Geothermal Exploration Process and Production Plants

Technology | Geothermal Energy

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2.Geothermal Exploration Process and Production Technologies

The exploration phase of a geothermal project aims at locating geothermal reservoirs for possible exploitation and at selecting the best sites for drilling production wells.

Before proceeding with the specific aspects of the process, it is necessary to consider the relevance of the preliminary survey phase which involves a work program to assess the already available evidence for geothermal potential within a specific area (perhaps a country, a territory, or an island).

The objectives of geothermal exploration are (Lumb, 1981):

1. Identify geothermal phenomena.
2. Ascertain that a useful geothermal production field exists.
3. Estimate the size of the resource.
4. Determine the type (classification) of geothermal field.
5. Locate productive zones.
6. Determination the heat content of the fluids that will be discharged by the wells in the geothermal field.
7. Compilation a body of basic data against which the results of future monitoring can be viewed.
8. Determination the pre-exploitation values of

environmentally sensitive parameters.

9. To acquire knowledge of any characteristics that might cause problems during field development

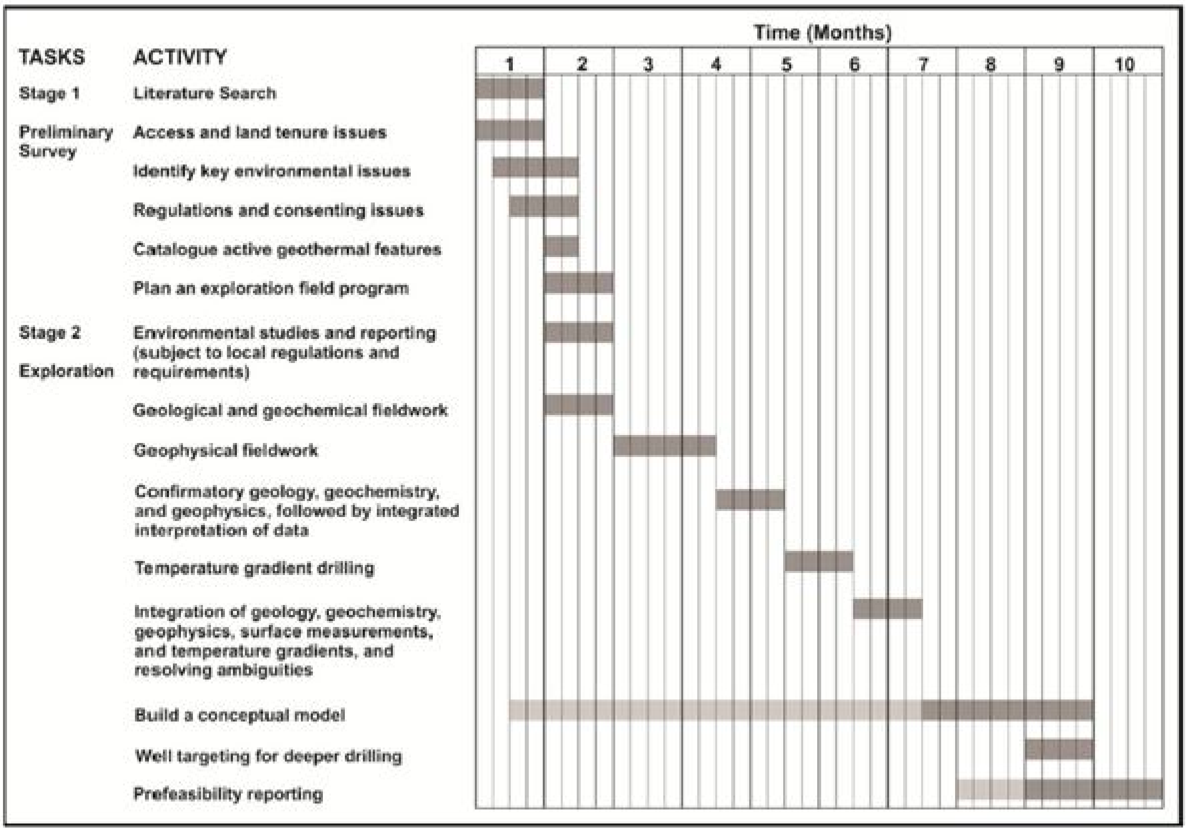


Fig.1 – Timeline for a well planned and effective surveying and exploration work program in a geothermal project

Exploration typically begins with gathering data from existing nearby wells and other surface manifestations, and goes on to surface and sub-surface surveying using geological, geochemical, and geophysical methods.

SURFACE STUDIES	GEOCHEMICAL SURVEYING	GEOPHYSICAL SURVEYING
• Gathering local knowledge • Locating active geothermal surface features • Assessing surface geology	• Geothermometry • Electrical conductivity • pH • Flow rate of fluids from active features • Soil sampling	• Gravity • Electrical resistivity • Magnetotelluric • Temperature gradient drilling • 2D & 3D Seismics

Table 1 – Surveying techniques used in the geothermal exploration

A decision to move to temperature gradient (or slim hole) drilling (defined and discussed later) may be recommended after the geological, geochemical and geophysical surveys have been completed.

When sufficient exploration data have been collected and analyzed, then selection sites and targets for the first few deep exploration wells maybe defined.

In general, the most common and applied disciplines with relative techniques are

- geology
- geophysics
- geochemistry
- drilling technology

2.1 Geology

A thorough understanding of the geology of the project area and how it fits into the surrounding regional geological and tectonic setting is crucial to understanding a given geothermal system.

Initial geological studies are focused on understanding the overall geology of the project area and identifying the most promising areas for more detailed exploration.

Later, efforts are focused on the most promising areas with the specific goal of understanding the permeability pathways that bring thermal fluids from their deep source to shallower parts of the system, where they can be economically exploited for geothermal power production.

Geological data for the project area should be presented in the form of geological maps, structural maps, stratigraphic columns, and cross sections for the project areas.

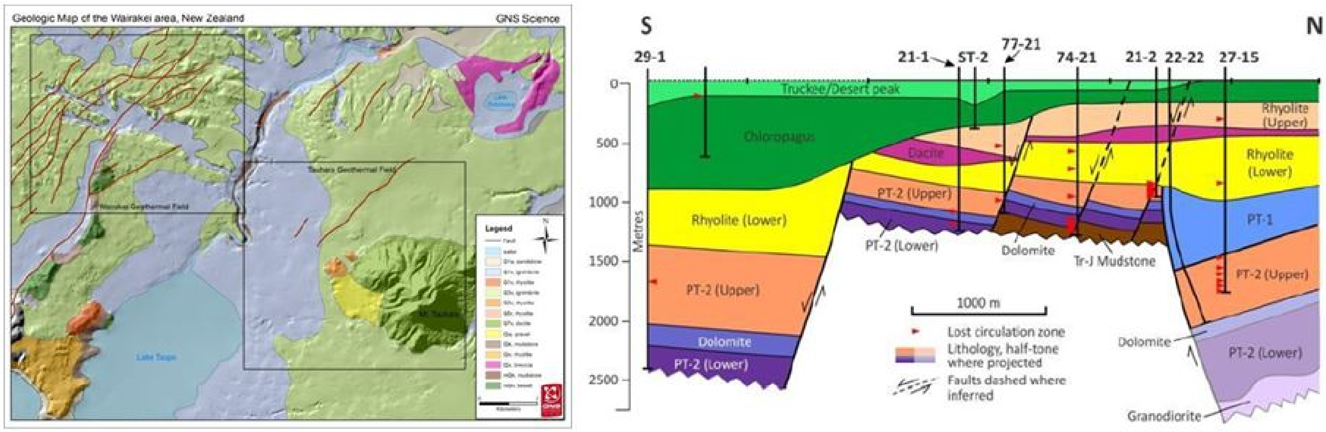


Fig.2 – Geological Data

1. Example of a geologic map (GNS Science, New Zealand)

2. Example of 2D geologic cross section (GeothermEx, Inc.)

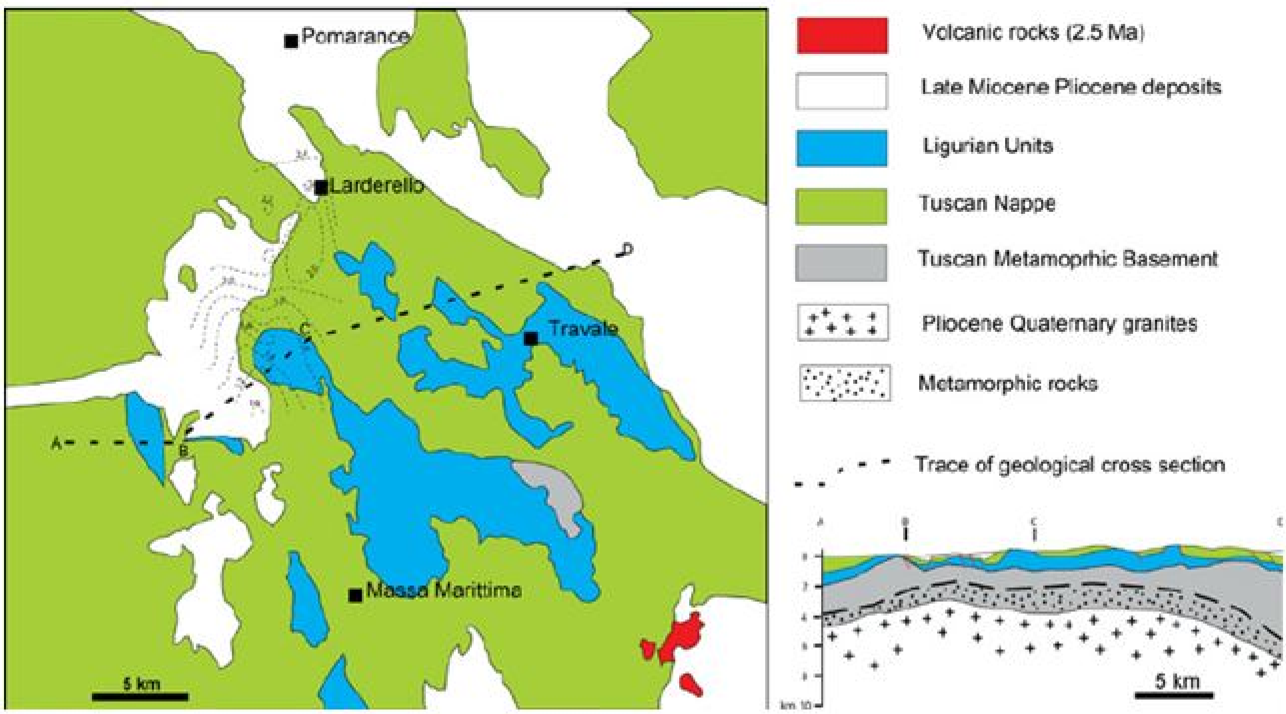


Fig.3 – Geological sketch map of the Larderello-Travale Geothermal field

2.2 Geochemistry

The basic philosophy behind using geochemical methods in geothermal exploration is that fluids on the surface (aqueous solutions or gas mixtures) reflect physicochemical and thermal conditions in the geothermal reservoir at depth.

The major goals of geochemical exploration are to obtain the subsurface composition of the fluids in a geothermal system and use this to obtain information on temperature, origin, and flow direction, which help locating the subsurface reservoir.

Geochemistry studies also support the assessment of potential operational issues that will come with development, such as wellbore scaling, corrosion, and concentrations of non-condensable gases.

In the exploratory phase the task of geochemistry is mainly to:

- Estimate subsurface temperatures by using chemical and isotope geothermometers as well as mixing models
- Identify the origin of the geothermal fluid, mainly with isotopic techniques
- Define chemical properties of the fluid with respect to environmental issues, scaling …
- Provide data to a conceptual model of the geothermal system

Fig.4 – Geochemical sampling at a thermal pool

The main categories of secondary geothermal fluids that can be encountered at the surface of geothermal systems are:

- geothermal steam
- boiled (and in some cases cooled) geothermal solutions
- mixed solutions involving shallow groundwaters and geothermal solutions (boiled or unboiled) or steam
- steam heated surface waters

a) b)

Fig. 5 – Types of Fumaroles

a. Thermal pools, fumaroles, gases and fluids

b. Gas sampling fumarole

2.3 Geophysics

Geophysical surveys help constrain understanding of stratigraphy, structure and heat flow.

Geophysical exploration of geothermal resources deals with measurements on the physical properties of the earth.

Geophysics aims to:

- delineate a geothermal resource
- outline a production field
- locate aquifers, or structures that may control aquifers in order to site wells
- Assess the general properties of the geothermal system

There are several geophysical methods used in geothermal exploration, depending on the physical parameters measured, each method has a specific application, depending on the physical properties of the target and how precisely these properties can be detected by the technology available

2.3.1 Potential Methods

Potential method based on density and magnetic properties of rocks and of the Earth potential fields:

- Gravity methods – used to detect geological formations with different densities

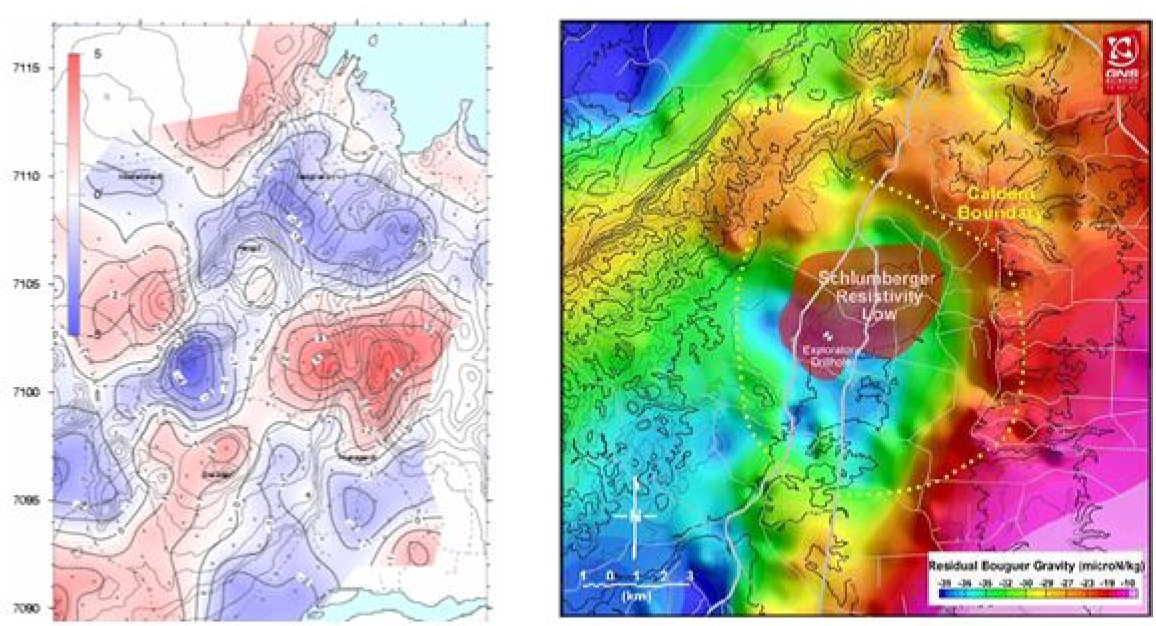


Fig.6 – Bouguer gravity map of the Hengill high-temperature area;

Example of gravity data (GNS Science, New Zealand). Areas of high gravity may indicate intrusions at deeper levels (Árnason, 2007)

2.3.2 Magnetic Methods

Magnetic Method widely used in geothermal exploration, often together with gravity measurements and seismic refraction, in mapping geological structures. In geothermal exploration, magnetic measurements generally aim mainly at locating hidden intrusives and possibly estimating their depth, or at tracing individual buried dykes and faults.

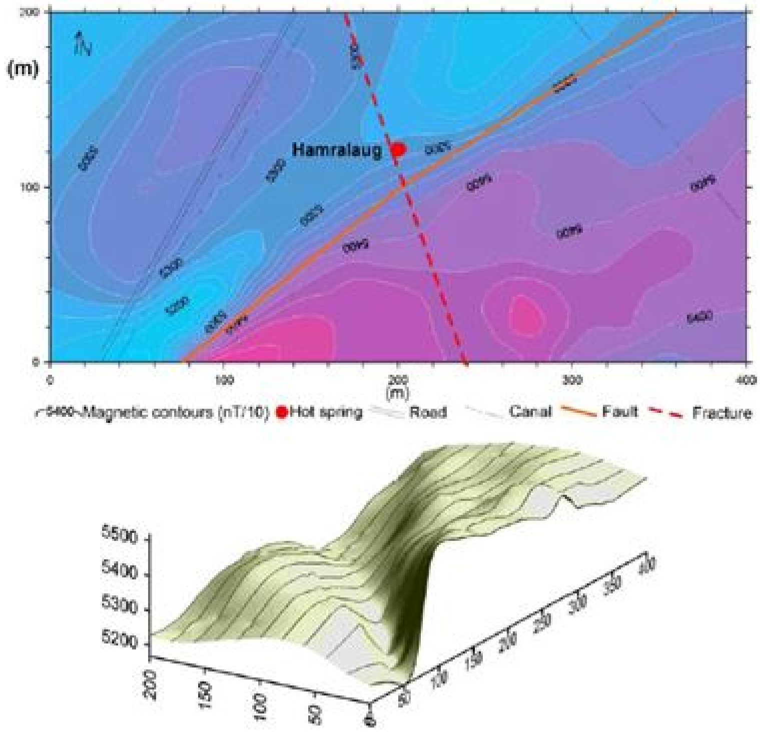


Fig. 7 – Magnetic measurements at the Ásgardur geothermal field in W-Iceland, presented both in a map and through 3D surfaces.

The main anomaly is typical for a fault, resulting from different magnetization of the rocks on each side of the fault (Ganbat, 2004)

2.3.3 Electrical Methods or Resistivity Methods

Electrical methods or resistivity methods are the most important geophysical methods in the surface exploration of geothermal areas, and as such the main methods used in delineating geothermal resources and production fields. The parameter of interest is the electrical resistivity of the rocks which correlates both with the temperature and alteration of the rocks which are key parameters for the understanding of the geothermal systems.

Electrical methods include:

- ***DC methods***, where current is generated and injected into the earth through electrodes at the surface and the measured signal is the electrical field generated at the surface.

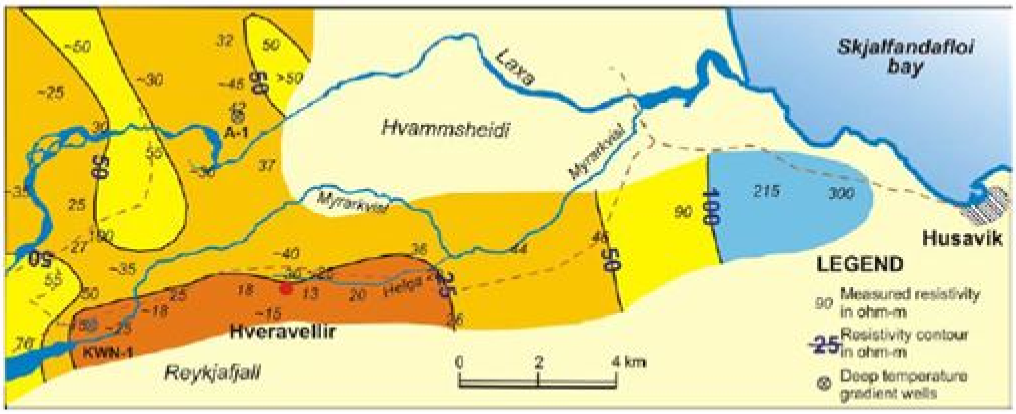


Fig. 8 – Resistivity map at 500 m depth b.s.l. from the Husavik area, N-Iceland, outlining the powerful Hveravellir low-temperature area (Georgsson et al., 2005)

The transient electromagnetic (TEM), where current is induced by a time varying magnetic field from a controlled source. The monitored signal is the decaying magnetic field at surface from the secondary magnetic field.

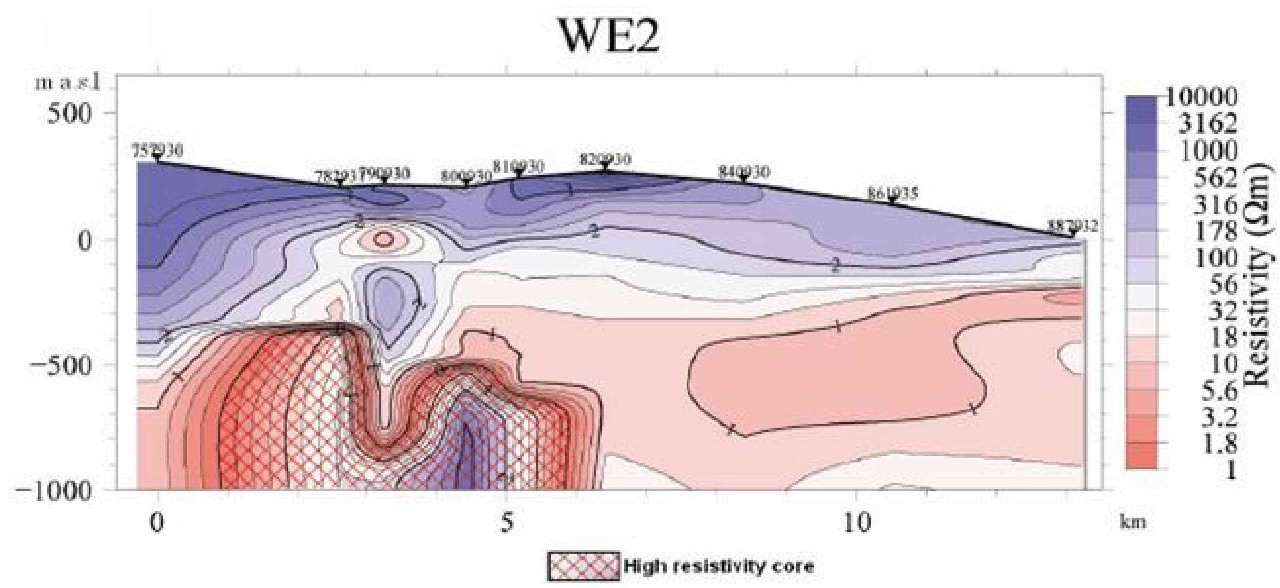
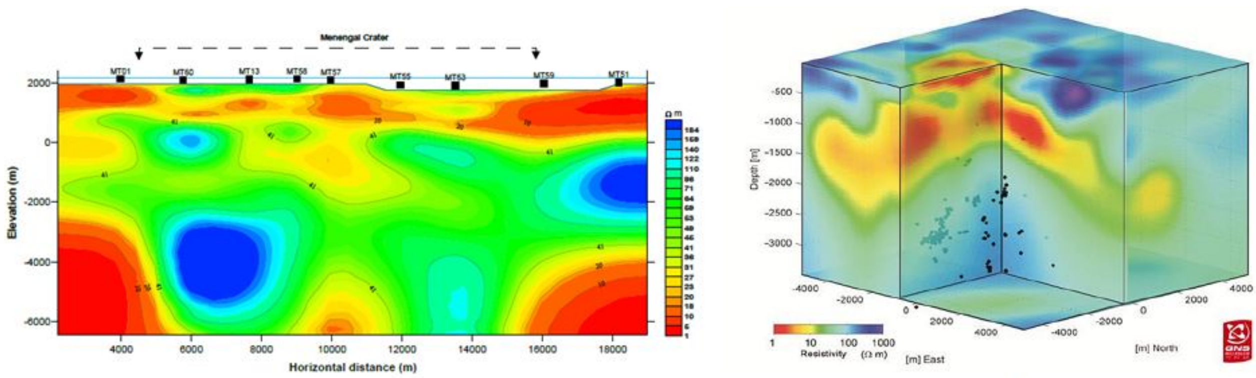


Fig. 9 – W-E trending TEM resistivity cross-section from the southwest part of the Hengill high-temperature geothermal area, showing a resistivity anomaly that may indicate a new geothermal field where no geothermal activity is known on the surface (Tsend-Ayush, 2006)

- ***Magnetotellurics (MT)*** where current is induced by the time variations in earth's magnetic field. The measured signal is the electromagnetic field at the surface.



a) b)

Fig 10

a) MT cross-section from the Menengai high-temperature area and crater in the Kenyan rift (Wameyo, 2005)

b) Example of 3D MT resistivity cross section (GNS Science, New Zealand).

2.3.4 Seismic Methods

Seismic methods rely on elastic waves which have different velocities when travelling through different rock types, and are refracted or reflected at discontinuities in or between formations. Active seismic measurements give information on the density of the formations, the porosity and texture, boundaries and discontinuities and fluid-filled zones and thus even temperature. The measurements are quite expensive, especially good reflection measurements.

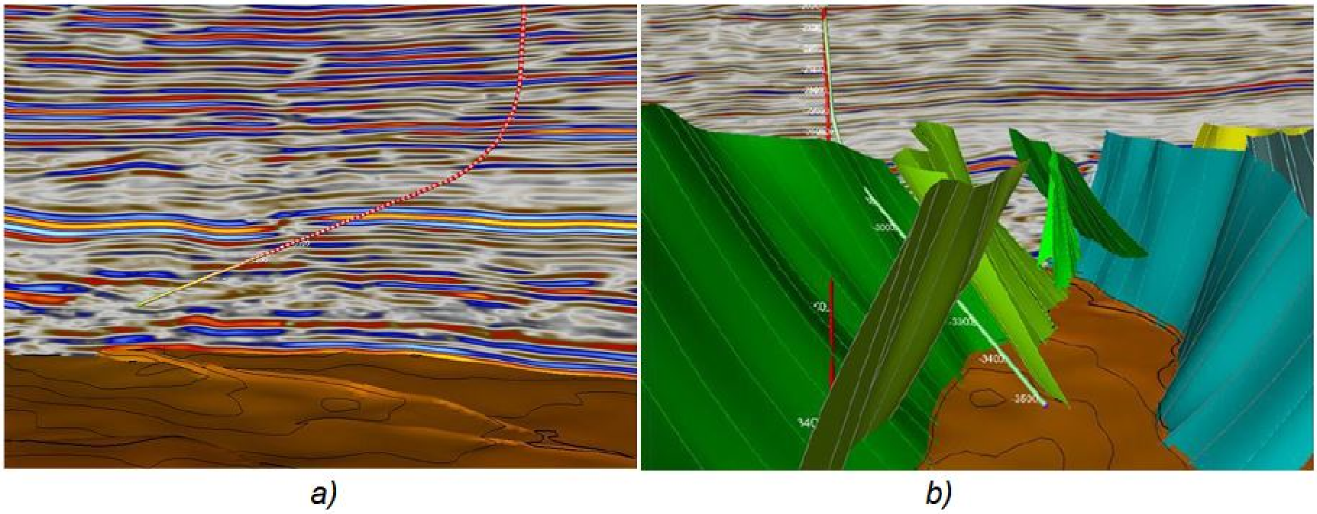


Fig. 11

a) Example of seismic section with planned borehole (Erdwärme Bayern GmbH & Co. KG-).

b) Example of seismic section with geological interpretation (Erdwärme Bayern GmbH & Co. KG-).

2.3.5 Conceptual model

All exploration data should be integrated into a conceptual model of the geothermal system under investigation. This model must respect and be consistent with all known information.

Existing well site(s) and proposed drilling target(s) can be presented on diagrams of the conceptual model, but should be accompanied by a narrative description of the rationale for selecting the proposed target(s).

The conceptual model will demonstrate a justifiable understanding of the geology, temperature, and fluid pathways within the geothermal system. By utilizing the conceptual model, the developer can select drilling sites that maximize the chances for a successful well based on all current data.

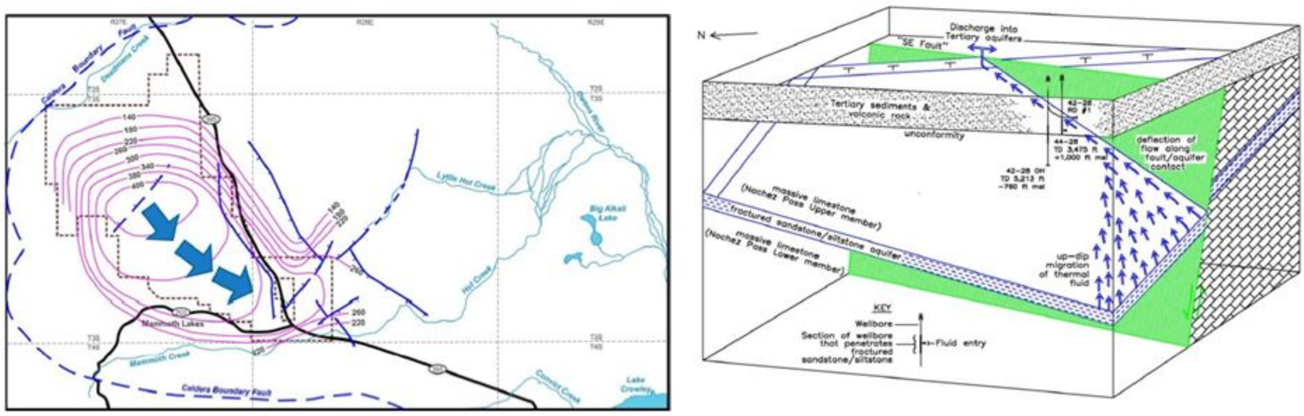


Fig.12 – Conceptual Model

a) Example of a conceptual model map (GeothermEx, Inc.; redrawn by GNS Science, New Zealand).

b) Example of a 3D conceptual block-model (GeothermEx, Inc.).

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2.3.6 Numerical Modeling

Once a suitable conceptual model has been constructed, it can form the basis of a numerical model. Numerical modeling is used to characterize in a quantitative way the physical processes at work within a geothermal system.

These are primarily fluid and heat flow processes, controlled by temperature and/or pressure gradients and permeability pathways.

A numerical model can test the validity of the conceptual model to explain the observed distribution of temperature and flow paths.

It can then forecast the future performance of the reservoir under conditions of exploitation (production and injection).

This is used to estimate the impact that geothermal exploitation will have on the resource, and hence possible degradation of the reservoir and power output.

The development and use of a numerical model involves a number of stages, from initial state modeling to history matching and then forecasts under a number of selected scenarios to predict the future behavior of the reservoir under various levels of production.

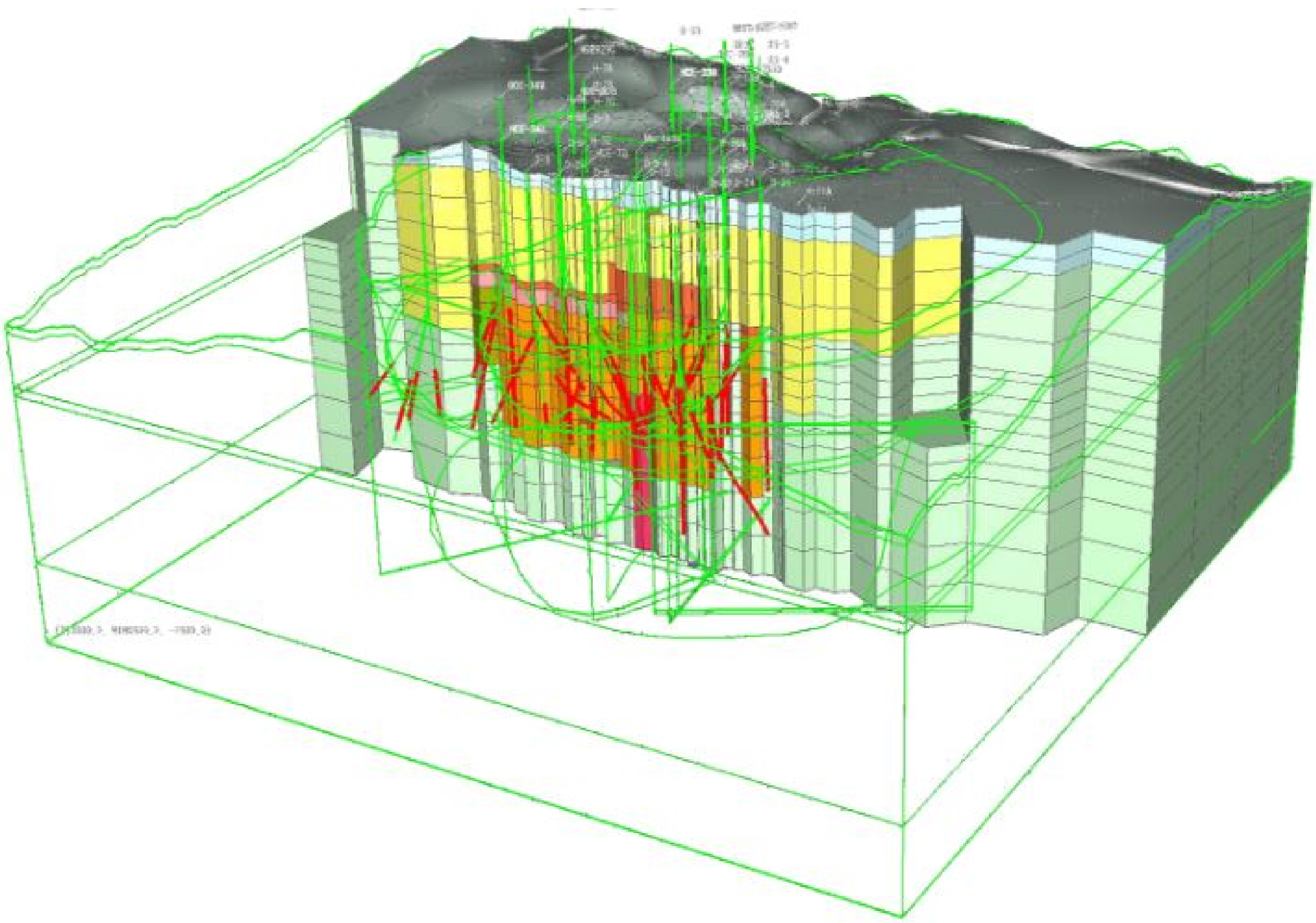

Fig. 13 – An example of a geothermal model (Serengeo)

2.4 Drilling

Geothermal drilling relies on technology used in the oil and gas industry modified for high temperature applications and larger well diameters.

Drilling of exploratory wells represents the final phase of any geothermal exploration program and is the only means of determining the real characteristics of the geothermal reservoir and thus of assessing its potential (Combs and Muffler, 1973).

Drilling the first wells in any project represents the period of highest risk and typically, at least two but more often three, deep wells are drilled to demonstrate the feasibility of commercial production and injection. More wells may be required, depending on the size of the project to be developed and the success in finding a viable geothermal resource with the first series of wells.

Drilling, logging and testing significantly improve the understanding of the resource, enabling:

1. refinement of the estimate of the heat resource
2. determination of the average well productivity (thus laying out the scope of future drilling)
3. selection of the well sites, targets, well path and design for the remaining production and injection wells
4. development of a preliminary design for the power plant and gathering system

Upon completion of the test drilling phase, the project moves towards full feasibility.

Fig. 14 – Geothermal well in Italy Venelle 2 – ENEL Green Power

2.4.1 Well Design

Design of a geothermal well is a "bottom-up" process. Location of the production zone determines the well's overall length, and the required flow rate determines diameter at the bottom of the hole – the well's profile above the production zone is then set by iteration of the successively larger casing strings required by drilling or geological considerations.

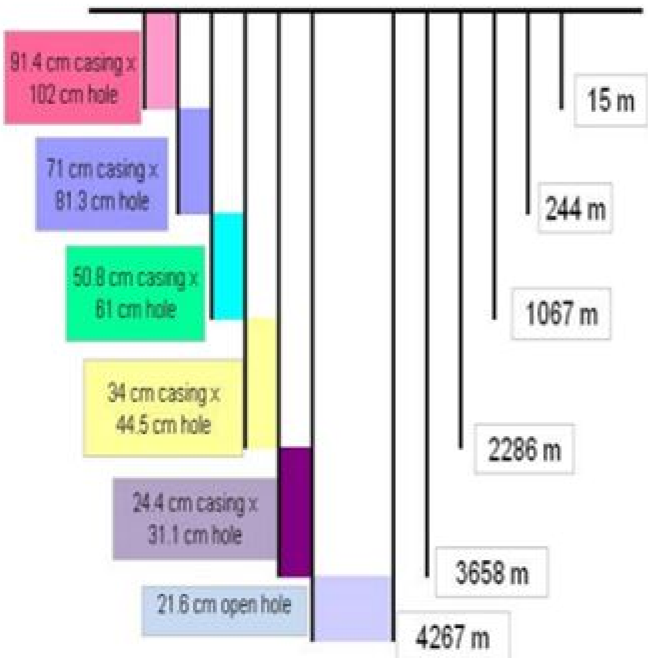

Fig. 15 – Representative geothermal well design

Typical rock types in geothermal reservoirs include:

- Granite
- Granodiorite
- Quartzite
- Greywacke
- Basalt
- Volcanic tuff

2.4.2 Slimhole Drilling

Typical geothermal exploration comprises drilling a large-diameter, production-size well and, if it shows the presence of fluid and high temperature, producing steam or brine from it while measuring the fluid temperature, and, ideally, downhole pressure.

Drilling slimholes is cheaper than production-size wells because:

- The rigs, casing and cementing, crews, locations, and drilling fluid requirements are all smaller
- Site preparation and road construction in remote areas is significantly reduced
- It is not necessary to repair lost-circulation zones before drilling ahead

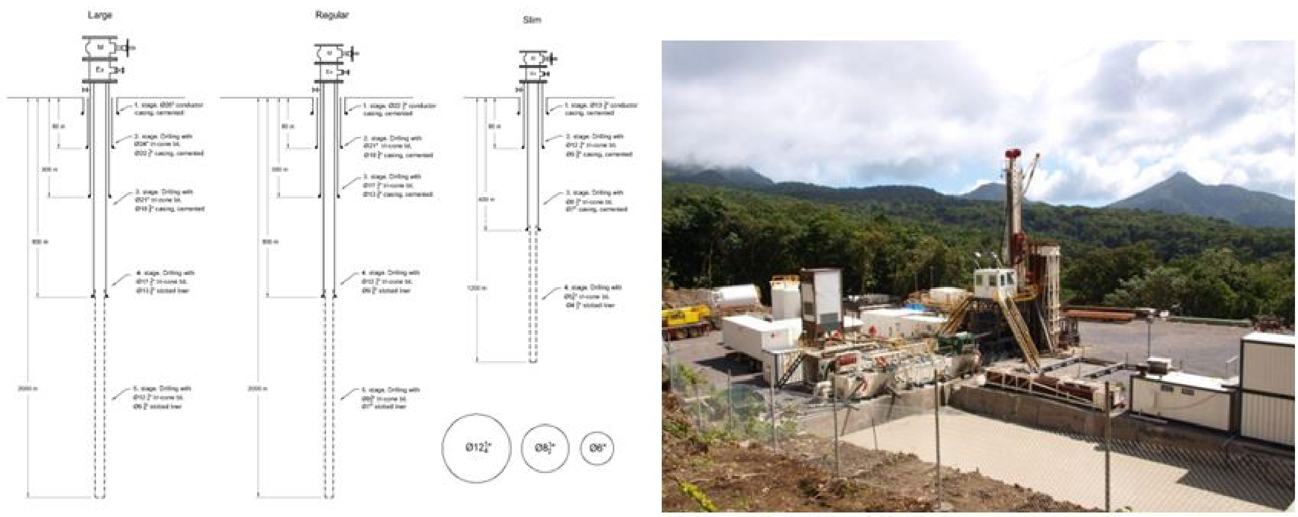

Fig. 16

a) Comparison of casing programs for three well types.

b) Rig drilling a slim hole

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2.5 Geothermal Drilling Operations

Geothermal drilling operations make use of several components and practices, some of this technology is shown and described below:

2.5.1 BITS

Because of the hard, fractured formations, roller-cone bits with tungsten-carbide inserts are almost universally used for geothermal drilling.

Research and development in hard-rock PDC bits is under way, so it is possible that these bits will come into wider use in geothermal drilling.

Fig. 17 – Geothermal drilling bits (tricones and PDC)

2.5.2 Drill Pipes and Casing

Geothermal wells must produce large fluid volumes and so tend to be larger diameter than oil/gas wells; typical geothermal production intervals are 219 to 340 mm in diameter.

Unlike oil/gas wells, geothermal production is from the open hole or through a slotted liner, not through tubing.

Drillpipe suffers both erosion and corrosion. Both of these problems are aggravated by high temperature. Erosion is common when air drilling, which is often done to avoid damaging the production interval with mud invasion, but properly hard-banding the tool joints will mitigate erosion. Casing problems, other than cementing, usually deal with corrosion and scaling.

Many high-temperature drilling problems with downhole tools and drilling fluids could be avoided or mitigated by using insulated drill pipe (IDP), which delivers cooler fluid to the bottom of the hole.

2.5.3. Drilling Fluids

Most geothermal drilling fluids are a fairly simple water/bentonite mixture with possible polymer additives. Large hole volumes and frequent lost circulation have a significant impact on drilling cost.

A technology that is useful with lost circulation is Dual-Tube Reverse Circulation (DTRC). This method uses a drillstring of two concentric tubes, with the drilling fluid passing down annulus between the inner and outer tubes, circulating out through the bit, and carrying the cuttings back up through the center tube. This means that it is only necessary to maintain fluid around the bit and bottom-hole assembly, so drilling with complete lost circulation is possible

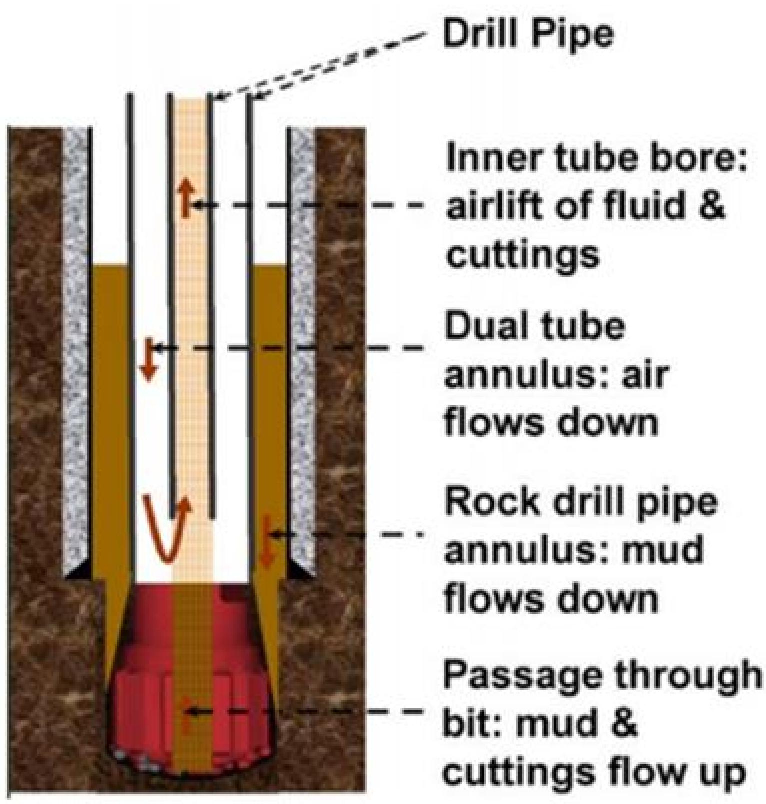

Fig. 18 – Diagram of DTRC

2.5.4 Well Control

There are two primary causes for loss of control:

- An unexpectedly hot formation is encountered at a shallow depth where the annulus pressure is insufficient to keep the drilling fluid or the formation fluid from flashing to steam
- Lost circulation causes the fluid level and the pressure in the wellbore to suddenly fall far enough for the same thing to happen.

2.5.5 Directional Drilling

Neither positive displacement motors nor steering and measurement-while-drilling (MWD) tools operate reliably at high temperature, so most corrections are done at depths where the formation is cooler than 175°C. High-temperature turbines have been demonstrated and service companies offer "high-temperature" positive displacement motors (PDM), but neither is extensively used in geothermal drilling.

2.5.6 Cementing

The principal differences between cementing geothermal and oilfield casing are the requirements on the cement itself because of high temperature, and the requirement that geothermal casings are cemented completely to surface to withstand thermal cycling.

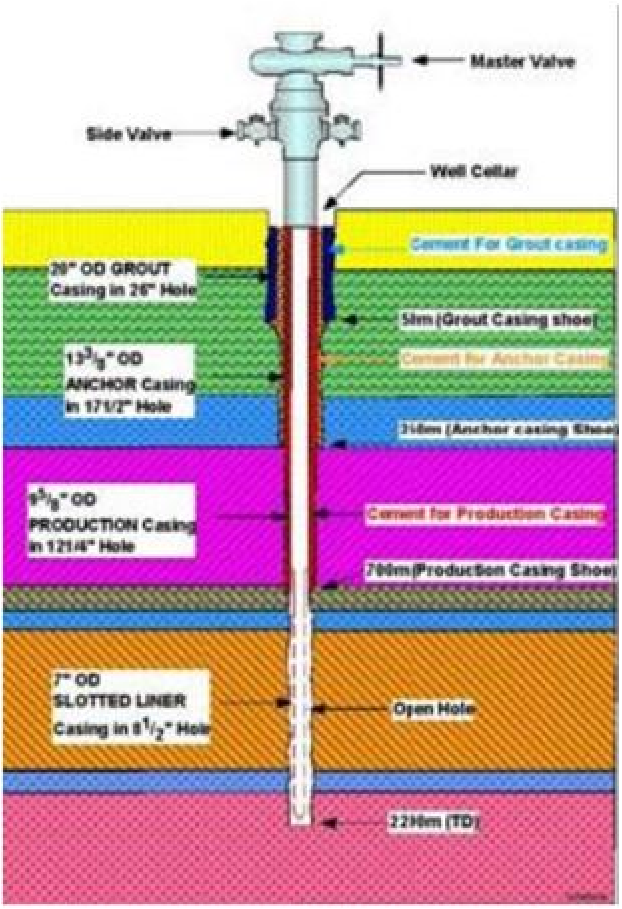

Fig. 19 – Typical geothermal well configuration and casing

2.6 Geothermal Well Completion

Thermal cycling in geothermal production and injection wells requires a complete cement sheath around the casing, and high production flow rates (often > 100,000 kg/hr) mean that casing is usually larger in diameter than for many oil/gas wells.

Whether the production interval is stable enough to be openhole or must be completed with a slotted liner.

2.7 Geothermal Energy Production Plants

Once a reservoir is found and characterized, surface technology, the power plant and related infrastructure, must be designed and equipment selected to optimize the use and sustainability of the resource. The goal is to construct an energy efficient, low cost, minimal-impact plan.

Many uses and technologies have been developed to take advantage of geothermal energy:

1. Geothermal energy for electricity production
2. Geothermal energy direct uses
3. Geothermal heat pumps

2.7.1 Geothermal Energy for Electricity Production

Most conventional power plants use steam to generate electricity. Whereas fossil-fuel plants burn coal, oil or gas to boil water, many existing geothermal power plants use steam produced by “flashing” (i.e. reducing the pressure of) the geothermal fluid produced from the reservoir. Geothermal power plants today can use water in the vapour phase, a combination of vapour and liquid phases, or liquid phase only. The choice of plant depends on the depth of the reservoir, and the temperature, pressure and nature of the entire geothermal resource.

The three main types of plant are

1. flash steam
2. dry steam
3. binary plants

All forms of current accepted geothermal development use re-injection as a means of sustainable resource exploitation.

A.FLASH STEAM PLANTS

The most commonly found geothermal resources contain reservoir fluids with a mixture of hot liquid (water) and vapour (mostly steam). Flash steam plants, making up about two-thirds of geothermal installed capacity today, are used where water dominated reservoirs have temperatures above 180°C. In these high-temperature reservoirs, the liquid water component boils, or "flashes," as pressure drops. Separated steam is piped to a turbine to generate electricity and the remaining hot water may be flashed again twice (double flash plant) or three times (triple flash) at progressively lower pressures and temperatures, to obtain more steam. The cooled brine and the condensate are usually sent back down into the reservoir through injection wells. Combined-cycle flash steam plants use the heat from the separated geothermal brine in binary plants to produce additional power before re-injection.

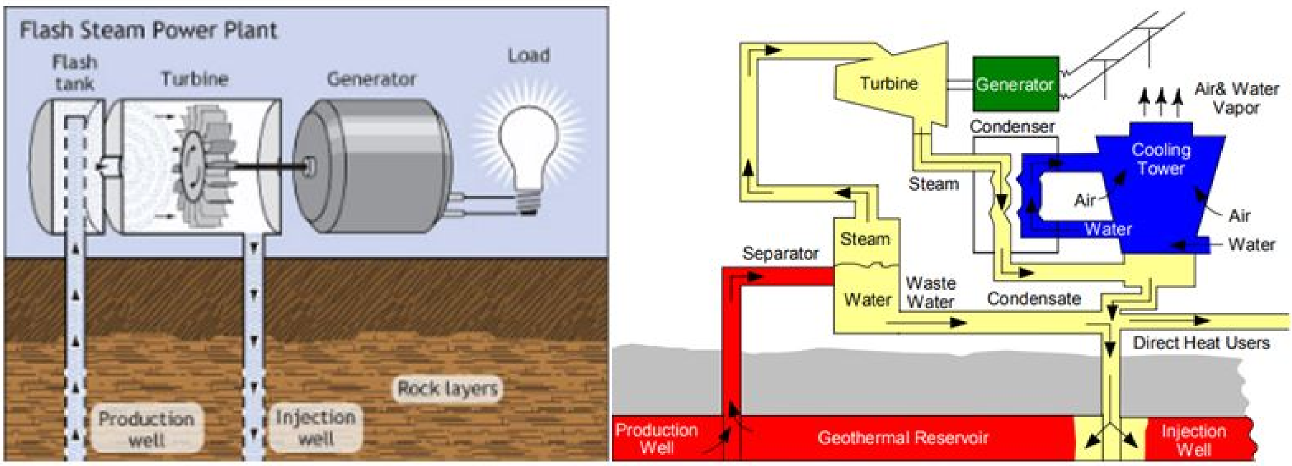

Fig. 20 – Flash Steam Power Plant Diagrams and Single Flash Steam Power Plant Schematic (from: Geo-Heat Center and U.S. Energy Dept)

B) DRY STEAM PLANTS

Dry steam plants, which make up about a quarter of geothermal capacity today, directly utilize dry steam that is piped from production wells to the plant and then to the turbine. Control of steam flow to meet electricity demand fluctuations is easier than in flash steam plants, where continuous up-flow in the wells is required to avoid gravity collapse of the liquid phase. In dry steam plants, the condensate is usually re-injected into the reservoir or used for cooling

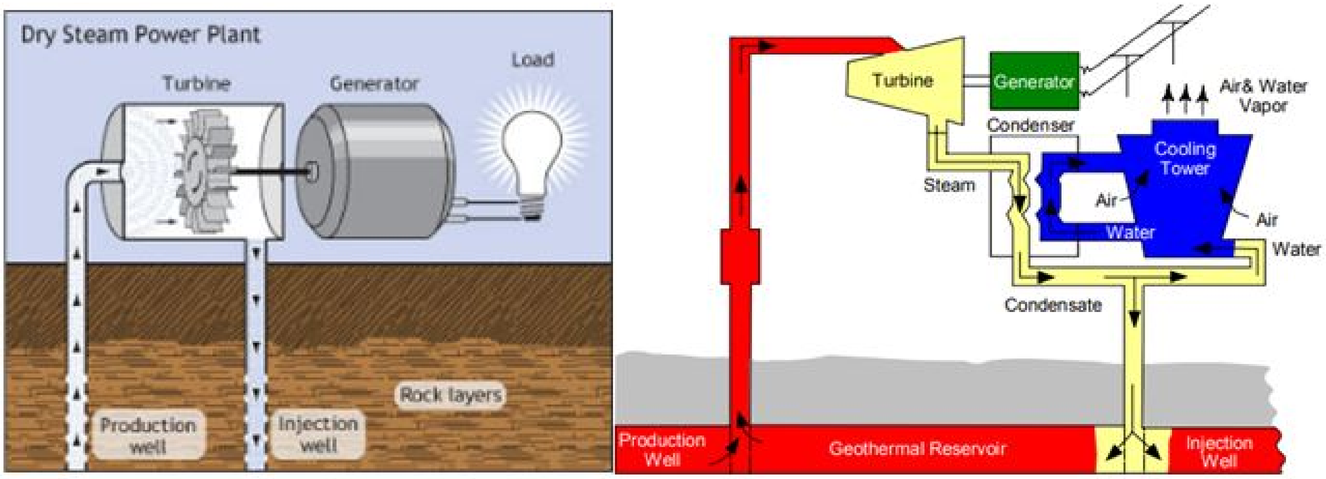

Fig. 21 – Dry Steam Power Plant Diagram and Power Plant Schematic (from: Geo-Heat Center and U.S. Energy Dept)

C) BINARY PLANTS

Electrical power generation units using binary cycles constitute the fastest-growing group of geothermal plants, as they are able to use low- to medium-temperature resources, which are more prevalent. Binary plants, using an organic Rankine cycle (ORC) or a Kalina cycle, typically operate with temperatures varying from as low as 73oC (at Chena Hot Springs, Alaska) to 180°C. In these plants, heat is recovered from the geothermal fluid using heat exchangers to vaporise an organic fluid with a low boiling point (e.g. butane or pentane in the ORC cycle and an ammonia-water mixture in the Kalina cycle), and drive a turbine.

Although both cycles were developed in the mid-20th century, the ORC cycle has been the dominant technology used for low-temperature resources. The Kalina cycle can, under certain design conditions, operate at higher cycle efficiency than conventional ORC plants. The lower-temperature geothermal brine leaving the heat exchanger is re-injected back into the reservoir in a closed loop, thus promoting sustainable resource exploitation. Today, binary plants have an 11% share of the installed global generating capacity and a 44% share in terms of the number of plants (Bertani, 2010).

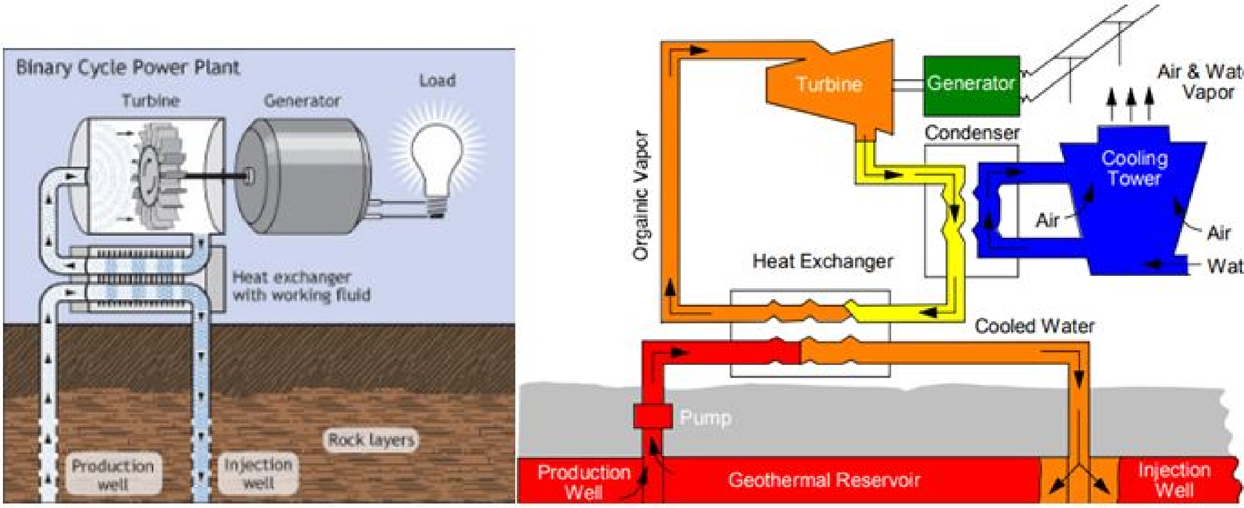

Fig. 22 – Binary Power Plant Schematic and Power Plant Diagrams (from: Geo-Heat Center and U.S. Energy Dept)

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2.7.2 Geothermal Energy Direct Uses

Although electricity production is nowadays under the lights because of the highly praised value of electricity, direct use of geothermal resources should not be neglected.

The direct use of geothermal resources is the use of the heat energy or the fluid from geothermal resources without intervening medium as opposed to its conversion to other forms of energy such as electrical energy.

Most direct use applications can be applied for geothermal fluids in the low to moderate temperature range 20 – 120°C. Low to medium temperature geothermal resources have been used for ages especially in a first time for bathing and later on for space heating and farming applications.

Low and medium temperature geothermal fields can be found in many places around the world. Such fields can hardly be utilized for power generation in steam turbines nor binary plants, mainly due to economic reasons. These fields might however fit perfectly for direct use applications.

Geothermal heat is used directly, without involving a power plant or a heat pump, for a variety of applications such as space heating and cooling, food preparation, hot spring bathing and spas (balneology), agriculture, aquaculture, greenhouses, and industrial processes. Uses for heating and bathing are traced back to ancient Roman times.

Geothermal energy is also used to heat buildings through district heating systems. Hot water near the earth’s surface is piped directly into buildings for heat. A district heating system provides heat for most of the buildings in Reykjavik, Iceland.

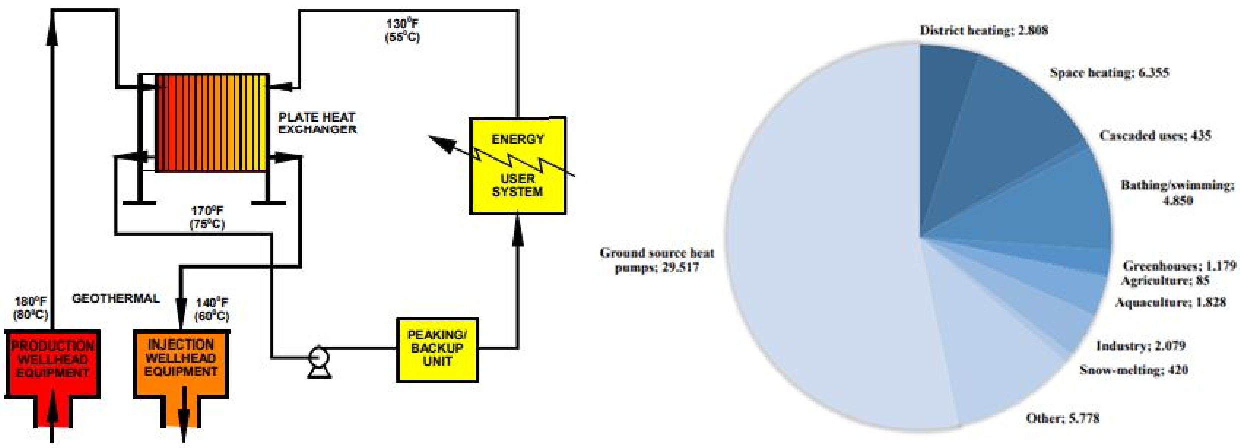

Fig. 23- Typical Direct Use Geothermal Heating System Configuration and direct use of geothermal heat in 2010 among the IEA-GIA countries (GWh/a)

2.7.3. Geothermal Heat Pumps (GHPs)

Geothermal heat pumps take advantage of the Earth’s relatively constant temperature at depths of about 10 ft to 300 ft. GHPs can be used almost everywhere in the world, as they do not share the requirements of fractured rock and water as are needed for a conventional geothermal reservoir.

Geothermal heat pump systems consist of basically three parts:

- the ground heat exchanger
- the heat pump unit
- the air delivery system (ductwork)

The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.

In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger.

The heat removed from the indoor air during the summer can also be used to heat water, providing a free source of hot water.

GHPs reduce electricity use 30–60% compared with traditional heating and cooling systems, because the electricity which powers them is used only to collect, concentrate, and deliver heat, not to produce it.

Geothermal heat pumps come in four types of loop systems that loop the heat to or from the ground and your house. Three of these – horizontal, vertical, and pond/lake – are closed-loop systems. The fourth type of system is the open-loop option. Choosing the one that is best for your site depends on the climate, soil conditions, available land, and local installation costs at the site.

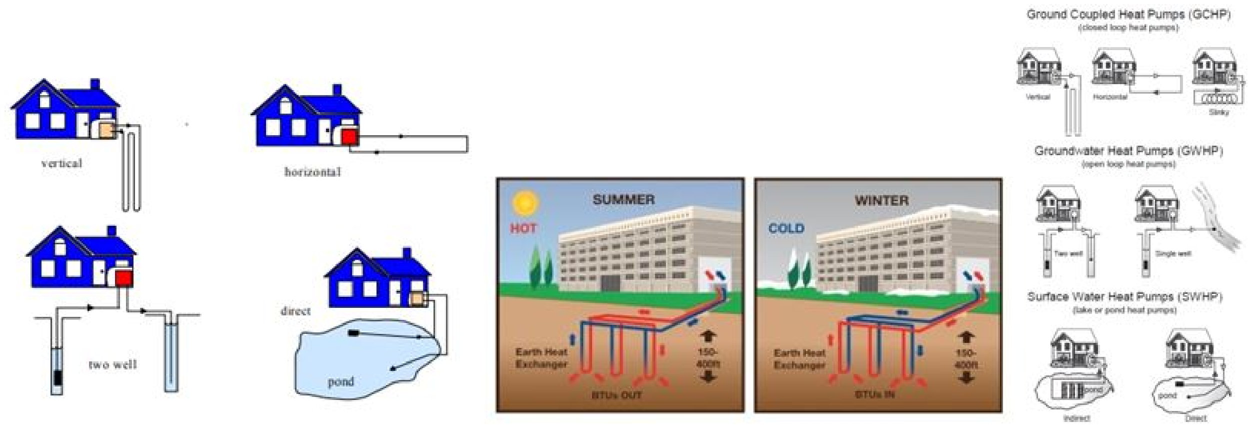

Fig. 24 – Simplified schemes of ground source heat pumps and Geothermal Heat Pump Diagrams

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Reference

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- *Geothermal systems and technologies, geothermal resources and reservoirs – Geothermal Communities (GEOCOM) project EU*
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