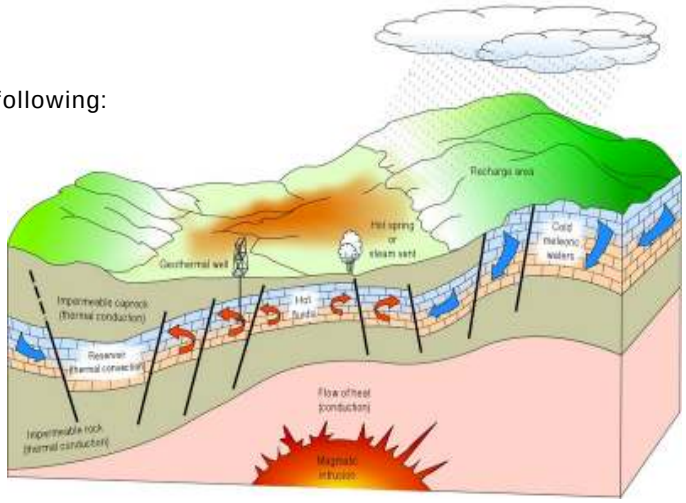
Applications of Magnetotellurics in Geothermal Exploration

APPLICATIONS IN GEOTHERMAL EXPLORATION

When exploring for geothermal energy, it is important to consider the following:

- What is geothermal energy?
- What are the components?
- What are the forms of geothermal energy?
- How are geothermal resources used?
- What geophysical surveys are applicable?
- Why is it important to survey before drilling?
- What are the stages in geothermal exploration?
- What are the objectives of geothermal surveys?



WHAT IS GEOTHERMAL ENERGY?

Geothermal energy is the energy contained in the heated rock and fluid that fills the fractures and pores within the earth's crust. It originates from radioactive decay deep within the Earth and can exist as hot water, steam, or hot dry rocks.

Commercial forms of geothermal energy are recovered from wells drilled 100-4,500 meters below the Earth's surface. The technology is well proven, relatively uncomplicated, and involves extracting energy via conventional wells, pumps, and/or heat exchangers.

Geothermal energy can be used directly or indirectly, depending on the temperature of the geothermal resource. Geothermal resources are classified as low temperature (less than 90°C), moderate temperature (90°C - 150°C), and high temperature (greater than 150°C). The highest temperature resources are generally used only for electric power generation and are found in volcanic regions. Low and moderate geothermal resources are found in most areas of the world.

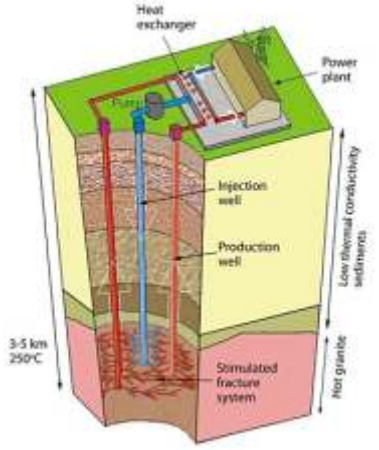
WHAT ARE THE COMPONENTS?

Geothermal systems are made up of four main components: a heat source, a reservoir, a fluid (the carrier that transfers the heat) and a recharge area. When defining a geothermal system, the principal consideration is the practicality of how much power can actually be produced.

In most instances, electric power generation is the reason for developing geothermal energy and the typical geothermal system must yield 10 kg of steam to produce one unit (kWh) of electricity. Therefore, a geothermal system must contain great volumes of fluid at high temperatures or a reservoir that can be recharged with fluids heated by the hot rocks.

Geothermal fields are found in rocks such as shale, limestone and granite, with the most common rock type being volcanic. Areas where thick blankets of thermally insulated sediment cover basement rock having relatively normal heat flow also house geothermal energy. The combination of these elements represents targets for the application of geophysical, geological and geochemical exploration techniques.

Applications of Spartan MT for Geothermal Exploration



3D cutaway showing electricity generation from a hot dry rock source

(Source: www.geothermal-resources.com.au)

HOW ARE GEOTHERMAL RESOURCES USED?

Various uses of this type of energy are indicated below:

1. Electricity Generation (power plants)
   - Dry Steam Power Plant
   - Flash Steam Power Plant
   - Binary Cycle Power Plant

2. Heat Production
   - District Heating
   - Industrial Process Heat
   - Agriculture
   - Aquaculture

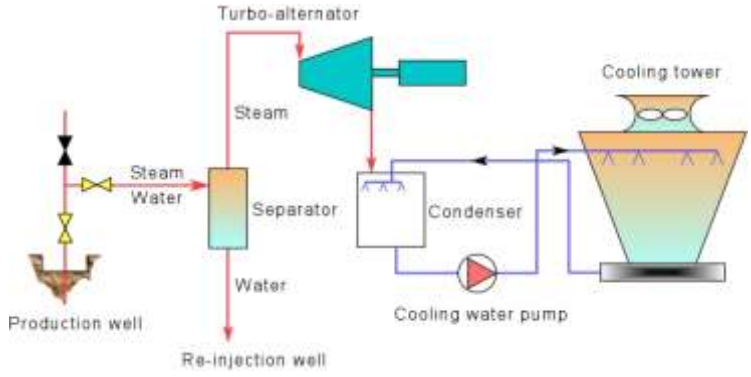
Electricity generation is the most important form of utilization of high-temperature geothermal resources (greater than 150 °C), while medium to low temperature resources (less than 150 degrees °C) are suited to many different types of applications.

WHAT ARE THE FORMS OF GEOTHERMAL ENERGY?

The basic forms of geothermal energy are:

- Hydrothermal Fluids
- Hot Dry Rock
- Geo-pressured Brines
- Magma
- Ambient Ground Heat

Below: A schematic diagram of a geothermal binary plant
The flow of geothermal fluid is in red, the secondary fluid in green, and the cooling water in blue. (Source: Dickson and Fanelli, 2003)



HOW IS GEOPHYSICS APPLIED FOR GEOTHERMAL EXPLORATION?

Geophysical methods play an important role in geothermal exploration as many exploration objectives can be achieved. Most geothermal exploration is done in shallow systems for low temperature geothermal resources; however, deep surveys, such as magnetotelluric (MT) surveys, are growing in application. Deep in this context refers to over 300 metres to 2000 metres.

Geophysical surveys are directed at obtaining the physical parameters of deep geological formations, either indirectly from the surface or from depth intervals close to the surface. These physical parameters include:

- Temperature (thermal survey)
- Electrical conductivity (electrical & electromagnetic methods, including MT)
- Propagation velocity of elastic waves (seismic survey)
- Density (gravity survey)
- Magnetic susceptibility (magnetic survey)

Applications of Spartan MT for Geothermal Exploration

Since electric and electromagnetic surveys are more sensitive to the presence of geothermal fluids than other survey types, they can aid in providing information regarding the existence of geothermal fluids within geologic structures.

Conversely, techniques such as seismic, gravity and magnetics (traditionally adopted in oil exploration) can provide valuable information on the shape, size, depth and other important characteristics of deep geological structures that could constitute a geothermal reservoir; however, they give little or no indication as to whether these structures actually contain the fluids. These methodologies are, therefore, more suited to defining details during the final stages of exploration, before the exploratory wells are situated.

The magnetotelluric ("MT") survey, in particular, is used extensively for reconnaissance purposes in geothermal exploration, and to a lesser degree in detailed follow-up exploration. The MT method offers a vast spectrum of possible applications, despite the fact that it requires sophisticated instrumentation. The main advantage of the MT method is that it can be used to define deeper structures than are attainable with the electric and other electro-magnetic techniques. The MT survey employs the earth's natural electromagnetic field, which contains a very wide spectrum of frequencies including very low frequencies that are useful in probing to depths of several tens of kilometres, and is used as an energy source to probe the earth.

Because each technique provides a different resolution and volumetric scope, integration of different geophysical methods can be used to design a complete model of a reservoir. Data acquired during these various survey methods can then be used to image fluid circulation and alteration zones. The specific characteristics of each geothermal prospect delineate the sequence in which geophysical methods are applied to the project; thus, it is not recommended to define a particular sequence of geophysical surveys as being applicable to all potential prospects.

WHY IS IT IMPORTANT TO SURVEY BEFORE DRILLING?

Today, the major problem confronting geothermal companies is how to efficiently, economically and effectively predict the optimal site location for drillholes in order to provide the best chance of intersecting productive thermal fluid channels and reservoirs deep beneath the subsurface.

Exploration techniques do not necessarily require a high level of resolution as the preferred approach is one that is capable of providing a high level of confidence before drilling. Current geophysical survey methods have vastly improved drilling effectiveness and have enabled many discoveries within the geothermal community while minimizing costly but nonproductive "dry holes."

Drilling costs are quite high in the geothermal industry (USD $0.5 to $1 million for shallow systems and USD $2 to $4 million for deep systems.) It is clear that decreasing the size and/or number of programs will lead to decreased costs; however, there is also a corresponding increase in the risk of failure or error. Finding the right balance between risk and cost is key to the economic success of the program.

Applications of Spartan MT for Geothermal Exploration

WHAT ARE THE STAGES IN GEOTHERMAL EXPLORATION?

Exploration programs are usually developed in stages- reconnaissance, pre-feasibility and feasibility. The less interesting areas are eliminated with each stage, concentrating on the areas which are most promising. Similarly, the exploration methods employed also become progressively more sophisticated and comprehensive as the program develops. In addition, both the size and the budget of the overall program should be proportional to its objectives as well as the significance of the resources that are anticipated to be found and the planned forms of utilization. The program should be flexible, allowing for re-assessment at each stage.

WHAT ARE THE OBJECTIVES OF GEOTHERMAL EXPLORATION?

When pursuing geothermal exploration, it is important to consider the following objectives as part of the program:

1. To identify geothermal phenomenon.
2. To ascertain that a useful geothermal production field exists.
3. To estimate the size of the resource.
4. To determine the type of geothermal field.
5. To locate productive zones.
6. To determine the heat content of the fluids that will be discharged by the wells in the geothermal field.
7. To compile a body of basic data against which the results of future monitoring can be viewed.
8. To determine pre-exploitation values of environmentally sensitive parameters.
9. To acquire knowledge of any characteristics that might cause problems during field development.

(*Source: Lumb, J.T., 1981. Prospecting for Geothermal Resources.)

KEY GEOTHERMAL COUNTRIES:

- USA- the United States has the largest geothermal industry in the world; Nevada and California have the highest geothermal capacity in the US.
- Indonesia, Philippines, Mexico, Iceland, Central America, New Zealand, Italy and Japan

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