Probing of high temperature geothermal reservoirs from electrical methods : *HiTi* EC project and the IDDP

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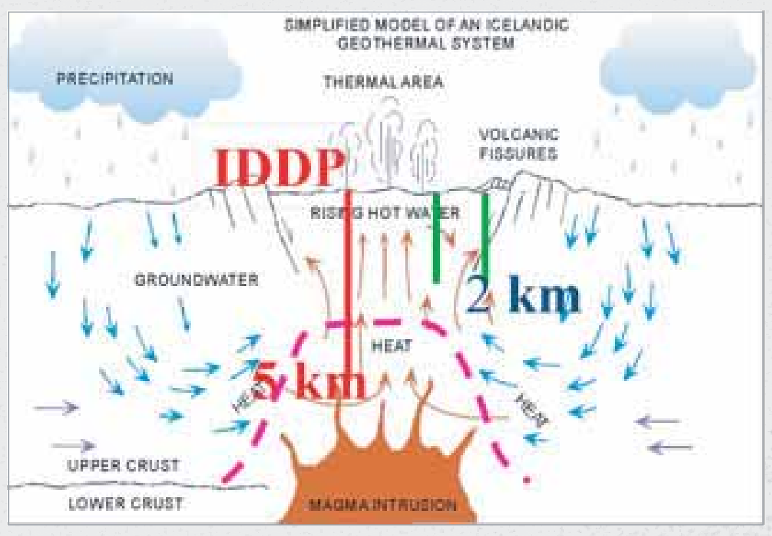
HiTI ("High Temperature Instruments") is a 3 year scientific project funded by the Europeen Commission as part of FP6.

The objective of HiTI is to develop and test innovative, reliable tools methods and instruments for the characterisation and exploitation of high-temperature unconventional geothermal energy resources.

IDDP

(Iceland Deep Drilling Project)

Temperatures greater than 300°C are commonly encountered in Icelandic wells drilled to depths of 2 to 3 km in high-temperature geothermal fields. The repeated seismicity under volcanic regions *(Reykjanes peninsula, Hengill rift, Krafla volcanic area)* creates fractures hence permeability in high temperature reservoirs at about 5 km depth. Supercritical conditions at such depth might be exploited to the benefit of a more efficient geothermal energy production.



Schematic view of an hydrothermal system, with IDDP project.

Geothermal site and plant at Krafla, NE Iceland

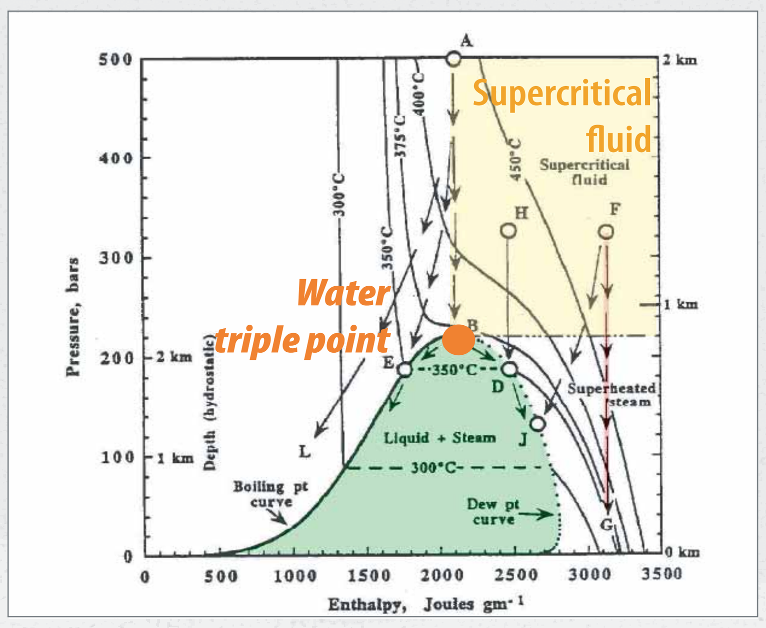
The Icelandic governement with the national agency for geothermal energy associated with a consortium of Icelandic companies (*Hitavelta Sudurnesja, Landsvirkjun, Orkuvelta Reykjavikur*), proposes to reach such reservoirs and supercritical fluids *(with T> 400°C)* at what is now believed to be drillable depth *(about 5 km)*.

This initiative is developped under the acronym of Iceland Deep Drilling Project **(IDDP)** under the coordination of **ISOR.** It offers the international geoscience community a unique opportunity *(a)* to investigate in situ the relationship between magmatism and fluid circulation, and *(b)* to study and sample fluids at supercritical conditions, in a context which resemble that of black smoker marine hydrothermal systems.

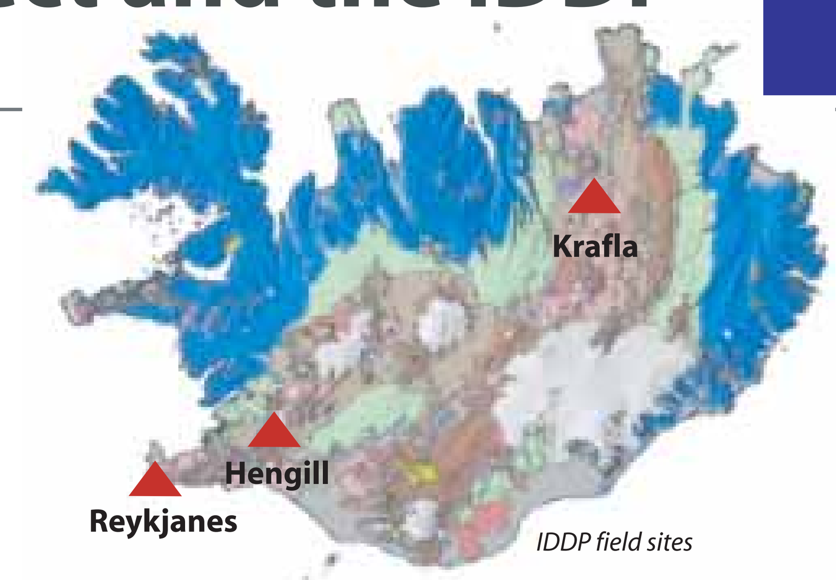
The project, beholded by **ICDP** and **NSF**, shall start with a **pilot borehole in the Krafla volcanic area.**
It will be drilled to 3000 m in 2008,
then cored to reach :

- 4000 m and about 400°C in 2009,

- 5000 m and about 500°C in2010.



Liquid-gas equilibrium diagram for water, with supercritical domain.



IDDP field sites

HiTI / field (Krafla, Iceland)

Abstract

The general objective of the HiTI EC project is to provide geophysical and geochemical sensors and methods to evaluate deep geothermal reservoirs up to supercritical conditions (T>380°C). Supercritical geothermal wells are still non-conventional but may provide a very efficient way to produce electricity from a clean, renewable source. A deep geothermal well is to be drilled in 2008 for this purpose into the NE Icelandic Krafla volcanic zone, as part of the IDDP ("Iceland Deep Drilling Project").

Aimed at exploring supercritical reservoirs, HITI is to develop, build and test in the field new laboratory or downhole tools and methods for deep high-temperature boreholes and a highly corrosive environment.

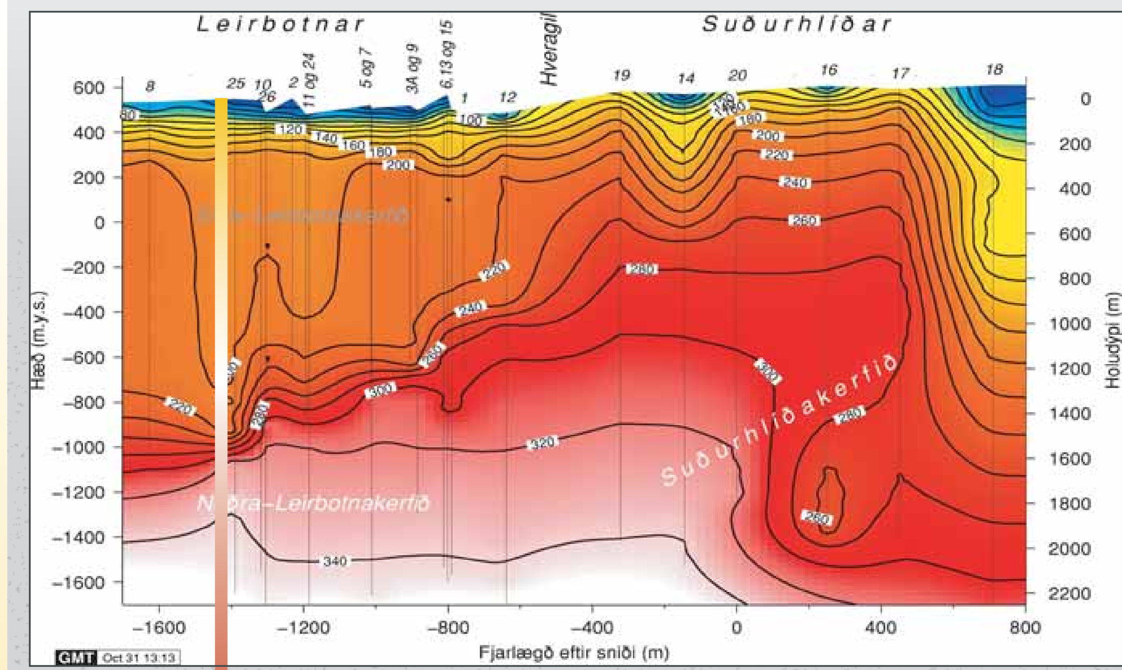
Hydrothermal veins from deep fluid circulation at supercritical conditions in a fossil system (Oman ophiolite).

The new set of tools and methods has been chosen to describe, in particular, the supercritical reservoir structure and dynamics. Slickline tools up to 450°C and wireline tools up to 300°C will be developed due to the present limitation in wireline cables (320°C). The more extreme, supercritical conditions will be explored taking advantage of cooling during the drilling phase.

For reservoir characterisation, the measured quantities are temperature and pressure (for in situ fluid, thermodynamic modelling of the reservoir and thermo-mechanical modelling of borehole integrity), natural gamma radiation and electrical resistivity (for basement porosity and alteration), acoustic signal (with borehole wall images for reservoir fracturing and in-situ crustal stresses) and reservoir storativity and equilibrium (from geothermometers and organic tracers). This poster focuses on solving the electrical problem as part of HiTI, and as a means to describe reservoir structure and dynamics.

This will include both laboratory and downhole measurements, aiming at describing the different components of the electrical signal, from alteration to porosity (matrix and fractures), and with the objective to identify in situ pore fluids in terms of salinity. This method will be developed first in a high temperature (200°C – 300°C) hole from the Krafla region, then applied to the IDDP hole.

Black smoker at the oceean floor, with nearby precipitation of metals.



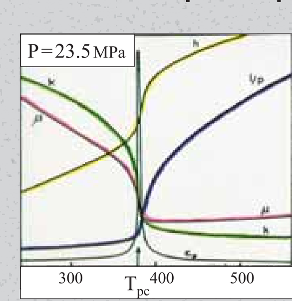
Electrical résistivity map of the Krafla volcano subsurface, NE Iceland

4 to 5 km

A multidisciplinary approach

The **HiTI project** proposes a joint analysis of petrological, petrophysical, geophysical, microstructural and geochimical properties of deep geothermal reservoirs, both in the field (IDDP and ISOR holes) and in the laboratory.

In the field, downhole geophysical measurements and images provide a description of structures penetrated by the hole. This description is made possible after calibration from core analyses in the laboratory. These are petrophysical, mineralogical and geochemical.



Water physical properties changes near the triple point (~380 °C) and at 23.5 MPa.

Innovative downhole tools and methods to characterize deep geothermal reservoirs

The technological objectives of **HiTI** are to design and test in the field :

- **new high temperature (> 300 °C) downhole investigation tools à** to face extreme opérationnal conditions,
- **new data analysis protocoles** for an integrated analysis of reservoirkey parameters,
- **new numerical models** to simulate downhole tools behaviour and to obtain a better caracterization of deep reservoirs.

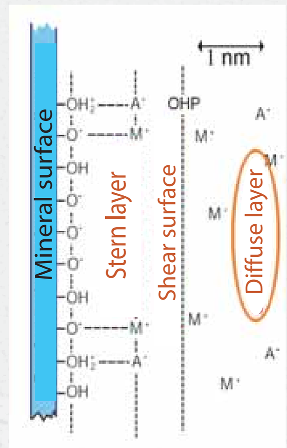
These tools will contribute to explore deep geothermal resources, producing a high resolution description of supercritical reservoirs in terms of porosity, fracturing, alteration, in situ stresses, as well as of nature and temperature of (pore) geothermal fluids.

Electrical conductivity of porous media : *one equation and 5 unknowns!*

$$C_o = \frac{C_w}{F} + C_s$$

=> C_w/F : volume term related to pore fluid salinity, rock température, porosity, and pore space topological structure in 3D

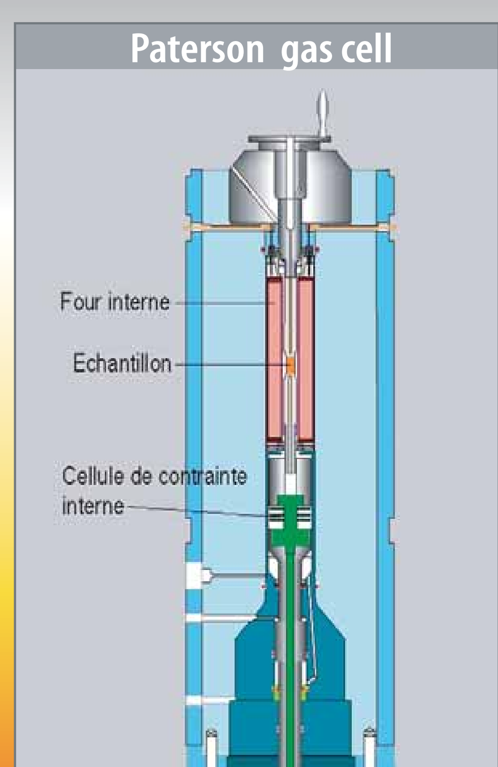
=> C_s : surface term related to the degree of alteration of the rock (therefore to past fluid circulation) and rock temperature



This system will be solved first cin the laboratory, from a set of measurements from minicores, and in situ (downhole), from geophysical measurements recorded with the new tools built as part of HiTI : natural gamma radioactivity or "GR" (Cs), borehole wall acoustic images or "BHTV" (fractures and porosity), physico-chimical drilling fluid properties (p, T, Cw) and electrical resistivity of the porous media from "DLL".

Hydrothermal vent (Rekjanes peninsula).

HiTI / laboratory (Montpellier, France)



Paterson press from GÉOSCIENCES Montpellier

In the laboratory, the aim of HiTI is to create *(with the Paterson press from Montpellier)*, supercritical conditions similar to that present at depths in deep, supercritical beneath geothermal reservoirs, in the vicinity of magmatic chambers *(from 500 to 600°C, and about 200 to 300 bars environ)*.

At such high pressure and high temperature conditions, the experiment conducted with the Paterson machine **on hydrated samples** will be focussed on :

- measuring petrophysical properties *(electrical and thermal),*
- studying the fragile-ductile transition in the presence of fluids,
- describing fracturing associated with thermal stresses *(if applicable)*,
- modeling fluid-rock interactions during these controlled experiments, either from a geochemical *(from isotopic analyses)* or petrographic point of vue *(from thin section analyses with a microsonde, before and after the experiment)*.

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