Towards a thermal tomography of the Rhine Graben

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Earth's thermal engine and balance are matters of fundamental interest as they record the global evolution of the planet since its formation and have controlled most tectonic processes through geologic era. Coupling thermal properties of the rocks with other physical parameters like wave velocity or electrical resistivity gives a scientific stake to the knowledge of the thermal regime at depth. The present geothermal activity and the hydrothermal paleofields that are the source of most of the exploited stock metal of the Earth are the superficial marker of the transfers that occur within the upper crust, between meteoric or sea water and heat sources within the thinned lithosphere or along plate boundaries. The knowledge of mechanisms that control heat distribution, in particular the transfer between deep-seated processes in the Earth, its surface and the atmosphere requires a joint integrated Solid-Earth science approach that corresponds to one of the main rationale of TOPOEUROPE. Moreover, this knowledge has a strong impact on society in terms of uses of the geothermal energy and exploration of hydrothermal paleofields, but also of sustainable development and rational use of natural resources. The concepts and methods developed for enhancing Geothermal Systems have significantly contributed to the knowledge of the solid earth and open innovative research fields. In this perspective, the Rhine graben represents a major target for investigating the concept of thermal tomography.

Enhanced geothermal systems

The heat engine of the Earth represents an infinite and renewable source of energy that could potentially satisfy a significant part of our needs. 3 main parameters condition the possibility to mine this heat: temperature that is directly dependant of the thermal gradient, a fluid flow and a reservoir depending of the natural permeability of the rocks (Fig. 1). While conventional geothermal resources already cover a wide range of uses for power and heat production in profitable conditions, the development of engineered geothermal systems still requires significant R&D investment. A large scientific and industrial community has been involved for more than 20 years in promoting Enhanced Geothermal Systems (EGS) and has been recently assembled in ENGINE, a Coordination Action of the 6th Framework Program, aimed at coordinating on-going actions concerning Unconventional Geothermal Resources (Fig. 2, Ledru et al., 2007). The project, that joins 35 partners (4 of them from Third Countries) and 19 countries, started on 1st November 2005; 3 conferences and 7 workshops have been organised. All material elaborated during the project are available through the web site at http://engine.brgm.fr. Proceedings, reports, abstracts and slides can be downloaded, presenting an updated framework of activities concerning (i) investigation, (ii) drilling, stimulation and reservoir assessment, (iii) exploitation, economic, environmental and social impacts. The achievement of this project will be a handbook defining best practices and proposing a road map for future demonstration projects.

The enhancement challenge requires the development of innovative methods for exploring, developing and exploiting geothermal resources that are not economically viable by conventional methods. This definition embraces different tracks for enlarging access to heat at depth in order to provide continuous base load-power and to contribute to reach the target of the European Strategic Energy Technology Plan, i.e. 20% renewable market penetration in 2020:

- stimulating reservoirs in Low Permeability Systems and enlarging the extent of productive geothermal fields by enhancing/stimulating permeability in the vicinity of naturally permeable rocks;
- improving thermodynamic cycles in order to ensure power production from water resources at medium temperature (from 80°C);
- improving exploration methods for deep geothermal resources;
- improving drilling and reservoir assessment technology;
- defining new targets and new tools for reaching supercritical fluid systems, especially high-temperature down-hole tools and instruments.

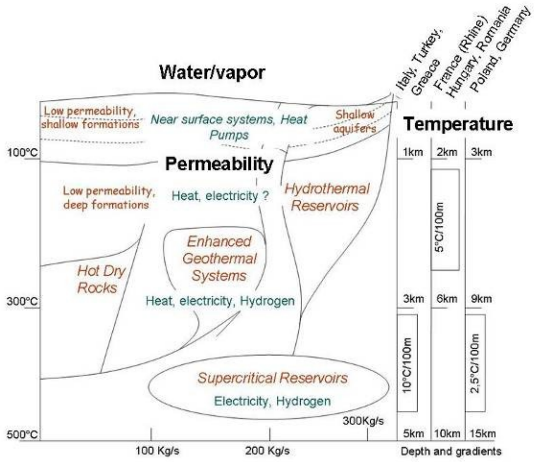

Figure 1: Sketch vision of the geothermal resources

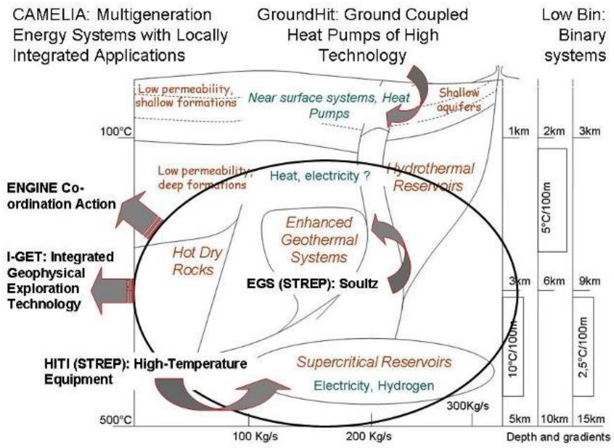

Figure 2: The 6th Framework Program of the European Commission dedicated to geothermal energy

Lessons learned from the Soultz EGS experiment, the sustainable development of the Larderello field in Italy, and the Icelandic geothermal power network, among other case histories, highlight the importance for coordinated research for technology improvement and for a continued reduction in cost through R&D developments. Thus, based on the Soultz experience, and thanks to significant progress in binary power plant technology, a new EGS power plant was done in the Upper Rhine graben on the German side and others projects are planned for the coming years, showing a learning curve effect.

R&D perspectives

What could be the next move to promote the development of geothermal energy? Concerning each topic, from the investigation stage to the exploitation of the resource, gaps and barriers are identified and evaluation in terms of risk-related and probability of success is in progress. Two R&D perspectives are already identified and presented.

Among the main scientific challenges the community has to face, and in order to reach the goals defined in the European Strategic Energy Technology Plan, it is necessary to evaluate the stored geothermal energy, i.e. the thermal potential available of the first tenth kilometres of the European continental crust. Such evaluation has been recently done for US and published in “The future of Geothermal Energy” (2006, Fig. 3), concluding that the extractable portion of heat mined from stimulated EGS reservoirs, would exceed 200,000 EJ or about 2,000 times the annual consumption of primary energy in the United States in 2005.

Such evaluation requires an updated knowledge of the geological infrastructure that implies well constrained information concerning lithology and geometry of the main geological units, depth of the basement, fracture network, stress field and strain partitioning within blocks, physical properties of the rocks (density, magnetic susceptibility, thermal conductivity, electrical reistivity, seismic velocity…), and if possible an estimation of internal gradients. A research target could then be the construction of a 3D geometrical model, constrained by integration of all available geological and geophysical information and analysis of the space of solutions resulting of a combined inversion of gravity and magnetic potential field. In a second stage, the attribution of heat conductivity and heat production rate to each voxel of the model could then be used to build of a thermal tomography by applying a far-field mantle heat flow and a surface temperature condition. Further development could then be envisaged to model convection phenomenon, especially in the vicinity of structural discontinuities. This methodology could be developed and tested within European Geological Surveys as a companion programme of the TOPO-EUROPE Research programme in which large datasets will be acquired and processed, providing a reassessed knowledge of the structure of the European lithosphere.

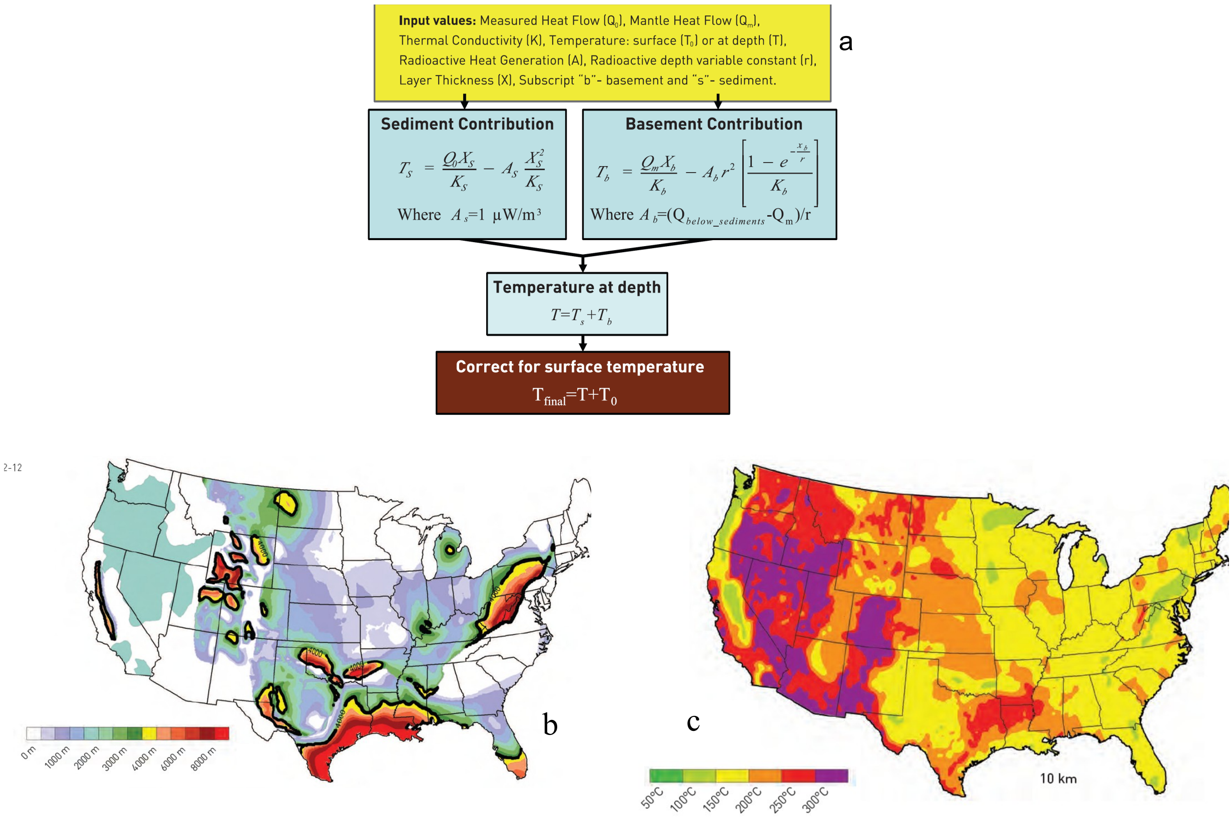

Figure 3: Calculation of temperature at depth in US (The future of Geothermal Energy, 2006). a: Flow chart for calculation of temperature at depth; b: Average thickness of sediments; c: Average temperature at 10 Km depth

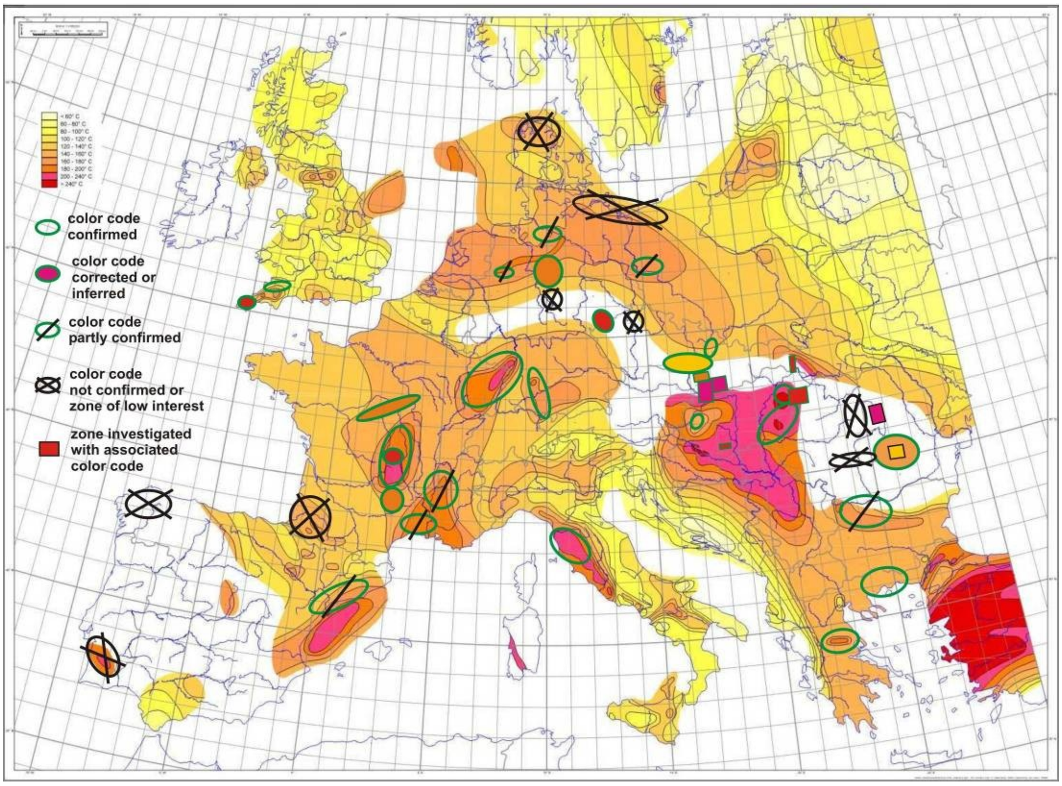

Figure 4: Map of the temperatures extrapolated at 5km depth as inferred from twenty to thirty years old individual maps, and validation of anomalously hot zones as revealed by a recent revision (Genter et al., 2003). The Rhine graben anomaly is clearly validated.

The Rhine graben is a geological system characterized by the highest thermal anomaly in Western Europe (Fig. 4, Genter et al., 2003). Calculated temperature at 5 km depth is expected to reach 250°C at least in some points and intensive exploration of oil and gas field has provided large datasets that can be used for reassessment of the geothermal resource. A project presently under preparation by the BRGM SGR Alsace and the geological surveys of Bade Wurtenberg and Rhénanie Palatinat plans the building of a comprehensive 3D model integrating information from geological data, digitised available seismic profiles, gravimetry and magnetic potential fields. This model will then be used for quantifying the thermal potential available at the regional scale within the first kilometres of depth of the Rhine Graben. Moreover an improvement in knowledge concerning the permeability and structure of potential reservoir at depth and temperature to depth prediction would open possibilities to use oriented drilling in order to better stimulate and enhance the natural permeability of the system depending of the stress field, lithostatic and fluid pressure and temperature conditions.

A second R&D perspective identified by the ENGINE network is linked to the stimulation process of the engineered geothermal systems. Set of methods have been applied for stimulation of the permeability on different geothermal sites in Europe and proven to be effective in a large range of environments. However, these tests are still a matter of trial and errors and further studies are needed to understand active processes during stimulation and better constrained physical and mechanical parameters. Data related to stimulation experiences are available in too few cases or not enough documented to enable the definition of a learning curve. A synthesis and computation of new models from available datasets of case histories (Basel, Soultz, Cornwall, Cooper Basin…) are needed to define experiences for in situ imaging and measuring while stimulating. Moreover, data collected during stimulation, whether chemical or mechanical (hydrofracturing mainly) provide an extremely valuable information about the dynamics of the lithosphere. For example, induced seismicity during the last stimulation event in Basel (December 2006) reveals how complex is the stress partitioning at few kilometres depth and shows that forced fluid circulation can influence a regional seismicity.

In **conclusion**, the interplay between geological knowledge at the regional scale, understanding of the coupling between deep-seated processes and superficial phenomenon and sustainable exploitation of georesources is considered as an innovative approach that deserves a new coordination action at the European scale in order to promote new R&D projects and mutualisation of resources.

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