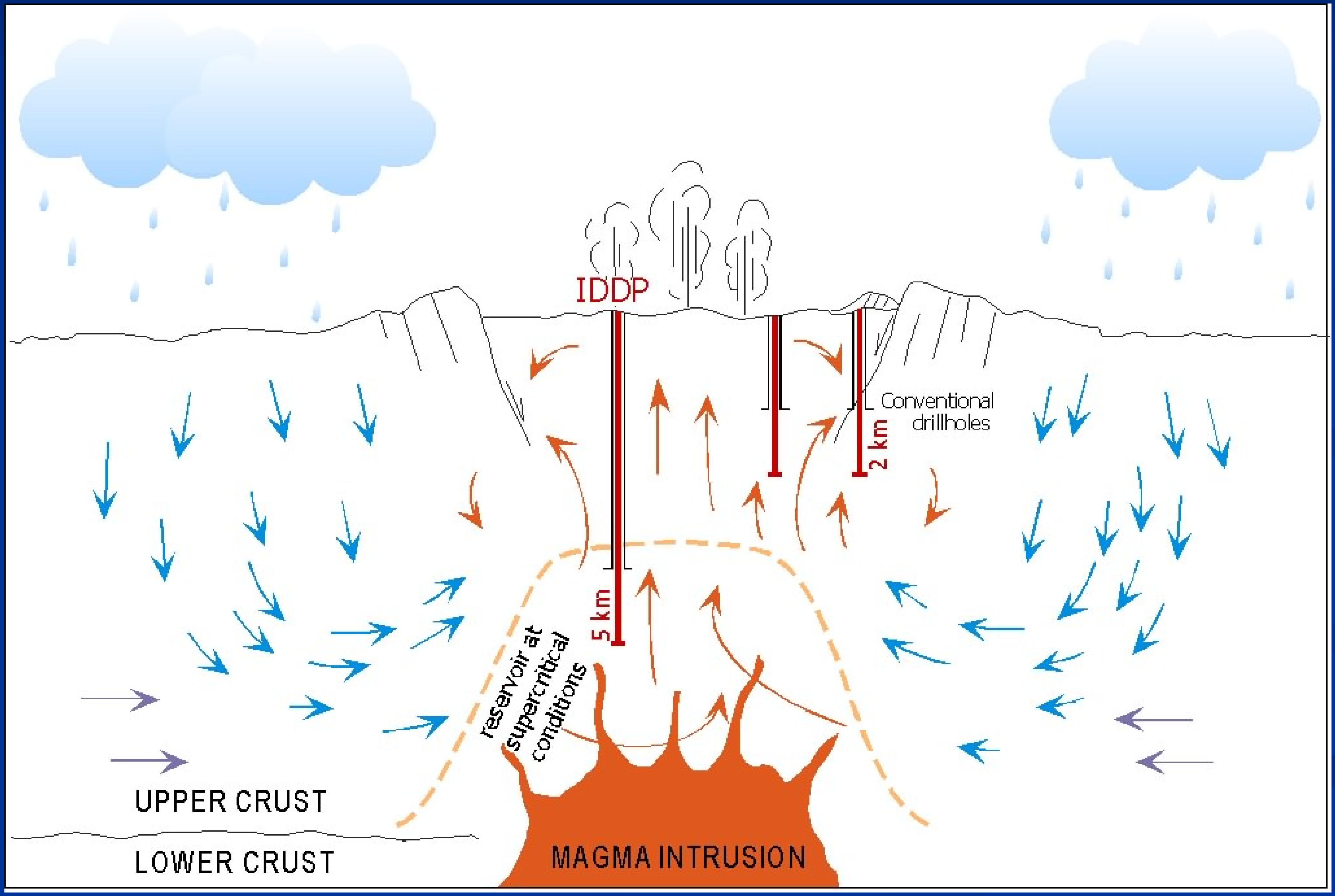
- Sharing costs of drilling and sampling
- Industry technical experience and expertise
- Feasibility study and site selection studies provided by Industry
- Huge data base of geophysical and borehole data available
- Many with alternative choices possible for siting boreholes

IDDP Feasibility Study 2003

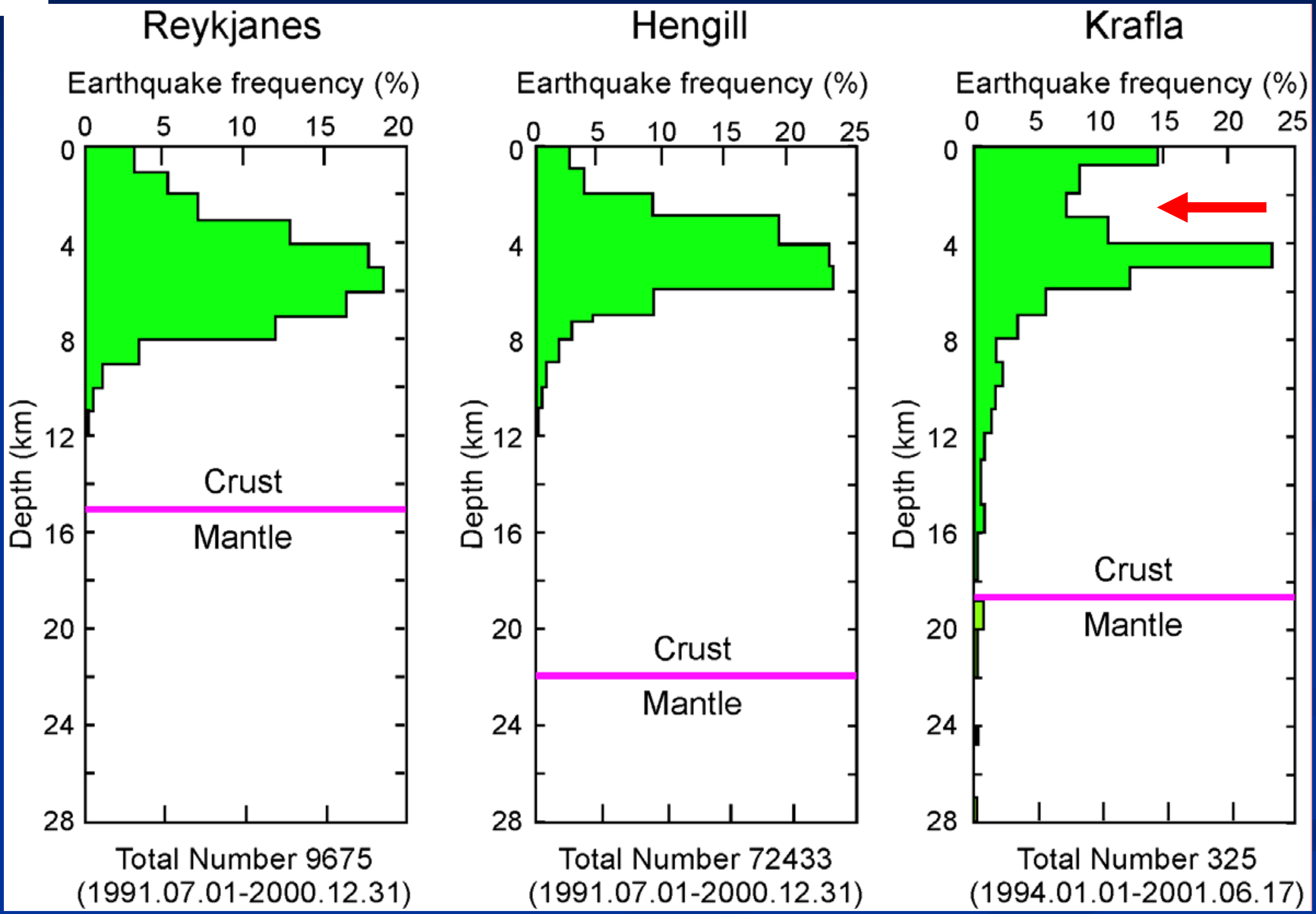
"If the wellhead enthalpy is to exceed that of conventionally produced geothermal steam, the reservoir temperature must be higher than 450°C. A deep well producing 0.67 m^3/s steam (~2400 m^3/h) from a reservoir with a temperature significantly above 450°C could, under favorable conditions, yield enough high-enthalpy steam to generate 40-50 MWe of electric power."


Alluvium
Historic lavas
Preshistoric lavas
Hyaloclastites
Interglacial lavas
Plio-Pleistocene formations
Tertiary formations
Rhyolites
High temperature area
Krafla
Hengill
Reykjanes
100 km
Simplified geological map of Iceland
compiled by
Haukur Jóhannesson and Kristján Sæmundsson

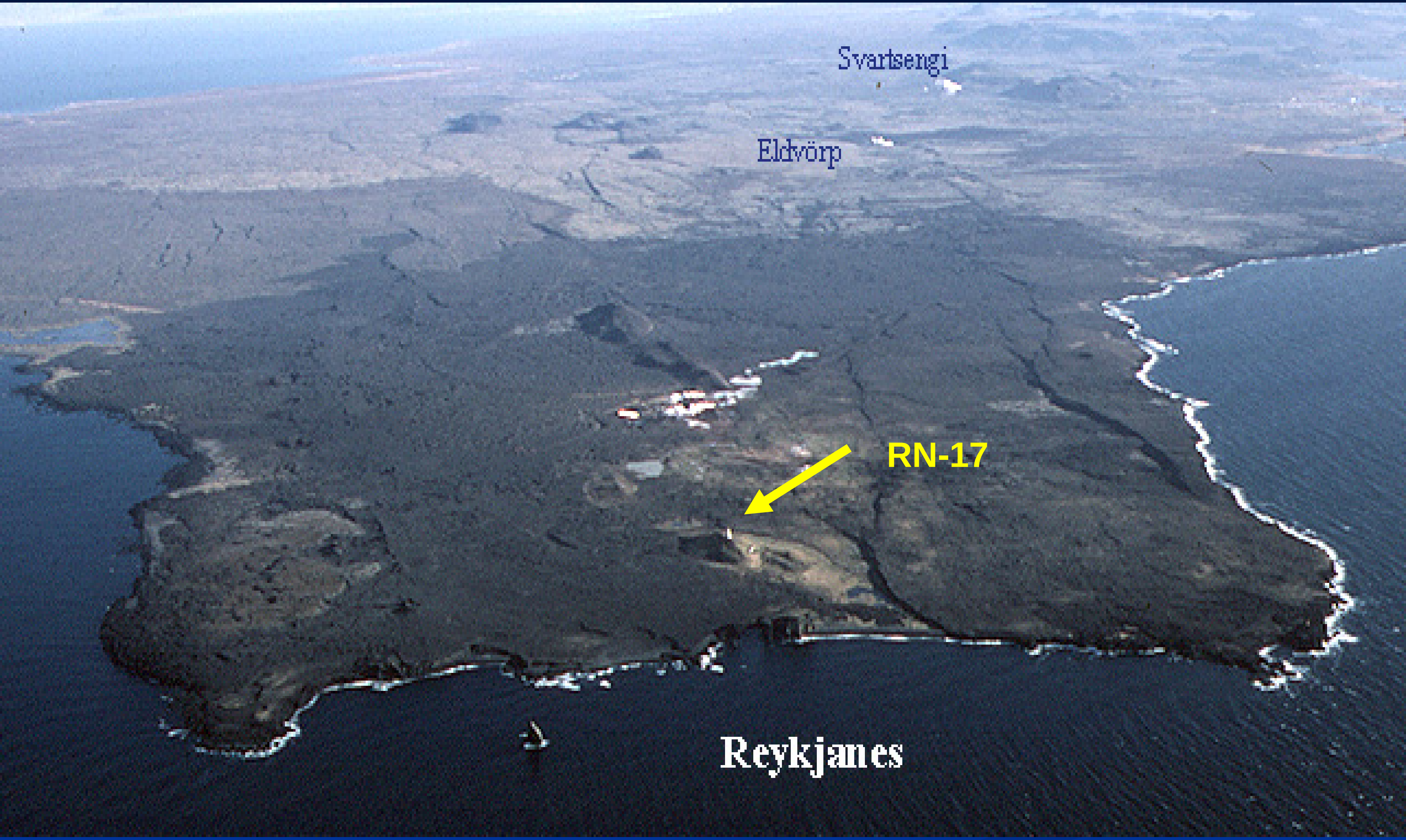
Simplified model of an Icelandic high-temperature geothermal system

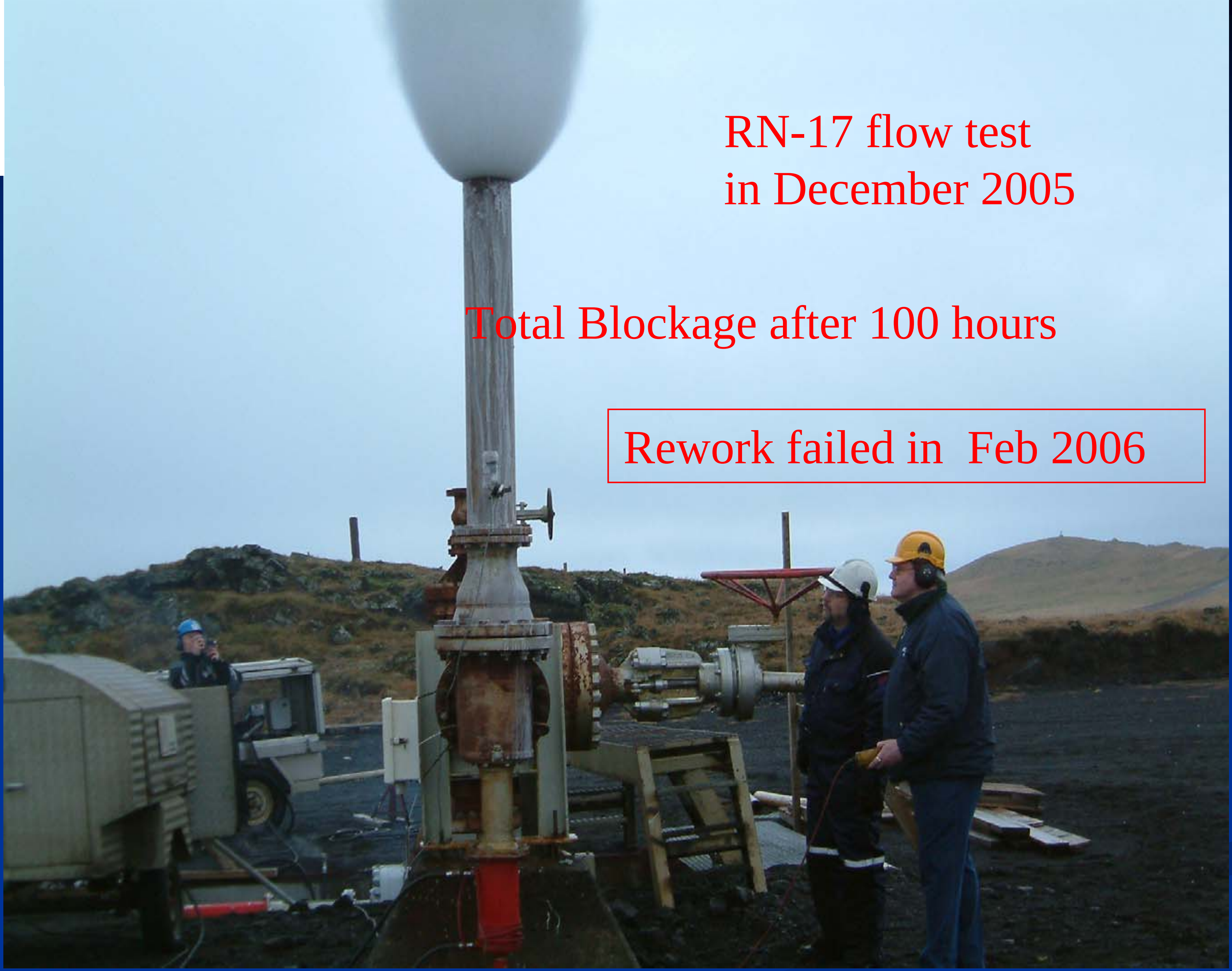


Earthquake frequency (0 – 5 on Richter scale)



The First Drill Site - Reykjanes Peninsula





RN-17 flow test
in December 2005

Total Blockage after 100 hours

Rework failed in Feb 2006

Criteria for Decision to Move Site of Drilling

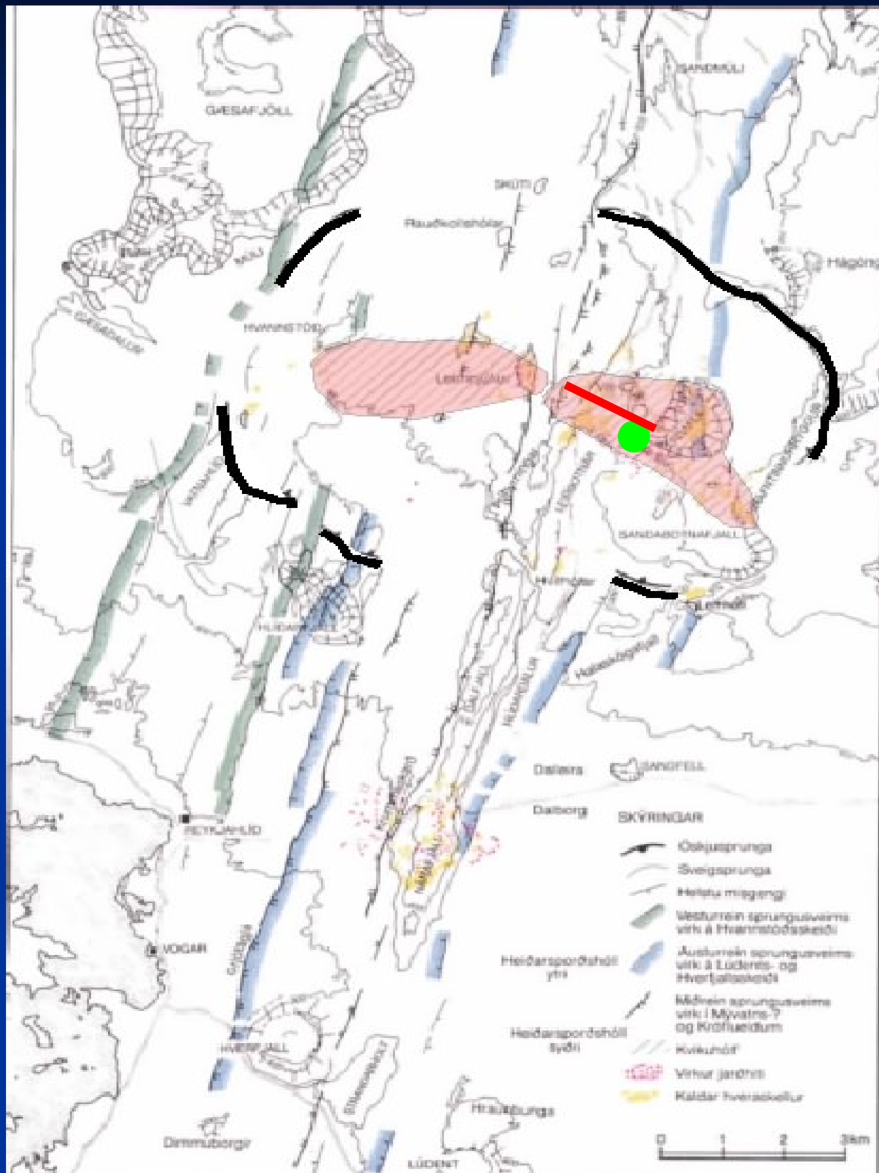
- Maintain economic objectives (improving the economics of geothermal energy by investigating supercritical environments)
- Maintain scientific objectives (supercritical hydrothermal environments)
- Maintain momentum & funding
- Optimize chances of success in site selection
- Maintain the long term focus (multi-year, multi-well program)

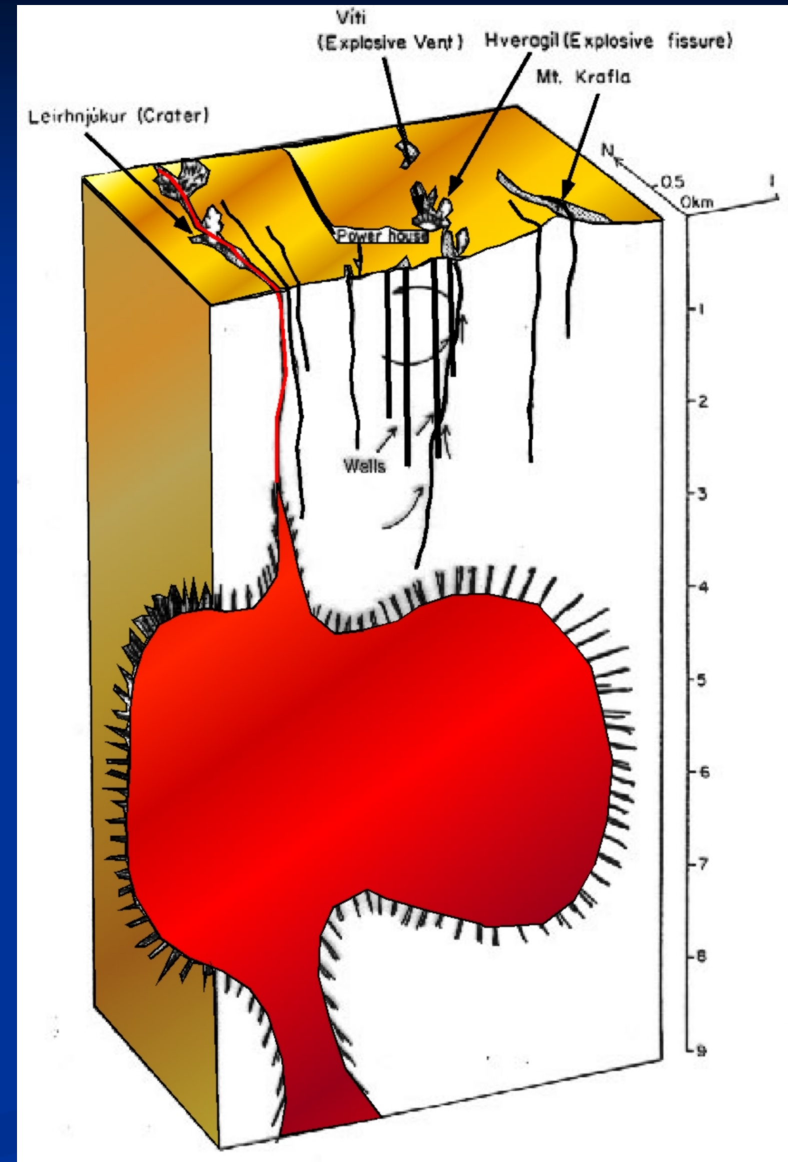
Krafla, Sept. 1977

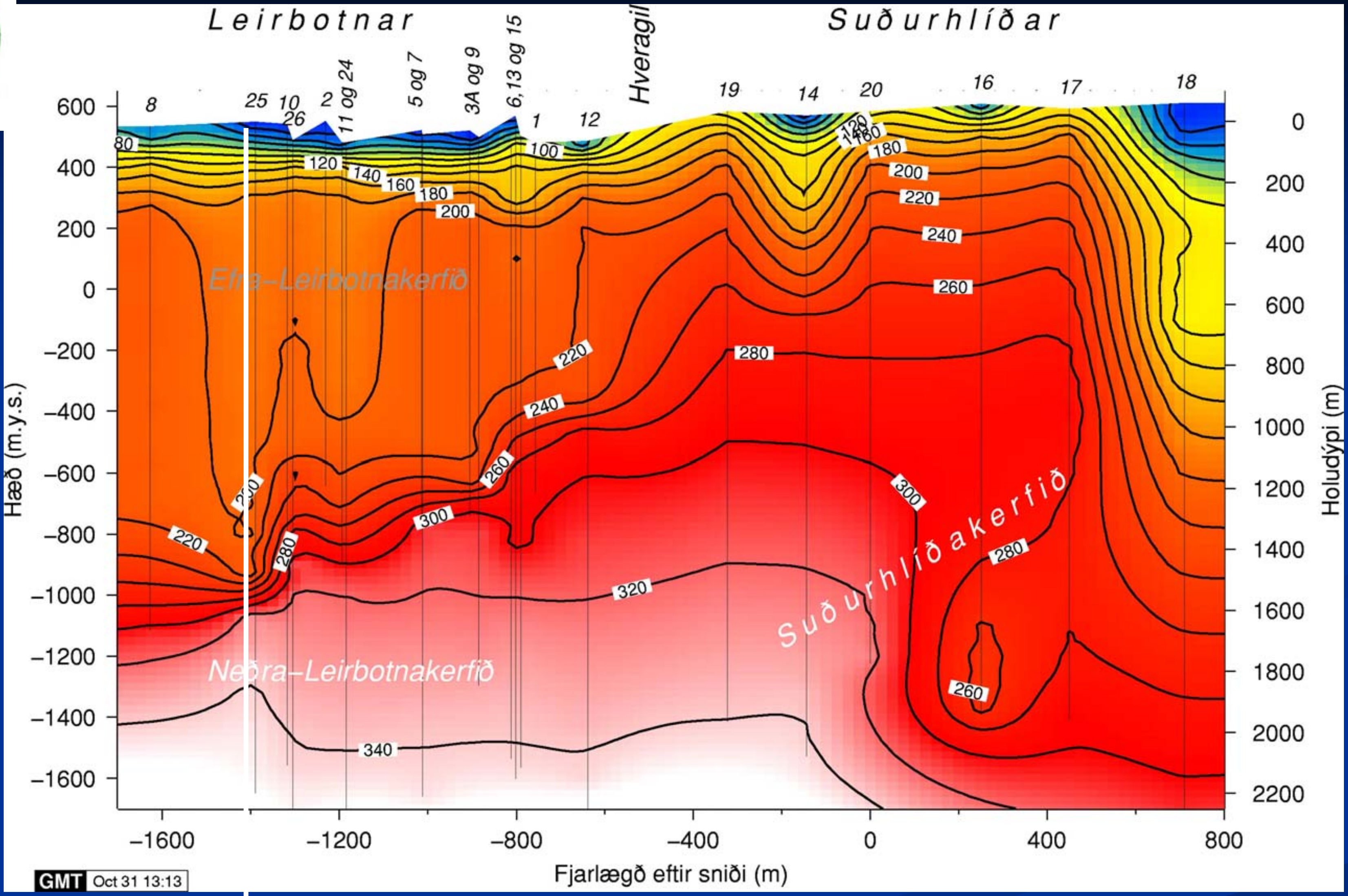

Krafla central volcano


IDDP-well
Krafla power plant

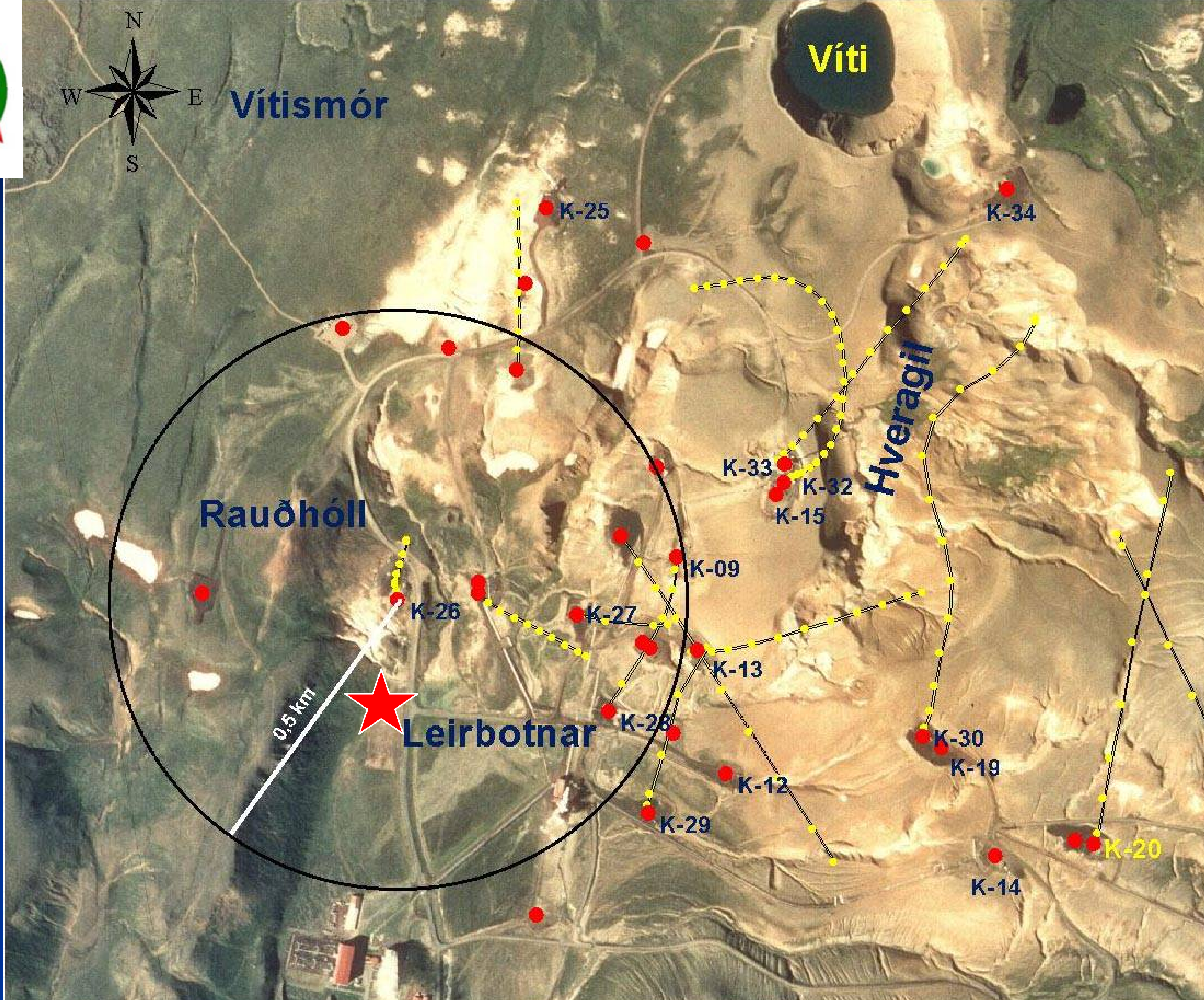
Krafla Central Volcano

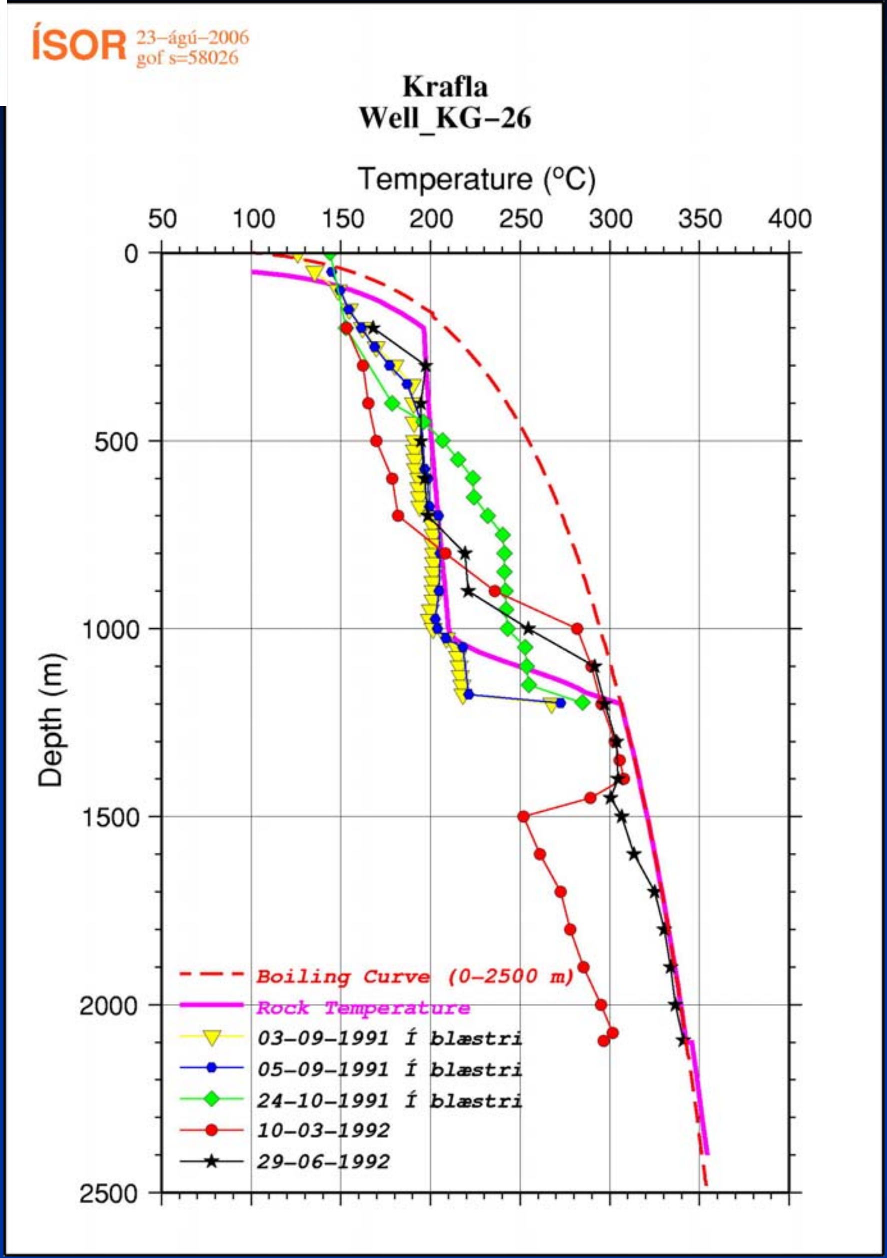


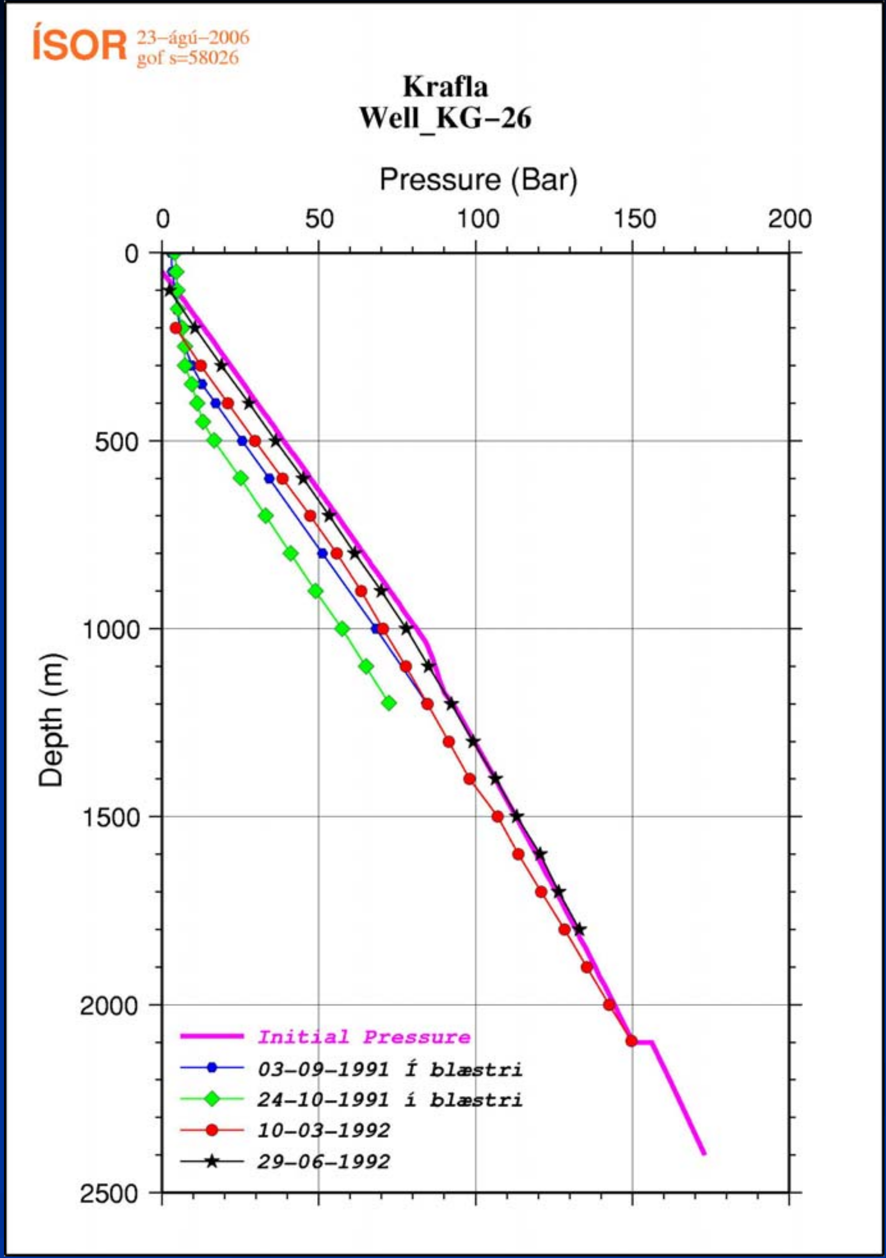



Leirbotnar
Suðurhlíðar
Hveragil
8
25
10
26
2
11 og 24
5 og 7
3A og 9
6,13 og 15
1
12
19
14
20
16
17
18
Efra–Leirbotnakerfið
Neðra–Leirbotnakerfið
Suðurhlíðakerfið
Hæð (m.y.s.)
Holudýpi (m)
Fjarlægð eftir sniði (m)
GMT Oct 31 13:13

~ 4-5 km


N
W
E
S
Vítismór
Víti
K-25
K-34
K-33
K-32
K-15
Hveragil
Rauðhóll
K-09
K-26
K-27
K-13
K-28
0,5 km
Leirbotnar
K-30
K-19
K-12
K-29
K-20
K-14

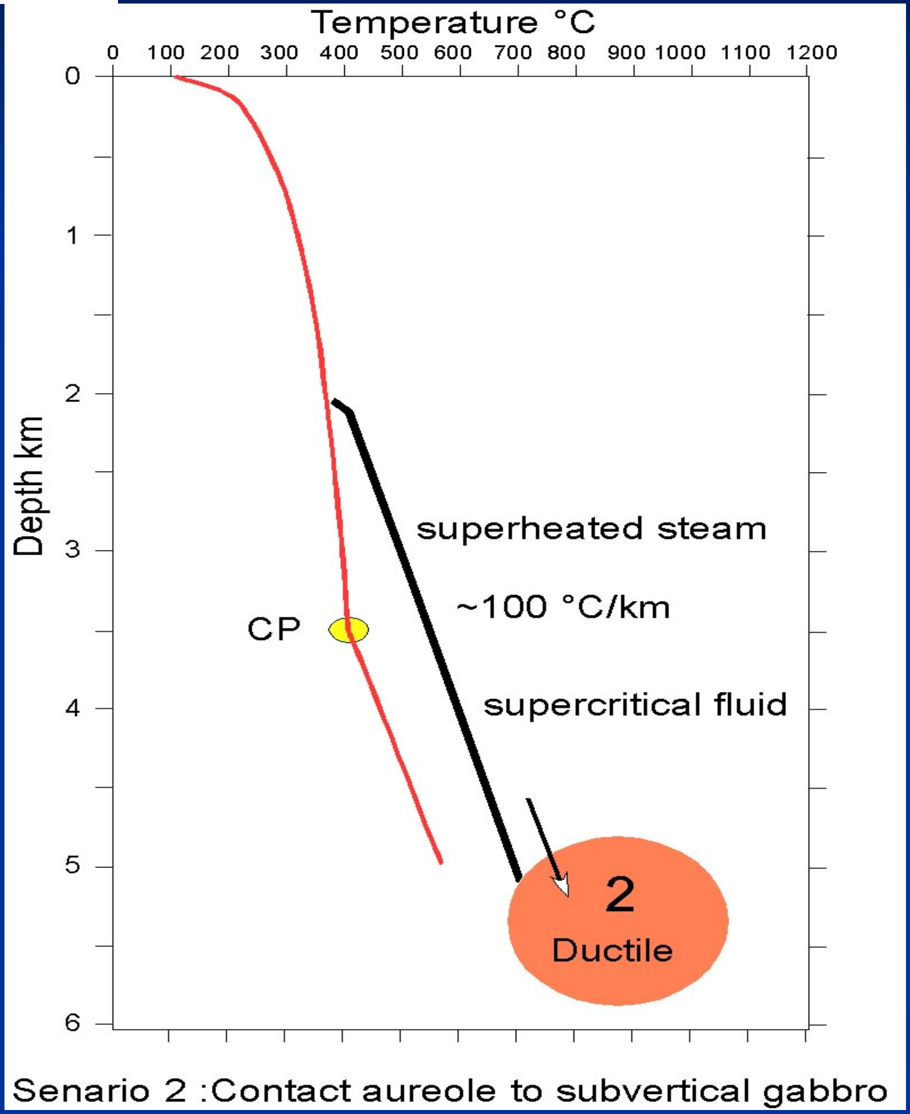


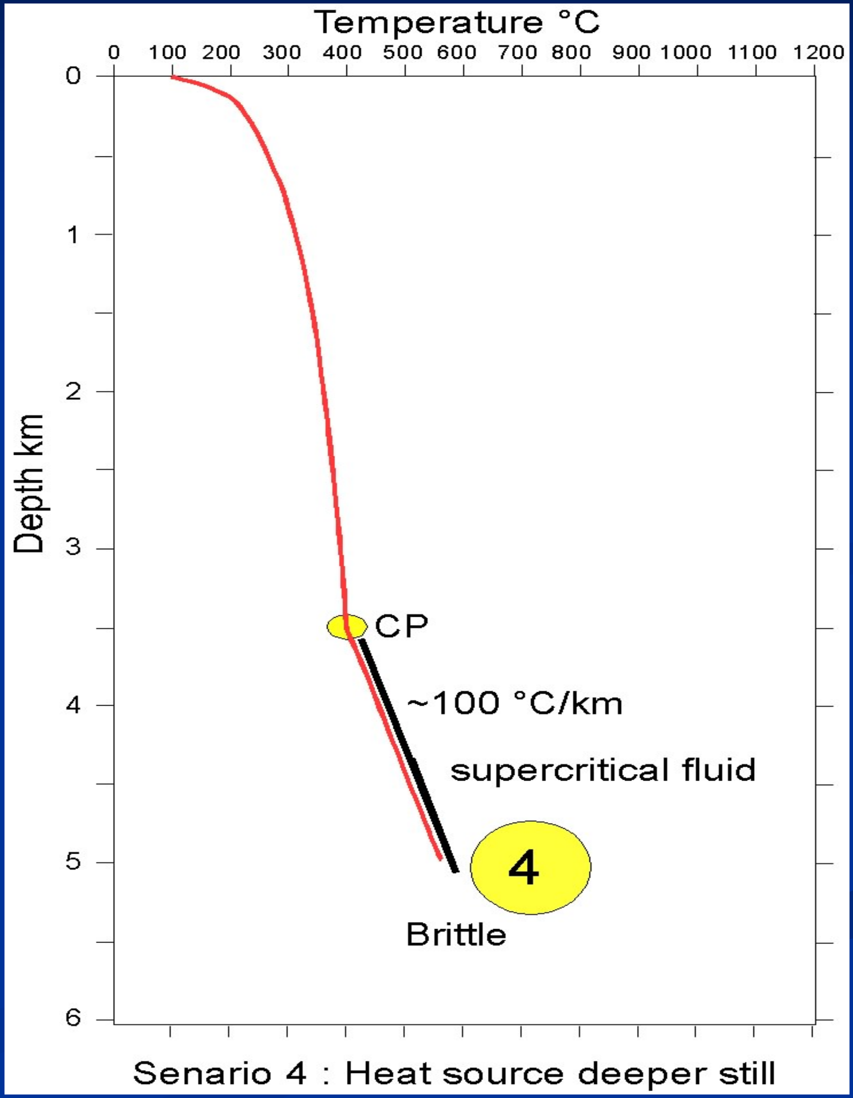


Fridleifsson, 2006

These are the type of drilling targets IDDP seeks

Depth of the production casing in Krafla will be ~3.5 km





Fridleifsson, 2006

Drilling & Science Plan

- Drill and take spot cores from 0 – 3.5 km depth
- Continuous coring from 3.5 to ~ 4.5 km depth
- Produce fluid samples from tests at 3.5 and 4.5 km depths
- Pressure, Temperature and flow-meter logs

- The drilling to 5 km is designed to penetrate into supercritical fluids which must underlie black smoker hydrothermal systems, and which play an extremely important role in heat transfer, hydrothermal alteration, and ore genesis

- Supercritical fluids have greatly enhanced rates of mass transfer chemical reaction

  - **These environments have never before been available for such comprehensive direct study and sampling**

Specific Scientific Goals

- Do natural supercritical fluids exist at drillable depths and do they have economic potential?
- What are the physical/chemical properties of natural supercritical fluid?
- How are supercritical fluids involved in coupling hydrothermal systems with magmatic heat sources?
- How do they affect chemical and mineral alteration, fracture propagation, permeability, and fluid flow at the magma/hydrothermal interface?

Wider Research Goals

Mid-ocean rifting and hot spots.

Volcanic & dike complexes.

Hydrothermal water-rock reaction

Fracturing, self-sealing and permeability.

Natural supercritical phenomena.

Heat transfer from magma.

Techniques for drilling, well completion and logging at high-temperatures

Industrial, and economic spin-offs.

Possible DUGR's of interest to the EC

- ICELAND - Krafla, Reykjanes, Hengill-Nesavallir, etc.
- ITALY - Larderello, Monte Amiata, Latera, Campi Flegrei.
- KURIL - Northern Paramushir, Baranskogo, Mendeleeva, Goryachi Plyazh
- KAMCHATKA – Kireunskaya, Apapelskaya, Tolbachinskaya - Geyser Valley, Karymsko Academicheskaya, Bolshebannaya, Mutnovskya, Khodutkinskaya, Pauzhetskaya, Koshelevskaya

Possible DUGR's of interest to the EC

- TURKEY – Nevsehir Caldera - Menderes Metamorphic Massif - Quaternary Volcanoes of Eastern Anatolia
- GREECE - Southern Aegean Volcanic Arc – Milos – Nisyros
- CANARY ISLANDS – Tenerife, Lanzarote, La Palma
- GUADALOPE – Bouillante
- AZORES

Suggestions for ENGINE

- Develop and get funding for MAJOR initiatives
- DUGR's should be an important component
- Make a EU wide assessment of DUGR potential
- Develop specific projects
- Develop collaborations with industry

Thank You!

htpp://www.iddp.is