IPGT Exploration Working Group

IPGT Exploration Whitepaper

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DESCRIPTION OF THE ISSUE

Exploration for hydrothermal and Enhanced Geothermal Systems (EGS) is fundamental to developing geothermal resources. Exploration technology and the synthesis of exploration data are of critical importance to the successful drilling of the first exploration and development wells for geothermal projects.

The key challenge to more successful exploration is improving our understanding of the features of a geothermal system that can be determined remotely through application of exploration technology in order to delineate drilling targets that will produce successful wells. To paraphrase the great petroleum geologist Wallace Pratt, geothermal "*is found in the minds of"* explorers. Ultimately discoveries depend on an earth scientist with a well-constrained conceptual model, an understanding of exploration tools suited to the exploration target and a commitment to risky drilling. Plus luck!

A second key challenge is the development of technologies that can determine temperature and subsurface structure that are suitable for production of hydrothermal fluids and/or suitable for stimulation.

An additional challenge, of special relevance to enhanced geothermal systems, is the ability to predict the evolution of potential reservoir rocks/compartments over lifetimes appropriate to geothermal production.

STATUS/GAP ANALYSIS

Exploration for hydrothermal-geothermal resources began in the early 20th century but did not become widespread until the second half of the century. Early exploration utilized temperature gradient/heat flow studies, geochemically based geothermometers and geophysical tools primarily developed by the mining and petroleum industries. Active seismic studies have been used only intermittently but are beginning to be utilized more frequently as the understanding of the importance of placing sources and geophones to increase the ration of signal to noise. More recent exploration has focused on magnetotellurics, various remote sensing techniques and active and passive seismic.

Geothermal exploration is most commonly associated with plate margins or tectonically active areas such as the Basin and Range of the Western United States. However, there is also potential associated with sedimentary basins both associated with plate margins such as the Imperial Valley systems in southern California and adjacent Mexico 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 ongoing petroleum production.

Assessment of geothermal potential in sedimentary basins relies heavily on drilling data from petroleum exploration or from temperature gradient and heat flow studies.

Exploration for EGS was first undertaken in the United States primarily utilizing temperature gradients and minimal understanding of the geologic environment. Succeeding development has placed more emphasis on finding a geothermal environment amenable to stimulation. The European project at Soultz 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. The experience at Soultz shows that such assumptions are not always appropriate.

The greatest gap in exploration technology in hydrothermal systems appears to be the inability to target reservoir permeability at depth. A secondary gap in some geologic environments, most notably the Basin and Range of the United States, is the lack of robust models of what constitutes the ideal target for exploration and what environments are not suitable. In other words, why geothermal systems occur where they do, and not elsewhere.

Exploration for EGS is still rudimentary hampered for the most part by uncertainty in the most appropriate geologic environment to operate, and the appropriate methodologies to extrapolate from shallow observations. 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 twofold:

- Develop suitable exploration models and methodologies for each of the geologic settings in which geothermal systems are found, and
- Develop tools and technology necessary to delineate adequate temperature and permeability in the subsurface of hydrothermal systems and to find geologic conditions amenable to stimulation of EGS.

To meet the first objective an effort must be made to understand the results of previous exploration so that we can build on the successes and failures of the past. Unfortunately, many surveys are run without an understanding of previous work or potential the data constraints. Many will also be interpreted out of context without any thought to a conceptual model of what a geothermal system in a given geologic environment might actually look like. Two important tasks should be considered to correct this limitation:

- Data should be collected from as many historic exploration projects as possible and the data should be made available for study.

- Robust conceptual models should be developed for each geologic environment important for geothermal development.

The second objective requires research and development of improved or new technology, particularly those for delineating fracture zones and subsurface permeability.

APPENDICES

Appendix 1 to this white paper presents a table initially by Ken Williamson listing the types of geothermal systems, the estimated U. S. resource base for each type and some of the exploration methods suitable for each environment.

Appendix 2 presents a table of exploration technologies for consideration as part of an exploration research package.

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Appendix 1: IPGT Exploration Whitepaper: Geothermal System Types

The purpose of this table is to enable researchers and funding agencies to visualize the entire space of geothermal power "TYPES", the size of the country's resource of each type, and the tools that are used in each of the 4 exploration phases. This should be a first step in determining which areas of geothermal exploration research can have the greatest impact on national energy supply.

		EXPLORATION PHASE			
	US RESOURCE BASE (MWe-30 yrs)*	**REGIONAL RECONNAISANCE**	**PROSPECT RANKING**	**EXPLORATION WELL TARGETING**	**FIELD DELINEATION**
TYPE		****note: table below is incomplete*****			
Fault circulation-HS	1,000	fluid geochemistry, satellite imaging, regional tectonics	shallow TGH, gravity, airborne imaging,	field geology, alteration mapping, area-specific geophysics	Drilling
Fault circulation-blind	5,000	satellite/airborne imaging, regional heat flow & seismicity,, tectonics	shallow TGH, gravity, airborne imaging,	field geology, alteration mapping, area-specific geophysics	Drilling
Magma-Hydrothermal-HS	10,000	fluid/rock geochemistry, volcanic age/type	MT-TDEM, field geology, rock geochemistry & age date	Deep TGH, detail MT-TDEM, field geology, alteration mapping, area-specific geophysics	Drilling
Magma-hydrothermal-blind	25,000	volcanic age/type, satellite imaging, airborne imaging/ EM	MT-TDEM, field geology, rock geochemistry & age date	Deep TGH, detail MT-TDEM, field geology, alteration mapping, area-specific geophysics	Drilling
Magma-hydrothermal-supcrit.	?	?	?	Deep hi-T fluid sampling (in known field)	Drilling
EGS-lithology	50,000	regional heat flow and basin analysis	heat flow, basin analysis, analogues	reflection seismic, sediment petrophysics	reflection seismic
EGS-structure	100,000	heat flow, reflection seismic, satellite imaging, first-motion	heat flow, analogues	Deep heat flow, reflection seismic	Drilling
EGS-HDR	500,000	heat flow, reflection seismic, satellite imaging, first-motion	heat flow, analogues	Deep heat flow, reflection seismic	N/A
Sedimentary basins — geopressured		oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — co-production		oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — normally pressured, sediment hosted		heat flow and temperature gradient studies, oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — normally pressured, fracture hosted		heat flow and temperature gradient studies, oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic

* roughly based on USGS 2009 study. Fault circulation is an independent estimate.

"STRAW MAN" SHOWING RESOURCE BASE PER COUNTRY BY TYPE, COUNTRY PRIORITY FOR EACH TYPE, AND TOOLS OF GREATEST PRIORITY IN RED. THIS EXAMPLE SHOWS NO PRIORITY OVERLAP BETWEEN ICELAND AND AUSTRALIA IN GEOTHERMAL TYPES, BUT E.G. SATELLITE IMAGING IS COMMON OVER SEVERAL TYPES FOR ALL COUNTRIES.

	US/ Iceland/ Australia RESOURCE BASE (MWe-30 yrs)*	TECHNOLOGY TIMELINE (YEARS)**	COUNTRY PRIORITY*** H/M/L			REGIONAL RECONNAISANCE	PROSPECT RANKING	EXPLORATION WELL TARGETING	FIELD DELINEATION
TYPE			USA	Iceland	Australia				
Fault circulation-HS	1,000/ 200/ 100	0-3	M	M	L	fluid geochemistry, satellite imaging, regional tectonics	shallow TGH, gravity, airborne imaging,	field geology, alteration mapping, area-specific geophysics	Drilling
Fault circulation-blind	5,000/ 500/ 200	3-6	H	L	L	satellite/airborne imaging regional heat flow & seismicity,, tectonics	shallow TGH, gravity, airborne imaging,	field geology, alteration mapping, area-specific geophysics	Drilling
Magma-Hydrothermal-HS	10,000/ 5,000/ 0	0-3	M	H	L	fluid/rock geochemistry, volcanic age/type	MT-TDEM, field geology, rock geochemistry & age date	Deep TGH, detail MT-TDEM, field geology, alteration mapping, area-specific geophysics	Drilling
Magma-hydrothermal-blind	25,000/ 10,000/ 0	3-6	H	H	L	volcanic age/type, satellite imaging, airborne imaging/ EM	MT-TDEM, field geology, rock geochemistry & age date	Deep TGH, detail MT-TDEM, field geology, alteration mapping, area-specific geophysics	Drilling
Magma-hydrothermal-supcrit.	?	5-10	L	H	L	?	?	Deep hi-T fluid sampling (in known field)	Drilling
EGS-lithology	50,000/ 100/ 50,000	5-10	H	L	H	regional heat flow and basin analysis	heat flow, select basin analysis, analogues	reflection seismic, sediment petrophysics	reflection seismic
EGS-structure	100,000/ 500/ 100,000	5-10	H	M	H	heat flow, reflection seismic, satellite imaging, first-motion	heat flow, analogues	Deep heat flow, reflection seismic	Drilling
EGS-HDR	500,000/ 5,000/ 1,000,000	10-50	H	M	H	heat flow, reflection seismic, satellite imaging, first-motion	heat flow, analogues	Deep heat flow, reflection seismic	N/A
Sedimentary basins — geopressured						oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — co-production						oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — normally pressured, sediment hosted						heat flow and temperature gradient studies, oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic
Sedimentary basins — normally pressured, fracture hosted						heat flow and temperature gradient studies, oil and gas drilling	heat flow, basin analysis, analogues	seismic studies	drilling, reflection seismic

* roughly based on USGS 2009 study. Fault circulation just a guess

** this is meant to represent the approximate time when the technology should be ready for field testing
Geothermal Types that are not yet proven, have greater time delays. EGS-HDR is judged to be furthest from prime-time

*** Priority for exploration research. Presumably based on accessible resource size, and probability of success if tool development is successful

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Appendix 2: IPGT Exploration Whitepaper

Topic framework - preliminary relevance

	TOPICS	EGS	HYTH
Identification	Airborne techniques	1	2
	InSAR	2	3
	Hyperspectral imaging	1	2
	IR imaging	1	2
	Surface fluid (gas+water) chemistry	1	3
	Surface alteration	1	2
	Seismicity	3	2
	Strain rate	3	3
	Interpretation of data	3	3
	Electromagnetic methods	2	3
Software	Visualization	3	3
	Joint inversion	3	3
	Data processing	3	3
	Fluid modelling	2	3
Exploration	Improving understanding of heat flow	3	2
	MT measurements	3	3
	Gravity	3	2
	Seismicity	3	3
	Drilling	3	3
	Stress measurements	3	2
	Lithology , age, hydrothermal alteration	1	3
	Detailed surface fluid (gas-water) chemistry	1	2
	Well fluid chemistry	2	2
Research	Petrophysics, high P and T	2	3
	Advanced geothermometry	1	3
	Resistivity	2	3
	Origin of deep conductors	2	3
	Rock taxonomy for EGS	3	2
	Applicability of thermal history data	2	2
	Fluid-fluid and fluid-rock interaction	2	2
	Geochemical model developments	2	2

1	less relevant
2	relevant
3	more relevant