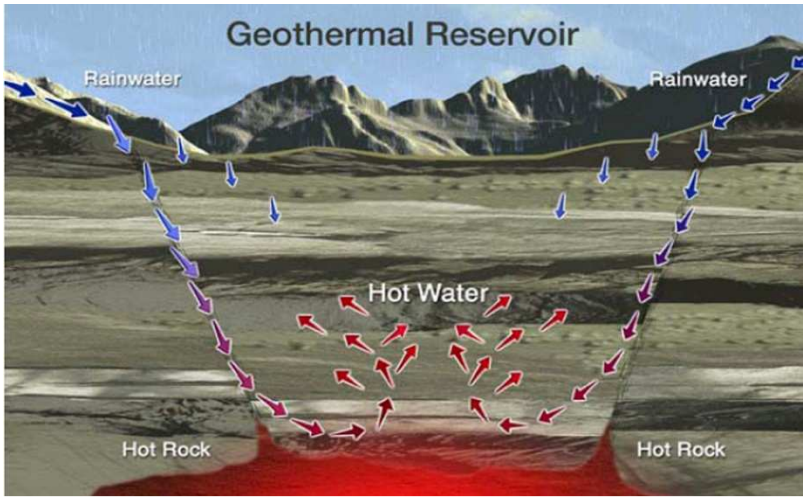
GEOTHERMAL SYSTEMS AND TECHNOLOGIES

2.GEOTHERMAL RESOURCES AND RESERVOIRS

2.1.Definition of geothermal resources

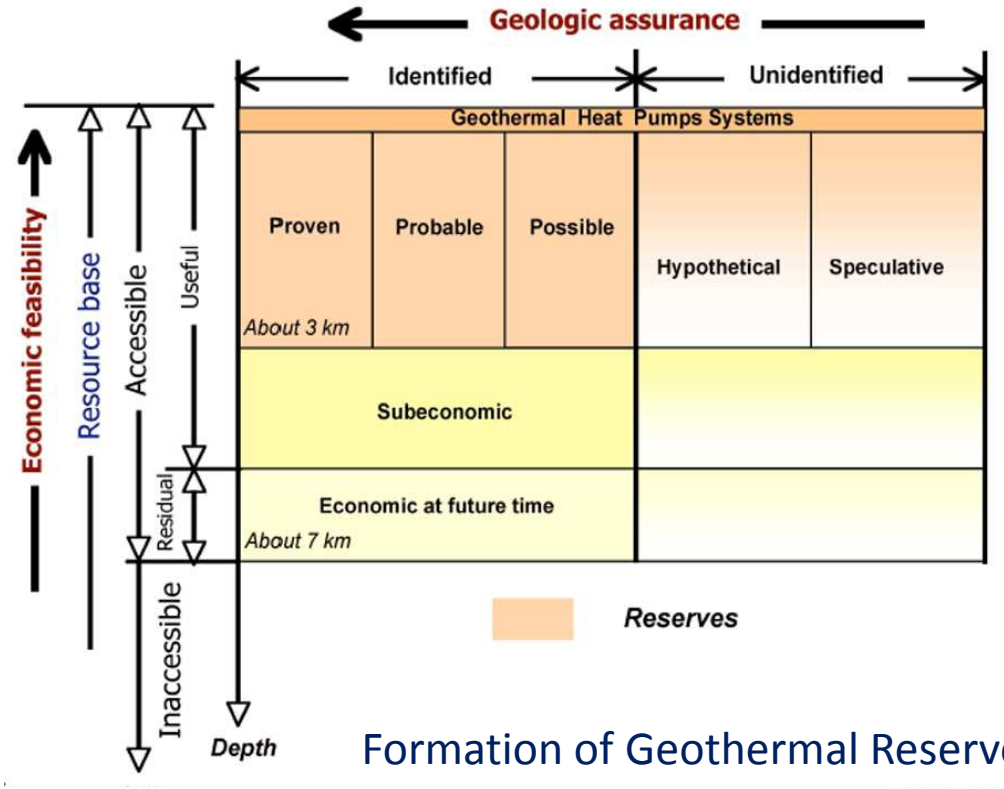
When water is heated by the earth's heat, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rocks and a geothermal reservoir can be created.

This natural collection of hot water is called a geothermal reservoir.



Formation of Geothermal Reservoir

2.1.Definition of geothermal resources



Formation of Geothermal Reservoirs

Terminology:

⇨ Accessible resource base;

⇨ Useful accessible resource base (= *Resource*);

⇨ Identified economic resource (=*Reserve*) and unidentified resources.

2.1.Definition of geothermal resources

The most common criterion to classify geothermal resources is based on the enthalpy of the geothermal fluids.

The resources are divided into: low, medium and high enthalpy (or temperature) resources.

A distinction is made between water- or liquid-dominated geothermal systems and vapor-dominated (or dry steam) geothermal systems.

The water-dominated systems, whose temperatures may range from < 125 to > 225°C, are the most widely distributed in the world.

2.1.Definition of geothermal resources

The Pohutu **Geyser** in New Zealand

In vapor-dominated systems liquid water and vapor normally co-exist in the reservoir, with vapor as the continuous, pressure-controlling phase.

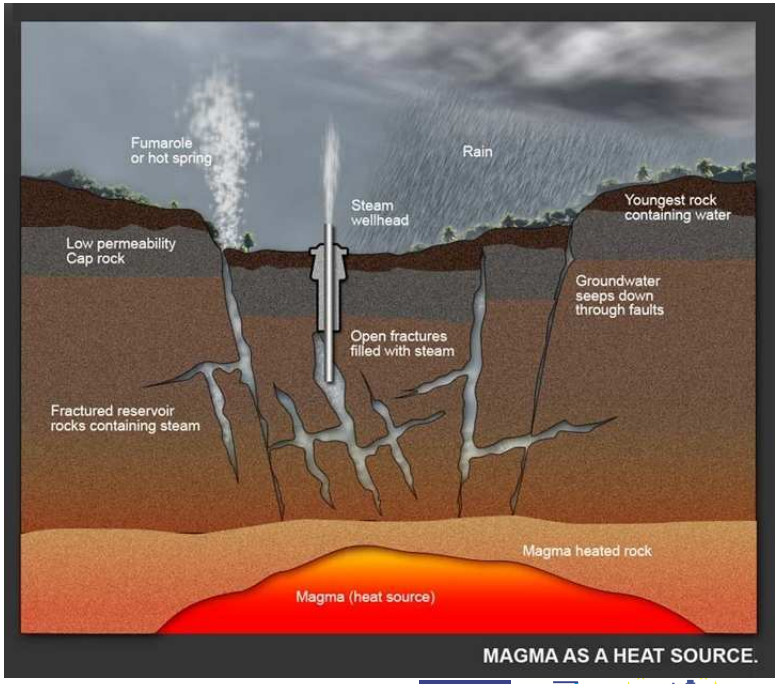
2.1.Definition of geothermal resources

Geothermal fluid.

"Hydrothermal" resource.

Vertical hydrothermal energy flows (convection) and horizontal hydrothermal energy flows.

Differences in pressure activate the energy flows



2.1.Definition of geothermal resources

Geyser

Geothermal resources are often discovered under certain land features such as:

- ⇨ Geyser
- ⇨ Fumaroles
- ⇨ Hot spring and pool
- ⇨ Silica sinter terrace
- ⇨ Thermal area
- ⇨ Mud pool
- ⇨ Algal mat

Fumaroles

2.1.Definition of geothermal resources

Hot spring and pool

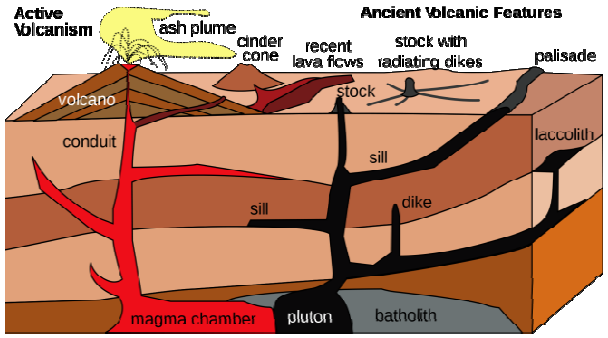
Silica sinter terrace

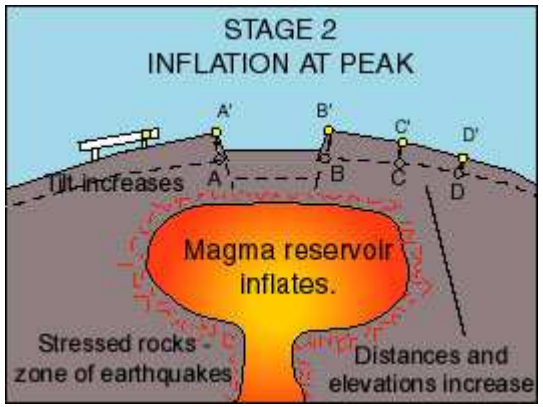
Algal mat

Thermal area

Mud pool

2.1.Definition of geothermal resources

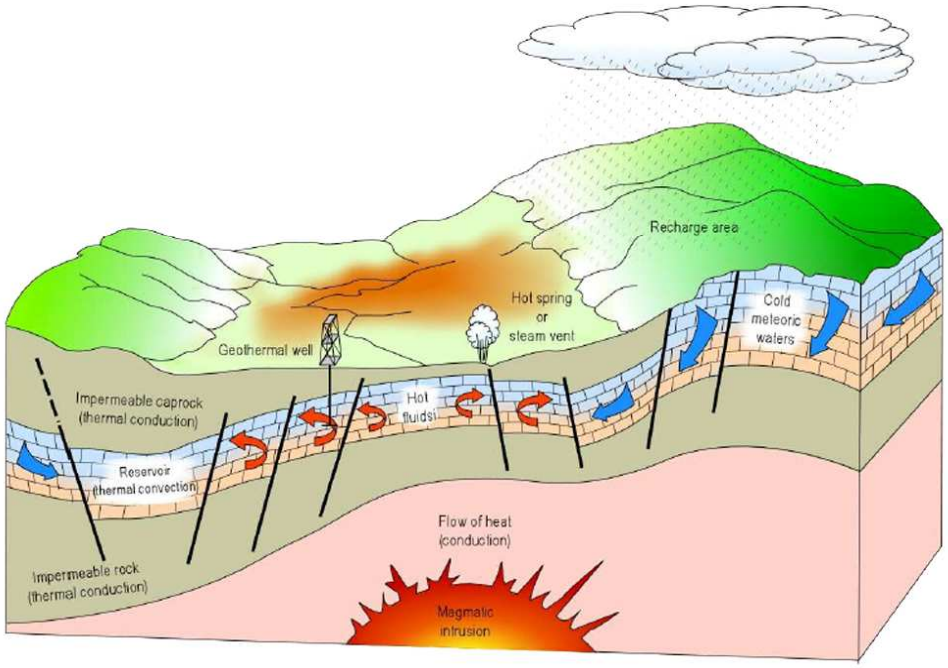




Most geothermal exploration and use occurs where the gradient is higher, and thus where drilling is shallower and less costly. These shallow depth geothermal resources occur due to:

- ⇨ Intrusion of molten rock (magma) from depth.
- ⇨ High surface heat flow.
- ⇨ Ascent of groundwater.
- ⇨ Thermal blanketing or insulation.
- ⇨ Anomalous heating of shallow rock by decay of radioactive elements.

2.2.Classification of geothermal resources



Schematic representation of ideal geothermal system

A common geothermal field consist of three parts: a thermal source, reservoir and fluids which act as heat carriers.

The thermal source could be magma penetration or a normal heat flow.

The reservoir consists thermally permeable rock formation. Geothermal fluids – meteoric, surface or magma origin; in liquid or vapor state with dissolved solid substances and gases.

2.2.Classification of geothermal resources

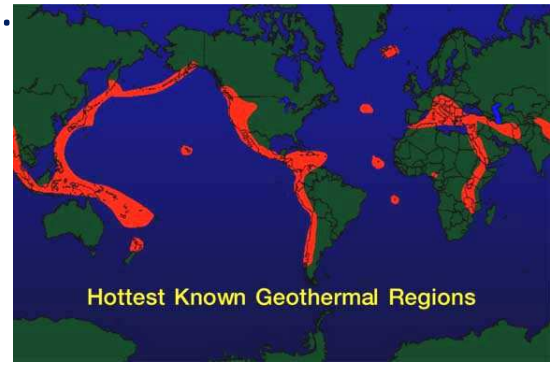
Geothermal systems are found in regions with a normal or slightly above normal geothermal gradient, and especially in regions around plate margins.

Normal geothermal gradient < 100^{o}C.

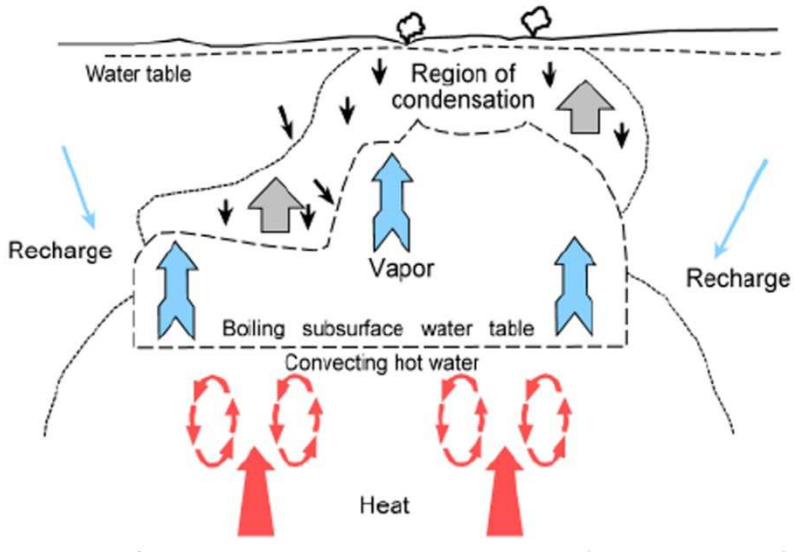
Slightly above normal gradient - wide range of temperatures.

Several classification criteria:

- the type of geothermal resource
- the type and temperature of fluids
- the category of the rock
- the heat source type and
- fluid circulation modes within the reservoir.



2.2.Classification of geothermal resources

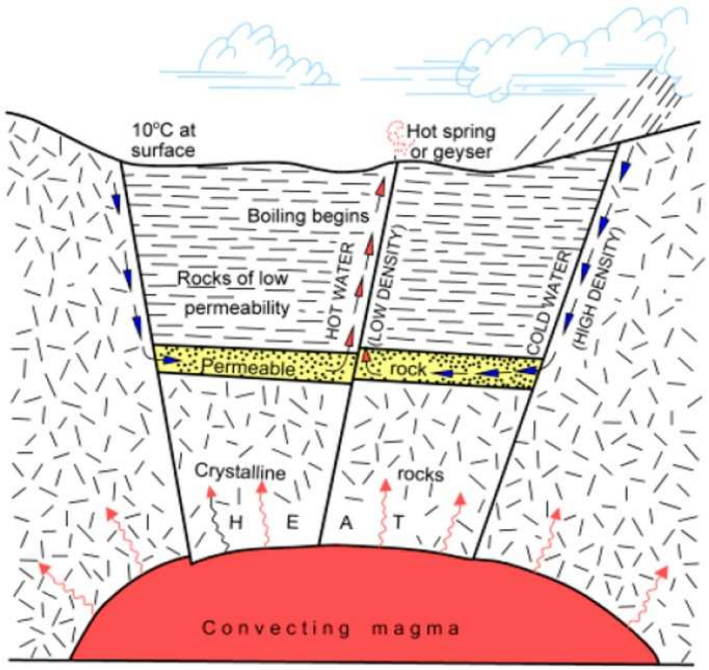


Vapor dominated geothermal resource

The geothermal system can be described as 'convecting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface'.

A geothermal system is made up of three main elements: a heat source, a reservoir and a fluid, which is the carrier that transfers the heat.

2.2.Classification of geothermal resources



Hot water dominated geothermal resource

The mechanism underlying geothermal systems is largely governed by fluid convection.

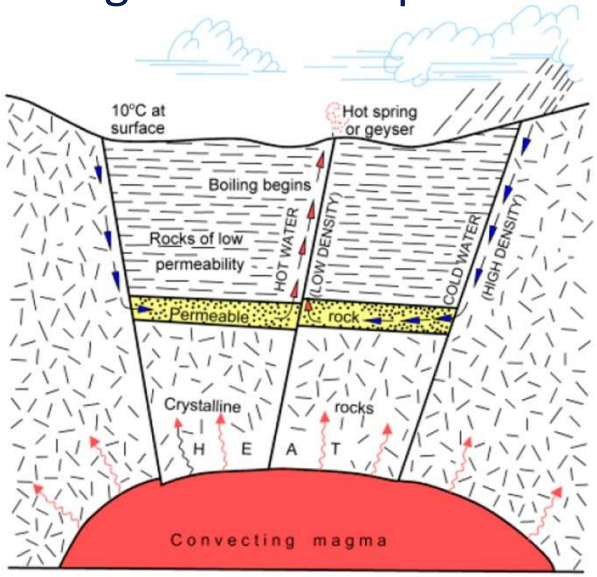
2.2.Classification of geothermal resources

Resource Type	Temperature range (˚C)
Convective hydrothermal resources	
Vapor dominated	240˚
Hot-water dominated	20 to 350˚+
Other hydrothermal resources	
Sedimentary basin	20 to 150˚
Geopressured	90 to 200˚
Radiogenic	30 to 150˚
Hot rock resources	
Solidified (hot dry rock)	90 to 650˚
Part still molten (magma)	>600˚

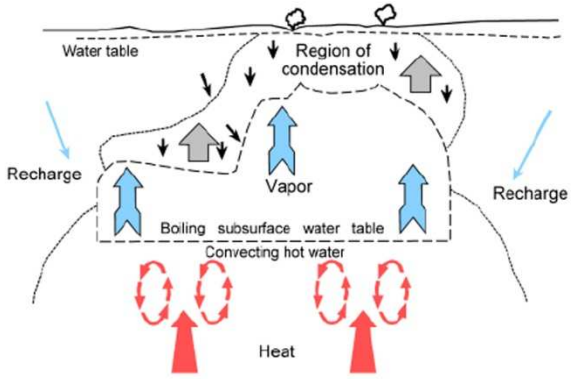
Geothermal Resource Types

2.2.Classification of geothermal resources

Convective hydrothermal resources according the predominant fluid phase are categorized as: vapor dominated (steam) or liquid-dominated (hot water).

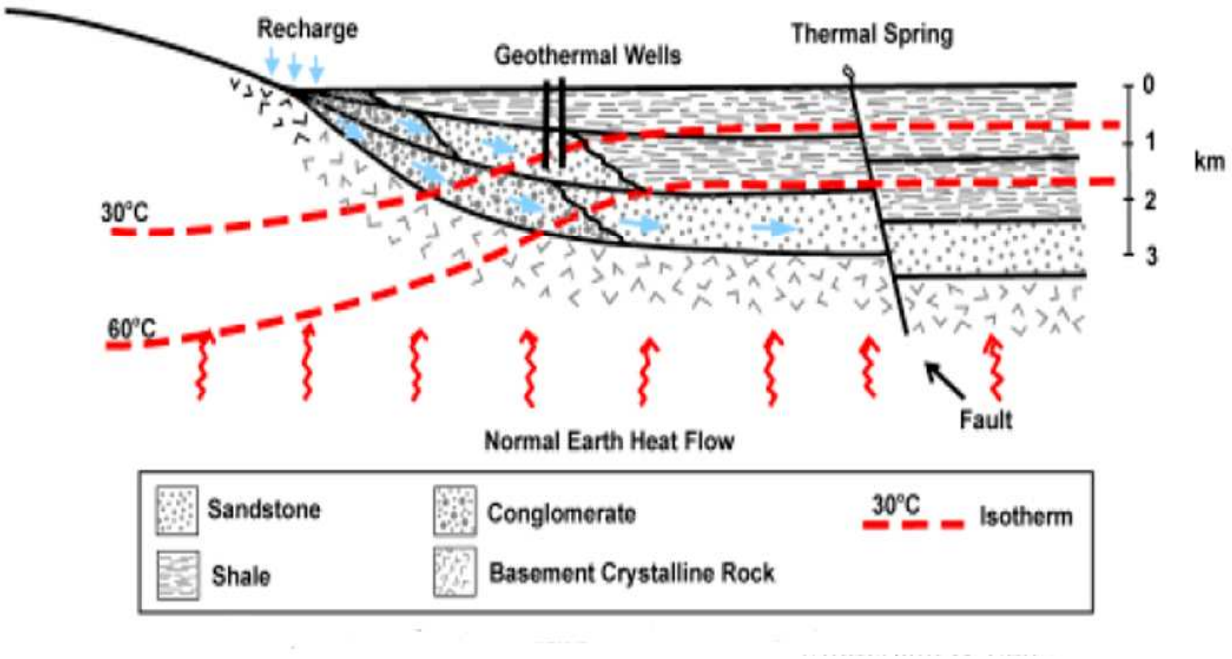


Hot water dominated geothermal resource



Vapor dominated geothermal resource

2.2.Classification of geothermal resources



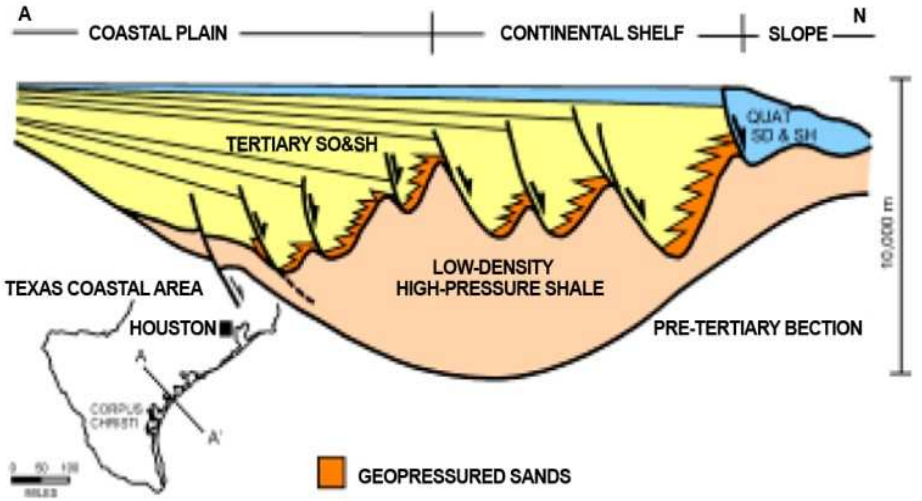
Sedimentary basin geothermal resource.

Sedimentary basins produce higher temperature resources than the surrounding formations.

2.2.Classification of geothermal resources

Geo-pressured resources occur in basin environments where deeply buried fluids contained in permeable sedimentary rocks are warmed in a normal or enhanced geothermal gradient by their great burial depth.

Radiogenic resources are found where granitic intrusions are near surface heating up the local groundwater from the decay of radioactive thorium, potassium and uranium.

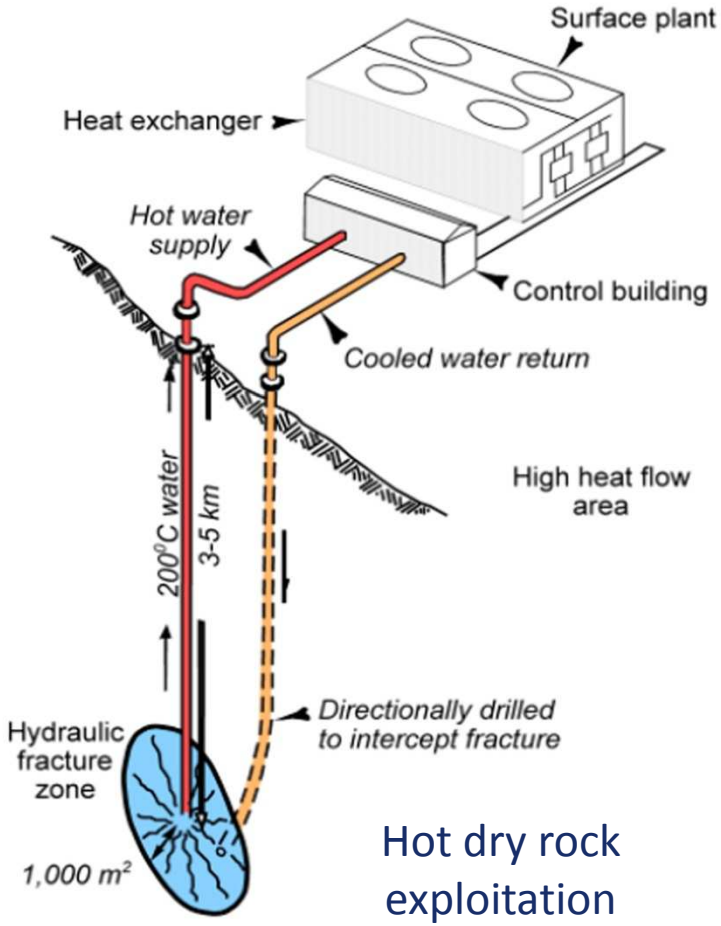


Geo-pressured geothermal resource

2.2.Classification of geothermal resources

Hot dry rock resources (HDR) or enhanced geothermal systems (EGS), with temperatures from 200 to 350°C, are defined as heat stored in rocks within about 10 km of the surface from which energy cannot be economically extracted by natural hot water or steam.

Molten rock or magma resources, with temperatures from 600 to 1400°C, have been drilled in Hawaii experimentally to extract heat energy directly from molten rock.



Hot dry rock exploitation

2.2.Classification of geothermal resources

The World Bank classifies the geothermal resources based on temp. as:

- ⇨ high temperature (>150°C),
- ⇨ medium-temperature (100-150°C), and
- ⇨ low-temperature (<100°C) resources.

The high-temperature reservoirs classified into several types based on the water temperature, pressure and phases. The reservoirs according the water phase:

- ⇨ warm water reservoirs,
- ⇨ hot water reservoirs, and
- ⇨ vapor-dominated reservoirs.

2.2.Classification of geothermal resources

Geothermal reservoir temperatures and common technologies

Reservoir temp.	Reservoir fluid	Common use	Technology commonly chosen
High temperature >220°C	Water and/or steam	Power generation Direct use	Flash steam Combined (flash and binary) cycle Direct fluid use Heat exchangers Heat pumps
Intermediate temperature 100-220°C	Water	Power generation Direct use	Binary cycle Direct fluid use Heat exchangers Heat pumps
Low temperature 50-150°C	Water	Direct use	Direct fluid use Heat exchangers Heat pumps

2.2.Classification of geothermal resources

A warm water reservoir is defined as one containing water at a sufficiently low temperature (<100°C) which can be exploited for district heating, agricultural purposes and balneological use, etc.

A hot water reservoir contains fluid in a liquid state in the temperature range of 100-250°C.

Vapor-dominated reservoirs are full of steam. The main characteristics of such system are:

- a discharge of steam only;
- the discharge comes from a region where the pressure is nearly constant with depth.