Geothermal projects: Exploration, Drilling, Plant, Exploitation, Operation& Maintenance





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Geothermal Innovation & Sustainability
Enel Green Power

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The Geothermal Value Chain

Integrated business model – Striving for Excellence

Enel Green Power

Centennial experience (since 1904) in geothermal electricity generation and fluid use

Project Development/ Finance	Exploration & Drilling	Plant design/ construction	Plant operation	R&D
• Acquire land rights • Risk evaluation depending on country and technology • Transmission System Access • Power sales contract negotiation • Acquisition of concessions	• Best practice in drilling target identification • Geological Model and reservoir evaluation • Predictive methodology for exploration of deep geo resources • Skills and equipment to drill vertical and deviated geothermal wells • Innovative flow testing programs to forecast well performance	• Well proven concept design in diverse technologies: dry steam , flash and binary • Provide an environment of competition in equipment procurement and construction • Standardize where possible	• Fully developed internal safety and operations procedures • Optimized geo-resource management (reservoir and power plant) for sustainable exploitation • In house maintenance and repair capability • Plants remotely monitored and controlled from a centralized location	• Low Enthalpy Innovative Geothermal Plants • Developing hybrid system • Plant improvement: acid gas components abatement • Improved efficiency and flexibility

EGP growth in traditional high temperature resources and also in binary technology

The Geothermal Value Chain
Prefeasibility, feasibility and project development

Enel Green Power

Prefeasibility

- Country level studies to rank opportunities
- Resource assessment & evaluation referred to new opportunities:
    - green fields
    - brow fields
    - fields in exploitation

Feasibility

- Surface exploration: definition, planning, execution, interpretation
- Data analysis and interpretation to define the preliminary Geothermal Model
- Deep exploration planning
- Mining project definition
- Environmental impact studies

Construction

- Wells location and target
- Site geology
- Wells construction addressing
- Logs & tests planning

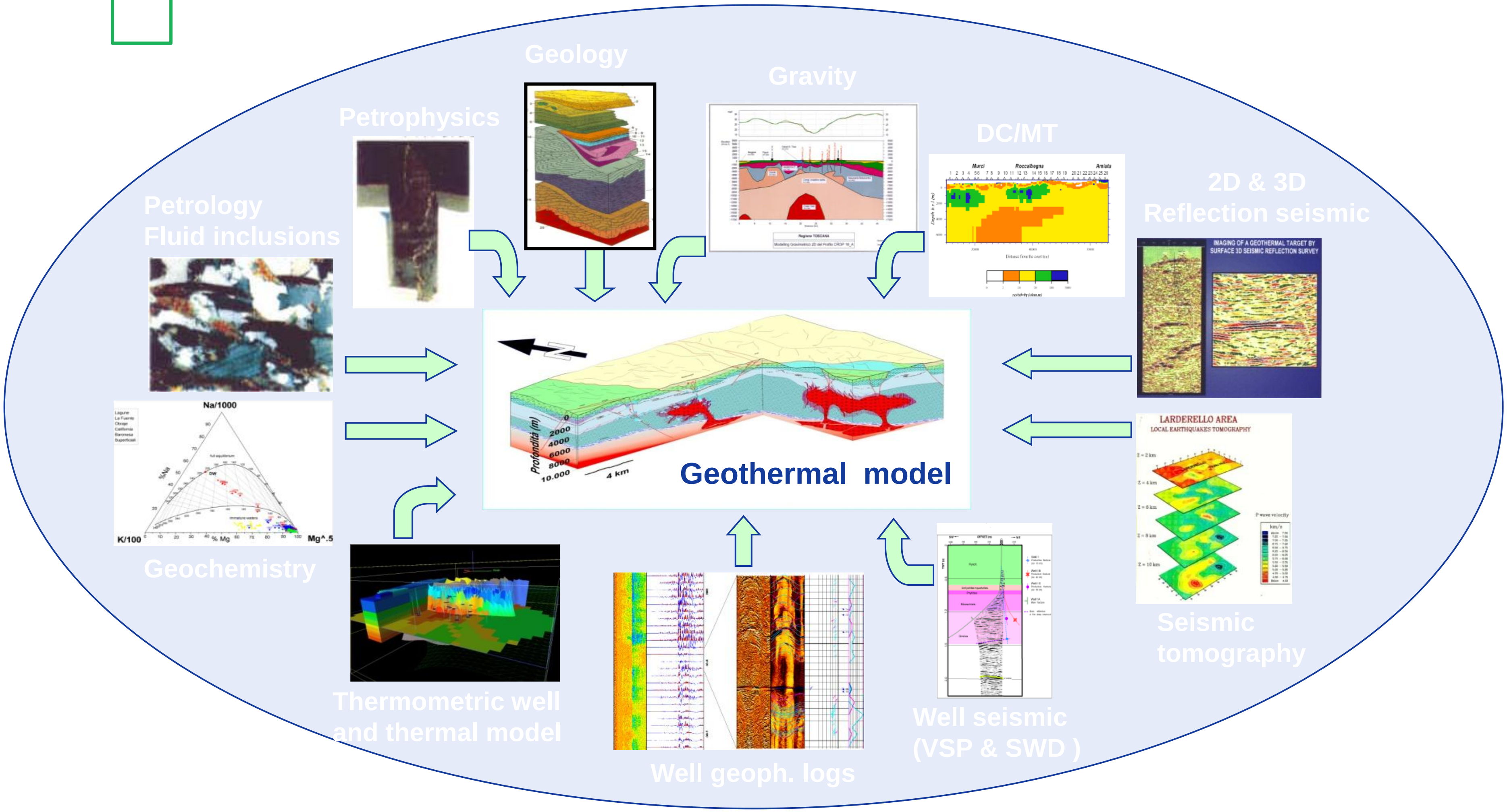
Field exploitation

- Monitoring plan definition
- Data collection and analisys
- Resource forecast
- Production recovery plan definition: make up wells, stimulation jobs, work over

The entire geothermal value chain covered

The Geothermal exploration

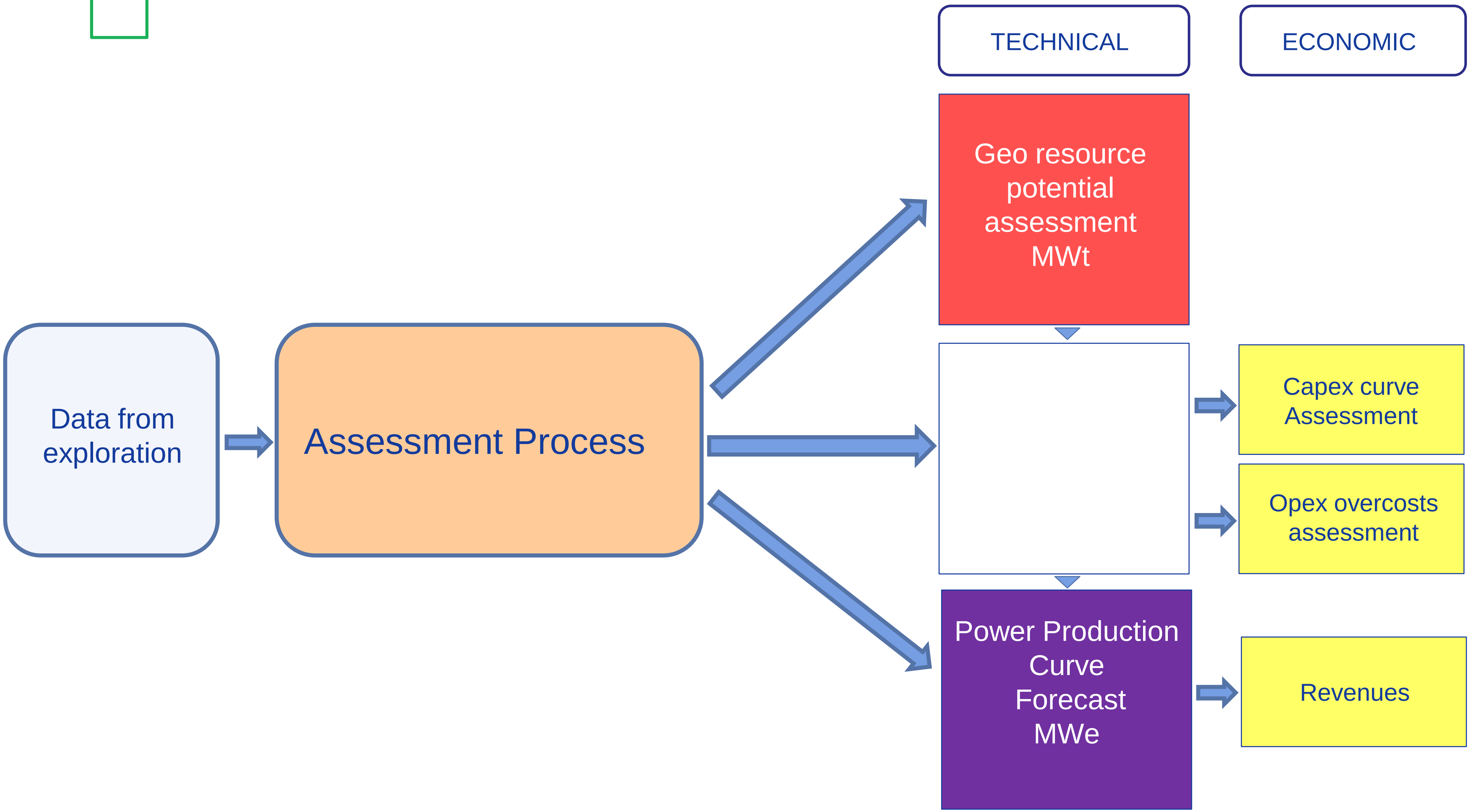
..a multidisciplinary approach



The joint interpretation is the key to get the most reliable geothermal model

New Geothermal project development

The assessment process



New Geothermal project development

The assessment process

Exploration Lease		Mining Lease	
SURVEY PROJECT	**EXPLORATION PROJECT**	**DEVELOPMENT PROJECT**	**EXPLOITATION / MINING**
ACTIVITIES IDENTIFICATION OF THE ENVIRONMENTAL CONSTRAINTS GEOLOGICAL SURVEYS GEOCHEMICAL SURVEYS GEOPHYSICAL SURVEYS	**ACTIVITIES** GEOPHYSICAL SURVEYS	**ACTIVITIES** 3D SEISMIC SURVEYS	**ACTIVITIES** Production and Reinjection wells Seismicity & Subsidence monitoring
TARGET(S) **IDENTIFICATION OF POTENTIAL RESERVOIR**	**TARGET(S)** **RESOURCE ASSESSMENT**	**TARGET(S)** **DEFINITION OF MINING**	**TARGET(S)** **MAXIMIZING PRODUCTION**
Surface ≈ 10^3 km^2 **Costs ≈ 3 k$/$km^2$**	Surface ≈ 10^2 km^2 Survey Costs ≈ 6 k$/$km^2$ Drill. Costs ≈ 150 k$/$km^2$	Surface ≈ 25 km^2 Costs ≈ 50 k$/$km^2$ Drill. Costs ≈ 1500 k$/$km^2$	

The Geothermal prefeasibility

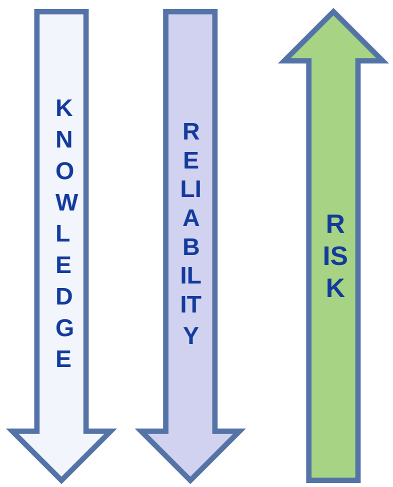
Geothermal projects assessment

The geothermal projects assessment is a **continuous improving process** along the project advancement

Goals, tools and methods, reliability of the assessments change with project development level

Project level

- **Green field (surface exploration)**
- **Brown field (Deep exploration)**
- **Construction**



Increasing With Project Progressing :

- The type and amount of available experimental data
- The type and effectiveness of appropriate tools for the assessment
- The **reliability** of the **resource assessment**
- The **accuracy** and **completeness** of the **Capex estimation**
- The technical data necessary for the final project design

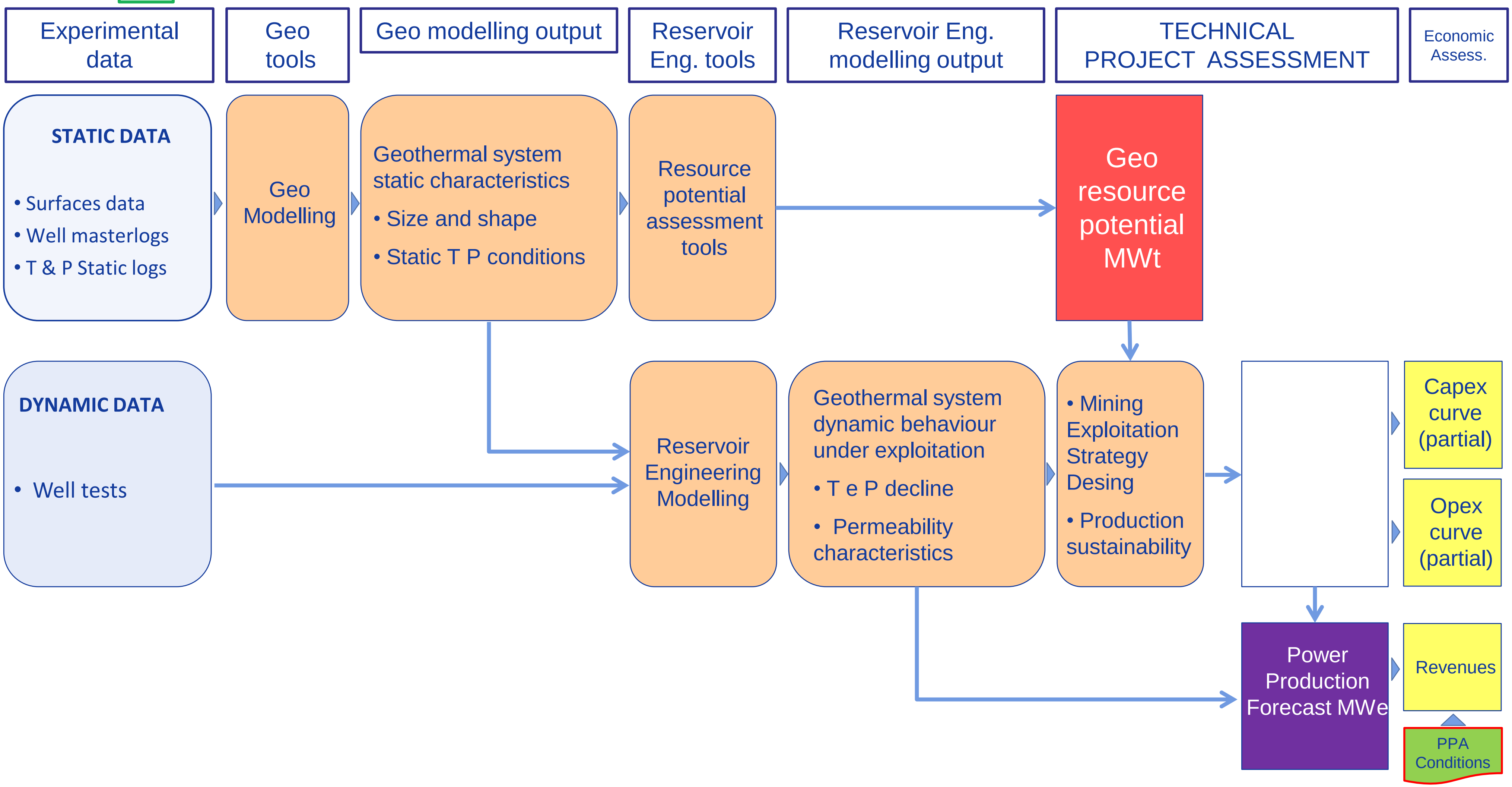
Decreasing With Project Progressing :

- The uncertainty of the assessment
- The project risk

Field in operation → The production sustainability has to be monitored and revised also during the whole field operational life in order to

New Geothermal project development

The assessment process



The Geothermal prefeasibility

Country geothermal scouting – The process

The **scouting process** steps

OUTPUT

1) **Preliminary assessment on bibliographic data**
   Data collection and data base organization
   Identifying and assessing areas of potential interest
   → Geothermal Atlas

2) **Preliminary Ranking on bibliographic data**
   Ranking criteria definition
   Application of Ranking criteria to the Atlas
   → Preliminary Geothermal Ranking

3) **In field studies**
   Preliminary areas selection
   On site reconnaissance and data collections
   Data evaluation and assessment updating
   → Atlas Updating

4) **Ranking updating**
   → Final Ranking

Step 1 > Step 2 > Step 3 > FINAL OUTPUT

The Geothermal prefeasibility

Country geothermal scouting – The Atlas

Data collection and data base organization

Identifying and assessing areas

Bibliographic data collection

- Natural manifestations inventory
- Chemical analysis and geochemical data
- Geological , tectonic, volcanological, hydrogeological data
- Geophysical surveys

Data base organization

- GIS Data and Geo-referenced Data within GIS SYSTEM
- Not Geo-ref Data within monographic sheets framework or technical report

- Locating and bounding areas on GIS base
- T Geothermometric estimation
- Preliminary conceptual modeling
- Areas size estimation
- Potential resource assessment (MWT)
- Environmental and logistical conditions evaluation (accessibility, morphology, protected areas, transmission line distance, ecc.)

Geothermal Atlas

Step 1 **Step 2** **Step 3** **FINAL OUTPUT**

The Geothermal prefeasibility

Country geothermal scouting – The Preliminary Ranking

Selection and analysis of the relevant topics

Choice of algorithm combining weighted relevant topics

Preliminary Geothermal Ranking

- Inferred Temperature
- Inferred size of the area
- Inferred potential (MW)
- Geothermal System Type
- Geological framework
  - Volcano-tectonic setting
  - Natural manifestations (temperature & distribution)
  - Fluid chemistry
  - Hydrothermal alteration
  - Mining exploitation activity

- Defining topic values

(numerical or qualitative scale)

- Defining topic weigh
- Defining topics combining algorithm
- Algorithm application for each area

Selection of the most interesting areas for further investigations on site

Step 1 | Step 2 | Step 3 | FINAL OUTPUT

The Geothermal prefeasibility

Country geothermal scouting – in field reconnaissance

Areas selection and in field reconnaissance plan definition → In field reconnaissance & data collection → Data evaluation and assessment updating → **Geothermal Atlas Updating**

In field reconnaissance & data collection:

- Preliminary reconnaissance
  - Natural manifestation census
  - Outcrops and hydrothermal alteration pointing
  - Access roads evaluation
  - Environmental constrains
  - Preliminary geological reconnaissance
- Geochemical survey

Data evaluation and assessment updating:

- Chemical analysis
- Data elaboration
- Data interpretation (geo-thermometric revised estimation)
- Assessment revision

Geothermal Atlas Updating → Ranking criteria application → **Final Ranking**

Step 1 | Step 2 | Step 3 | FINAL OUTPUT

The Geothermal feasibility

Main target and phases of the exploration

Ascertain the presence of a geothermal resource and assess the technical- economical feasibility of its exploitation

Two phases

SURFACE EXPLORATION

DEEP EXPLORATION

Mining target delineation and characterization

Index of the main methods applied by Enel Green Power

Surface Exploration tools

- Geology and hydrogeology
- Geochemistry
- Geophysic
  - Gravity
  - Magnetotellurics (MT)
  - Reflection Seismic

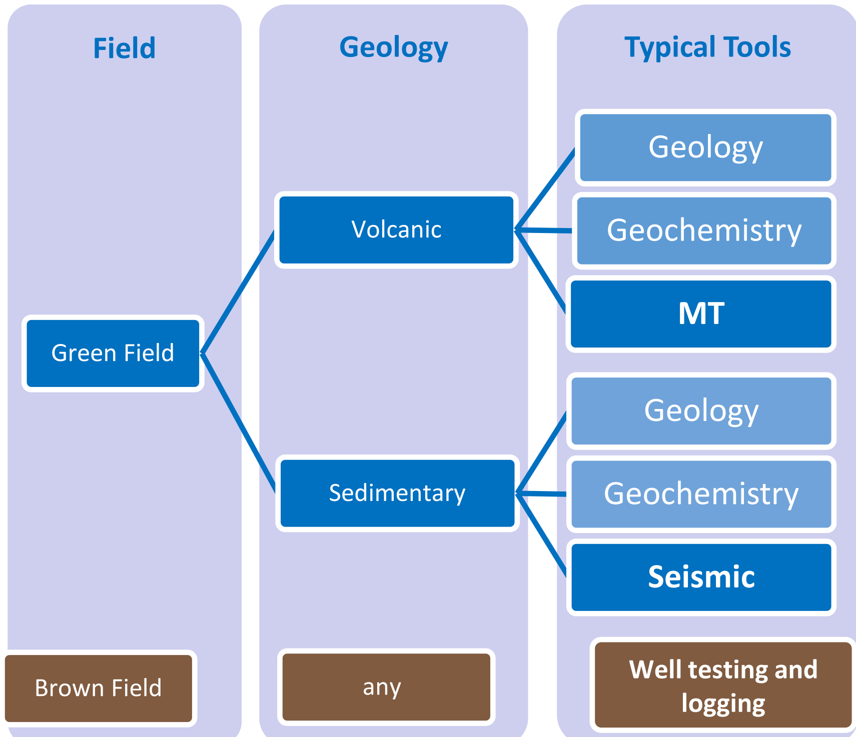
Deep Exploration tools

- Well testing and logging

Final goal is the reduction of the mining risk

Geothermal exploration

Typical field implementation of the skills



Reflecton seismic would be the most poweful survey for exploration and well targeting but:

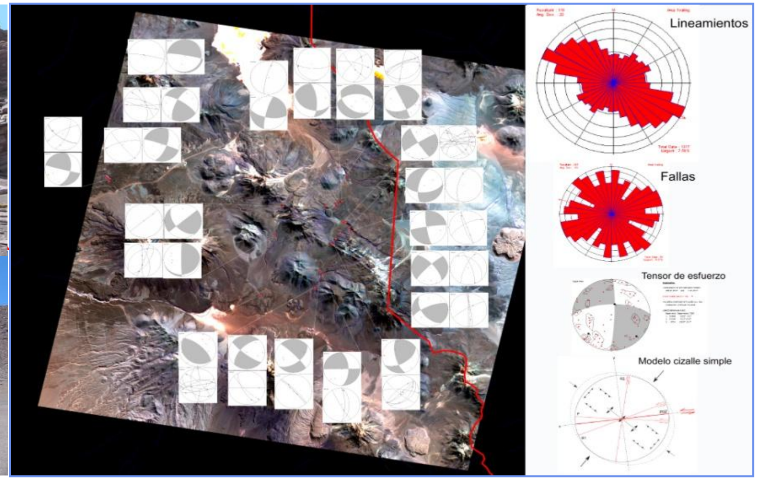
- doesn't work well in volcanic environment
- it is expensive (~10 times the MT)

Exploration skills for well targeting and reservoir modeling can be helpfully used at any stage of the project: **green and brown fields and fields under exploitation**

Surface exploration

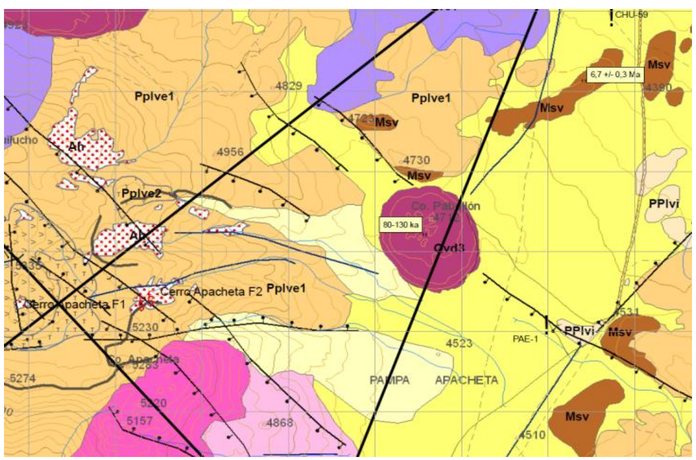
Geological and hydrogeological surveys

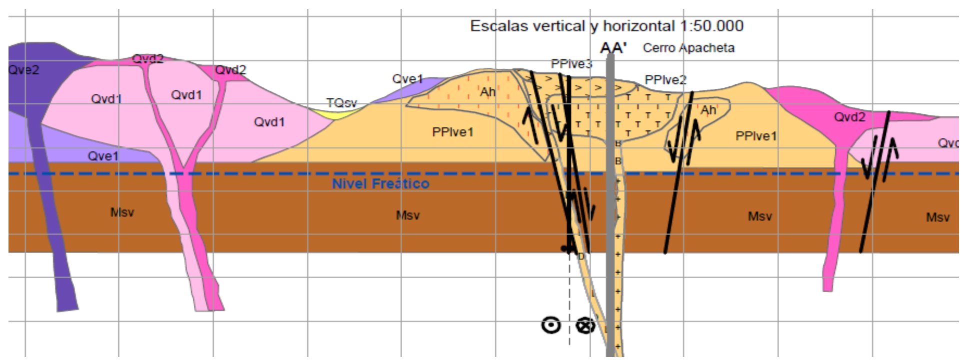
Surface geological reconstruction



Structural analysis of faults and lineamentes

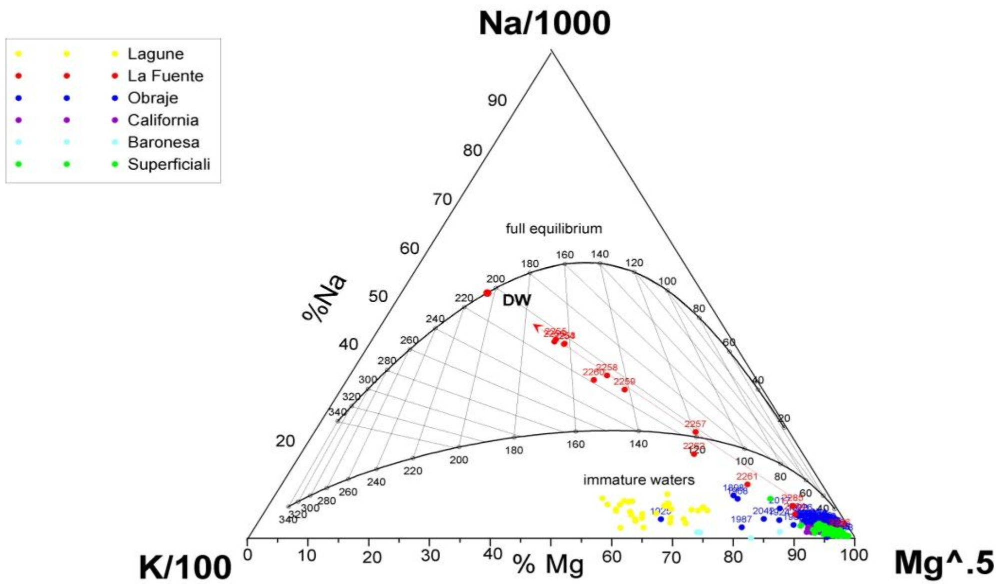
Studies of mineralization and hydrothermal alteration





Reconstruction of the geological model of the area by field recognition and satellite image analysis

Surface exploration
Geochemistry survey



Collection and analyses of water and gas samples from natural geothermal manifestations (thermal springs, fumaroles, etc.), freshwater and well.

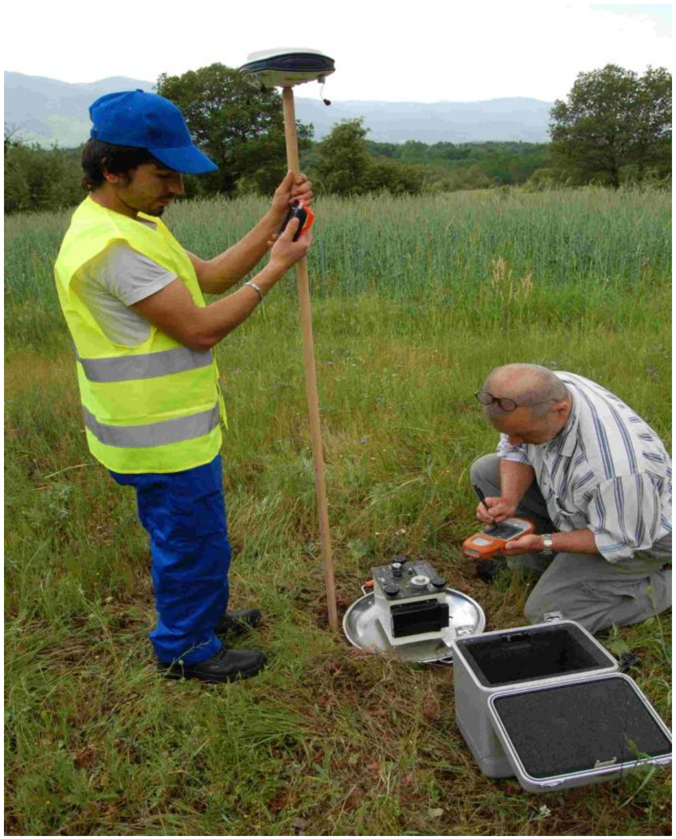
Two main targets:

- identification of areas with geothermal reservoir indicators (H_3BO_3, CO_2, NH_3, H_2S, etc.).
- estimation of the reservoir temperature and the recharge origin (Isotopic geochemistry).

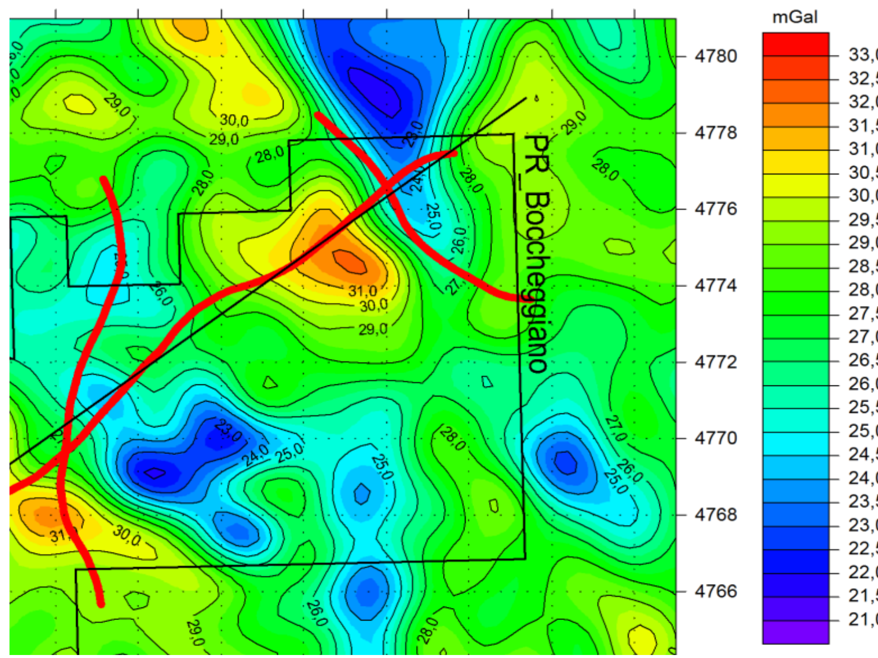
This activity is particularly useful in the prefeasibility phase

Surface exploration

Gravity survey



Gravity anomalies, are directly related to the distribution of the density in the earth, therefore can give indications on the structural geology.

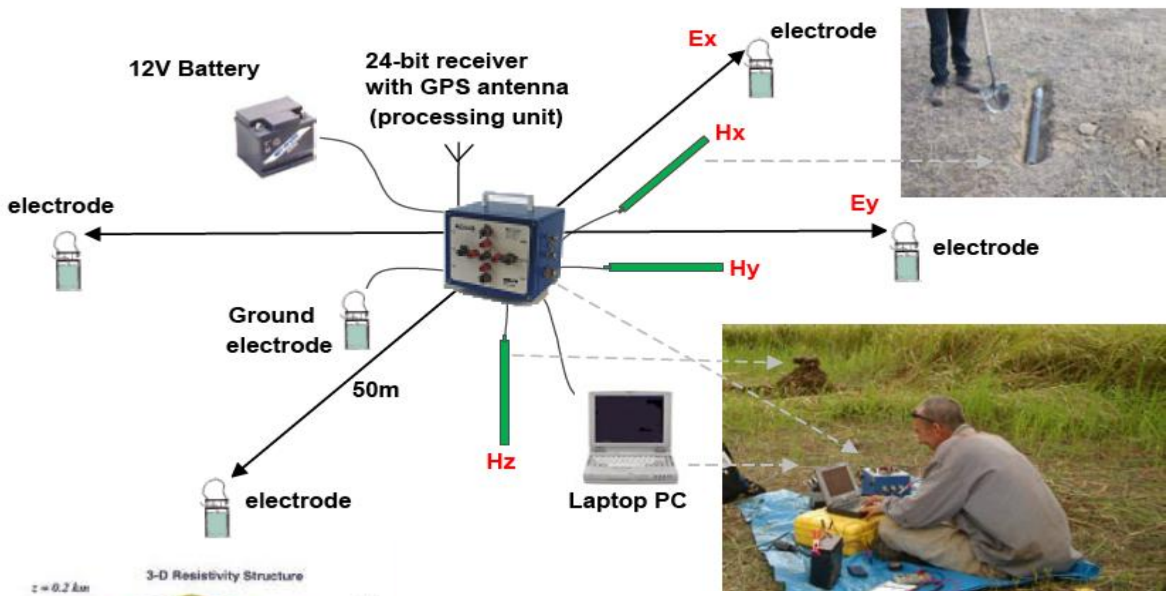


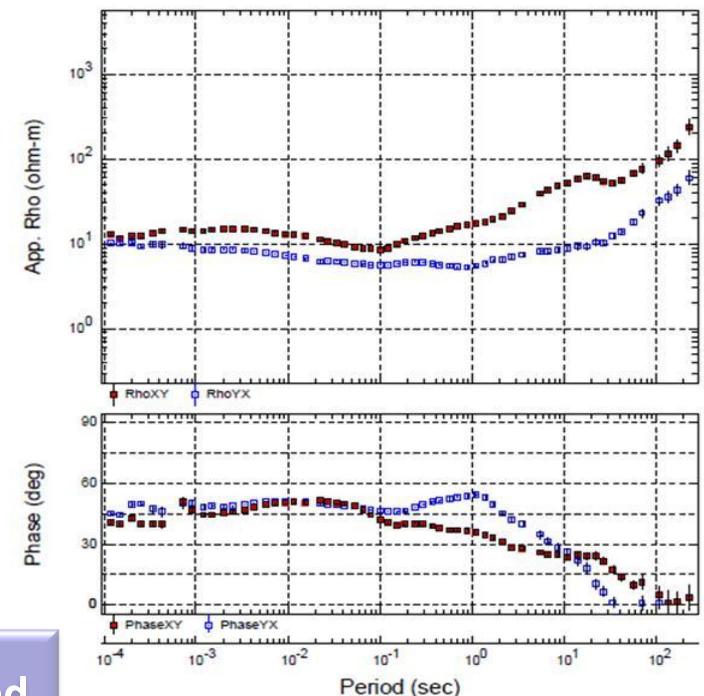
The cheaper and clever geophysical survey

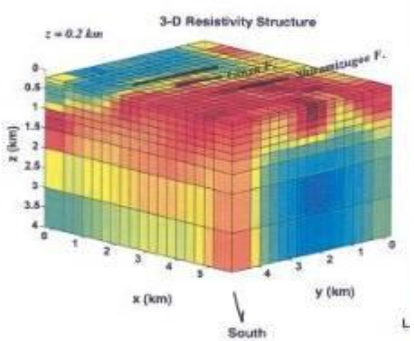
Surface exploration

Magnetotelluric survey (MT)

MT is a method for determining the resistivity of the earth by analyzing the change in time of the natural electric and magnetic fields.



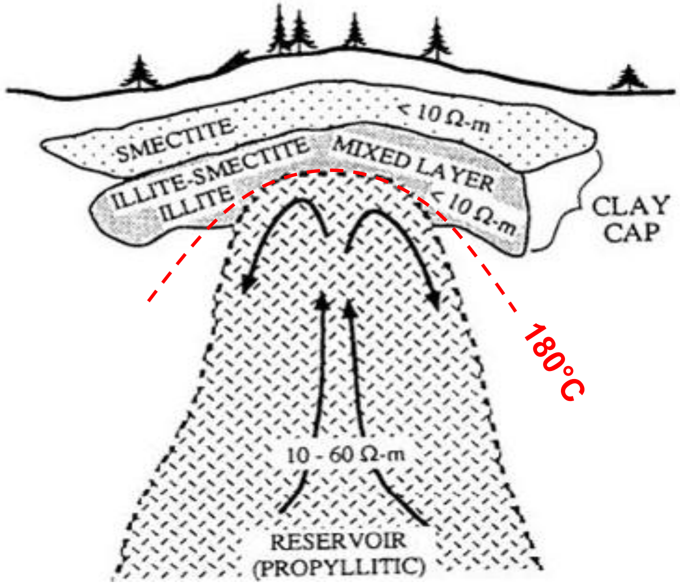


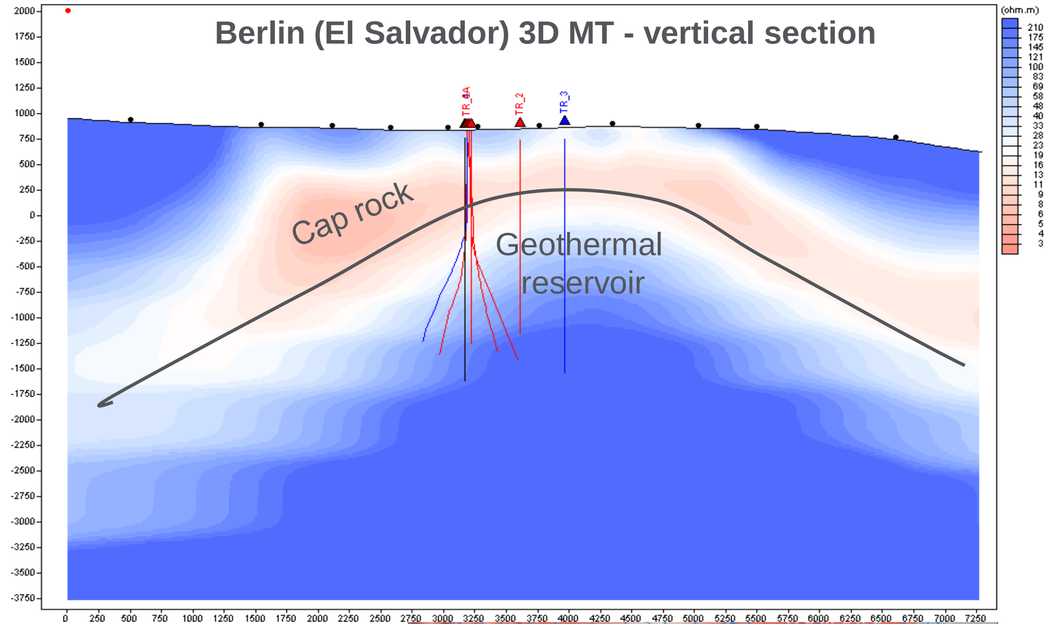


3D inversion modelling gives a detailed distribution of the conductive anomalies

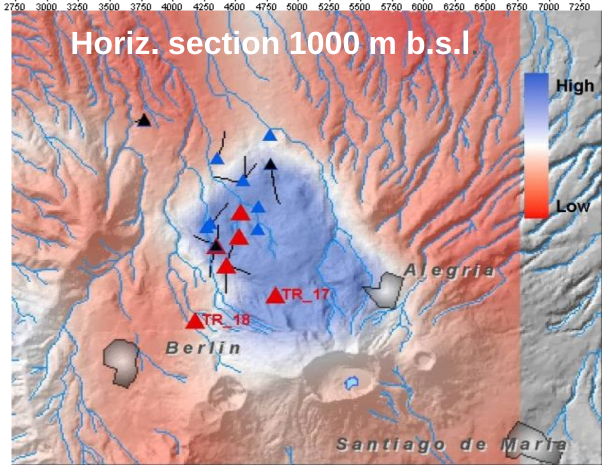
Surface exploration

Magnetotelluric survey – Volcanic environment





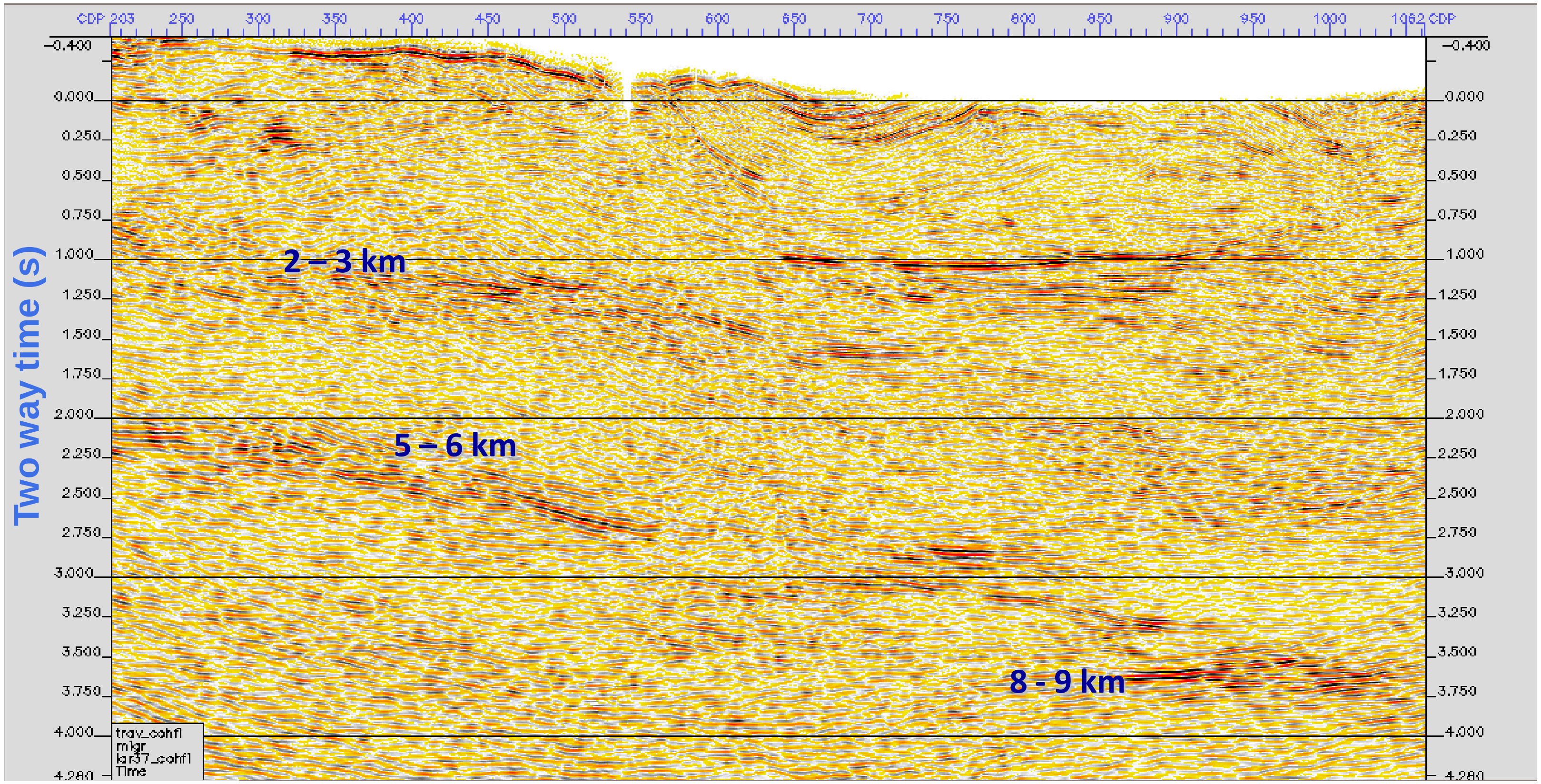
In volcanic environment hydrotermal fluids circulation at T <180 ° C, produces argillitic mineralization with low electrical resistivity (<10 ohm.m), while circulation at T> 180°C produces propylitic mineralization highly resistive (10-100 ohms. m).



In the volcanic environment MT may show features directly linked to a geothermal system

Surface exploration

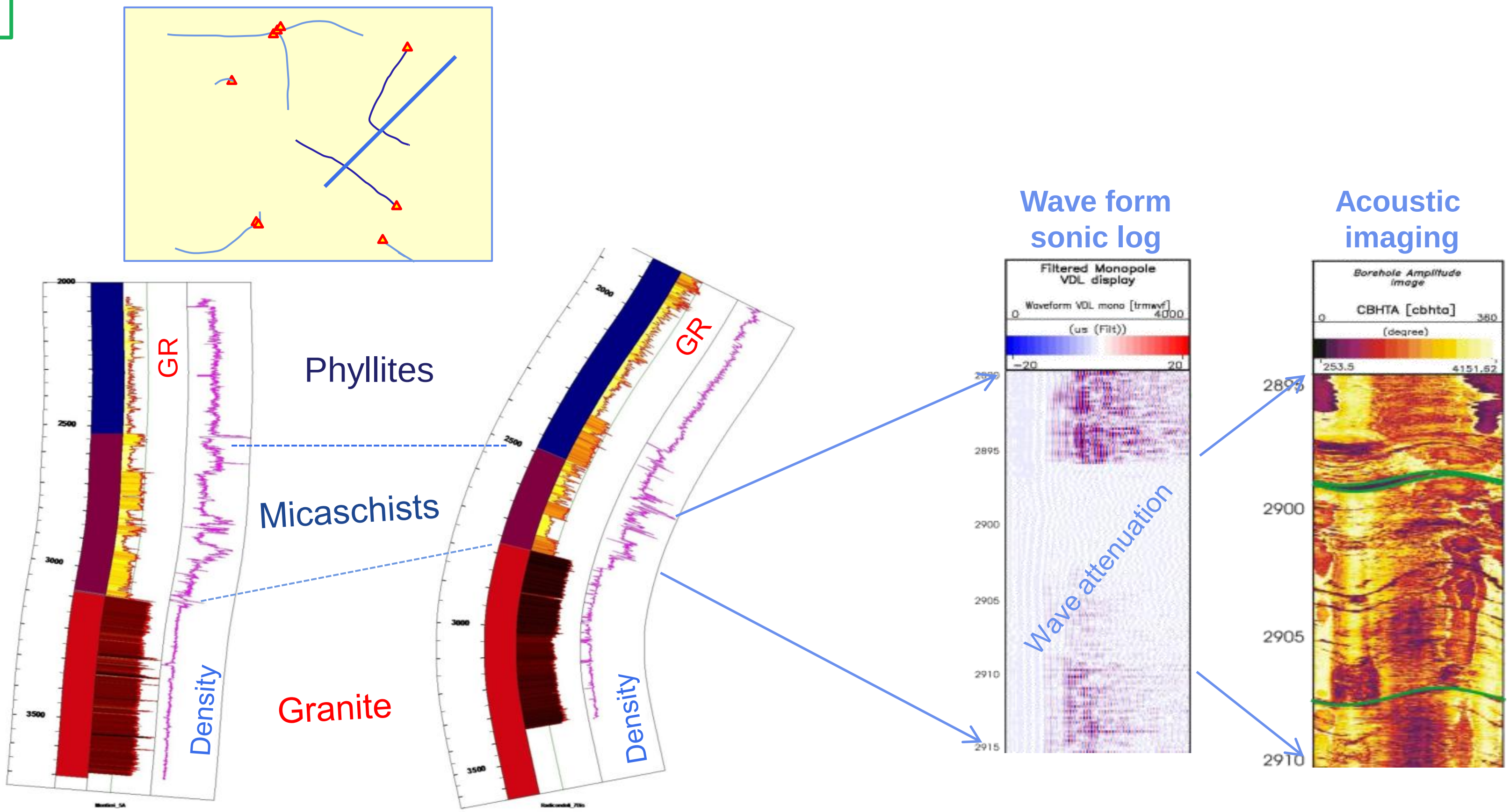
Reflection seismic - the most powerful investigation method in sedimentary geological environment



Direct indications of the structural geology up to several kilometers with high resolution (order of tens of meters)

Deep exploration

Well logging: tools for the direct characterization of the reservoir

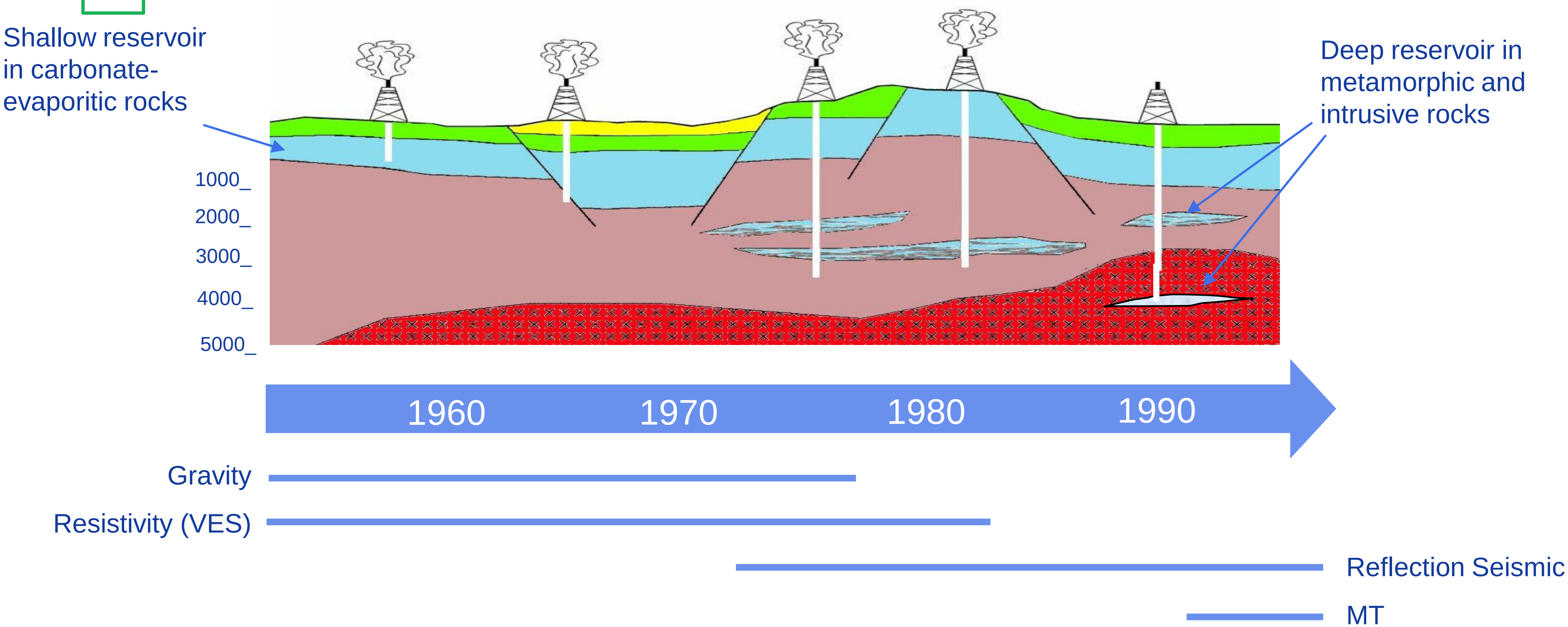


Stratigraphic reconstruction and well correlation

Characterization of fractured layers into the reservoir

Surface exploration

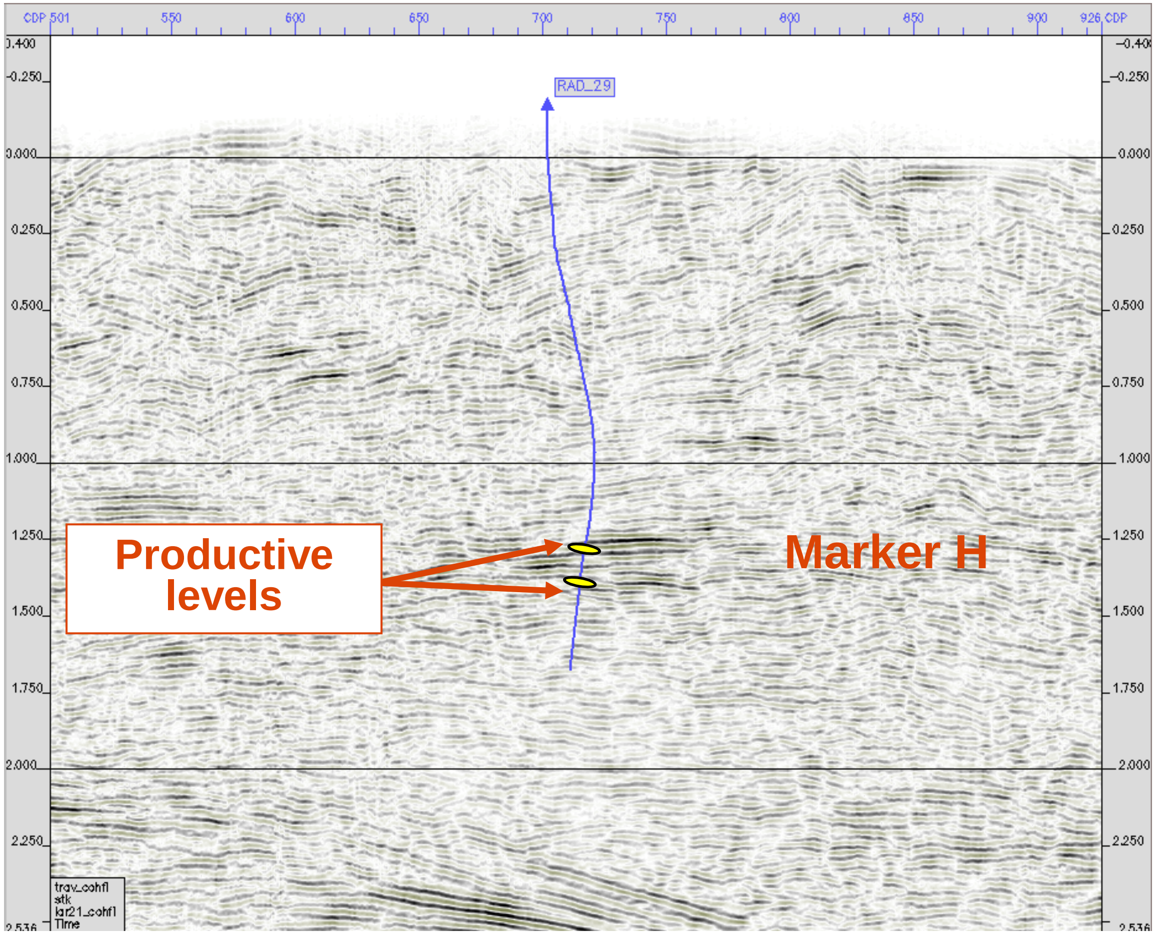
Time evolution of the geothermal targets (Larderello case)



The increasing of the investigation depth and of the drilling cost, requires to apply more powerful and accurate targeting tools

Correlation fractures/seismic reflections

The H horizon



Encouraging correlation between fractured levels and seismic reflections

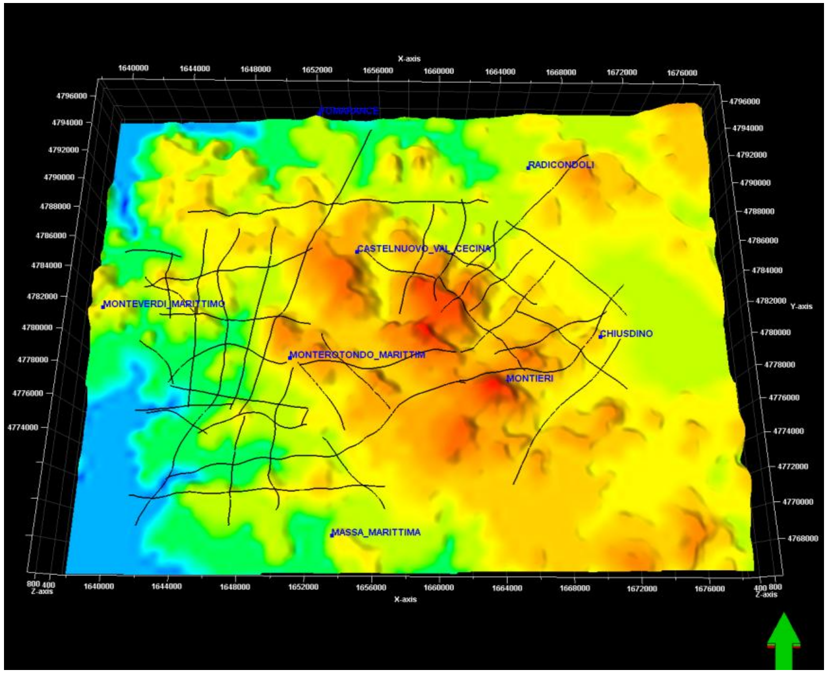
These signals are characterized by high amplitudes and correspond to the H seismic horizon inside the metamorphic basement

The H marker constitutes a target for drilling

Seismic method can significantly help in the detection of fractured levels, thus reducing the mining risk

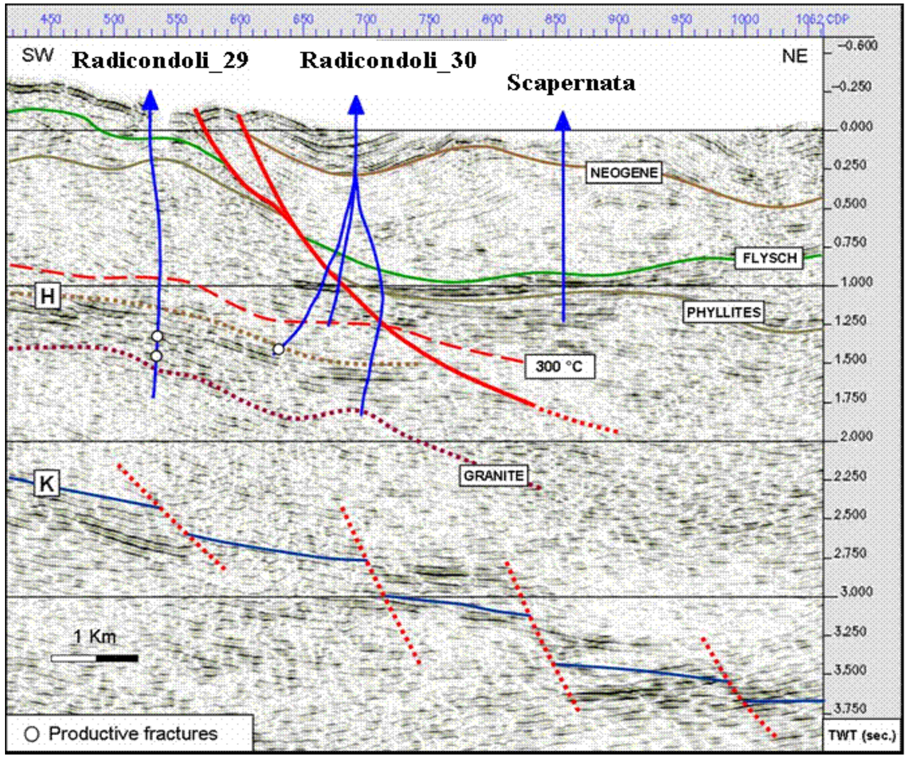
2D seismic dataset: Larderello – Travale area

Year of acquisition	Source	Fold	N° of channels	Group interval [m]	Sampling rate [ms]
1976	Dynamite	6	48	50	2
1986	Vibroseis	24	96	30	4
1987	Vibroseis	30	120	30	4
1993	Vibroseis	30	120	30	2
2000	Vibroseis	32	192	30	4

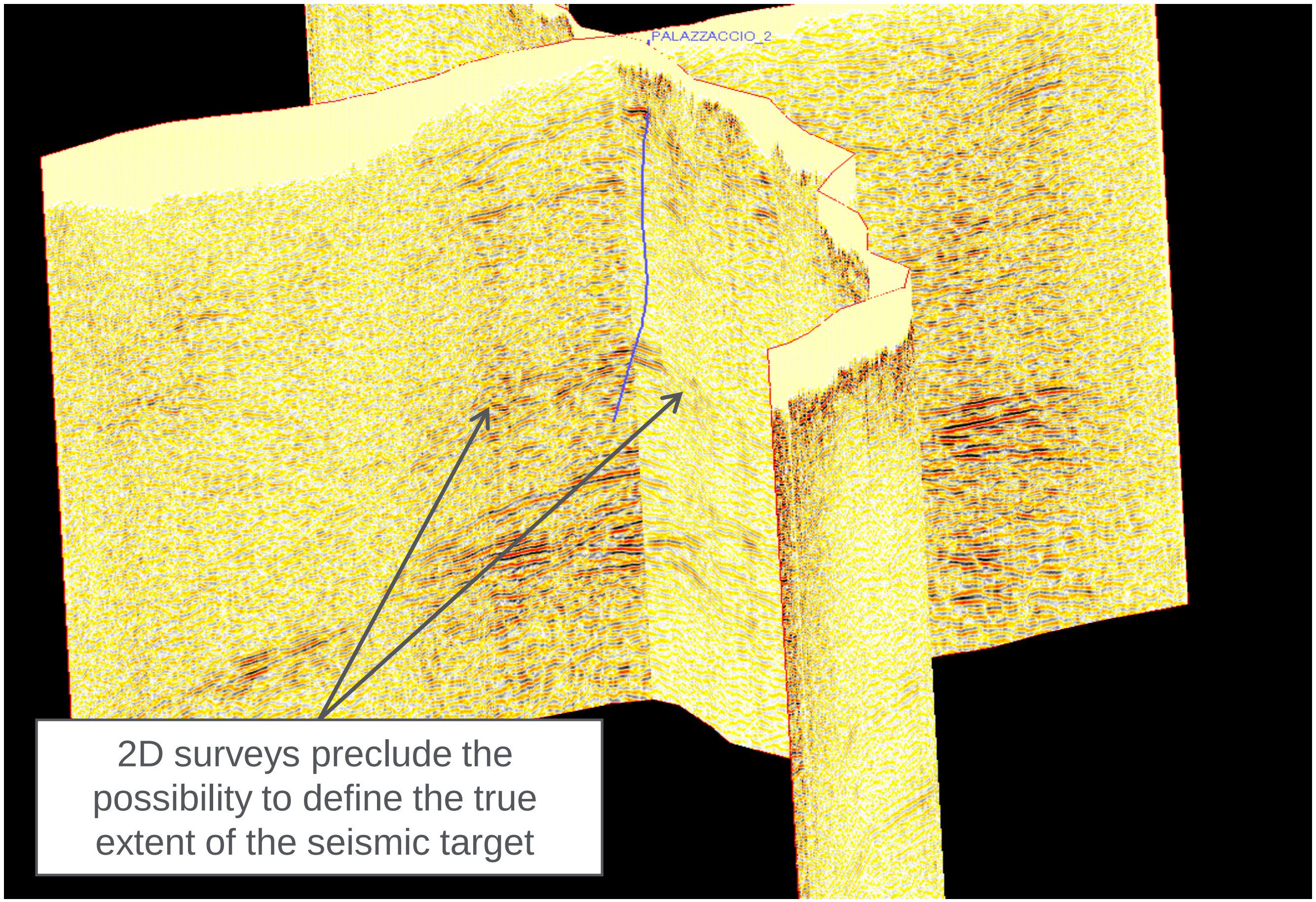


50 seismic lines for a total of about 600 km

Integrated interpretation of seismic and well data for the reconstruction of the main geological and structural elements



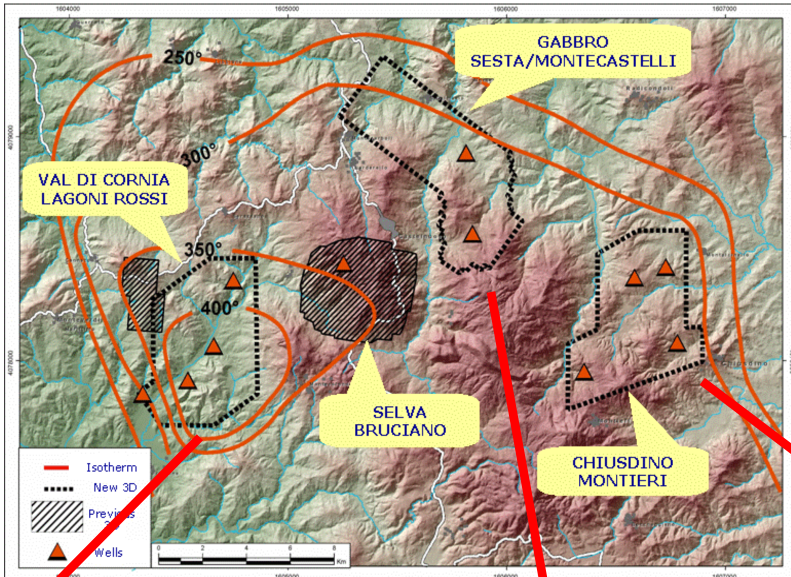
3D survey in the Larderello-Travale area

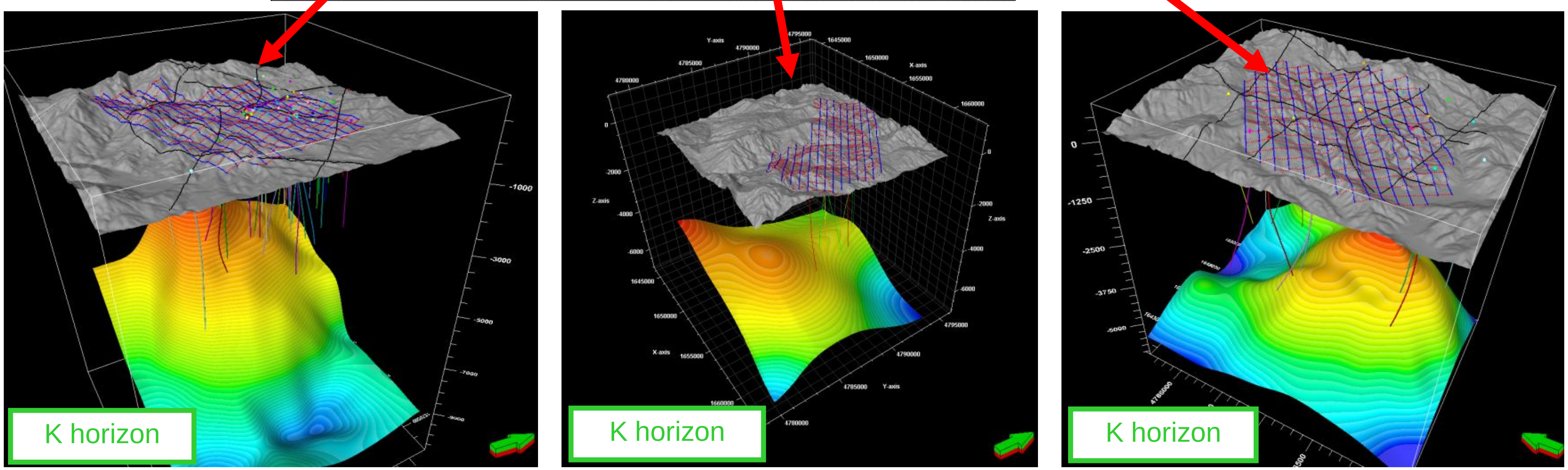


It is difficult to give a target to wells located outside the seismic lines

Recent 3D seismic surveys

Larderello – Travale area





Source lines

Receivers lines

Main acquisition parameters

Source type: dynamite

Bin dimension: 25 x 40 m

Offset range: 0 – 3000 m

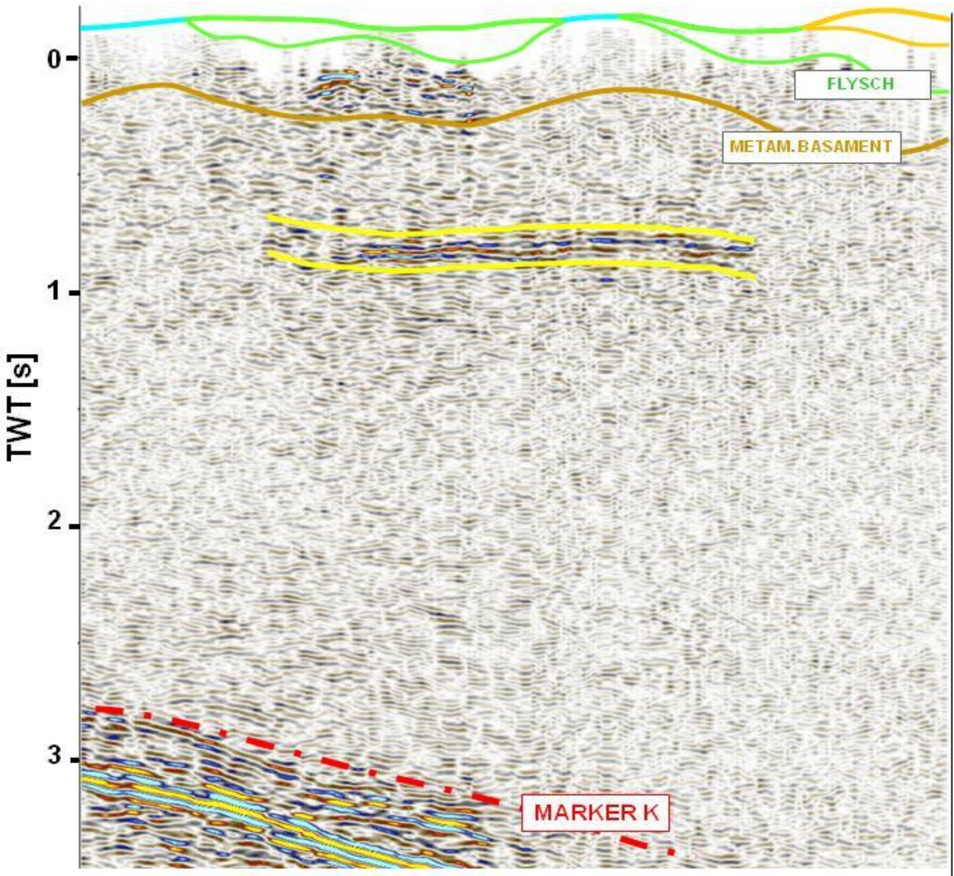
Fold: 1600%

Target depth: 3000 – 4000 m

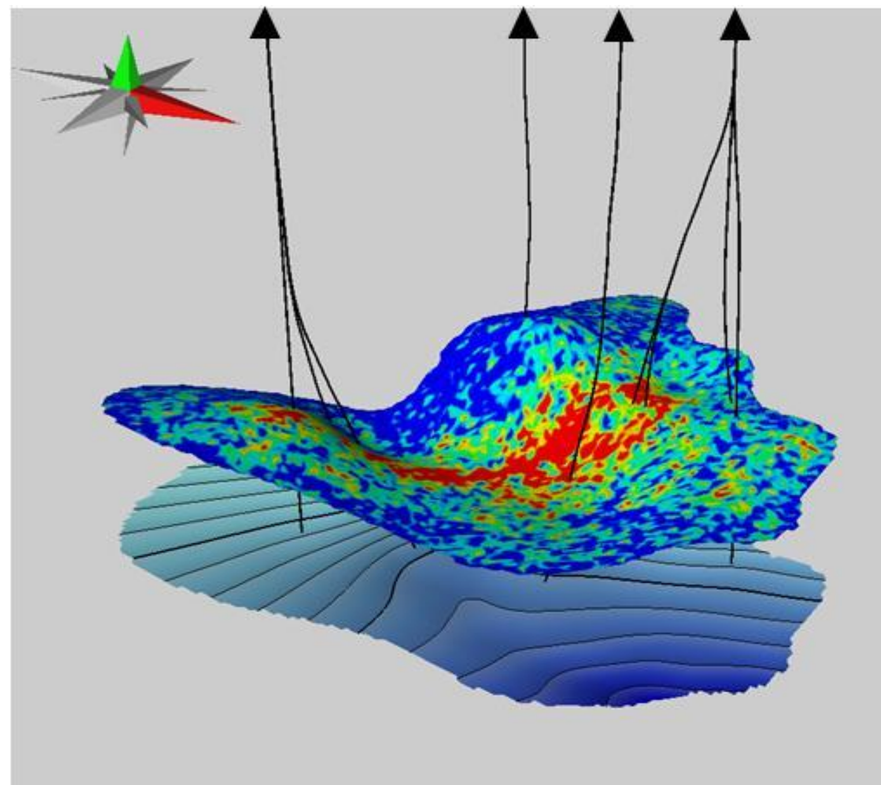
Identification of drilling targets

Amplitude analysis of the H marker (Montieri-Chiusdino)

Dataset processed in an "amplitude preserving" way

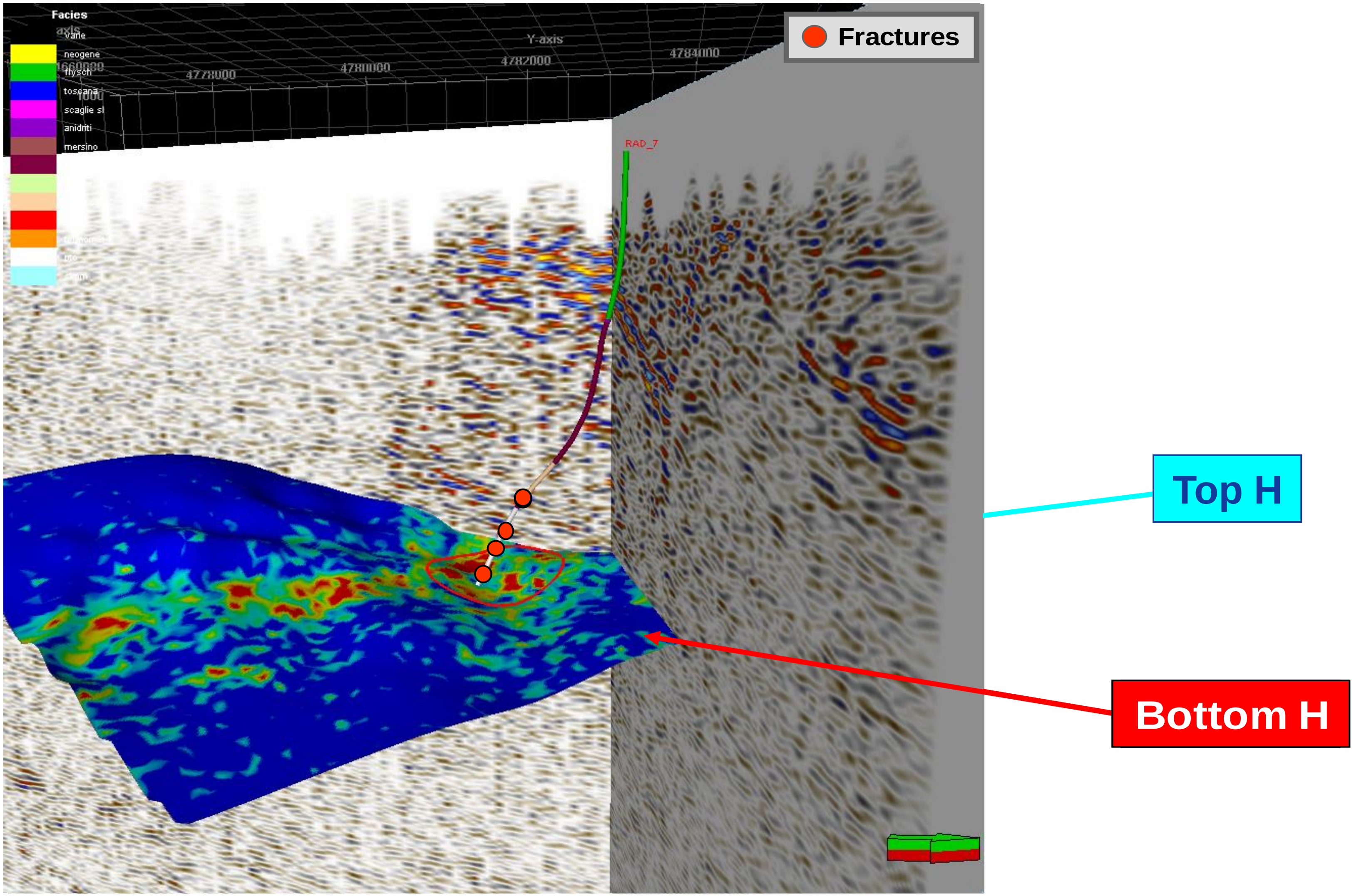


The amplitude analysis carried out on the H horizon allowed the identification of the target for drilling



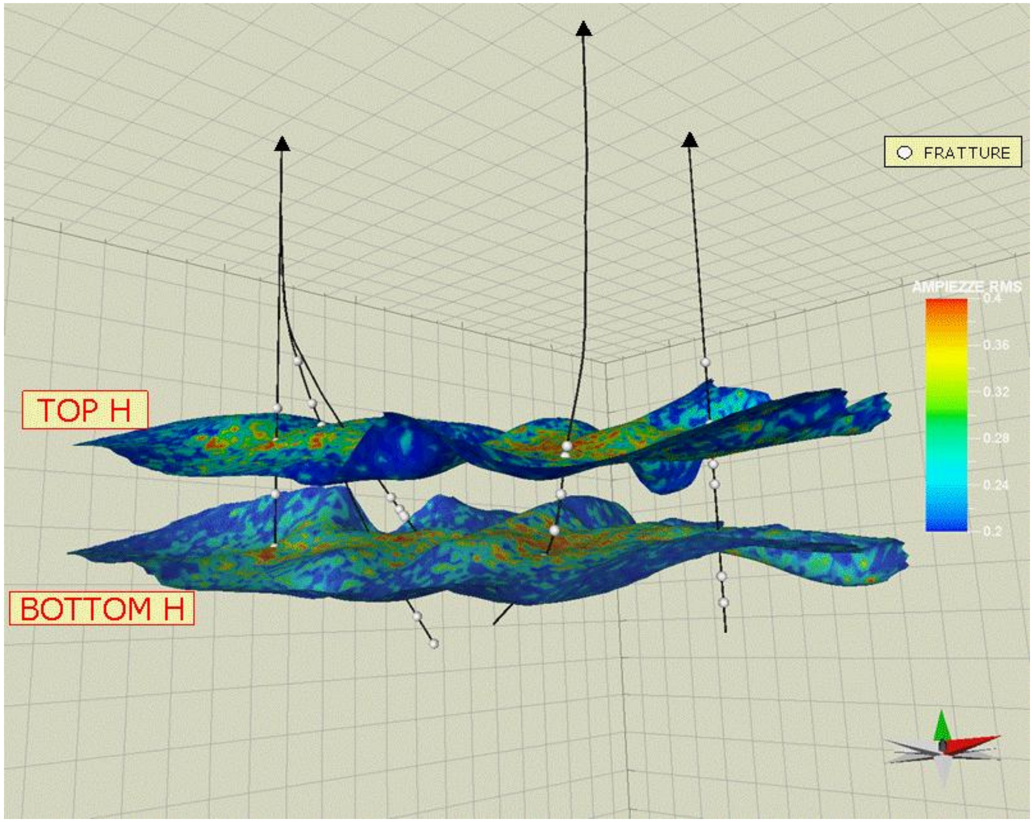
Seismic target for the drilling

An example of the result (Montieri-Chiusdino area)



Productivity of the seismic target
Montieri – Chiusdino area

Correlation between fractures detected in wells and seismic reflectors

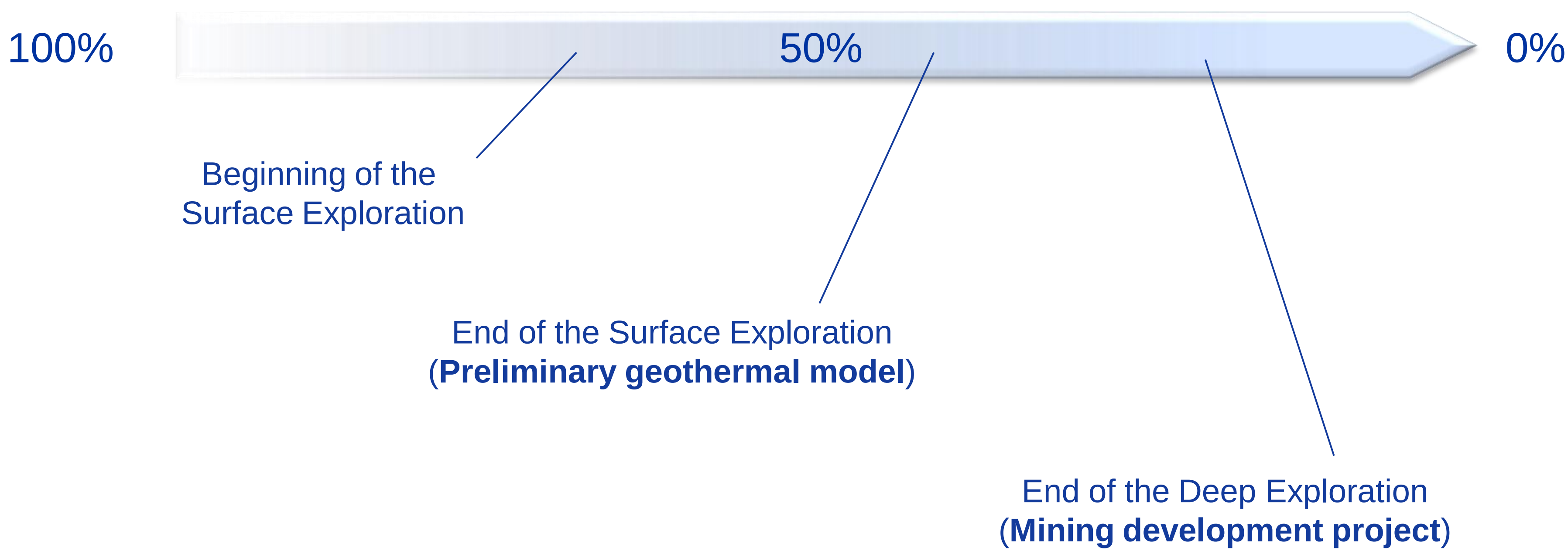


The correspondence between seismic marker and fractured zones was statistically significant

In the Montieri - Chiusdino area more than 70% of the production comes from the H marker

The Geothermal feasibility

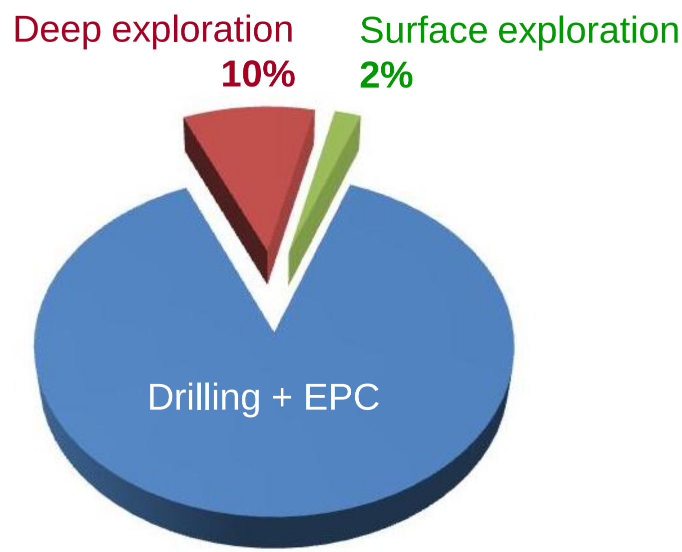
Evolution of the mining risk (qualitative)



Mining risk can be reduced, but not entirely eliminated

The Geothermal feasibility

Allocation of exploration costs for a geothermal project



A minimum cost for a safer overall investment

Geothermal project's evaluation process

Target & main elements

- Area's potential in terms of sustainable electrical capacity
- Evaluation and definition of all the technical aspects that affect the required Capex & Opex
  - Expected well's deliverability
  - Well's depth
  - Interference effects
  - Scaling or corrosion effects
  - Gas content
- Designing of the exploitation strategy
- Forecast the reservoir evolution (resource availability and/or temperature decline) along the project lifetime

MWe	Resource assessment (technology & plant size)
#	required wells
MWe/well	M$/well
Spacing	wells per pad
$	Opex
%	Parassitic losses

Prod. & Reinj.: where and how much

Production evolution and make up wells

Complex process that requires to define many parameters and to foresee their evolution along the time

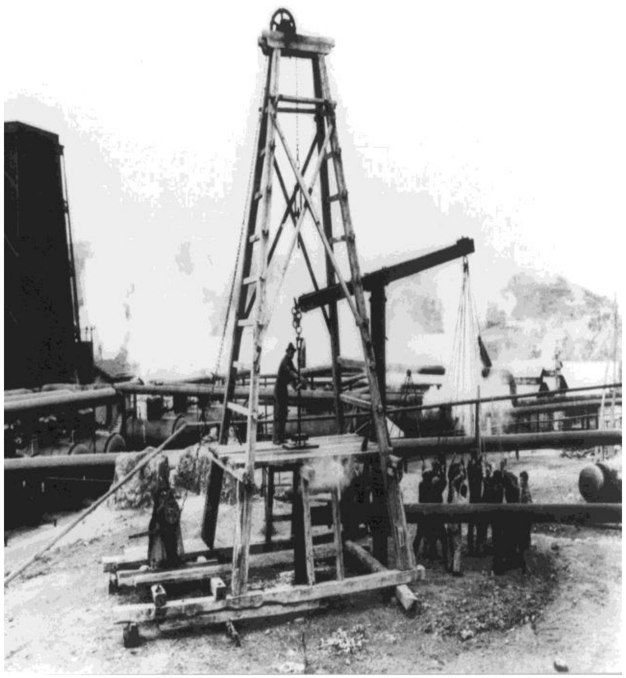
Deep exploration
Final assessment

Once completed the drilling of deep wells it will be issued a final geothermal model that will define *size, temperature, productivity and fluid characteristics* of the geothermal reservoir.

At the end of the exploration the feasibility of an exploitation project will be quantitatively assessed (Project System)

Geothermal Drilling

Drilling rigs evolution



At the beginning of 20th century… now …..

Geothermal Drilling
EGP drilling rigs

Rigs detailed list

Type	n°	Max depth (m)	Features
HH 300	1	6000	Advanced Automatic track-mounted RIG
Mas 6000 E	5	6000	Traditional High Potentiality RIG
MR 7000 E	1	2000	Traditional Medium Potentiality RIG
ST6	1	1000	Traditional Low Potentiality RIG
TOTAL RIGS	8		

3 rig crews operating

365 days/year

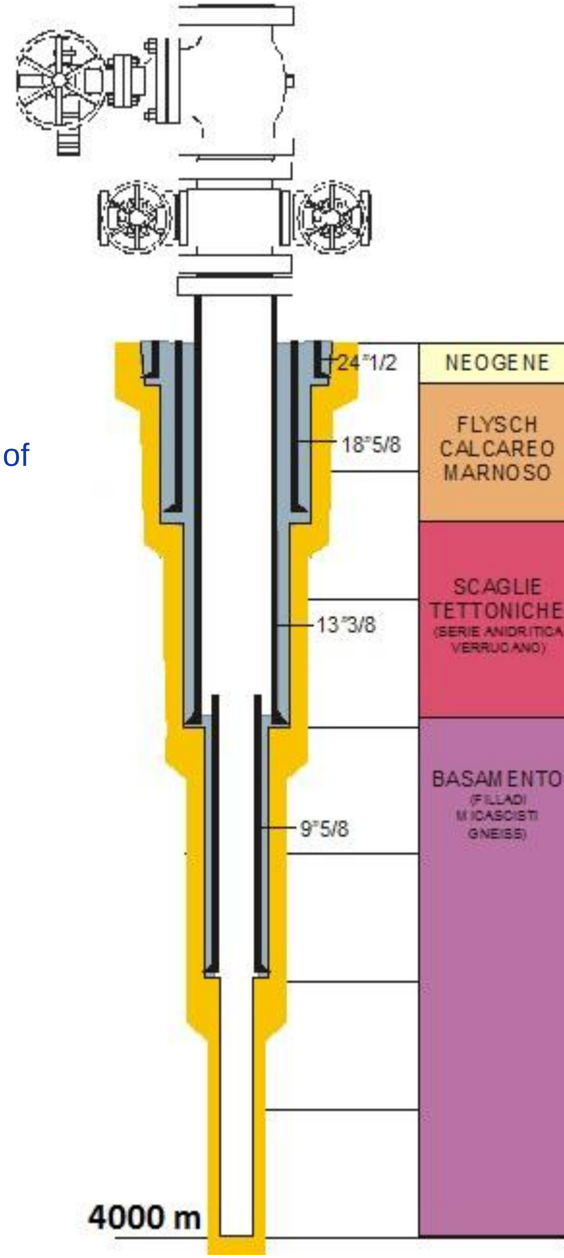
HH300

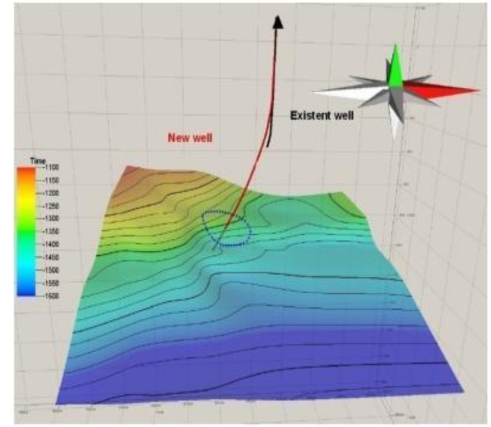
Mas 6000 E

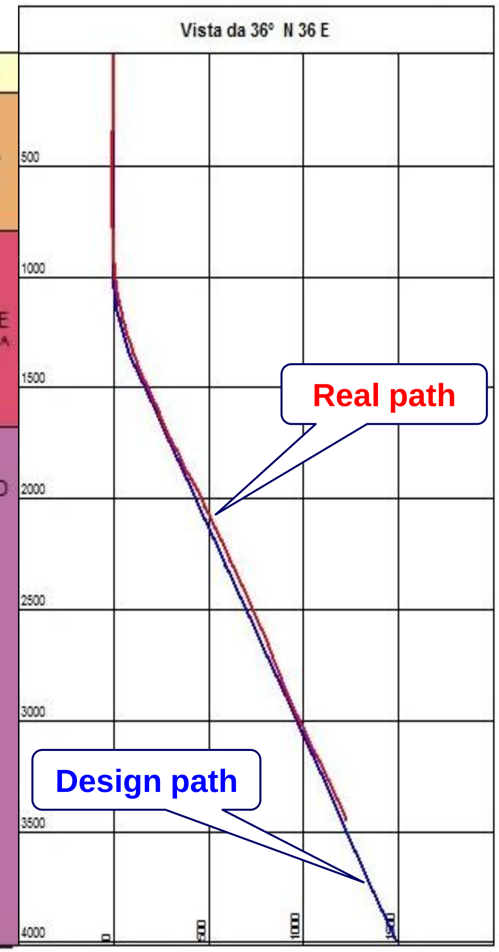
Geothermal Drilling

State of art

- High average **depth** of wells from **3500**m to **4500**m
- **Directional drilling** on specific targets with a displacement of over 2000m
- **Advanced** automatic trailer-mounted **rig technology**
- **Cementing technologies** for deep and **high temperature** wells (350°C) and geothermal oriented **tools**
- **Safety** and **environmental** compliance
- **Standard times of drilling activity** ~190 days
  - » Rig moving ~35 days
  - » Drilling ~145 days
  - » Well Testing ~10 days







Geothermal Drilling

Main Process

DRILLING DEPARTMENT

Mining Development Configuration

- Mining Proposal
- Investment Authorization
- Budget Approval
- Project Assignment to the Project Manager

Development

- Well Design
- Specific Permitting Processes
- External Resources Planning and Management (materials, contracts and services)
- Quality Systems

Rig Moving

- Well pad Lay-Out definition
- Machineries and Equipments O&M
- External Resources Management

Execution

- Mining Activity Management
- Drilling Rig Operation
- Management of all other processes supporting the well drilling and completion
- External Resources Management
- Well Testing

Well O&M

- Well Operation & Maintenance

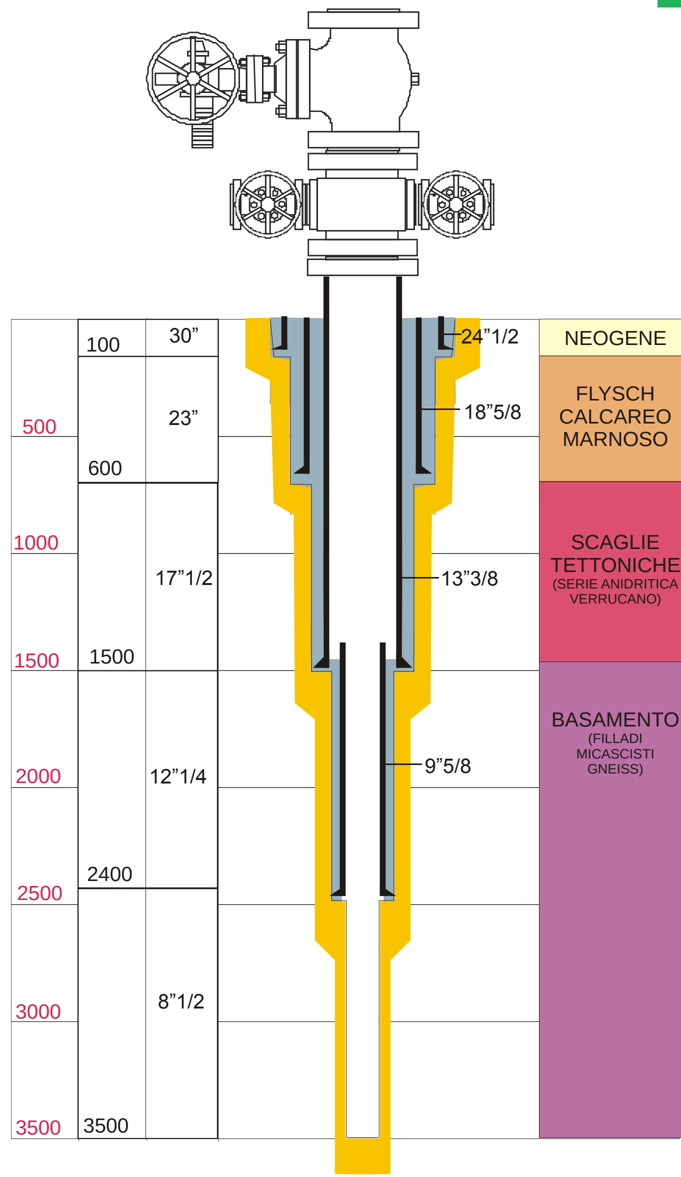
Standard well diagram of a geothermal well

Main data

- Average depth: 4000 m

- Duration of drilling activity: ~190 gg
  - » Moving ~35 gg
  - » Drilling ~145 gg
  - » Tests ~10 gg

- Budget cost: ~6.350 k€
  - » Moving ~450 k€
  - » Drilling ~5.900 k€



Standard well
Major components.. about 6000!

Standard well

Moving

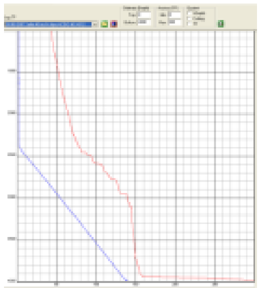
Standard well
Drilling data acquisition

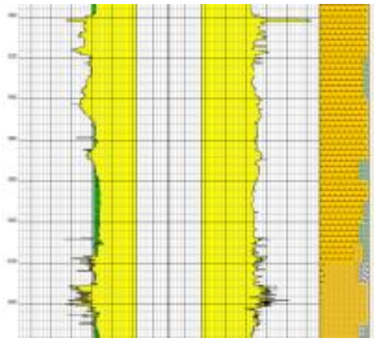
Cements and Fluids
Main tasks and skills

- Design of cement jobs in geothermal wells
- Execution of cement jobs, water pumping and stimulation jobs (basic or acid mixtures) (115 jobs per year)
- Maintenance of all the cementing equipment
- Technical management and supervision of all the services related to cementing, stimulation and drilling fluids
- Tuning of the cement slurries in the Cements and Fluids Lab
- Research & Development on drilling fluids

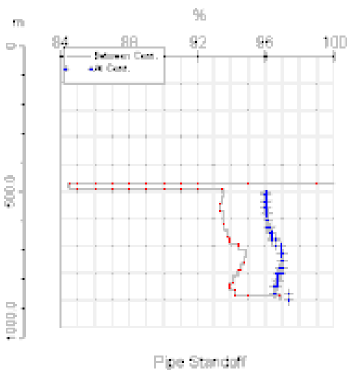
Cements and Fluids
Cement job design

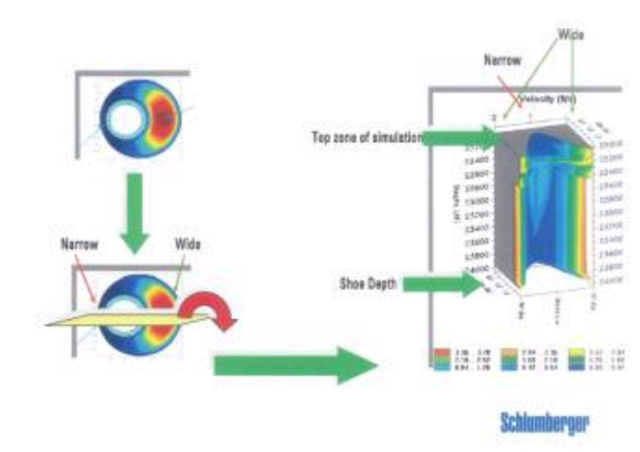
- Design of the job taking considering all the available data and, if necessary, acquisition of missing data

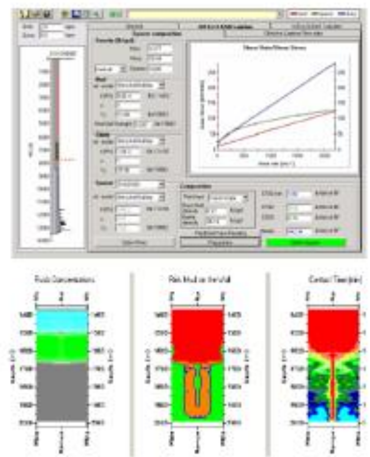


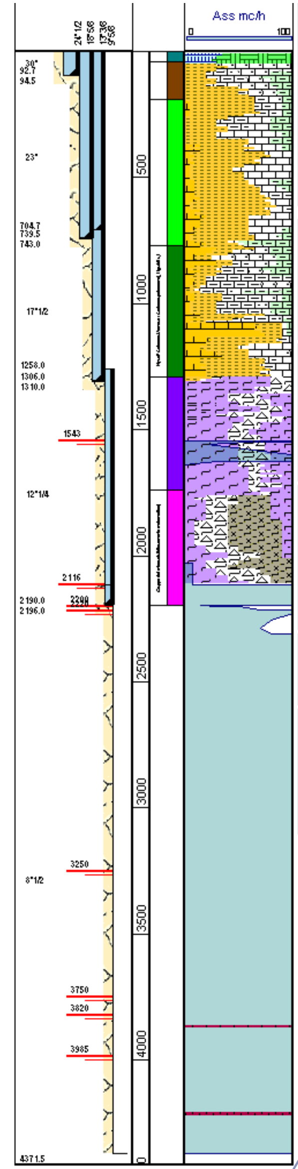


- Definition of the best cementing strategy by means of specific software









Cements and Fluids

Cement job execution

- Placing on site of all the needed equipment and materials
- Set up of the cement
- Execution of the job



Cements and Fluids

Cement job execution

Dry cement tank

Water + Additives tank

Cement

Water

Service Company cementing Unit to set up the cement

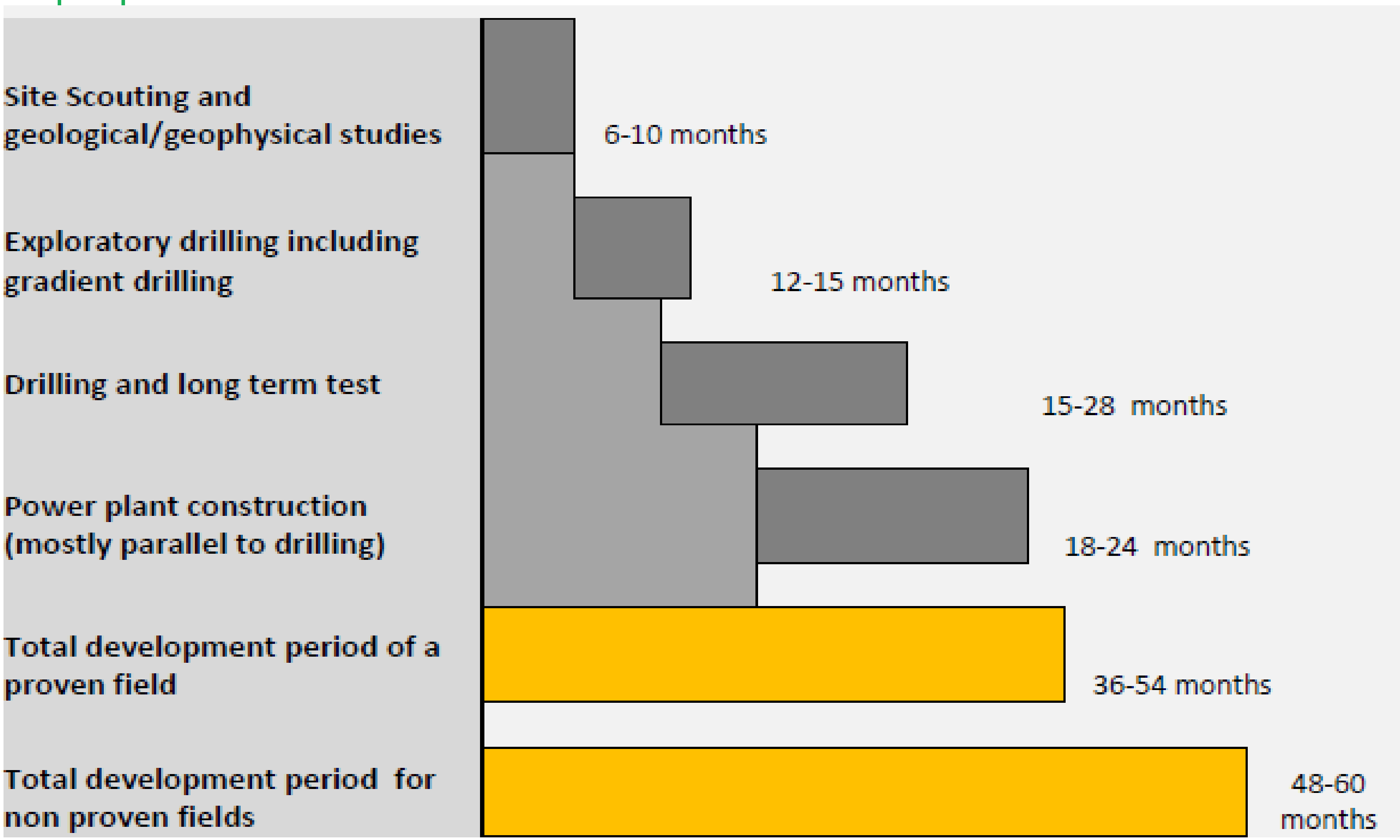
Batch mixer for the best mixing and homogenization of the cement

Overfeeding Pump

Cementing Unit

Pumping into the wellbore

An entire Geothermal project
Average time-schedule



Geothermal Project Life Cycle

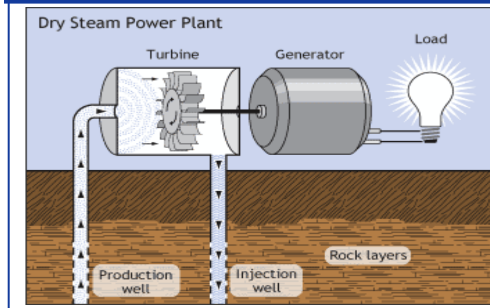
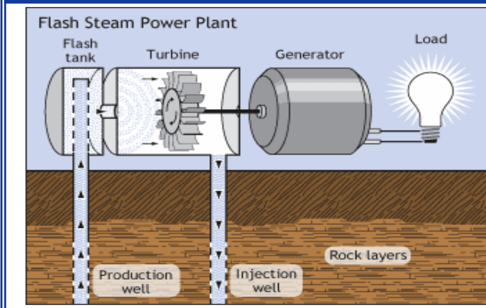
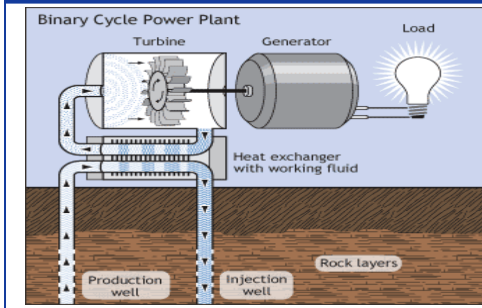
The geothermal resource

The different geothermal system

Depth	Reservoir	Exploitation
0 - 500 m	Dry Shallow Reservoir	Heat pumps – Heat exchange
500 – 5000 m	Hydrothermal Systems: shallow and deep reservoir	Electricity generation - Conventional technologies
More than 5000 m	Hot deep dry rock reservoir	Enhanced geothermal systems- Future perspectives

Exploitation and technologies driven by reservoir characteristics

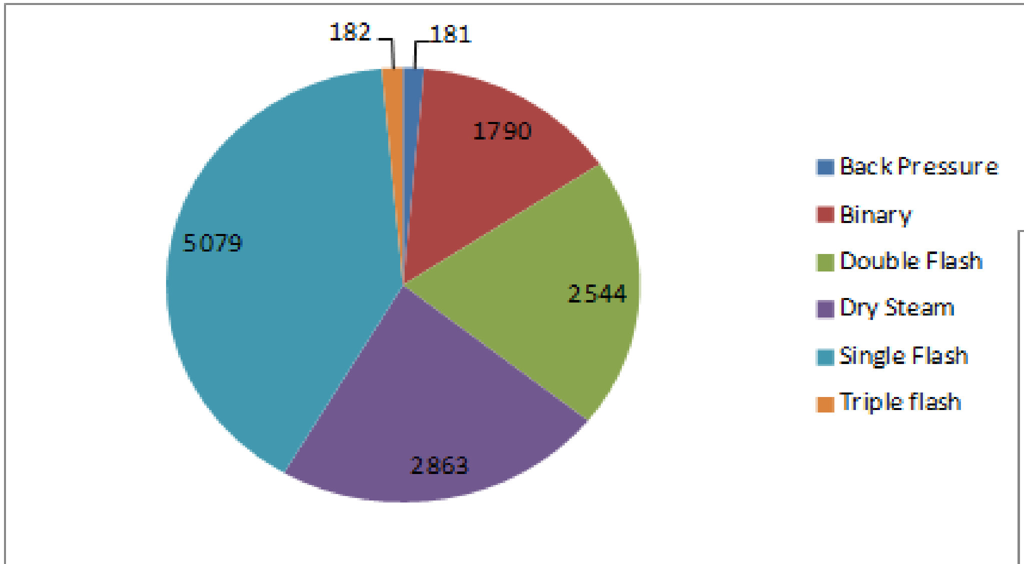
The geothermal resource
The different geothermal power conversion technologies

Dry steam power plants	Flash steam power plants	Binary cycle power plants
		
Dry Steam.	Water with temperatures higher than ~180ºC.	Water at lower temperatures between ~ 110-180ºC.

Aver. size (MW)	~45	~35	~5

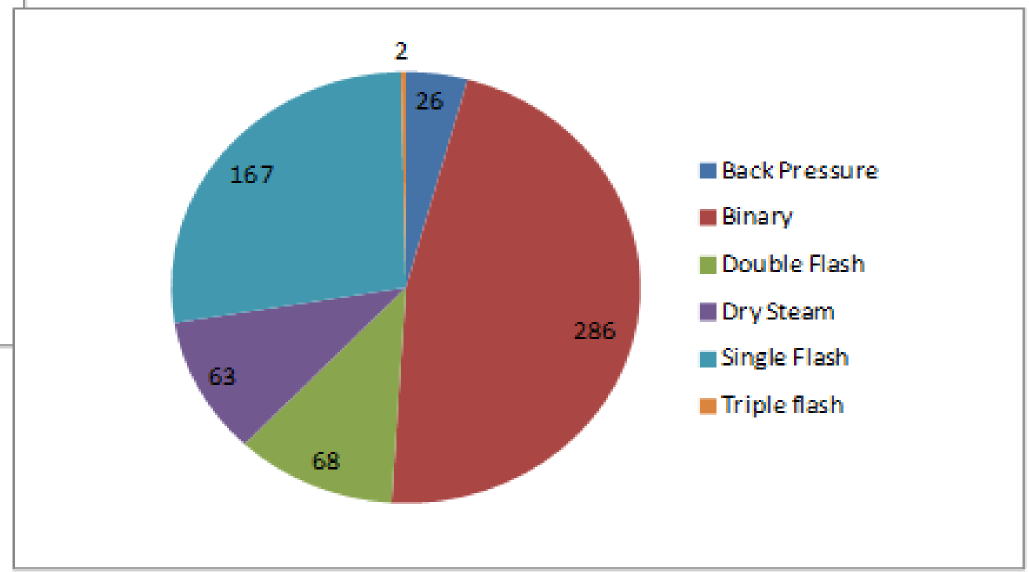
The geothermal resource

The different geothermal power conversion technologies



Installed capacity in MWe for each typology

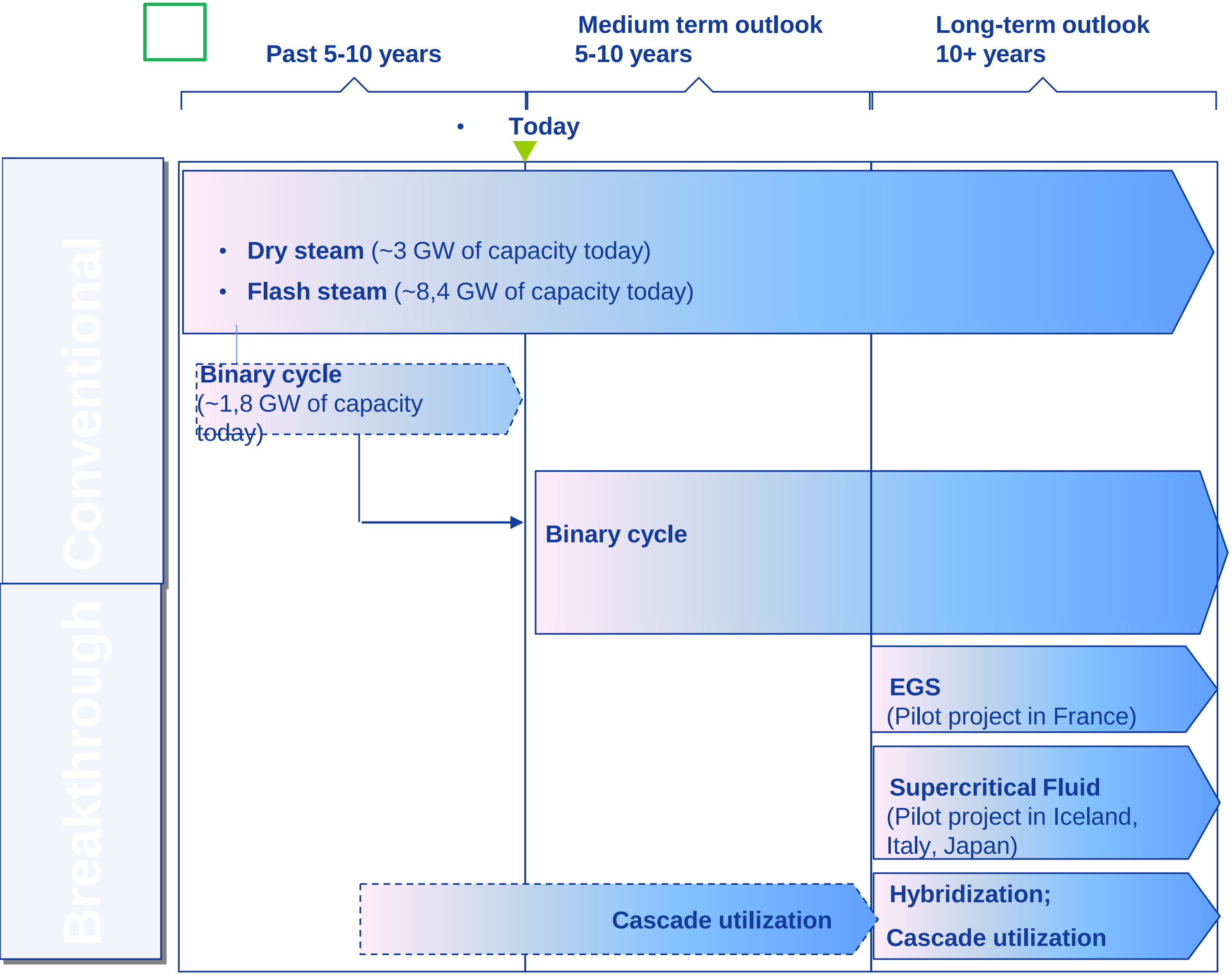
Number of units for each typology (total 613)



Country	Back Pressure	Binary	Double Flash	Dry Steam	Hybrid	Single Flash	Triple flash	TOTAL
Africa	48	11				543		602
Asia		236	525	484		2514		3758
Europe		268	273	795		796		2133
Latin America	90	135	510			908		1642
North America		873	881	1584	2	60	50	3450
Oceania	44	266	356			259	132	1056
TOTAL	**181**	**1790**	**2544**	**2863**	**2**	**5079**	**182**	**12640**

The geothermal resource

The different geothermal power conversion technologies

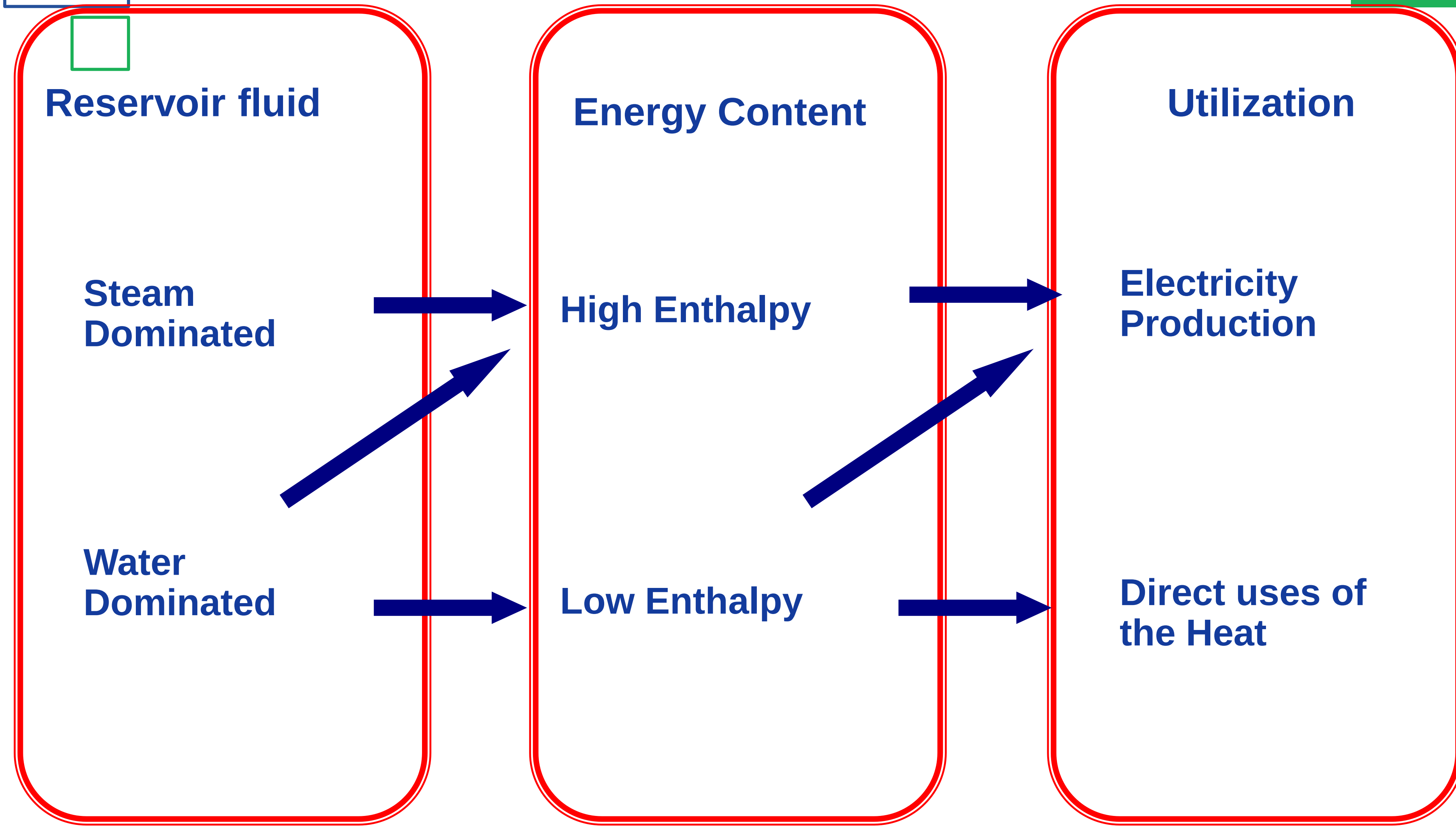


- **Mostly proven** and cost-effective technologies
- **Incremental plant technological advances** going forward
- **Binary only** as an **ancillary** application due to infancy stage of technological development (i.e., higher costs)

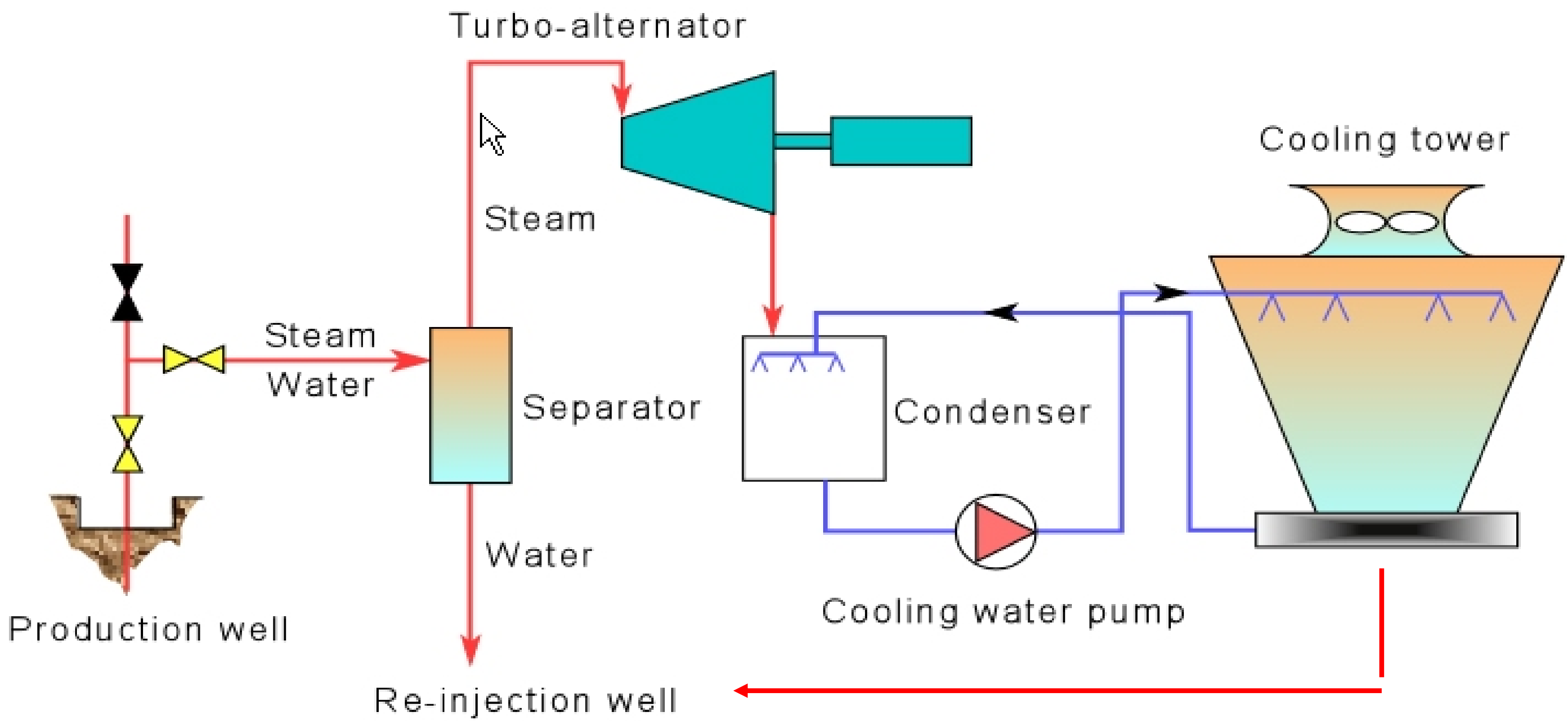
- **Binary** proven to be a **self-standing technology**, increasing overall installable potential
- **Economics** not yet in line with steam technologies (dry and flash), **expected to improve in the long term**

- **Technology still in "development"** phase
- **Under certain technological development outlook** (i.e., fast decrease in technology costs), expected to **increase installable potential**
- **Cascade utilization are already present in the market**

The geothermal resource



Geothermal Electricity: flash and dry steam plant



Geothermal flash power plant

Geothermal Electricity: flash and dry steam plant

Geothermal sheeps – New Zealand

Larderello – Italy

Geothermal Electricity: flash and dry steam plant

Larderello – Italy

Geothermal Electricity: flash and dry steam plant

Berlin – El Salvador

Geothermal Electricity: binary plant

There is a

“pot of gold ”

at the

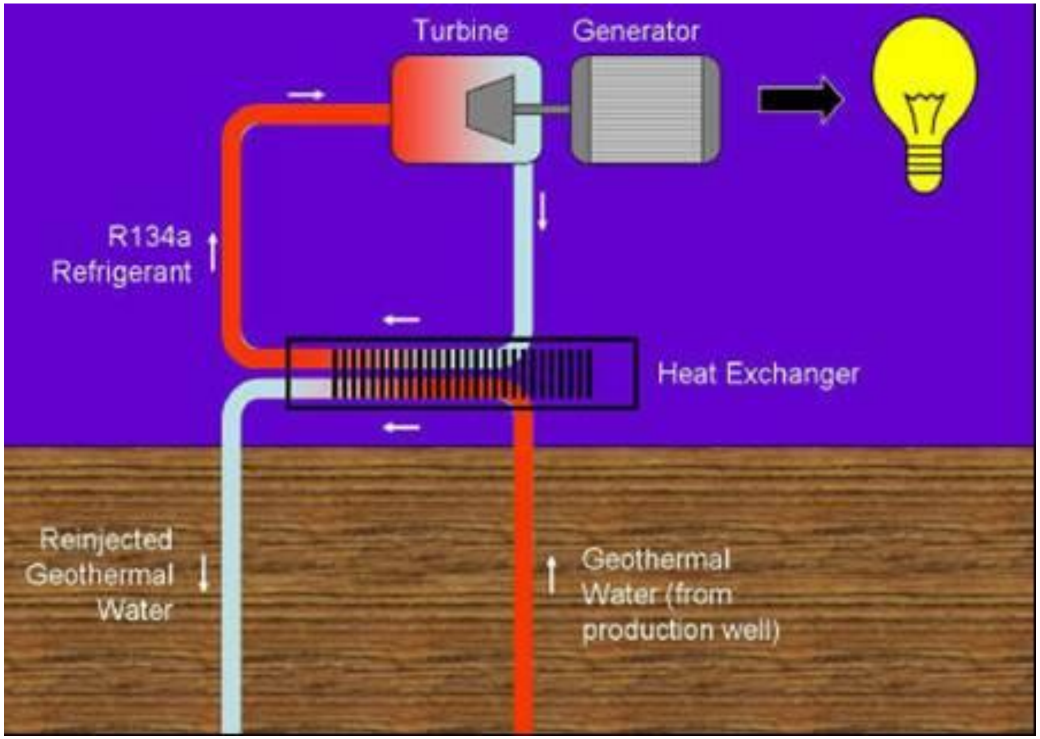
end of the

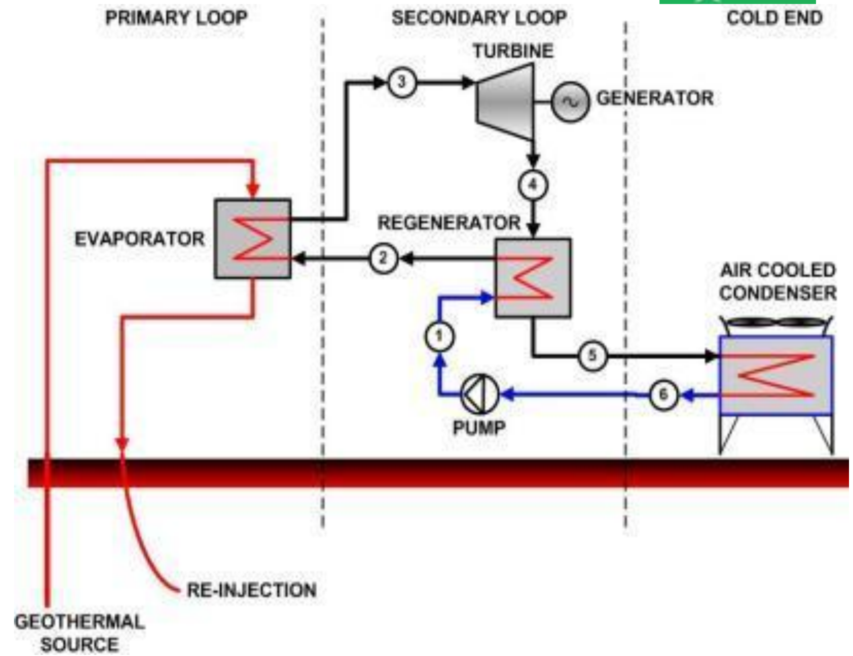
rainbow

-

USA

Geothermal Electricity: binary plant





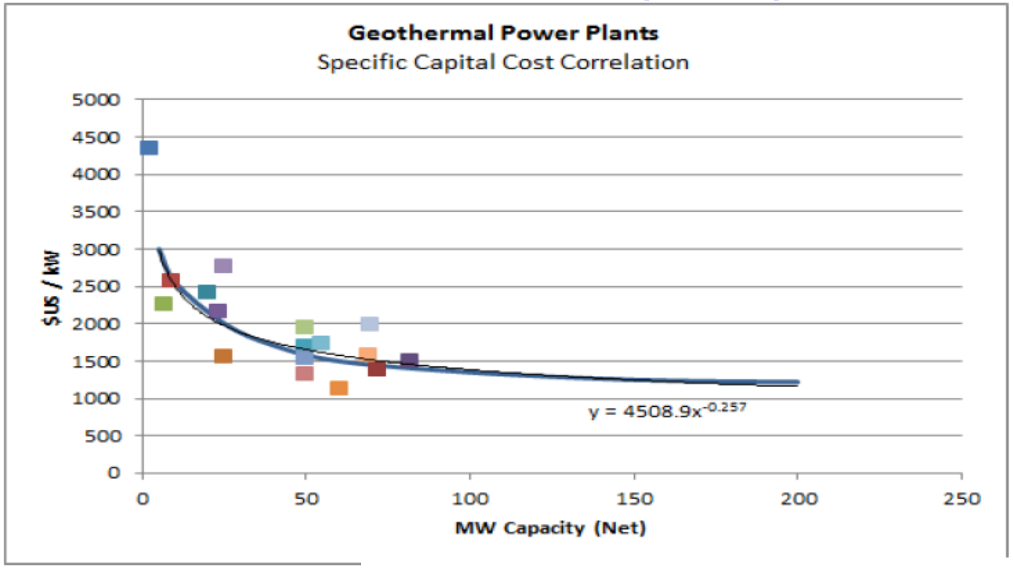
Geothermal binary power plant

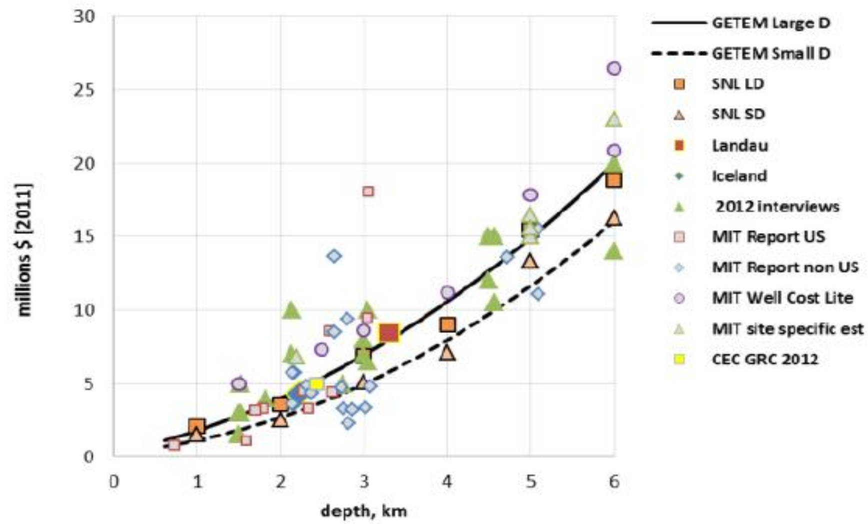
Geothermal Electricity: binary plant

Geothermal Electricity: binary plant

The Geothermal cost

Effect of well depths, plant size and summary table

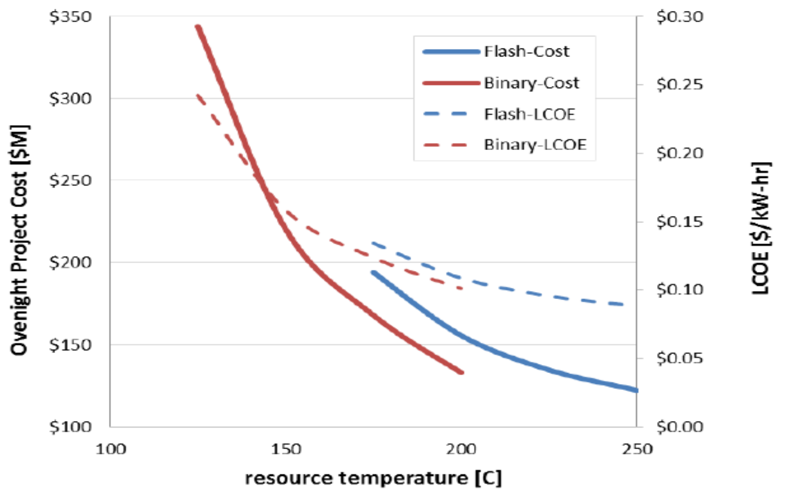


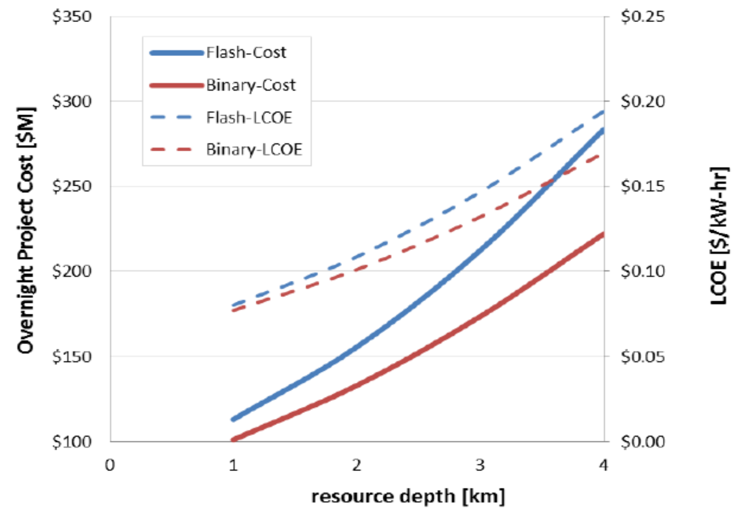


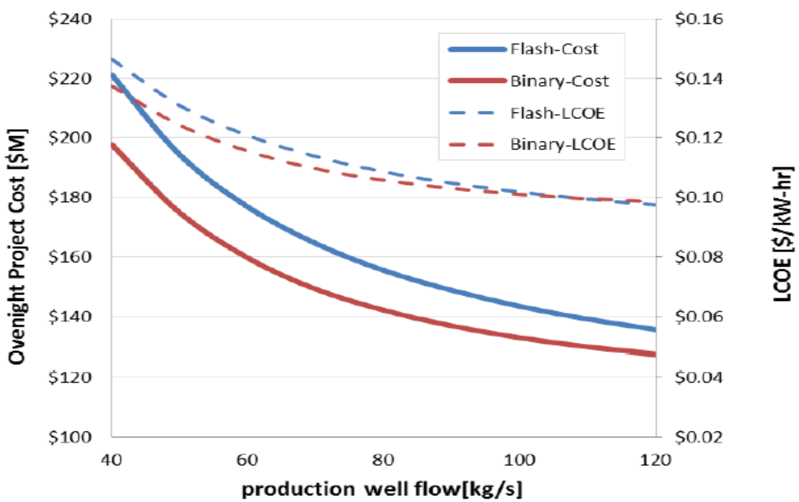
MINIMUM UNIT COST based on a 30 MW, medium enthalpy, average values of depth, flow rate and success ratio

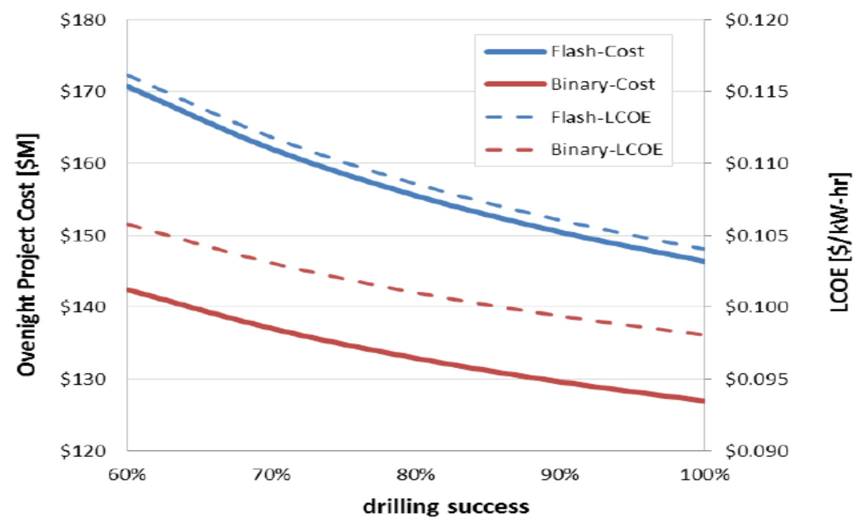
Cost item	Unit	Magmatic Geothermal Source	Hot Sedimentary Aquifer Geothermal Source	Engineered Geothermal System Geothermal Source
Wells	$/kW_e$	1,250	4,545	7,500
Steam Above Ground System (SAGS)	$/kW_e$	400	550	550
Power plant	$/kW_e$	1900	2700	2400
Overall Cost	$/kW_e$	3,550	7,795	10,450
Operation and maintenance (variable) power plant	$/kWh	0.01	0.01	0.01
Operation and maintenance (variable) steam field	$/kWh	0.006	0.006	0.007

The Geothermal cost
Sensitivity studies

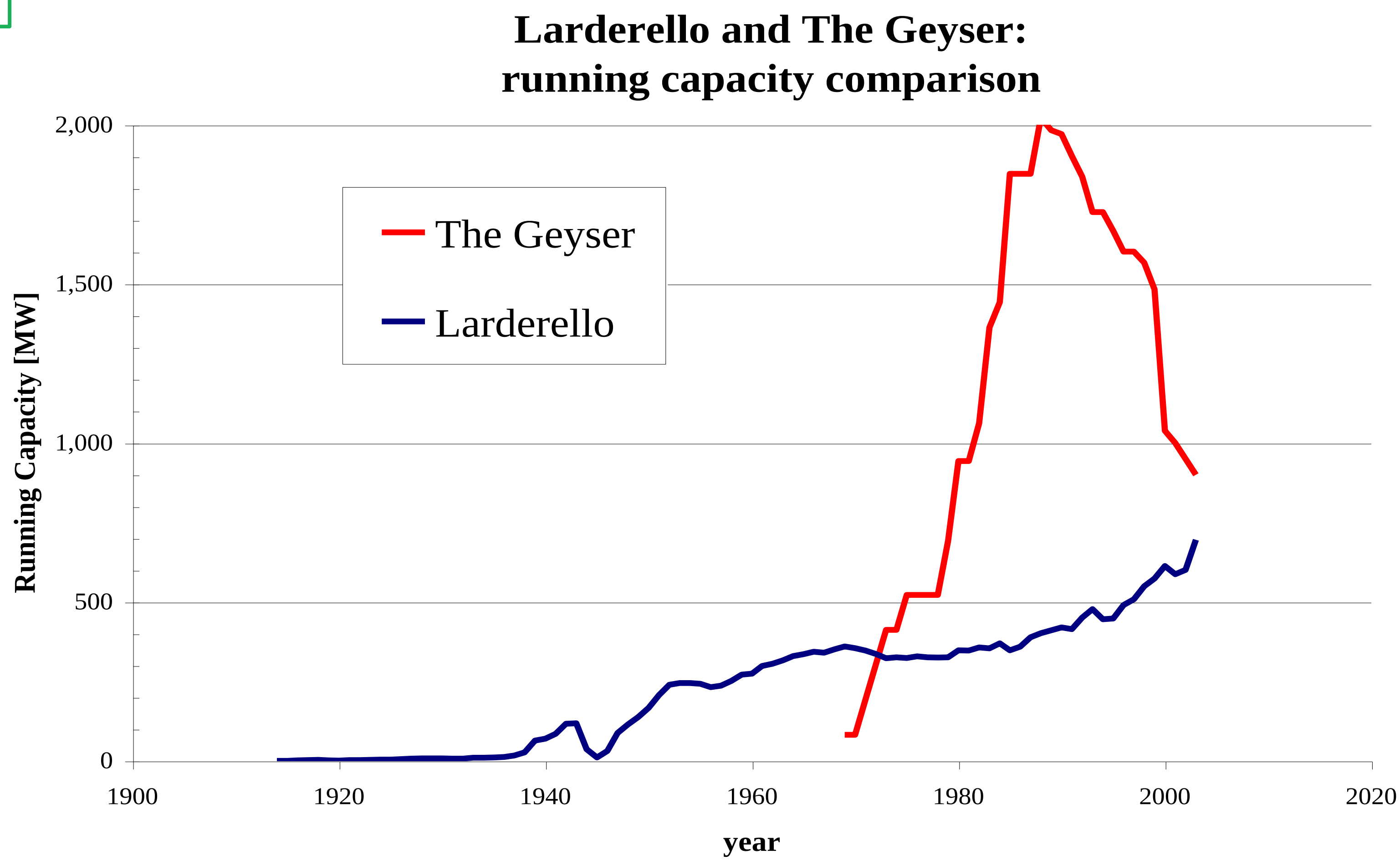






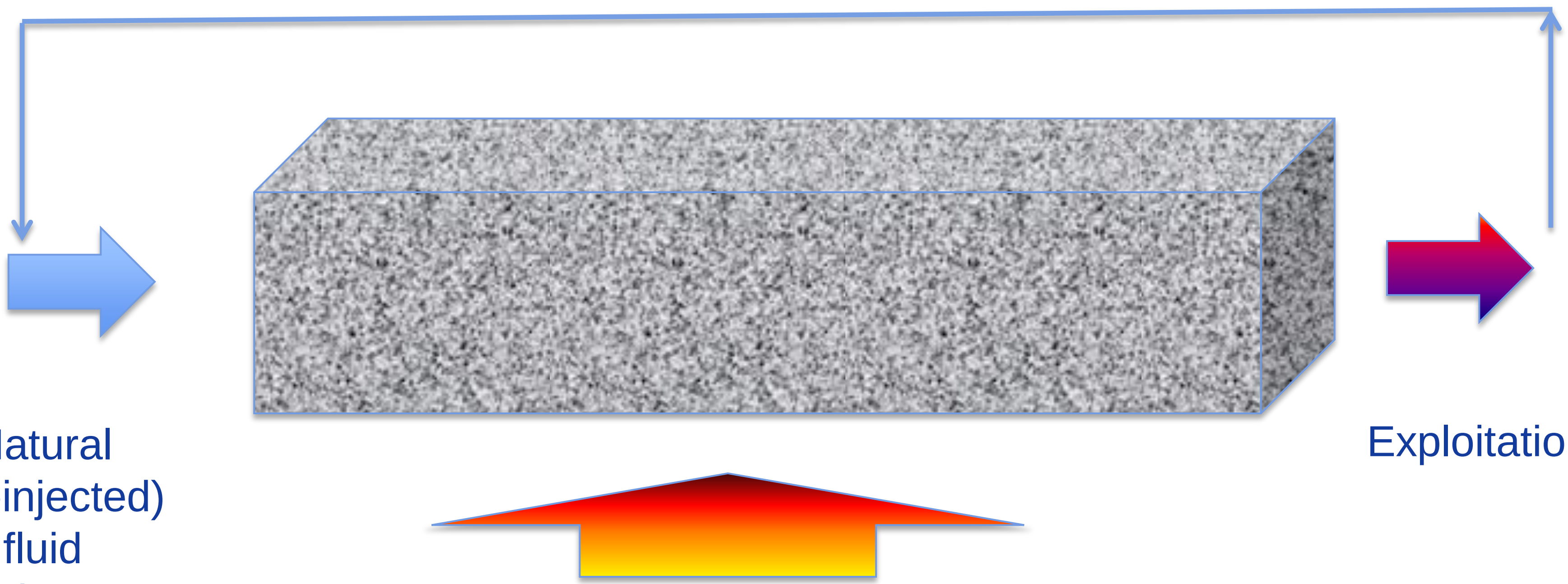


Sustainable Development



Sustainable Development

Sustainable Development

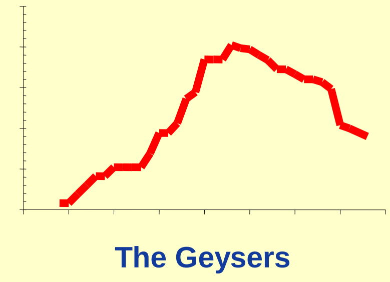


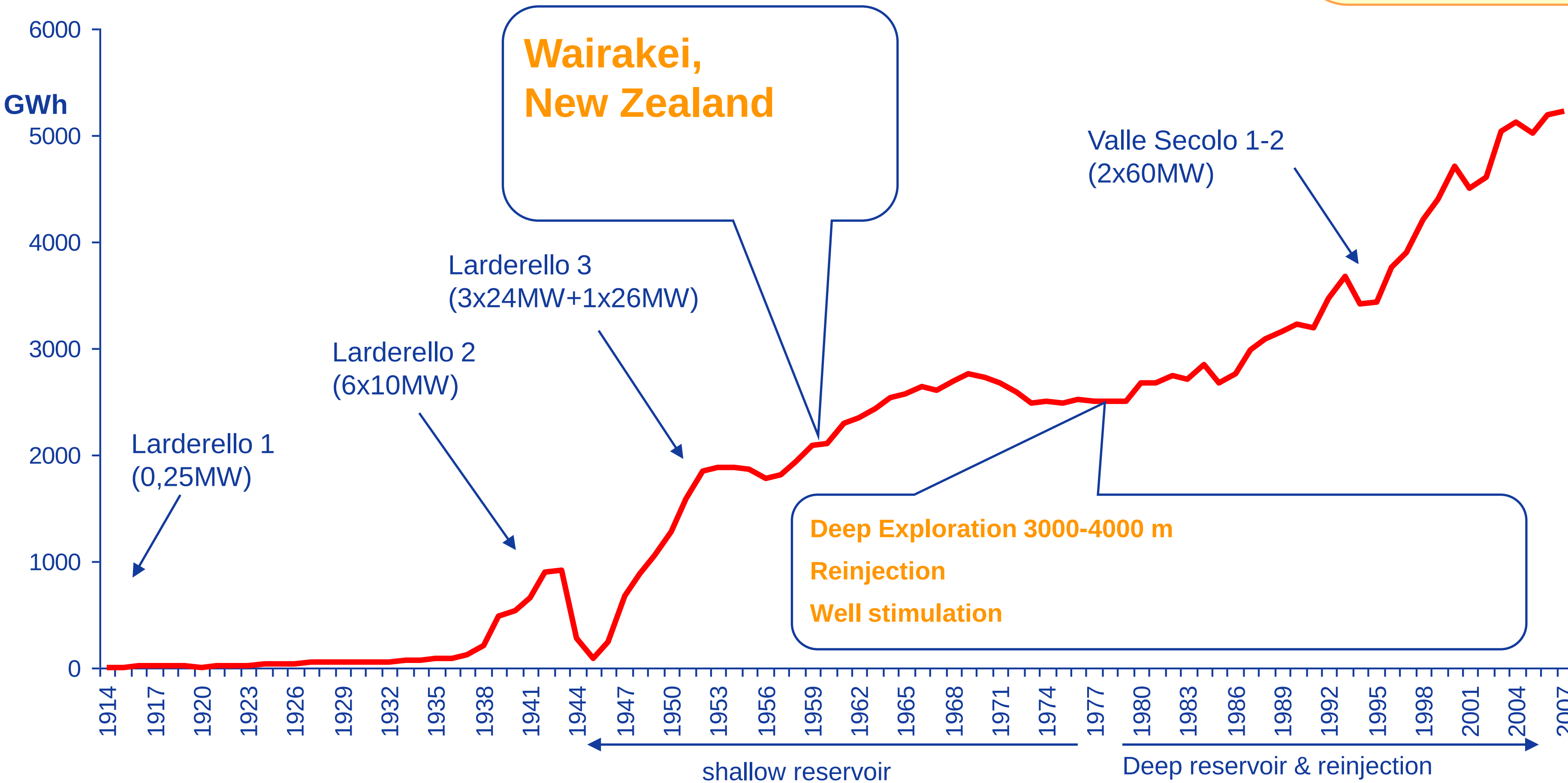
Sustainable Development

299 Tcal heat supply

3,5 MT CO_2 avoied

1,1 MTep saved





THANKS FOR YOUR KIND ATTENTION!