International Partnership for Geothermal Technology

Exploration Whitepaper

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Nb: The final result of the white paper was a collaborative work by the conveners done in cooperation with the teams of the five countries.

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INTRODUCTION

Geothermal energy (heat from the Earth) is a candidate for becoming one of the main energy resource in the future. It is a clean energy resource and renewable on large timescales. The most common geothermal energy resources are often classified into three main types:

- Naturally convective geothermal systems in volcanic and/or tectonically active environments.
- Hot fluids in deep sedimentary aquifers.
- Hot but low permeability/dry rocks.

The first two types possess the necessary working fluids to convey the energy to the surface. The third type, which is probably the most abundant and important one in global perspective, has to be engineered by producing permeability and providing working fluids for the heat extraction (Enhanced Geothermal Systems, EGS).

The three types of geothermal resources above have different characteristics and inner processes. The understanding of these characteristics and processes and their detectible signatures is the basis for geothermal exploration. Considerable experience has been gained in exploration for and development of the first two types, but to a lesser extent for the third one.

DESCRIPTION OF THE ISSUE

Effective exploration tools and methodologies for hydrothermal (high, moderate or low temperature resources) and enhanced geothermal systems are fundamental to realistic resource / capacity assessment, prioritisation and development decision-making, and best utilisation of the geothermal resource – i.e. mitigation of financial and development risk. Exploration technology and the synthesis of exploration data are of critical importance for all stages of a geothermal project, from the successful targeting and drilling of the first exploration well(s), as part of a flexible drilling strategy (e.g. slimhole or conventional drillhole design), to appraisal and production drilling, and later field management and plant operation.

The key challenge for future successful geothermal exploration is improving our ***understanding of the characteristics of geothermal systems and past and ongoing processes***, particularly features that can be determined remotely through application of advanced or innovative exploration technologies. These new tools will aid delineation of drilling targets and help identify issues that might impact (positively or detrimentally) on resource development. Ultimately, discoveries depend on the team of geoscience and modeling specialists developing a well-constrained conceptual model of the resource, understanding the limitations of the model and information obtained – i.e. utilising tools most suited to the exploration targets - and confidence from the obtained data to make hard decisions, including a commitment to drill.

A second key challenge is to ***improve tools*** that can provide reliable information on subsurface temperature and chemistry of deep reservoir fluids, and to develop new techniques (complementary to, and advancing, existing geophysical and down-hole logging tools, and geological insights, e.g. 3D visualisation and modeling) to predict subsurface structure, temperature and rheology (physical rock properties), which will be useful for production of hydrothermal fluids and stimulation. Indeed, of special relevance to development of EGS systems, is the ability to predict the evolution of potential reservoir rocks/compartments over lifetimes appropriate to geothermal production.

STATUS/GAP ANALYSIS

Exploration of hydrothermal-geothermal resources for electric power generation began in the early 20th century, but was not pursued widely and in earnest until the second half of the last century. Early exploration utilised temperature gradient/heat flow studies, geochemical surveys (including application of geochemically-based geothermometry) and geophysical tools (e.g. DC resistivity, gravity and magnetics) first developed by the mining and petroleum industries and by groundwater studies. More recently, exploration has focused on electromagnetic methods and various remote sensing applications. To date, active and passive seismic techniques have been used only intermittently, but are now being utilised more frequently to understand subsurface structure and controls on fluid flow in geothermal systems in various tectonic settings.

Geothermal exploration is most commonly associated with plate margins or volcano-tectonically active areas such as in Italy, Iceland, Taupo Volcanic Zone in New Zealand, and Basin and Range of the Western United States. There is also resource potential associated with sedimentary basins in the plate margin setting, such as the Imperial Valley geothermal systems in southern California and Mexico and the Eastern part of Europe, and within active petroleum provinces such as geopressured-resources in the U.S Gulf Coast, hot sedimentary aquifers in Australia, or thermal fluids associated with past or ongoing oil and gas production (several countries). Assessment of geothermal potential in sedimentary basins relies heavily on exploration survey and drilling data from petroleum exploration and temperature gradient / heat flow studies.

Field-based exploration for EGS was first undertaken in the United States of America primarily utilising temperature gradients, which lead to pioneering work at Fenton Hill (New Mexico) and subsequent investigations in United Kingdom, Europe and Japan, although these project were all hindered by a minimal understanding of their respective geologic environments. Succeeding development has placed more emphasis on finding a geothermal environment amenable to stimulation. The European project at Soultz-sous-Forêts (France) was developed in a tensional environment. In Australia, EGS potential was initially realised on the basis of deep drilling, with temperature data and geology used to investigate both crystalline reservoirs and deep sedimentary basins. Increasingly EGS targeting is based on extrapolations of shallow gradient data extrapolated assuming steady-state conductive thermal regimes, although the experience at Soultz-sous-Forêts shows that such assumptions are not appropriate.

The greatest challenge for the exploration of active hydrothermal systems is the difficulty to delineate, and therefore target, reservoir permeability, particularly at depth. It is also suggested that a lack of robust models for some geologic environments should be addressed, most notably the Basin and Range of the United States, i.e., to resolve what constitutes the ideal target for exploration and what environments are not suitable. In other words, why particular (high-temperature?) geothermal systems (with particular characteristics) occur where they do, and not elsewhere.

Exploration for EGS is still hampered by uncertainty regarding the most appropriate geologic environment to operate, although what might constitute EGS in the Iceland, New Zealand or Japan, and/or with Australia and the United States, and consequently the appropriate methodologies to extrapolate information from shallow observations (surface to, say 3 km depth) to deeper setting. Just as for exploration and evaluation of "conventional" hydrothermal systems, robust criteria for assessing when conductive regimes apply are crucial. It is likely that several or all of the current EGS target types will be amenable to stimulation and development. In that case, more than one exploration model and set of techniques may be necessary.

OBJECTIVES

The objectives of exploration technology development are fivefold:

- Increase research and development that improve energy extraction efficiency from geothermal systems by reducing the drilling risk

- Promote research in the fields of physics, chemistry, geology and engineering to increase our basic understanding of geothermal systems and their dynamics. Such work is the basis behind improved tools for exploration and running geothermal as a sustainable and efficient energy source.

- Develop rigorous assessment criteria, protocols and appropriate exploration models, and methodologies for geothermal systems and energy, including high- and low-temperature systems and enhanced geothermal systems.

- Develop new methods to estimate better the subsurface temperature and reservoir permeability prior to deep drilling and the size of geothermal areas for assessing the production potential.

- Develop technical tools and technologies to delineate better reservoir characteristics. Including zones of enhanced permeability, resource temperature and heat transfer

To meet these objectives, greater effort must be made to understand the results of previous exploration programmes, so that we can (without judgment) build on the successes and failures of the past. Unfortunately, many geoscientific surveys are undertaken without understanding the implications of previous work or potential constraints / limitations of the data obtained. There are clearly cases, where exploration geosciences survey data and drilling results have been interpreted out of context, or with little consideration of the likely conceptual model of the geothermal system/geologic environment, or experience or past surveys in other (similar) geological settings. Two important tasks should be considered to correct this limitation:

- establish a database of exploration survey results (in the form of published and unpublished exploration geoscience and drilling results, case studies and relevant data etc) from as many projects as possible (both successfully developed, and discontinued), with the data (quality assessed by appropriate specialists) made available for further study, leading to...

- development of robust, conceptual geothermal system models for a wide range of geologic environments (e.g. island-arc, continental, rift settings etc), which will provide the blue-print (bearing in mind, that all geothermal systems display unique characteristics due to local heterogeneities) for designing appropriate exploration surveys and cost effective, low risk drilling strategies to prove geothermal resource viability.

The second objective requires significant financial investment in research and development to improve and/or develop new advanced, innovative exploration technologies, particularly those for delineating deep-seated fracture zones and subsurface permeability, and understanding the rheology (including fluid-rock interactions, and susceptibility to induced fracturing) of reservoir hosting rock masses.

What is needed is to develop methods or advance existing techniques to monitor geothermal processes, to understand the system/the processes and an integrated approach – process modelling. A part of this is developing the associated software.

Advancement in existing techniques

- Heat flow
- Geophysical methods (EM, gravity, seismicity)
- Geochemical methods (fluid chemistry, reservoir modelling)
- Geology (lithology, tectonics and alteration)
- Drilling
- Sampling and measurement techniques

Integrated approach

- Processes modelling
- Heat, fluid flow and fluid-rock interaction
- Integrated geothermal physics, chemistry and geology modelling
- Dynamics of geothermal systems

Associated software

- Visualization
- Data processing
- Joint geophysical modelling
- Joint heat transfer, hydrology and geochemistry modelling