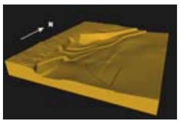
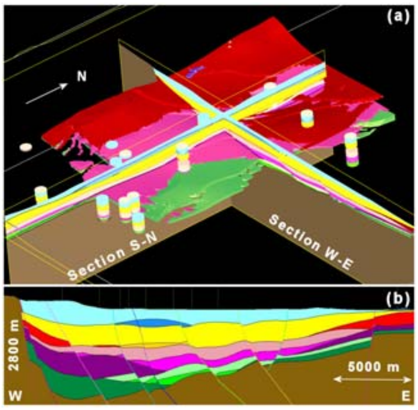
22-24/09/2008, Florence, Italy



3D geological modelling and geothermal assessment of the Limagne basin (France)

This work consists in assessing the geothermal potential of the Limagne area (Massif Central, France) in 3D by building a geological model and computing a thermal model. The reservoir is a Tertiary graben belonging to West European rift system characterized by a geothermal anomaly with Tertiary clastic reservoirs. In order to better understand the geometry of geology, various geological and geophysical data acquired during various campaigns are re-interpreted to construct a coherent 3D model. The new interpretation consists in a 35km x 30km x 5km geological model extending from the basement to the surface of the basin. The geometry of the geological model is used to constrain a 3D numerical diffusive temperature model based on the measured thermal conductivity of the various geological units and on thermal boundary conditions. The total amount of geothermal energy available for each aquifer is computed, and the geothermal potential i.e. the recoverable energy, is mapped over the entire model.

3D Geological modelling

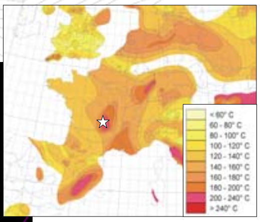


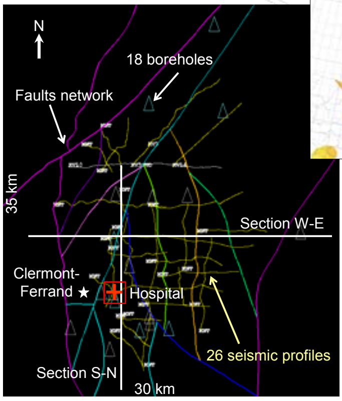
> View of the Limagne basin geological model (30 km x 35 km x 5 km).
(a) 3D view from S-E of the 4 detrital formations volumes ("Reservoir") in the central part of the model. Boreholes and two cross-sections are shown in the area.
(b) W-E section of the whole basin.

> Geological pile derived from the broad geological knowledge of the basin. Formations from the four sedimentary sequences (S1 to S4) and cycle ("Reservoir", "Intermediate" and "Top") are deposited on the "Basement". The sequences are separated by erosional surfaces (Erode relation for the top series of the four sequences). Each formation is modelled using independent potential fields because the variability of thickness is not correlated from a formation to another.

Geological setting

> European map of the temperatures extrapolated at 5 km depth from Hurtig et al., 1991.





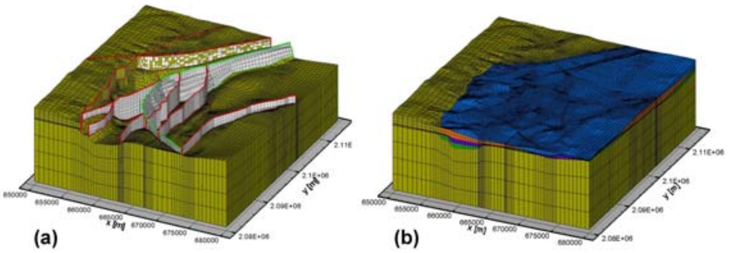
> Modelled area.
The model was built using boreholes and seismic profiles collected over the last 25 years.

The Limagne d'Allier Tertiary basin is located north of Clermont-Ferrand, oriented NNE to NS and bounded by regional faults. The Allier basin has been investigated more thoroughly than the other basins since it is deeper and displays higher temperature gradients. Overlying the Limagne d'Allier basement, four main sedimentary sequences fill the basin: Middle Eocene (S1), Upper Eocene (S2), Rupelian (S3) and Chattian (S4). Each sequence is composed of a sedimentary cycle ranging from detrital formations at the base ("Reservoir"), followed by alternating layers of detrital and carbonate sediments ("Intermediate"), and capped by formations of marls and carbonates at the top ("Top").

An original methodology has been developed in BRGM (French Geological Survey) to interpolate at the same time geological contacts locations and dips of the formations. The model is calculated by co-kriging these 2 types of data to obtain a combination of 3D potential field describing geology. A geological pile allows automatic computation of intersections and volume reconstruction using the geological history of the area and the relationship between geological units (Calcagno et al., 2008). This methodology is implemented in the 3DGeoModeller software (3dweg.brgm.fr and www.geomodeller.com).

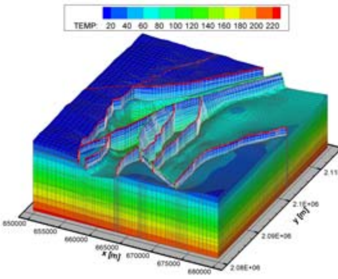
The geological layers are discretized using hexahedra and prisms (3D elements). Faults are discretized using squares and triangles (2D elements). A Finite Element mesh is built using the Winfra mesh generator and the Orion extension. Both tools are developed at GEOWATT AG. The resulting mesh is an unstructured mesh composed of more than 100'000 elements. A diffusive thermal temperature model is applied and temperatures of the aquifers are extracted from the model. The geothermal potential of the region is estimated by combining temperature and thickness of the aquifers.

Meshing the geological model



> Views of the Limagne Finite Element Mesh adapted from the geology model.
(a) 3D view of the basement and of the faults.
(b) 3D view of the basement and of the formations S1, S2, S3 and S4 (from bottom to top).

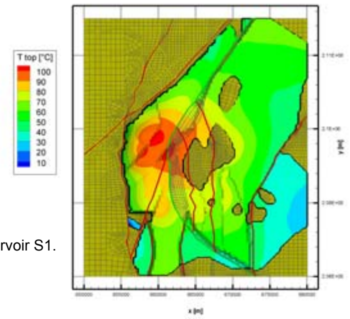
3D diffusive thermal modelling



> 3D temperature distribution in the Basement and in the faults.

Layer	Measured Thermal Conductivity [W m^{-1} K $^{-1}$]	Assumed Heat Production [W m^{-1} K $^{-1}$]
from –5000 to top MTER	3.00	$3.0\cdot10^{-6}$
from top MTER to top S1	2.25	$0.5\cdot10^{-6}$
from top S1 to top S2	2.40	$0.5\cdot10^{-6}$
from top S2 to top S3	2.30	$0.5\cdot10^{-6}$
from top S3 to topo	2.20	$0.5\cdot10^{-6}$
Faults	3.00	$0.5\cdot10^{-6}$

Surface temperature	10 °C
Bottom Heat Flow	105 mW m^{-2}



> Temperature extracted at the top of the Reservoir S1.

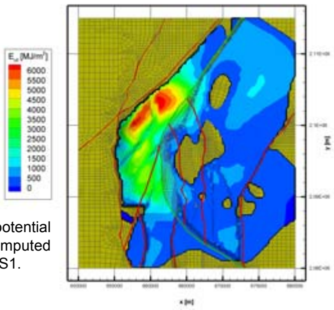
Geothermal potential estimation

$$E_{HIP} = \rho c_P \cdot V \cdot (T_{prod} - T_{reinj})$$

E_{HIP}	heat in place
ρc_p	rock's heat capacity (2.2 10^6 J.m^{-3}.K^{-1})
V	resource volume
T_{prod}	fluid's production temperature (temperature of the rock)
T_{reinj}	fluid's reinjection temperature (30°C)

$$E_{UT} = R \cdot E_{HIP}$$

E_{UT}	recoverable heat
R	recovery factor (5%)



> Geothermal potential E_{UT} [MJ·m-2] computed in the Reservoir S1.

> **References**

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Computations show that aquifer S1_Reservoir seems to be the best potential target for a geothermal exploitation, due to high temperatures and to a thickness up to 1000 m. This conclusion could be questioned by the fact that the hydraulic conductivity of this aquifer seems quite low (0.02 mD=2·10^{-9} m/s at 80 °C, cf. Dagallier, 2004). This parameter was only indirectly taken in account in the computation of the utilisable energy. On the other side, it is possible for the potential of aquifers S2_Reservoir and S3_Reservoir to be higher than predicted, thanks to a good hydraulic conductivity (this is clearly the case for S3_Reservoir). The temperature model could be enhanced by better temperature data and a detailed analysis of hydrogeological behavior of the system in order to take in account advection processes in the numerical model.

Authors

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