Part II – Introduction to deep geothermal energy: play types, potential estimation methods, geothermal modelling, classification of resources/reserves

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Basic concepts of deep geothermal energy

Geothermal energy: basic concepts

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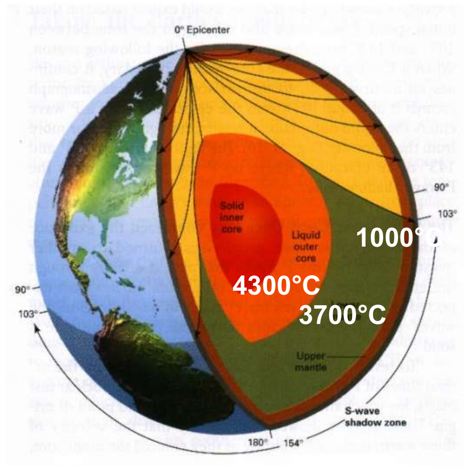
Earth's heat sources:

- „residual" heat of the Earth interior (mantle and core)
- decay of radioactive isotopes: U238, U235, Th232, K40 (crust)
- solar radiation (limited 5-25 m below the ground)



Internal heat production: 20TW

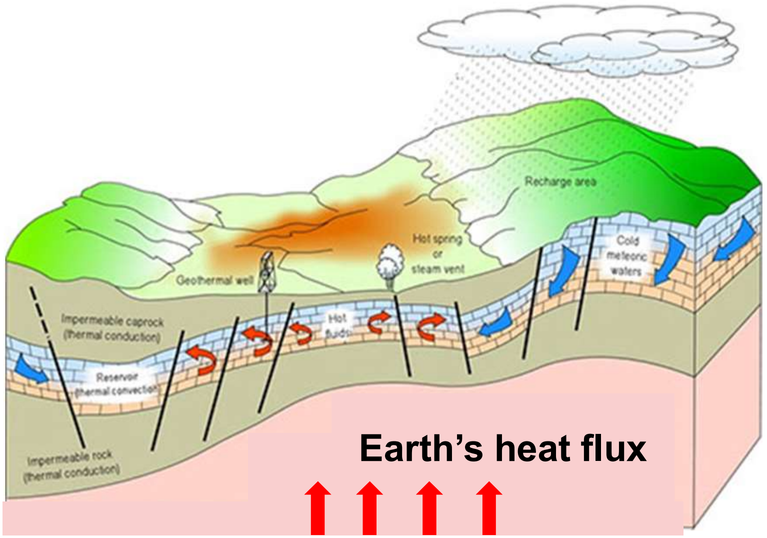
Measured heat flow Qs = 44TW

Earth cools down 2X quicker than heat production, however the heat content of the Earth would take over 10^9 years to exhaust via global terrestrial heat flow *(practically inexhaustable on human-scales)*

BUT HOW MUCH CAN BE EXTRACTED?

Geothermal energy: basic concepts

Deep hydrothermal

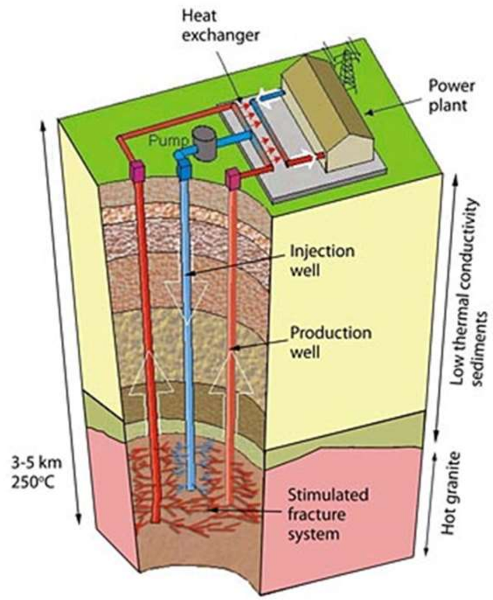


Elements: heat source, reservoirs, carrying medium (fluid), recharge

Fluid convection: heating → thermal expansion of groundwater → rising and replacement by recharging colder meteoric water

Extraction of heat energy: production of thermal groundwater

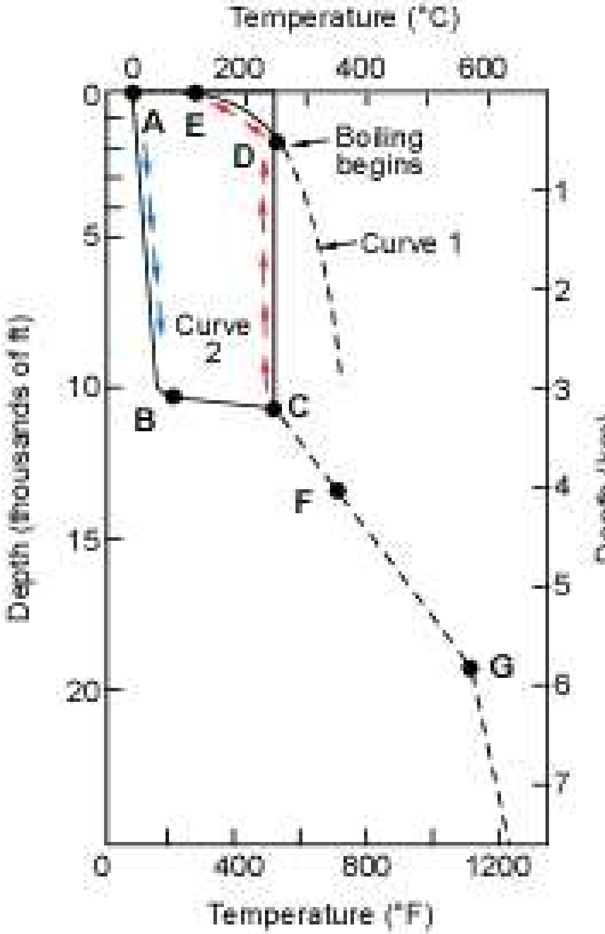
Deep stimulated (HDR/EGS)

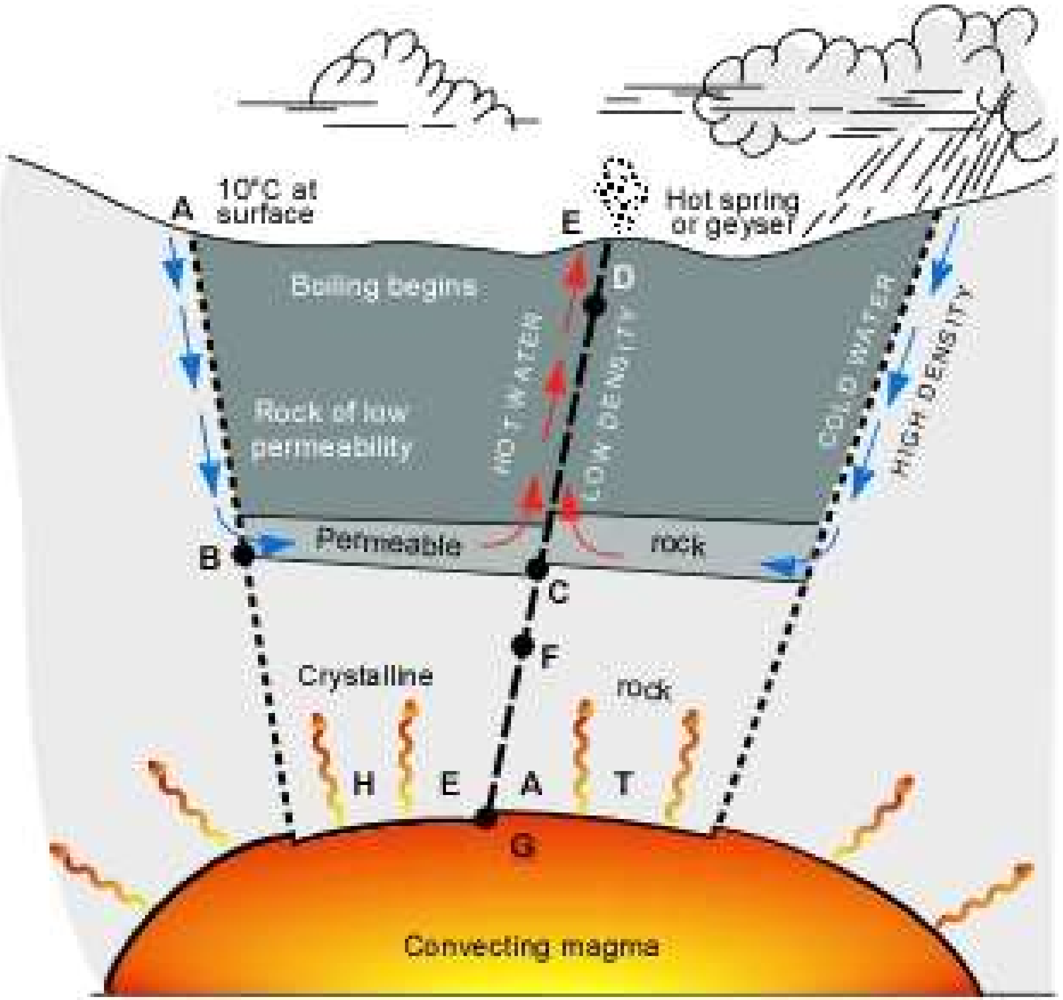


Artificially created and enlarged fractures as „heat exchangers” in deep lying hot rock bodies

Extraction of heat energy: circulating water via production and reinjection wells

Conceptual model of a high-temperature geothermal system





reference curve for the boiling point of pure water

White, 1973

Classification of geothermal resources

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100	≤150	≤190
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

(a) Muffler and Cataldi (1978).
(b) Hochstein (1990).
(c) Benderitter and Cormy (1990).
(d) Nicholson (1993).
(e) Axelsson and Gunnlaugsson (2000)

Geothermal Play Types

Geothermal play: definitions and basic concepts

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Concept from petroleum geology

A geothermal play: a geological setting that includes a heat source, heat migration pathway, heat/fluid storage capacity (reservoir), and the potential for economic recovery of the heat.

A conceptual model on how a number of geological factors might generate a recoverable geothermal resource at a specific structural position in a certain geologic setting.

The characteristics of individual geothermal systems are a function of site-specific variables:

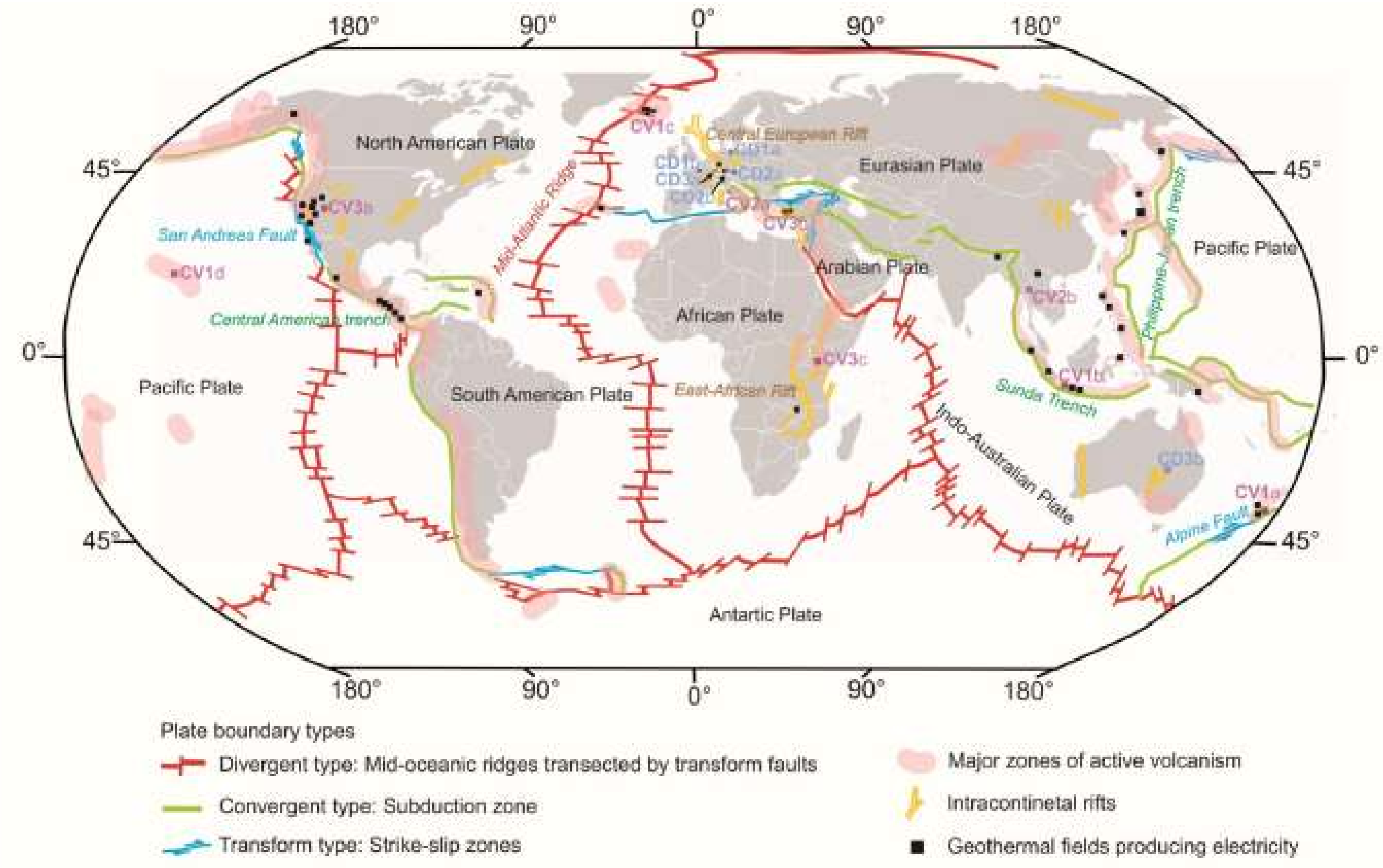
- **the nature and depth of the heat source;**
- **the dominant heat transfer mechanism;**
- **permeability and porosity distribution;**
- **rock mechanical properties;**
- **fluid/rock chemistry;**
- **fluid recharge rates/sources.**

Identify the play type → focussed exploration strategy

Play type classification

6 broad geothermal play types according to plate tectonic setting

- **the nature of the heat source (magmatic or non-magmatic),**
- **the dominant heat-transfer mechanism is convection (all modes of shallow and deep natural groundwater flow) → *heat accumulation*, or conduction (heat transfer among rock particles) → *heat distribution***



Gehringer and Loksha, 2012, Moeck 2014

Play types – geological continuum

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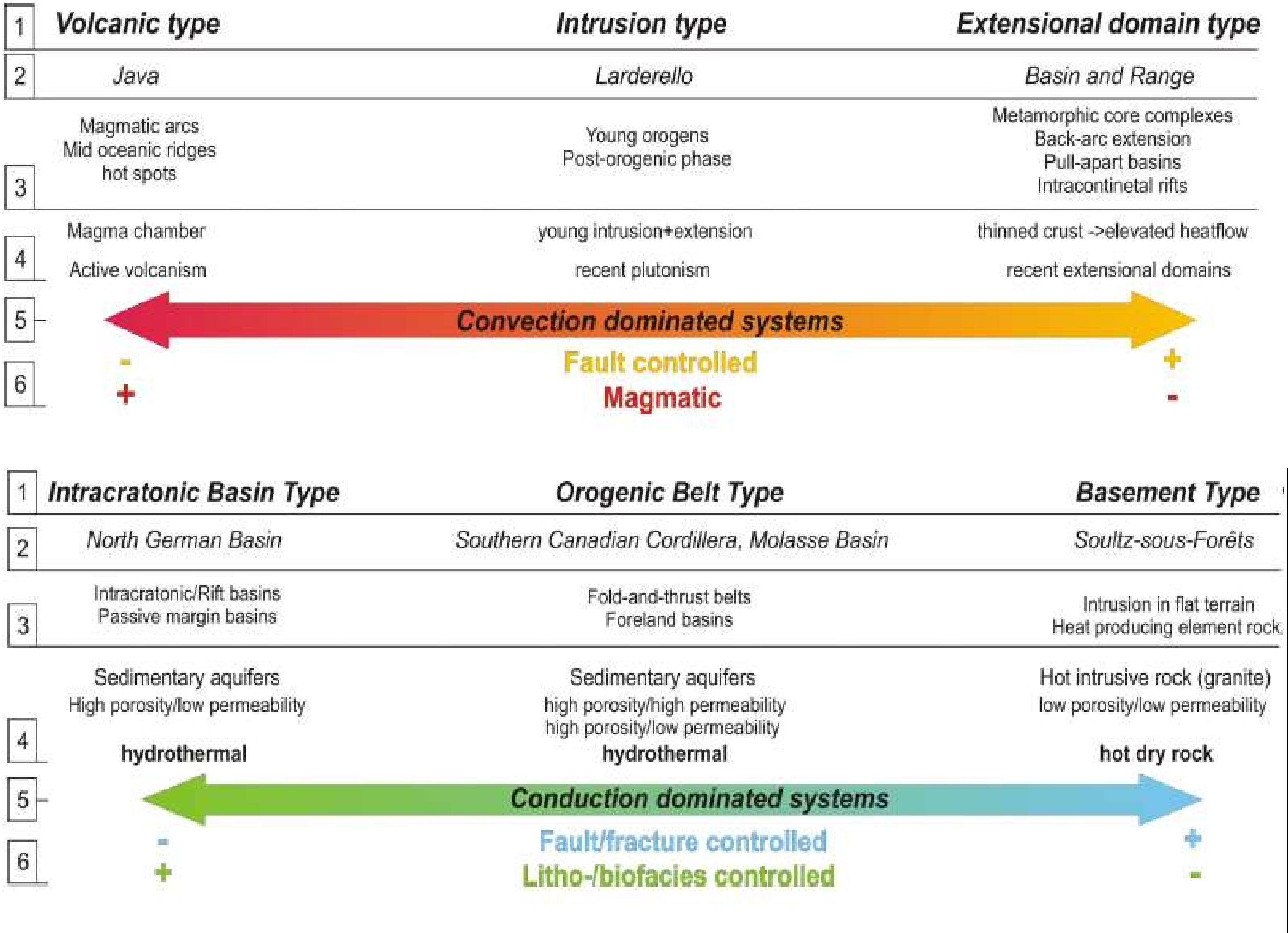

Moeck 2013

Type			Geologic Setting	Heat Source	Dominant Heat Transport Mechanism
Convection Dominated	**CV-1:** Magmatic	**CV-1a:** Extrusive	Magmatic Arcs, Mid Oceanic Ridges, Hot Spots	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation
		CV-1b: Intrusive	Magmatic Arcs, Mid Oceanic Ridges, Hot Spots	Active Volcanism, Shallow Magma Chamber	Magmatic-hydrothermal Circulation, Fault Controlled
	CV-2: Plutonic	**CV-2a:** Recent or Active Volcanism	Convergent Margins with Recent Plutonism (< 3 Ma), Young Orogens, Post-orogenic Phase	Young Intrusion+Extension, Felsic Pluton	Magmatic-hydrothermal Circulation, Fault Controlled
		CV-2b: Inactive Volcanism	Convergent Margins with Recent Plutonism (< 3 Ma), Young Orogens, Post-orogenic Phase	Young Intrusion+Extension, Felsic Pluton, Heat Producing Element in Rock	Hydrothermal Circulation, Fault Controlled
	CV-3: Extensional Domain		Metamorphic Core Complexes, Back-arc Extension, Pull-apart Basins, Intracontinental Rifts	Thinned Crust+Elevated Heatflow, Recent Extensional Domains	Fault Controlled, Hydrothermal Circulation
Conduction Dominated	**CD-1:** Intracratonic Basin		Intracratonic/Rift Basins, Passive Margin Basins	Lithospheric Thinning and Subsidence	Litho/Biofacies Controlled
	CD-2: Orogenic Belt		Foreland Basins within Fold-and-thrust Belts	Crustal Loading and Subsidence Adjacent to Thickened Crust	Fault/Fracture Controlled, Litho/Biofacies Controlled
	CD-3: Crystalline Rock - Basement		Intrusion in Flat Terrain	Heat Producing Element in Rock, Hot Intrusive Rock	Hot Dry Rock, Fault/Fracture Controlled

Moeck and Beardsmore 2014

Convection-dominated Geothermal Play Types = „Active” geothermal systems

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‘high temperature’ (>200°C) geothermal reservoirs shallower than 3,000 m

lie adjacent to plate tectonic margins or in regions of active tectonism, active volcanism, young plutonism (< 3 Ma), or regions with elevated heat flow due to crustal thinning during extensional tectonics

heat is transported efficiently from depth to shallower reservoirs or the surface by the upward movement of fluid along permeable pathways

Groups according to the nature of the heat source:

(I) magmatic arcs above subduction zones in convergent plate margins (e.g. the Indonesian Sunda Arc or the Philippine-Japan Arc);

(II) divergent margins located within oceanic (e.g. the Mid-Atlantic Ridge) or intracontinental settings (e.g. East African Rift);

(III) transform plate margins with strike-slip faults (e.g. the San Andreas Fault in California or Alpine faults in New Zealand);

(IV) intraplate ocean islands formed by hot spot magmatism (e.g. Hawaii)

Convection dominated - Magmatic Play Types (CV1) – Extrusive (CV1a)

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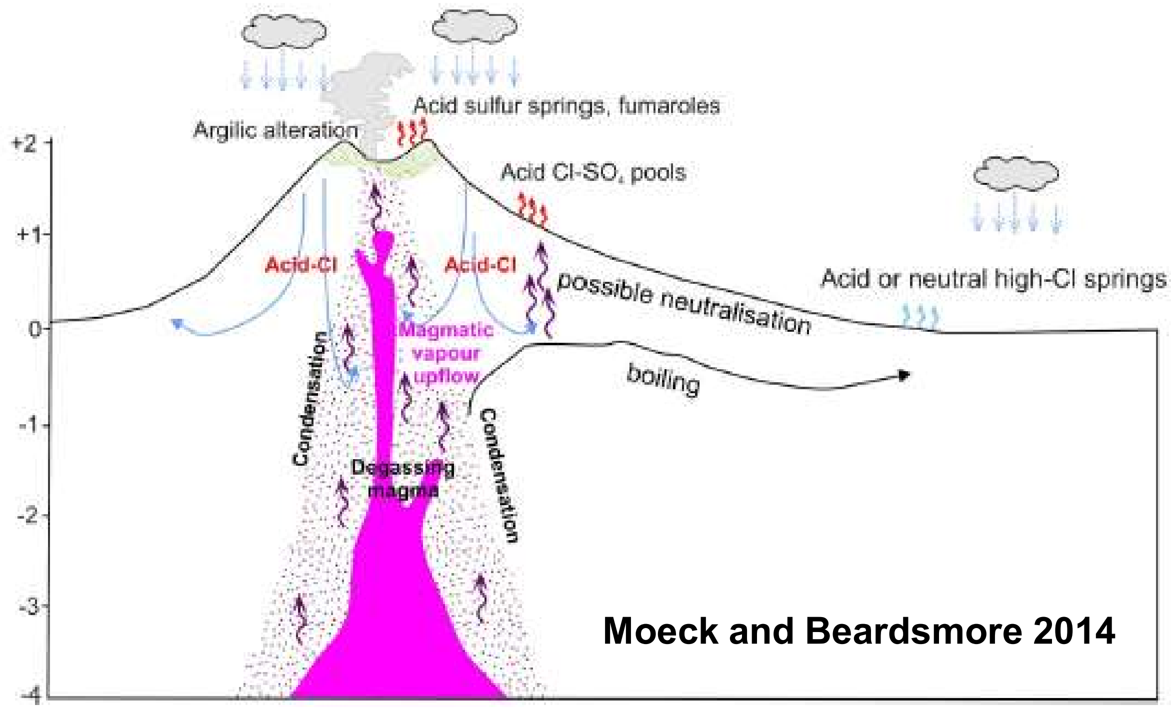

shallow, intense heat source in the form of a young magma chamber

an upflow zone and an outflow zone, controlled by the topography of the volcano

Iceland, Java, South American Andes

Convection dominated - Magmatic Play Types (CV1) – Intrusive (CV1b)

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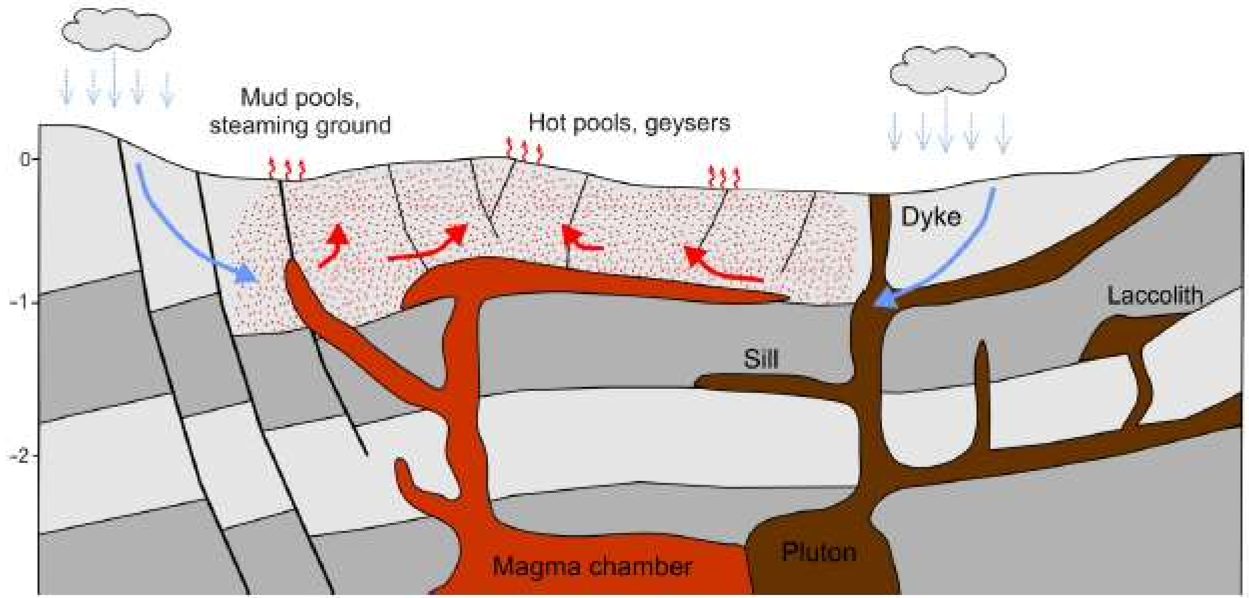

Moeck and Beardsmore 2014

- **an active magma chamber that does not lead to volcanism**
- **active faulting → deep rooted magmas can intrude beneath flat terrain with an upflow of liquids.**
- **formation of hot springs, fumaroles, boiling mud pools and other geothermal surface manifestations**
- ***Taupo Volcanic Zone (New Zealand)***

Convection dominated - Plutonic Play Types (CV2)
Recent or active volcanism (CV2a)

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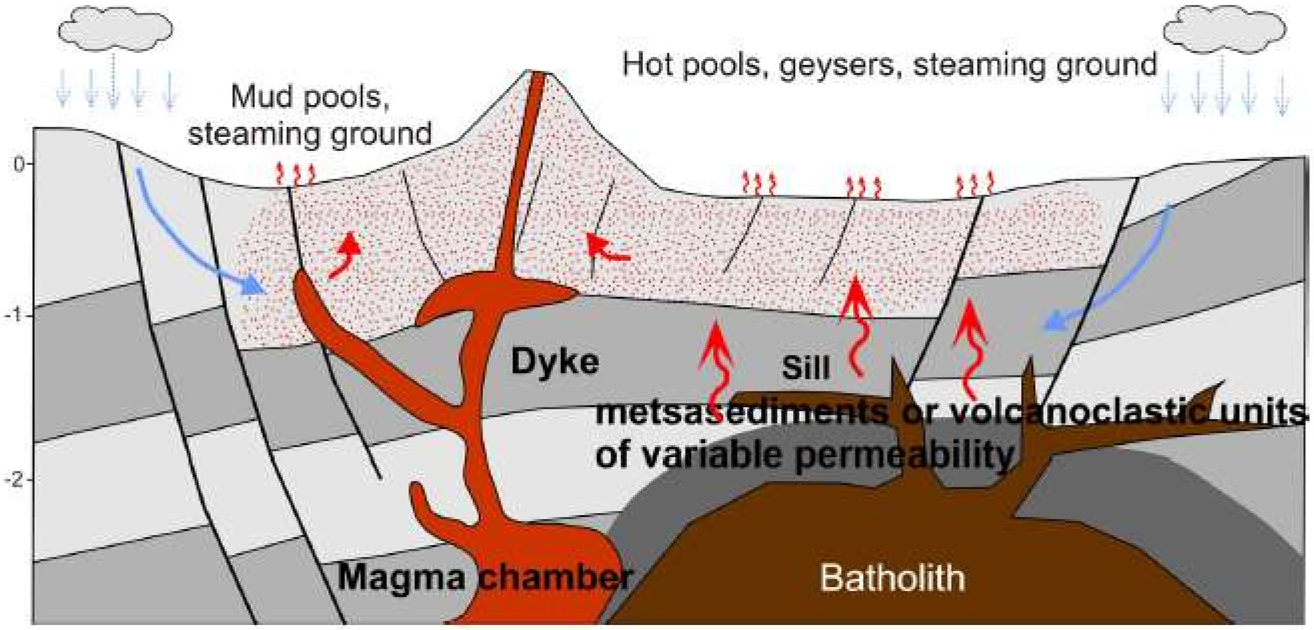

Moeck and Beardsmore 2014

recent plutonism, cooling igneous body with active volcanism

surrounding mountain ranges provide high recharge rates of circulating meteoric water, driving a hydrothermal system with possible vapor partition above the hot rock

a vapor-dominated layer (H-horizon) above a fluid-dominated layer (K-horizon)

Lardarello geothermal system , Italy

Convection dominated - Plutonic Play Types (CV2)
Inactive volcanism (CV2b)

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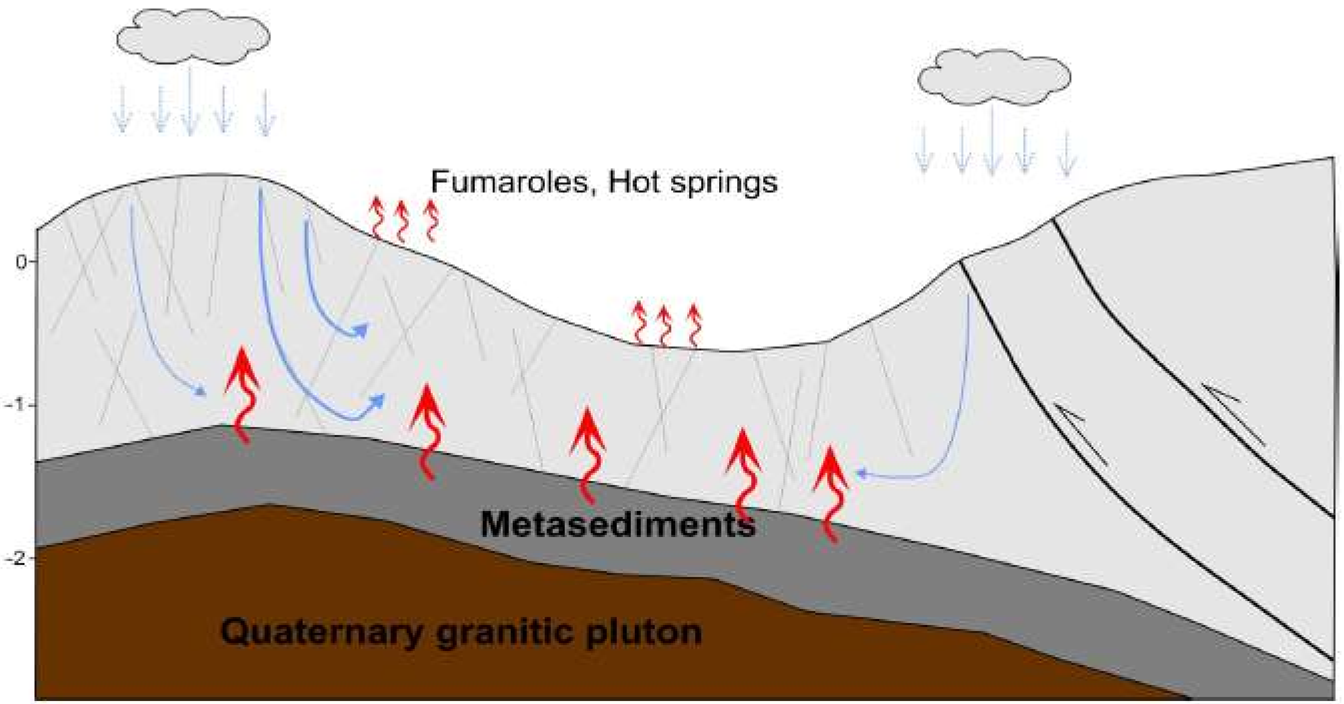


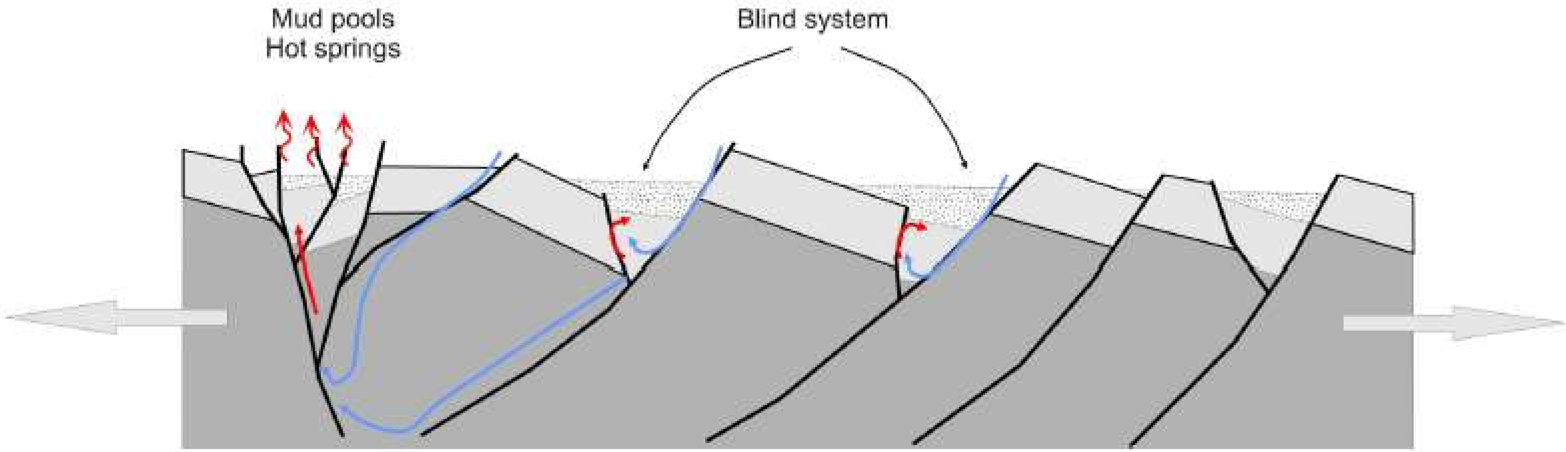
Moeck and Beardsmore 2014

mature subduction zones and decaying volcanism in continental crust

fore- or back-arc regions of fold-thrust belts along subduction zones

Geyers geothermal field in California

Convection dominated – Extensional domain Play Type (CV-3)



Moeck and Beardsmore 2014

mantle is elevated due to crustal extension and thinning, which is the main heat source (no volcanism)

resulting high thermal gradients facilitate the heating of meteoric water circulating through deep faults or permeable formations

Great Basin (Western USA), Western Turkey, Upper Rhine Graben, African Rift,

PANNONIAN BASIN

Convection-dominated Geothermal Play Types = „Passive” geothermal systems

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absence of fast convective flow of fluids

passive tectonic plate settings: no significant recent tectonism or volcanism → temperature increases steadily (although not necessarily linearly) with depth

Favorable tectonic settings for conduction-dominated Geothermal Play Types:

(I) extensional, divergent margins and grabens, or lithospheric subsidence basins (North German Basin, Otway Basin in Australia);

(II) foreland basins within orogenic belts (Molasse Basin north of the Alps, or the Western Canadian Sedimentary Basin east of the Rocky Mountains);

(III) crystalline basement underlying thermally insulating sediments (the Big Lake Suite Granodiorite beneath the Cooper Basin in Australia)

low permeability potential reservoirs such as tight sandstones, carbonates or crystalline rock can only be developed using engineered geothermal systems (EGS) technology

Conduction dominated – Intracratonic basin Play Type (CD-1)

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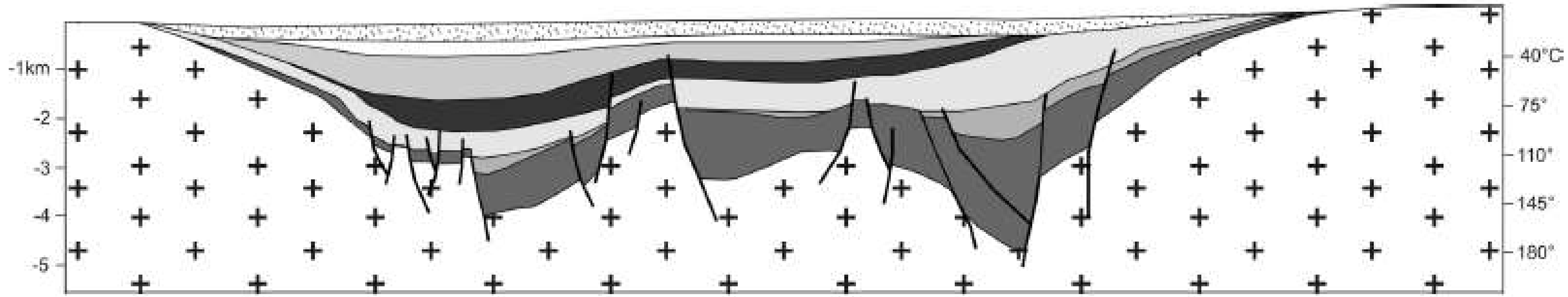
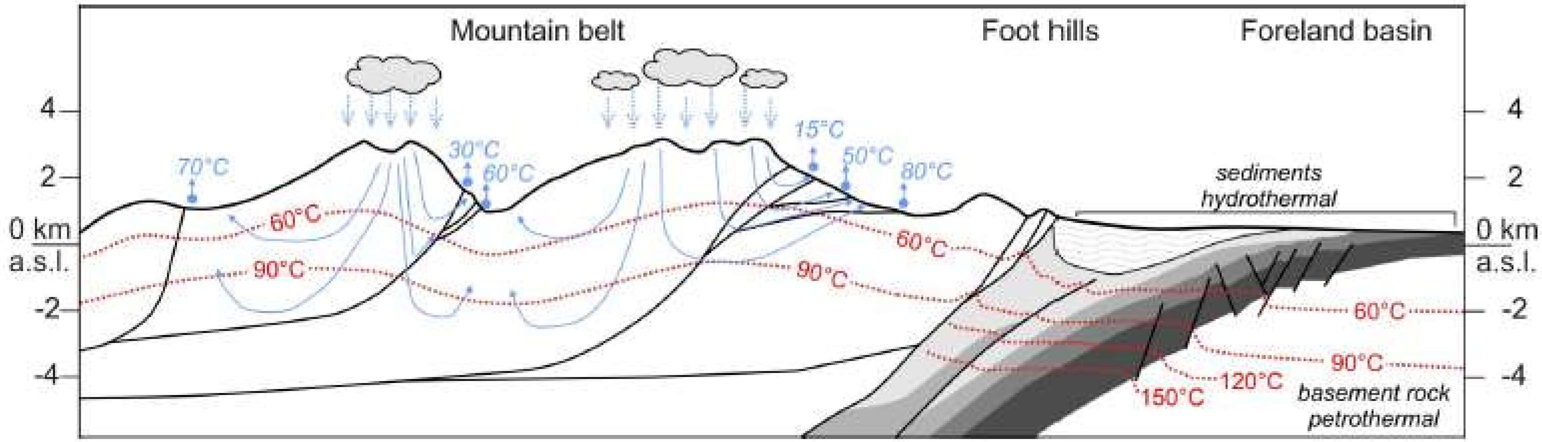


Moeck and Beardsmore 2014

- Reservoirs in thick sedimentary squence in thermal sag basins, fossil rift grabens
- Lithology, fault and diagenesis control on porosity/permability patterns
- Avergage, high, or low heat flow
- Formations above salt diapirs might provide suitable geothermal reservoirs for district heating because high thermal conductivity of salt rock causes local positive thermal anomalies in the overburden

Conduction dominated – Orogenic belt
Play type (CD-2)



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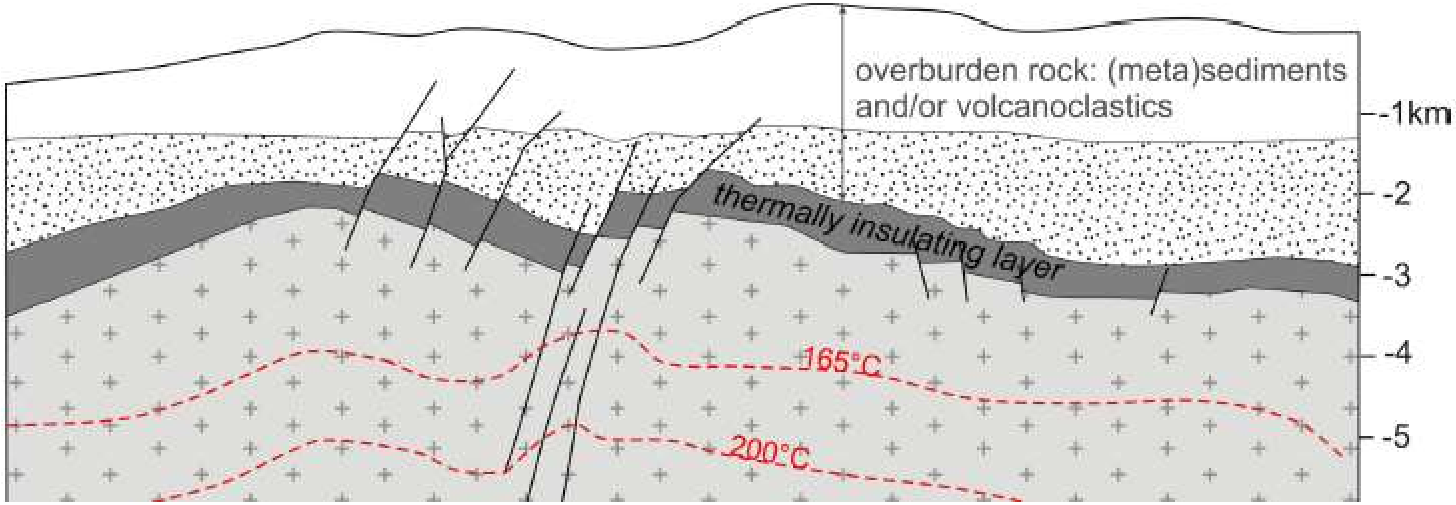
sedimentary reservoir within a foreland basin or orogenic mountain belt

significant crustal subsidence (km) towards the orogen due to the weight of the thickened crust of the orogenic belt and loading of erosional products from the mountain belt → wedge shape of foreland basins: progressive deepening of potential aquifer rocks towards the orogen, with an associated increase in temperature

within the orogenic mountain belt itself, the conductive thermal regime can be locally disturbed where groundwater infiltration cools the rock mass

Conduction dominated – Basement Play Type (CD-3)



Moeck and Beardsmore 2014

faulted or fractured crystalline (usually granitic) rock with very low natural porosity and permeability but storing vast amounts of thermal energy (high radiogenic heat generation - U, Th)

can be developed by EGS technologies

Geothermal potential and estimation methods

Geothermal potential – definition

According to the recommendation of International Geothermal Association (IGA):geothermal potential = **the exploitable amount of geothermal energy during a year** → also depends on technical and economical parameters.

Several (and no uniform) approaches worldwide

I. Prediction from production data: extrapolated from the annual production rates

II. Static resource estimation: based on the total volume method

III. Dynamic resource estimation: water and heat recharges also considered

Resource estimation methods

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Static: Heat in Place calculation (volumetric method)
[Muffler és Cataldi (1978), Mufler (1979)]
$H_0 = c \times V \times \Delta T$ – huge numbers, not exploitable

Dynamic: water and heat recharge (poro/permeability, conductive/convective heat flow)

Recovery factor (R): economically exploitable part of HIP

$H_1 = R \times H_0$

Empiric estimations *(Williams et al. 2008)*

- Hydrogeothermal systems: R=0,1-0,25
- Fractured reservoirs: R=0,08-0,2

Production-reinjection doublet *(Lavigne 1978)*
$R = 0{,}33 \times T_{reservoir} - T_{inj} \;/\; T_{reservoir} - T_{surface}$

Without reinjection *(Gringarten 1978)*
R=0,1

Elements of geothermal potential estimation

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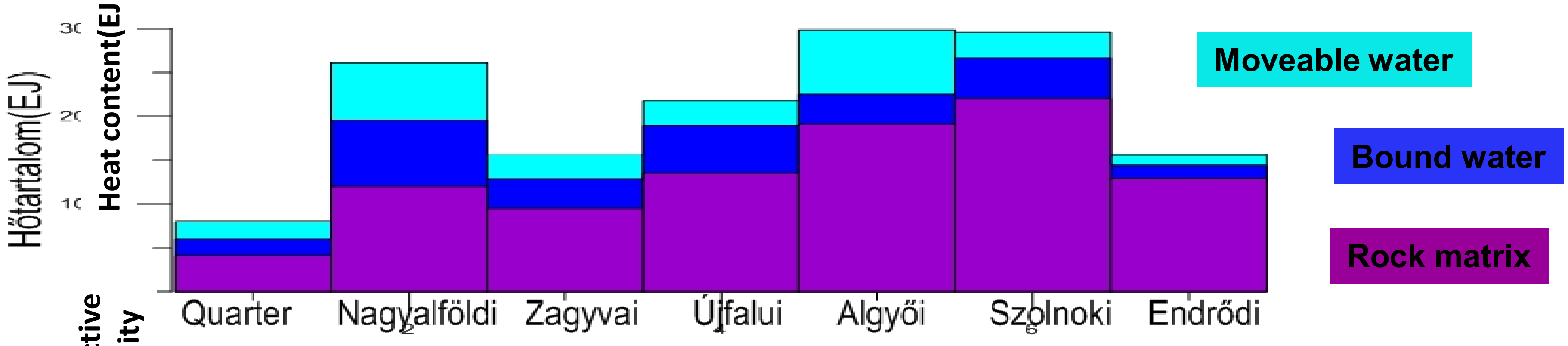
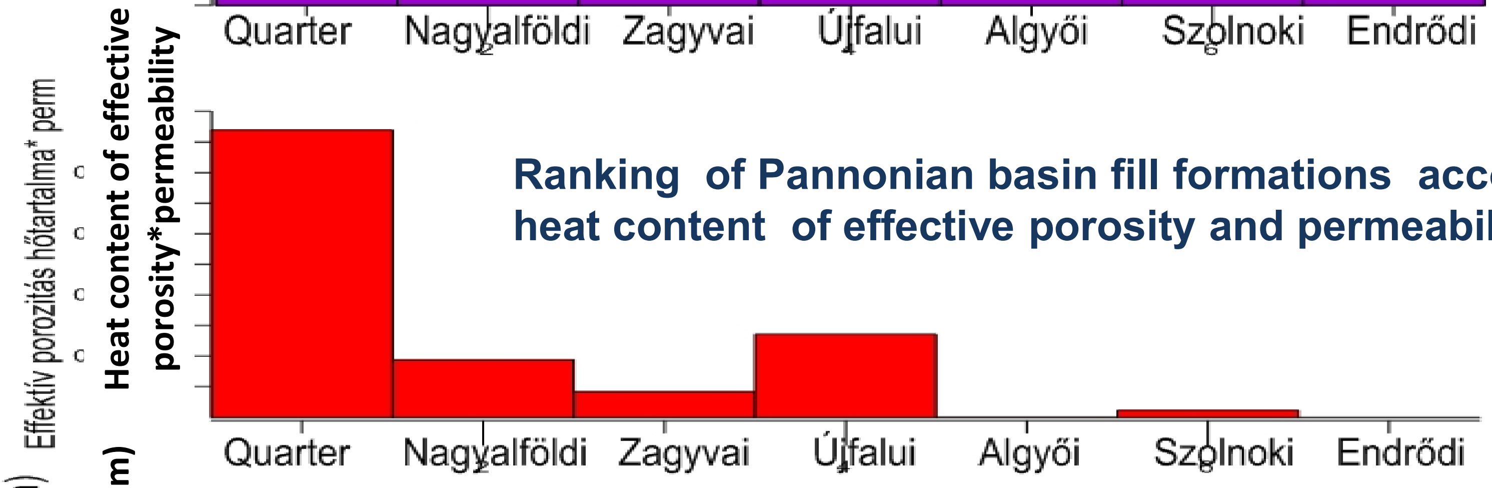
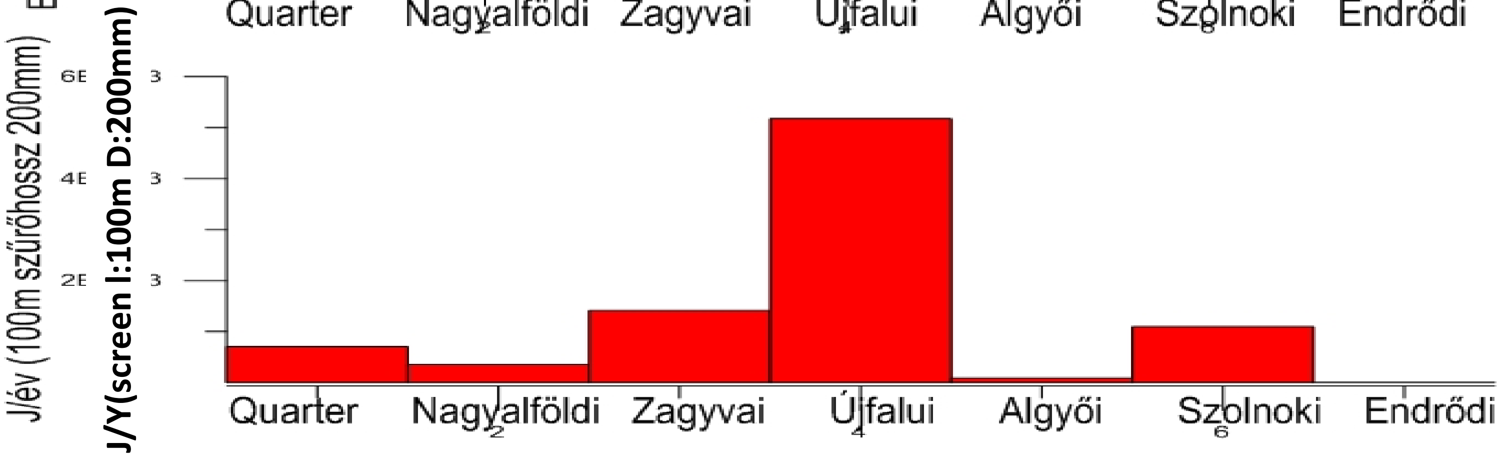
1. Local porosity model (porosity components)
2. Porosity versus depth (compaction trends in basin fill sediments)
3. Thermal parameters (specific heat conductivity and heat capacity)
4. Estimation of permeability using porosity
5. Temperature, as function of depth (geothermal gradient)
6. Clay content of porous sediments
7. Carbonates in the basement (maps, and estimated thickness)
8. Thickness of altered zones and basic conglomerates on top of basement rocks
9. Geothermal heat flow (measured and estimated from basin depth)
10. Estimation of technical parameters

Ranking of the Pannonian basin filling formations according to porosity components





Ranking of Pannonian basin fill formations according to heat content of effective porosity and permeability



Ranking of the Pannonian basin fill formations according to heat content of effective porosity taking into account the estimated technical parameters and temperature

Monte Carlo Simulation

- The elements of the physical model (reservoir parameters) are handled as probability variables.
- The expected value, standard deviation stems from measuremed data, or from apriori knowledge.
- Sorting ascending order the results of calculations using variables with noise originated from random number generator, performed at least thousand times, which gives a probability distribution.
- From the distribution we get the size of resource according the probability levels P90, P50, P10

Heat in Place calculations using Monte Carlo simulation

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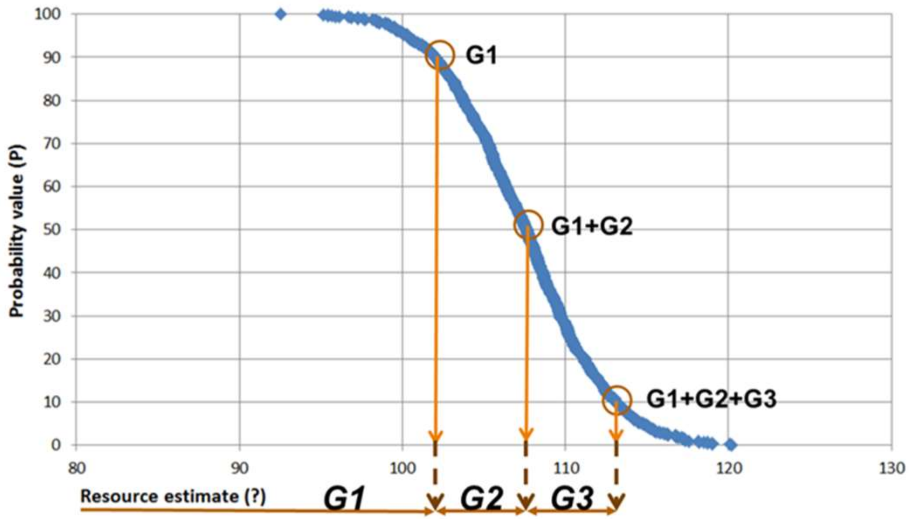
	Input parameters					**Calculated parameters**			
	A	B	C	D	E	F	G	H	**I**
	Reservoir area (km^2)	Reservoir thickness (km)	Porosity (V/V)	Reservoir temperatur e (˚C)	Recovery factor	**Total volume (km^3)**	**Pore volume (km^3)**	**Porosity heat content (PJ)**	**Recove-rable heat (PJ)**
Calculation formula						A*B	C*F	4.187*G*(D-30)	**(H*E)**
MIN	***e.g. 10***	***e.g. 0,2***	***e.g. 0,05***	***e.g. 80***	***e.g. 0,1***				
MAX	***e.g. 20***	***e.g. 0,5***	***e.g. 0,1***	***e.g. 120***	***e.g. 0,2***				

G1: Quantities associated with a high level of confidence (low estimate – P90)

G2: Quantities associated with a moderate level of confidence (best estimate – P50)

G3: Quantities associated with a low level of confidence (high estimate – P10)



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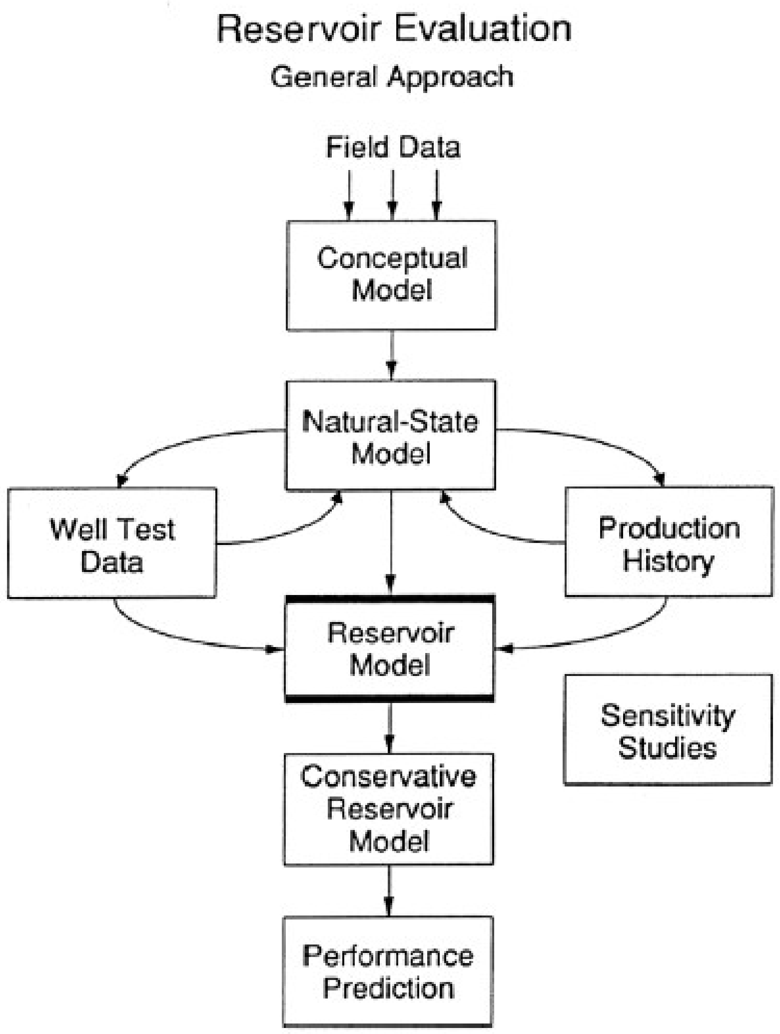
Geothermal processes – a numerical approach for reservoir evaluation

General approach to reservoir evaluation

- Data collection
- Building a conceptual model
- Natural state numerical modelling
- Production modelling



Bodvarsson and Witherspoon, 1989

Components of a conceptual model

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- **Reservoir geometry**
- **Distribution of hydraulic and thermal properties**
- **Directions of fluid movement**
- **Location of inflow/outflow zones, and hydraulic boundaries**
- **Location of heat inputs and outputs**
- **Temperatures**
- **Two-phase zones**

DATA SOURCES

- ***Geological data***
  - ***Data from surface outcrops (structure, lithology)***
  - ***Borehole data (stratigraphy, hydrothermal alterations)***
- ***Geochemical data***
  - ***Chemical composition***
  - ***Geothermometers***
- ***Heat and mass flow measurements***
  - ***Temperature and discharge of springs, geysers and fumaroles***
  - ***Temperature gradient measurements in shallow boreholes***
- ***Geophysical data***
  - ***Surface geophysical data: Resistivity, gravity, seismics, self-potential***
  - ***Down-hole data: well logs, T and P profiles, flow rates, flowing enthalpies***

The purpose of numerical modelling

- To understand the physical functioning of a system
- To estimate generating capacity
- To design/optimise geothermal utilisation system
- To predict the behaviour of the system (temperature, pressure) during extraction
- To estimate chemical changes during production
- To predict environmental impacts
- To help evaluating different conceptual models of the field
- Etc.

Geothermal processes in numerical models: groundwater flow equation

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Diffusion equation:

$$S_0 \frac{\partial h}{\partial t} = \nabla(K(\nabla h + \chi e)) + Q$$

$$K = \frac{k\rho^f g}{\mu^f}$$

S_0 – specific storage (m^{-1})
H – hydraulic head (m)
T – time (t)
χ - buoyancy coefficient (l)
E – gravitational unit vector (l)
Q – sources and sinks (s^{-1})
K – hydraulic conductivity tensor ($m\ s^{-1}$)
K – permeability tensor
ρf – fluid density ($kg\ m^{-3}$)
g – gravity
μ^f – dynamic fluid density ($kg\ m^{-1}\ s^{-1}$)

Geothermal processes in numerical models: heat transport equation

Darcy equiation:

$$q = -K(\nabla h + \chi e)$$

Heat transport with conductive and advective parts

$$(\rho c)_g \frac{\partial T}{\partial t} = \nabla \lambda_{cp} \nabla T - \rho_f c_r q T + H$$

conductive advective

T – temperature (K)
C –specific heat (J kg^{-1} K^{-1})
$(\rho c)_g$ – bulk volumetric heat capacity (J m^{-3} K^{-1})
H – sources and sinks (W m^{-3})

Fully coupled due to T dependence of density and viscosity

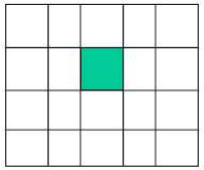
Numerical models to solve heat and flow transport equations

Data needed :

- **discretization in 3 dimensions (∂x, ∂y, ∂z)**
- **hydraulic and thermal properties**
- **initial conditions**
- **boundary conditions**

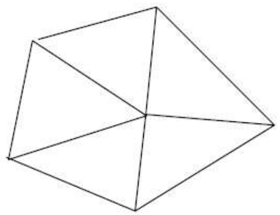
Discretisation methods

Finite differences



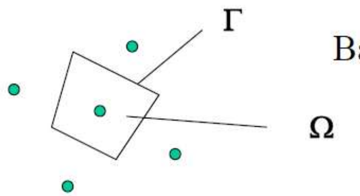
Balance of box

Finite elements



Balance over patch

Finite volumes



Balance over FV

Boundary conditions

- Model base: upflow rates + enthalpies, heat flow
- Top boundary: constant temperature and atmospheric pressure, recharge
- Lateral boundaries:
  - No-flow
  - Background temperature + pressure
  - In/outflow rates + enthalpies

Calibration

- Flow rates and enthalpies of wells
- Temperature and pressure profiles
- Production enthalpies and pressure changes
- Pressure (head) time series

Classification of geothermal resources / reserves

Classification: Categories of Geothermal Potential

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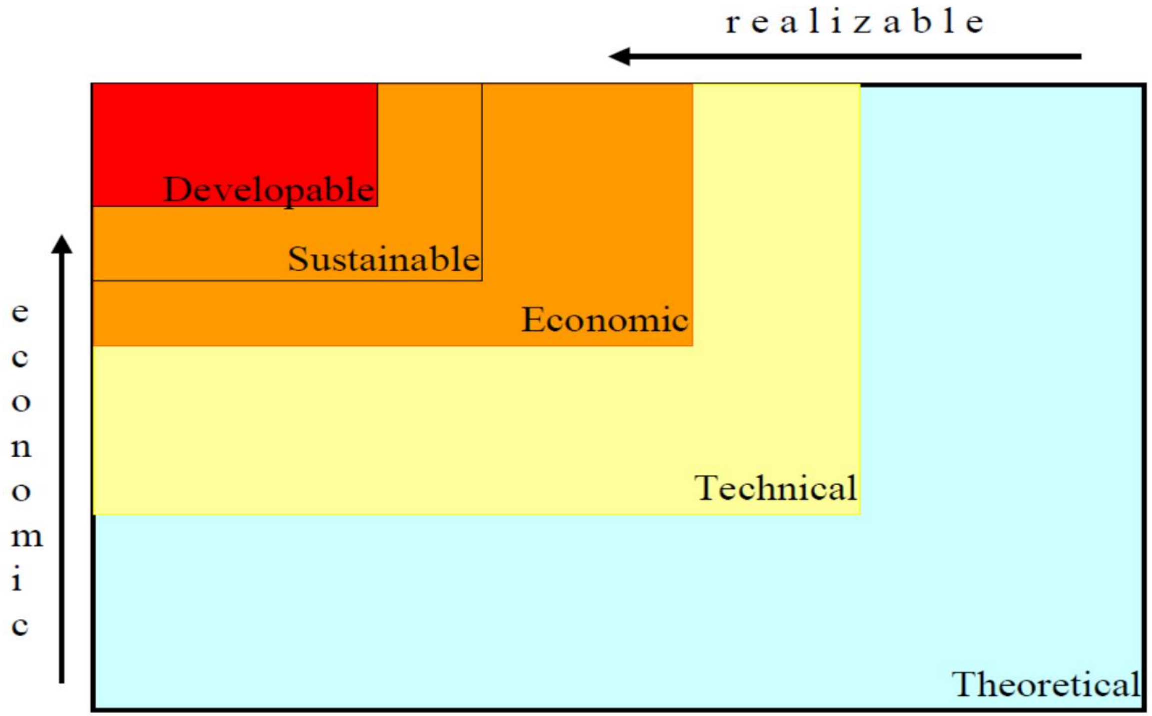


Rybach, 2010

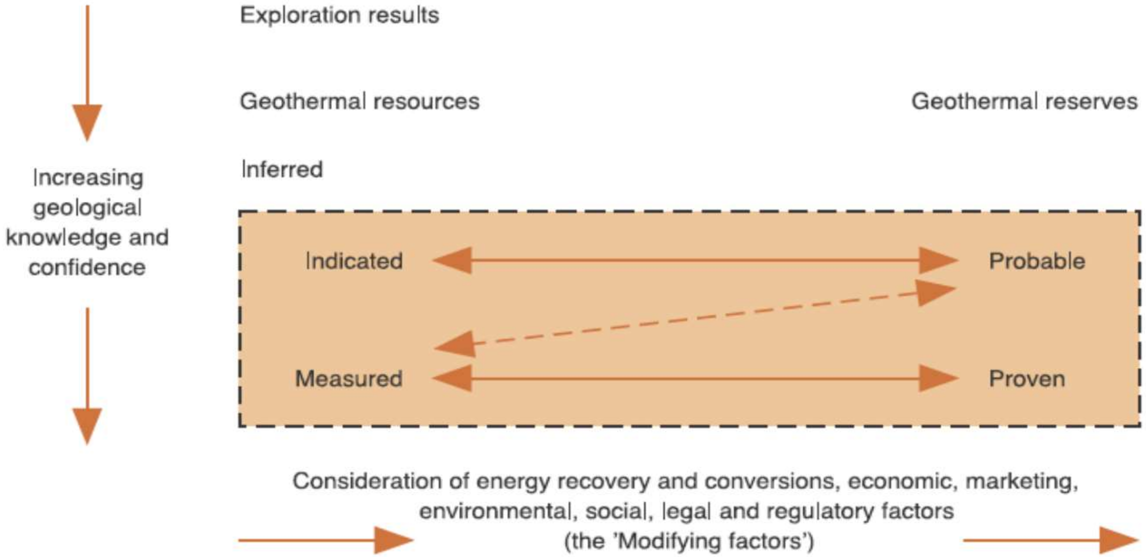
Theoretical = physically usable energy supply (heat in place).

Technical = % of theoretical potential that can be used with current technology.

Economic = time & location dependent % of technical potential that can be economically used.

Sustainable = % of economic potential that can be used by applying sustainable production levels (regulations, environmental restrictions).

Classification: CanGEA/AGEA



Geological Confidence/"Modifying Factors" CanGEA/AGEA 2010

	Exploration Results	Geothermal Resource			Geothermal Reserve	
		Inferred	Indicated	Measured	Probable	Proven
Commerciality	No implications regarding commerciality.	Commerciality not yet established. Probably feasible with current or future technology, prevailing and/or more favourable market conditions.			Commercial. Feasible with existing technology and prevailing market conditions.	
Definition	Data from exploration that is of material value to Geothermal Resource estimation, but which in itself is insufficient to define a Geothermal Resource category.	The Recoverable Thermal Energy within an area/ volume that has enough direct indicators of Geothermal Resource character or dimensions to provide a sound basis for assuming that a body of thermal energy exists, estimating temperature and having some indication of extent.	The Recoverable Thermal Energy within a more reliably characterised volume of rock than the Inferred Geothermal Resource. Sufficient indicators to characterise temperature and chemistry, although with few direct measures indicating extent.	The Recoverable Thermal Energy within a drilled and tested volume of rock within which well deliverability has been demonstrated, with sufficient indicators to characterise temperature and chemistry and with sufficient direct measurements to confirm the continuity of the reservoir.	That part of an Indicated Geothermal Resource for which commercial production for the assumed lifetime of the project can be forecast, or: That part of a Measured Geothermal Resource for which commercial production for the assumed lifetime of the project cannot be forecast with sufficient confidence to be considered a Proven Geothermal Reserve. The chance of occurrence is 'more likely than not'.	Applies directly to production satisfying all Modifying Factors. Directly related to that part of a Measured Geothermal Resource for which commercial production for the stated lifetime of the project can be forecast with a high degree of confidence.

The UNFC-2009 classification scheme

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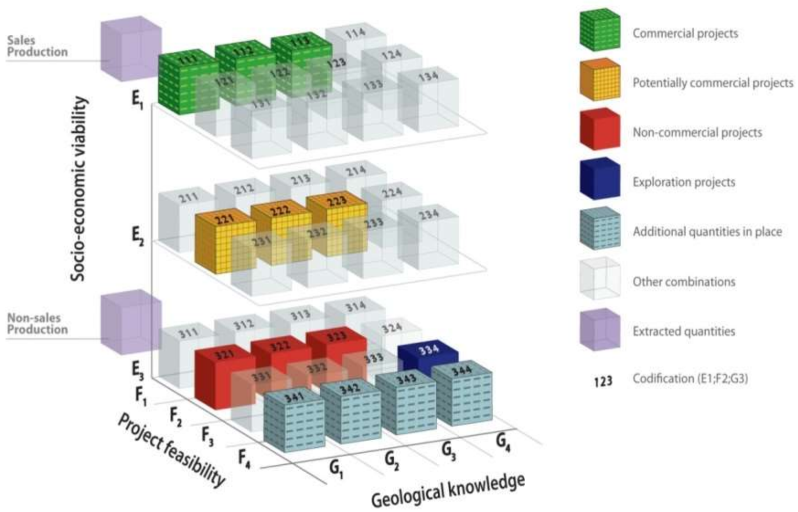


Generic, principles-based system

Classifies a certain project in a numerical and language independent coding scheme.

https://www.unece.org/fileadmin/DAM/energy/se/pdfs/egrc/egrc7_apr2016/ECE.ENERGY.GE.3.2016.6_e.pdf

E-axis: 'Economic and social viability' (degree of favourability of social and economic conditions in establishing commercial viability of project , e.g. market prices, relevant legal, regulatory, environmental and contractual conditions)

F-axis: 'Field project status and feasibility' (maturity of studies and commitments necessary to implement project)

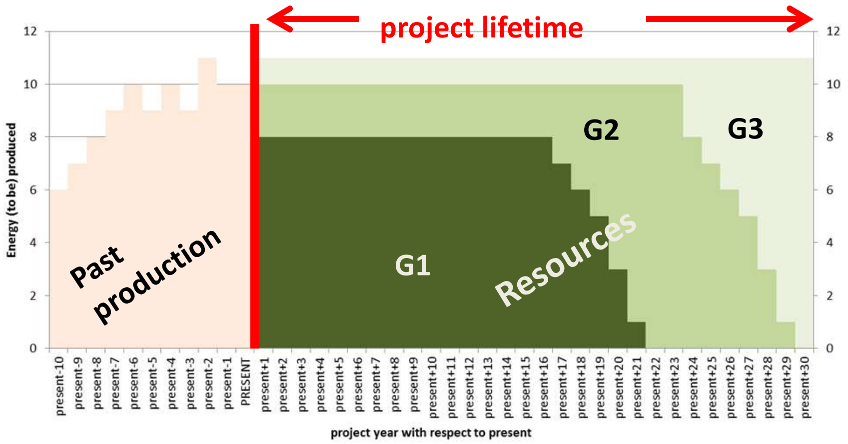
G-axis: ' Geological knowledge' (level of confidence in the geological knowledge and potential recoverability of the quantities)

The classification process

1) **defining a project**, link between a geothermal energy source (*equivalent to the terms 'deposit' or 'accumulation' used for solid minerals and fossil fuels*) and the product (*heat, electricity*)

2) **estimating the quantities of energy that can be recovered** and delivered as 'products' by the given project from the effective date of the evaluation forward (till the end of the project lifetime/limit)

Estimation method / quantification (e.g. scenario, probabilistic) is NOT PART of the classification exercise! – no standard method uniformly accepted



3) **classifying the quantified geothermal energy** resource based on the criteria defined by the **E, F and G (sub)categories**

Part II – Introduction to deep geothermal energy: play types, potential estimation methods, geothermal modelling, classification of resources/reserves

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Methods to outline and characterize potential geothermal reservoirs at regional scales

(Experiences from TRANSENERGY project)

Geothermal reservoir: Subsurface region where the rocks contain hot fluidum, which is exploitable economically

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Approach	*Extent of the reservoir*	*Characterization*
-geological volume	geological-hydrogeological units; regional scale	location, geometry, lithology, temperature
-economical estimation;	thermal energy can exploited economically	resource cost estimation
-engineering	surroundings of wells	well test permeability, yield

The aim of outlining and characterization of reservoirs in TRANSENERGY:

-to identify potential geological/hydrogeological units containing thermal water
-to provide information about utilization possibilities (especially for energy purposes) for stakeholders and decision makers
(Not suitable for geothermal well design)

Thermal water: higher than 20°C, but reservoir outlining and characterization restricted higher than 50°C

Method used in the TRANSENERGY project

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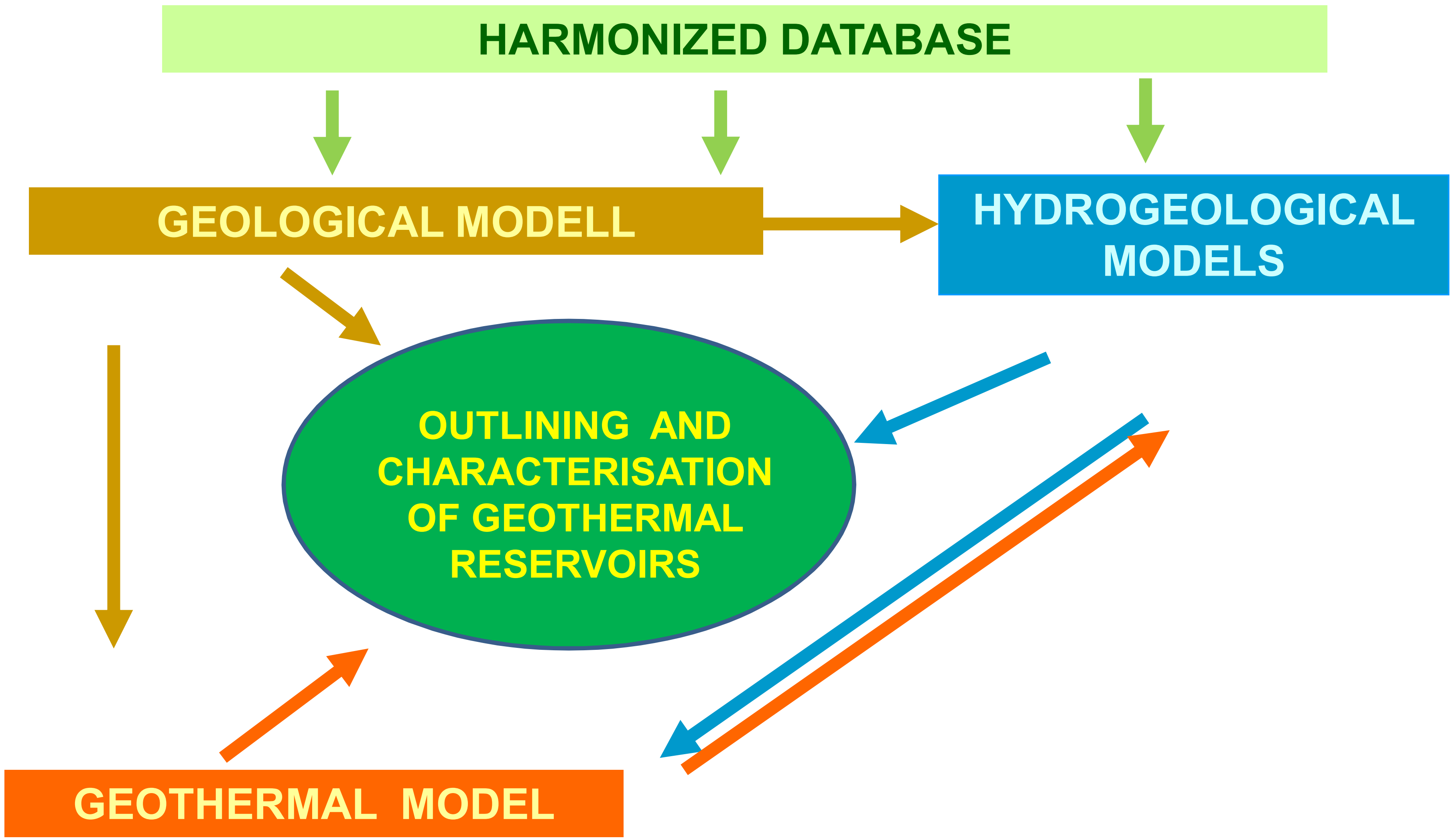
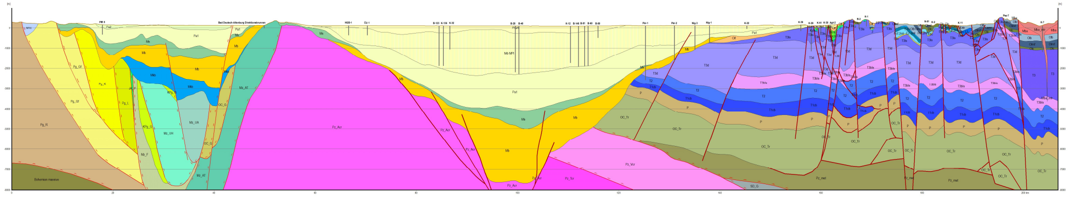
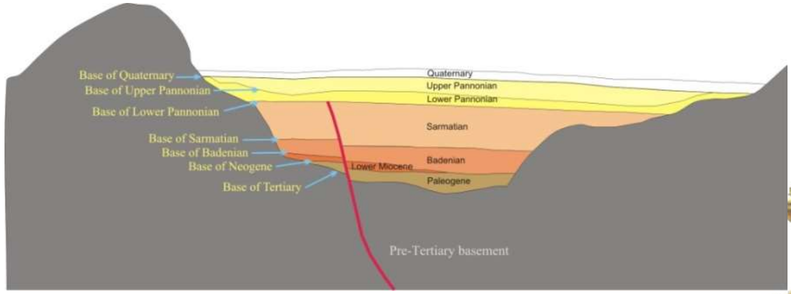
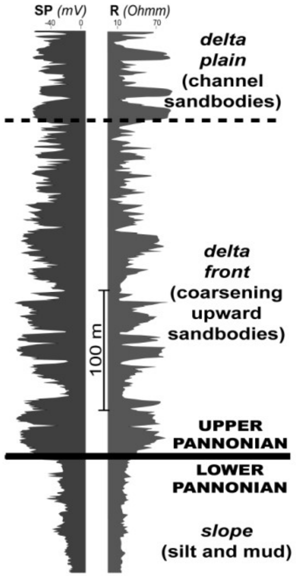
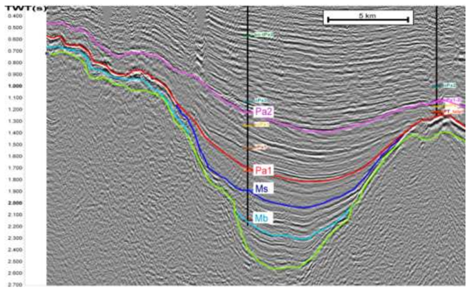


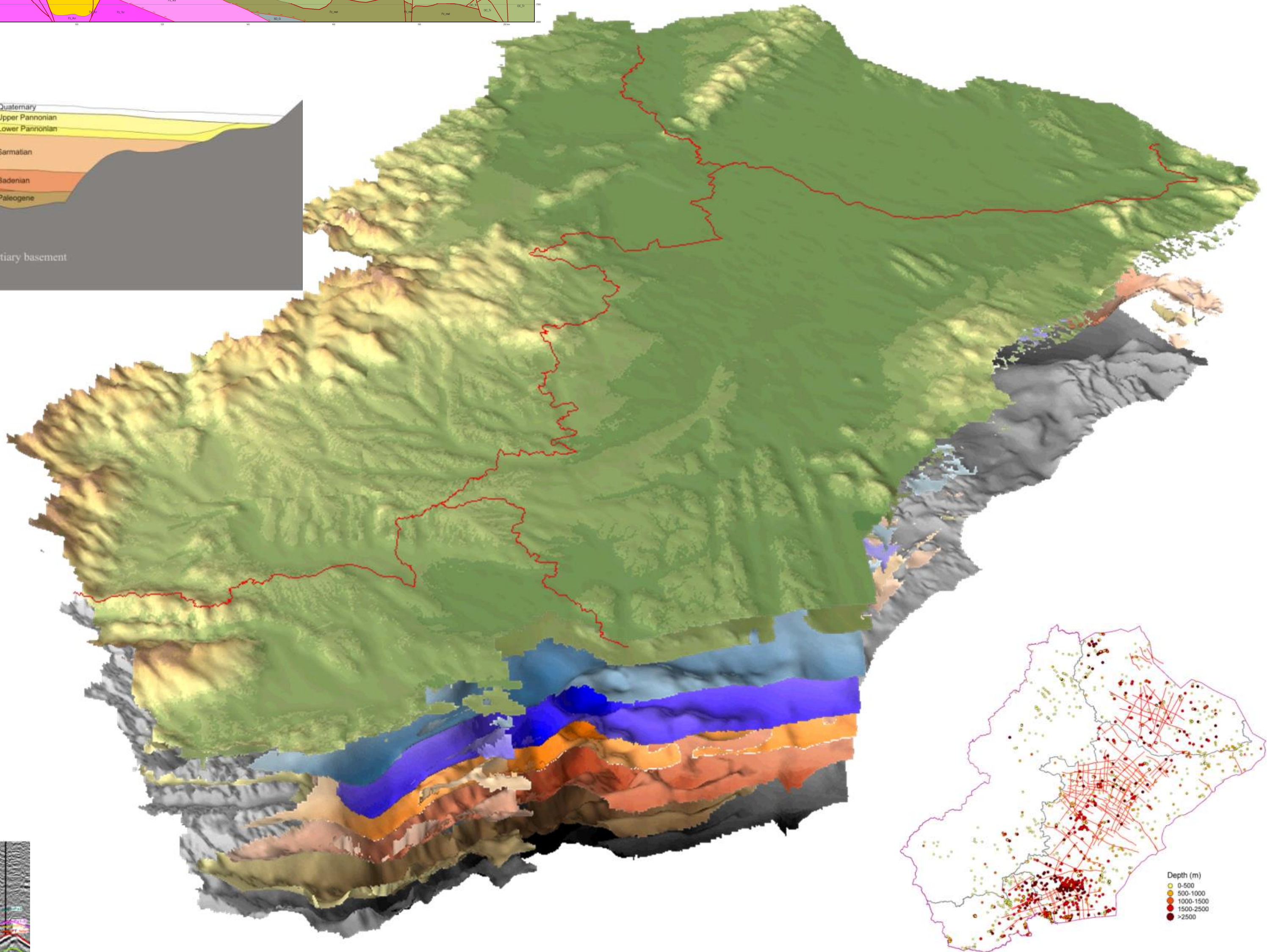
„Flying carpet" 3D geological model











Harmonization of geological data

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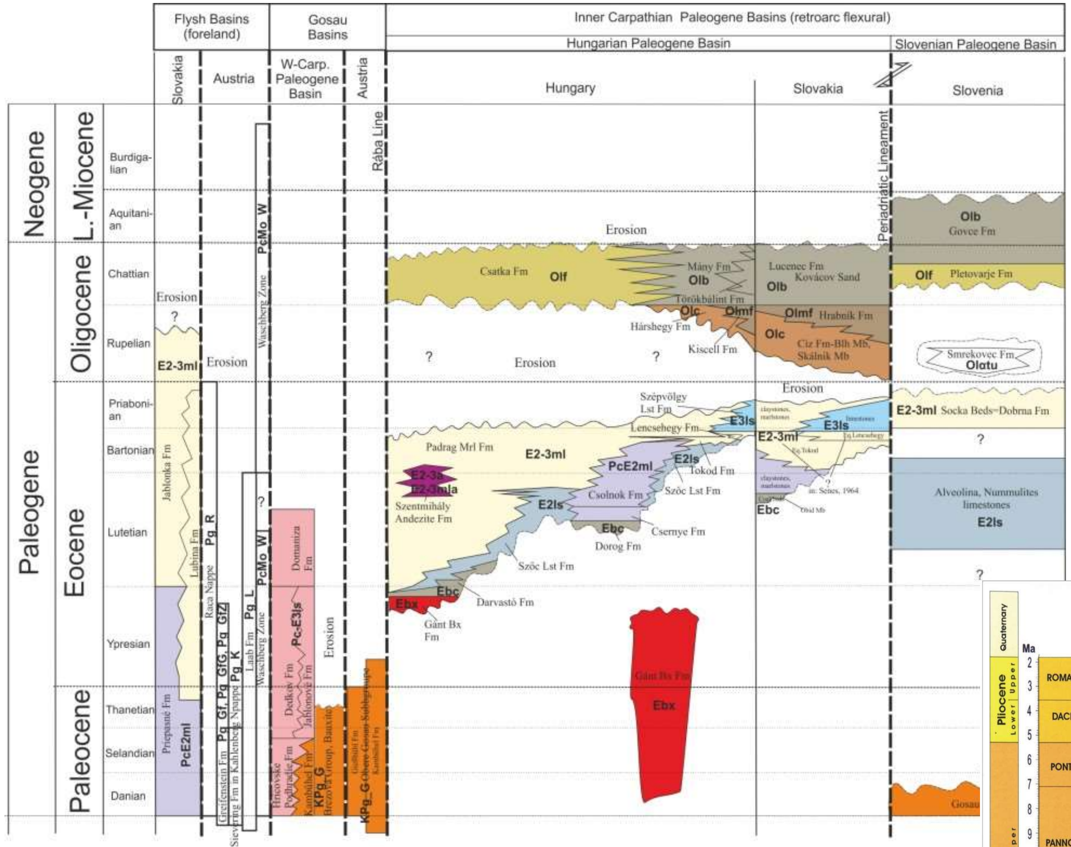

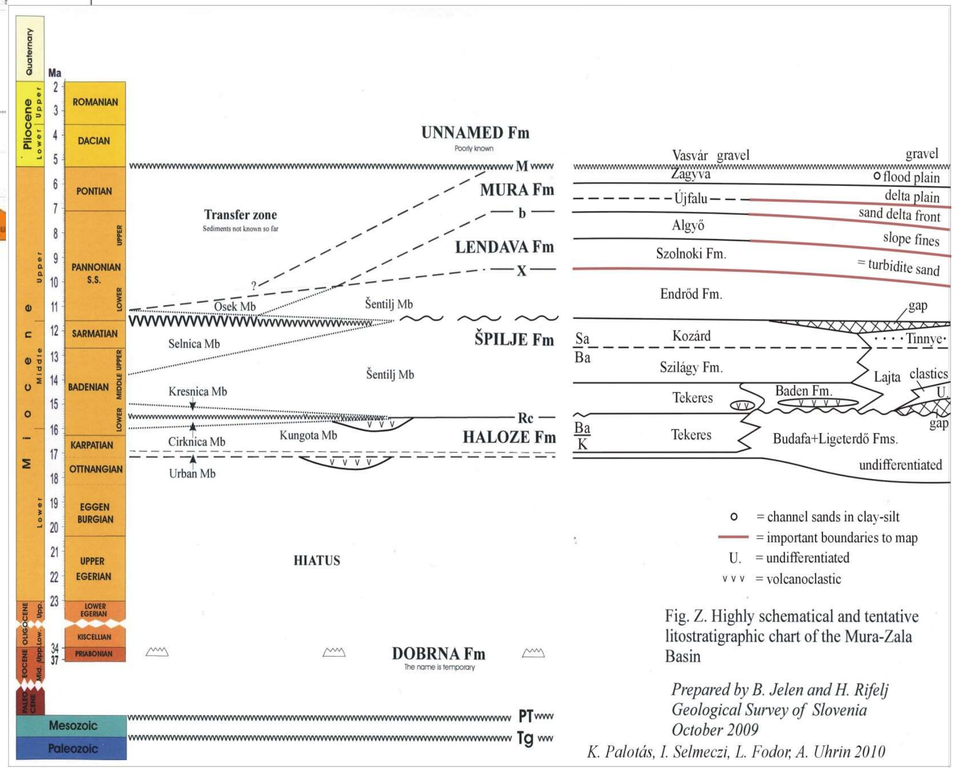

Fig. Z. Highly schematical and tentative litostratigraphic chart of the Mura-Zala Basin

3D geothermal model

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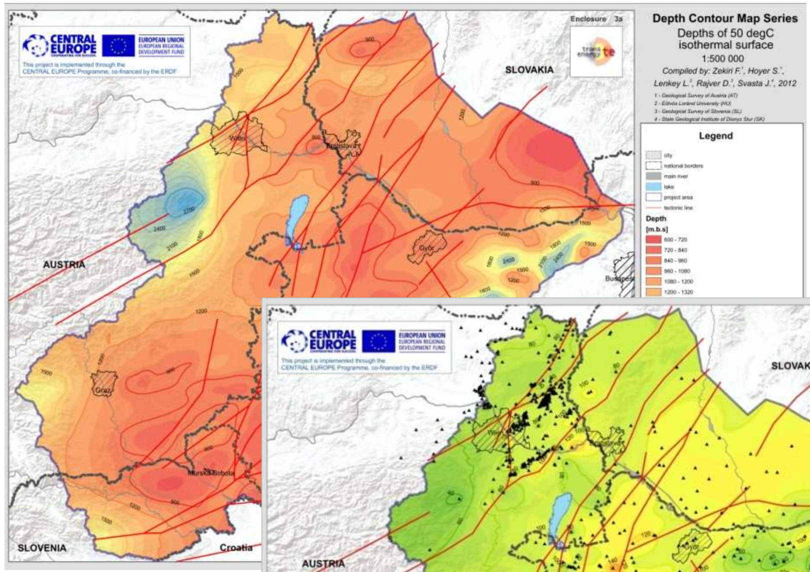
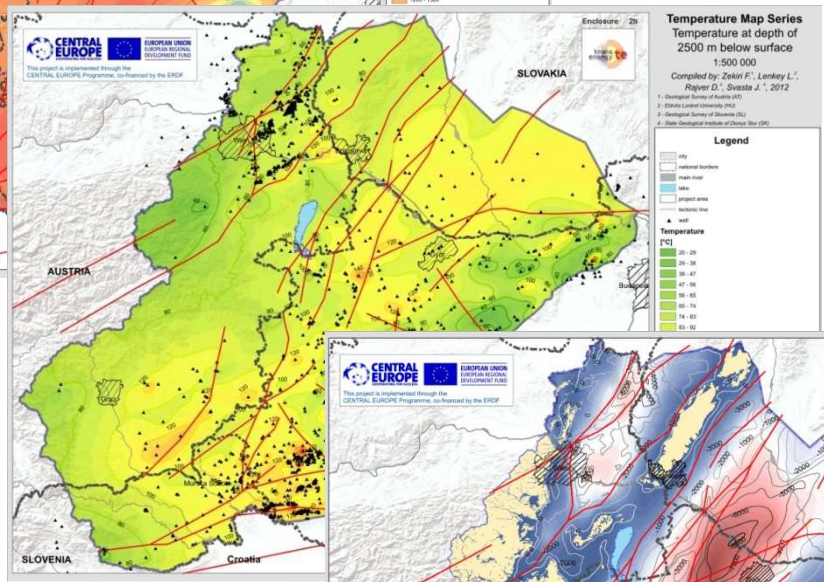
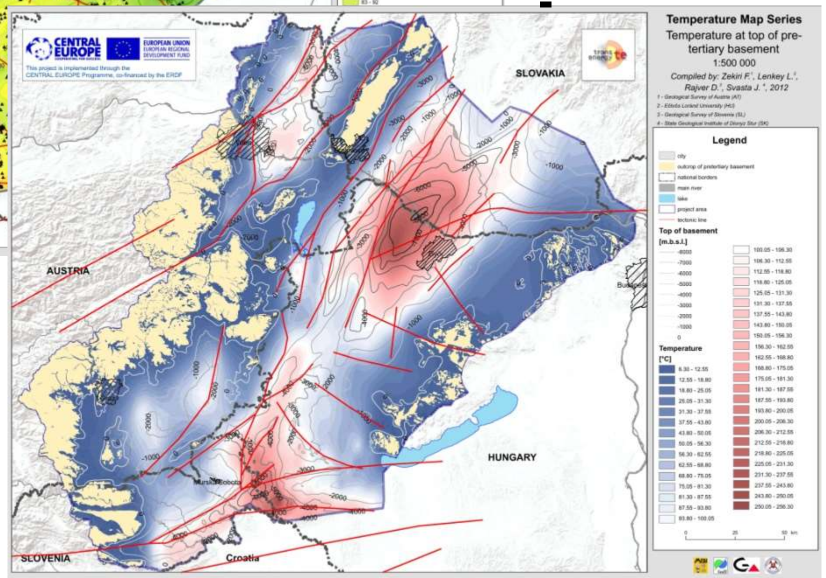


Contour maps of isotherm surfaces:
- -50 °C
- -100 °C
- -150 °C



Temperature map in different depths:
- -100 m
- -2500 m
- -5000 m
- -



temperature at the top of the basement

Reservoir types in the Pannonian Basin

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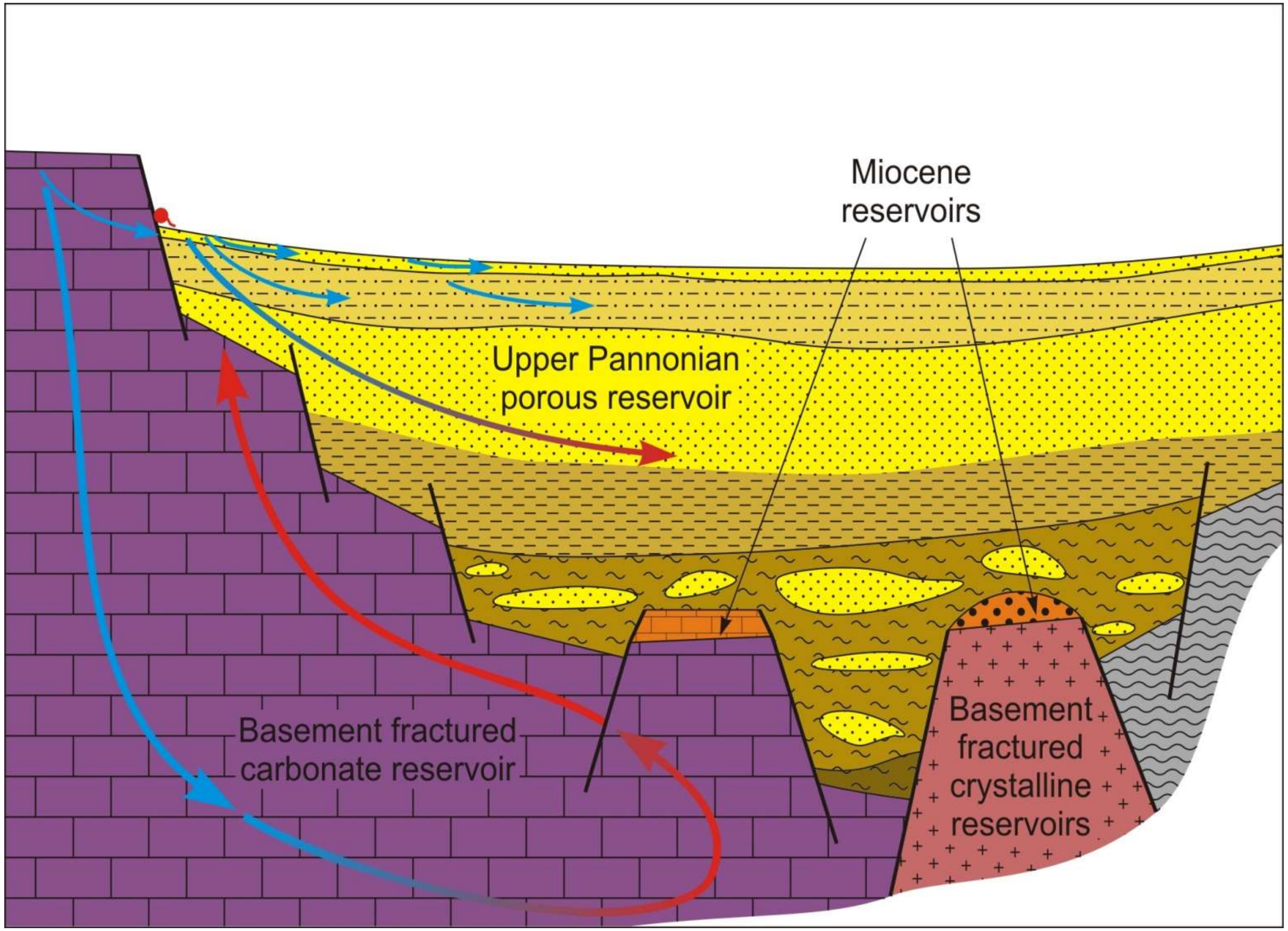
Main reservoir categories:



Sub-categories:

Type of aquifer:

- porous reservoirs
- reservoirs with double porosity
- fractured or karstified carbonate reservoirs
- fractured crystalline reservoir

Temperature:

- 50-100 ° C
- 100-150 ° C
- above 150 ° C

Hydrogeochemical composition

Maps of the potential reservoirs

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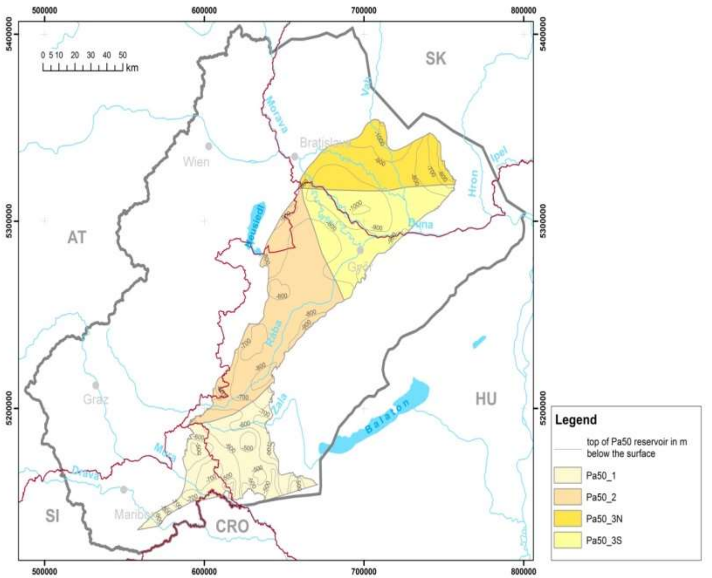
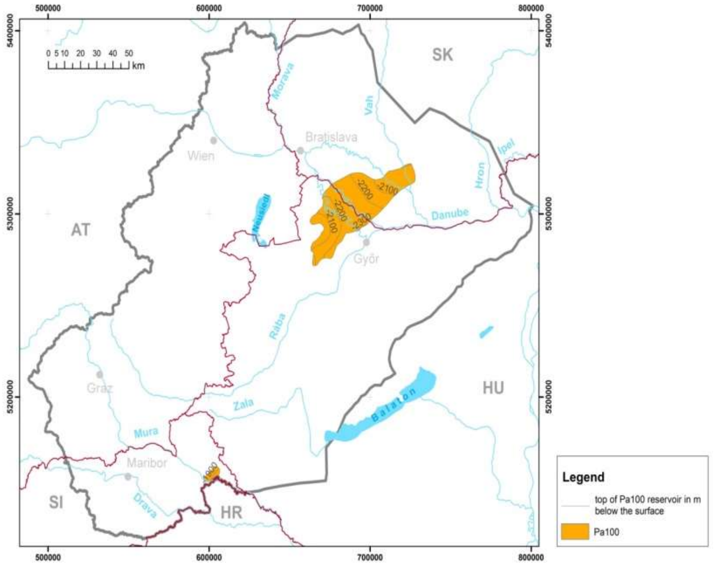
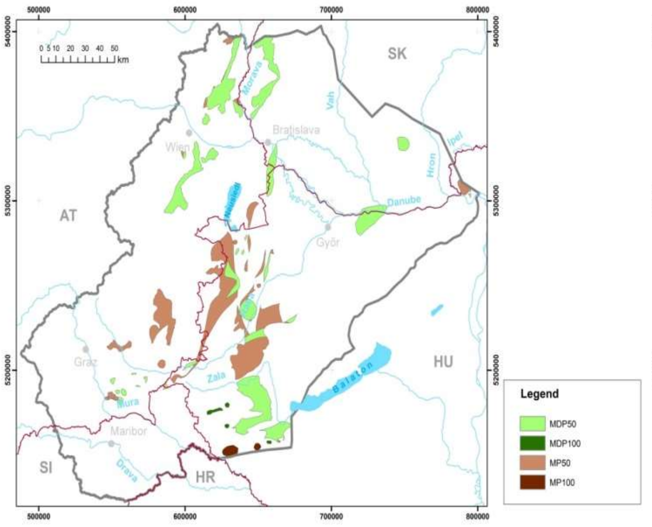
Potential Upper Pannonian reservoirs

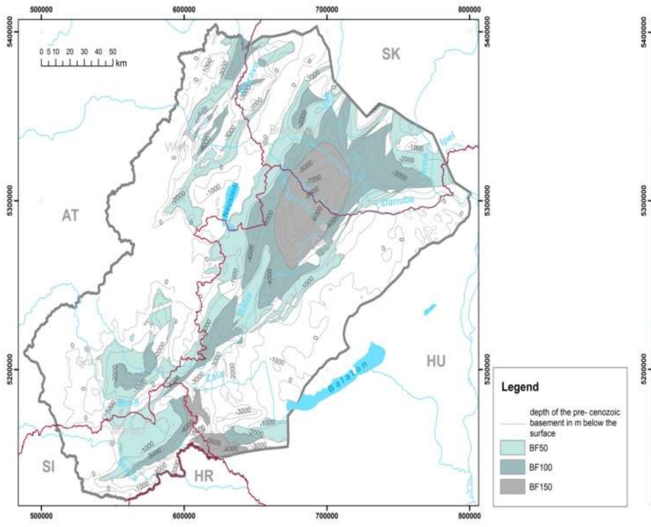




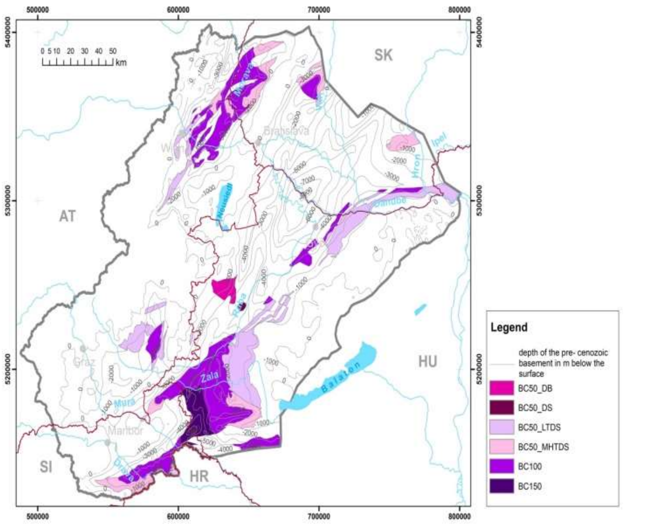
Potential Miocene reservoirs



Potential basement fractured crystalline reservoirs



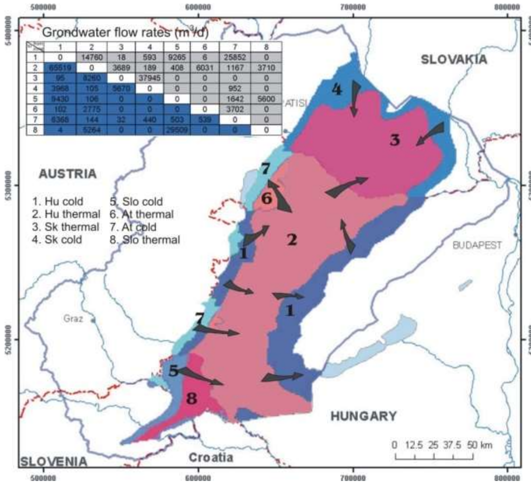
Potential fractured carbonate basement reservoirs



Characterization of reservoirs

- Hydraulic connections
(Mainly stagnant; Part of regional gravitational flow system)
- Hydrochemical character
- TDS (mg/l), (intervall of TDS values)
- Reinjection possibility
 Promising in larger fracture zones; R&D necessary before applications
- Max. and Min. depth of top of reservoir
m bsl
- Potential utilization
 balneology, direct heat, combined heat and power

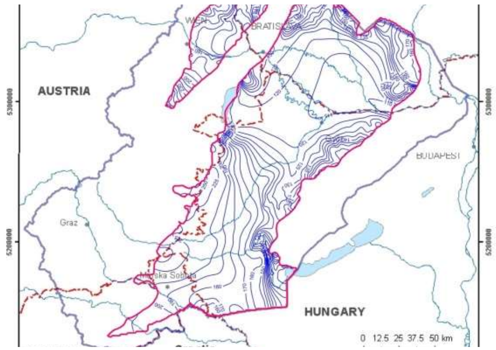
Other inputs to assisit reservoir characterization – Hydrogeological models



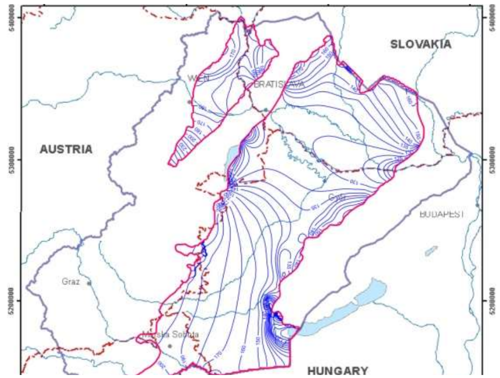
	1	2	3	4	5	6	7	8
1	0	14760	18	593	9265	6	25852	0
2	65519	0	3689	189	408	6031	1167	3710
3	95	8260	0	37945	0	0	0	0
4	3968	105	5670	0	0	0	952	0
5	9430	106	0	0	0	0	1642	5600
6	102	2775	0	0	0	0	3702	0
7	6365	144	32	440	503	539	0	0
8	4	5264	0	0	29509	0	0	0

Computed budgets of the major delineated groundwater bodies, including trans-boundary water transfers

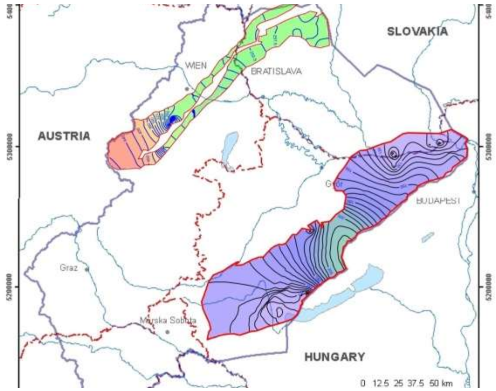
Calculated cold groundwater heads

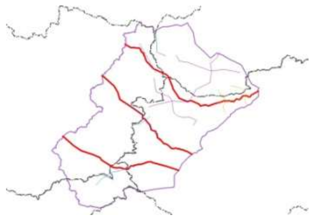


Calculated thermal water heads of the Upper Pannonian (below 450 m)

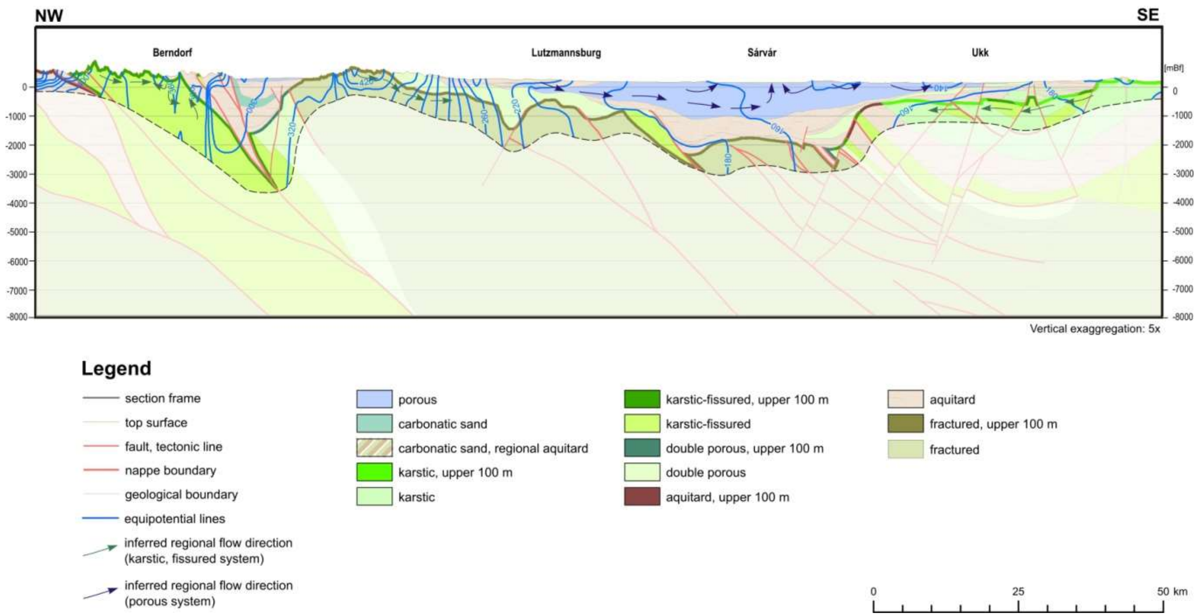


Calculated karstwater heads in the thermal karst systems

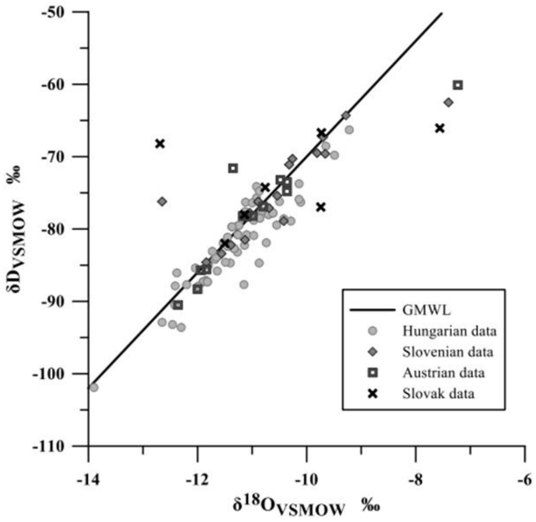




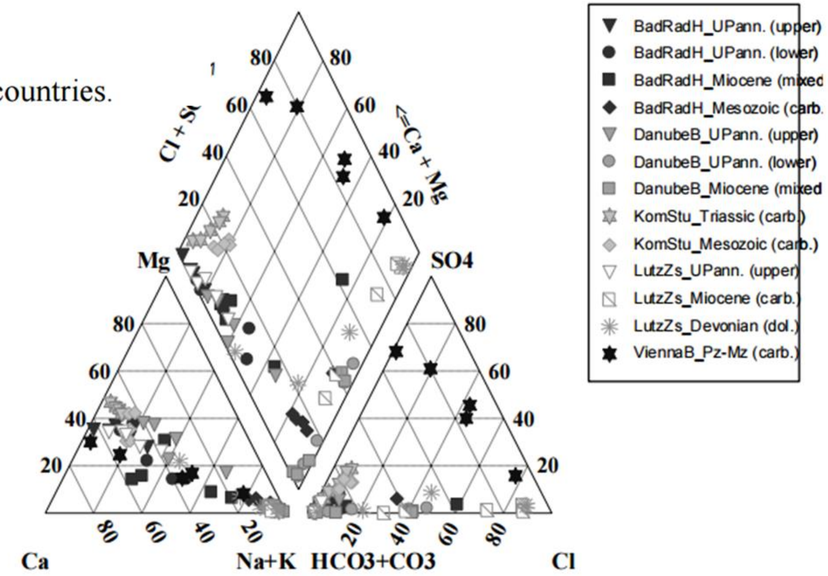
Hydrogeological cross section SA2



Other inputs to assisit reservoir characterization – regional hydrochemical analyses

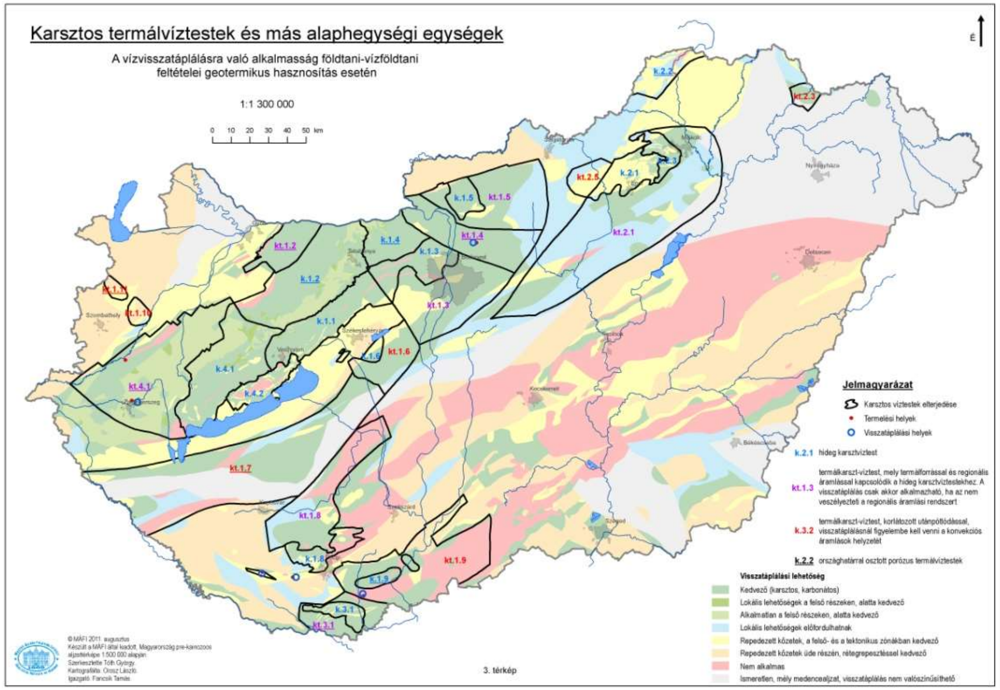


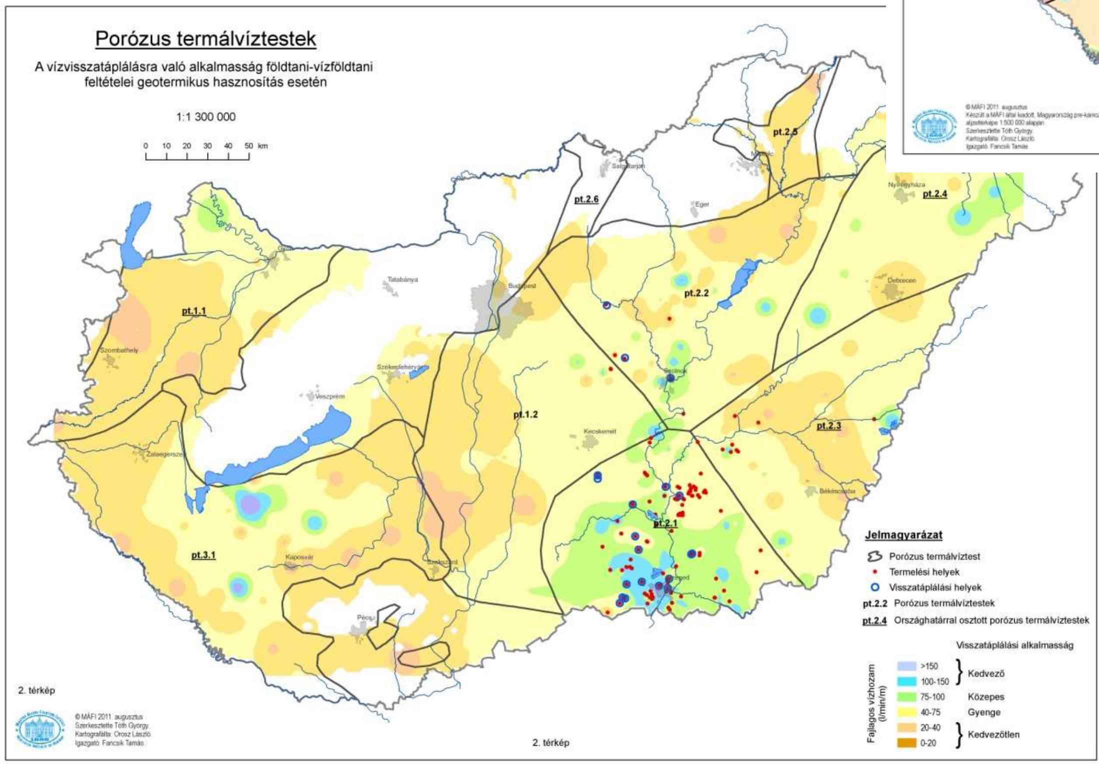
δ^{18}O versus δD distribution of groundwaters from different formations in the four countries.



Anion and cation distribution of groundwaters from different formations in the four countries

Other inputs to assisit reservoir characterization – Overview of reinjection possibilities





Summary table of main reservoir types and their characterization

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Reservoir type	Map code	Type of aquifer	Hydraulic connections	Top of reservoir		Hydrochemi-cal character	TDS (mg/l)					Potential utilization
				highest level (m asl)	lowest level (m asl)		min	max	median (P50)	10% percentile	90% percentile	
Upper Pannonian 50-100 °C	Pa50_1	porous	Part of regional gravitational flow system	-430	-1030	$NaHCO_3$	340	8100	1100	600	2900	direct heat, balneology
Upper Pannonian 50-100 °C	Pa50_2	porous	Part of regional gravitational flow system	-540	-950	$NaHCO_3$; locally $NaHCO_3Cl$	4700	13900	10500	5600	12600	direct heat, balneology
Upper Pannonian 50-100 °C	Pa50_3S	porous	Part of regional gravitational flow system	-600	-1000	$NaHCO_3$, $NaHCO_3Cl$	900	3200	1500	1100	2600	direct heat, balneology
Upper Pannonian 50-100 °C	Pa50_3N	porous	Mainly stagnant, partly connected to regional gravitational flow system	-450	-1030	NaCl, $NaClHCO_3$, $NaHCO_3$	1300	21900	5700	1900	16500	direct heat, balneology, partly restricted due to high TDS and limited hydraulic connections
Upper Pannonian 100< °C	Pa100	porous	Partly connected to regional gravitational flow system	-1830	-2310	NaCl, $NaClHCO_3$, $NaHCO_3$	1300	20800	2700	1300	11400	direct heat, combined heat and power (binary)