GEO ALLIANCE
Driving Sustainable Urban Futures

TRAINING MATERIALS GEOTHERMAL ENERGY

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Iceland Liechtenstein Norway grants
Norway grants

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Module 1

Introduction to Geothermal

Module 1. Learning objectives

To understand the concept behind geothermal energy production

To understand the role of geothermal in energy transition strategy

To understand existing business context for geothermal market in World and Europe, main challenges and opportunities

What is geothermal?

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- Geothermal energy is the heat that comes from the Earth's core. This heat is stored in rocks and fluids beneath the Earth's surface and can be found as hot water or steam. It is a renewable energy source because the Earth continuously produces heat, making it an endless resource.
- Geothermal energy can be used for:
- **Heating and Cooling:** It can directly heat buildings through geothermal heat pumps.
- **Electricity Generation:** Geothermal power plants convert steam or hot water into electricity.
- **Hot Water Supply:** In some areas, geothermal resources are used for hot water or spa bathing.
- This energy source is clean, reliable, and sustainable. It does not produce greenhouse gases and is available 24/7, making it an important option for reducing our reliance on fossil fuels.

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The source of geothermal heat

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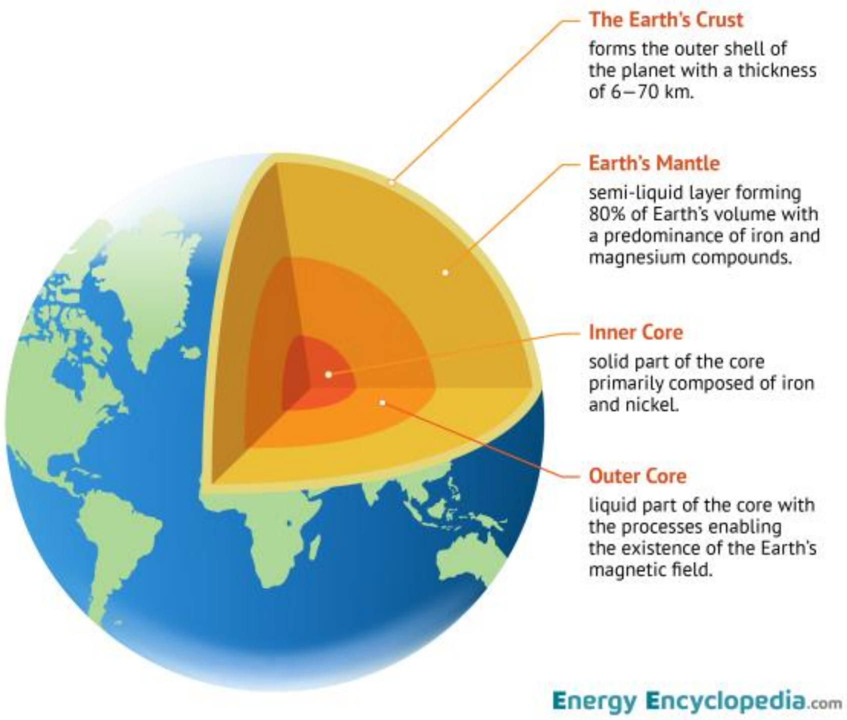
- Geothermal energy is derived from the Earth's internal heat. This heat originates from two primary sources:
- **Residual Heat** from Earth's Formation: When the Earth was formed, it was a molten mass, and some of that heat remains trapped within the planet. Over billions of years, this residual heat has been gradually radiating outward, providing a continuous source of geothermal energy.
- **Radioactive Decay:** The Earth's crust contains radioactive elements, such as uranium, thorium, and potassium. As these elements decay over time, they release heat in a process known as radioactive decay. This heat contributes significantly to the Earth's internal temperature.

- Together, these two sources generate the heat stored in the Earth's mantle and crust, which is accessed in geothermal energy systems. The heat rises to the surface through volcanic activity, hot springs, geysers, and tectonic activity, and can be harnessed for electricity generation, direct heating, and other uses.

- Seismic fractures make it easier for groundwater to flow



Source of image: EnergyEncyclopedia.com

https://www.energyencyclopedia.com/en/free-downloads/images/structure-of-the-earth-87

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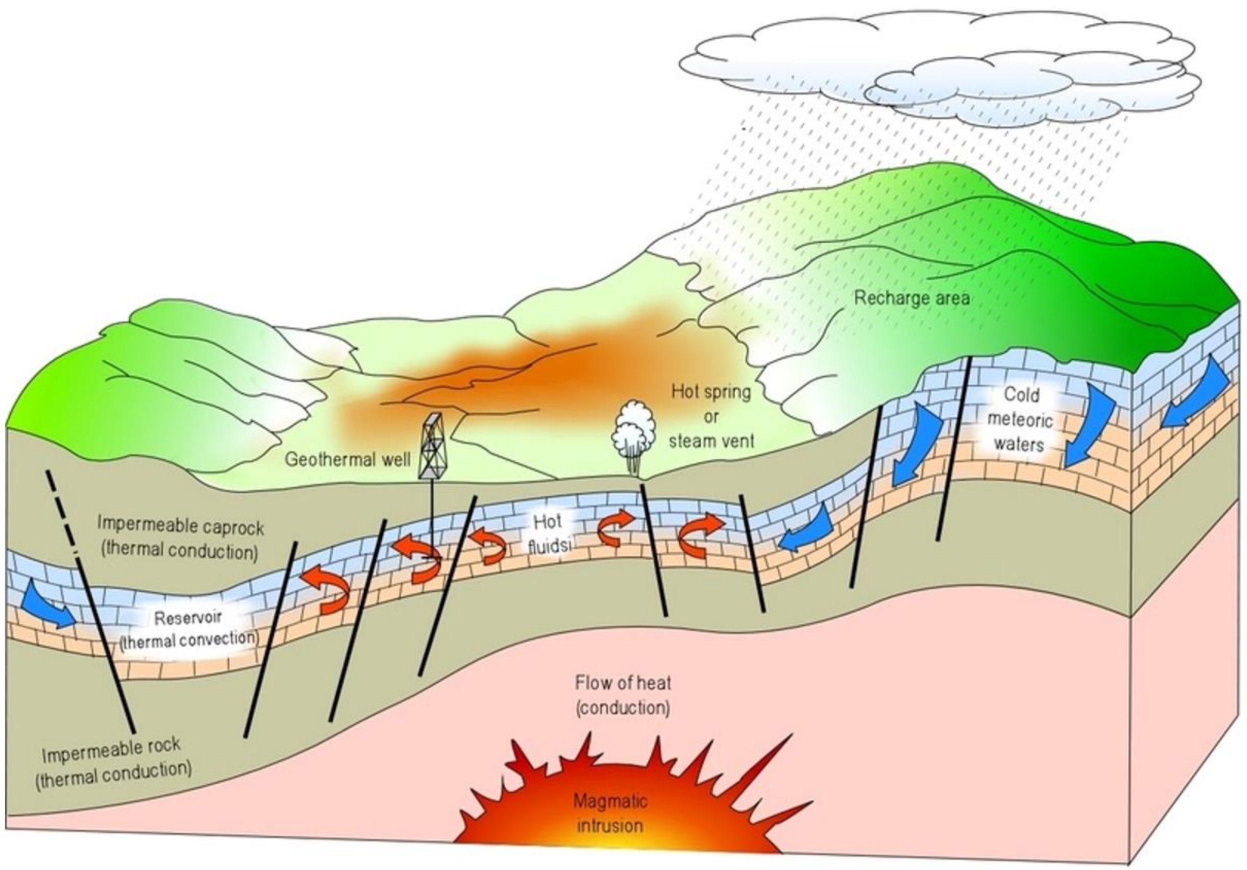
Convection by geothermal fluid?

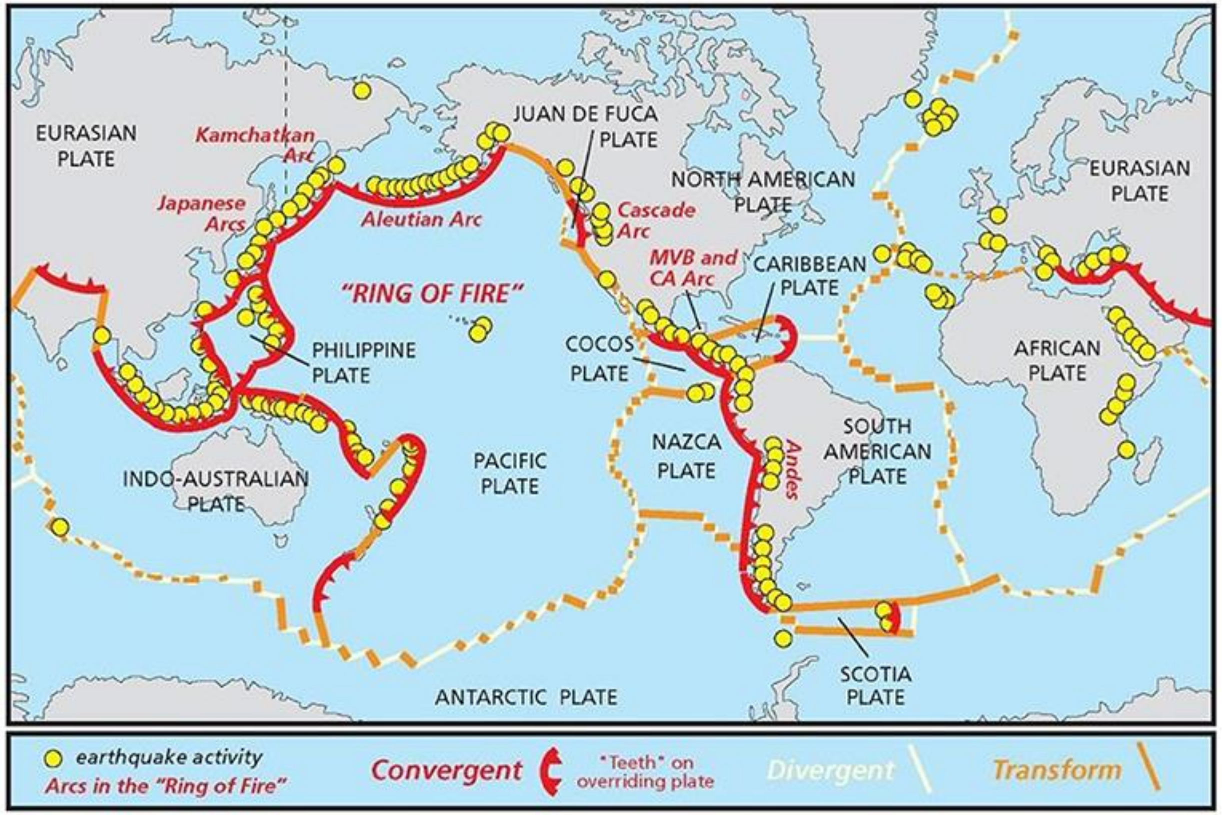


Picture is taken from opensource article:
Jie Zhu et all, 2022 **324**
Geothermal Resource Exploration in Magmatic Rock Areas Using a Comprehensive Geophysical Method **https://doi.org/10.1155/2022/5929**

https://onlinelibrary.wiley.com/doi/10.1155/2022/5929324

Location of the most prolific geothermal areas

- Geothermal energy is most abundant in regions with high tectonic activity, particularly along the Ring of Fire
- Countries like Iceland, New Zealand, and Indonesia are rich in geothermal resources due to frequent volcanic activity and tectonic plate movements. Iceland, for example, sits atop the Mid-Atlantic Ridge, making it a global leader in geothermal energy for electricity and heating.
- Other notable geothermal regions include the East African Rift, where countries like Kenya harness geothermal energy from the splitting African plate.
- California in the U.S. also has significant geothermal fields, especially in the Geysers region. Mexico, Italy, and Turkey also have substantial geothermal potential, contributing to their energy supply.



Picture source:
Plate Tectonics and Our National Parks (2020)
•Text and Illustrations by Robert J. Lillie, Emeritus Professor of Geosciences, Oregon State University [E-mail]
•Produced under a Cooperative Agreement for earth science education between the National Park Service's Geologic Resources Division and the American Geosciences Institute.

https://www.nps.gov/subjects/geology/plate-tectonics-the-unifying-theory-of-geology.htm#collapseCollapsible1581436791893

Types of geothermal resources

RESOURCE TYPE BASED ON TEMPERATURE	GEOGRAPHICAL AND GEOLOGICAL LOCATION	USE/TECHNOLOGY
High: >200°C	Globally around boundaries of tectonic plates, on hot spots and volcanic area	Power generation with conventional steam, flash, double flash, or dry steam technology
Medium: 150-200°C	Globally mainly in sedimentary geology or adjacent to high temperature resources	Power generation with binary power plants, e.g., ORC or Kalina technology
Low: <150°C	Exist in most countries (average temperature gradient of 30°C/km means that resources of about 150°C can be found at depths of about 5 km)	Direct uses (space and process heating, etc.) and, depending on location and power tariff offered, power generation with binary power plant

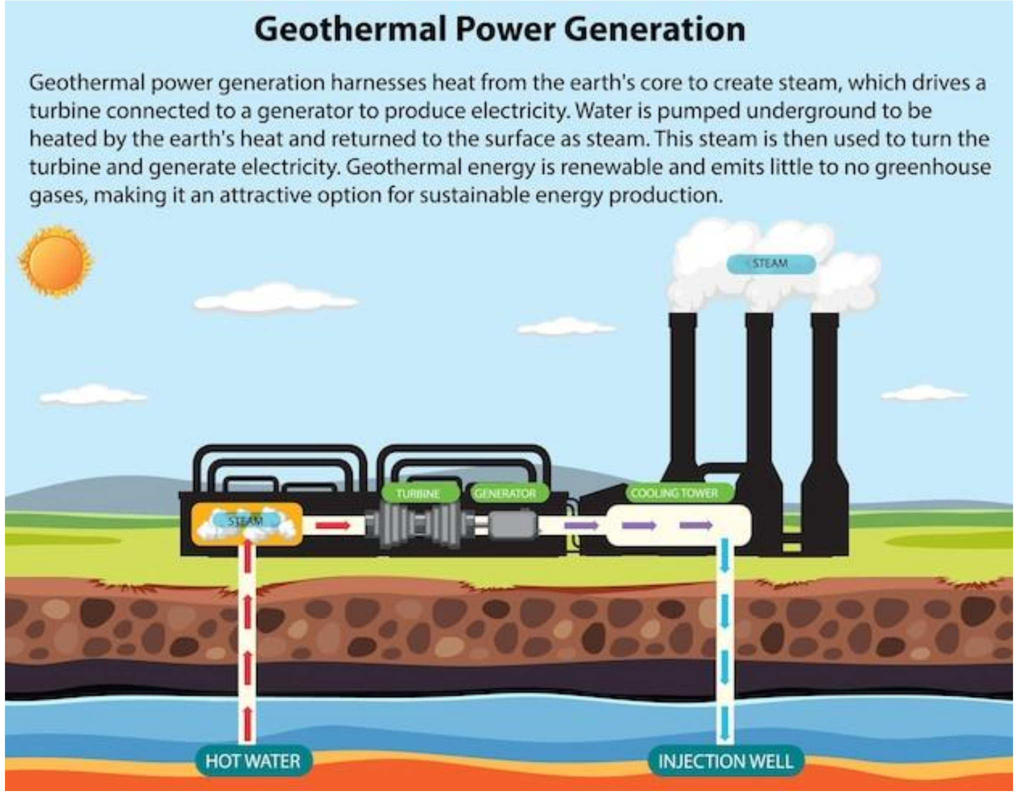
- Low and high temperature resource type is also called low- and high enthalpy systems

Use of geothermal for electrical generation

Geothermal power plant generates electricity by harnessing heat from deep within the Earth, typically from geothermal reservoirs (hot water or steam) found below the surface. This heat is used to produce steam, which drives a turbine connected to an electricity generator.

Geothermal plants require access to geothermal resources (hot water or steam) underground, meaning they are best suited for regions with geothermal activity (e.g., Iceland, California, New Zealand).

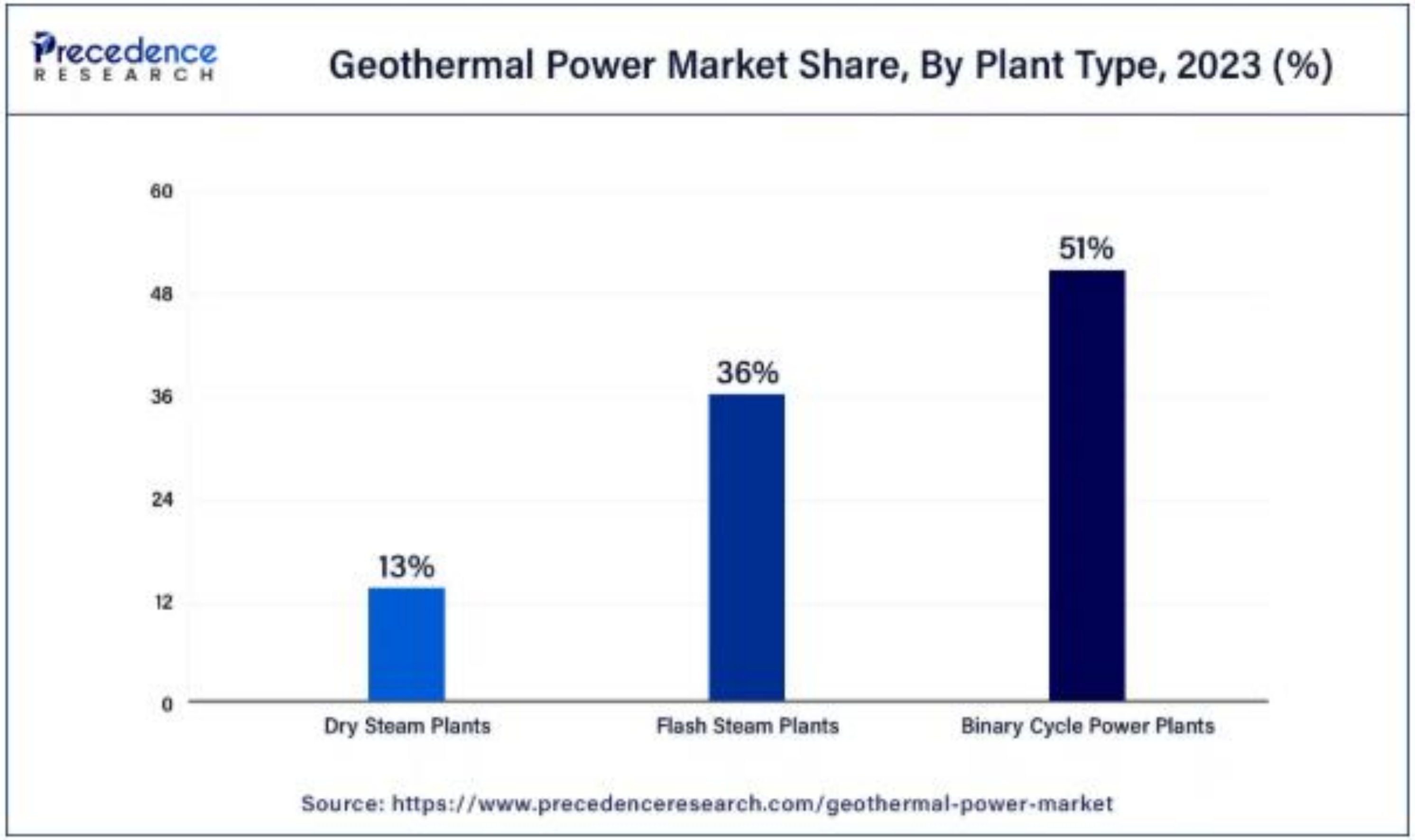
Low enthalpy geothermal are likely to be not profitable



Designed by Freepik
https://www.freepik.com/free-vector/geothermal-power-generation-infographic_39988674.htm#fromView=keyword&page=2&position=19&uuid=38eacf3d-e69e-4e7c-a9b7-c72da1ec9dbc&query=Geothermal+Power+Station

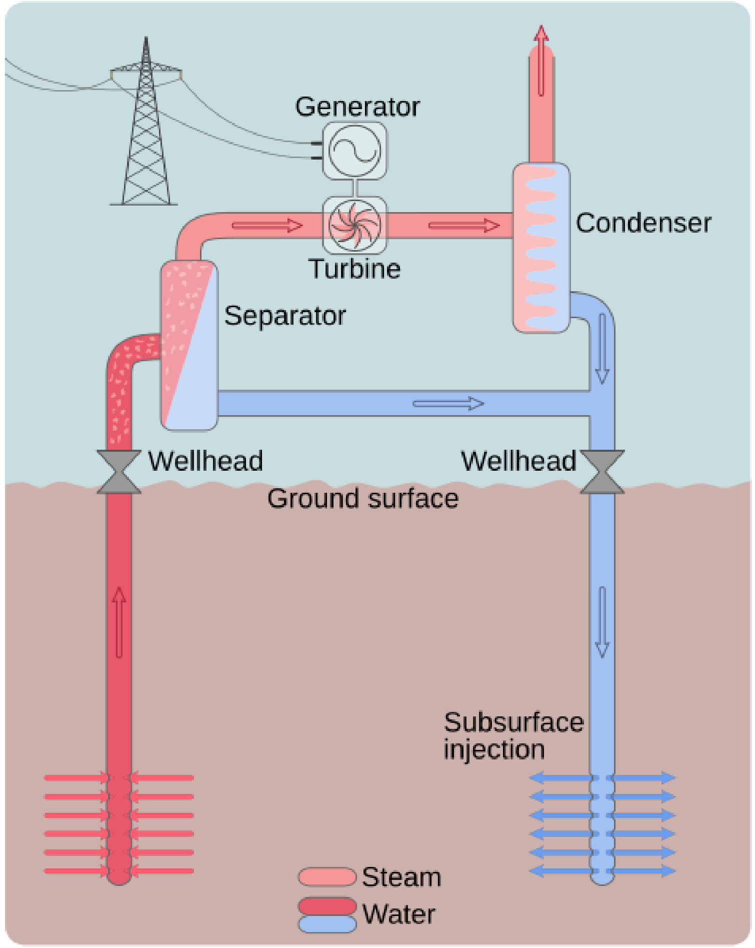
Types of geothermal by technology

- Dry Steam Plants:
- Flash Steam Plants:
- Binary Cycle Plants:



Types of geothermal by technology

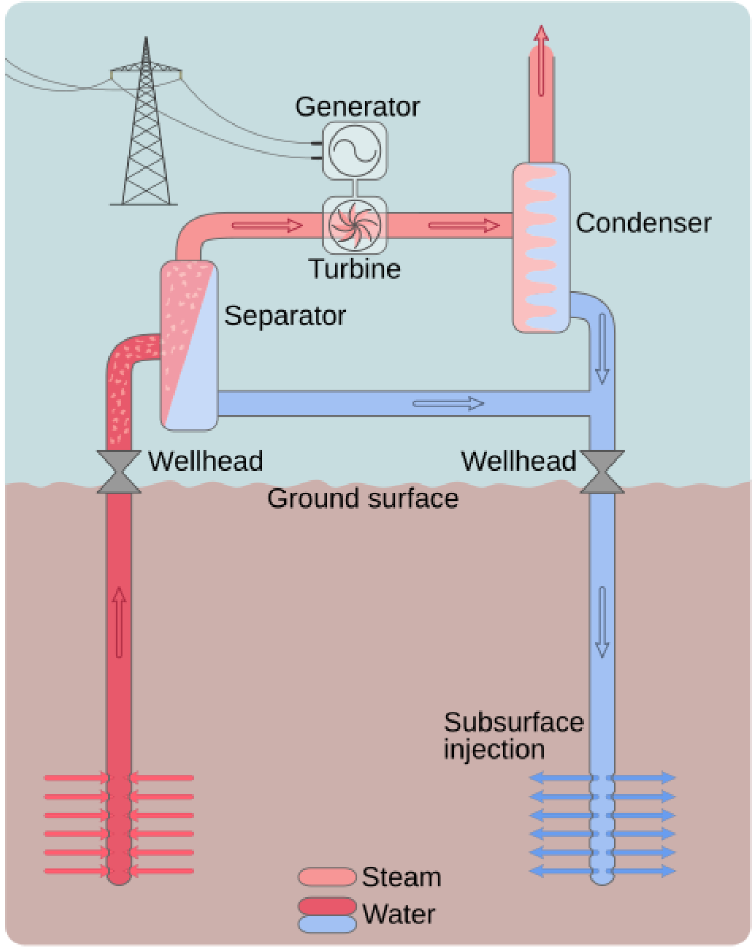
- **Dry Steam Plants**:
  - **Definition**: These plants use steam directly from the geothermal reservoir to drive the turbine.
  - **How it works**: The steam extracted from the Earth's crust is used to turn the generator directly, without the need for a secondary heat transfer fluid.
  - **Example**: The **Geysers** in California is the largest dry steam field in the world.



Source of image: https://en.wikipedia.org/wiki/File:Diagram_HotWaterGeothermal_inturperated_version.svg

Types of geothermal by technology

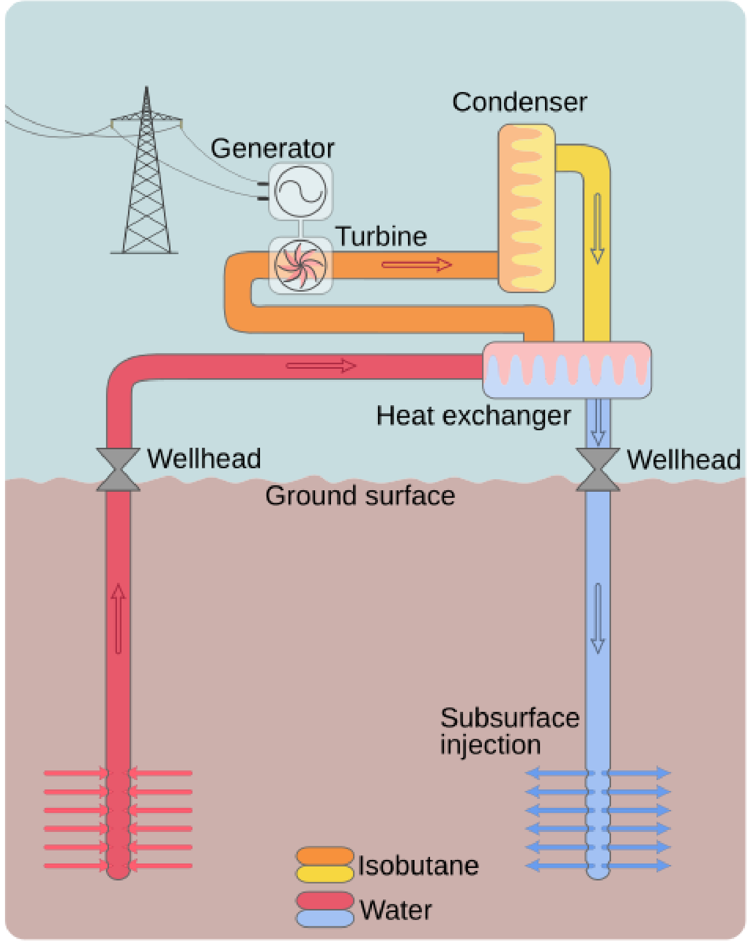
- **Flash Steam Plants**:
  - **Definition**: These plants use hot water from the geothermal reservoir that is under high pressure. When pressure is reduced (flashed), some of the water turns to steam, which is then used to generate electricity.
  - **How it works**: Hot water is extracted, and its pressure is quickly reduced, causing a portion of the water to flash into steam, which drives the turbine.
  - **Example**: Common in places like **New Zealand** and **Iceland**, where geothermal reservoirs are under high pressure.



Source of image: https://en.wikipedia.org/wiki/File:Diagram_HotWaterGeothermal_inturperated_version.svg

Types of geothermal by technology

- **Binary Cycle Plants**:
  - **Definition**: These plants transfer heat from geothermal water to a secondary fluid with a lower boiling point, which then vaporizes and drives the turbine.
  - **How it works**: The geothermal water never comes into direct contact with the turbine. Instead, it heats a secondary fluid in a heat exchanger, which is then vaporized to power the generator.
  - **Example**: Often used in areas with lower temperature geothermal resources, such as parts of **California** and **Turkey**.



Source of image: https://commons.wikimedia.org/wiki/File:Geothermal_Binary_System_(alt_version).svg

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Pros and Cons of geothermal technologies

Plant Type	Pros	Cons
Binary Cycle	- Works with low-temperature resources	- Lower power output compared to other types
	- Closed-loop system with low emissions	- More complex and expensive installation
	- Environmentally friendly with low emissions	- Secondary fluid maintenance required
Flash Steam	- More efficient than binary cycle with medium-temperature resources	- Requires higher temperature geothermal resources (above 350°F)
	- Widely used and established technology	- Risk of resource depletion without reinjection
	- Moderate to high power output	- Can release harmful gases, needing management
Dry Steam	- Highest efficiency and power output	- Limited to rare dry steam resources
	- Direct use of steam	- Higher environmental impact due to emissions
	- Reliable power generation	- High initial infrastructure and drilling costs

Pros and Cons of geothermal power

ADVANTAGE	DOWNSIDE/CHALLENGE
Globally inexhaustible (renewable)	Resource depletion can happen at individual reservoir level
Low/negligible emission of CO_2 and local air pollutants	Hydrogen sulfide (H_2S) and even CO_2 content is high in some reservoirs
Low requirement for land	Land or right-of-way issues may arise for access roads and transmission lines
No exposure to fuel price volatility or need to import fuel	Geothermal "fuel" is non-tradable and location-constrained
Stable base-load energy (no intermittency)	Limited ability of geothermal plant to follow load/respond to demand
Relatively low cost per kWh	High resource risk, high investment cost, and long project development cycle
Proven/mature technology	Geothermal steam fields require sophisticated maintenance
Scalable to utility size without taking up much land/space	Extensive drillings are required for a large geothermal plant

Source | *Authors.*

There is some (increasing) ability to respond to demand

Geothermal power vs other power sources

Criteria	Geothermal	Natural Gas	Wind	Solar
Energy Source	Renewable, continuous	Fossil, non-renewable	Renewable, intermittent	Renewable, intermittent
Environmental Impact	Low emissions	High emissions	Low emissions	Low emissions
Reliability	24/7, stable, baseload	Dispatchable, on-demand	Intermittent, weather-dependent	Intermittent, weather-dependent
Cost of Generation	High initial, low operating	Moderate initial, variable operating	Moderate initial, low operating	Moderate initial, low operating
Capacity Factor	High (70-90%)	Moderate to high	Variable (20-40%)	Variable (15-25%)
Scalability	Limited by location	Highly scalable	Scalable with land and wind	Highly scalable

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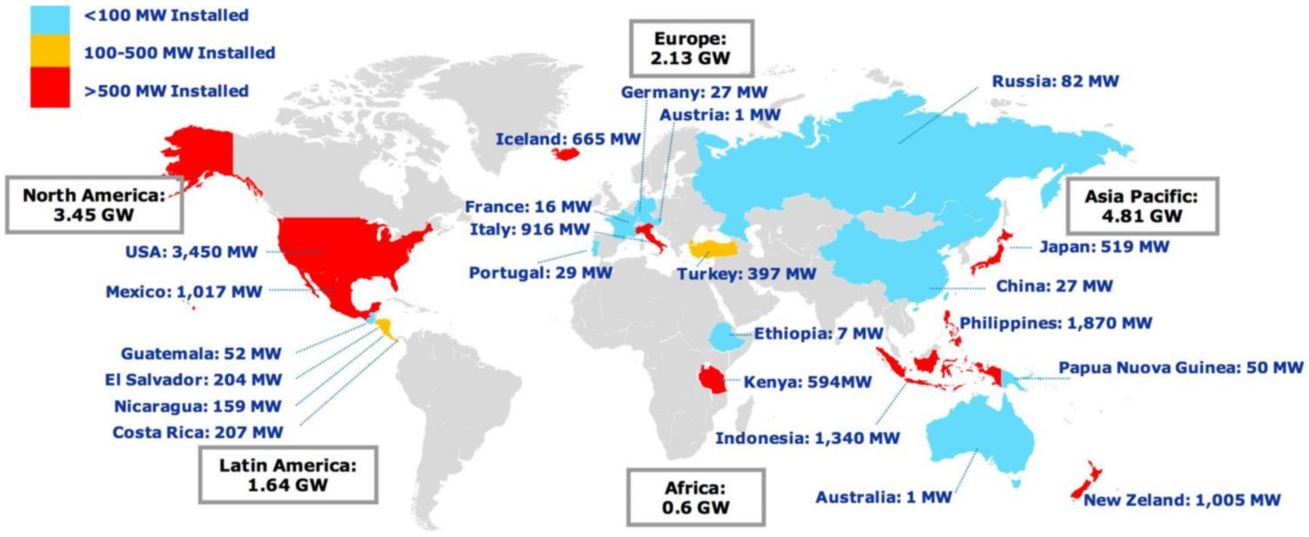
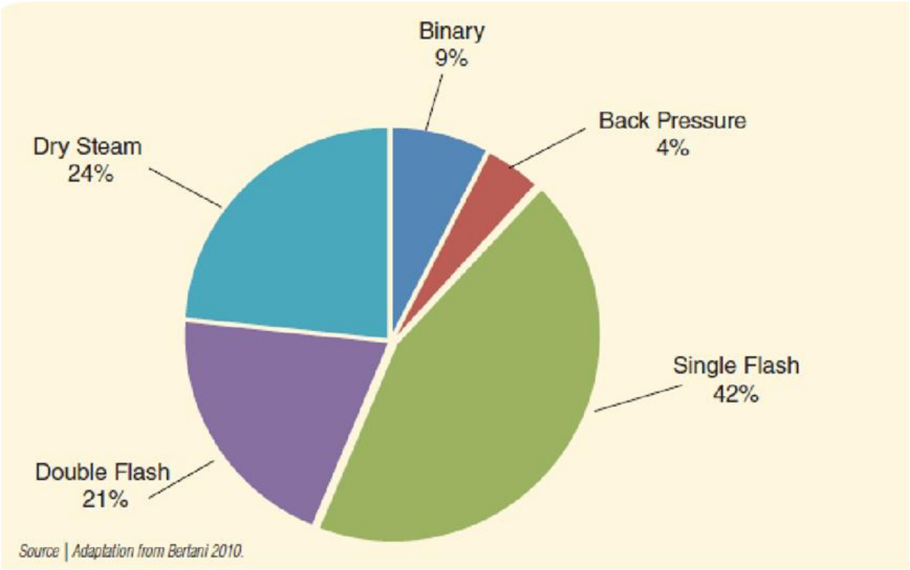
Use: Power generation by location and technology

World's installed capacity.

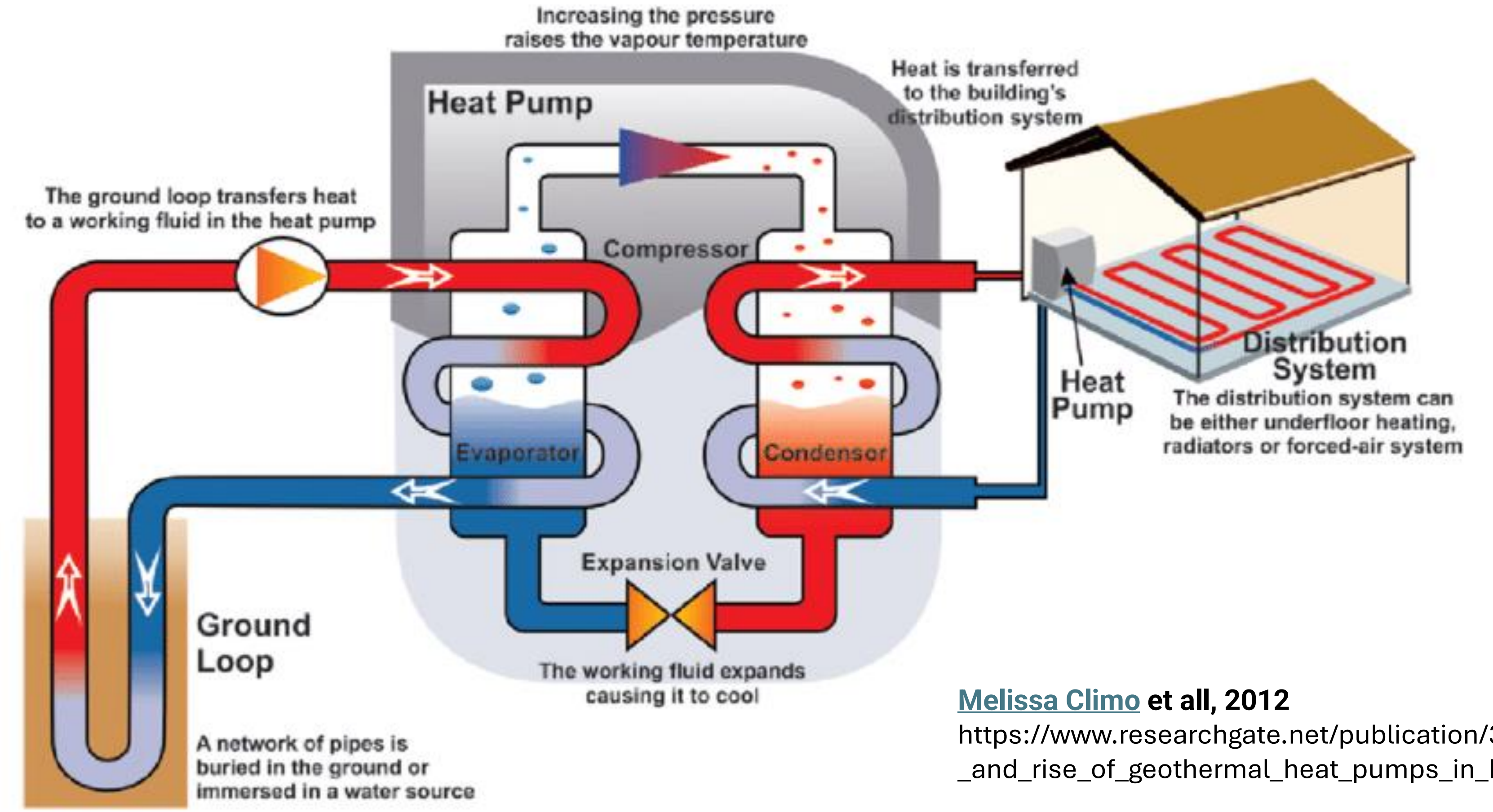




- https://geothermalresourcescouncil.blogspot.com/2016/01/global-outlook-for-geothermal-industry.html

Document Library/FINAL_Geothermal%20Handbook_TR002-12_Reduced.pdf

How geothermal energy is used for heating & cooling. Heat pump schematic



Melissa Climo et all, 2012
https://www.researchgate.net/publication/316919670_The_rise_and_rise_of_geothermal_heat_pumps_in_New_Zealand

How geothermal energy is used for heating & cooling Heat pump schematic

How Geothermal Heat Pump Works

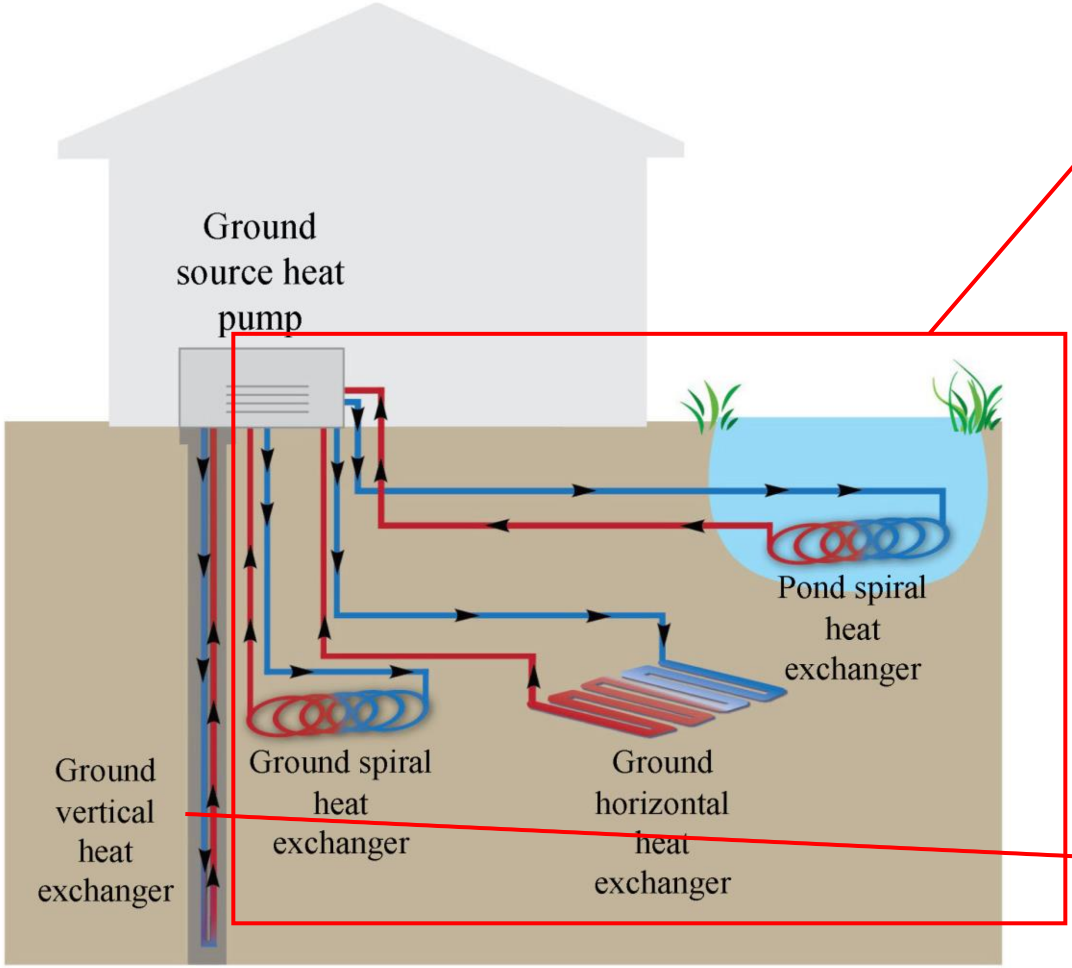
•**Winter Operation (Heating Mode):**

- The system pumps a fluid through the underground loops, where the temperature of the ground is warmer than the outdoor air in winter.
- The heat transfer fluid absorbs this geothermal heat as it passes through the pipes.
- The heat pump extracts the thermal energy from the fluid and compresses it, raising the temperature further.
- This warm air is then distributed into the building through ducts or radiant systems to heat the indoor space.

•**Summer Operation (Cooling Mode):**

- In summer, the process reverses. The heat pump moves heat from the indoor air into the cooler ground through the underground loops.
- The heat transfer fluid absorbs the heat from the building and carries it underground, where it is released into the cooler soil or water.
- The now-cool fluid is circulated back into the building, lowering indoor temperatures.
- The system provides cooling by transferring heat from the indoor air to the ground, which remains at a stable and cooler temperature year-round.

How geothermal energy is used for heating & cooling
Heat pump schematic



Shallow geothermal (house heating)

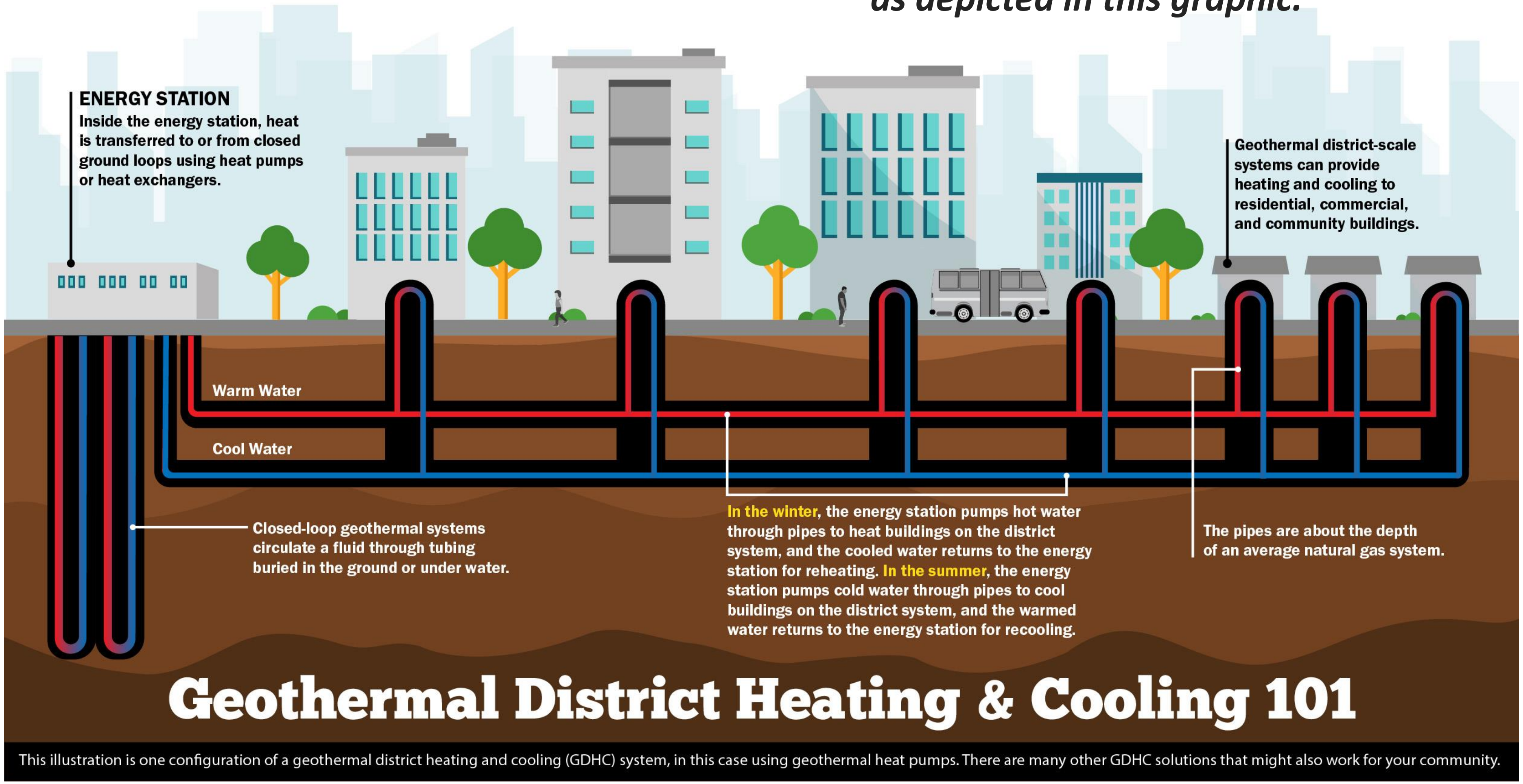
Deep geothermal well

University UPG Piolesti campus: Georegisters for extraction of ground heat. Innovation Norway Grants

Source of image: https://basc.pnnl.gov/resource-guides/ground-source-heat-pumps

Geothermal plant district heating

Geothermal heat pumps can be scaled up to meet an entire community's heating and cooling needs on a single network, as depicted in this graphic.



Source of image: https://www.energy.gov/eere/geothermal/geothermal-district-heating-cooling

Geothermal plant district heating. Example. Energy station Romania Beius

Source of image
https://www.energy.gov/eere/geothermal/geothermal-district-heating-cooling

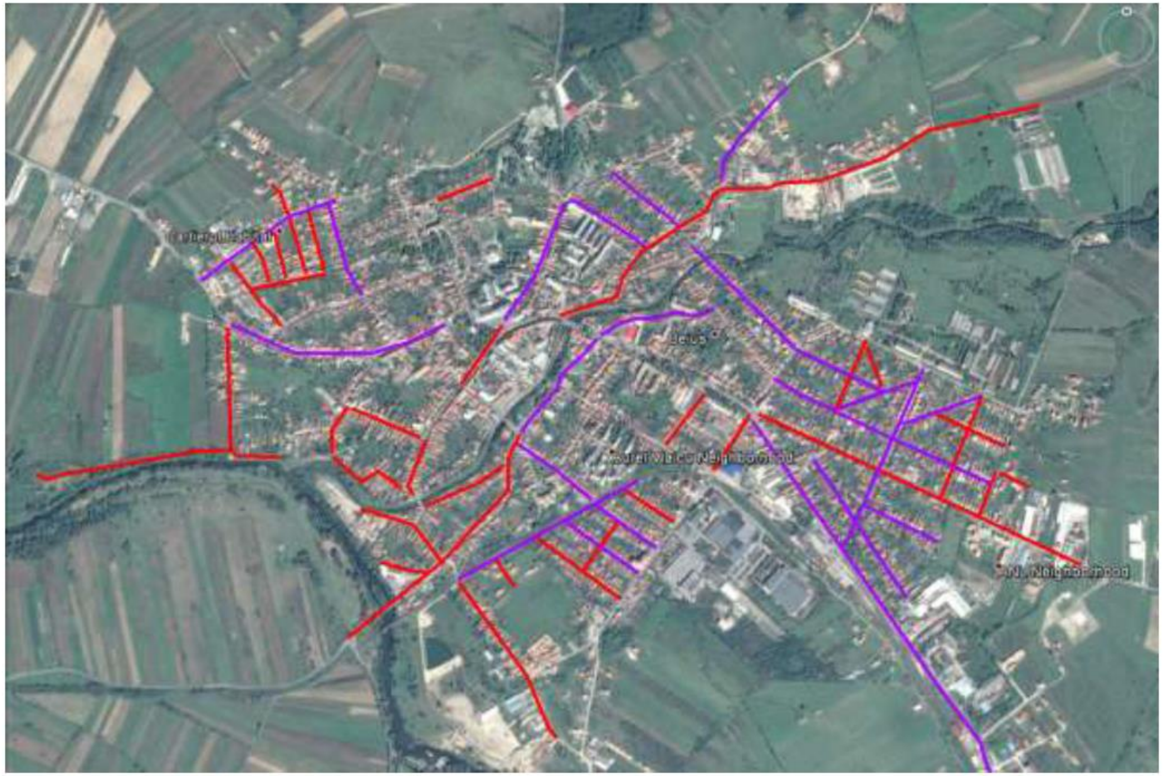
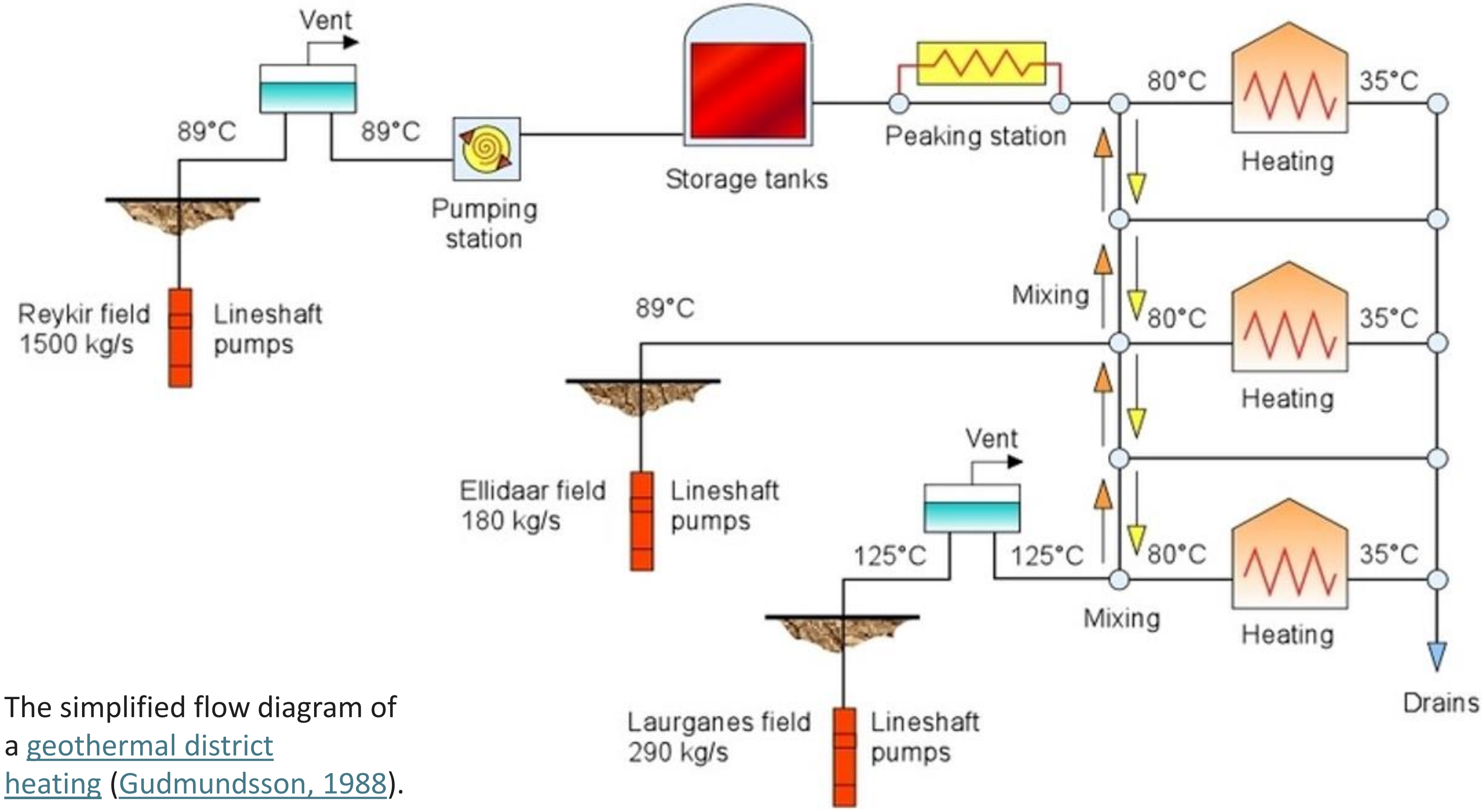


Figure 14.: *Layout of the current district heating system*

Source of image
TRANSGEX SA

Geothermal plant district heating



The simplified flow diagram of a geothermal district heating (Gudmundsson, 1988).

Geothermal heat pumps can be scaled up to meet an entire community's heating and cooling needs on a single network, as depicted in this graphic.
Here is example of heating from multiple fields

Use of geothermal for Hot Water Supply

Types of Geothermal Baths

- Natural Hot Springs: Often found in volcanic regions, these springs are a direct result of geothermal heat rising to the Earth's surface.
- Artificial Geothermal Pools: Created by drilling into the geothermal reservoirs to access hot water, which is then piped into specially designed spa pools.
- Thermal Spas: These spas are powered by geothermal water or heat, providing a variety of treatments such as hot tubs, steam rooms, and therapeutic baths.

Geothermal Spa Operations

- Hot Spring Extraction: In geothermal spas, water is drawn from deep underground reservoirs or from surface hot springs.
- Water Recycling: Many spas incorporate water recycling techniques, where the geothermal water is used multiple times before being cooled and released or reinjected into the ground.
- Energy Efficiency: Geothermal spas are energy-efficient because they utilize the Earth's natural heat, minimizing energy costs for heating water.

Source of image
https://www.theguardian.com/world/2023/nov/09/iceland-blue-lagoon-geothermal-resort-closes-seismic-storm-volcanic-eruption-fears

Geothermal energy efficiency

- High Capacity Factor: Geothermal power plants generally operate at a high capacity factor (around 70-90%), meaning they can produce electricity consistently and reliably, unlike intermittent sources like solar or wind.
- Thermal Efficiency: Geothermal plants typically have a thermal efficiency of 10-20%. This is the percentage of thermal energy from the Earth that is converted into usable electricity. While this is lower compared to some other forms of energy, the continuous and predictable nature of geothermal energy compensates for this.

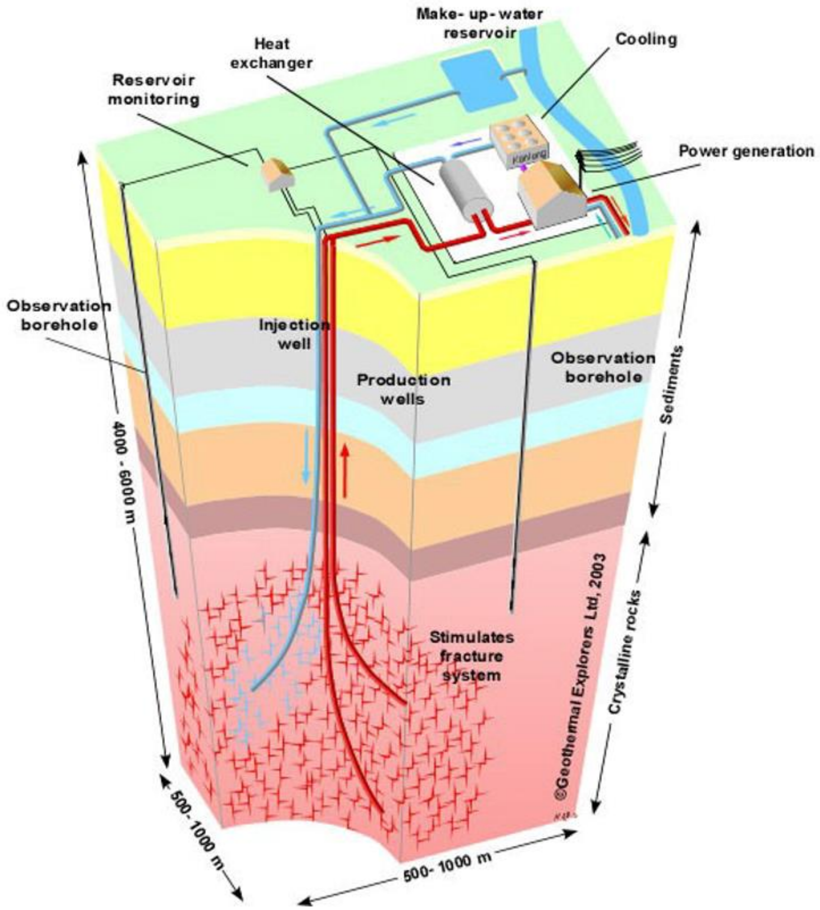
Geothermal projects enhancement technologies

Enhanced Geothermal Systems (EGS)

•**Definition**: EGS involves creating artificial geothermal reservoirs in areas without natural hydrothermal resources by injecting water into hot dry rocks.

•**Goal**: Expands geothermal energy potential to regions where traditional geothermal systems are not naturally present.

•**Process**: Water is injected into deep wells, fractures are created in the rock, and the heated water is then pumped back to the surface to generate electricity.

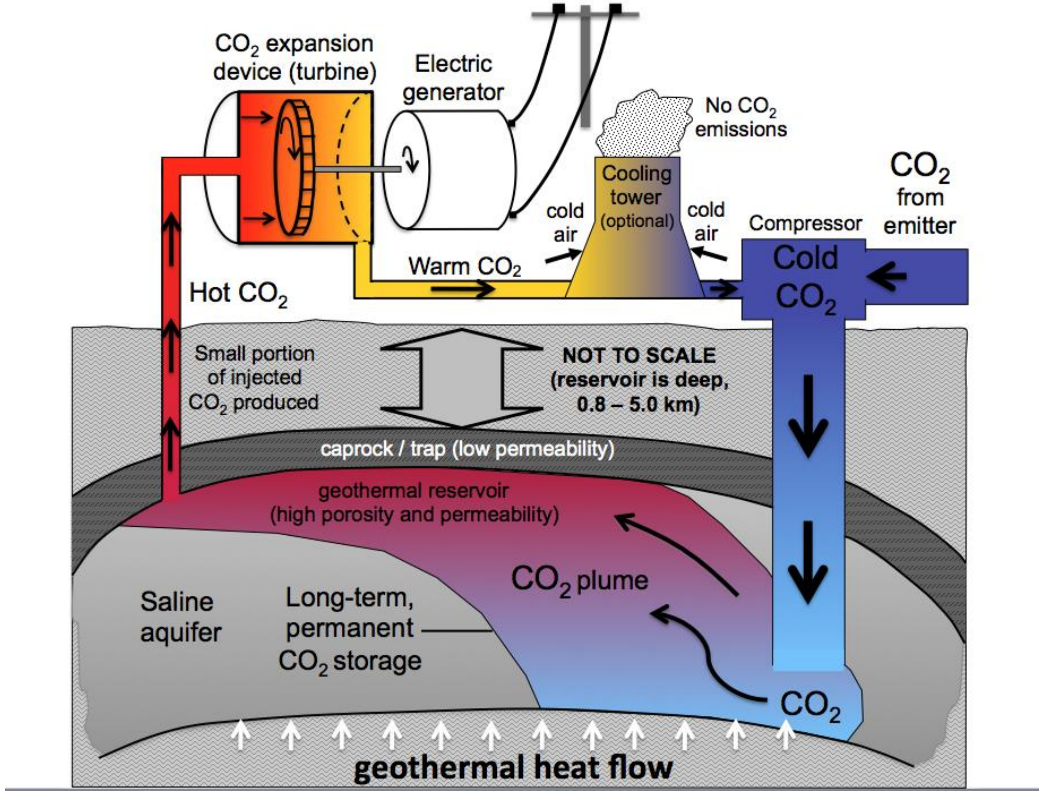


Geothermal Explorer LTD 2005

Geothermal projects enhancement technologies

CO_2-Based Enhanced Geothermal Systems

- **Definition**: Utilizes **supercritical CO_2** instead of water to enhance heat extraction from geothermal reservoirs.
- **Goal**: Improve heat transfer efficiency and reduce environmental impacts, as CO_2 can be injected back into the Earth, potentially contributing to carbon sequestration.
- **Benefit**: Increases geothermal energy production and allows for the integration of geothermal energy with carbon capture initiatives.



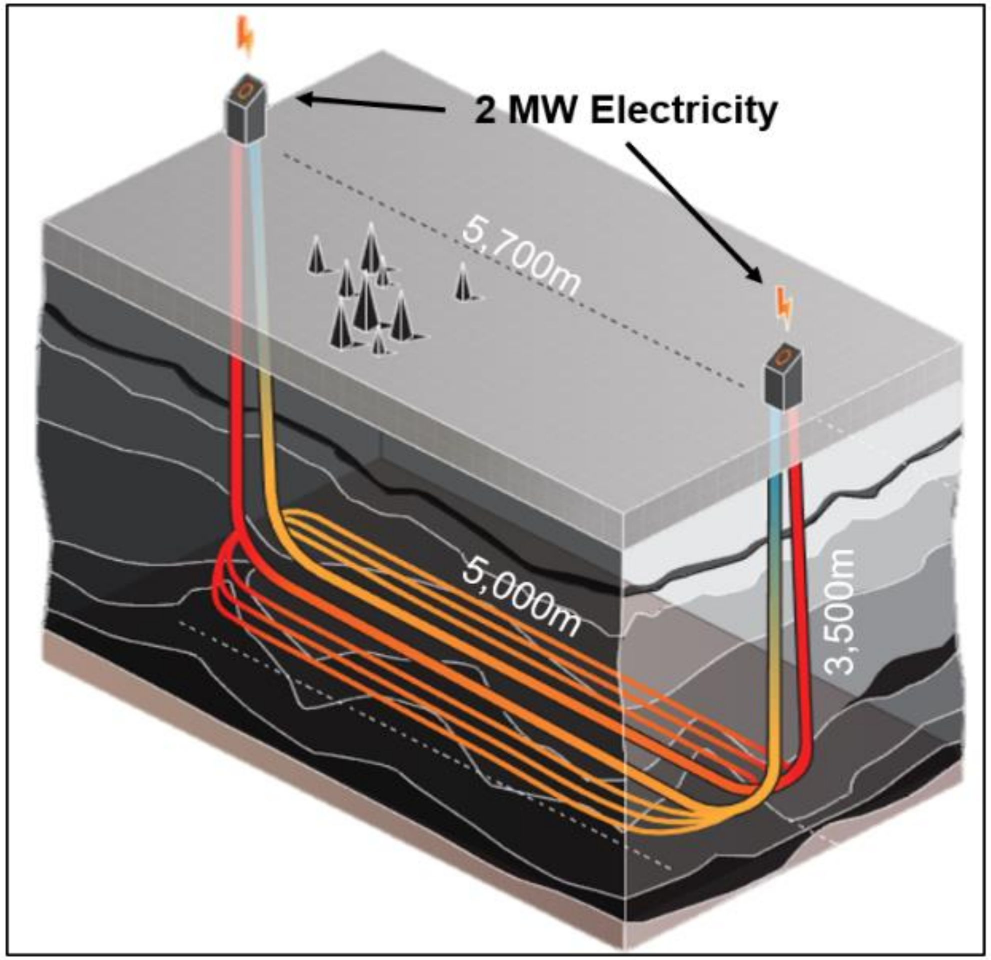
Source of image
https://www.thinkgeoenergy.com/university-spin-off-plans-on-using-co2-for-the-extraction-of-geothermal-heat/

Geothermal projects enhancement technologies

Closed-loop systems

•**Definition**: Technology Eavor-LoopTM, consists of large U-tube shaped wells at depths of around 3 km, with several km of multilateral horizontal wellbores. Two drilling rigs are operated simultaneously from both sites and intersect the multilateral wellbores at depth. Water is circulated in the inlet well, through the parallel wellbores to extract heat by conductive heat transfer with the rock. The water then rises up the outlet wellbore at a higher temperature. The density and temperature difference between the inlet well and outlet well create a thermosiphon which drives the flow, without any pumping power.

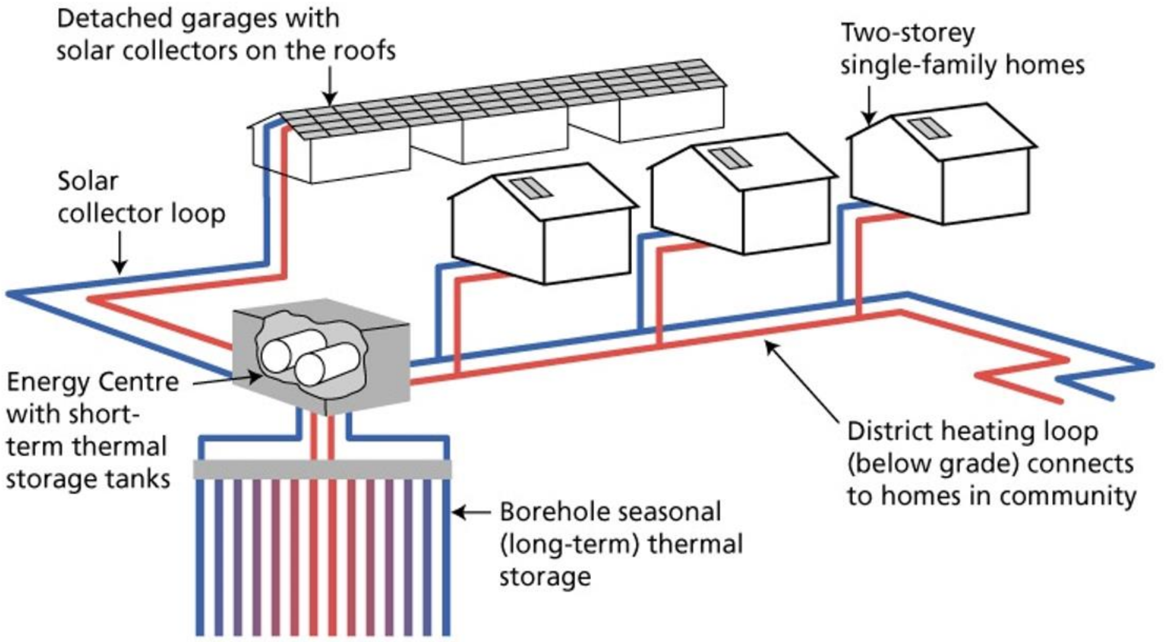
•**Benefit**: With the use of conduction, Eavor does not require a permeable reservoir to produce fluids, like traditional geothermal. Their main requirement for a reservoir is heat.



[Picture: The conceptual model of a closed-loop heat exchange through connecting wells in hot rock settings to extract the heat, here the concept of the pilot project by Eavor Technologies, Inc. From Canada – picture source: Eavor Technologies]

Geothermal projects enhancement technologies

- **Geothermal Energy Storage**
- **Technology Focus**: Integrating **thermal energy storage** (TES) with geothermal power systems to store excess thermal energy for later use.
- **Goal**: Address intermittency issues by storing energy generated during peak production and releasing it when demand is higher or when generation is low.
- **Benefit**: Improves grid stability and allows geothermal to contribute to balancing renewable energy sources like solar and wind.



http://www.dlsc.ca/index.htm

Gudrun Saevarsdottir, ET1

Thermal energy storage

Heat might be produced at a steady "baseline" power, for example by Waste To Energy Plant. Thermal Power for district heating demand is variable, following season.

Geothermal has a limited ability to respond to demand

Distribution also needs for short or long period storage.

Two Types of thermal storage:

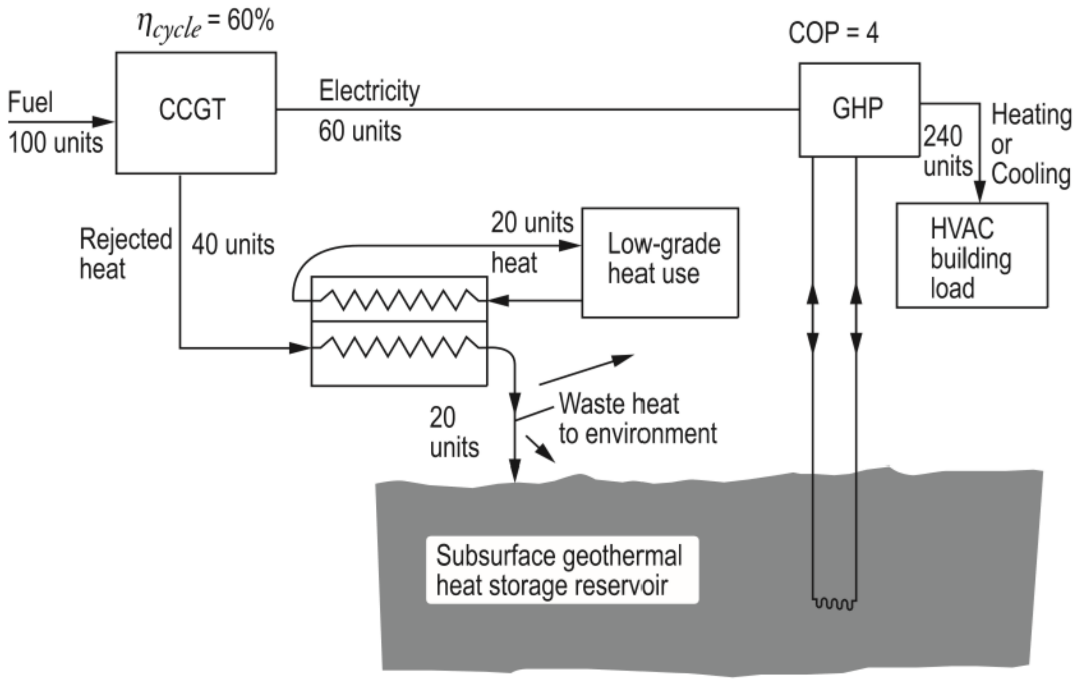
-Associated with temperature change

AE = mcAT

-Latent energy:

Associated with phase change. T = constant
molten salts, salt hydration

.



Source:Reykjavic Univesity

Geothermal projects enhancement technologies

- **Co-Production of Geothermal and Other Resources**
- **Definition**: Simultaneously extract geothermal energy and other resources, such as **lithium**, **minerals**, or **freshwater** from geothermal brines.
- **Goal**: Maximize resource extraction, improve the economics of geothermal projects, and help meet demand for critical materials (e.g., lithium for batteries).
- **Benefit**: Diversifies revenue streams and enhances the sustainability of geothermal operations.

https://www.linkedin.com/pulse/geothermal-gas-harnessing-earths-heat-power-oil-future-malvin-delgado-csemf/?trackingId=y6OJ%2F2uuQwCnlODH9ZlJaw%3D%3D

Exploring of possibilities to use geothermal for energy consuming oil&gas operation

Case Studies

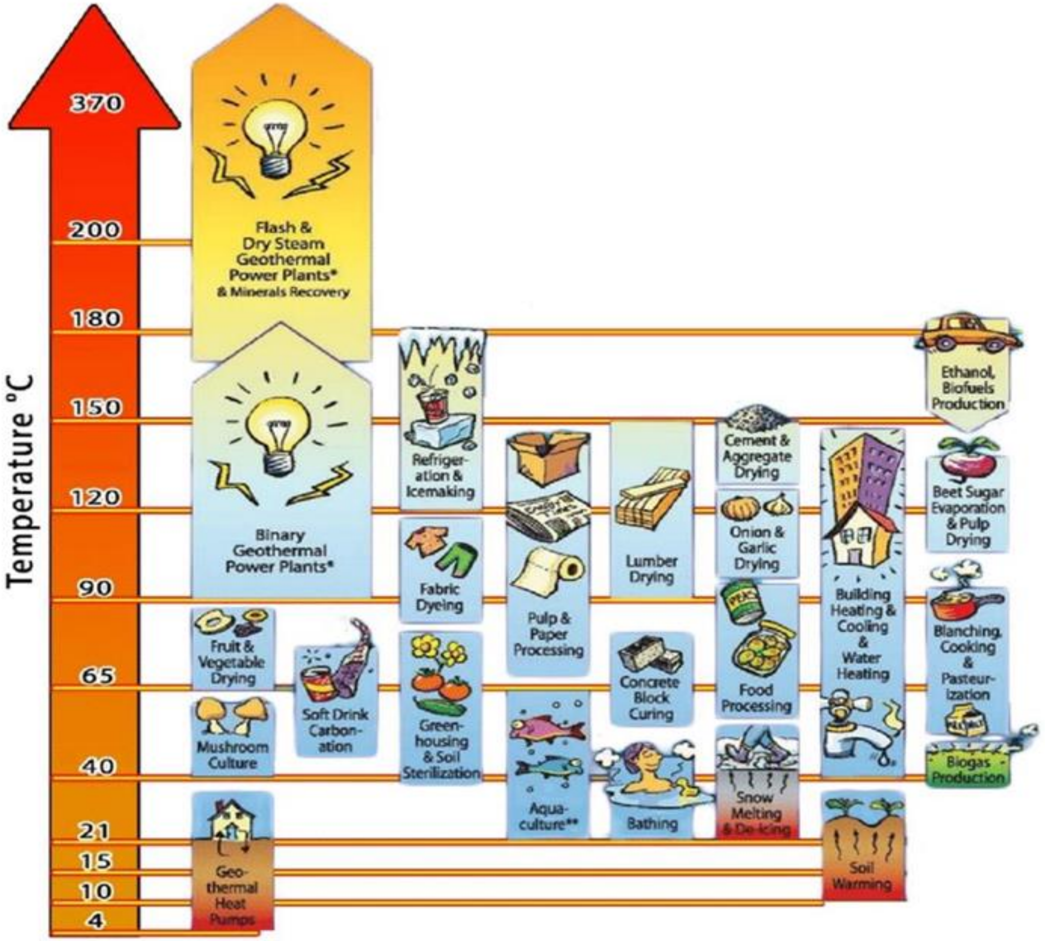
Several successful projects demonstrate the potential of geothermal energy in oil and gas operations:

- **Chevron's California Geothermal EOR**: Chevron has been a leader in integrating geothermal energy into its oil and gas operations. At its Kern River oil field in California, Chevron uses geothermal energy to generate steam for enhanced oil recovery. The project has improved oil recovery rates while significantly reducing emissions and energy costs.
- **ExxonMobil's Pilot Geothermal Project (USA)**: ExxonMobil has launched a pilot project to explore the use of geothermal energy in its operations in the U.S. The project involves using geothermal heat to power drilling rigs and provide steam for EOR, with early results indicating significant operational savings and sustainability improvements.
- **Pertamina's Geothermal and Oil Integration (Indonesia)**: Pertamina, Indonesia's state-owned oil and gas company, has successfully integrated geothermal energy into its operations. In Indonesia, where geothermal potential is high, Pertamina uses geothermal energy for both power generation and enhanced oil recovery, reducing its reliance on fossil fuels and lowering emissions.

Geothermal projects enhancement technologies. Cascade system

Multipe use: Electricity to Agriculture to District heating to Tourism

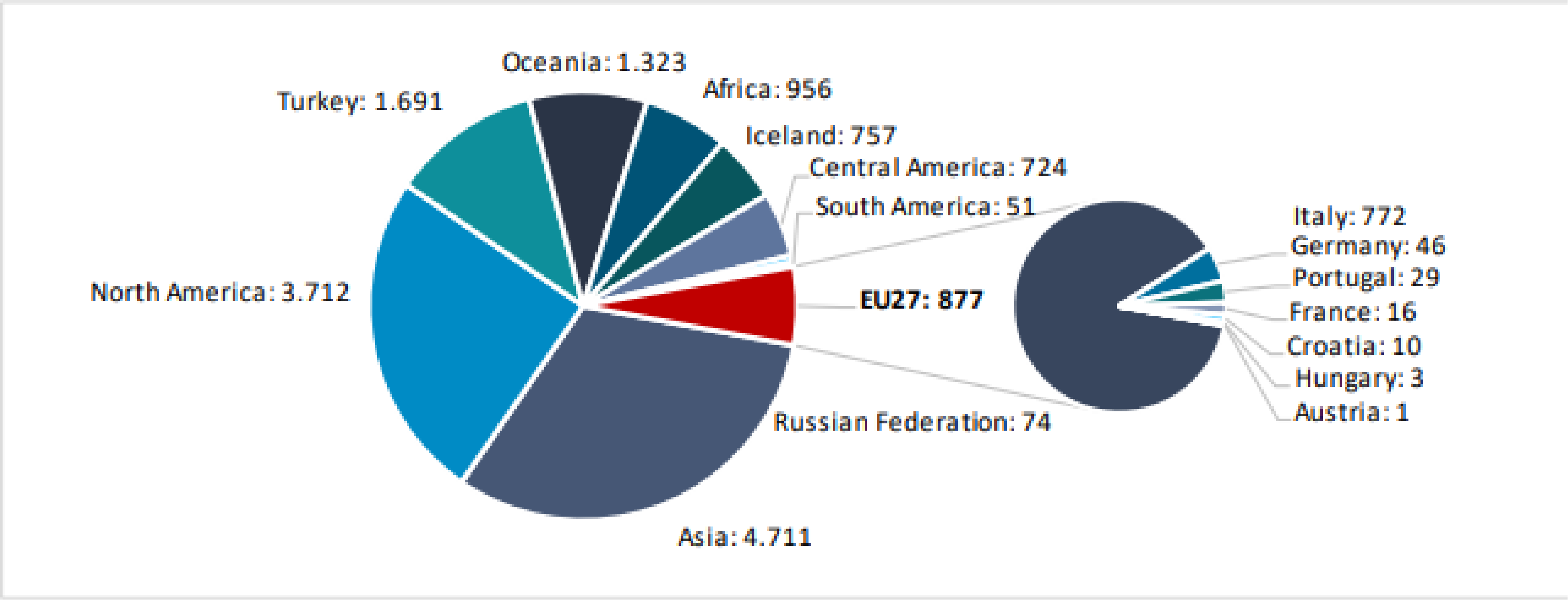
- Costs recouped across multiple revenue streams
- Strengthens business case of geothermal
- Community oriented.



Sorce of image
Geotropy
https://geotropy.is/why-geothermal

Geothermal market. Status

Figure 1: Global geothermal installed and connected capacity in 2022 (MW)



Source: Author's own elaboration, based on: Renewable Capacity Statistics 2023, IRENA, 2023; Eurostat [nrg_inf_epcrw].

Geothermal market. Development Europe. Power

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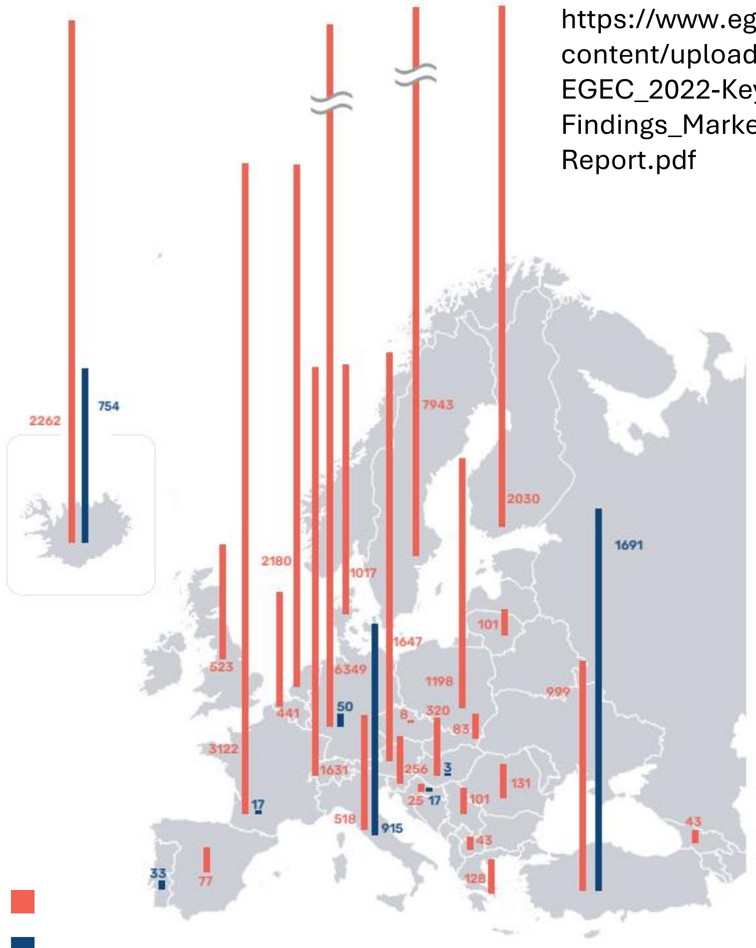
According to https://www.egec.org/ report

- As of 2023, Europe boasts an installed capacity of over 3.5 GWe in geothermal electricity, distributed among 143 operational plants. These facilities collectively generate approximately 20 TWh/year, with the EU specifically contributing about 7 TWh/ year.
- Despite its potential, regulatory uncertainties pose a substantial challenge. While EU legislation acknowledges geothermal energy as eligible for public funding, concrete implementation has been delayed, particularly impacting countries like Turkey and Italy, where reforms to financial incentives and awaited subsidy schemes (FER 2) have slowed progress.
- The COVID-19 pandemic further complicated matters by causing delays in permitting processes and disrupting supply chains crucial for geothermal projects. Concurrently, the political situation negatively impact equipment availability and inflation, thereby straining project financing efforts.



GEOTHERMAL FOR HEATING AND COOLING (MWTH)
ELECTRICITY (MWe)

https://www.egec.org/wp-content/uploads/2024/07/EGEC_2022-Key-Findings_Market-Report.pdf

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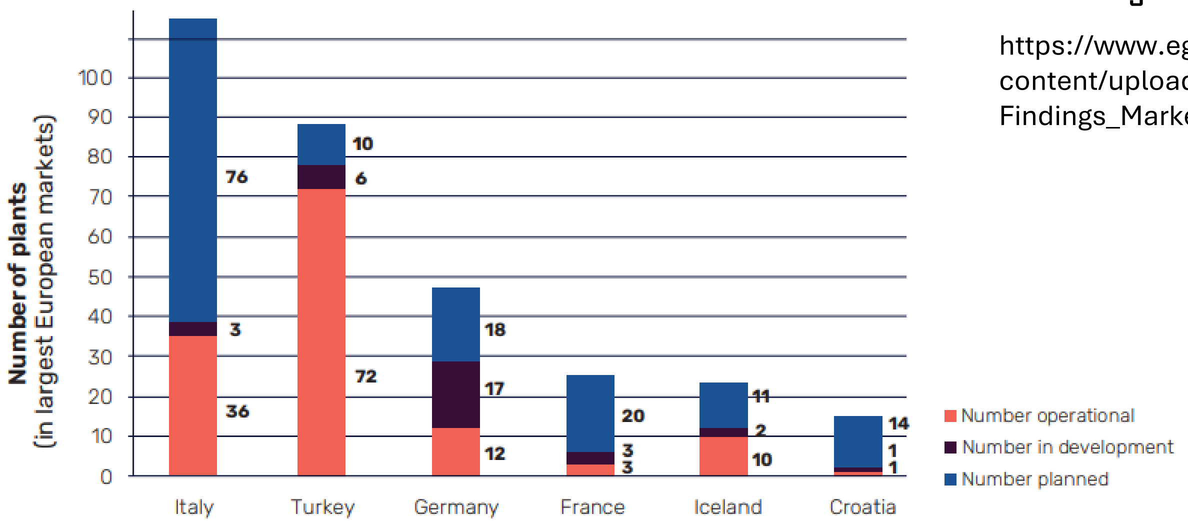
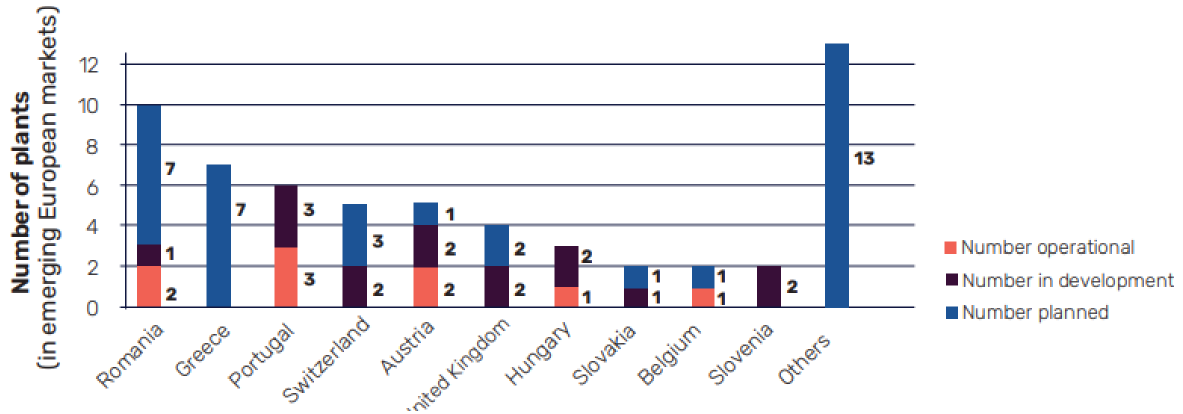
Geothermal market. Development Europe. Power

According to https://www.egec.org/ report

https://www.egec.org/wp-content/uploads/2024/07/EGEC_2022-Key-Findings_Market-Report.pdf

Number of geothermal power plants: installed, planned and under investigation





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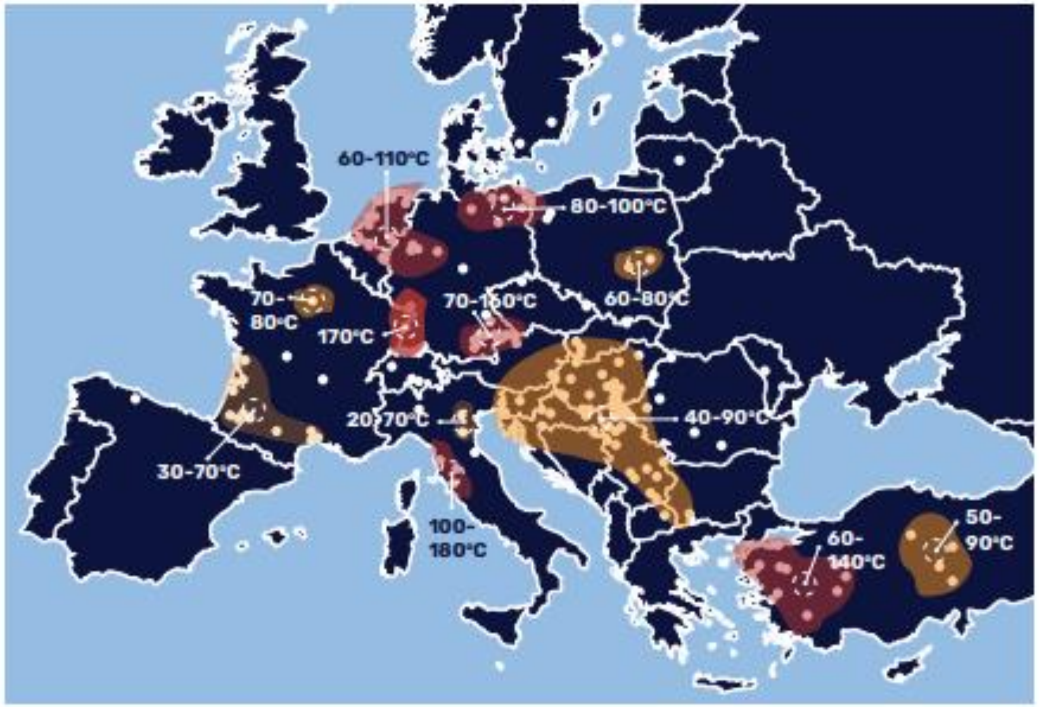
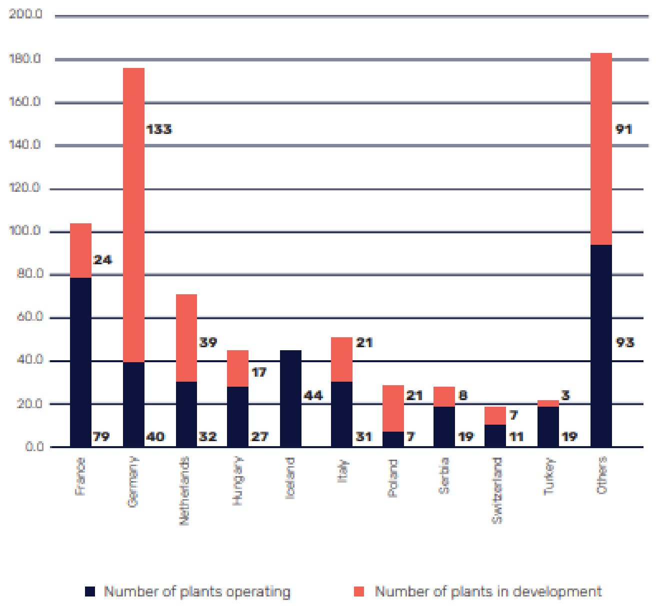
Geothermal market. Development Europe. Heating

Mapping of main geothermal district heating and cooling reservoirs with existing systems and temperature



Number of geothermal district heating ahd cooling operating and in development (largest and emerging European markets)

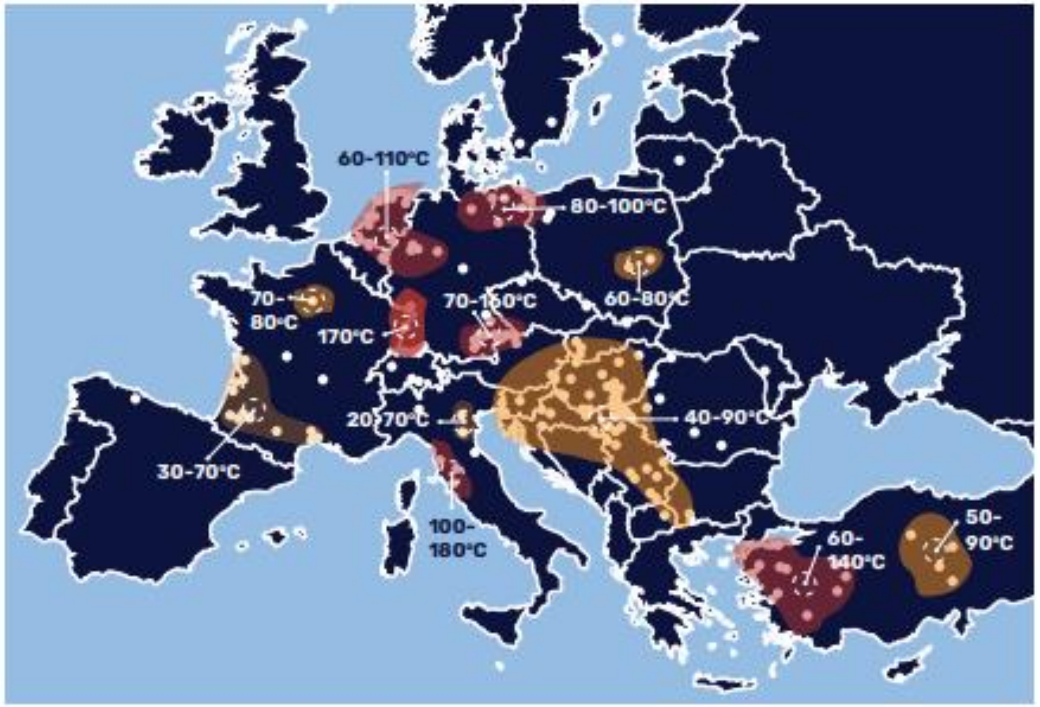


https://www.egec.org/ report

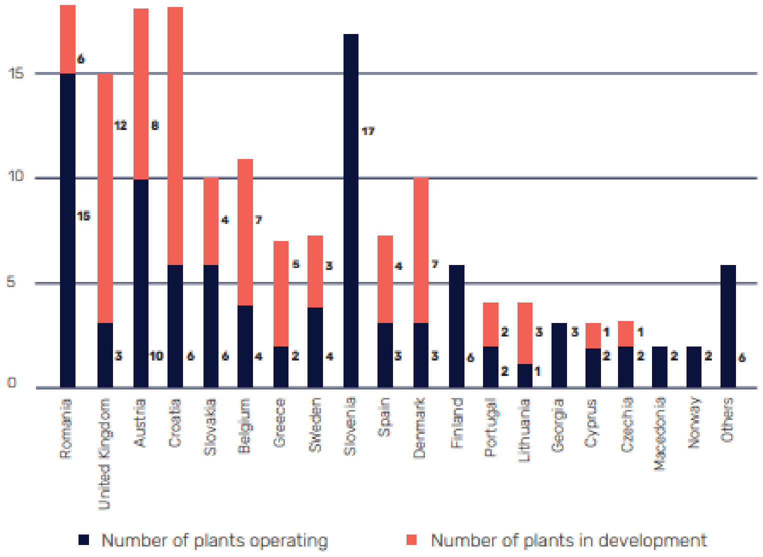
https://www.egec.org/wp-content/uploads/2024/07/EGEC_2022-Key-Findings_Market-Report.pdf

Geothermal market. Development Europe. Heating

Mapping of main geothermal district heating and cooling reservoirs with existing systems and temperature



Number of emerging geothermal district heating ahd cooling operating and in development (largest and emerging European markets)



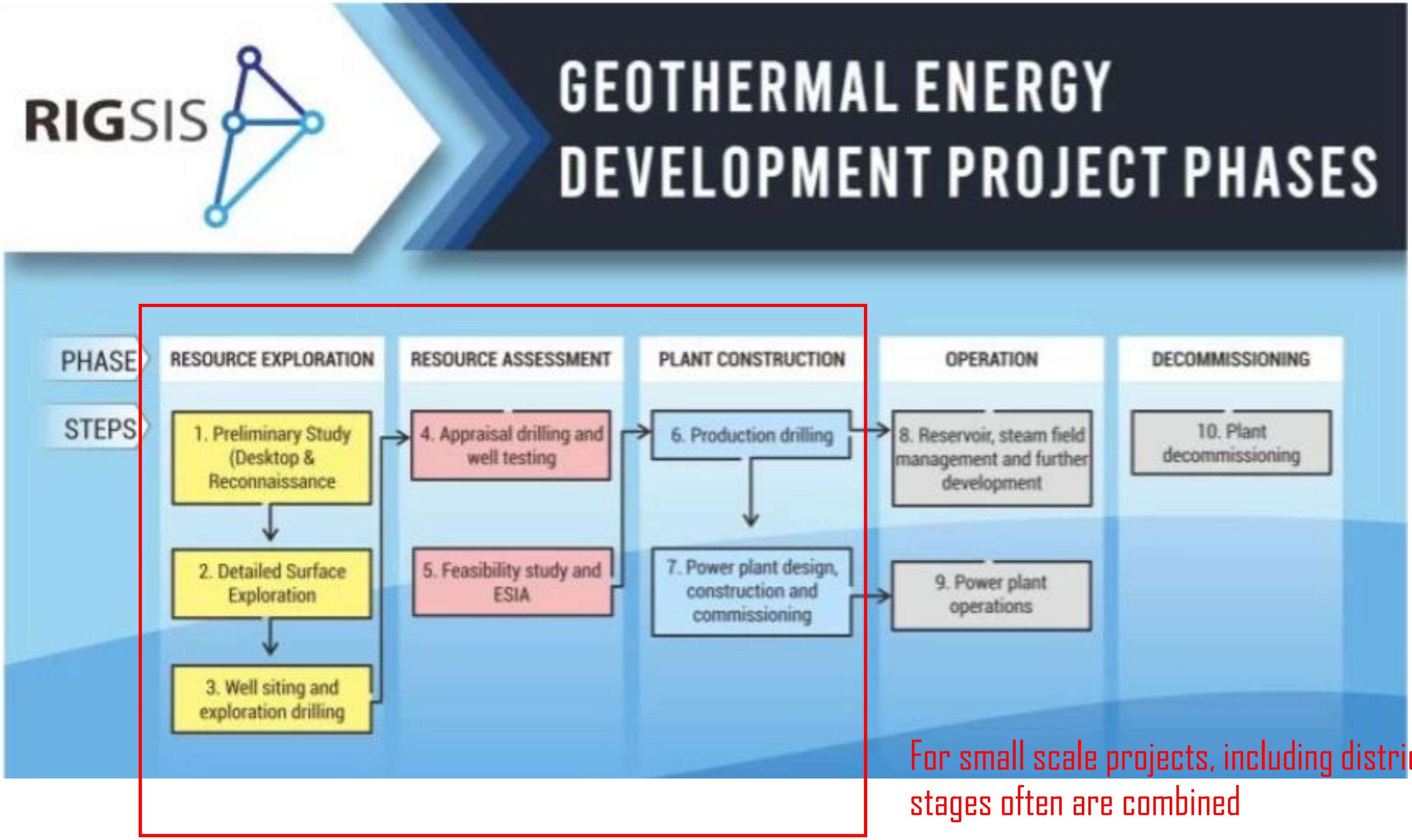
https://www.egec.org/ report

https://www.egec.org/wp-content/uploads/2024/07/EGEC_2022-Key-Findings_Market-Report.pdf

List of key players in geothermal market

1. ABB Limited
2. Aboitiz Power Corporation
3. Calpine Corporation
4. ENEL Green Power SpA
5. Energy Development Corporation
6. Kenya Electricity Generating Company PLC
7. Ormat Technologies Inc.
8. Pertamina Geothermal Energy
9. Mitsubishi Hitachi Power Systems Inc.
10. Toshiba Corporation
11. Korea Electric Power Corporation
12. Siemens AG
13. EDF Group
14. Yokogawa Electric Corporation

Geothermal project maturation



Source of image RIGSIS https://rigsis.com/2021/04/geothermal-energy-development-project-phases/

For small scale projects, including district heating these stages often are combined

Geothermal Project costs

Investment and financial need for geothermal projects: typical project volume: €20 – 30 Mio. depending on project type (e.g. electricity, district heating or P).

exploration	wells	insurances
1-2 Mio. €	10-15 Mio. €	0,5 Mio. €

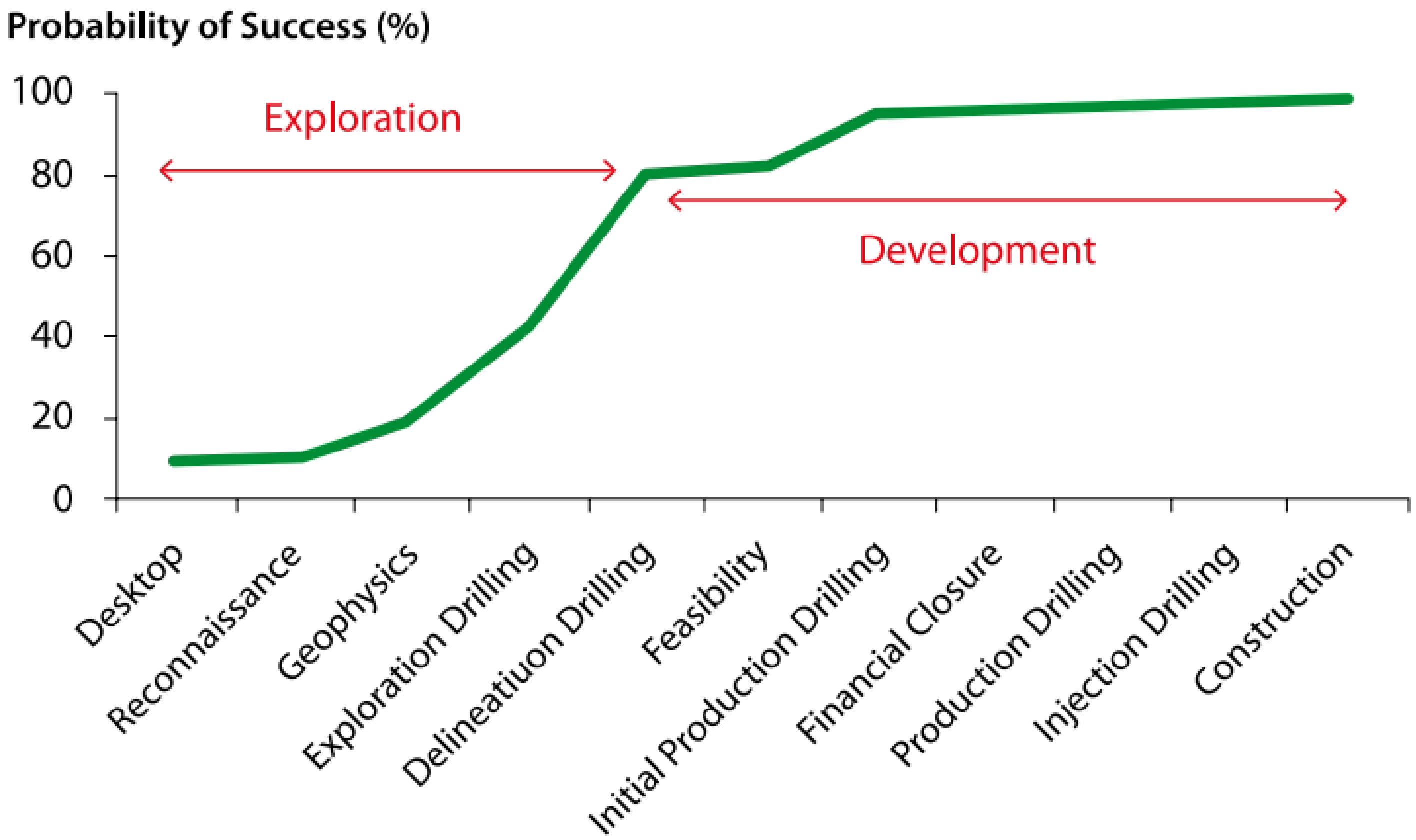
power plant (4-5 MWTH)	energy center	network
1-2 Mio. €	1 Mio. €	10-15 Mio. €

Source: GEODH Report 2014
http://geodh.eu/wp-content/uploads/2012/07/GeoDH-Report-2014_web.pdf

- Geothermal space and district heating systems are capital (PX) intensive. The main costs are generated by initial investments for production and injection wells, down-hole and surface feed pumps, pipelines and distribution grids, monitoring and control equipment, peaking stations, and storage tanks.
- Operating expenses (PX), nevertheless, are much lower than in conventional systems, consisting of pumping power, system maintenance, operation and control.

Geothermal project risks profile

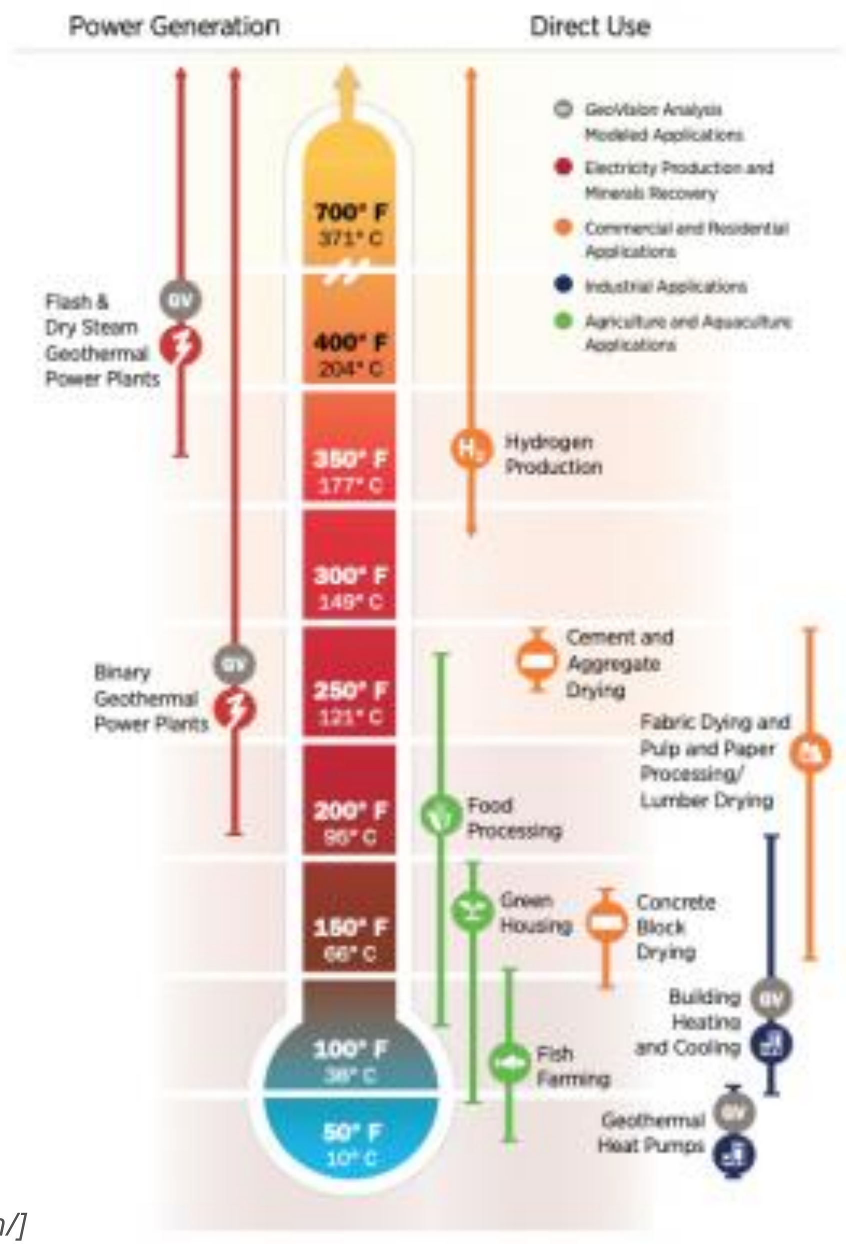
Exploration wells have a relatively high success rate (80-90%) in developed regions and low success rate (20-60%) in not yet explored areas. To establish a comparison, in oil and gas exploration a success ratio of 20% is considered as rather good, taking into account the geophysical campaign carried out before (with huge associated cost)which allows for a much better prognosis of geological conditions which is not the case in geothermal exploration.



Source: GEODH Report 2014
http://geodh.eu/wp-content/uploads/2012/07/GeoDH-Report-2014_web.pdf

Use of geothermal for different i

Today, geothermal energy is being utilised either in power generation (electricity) or directly in the form of heat (so called „direct use“).



Picture: An adaptation of the Lindal Diagram in the U.S. GeoVision report by the U.S. Department of Energy, p. 14 – source: [https://www.energy.gov/sites/default/files/2019/06/f63/2-GeoVision-Chap2-opt.pdf Source of adapted picture https://www.thinkgeoenergy.com/geothermal/geothermal-energy-production-utilisation/]

Module 2

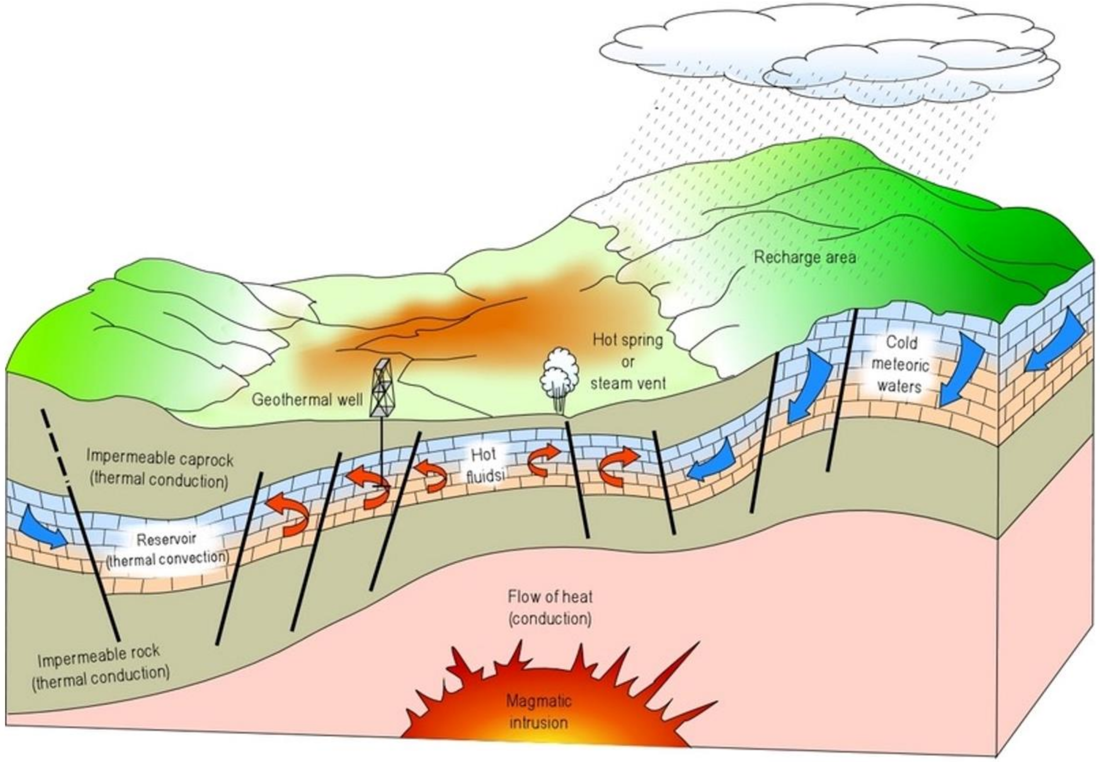
GeoScience for Geothermal Projects

Learning objectives

- To understand key principle what is geothermal reservoir
- To understand what are the main parameters of geothermal reservoir to be assessed by geoscientists
- To understand main geophysical methods used in G&G studies for geothermal
- To understand in more details benefits from use of geophysical surveys

What is geothermal reservoir

- A **geothermal reservoir** is a subsurface area where heat is stored within the Earth's crust, typically in the form of hot water, steam, or hot rocks.
- The reservoir consists of a **heat source**, a **geothermal fluid** (hot water or steam), and a **permeable rock** layer that allows fluid flow.
- **Reservoirs** can be **hydrothermal** (water-based) or **hot dry rock** systems (where heat is stored in dry rock, requiring artificial fluid injection).



Picture is taken from opensource article:
Jie Zhu et all, 2022 **324**
Geothermal Resource Exploration in Magmatic Rock Areas Using a Comprehensive Geophysical Method **https://doi.org/10.1155/2022/5929**

https://onlinelibrary.wiley.com/doi/10.1155/2022/5929324

Content

Module 1

Geothermal energy concept overview

Geothermal business. How does it look?

Setting the scene and motivation

Module 2

Geoscience for geothermal

Geophysical methods for geothermal

Module 3

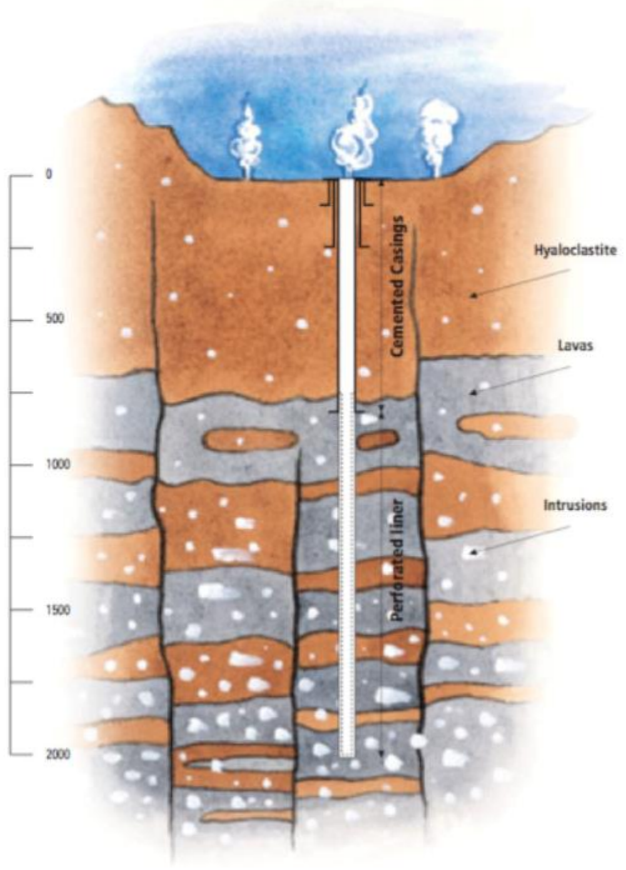
Geothermal in Romania

Case study examples (separate presentations):

1. Geothermal energy project Beius – feasibility study for implementing of Electrical and Seismic surveys
2. Examples of Beius and Tasnad geothermal projects – business aspects
3. Reprocessing of legacy seismic data possibility in Romania

Depletion of geothermal reservoir

- Low grade geothermal is pumped up from boreholes.
- High temperature geothermal fluid flows spontaneously up the well.
- Depletion of the resource depends on the relative magnitude of heat stored in the rock and fluid flow through it.
- Fluid flow constraints lead to receding water level in well. Pumping costs limit production.
- Thermal constraints lead to decreasing temperature. Value of fluid decreases with temperature.
- Sustainable production is possible.
- Depleted areas can renew capacity if rested
- Fluid must be reinjected to sustain reservoir pressure



www.hr.is

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Geoscience in Geothermal Energy Projects

1. Reservoir characterization

•**Geological Surveys**: Identify locations with the right geological conditions (e.g., volcanic activity, fault zones, and hot rock formations), structural geology, interpretation of results geophysical methods.

•**Geophysical Methods**: Use techniques like seismic reflection, magnetotellurics, and resistivity surveys to map subsurface structures and determine resource potential.

•**Geochemical Analysis**: Study fluid chemistry from hot springs or wells to assess temperature, salinity, and mineral content, which helps in estimating the resource's longevity.

2. Thermal Gradient and Heat Flow

•**Temperature Profiling**: Measure the temperature at different depths to identify geothermal gradients and estimate the heat flow within the Earth.

•**Well-Logging**: Conduct temperature, pressure, and resistivity logging in exploratory wells to assess heat distribution and reservoir characteristics.

3. Reservoir Modeling and Simulation

•**Numerical Models**: Use computational models to simulate heat transfer, fluid movement, and pressure changes in the geothermal reservoir over time.

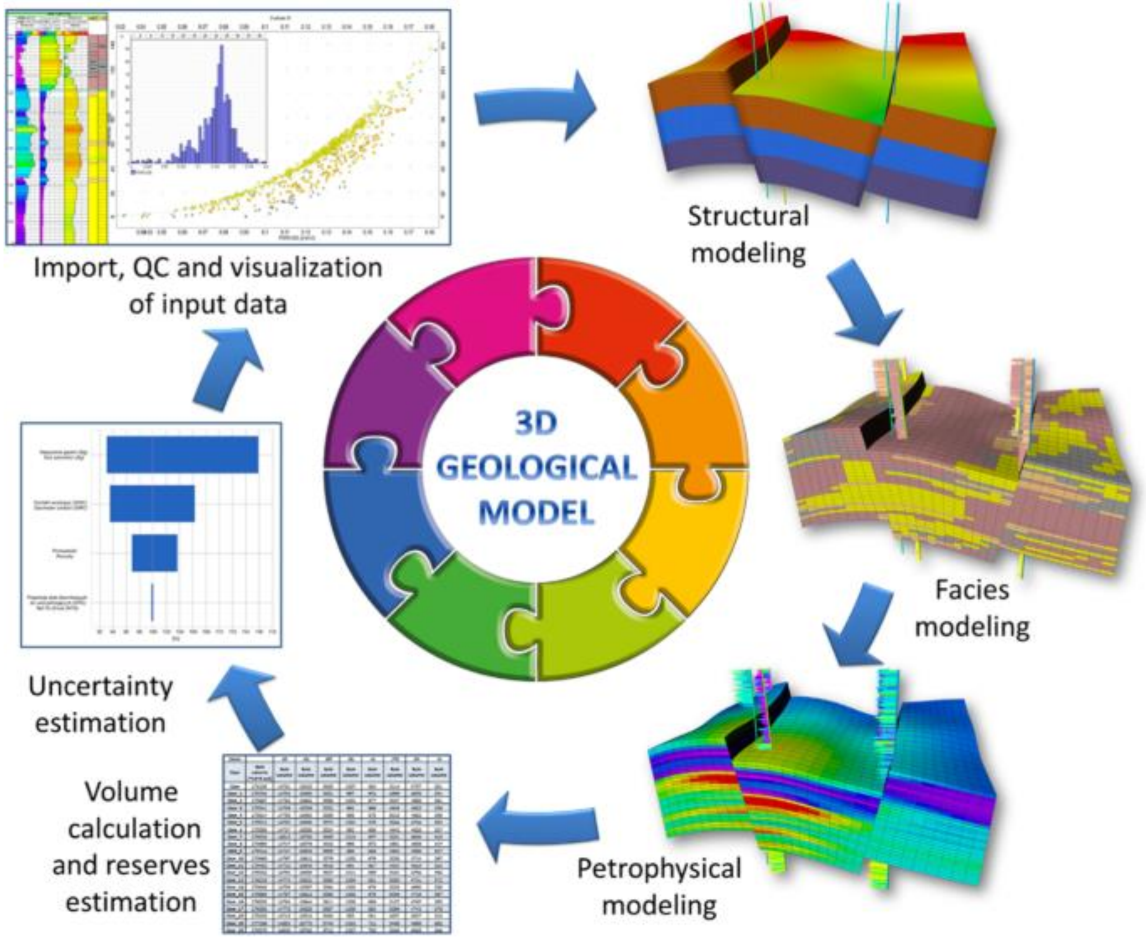
•**Reservoir Dynamics**: Analyze the capacity and sustainability of the geothermal resource, predicting long-term performance and potential risks like reservoir depletion.

Key parameters of geothermal reservoirs

- Thermal gradient,
- porosity,
- permeability,
- fault/fractures,
- lithofacies and mineralogy,
- fluid volume and rock-fluid interaction.

According to Bohnsack et al. [9], fractures, porosity, and permeability of the rock matrix, and karstification are steering elements concerning the storage and transfer of fluids

Traditionally geothermal projects data acquisition programs often very limited to almost absent. In general industry suffers from lack of data base and access to well, geophysical data

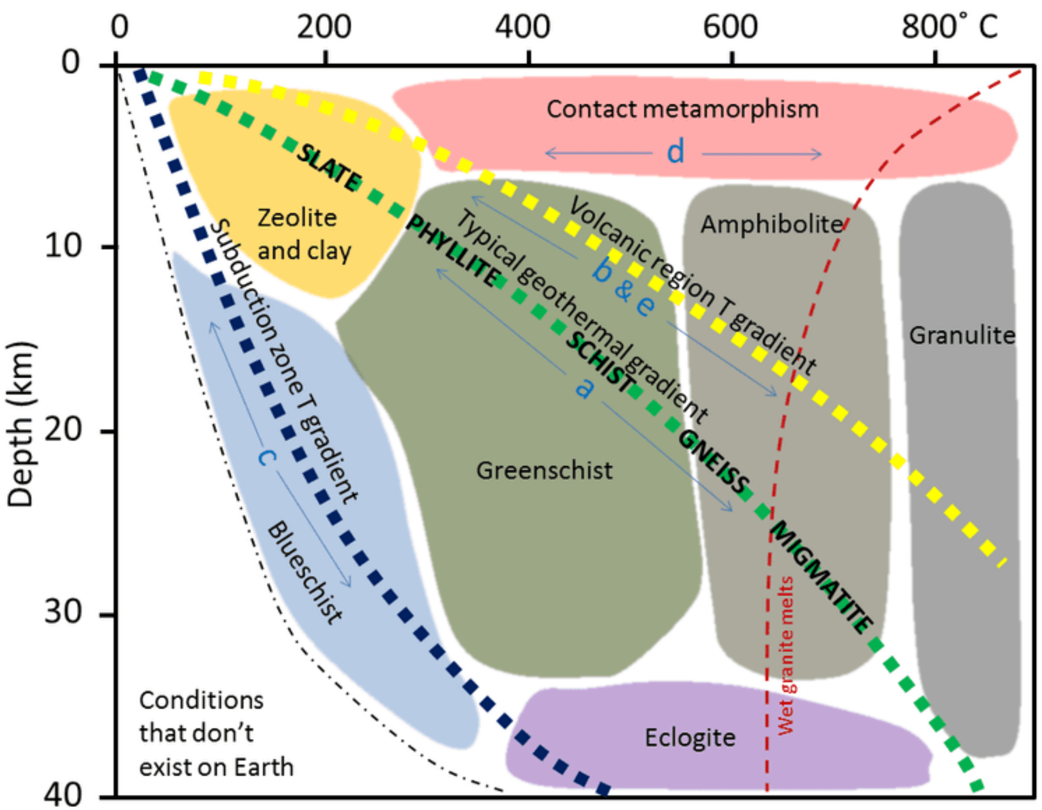


Source: Wachowicz-Pyzik, A., Pająk, L., Papiernik, B. & Michna, M., 2015. The application of numerical modeling to geothermal investments. Computer Assisted Methods in Engineering and Science, 22: 385–395

Thermal gradient and heat flow

Geothermal gradient
Conductive heat flux, H, is related to the geothermal gradient by $H = \lambda dT/dz$, where λ is the thermal conductivity and dT/dz is the geothermal gradient. For rocks, λ ranges from approximately 1.5 to more than 10 W (m °C)$^{-1}$, with most igneous rocks falling into a narrower range between 1.8 for basalt and 3.5 W (m °C)$^{-1}$ for granites (Roy et al., 1981). In older, stable continental cratons, the geothermal gradient may be as low as 10 °C km^{-1}, whereas in active volcanic regions it may be more than 100 °C km^{-1}. A typical geothermal gradient of ≈ 25 °C km^{-1} gives a conductive heat flux of ≈ 60 mWm^{-2}.

- **Temperature Profiling**: Measure the temperature at different depths to identify geothermal gradients and estimate the heat flow within the Earth.
- **Well-Logging**: Conduct temperature, pressure, and resistivity logging in exploratory wells to assess heat distribution and reservoir characteristics.

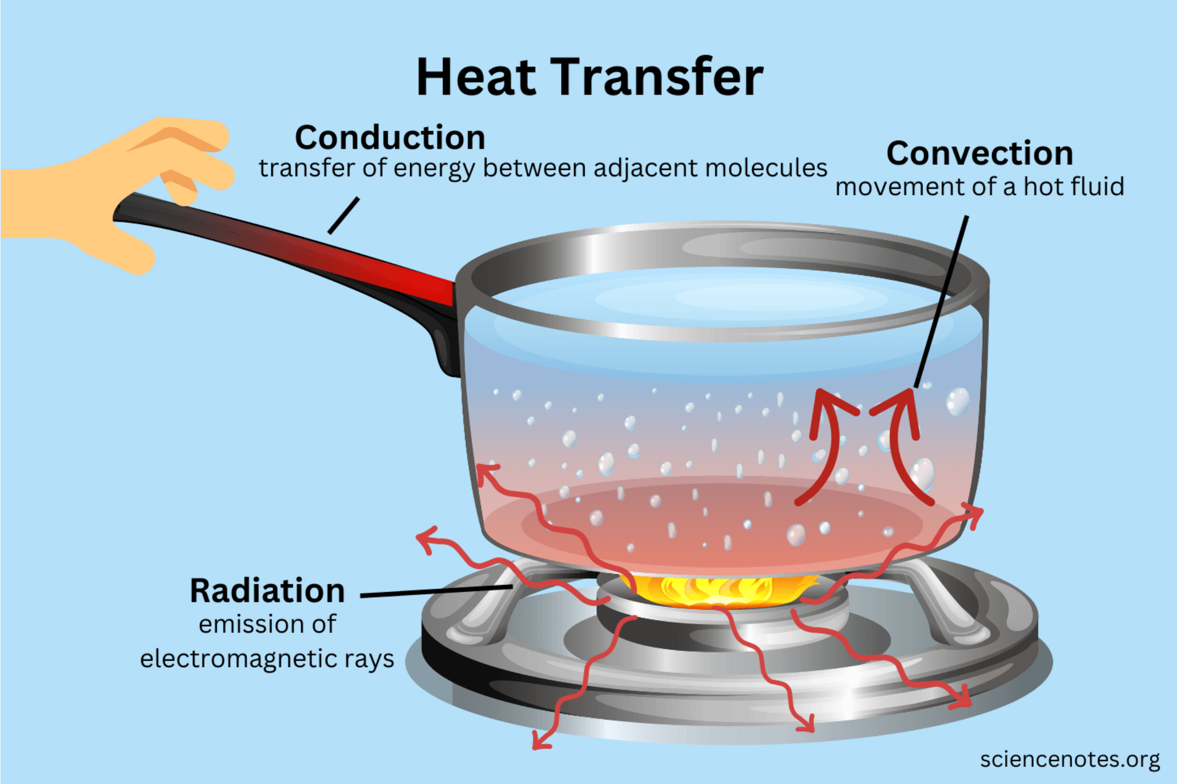


Source of image
Chapter 7 Metamorphism and Metamorphic Rocks
Electronic textbook Physical Geology – 2nd Edition
https://opentextbc.ca/geology/chapter/7-3-plate-tectonics-and-metamorphism/

Thermal gradient and heat flow

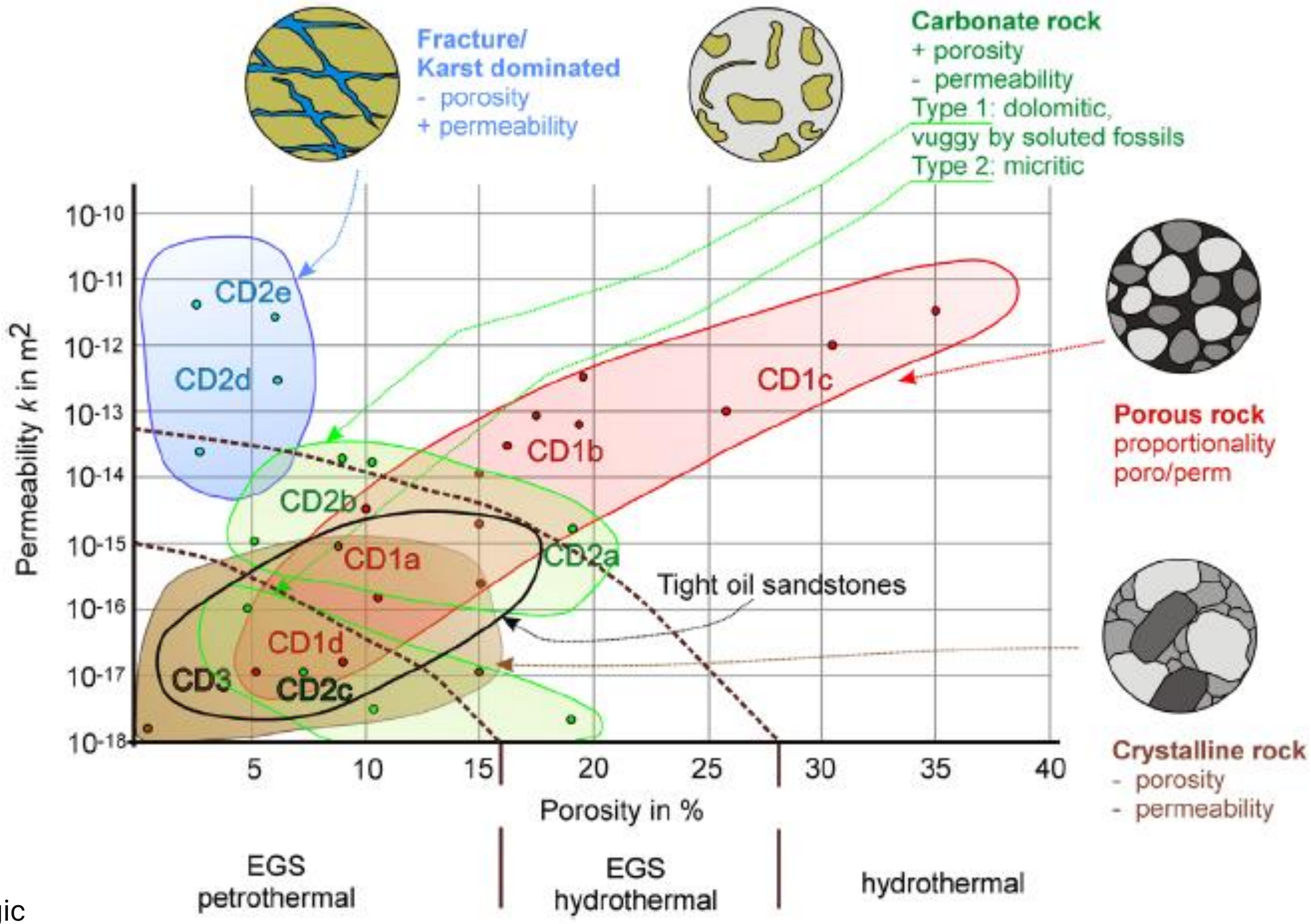
Conductive vs convective flow

- Conductive heat flow dominates in low-permeability rocks and stable regions
- Convective heat flow occurs in areas with high fluid circulation or magmatic activity
- Mixed conductive-convective systems found in many geothermal reservoirs
- Convective systems typically exhibit higher heat transfer rates and geothermal potential
- Heat flow regime influences reservoir temperature distribution and recharge mechanisms



Porosity & Permeability in geothermal

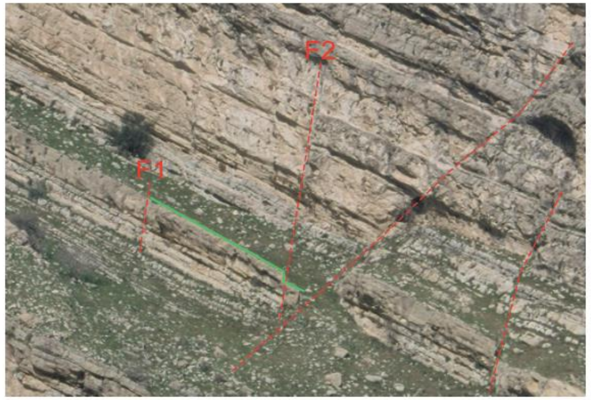
- Mainly profitably operated geothermal reservoirs are so-called hydrothermal
- EGS reservoirs are relatively recent concept however with promising potential
- Important for geothermal, especially low enthalpy, reservoir is continuity of reservoir, relatively small variation of properties
- If in oil and gas dominant reservoir type is porous, in geothermal often is fractured reservoir. Prediction of fractures is one of important task in geothermal geoscience



Source of image
Inga S. Moeck Catalog of geothermal play types based on geologic controls, September 2014, Renewable and Sustainable Energy Reviews 37(1853):867–882
DOI:10.1016/j.rser.2014.05.032

Fractures and faults. Types of fractures

- **Classification of natural cracks (Ronald A. Nelson, BP Amoco 2001):**
- Tectonic (arising due to external influences in relation to the rock)
- Regional (arising due to external influences in relation to the rock or internal processes in the rock and having a regional extent with constant or close to constant parameters)
- Contraction cracks (caused by processes occurring inside the rock – drying, thermal cooling, etc., physical, chemical weathering)
- Exogenous cracks (arising in the process of stress relief during the emergence of rock to the surface, weathering)



https://sci-hub.se/https://doi.org/10.1144/1354-079305-675

Ronald A.Nelson, BP Amoco 2001

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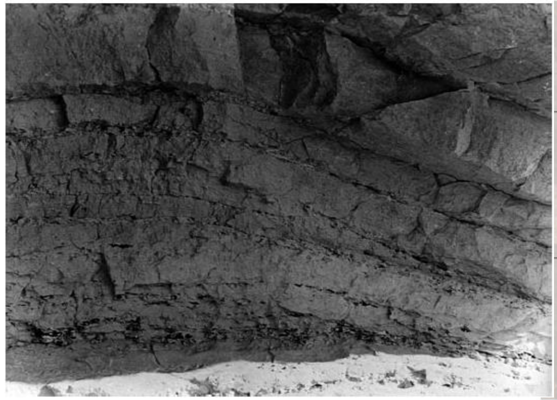
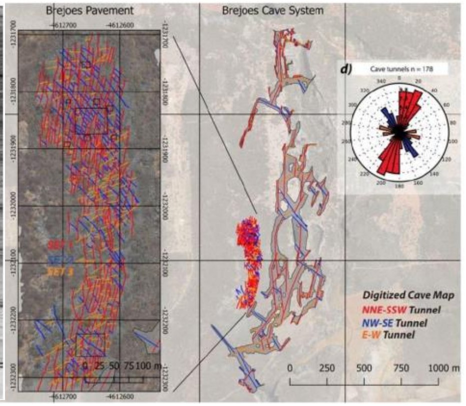


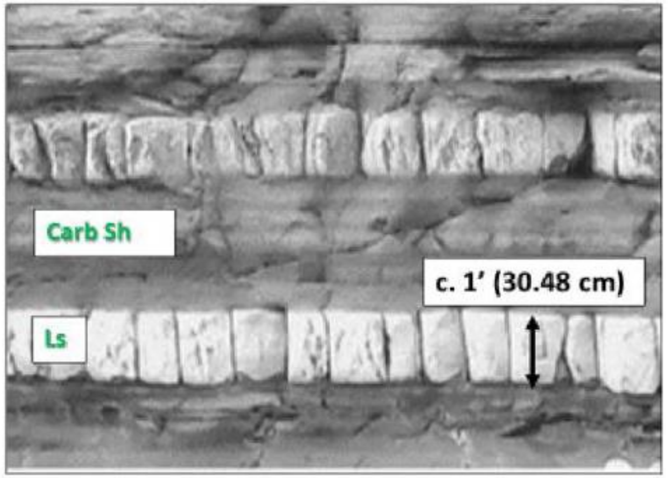
Ronald A.Nelson, BP Amoco 2001



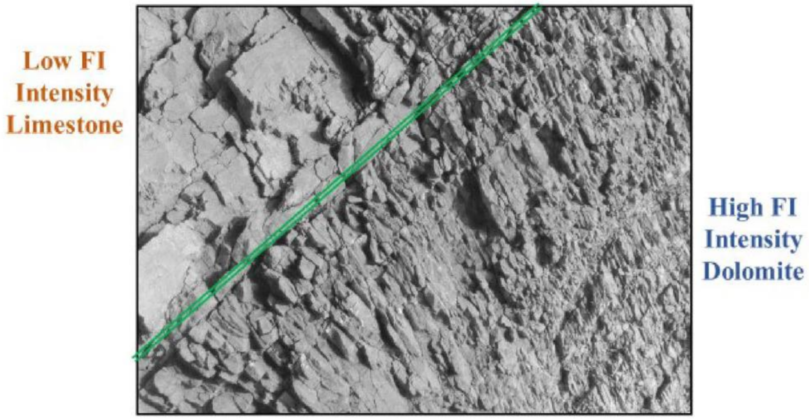
(Boersma et al. 2019).

Influence of Mechanical Properties of Rock on Fracture Intensity

- The mechanical properties of the rock are a key aspect in predicting the fracturing of tectonic genesis
- Mechanical property prediction is an indirect method for predicting fractures and is used in conjunction with the mapping of fracture zones based on attribute analysis

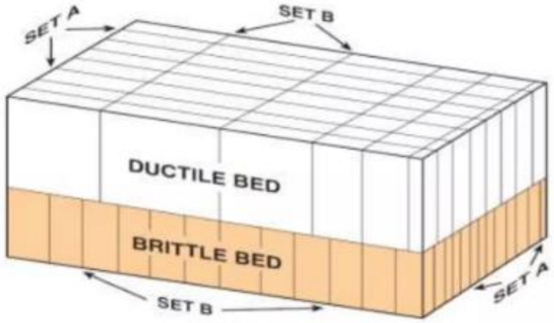


Ronald A. Nelson, BP Amoco 2001



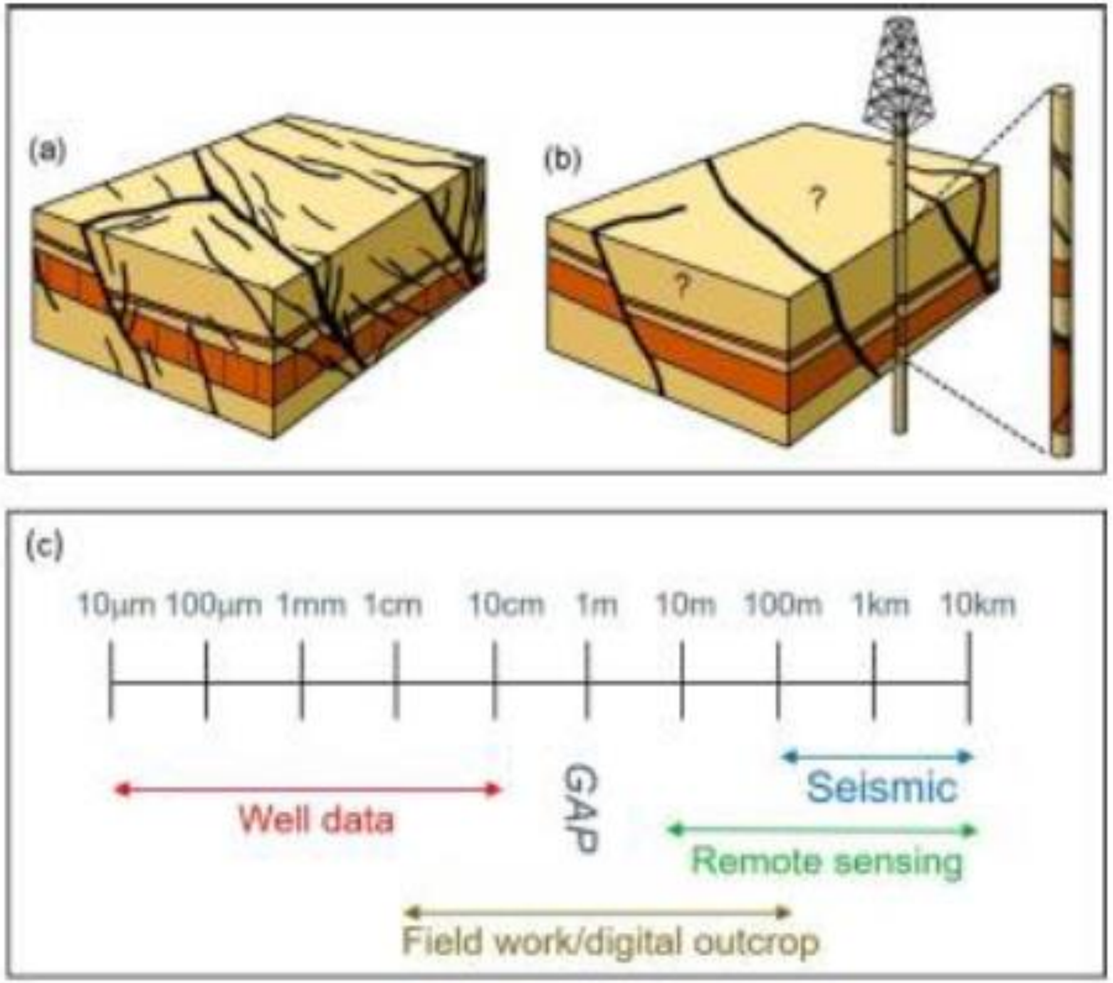
Paleozoic Carbonates Sawtooth Mnts. Montana

From Nelson (2001)



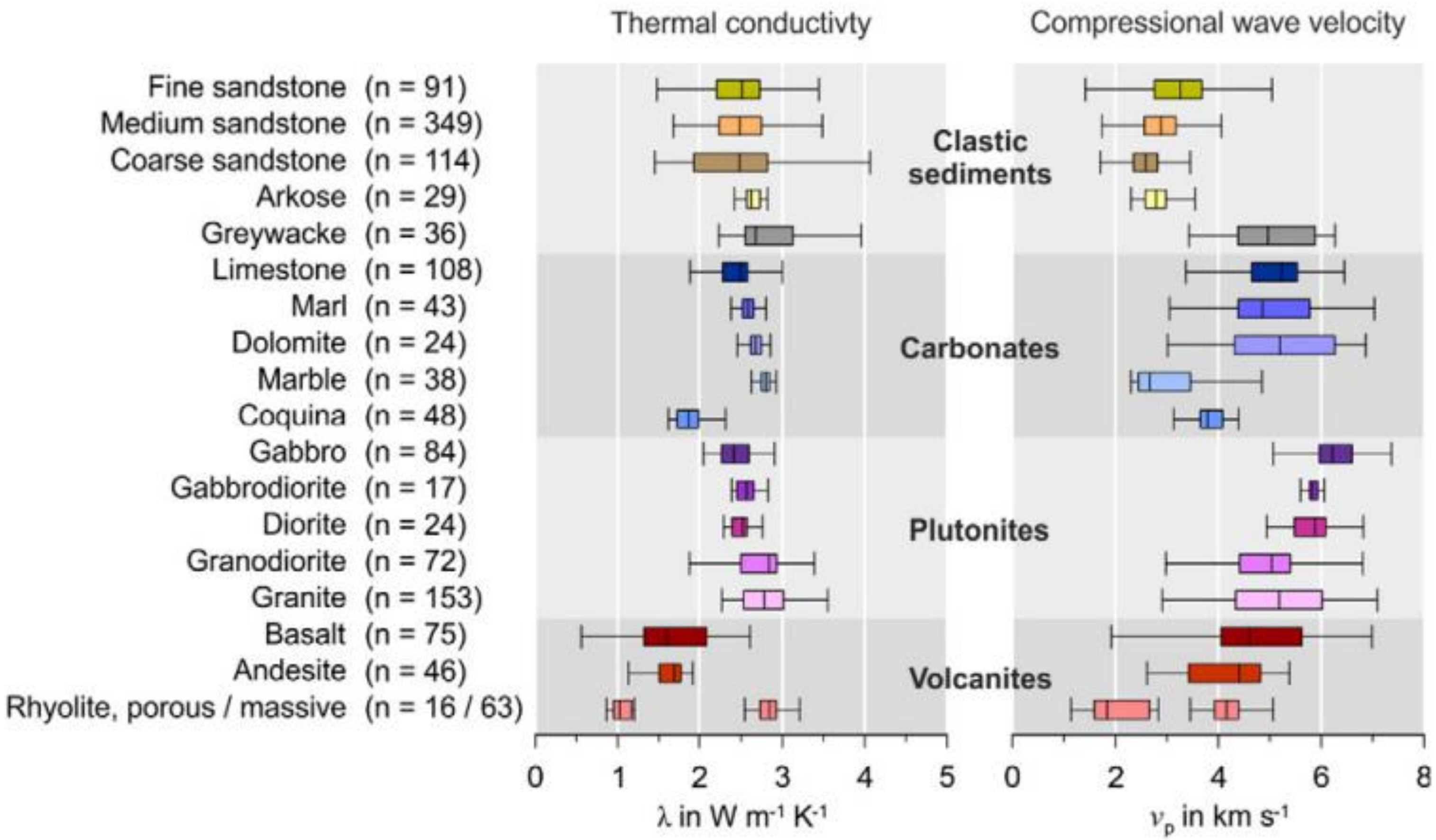
The scale of fracturing relative to different methods of study. Omitting the resolution of methods.

- Seismic data have low resolution and are able to display only large faults
- Well data has a higher resolution, but does not show the extent of large faults and fractures
- There is a lack of information between the two types of data, which can only be filled by studying analogs, outcrops, conceptual modeling.



Rock thermal properties

- Thermal conductivity of rocks influences heat transfer rates and gradient steepness
- High conductivity rocks (quartz-rich) efficiently transfer heat, potentially lowering local gradients
- Low conductivity rocks (clay-rich) act as insulators, potentially increasing local gradients
- Specific heat capacity affects the rock's ability to store thermal energy
- Radiogenic heat production in certain rock types (granites) can increase local geothermal gradients



P. Mielke *, K. Bär, I. Sass Technische Universität Darmstadt, Department of Geothermal Science and Technology, Germany, Journal of Applied Geophysics 140 (2017) 135–144

Fluid composition in geothermal

1. pH

- **Significance**: The pH level indicates the acidity or alkalinity of geothermal fluids, which can influence mineral scaling, corrosion, and fluid behavior in the reservoir.
- **Typical Range**: Geothermal fluids usually range from mildly acidic (pH 4-6) to neutral or slightly alkaline (pH 7-9).

2. Dissolved Gases

- **Significance**: Dissolved gases such as **carbon dioxide (CO_2)**, **hydrogen sulfide (H_2S)**, **methane (CH_4)**, and **hydrogen (H_2)** are crucial for understanding reservoir chemistry, potential for acid corrosion, and geothermal fluid behavior.
- **Impact**: Gases like H_2S are toxic and corrosive, and CO_2 may contribute to greenhouse gas emissions.

Fluid composition in geothermal

3. Major Ions and Salts

- **Significance**: The concentrations of key ions in the geothermal fluid reveal the composition of the fluid and help identify the source and geological characteristics of the reservoir.
- **Common Ions Measured**:
  - **Chloride (Cl^-)**: Indicates the presence of seawater or deep-sourced geothermal fluids.
  - **Sodium (Na^+)** and **Potassium (K^+)**: Common in geothermal brines and help assess fluid salinity.
  - **Calcium (Ca^{2+})**, **Magnesium (Mg^{2+})**, and **Sulfate (SO_4^{2-})**: Important for understanding mineral precipitation and scaling potential.

4. Silica (SiO_2)

- **Significance**: Silica is a major component in many geothermal fluids. It's a key indicator of temperature and reservoir conditions. High silica concentrations often point to high-temperature reservoirs.
- **Impact**: Silica can precipitate as scale, clogging wells and equipment.
- **6**

Corrosion and scale problems can occur frequently in hydrothermal systems

Example from article Aniko N. Toth1, Peter Szucs, 2018

Type of geothermal

5. Trace Elements and Metals

- **Significance**: The presence of trace elements like **arsenic (As)**, **boron (B)**, **fluoride (F)**, **iron (Fe)**, **copper (Cu)**, and others help assess potential environmental impacts, toxicity, and scaling issues.
- **Impact**: High concentrations of these metals may require mitigation strategies to prevent pollution or equipment damage.

6. Total Dissolved Solids (TDS)

- **Significance**: TDS measures the overall salinity of geothermal fluids, which is important for understanding the fluid's mineral content, scaling potential, and reinjection feasibility.
- **Impact**: High TDS can lead to scaling and reduce fluid mobility in the reservoir.

7. Isotopic Composition

- **Significance**: Stable isotopes of elements like **hydrogen (δ^2H)**, **oxygen ($\delta^{18}O$)**, and **carbon ($\delta^{13}C$)** can provide insights into the source of the geothermal fluid, age, and mixing processes.
- **Use**: Helps determine whether the geothermal fluid is meteoric (rainwater-derived) or magmatic (derived from deep sources), which is critical for resource management.

https://geocom.geonardo.com/assets/elearning/3.2.Corrosion&Scalling.pdf

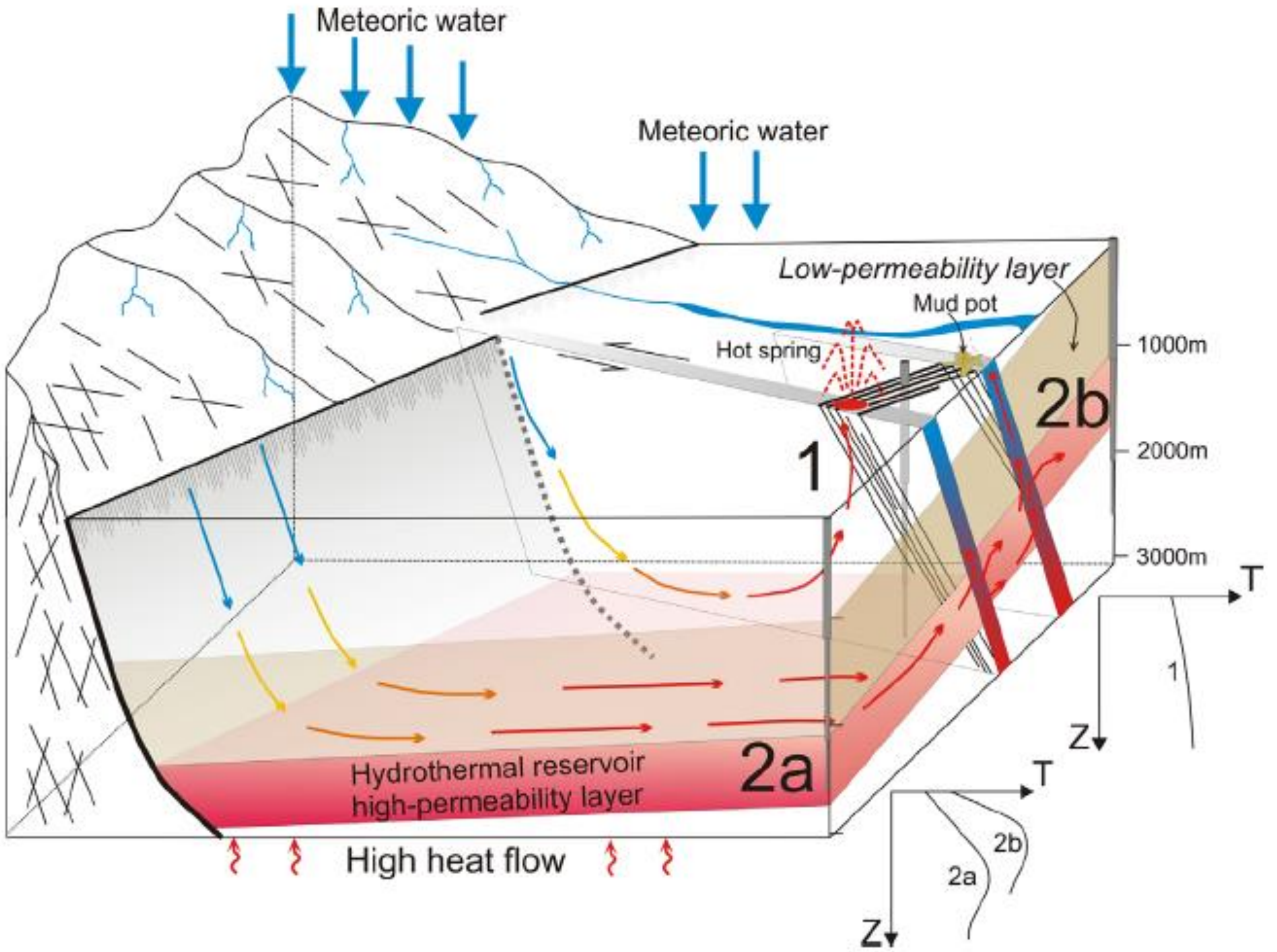
Types of geothermal systems

- Convection dominated geothermal
  - Magmatic
  - Non-magmatic
- Conduction dominated geothermal
  - Igneous
  - Non-magmatic (Intra-cratonic basins & orogenic belts

Types of geothermal systems

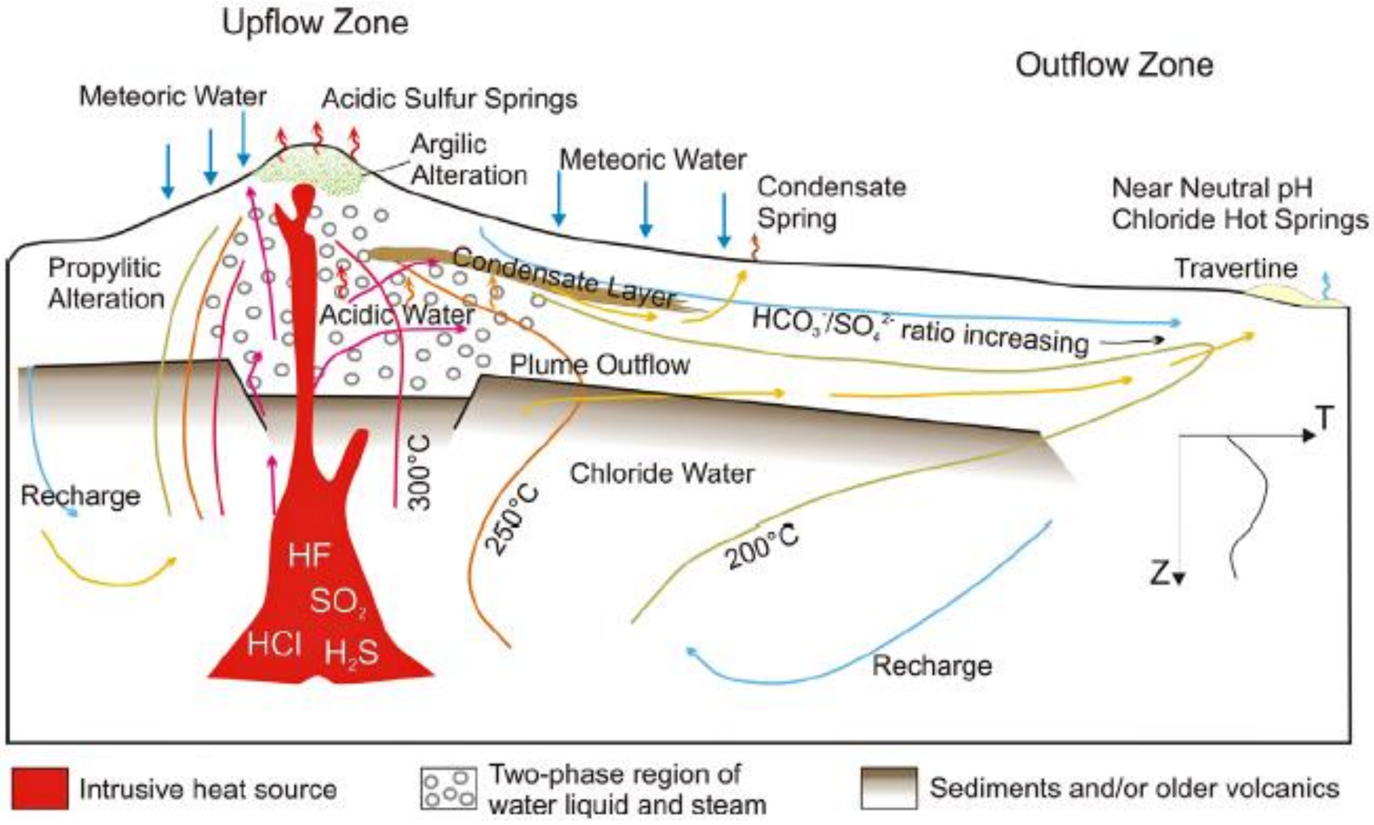
- Non-magmatic active geothermal play system in active extensional terrains with different types of reservoirs

Source: article Catalog of geothermal play types based on geologic controls Inga S.Moeck, 2014).



Types of geothermal systems

- Geothermal play type related to an active volcanic field typical for amagmatic arc setting above a subduction zone

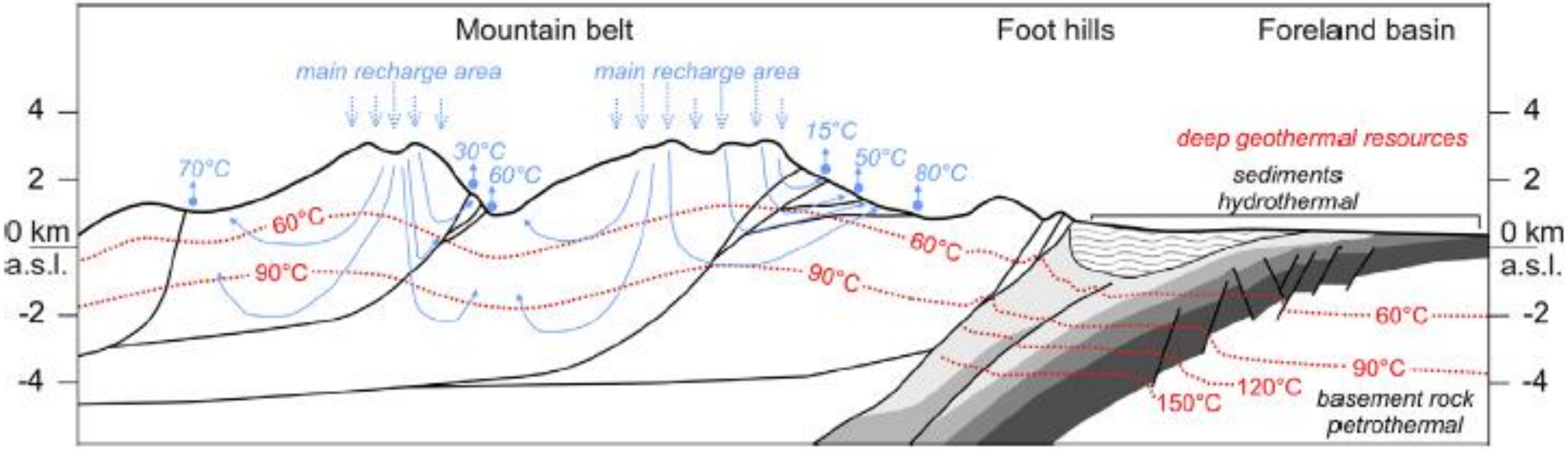


Source of image
Inga S. Moeck Catalog of geothermal play types based on geologic controls, September 2014, Renewable and Sustainable Energy Reviews 37(1853):867–882
DOI:10.1016/j.rser.2014.05.032

Types of geothermal systems

- Geothermal play types in orogenic belt and adjacent foreland basins.

Source of image
Inga S. Moeck Catalog of geothermal play types based on geologic controls, September 2014, Renewable and Sustainable Energy Reviews 37(1853):867–882
DOI:10.1016/j.rser.2014.05.032



Exploration for geothermal

Geothermal Play Type	Geological Characteristics	Exploration Methods
1. Volcanic (Magmatic)	- Active volcanic regions with shallow magma bodies or hot volcanic rocks. - High heat flow and abundant fluid reservoirs.	- Surface Geothermal Gradient Surveys (heat flow mapping) - Magnetotellurics (MT) (detect molten rock) - Geochemical Surveys (sampling fumaroles, hot springs, and volcanic gases) - Geological Mapping (identify recent volcanic activity, fault systems)
2. Rift and Basin	- Tectonic plate boundaries, continental rift zones, and sedimentary basins. - Often deep geothermal reservoirs with high permeability.	- Reflection seismic in volcanic areas often gives poor results - Geochemical Sampling (hot springs and wells) - Magnetotellurics (MT), AMT, (deep conductive zones) - Airborn magnetic surveys - Gravity Surveys (detect subsurface density variations) - Geothermal Gradient and Temperature Surveys (surface mapping) - Analysis of fault evolution to identify the fault blocksand settings with higher fracture density
3. Hot-Dry-Rock (HDR)	- High heat flow in areas with low permeability, often in crystalline or granite rocks. - Requires engineered fluid circulation to create a viable geothermal system.	- Seismic Reflection and Refraction (deep structure and fractures mapping) - Microseismic Monitoring (monitor induced fractures) - Geothermal Gradient Surveys (heat flow and temperature measurement) - Drilling and Well Logging (rock characteristics and temperature at depth) - Hydraulic Fracturing (enhance fluid circulation in low-permeability rock)

Exploration for geothermal

Geothermal Play Type	Geological Characteristics	Exploration Methods
4. Sedimentary Basins	- Found in sedimentary rock layers, with deep aquifers or hot fluid reservoirs. - Typically deep geothermal reservoirs.	2D/3D seismic surveys. Re-processing of existing seismic reflection data, existing well data is often available (but not always accessible) from hydrocarbon exploration. Joint interpretation of magnetotelluric and reflection seismic data
5. Crystalline Basement Rocks	- High-temperature gradients in fractured basement rocks (granite, basalt). - Typically older continental regions.	- Geological Mapping (identify active volcanic systems, fault lines) -Magnetotelluric and gravity to detect the granitic body and reflection seismic to identify fracture zones - Geochemical Analysis (sampling fumaroles, hot springs, gases) - Geosystem analysis is necessary to estimate stress field and hydromechanical conditions. Relatively early, the first exploration well is drilled to obtain petrophysical and mineralogical parameters and to verify the stress field for stimulation concepts. - Geological Mapping (identify active volcanic systems, fault lines)

Source of image
Inga S. Moeck Catalog of geothermal play types based on geologic controls, September 2014, Renewable and Sustainable Energy Reviews 37(1853):867–882
DOI:10.1016/j.rser.2014.05.032

Potential for use of well geophysics

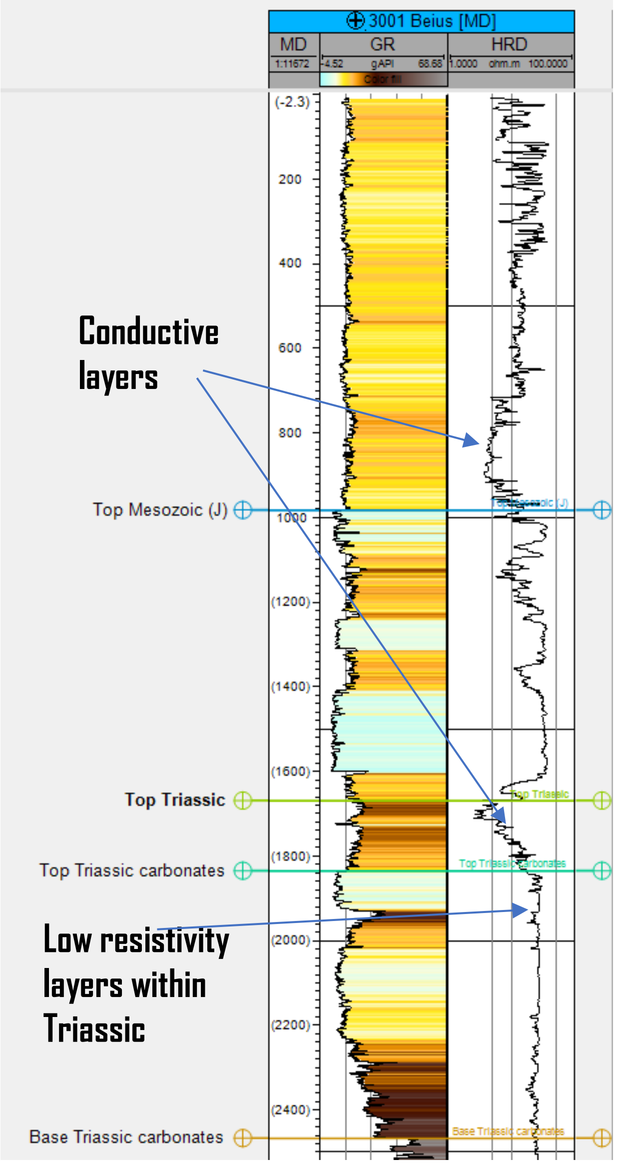
During drilling, the information derived from well logging is used to

- validate the predicted depth of the penetrated zone tops and geothermal reservoir.
- correlate the geothermal well with the offset wells used to study the geothermal reservoir.
- estimate reservoir parameters
- to optimize the well design of the second well of the geothermal doublet.

- Formation evaluation is the term used in the hydrocarbon industry to determine the ability of a borehole to produce hydrocarbons.
- In geothermal formation evaluation is used to determine the ability of the drilled reservoir to produce geothermal fluids. This implies determining the ability of the geothermal reservoir to allow fluid flow by estimating its porosity and permeability as well as the depth and thickness of the reservoir and the vertical location of its producing layers.

- Many of well logs used in oil and gas are relevant for geothermal reservoir characterization

- Well logs used in open hole and cased hole (limited amount of methods), used during drilling (LWD, MWD) and wireline



Well data - curtesy of TRASGEX company

Potential for use of well geophysics

Logging tool / Uses	Lithology	Stratigraphy correlation	Depositional environment	Fracture identification	Over-pressure identification	Porosity	Permeability	Shale volume	Formation water salinity	Seismic
Caliper		-		-			-			
SP (*obsolete?*)		-	-				-	+	*	
Resistivity	-	-	-		+	+	-		-	
Gamma ray	+	-	-	-				+		
Sonic	+	-	-	*	+	*	-	+		*
Density	+	-	-	+	-	*	-	+		*
Neutron	+	-	-			*	-	+		
NMR[7]	+	-	-			*	+	+		
Fluid testing and sampling					*		*		*	
Borehole imaging[8]			*	*						

- essentially qualitative use

+ semi-quantitative and quantitative uses

* strictly quantitative

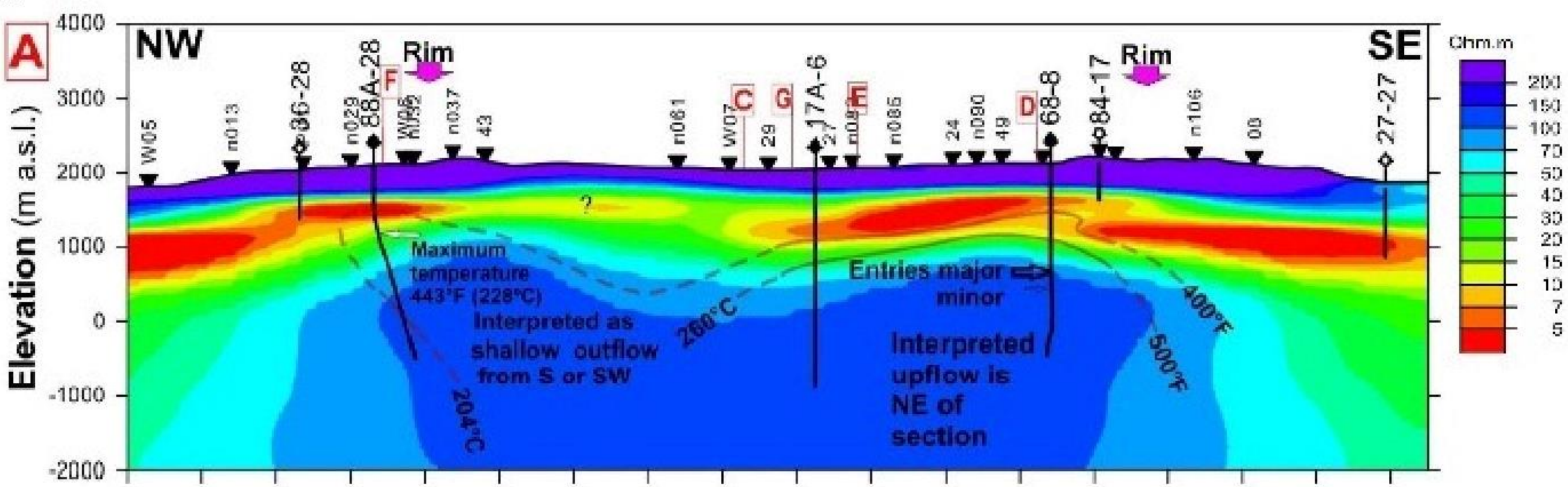
Exploration: Resitivity surveys

Magnetotellurics uses naturally occuring variations in earth's electromagnetic field to measure resistivity.

Higher frequencies give better resolution but less penetration depth and vice versa.

Current induced from electrodes can also be used.

Inversion techniques are used to map out resistivity of subsurface. Resistive anomalies can be interpreted.

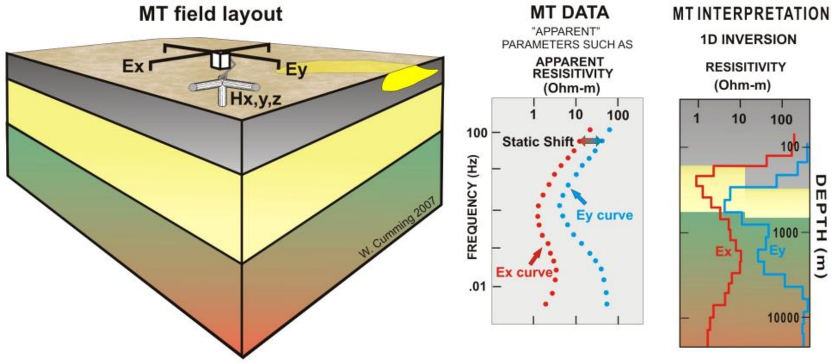


Source:Reykjavic Univesity

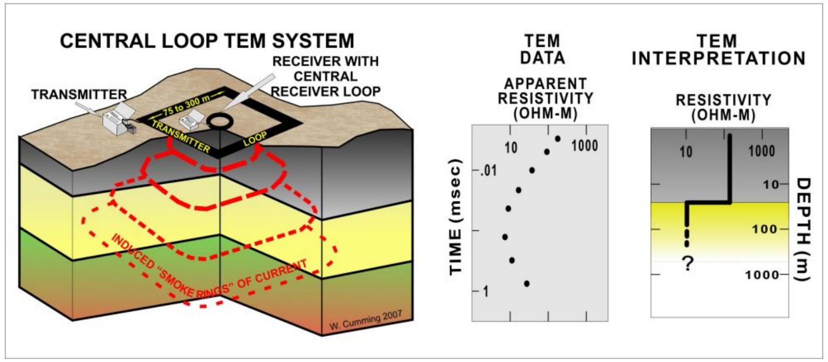
Potential improvements from using electric surveys (MT, TEM)

Addressed parameter	Applicability of TEM	Applicability of MT
Geoelectric section	High with high resolution	Medium resolution to greater depth
High Contrast horizons mapping	high	high
Medium contrast, thin horizons mapping	medium	medium
Faults mapping	high	medium
Mapping of faults with high temperature fluids	medium	low
Mapping of zones with high porosity and therefore higher water content within target interval	medium	medium
Identification of deep heat sources (intrusions, granitic bodies)	not possible because of low depth of investigation	medium

- MT surveys are easier in execution with low cost 1K – 2.5KEUR per km, low mobilization fee

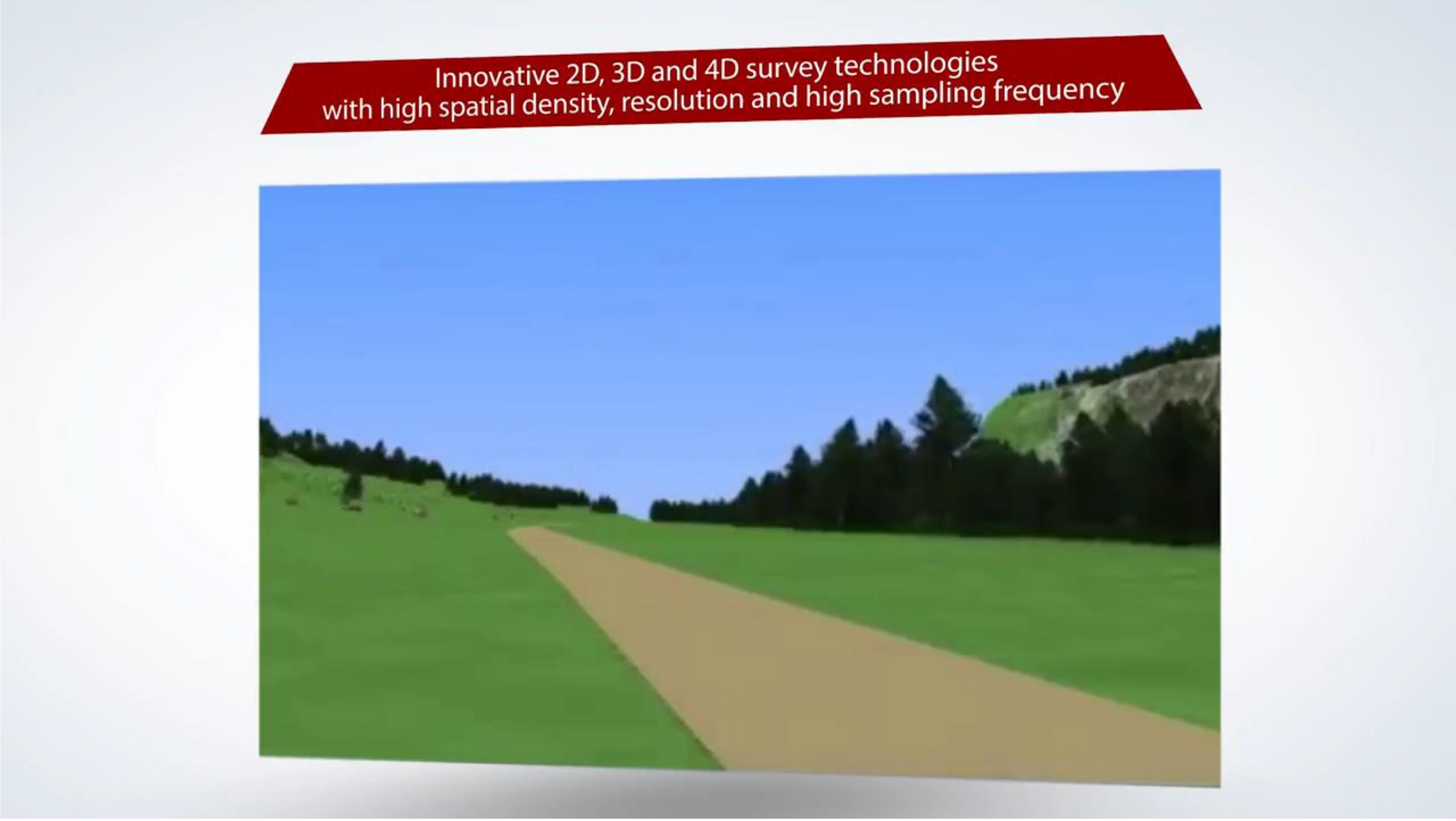


Cumming W., Mackie R. 2010



- To achieve 3-4km depth is required to use linear system, size of transmitter loop must be 500x500m and 1000x1000m to achieve 4-6km depth

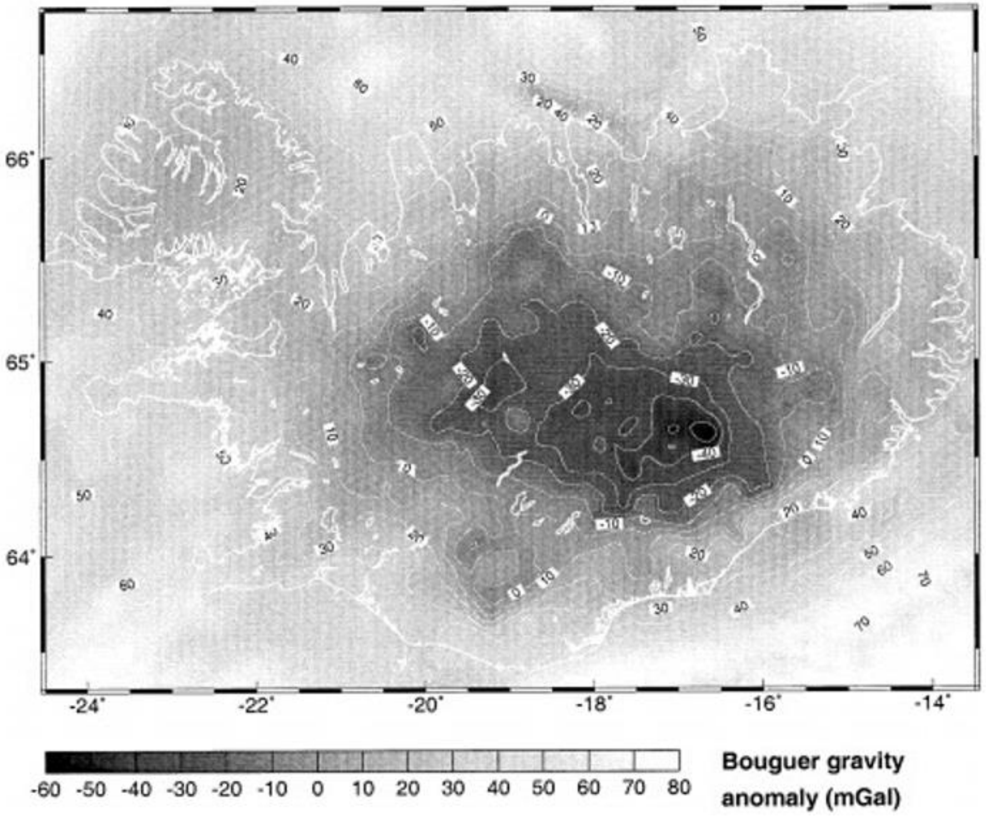
Technical challenges of applying TEM for deep reservoirs in agglomerated area



Exploration: Gravimetry

PSS-Geo

Gravimetric anomalies can indicate variations in densitiy and might, in some cases, imply temperature in some cases.



Source:Reykjavic Univesity

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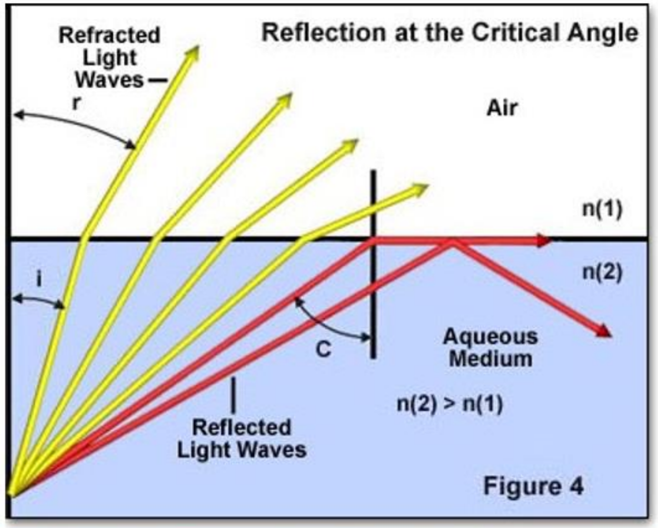
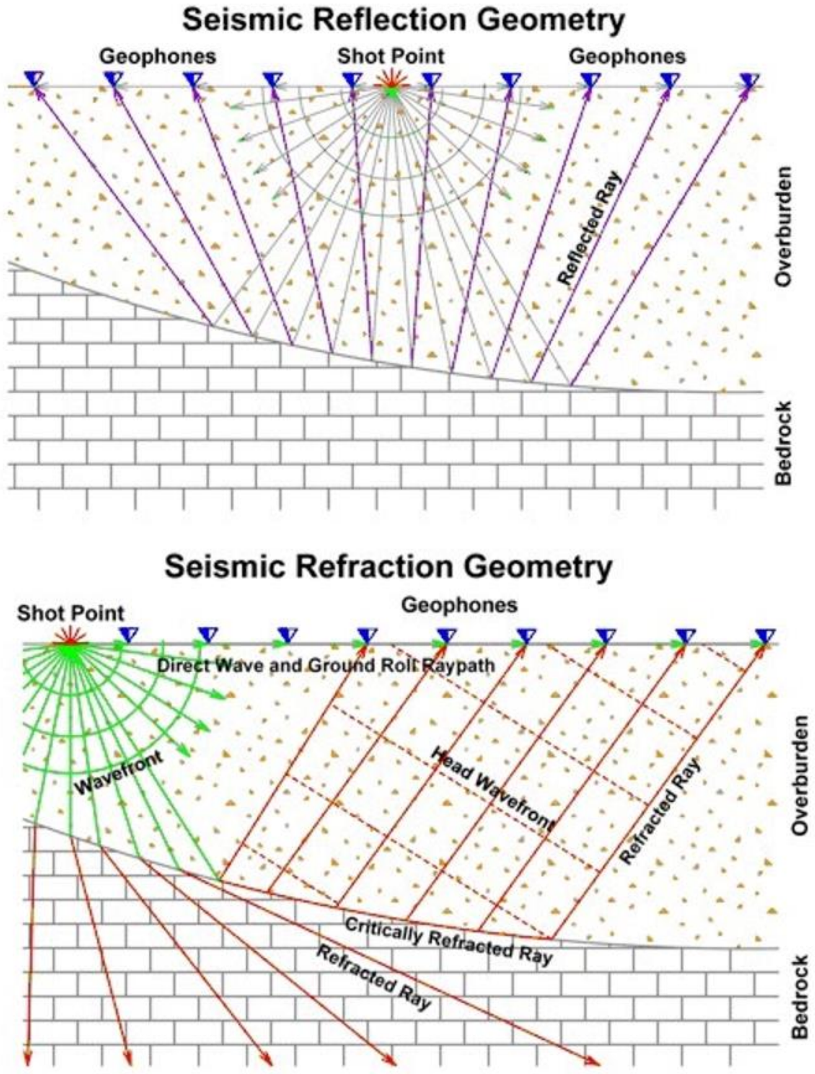
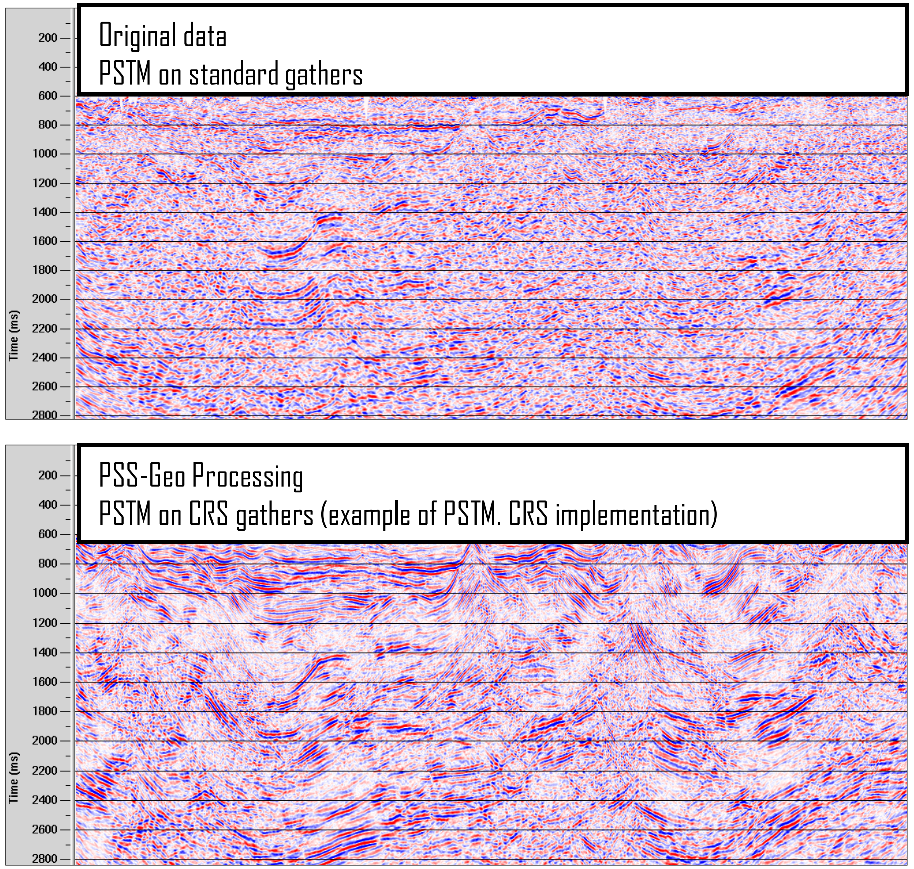
Seismic surveys





Potential improvement from using 2D seismic surveys based on previous studies

Addressed parameter	Importance for geothermal project	Expected accuracy	Possibility to achieve results in Beiuş, Oradea
Horizons mapping	critical	20-50m	Available legacy 2D seismic data
Mapping of small features within target intervals	critical	20-50m	Processing technologies need to be tested to achieve interpretable image of certain sequences
Major and medium size faults/fractures	critical	certain for major faults (more then 30-70m amplitude)	
Faults with high heat flow	important, but value is not yet proven	can not be defined by seismic directly unless geological concept is developed	A regional concept for high heat flow faults should be developed as a part of regional project
Small scale fractures	good to have	Indirect indicators on seismic attributes Certain mapping possible using 3D seismic, or near well VSP	Most likely quality of 2D legacy seismic will not allow to achieve accurate results Acquisition of new 3D seismic data should be financially evaluated.
Reservoir properties (porosity, permeability)	good to have	2-5%, requires well data for calibration	

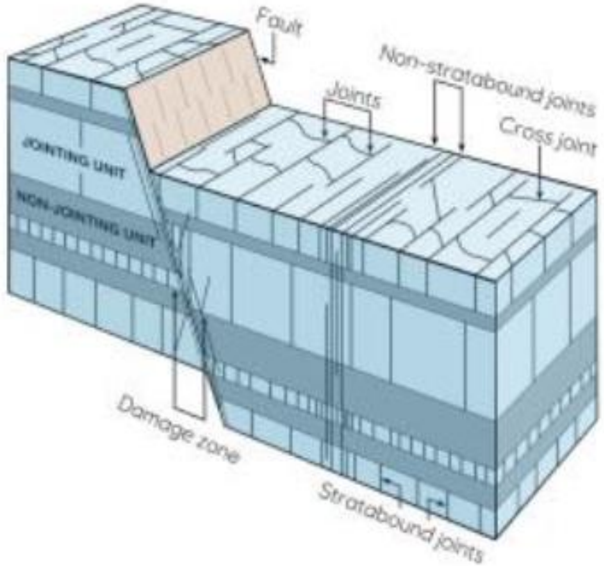


PSS-Geo processing examples for 2D legacy data

Seismic technologies for fracture studies

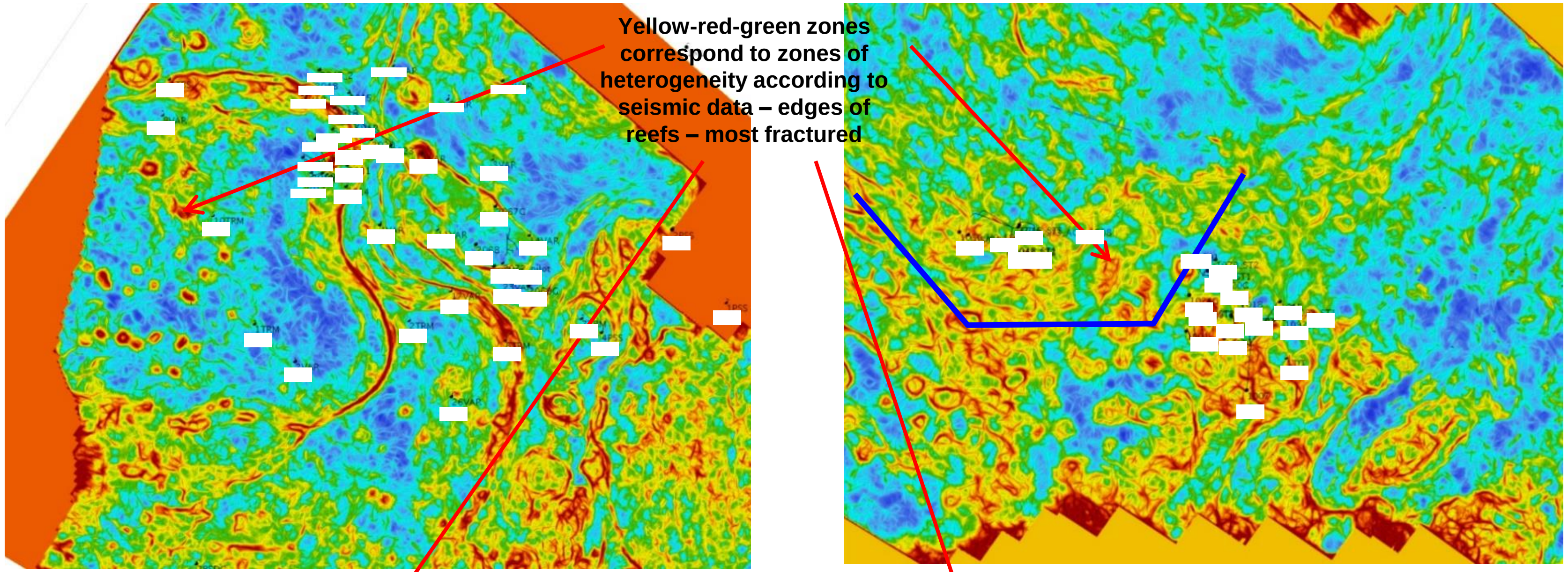
The main request for seismic exploration is the prediction of fracture density along the lateral, the prediction of mechanical parameters for performing mechanical modeling.

All seismic methods for the study of fractures are indirect, as they investigate effects that may indicate the presence of fractures, but do not directly record the presence of fractures:
Post Stack seismic attributes
Geometric attributes (angles of incidence, curvature, azimuths)
Q-factor
Attributes based on coherence, curvature
Attributes Fault likelihood, Thin Fault likelihood
Attribute Ant Tracking
PreStack seismic attributes
Study of anisotropy of longitudinal waves along distances and azimuths
Prediction of mechanical parameters according to the data of elastic methods

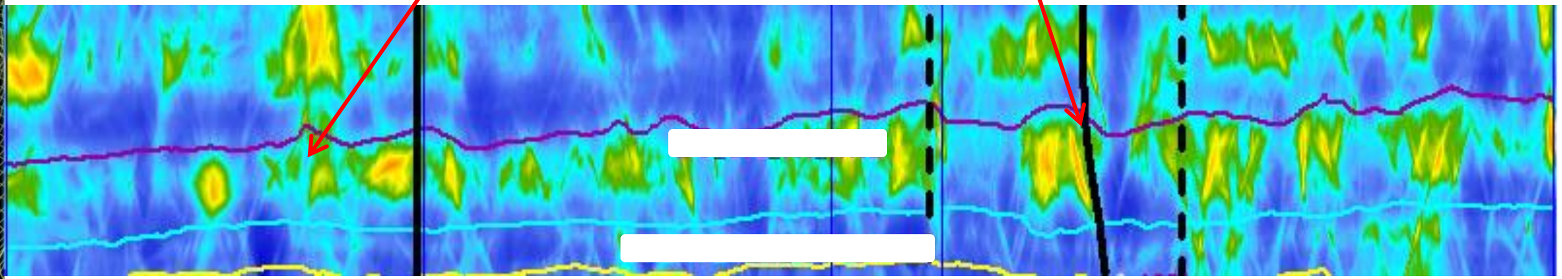


Example of fracture prediction for carbonate rocks

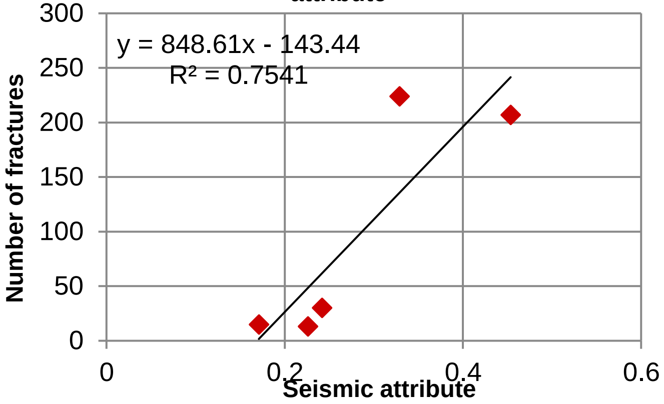
Attribute Map



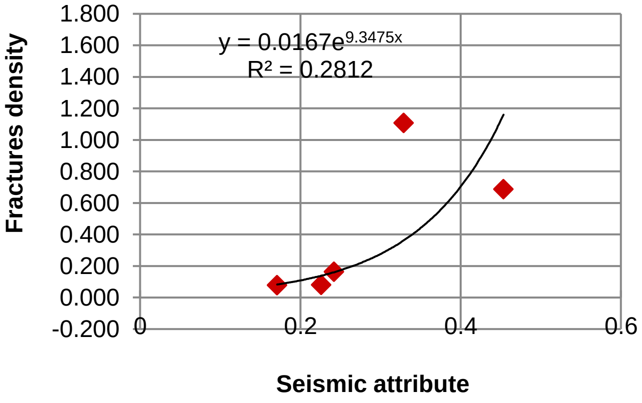
Time Section



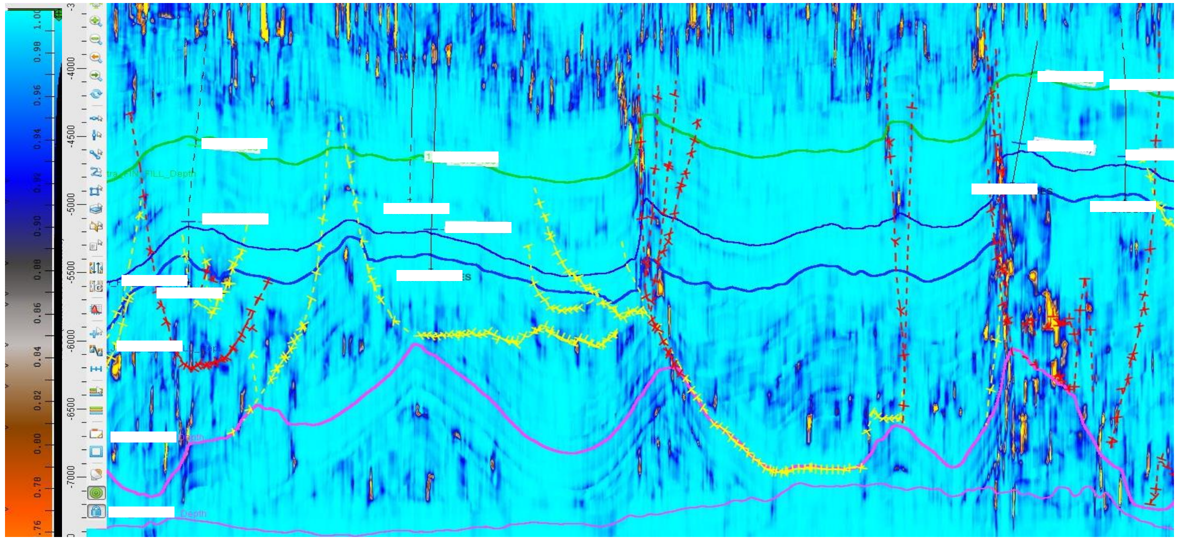
Graph of the dependence of the density of the number of fractures in the reservoir interval on the values of the seismic attribute



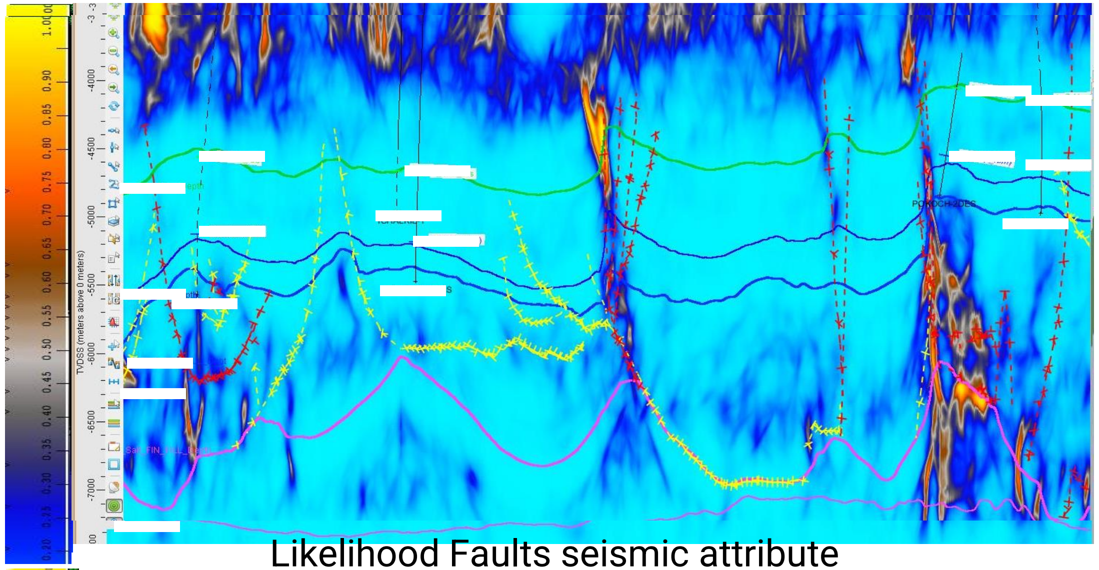
Graph of Fracture Density/Reservoir Thickness vs. Seismic Attribute Values



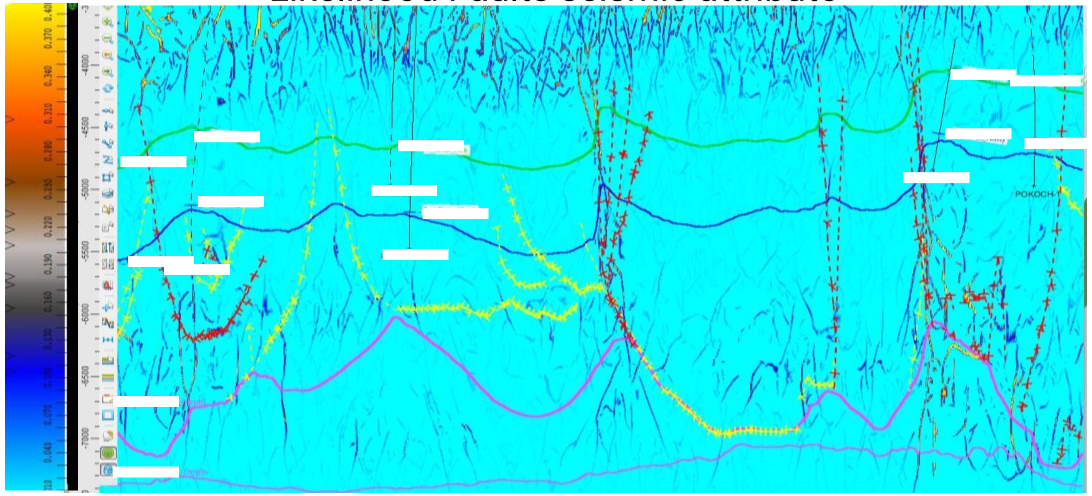
Analysis of Attributes



HR-SMB Seismic Attribute



Likelihood Faults seismic attribute



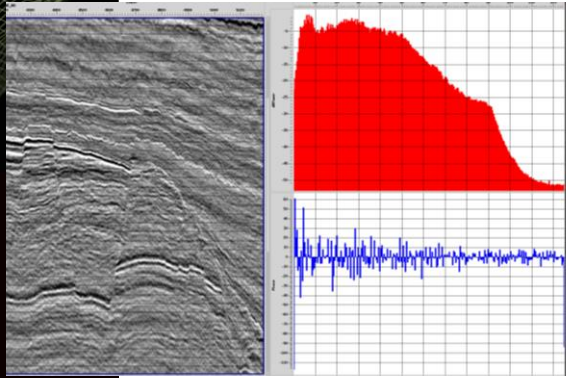
Seismic Attribute Likelihood Thin Faults

- Zones of tectonic Fractures and implicit thin elements are visible on seismic attributes both in fault zones and outside them.
- The seismic attribute combines the clarity and detail of faults according to the Likelihood Faults attributes

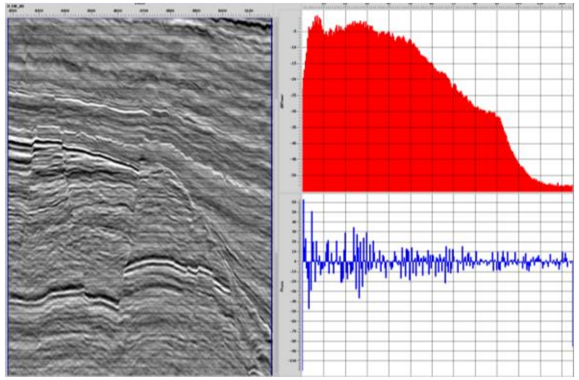
Tensor-based Structural smoothing process

Tensor based edge preserving structural smoother

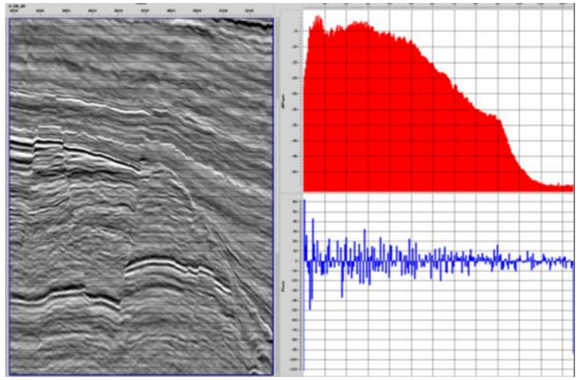
Raw mig Stack



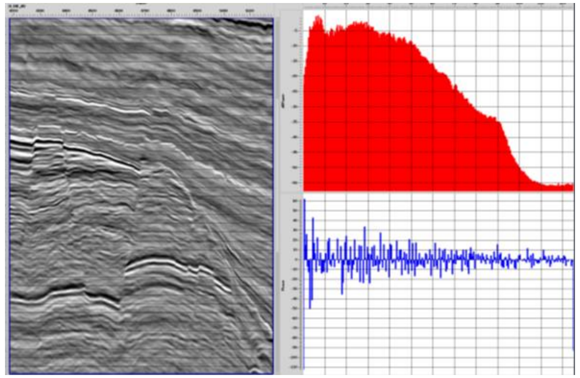
Strenth 8



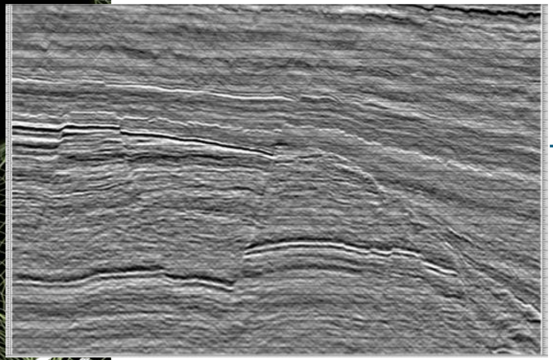
Strenth 16



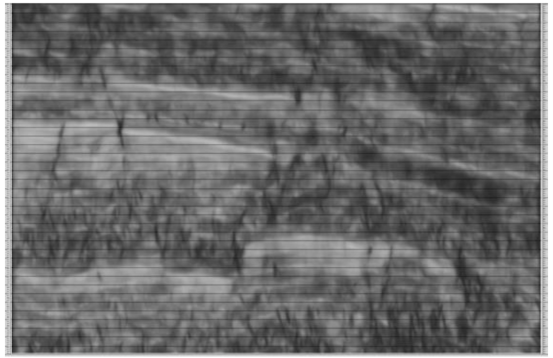
Strenth 32



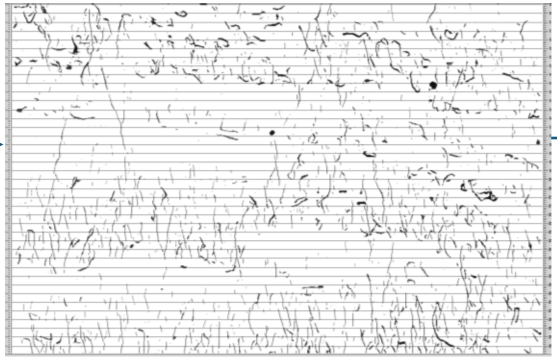
Raw mig Stack



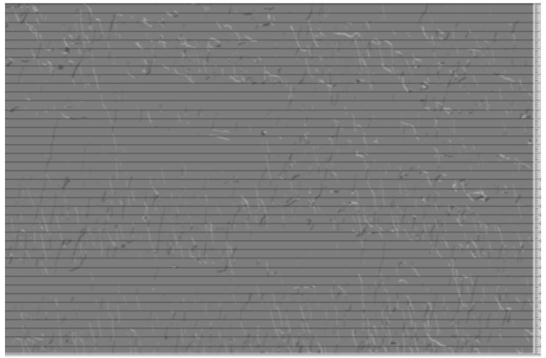
Fault likelihood



Thinned Fault likelihood



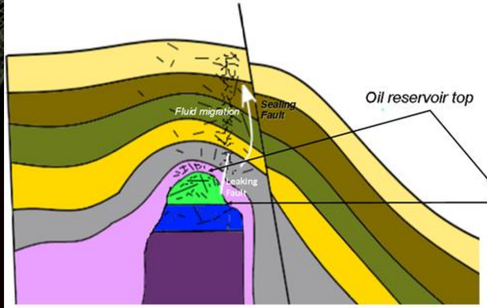
Fault Tracking



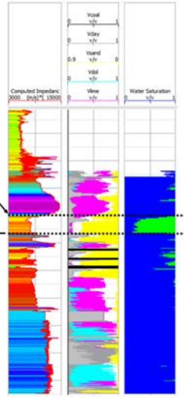
Prediction of Sealing or leaking faults when no wells available – PSS-Geo proprietary technology

PSS-Geo

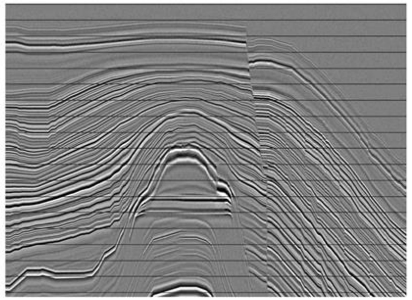
Modeling of Reservoir and Leaking & Sealing Faults



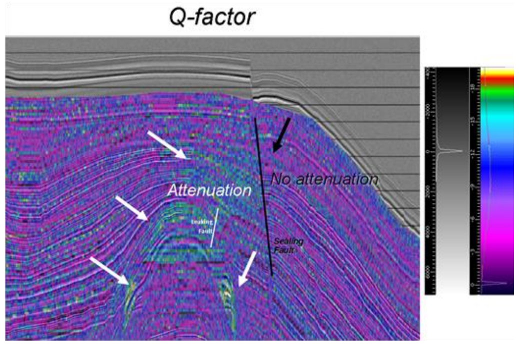
a) Model of Reservoir and fluid leaking trough the fault (in white). Fractured rocks above reservoir tough which fluid is migrating. Sealing Fault in black.

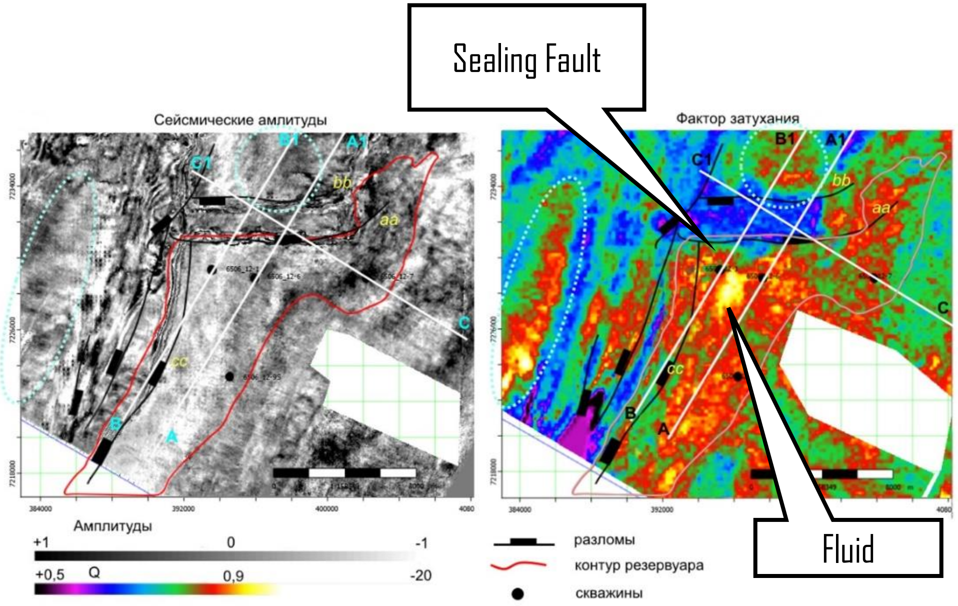


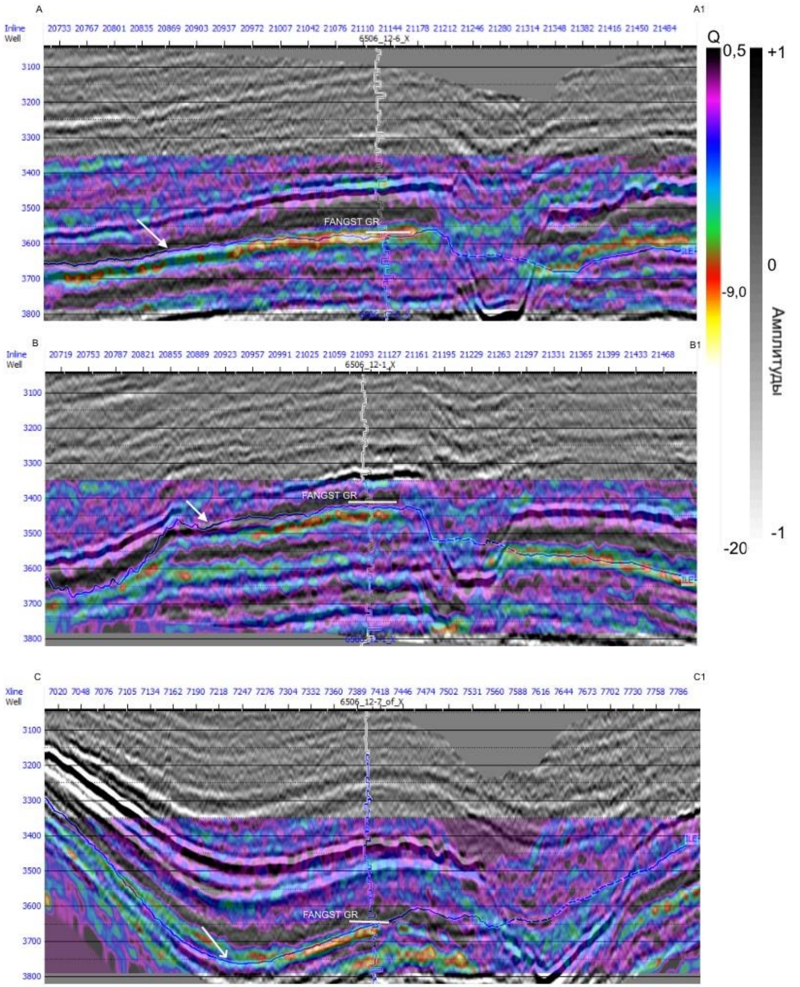
c) Real logs used in seismic modeling



c) Synthetic seismic of model a).







- Presented on GeoConvention 2018
- EAGE 2018

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Module 3

Geothermal in Romania

Case studies

Learning objectives

- To understand status of geothermal industry in Romania
- To get aware about current projects and their geological features
- To study example how seismic and electric surveys can be evaluated for use in geothermal
- To understand real case of waste-to-energy plant

Content

Module 1

Geothermal energy concept overview

Geothermal business. How does it look?

Setting the scene and motivation

Module 2

Geoscience for geothermal

Geophysical methods for geothermal

Module 3

Geothermal in Romania

Case study examples (separate presentations):

1. Geothermal energy project Beius – feasibility study for implementing of Electrical and Seismic surveys
2. Examples of Beius and Tasnad geothermal projects – business aspects
3. Reprocessing of legacy seismic data possibility in Romania

Geothermal in Romania
Heating, Power, Direct use

- According to the IRENA study, Romania has an installed a geothermal electricity capacity of 0.05 MWe and 245 MWth geothermal installed capacity for heating and cooling
- More than 250 boreholes at depths between 800 and 3,500 meters have indicated the presence of geothermal resources at temperatures of 40-120°C
- Since 1960 geothermal water started to be used in Romania for recreation purposes, geothermal industrial production started in 1980. Since 1990/1991 two companies operate geothermal: TRANSGEX S.A. (Bihor, Satu Mare counties, Pannonian Basin), FORADEX (Banat county, Olt Valley, and Bucharest region, Pannonian Basin)

Heat flow maps Romania. Estimated temperatures at 3000m

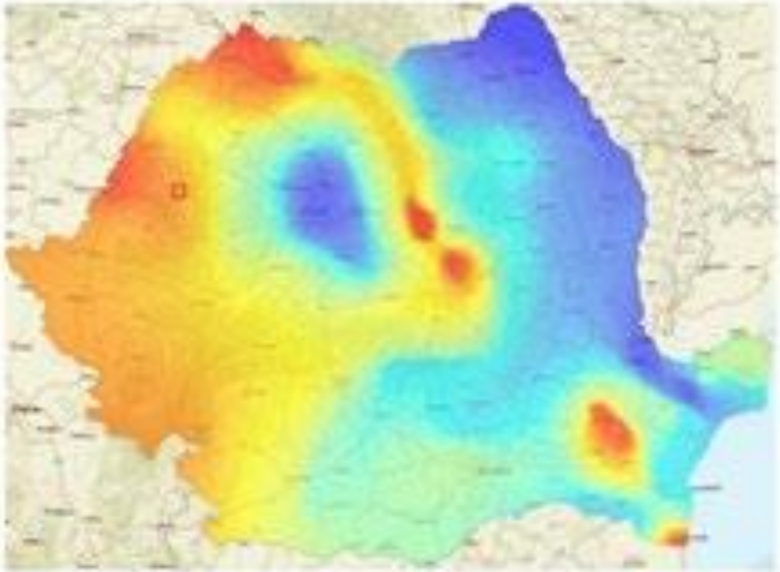


Figure 33 Heat flow in Romania (Raster resulted by interpolation of heat flow isolines - mW/m² -from Map of heat flow, Visarion et al, 1985)

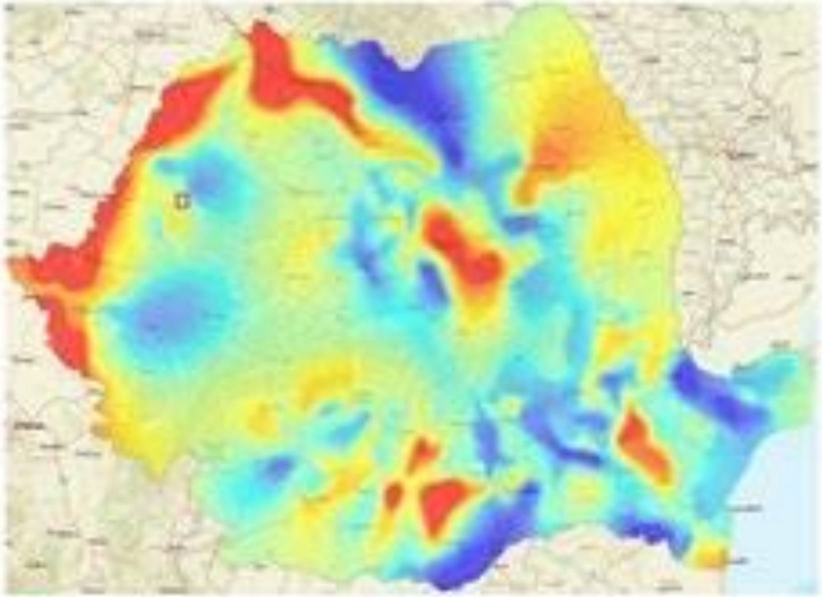
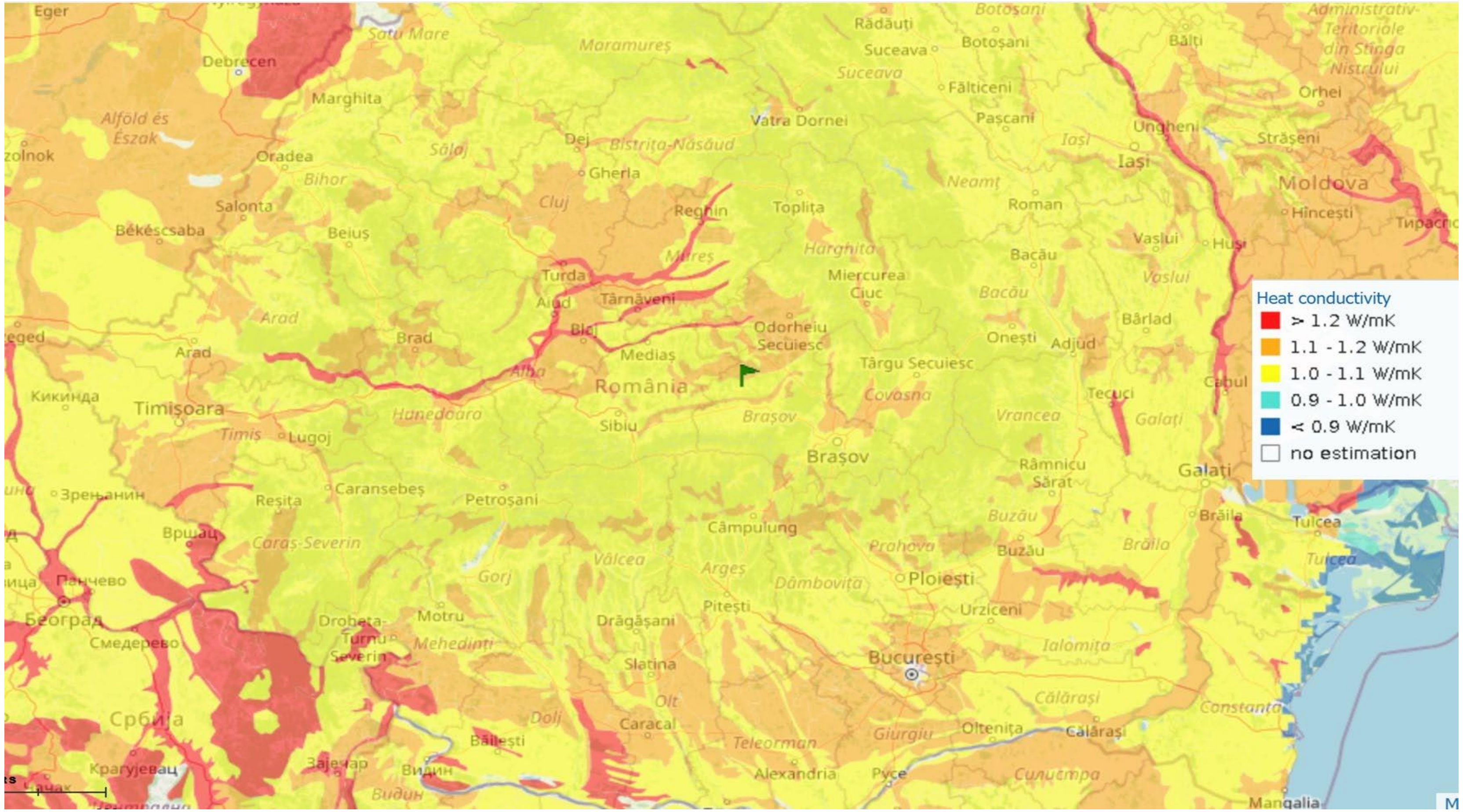


Figure 34 Map of temperatures at 3000 meters depth (Raster resulted by interpolation of geoisotherms - °C - from Map of heat flow, Visarion et al, 1985)

Public/published existing maps

Heat conductivity for shallow geothermal (house heating)



Geothermal reservoirs

Western Romania

Pannonian aquifer
- 2500 km²
- basement Neocene sandstone
- 800 – 2400 m depth
- 50-85°C
- TDS 4-5 g/l, carbonate scale, CH_4

Oradea reservoir (310 l/s recharge)
- 75 km²
- Triassic limestone & dolomites
- 2200 – 3200 m depth
- 70-105°C
- TDS 0.9-1.2 g/l

Bors confined reservoir
- 12 km²
- Triassic limestone & dolomites
- 2500 m depth
- >120°C
- TDS 13 g/l
- 5 Nm³/m³ gas content (70% CO_2, 30% CH_4)
- very high scaling potential

Beius reservoir
- 47 km²
- Triassic calcite & dolomite
- 1870 – 2370 m depth
- 84°C
- TDS 0.5 g/l, CO_2, H_2S traces
- Depth: 2.5 – 3 km

Ciumeghiu reservoir
- 5 MW_{th} potential
- gritstone
- 2200 m depth
- 105°C
- TDS 5-6 g/l, 3 Nm³/m³ CH_4

Source of image:

https://stirileprotv.ro/stiri/actualitate/apele-geotermale-ar-putea-castiga-lupta-romaniei-pentru-energia-ieftina-si-regenerabila.html

Geothermal reservoirs

Cozia-Calimanesti reservoir

- 28 km²
- Senonian siltstones
- 2700 – 3250 m depth
- 70-95°C
- TDS 15.7 g/l
- 1-2 Nm³/m³ CH_4

Source of image:

https://stirileprotv.ro/stiri/actualitate/apele-geotermale-ar-putea-castiga-lupta-romaniei-pentru-energia-ieftina-si-regenerabila.html

Geothermal reservoirs

Geothermal resources in Bucharest-Ilfov Region

Otopeni geothermal reservoir (Rosca et al., 2010)

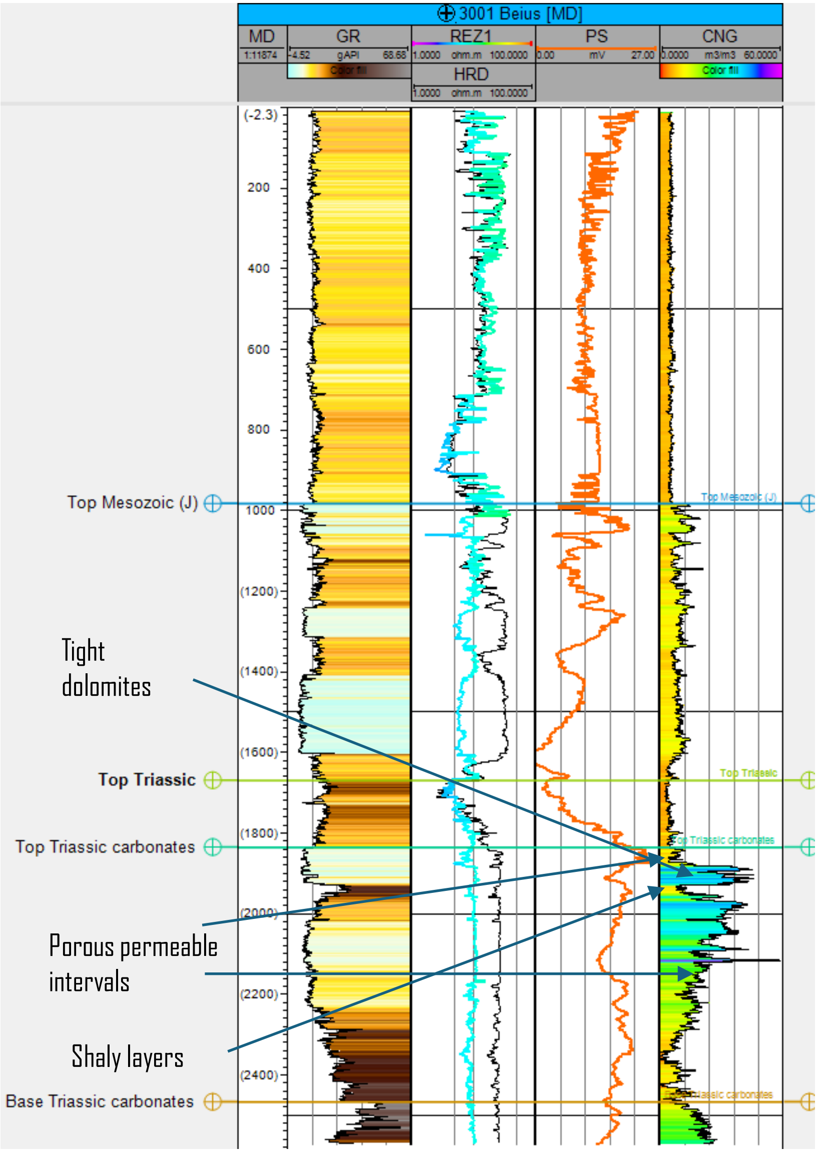
- Location: North of Municipality of Bucharest (North of Ilfov County)
- Area: 300 km²
- Drilled wells: 24 (18 wells – production or injection)
- Geology structure: sedimentary rocks (limestone and dolomites)
- Location of geothermal aquifer: 2000-3200 m
- Temperature gradient: 2.3 ÷ 2.6 ºC/100 m
- Wellhead temperature: 58 – 84 º C
- Flows: 22 ÷ 28 l/s

Source of image:

https://stirileprotv.ro/stiri/actualitate/apele-geotermale-ar-putea-castiga-lupta-romaniei-pentru-energia-ieftina-si-regenerabila.html

Current status of well geophysics use for exploration and appraisal purposes. Example Beius

Well	Available log data
4005	Resistivity, lithology description
4006	
4004	Resistivity, GR, NGR
4081	SP, Resistivity, GR, NGR, Density
4767	Microresistivity, GR, Neutron, CALI, Resistivity, SP, lithodescription
4796	
4797	GR, NGR, Density, SP, Resistivity, litho description
4795	GR, Resistivity, litho description
1715	SP, GR, rock description, Resistivity, NGR, Density
1716	SP, GR, petro interp, resistivity, CALI
1717	SP, Resistivity
1709	SP, GR, CALI, Resistivity, NGR, Density, petro intepretation
1731	GR, CALI, Resistivity, SP (relatively new log suite but not relevant because well did not penetrate Triassic)
3001	SP, CALI, Resistivity, GR
3005	
3004	Weatherford (ILL, Neutron, Density, GR, MPD – Compact photodensity)
3003	



Well data - curtesy of TRASGEX company

- Well log data is used at time of well completion decision making, some interpretation is done by logging contractors for individual wells. Log data is not digitized to be actively used in interpretation.
- Core data is not often available for The Operator
- Well data can be used more extensively for purpose of creating more detailed geological concept. It may help to derisk reservoir performance.
- Based on communication with Romanian expert such situation is common in geothermal projects

Current status of geophysics use for exploration and appraisal purposes

PSS-Geo
Transgex

- G&G work is based on wells and regional studies available in the area. Used well information generally include stratigraphy, macro core and cuttings description, observations during drilling
- Water properties measurements are more regulated, detailed water composition analysis have been done in frame of several recent researches [1, 3] and as part of process addressing scaling issue work in neighbor Borş geothermal field [2].
- Geophysical surveys are not currently used or considered by The Operator in G&G modelling of future well planning.
- Number of recent studies addressing use of seismic 2D surveys and Magnetotelluric electrical surveys. Most of them are involving University of Bucharest. The outcome of the studies include processed seismic lines and structural interpretation of main surfaces. Information about well use during seismic interpretation have not been in the articles. None of found works is addressing directly commercial projects, done for research purposes.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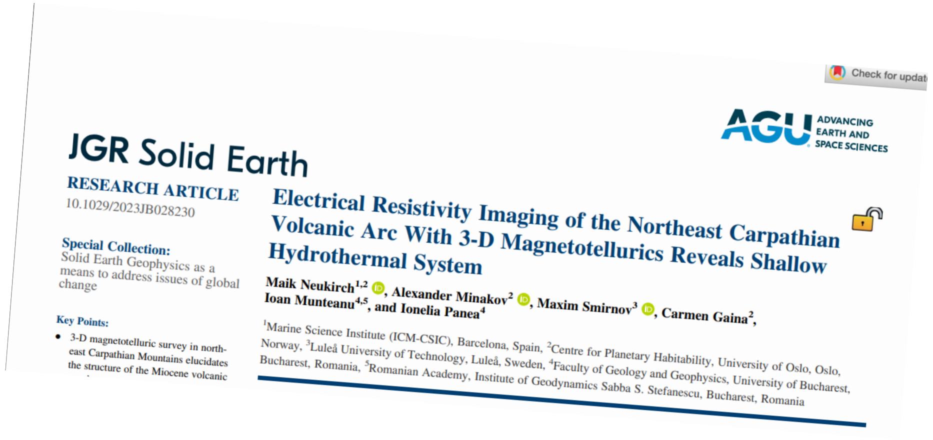
Pure and Applied Geophysics
CrossMark
Geophysical Analysis of Major Geothermal Anomalies in Romania
Ionelia Panea and Victor Mocanu

Scientific Research Publishing
Open Journal of Geology, 2020, 10, 53-70
https://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570
Imaging of Hidden Structures from the North Apuseni Mts, Romania, Using Narrow-Angle Seismic Reflection Data
Ionelia Panea

Received: 14 September 2022 | Revised: 3 May 2023 | Accepted: 7 August 2023
DOI: 10.1111/ter.12677
RESEARCH ARTICLE
Terra Nova WILEY
Miocene tectonic activity at the boundary between NE Pannonian and NW Transylvanian basins (Romania): Insight from new seismic data
Ionelia Panea[1] | Ioan Munteanu[1] | Carmen Gaina[2] | Victor Mocanu[1] | Relu Dumitru Roban[1] | Catalin Florin Bouaru[1] | Geysir-BaiaMare Working Group

CHPM2030
CHPM2030 DELIVERABLE D6.2.3
REPORT ON PILOTS: EVALUATION OF THE CHPM POTENTIAL OF THE STUDY SITE, ROMANIA

[1] Balassa et all: DOI:10.35925/j.multi.2023.4.6
[2] STĂNĂŞEL et all 2005
[3] Petrescu-Mag et all 2009


JGR Solid Earth
AGU ADVANCING EARTH AND SPACE SCIENCES
RESEARCH ARTICLE
10.1029/2023JB028230
Special Collection: Solid Earth Geophysics as a means to address issues of global change
Key Points:
- 3-D magnetotelluric survey in north-east Carpathian Mountains elucidates the structure of the Miocene volcanic
Electrical Resistivity Imaging of the Northeast Carpathian Volcanic Arc With 3-D Magnetotellurics Reveals Shallow Hydrothermal System
Maik Neukirch[1,2], Alexander Minakov[2], Maxim Smirnov[3], Carmen Gaina[2], Ioan Munteanu[4,5], and Ionelia Panea[4]
[1]Marine Science Institute (ICM-CSIC), Barcelona, Spain, [2]Centre for Planetary Habitability, University of Oslo, Oslo, Norway, [3]Luleå University of Technology, Luleå, Sweden, [4]Faculty of Geology and Geophysics, University of Bucharest, Bucharest, Romania, [5]Romanian Academy, Institute of Geodynamics Sabba S. Stefanescu, Bucharest, Romania

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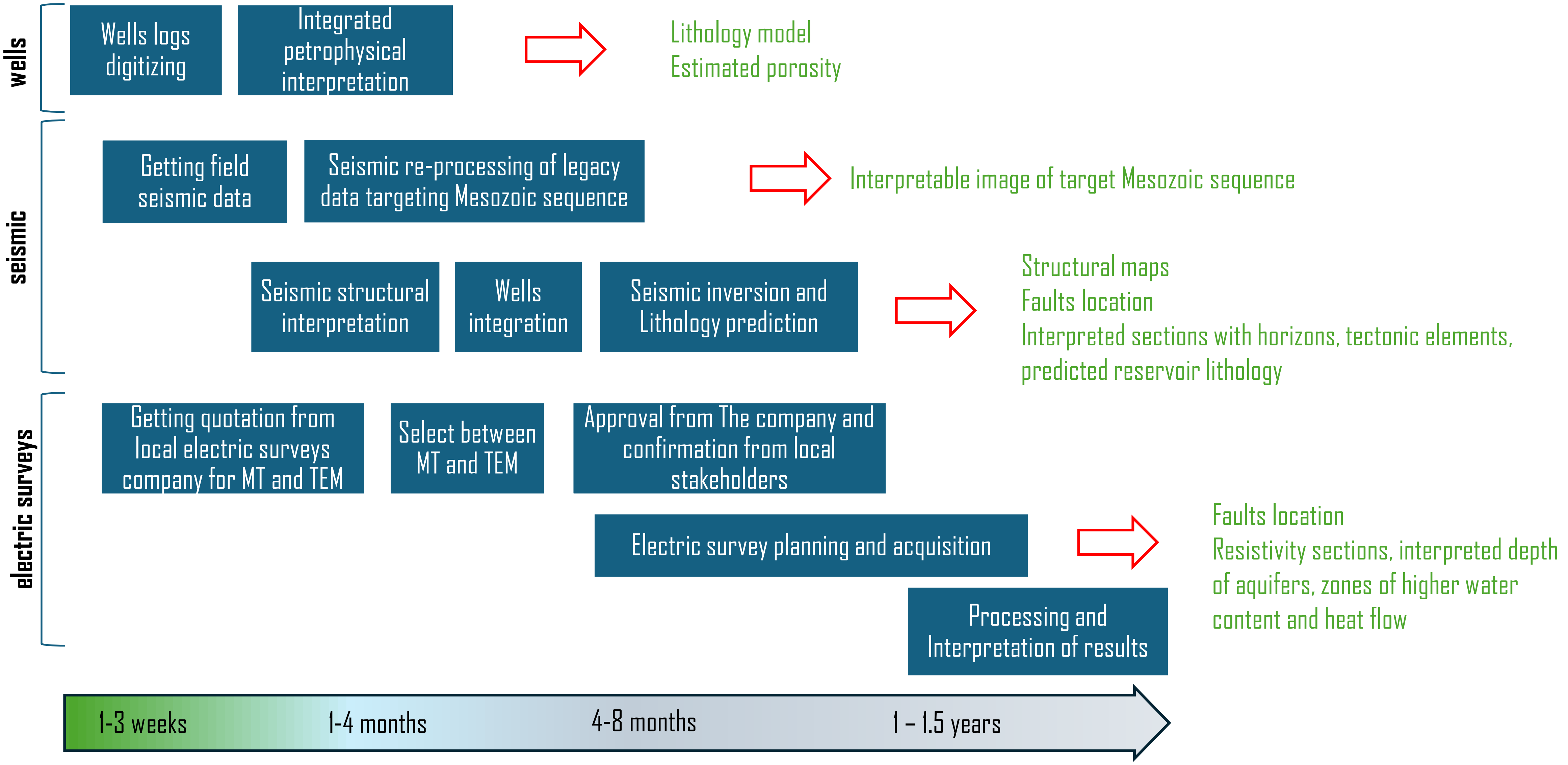
Recommended workflow for integrated analysis of geophysical data for Romanian projects



Module 3

Geothermal in Romania

Case studies

Available in separate presentations in project folder.
If you did not find please send email to vita@pss-geo.com