

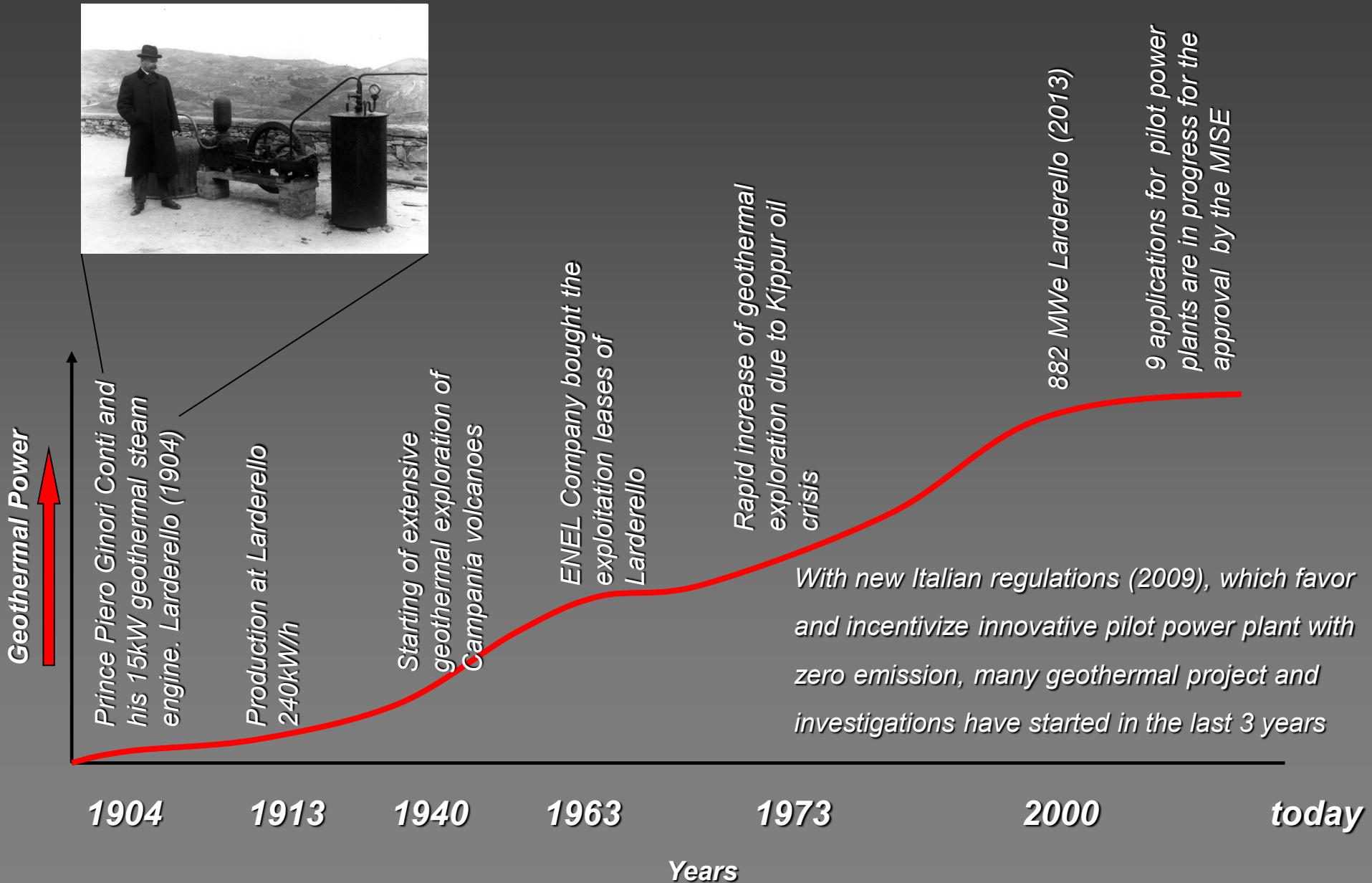
Campi Flegrei Deep Drilling Project and geothermal activities in Campania Region (Southern Italy)

Stefano Carlino
ISTITUTO NAZIONALE di GEOFISICA e VULCANOLOGIA
INGV- SEZIONE di NAPOLI
OSSERVATORIO VESUVIANO



Le risorse geotermiche a media ed alta entalpia nella Sicilia Orientale, Paterno' | CT | 3 maggio 2013

Geothermal exploration and exploitation in Italy.....since 1904



Geothermal Projects of INGV

SIMPAS: monitoring of gas emission from geothermal power plants, POR CREO FESR 2007-2013 (ended in April 2012)

GEISER: Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs
FP7-ENERGY-2009-1 (June 2013)

Exploitation permissions for two 5MWe pilot plant (ongoing)
(ISCHIA ISLAND "**Forio**" and CAMPI FLEGERI "**Scarfoglio**"
INGV-TADDEI and *Geoelectric* Companies agreement)

CFDDP : Campi Flegrei Deep Drilling Project
(first phase concluded in December 2012)

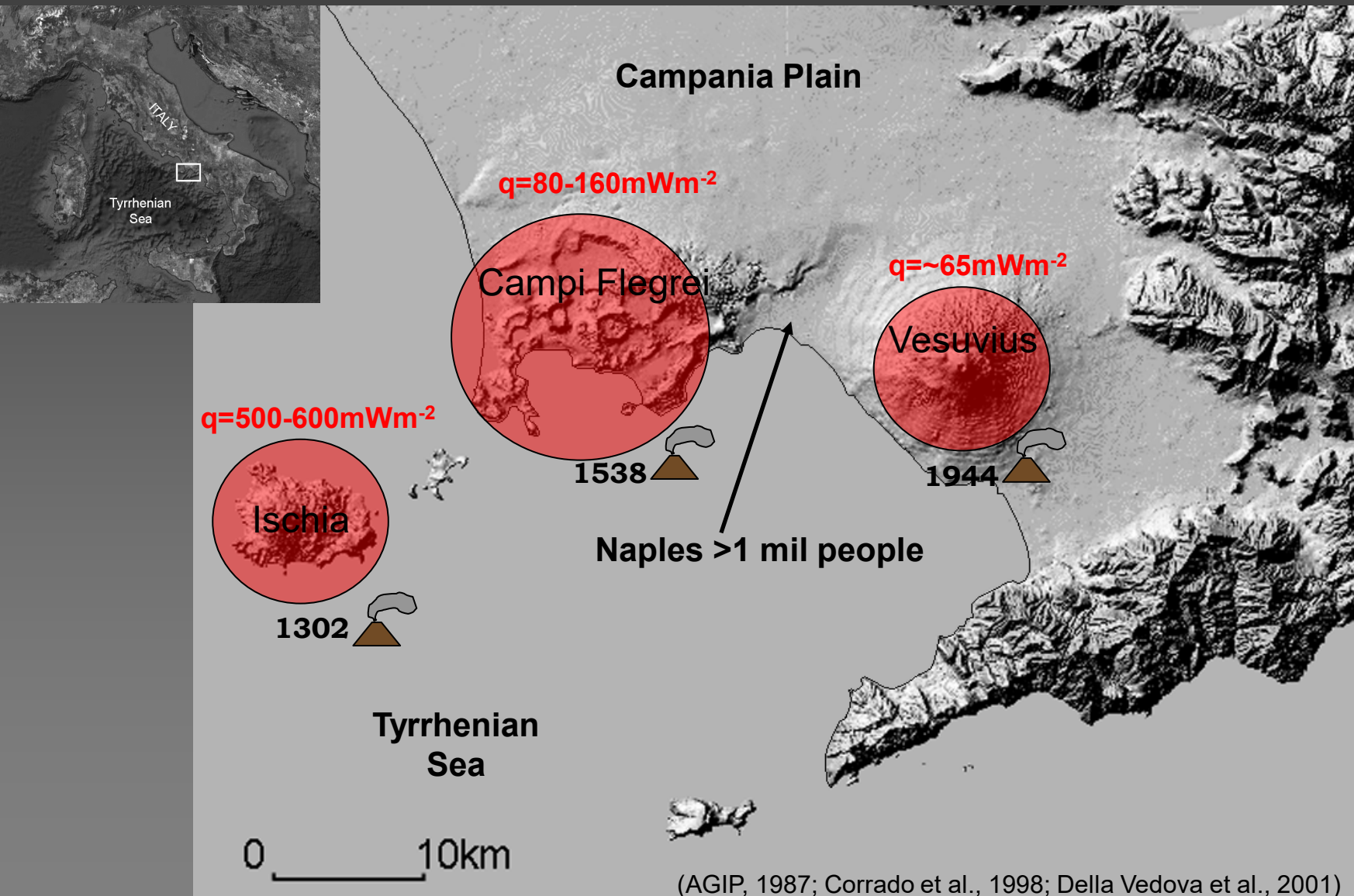
START (tri-generation power plant -western sector of Naples)

*New Estimates of Capacity for Italy (Italian
Technological Alliance, 2011)*

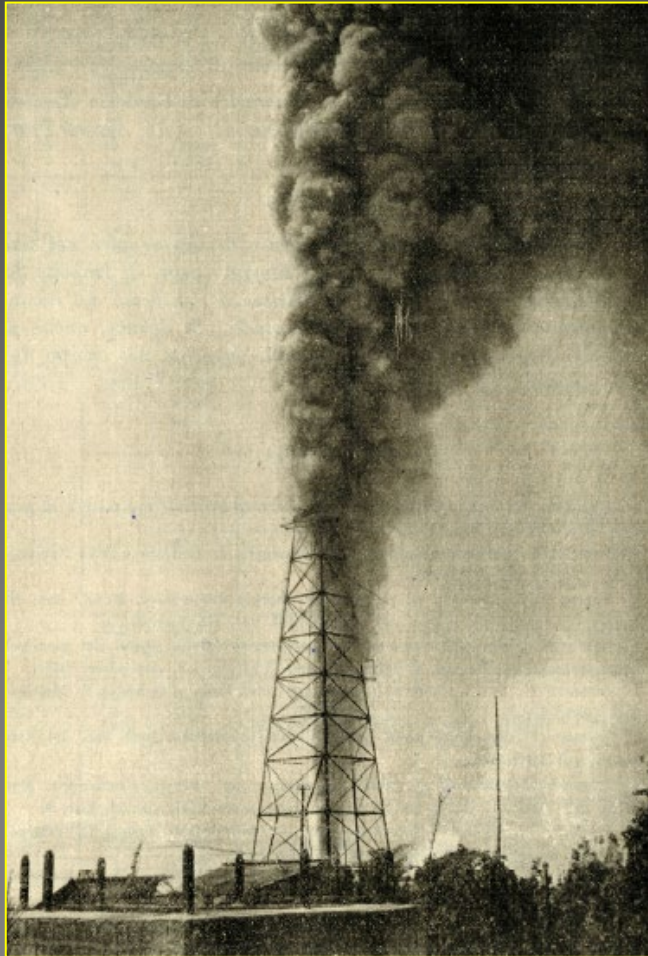
*More than 5 GWe
corresponding to more than 10% of
electrical needings for Italy*

*In Campi Flegrei-Ischia volcanic district: >17
GWt thermal, >1.7 GWe electric, about 30%
of total (Carlino et al., 2012)*

The active Campanian volcanoes

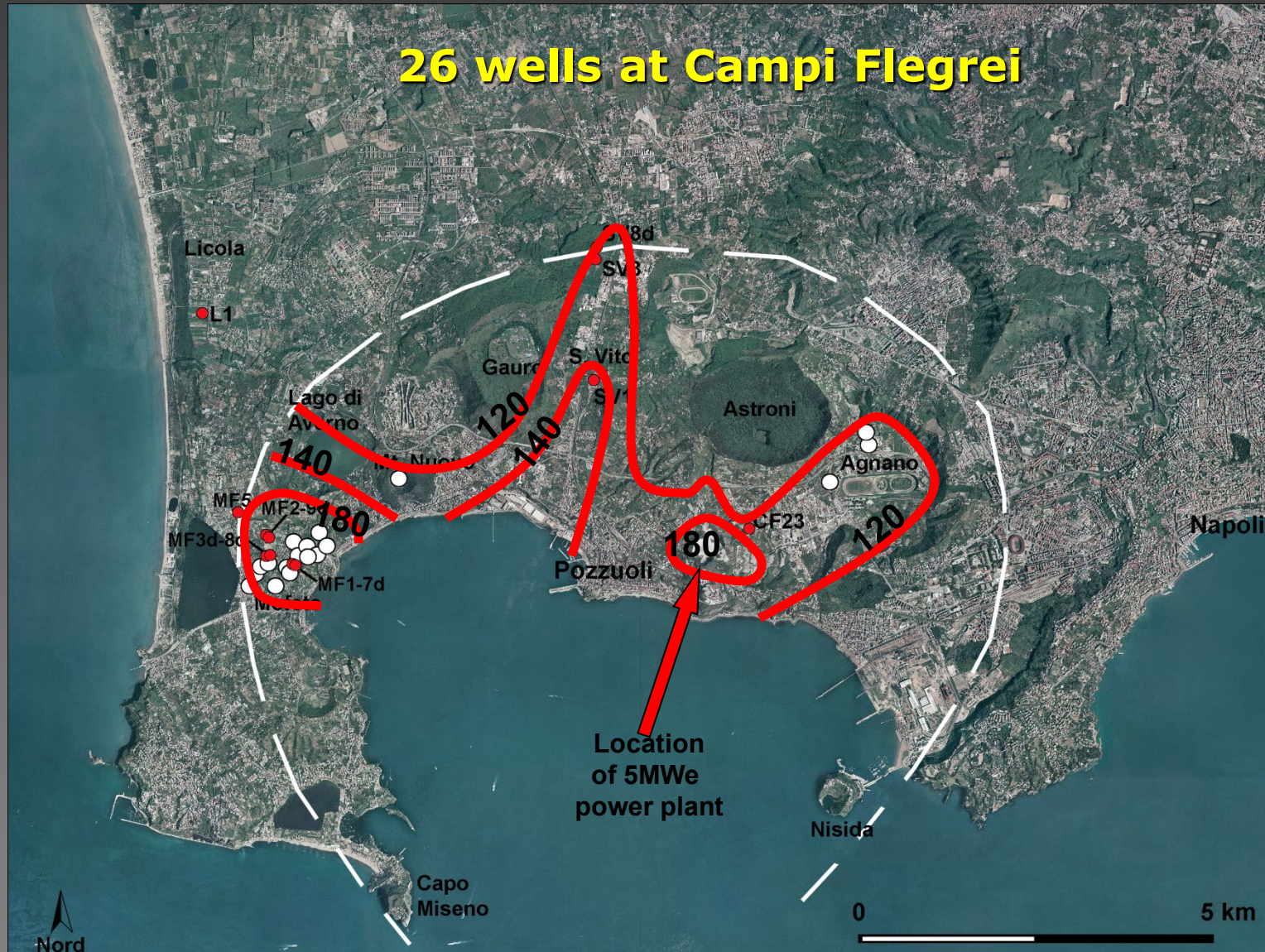


**A numbers of geothermal data are inferred from
1939 to 1985 geothermal researches in Campania:
177 wells drilled (max depth 3046m) (AGIP, 1987)**



**Geothermal exploration at
Campi Flegrei and Ischia**





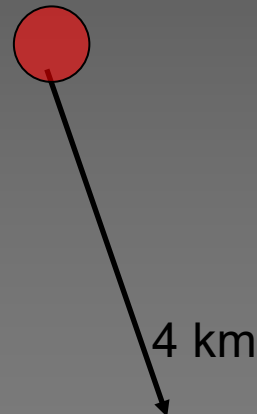


- Deep > 200m
- Shallow < 200m
- Caldera rim
- Deepest well
1156 m
- Geothermal
Gradient
140/220° Ckm⁻¹

1 well at Vesuvius

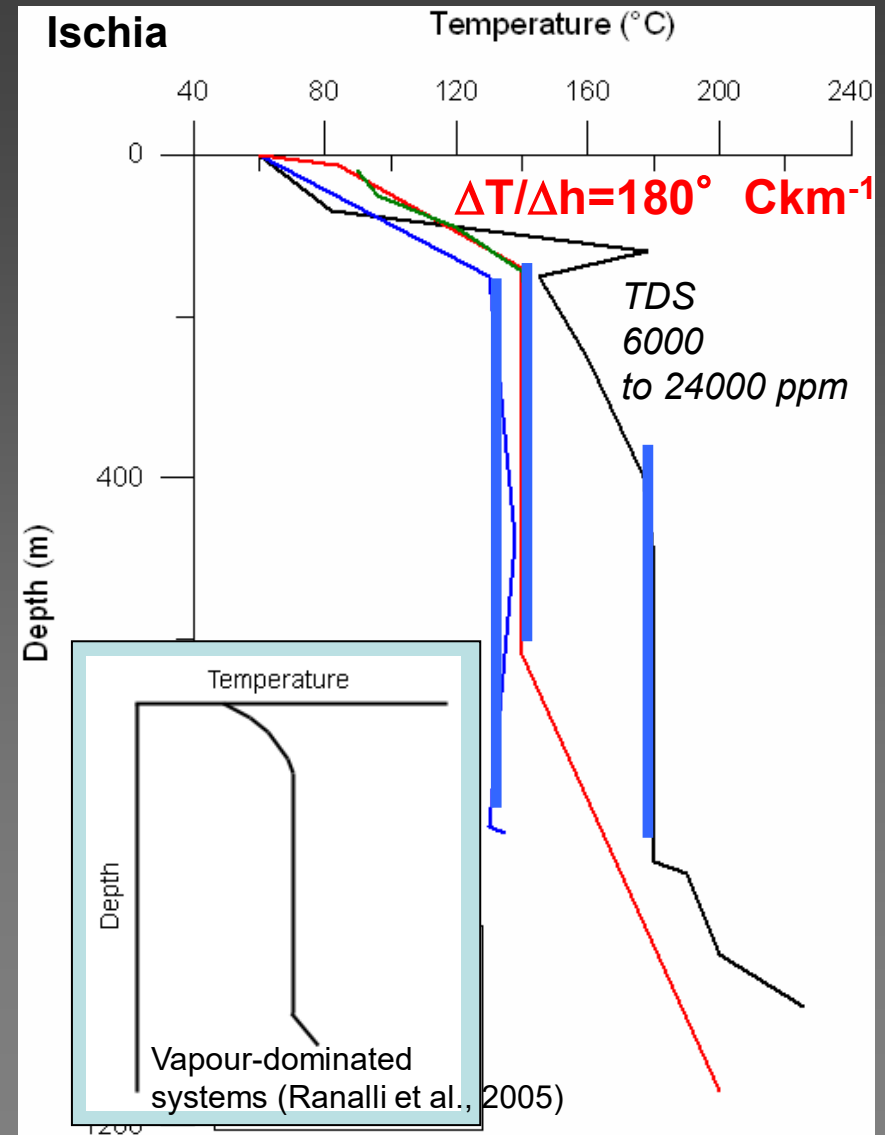
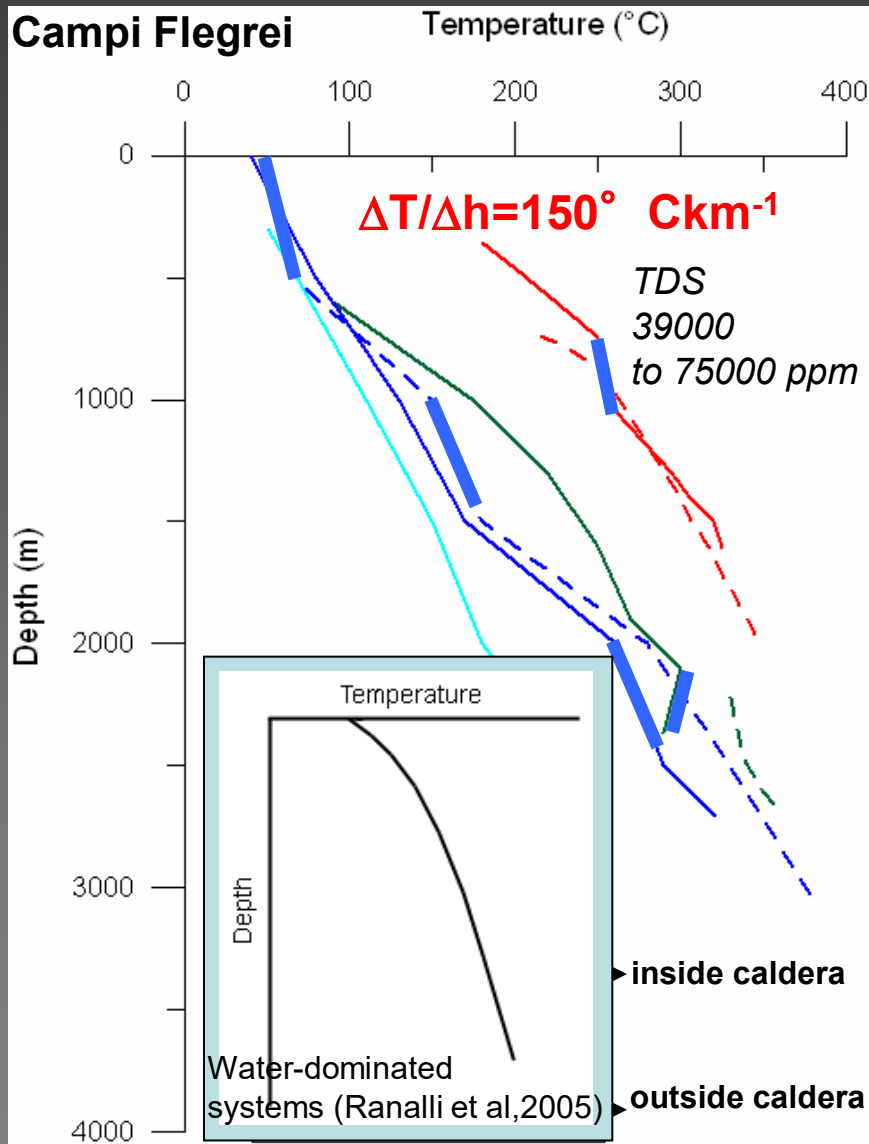
**Well depth
2072 m**

**This is the only
well of Campanian
volcanic area where
the carbonatic rocks
were encountered
(Brocchini et al., 2001)**



**Geothermal
Gradient
30° Ckm⁻¹**

Temperatures of Phlegreans district





Data from AGIP-ENEL (1987) during productive tests (Campi Flegrei)

Temperature at well head: min 150° C, max 250° C;

Average flow rate: 55kgs⁻¹;

Specific heat of geothermal fluid: 3kJkg⁻¹K⁻¹ (T=180° C);

Density: 1.08kg l⁻¹ (con T=180° C);

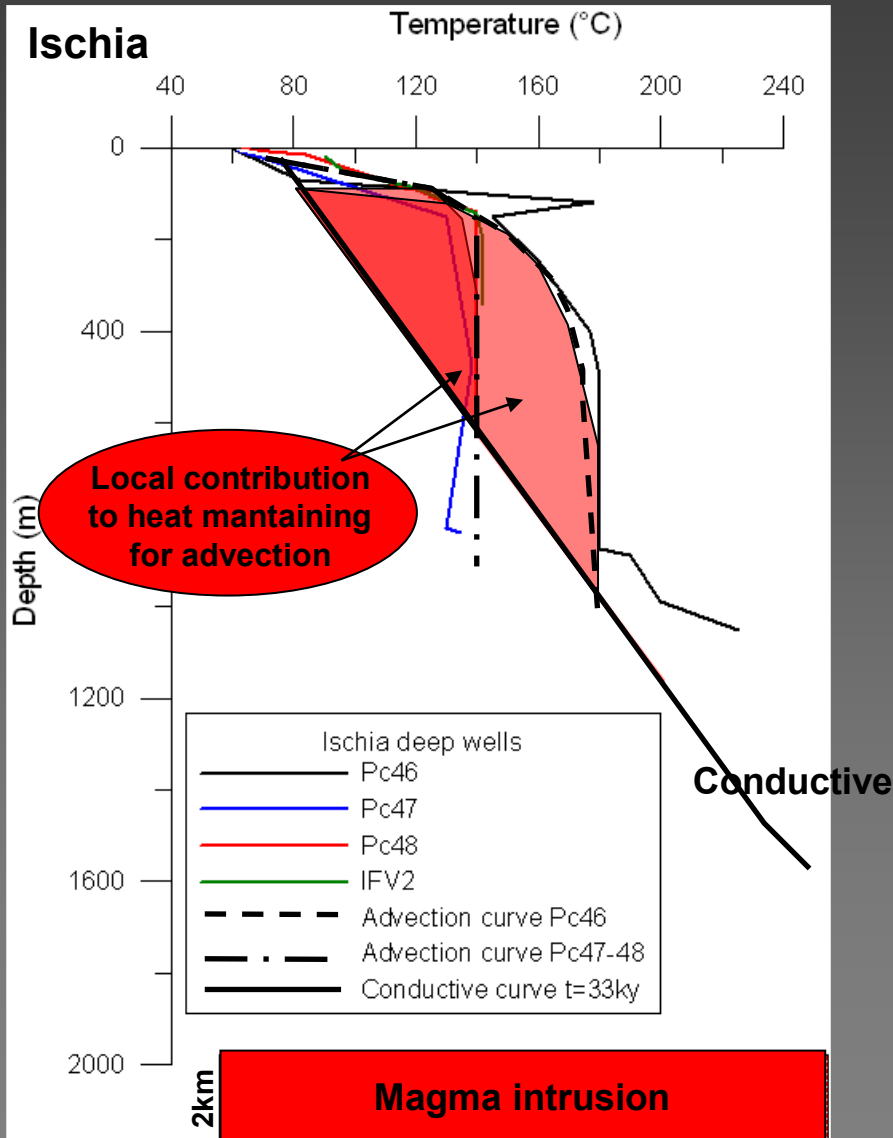
Salinity: 30.000 TDS (ppm)in the reservoir (T=247° C, depth 500-900m);

Vapor phase: 30-40%;

Not condensable gases <2% weight;

Well head pressure: 8bar.

Temperatures and heat transport



Conduction

$$T_{(y,t)} = \frac{Q}{2\rho c \sqrt{\pi k t}} e^{-y^2/4kt} \quad (1)$$

(one-dimensional solution)

Advection

(Turcotte and Schubert, 2001)

$$T = T_r - (T_r - T_0) \cdot \exp\left(-\frac{\rho_f c_f v}{\lambda} y\right) \quad (2)$$

(one-dimensional solution in a porous media)

Q = heat content, $6 \cdot 10^{12} \text{Jm}^{-2}$

k = thermal diffusivity, $1 \text{mm}^2 \text{s}^{-1}$

λ = thermal conductivity, $3.35 \text{Wm}^{-1} \text{ } ^\circ \text{C}^{-1}$

ρ = rocks density (average), 2300Kg m^{-3}

ρ_f = fluids density, 1000kg m^{-3}

c = magma specific heat, $1 \text{kJ kg}^{-1} \text{K}^{-1}$

c_f = fluids specific heat, $4.815 \text{J kg}^{-1} \text{K}^{-1}$

T_r = geoth reservoir temperature, $140-180 \text{ } ^\circ \text{C}$

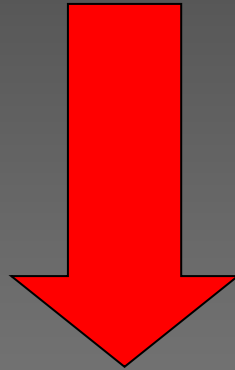
T_0 = surface temperature, $60 \text{ } ^\circ \text{C}$

t = time, 33ky

y = depth, down to 900 m

v = Darcy velocity porous media, $6.7 \cdot 10^{-8} \text{ms}^{-1}$

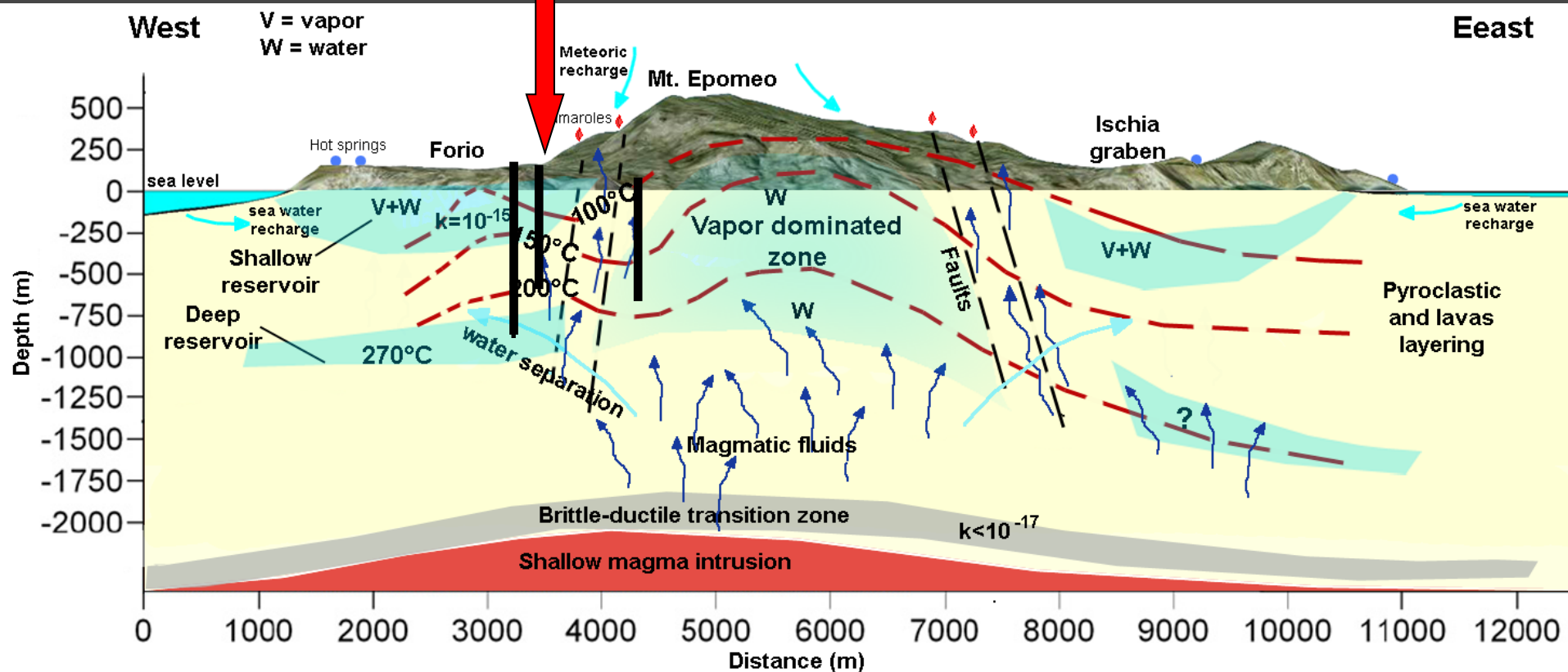
*Exploitation permissions
ISCHIA ISLAND “Forio” and CAMPI FLEGREI
“Scarfoglio” (5MW Pilot Power Plants)*



*Approved in the first phase of evaluation by
MISE (Department of Economic Development)
Waiting for Environmental Impact Assessment*

Ischia Island

5MW geothermal power plant

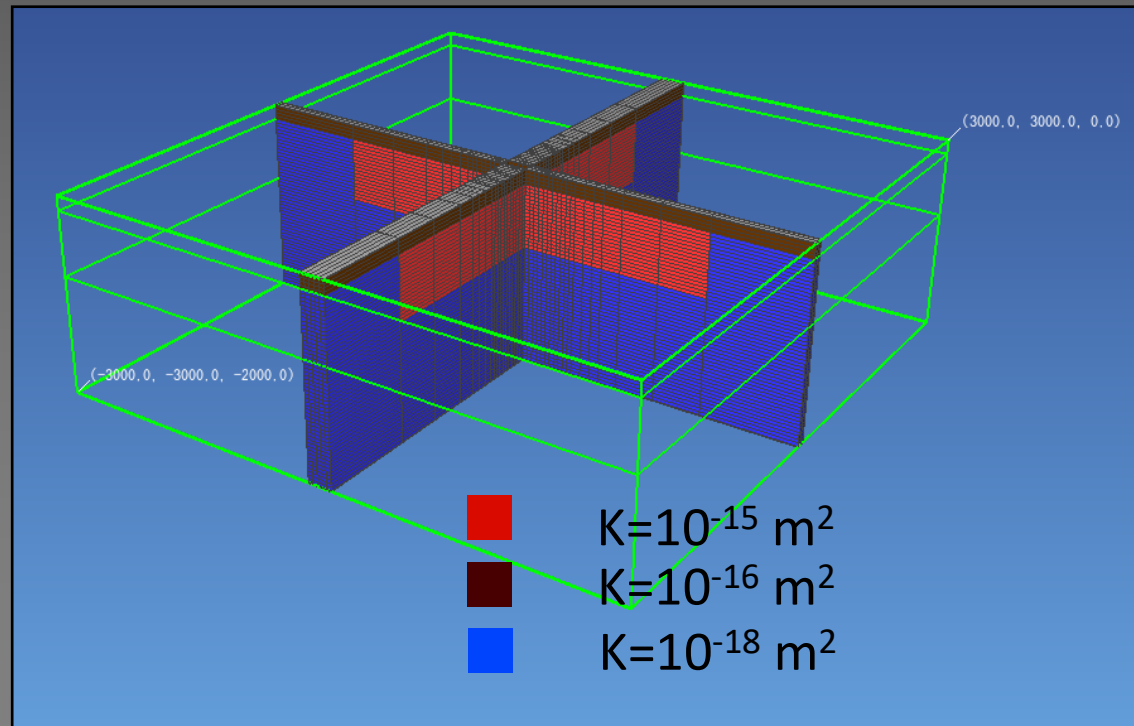


Conceptual model of geothermal reservoir of the island

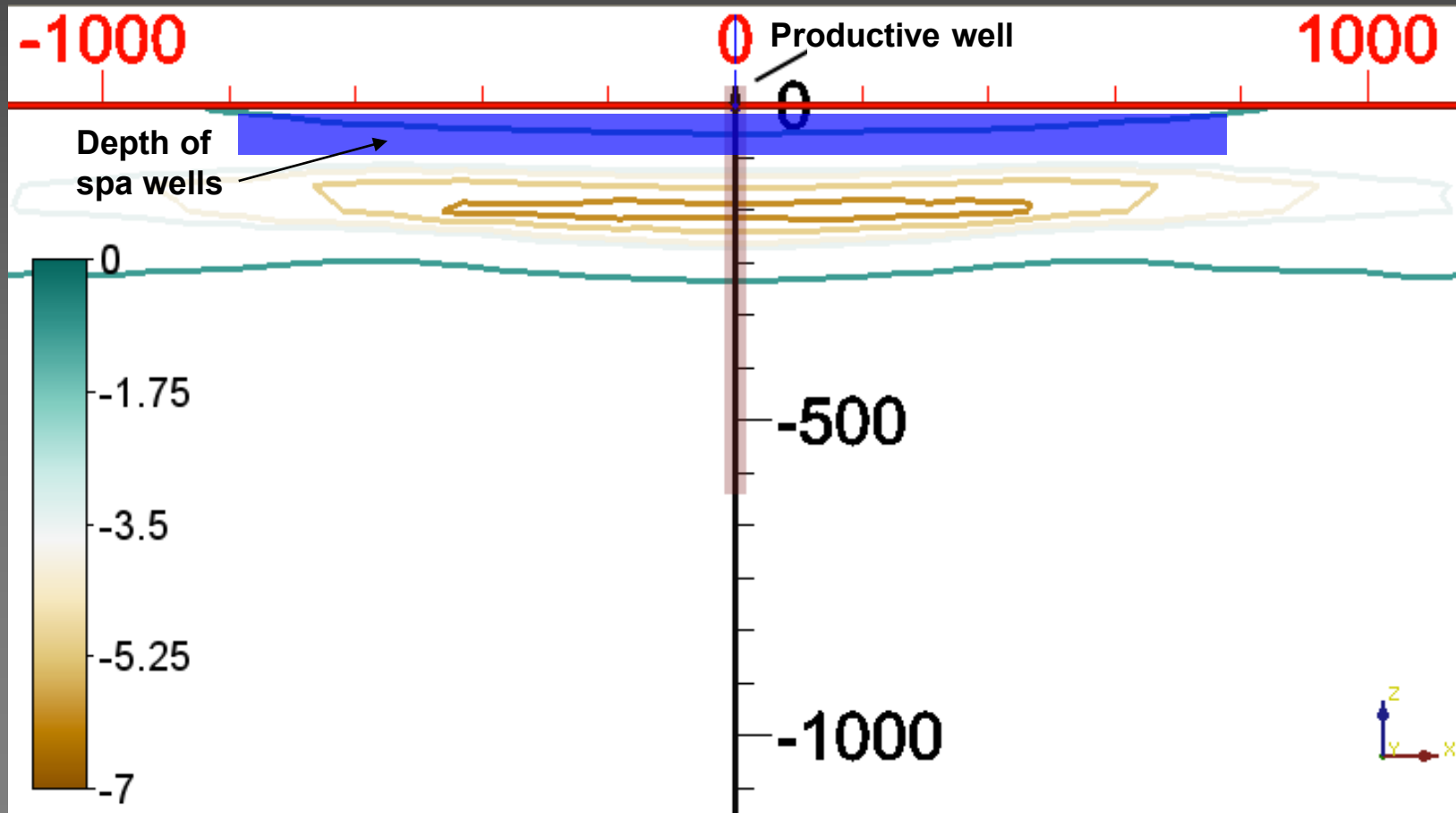
Ischia Island: sustainability of geothermal resource

Simulation (*TOUGH CODE*) of DT and DP for these conditions:

- finite volume resolution of Mass and Energy balance equation;
- convective flow in a porous media (Darcy law);
- conduction is also considered;
- withdrawal of 80tonh^{-1} of fluid at temperature of 150°C (5MWe);
- 600 m deep borehole (convective fluids zone);
- 30 years of exploitation;
- volume= 18km^3 ;
- porosity= 0.2;
- $\rho=2400\text{kgm}^{-3}$;
- saturated two phase $\square$
(mixture vapor + water)



DT after 30 years around the productive well



Die Bucht der Kanzlerin

Was Sie hier sehen, sah die Kanzlerin von ihrer Ferienvilla auf Ischia. 8 Tage lang machten Angela Merkel (54) und Joachim Sauer (60) bei rund 20 Grad Osterurlaub in der Maronti-Bucht. Seit mehr als 10 Jahren reist das Paar im Frühjahr auf die Insel im Golf von Neapel. Ischia ist 32 Kilometer von Neapel entfernt. Die Autofähre braucht 90 Minuten, das Tragflächenboot 49. Die Insel ist 10 Kilometer lang und 7 Kilometer breit und hat 62 000 Einwohner. An diesem Wochenende wird die Kanzlerin wieder in Deutschland erwartet – ihr Mann feiert heute seinen 60. Geburtstag.

BAI HOTEL „ZASA BONA“
Der gesamte stufenförmige Komplex umfasst zwei 3-Sterne-Hotels „Zasa Bona“. Das 50-Zimmer-Hotel hat einen Privatsalon, Tennisplatz, Pool und Fitness-Center.

DIE THERME

Witten Meurer machte Ischia bekannt. Rund um Quindici verstreut auf der Insel, während eines Osterurlaubs besuchte die Kanzlerin mehrfach die Agroturisti-Apudis-Thermalanlagen, die zum 4-Sterne-Hotel „Albanus“ gehören. Tageskarte: 25 Euro. Zu der Anlage gehören zwölf Thermo- und Mineralbäder, Naturgetränk-Sauna, Wellness- und Beauty-Center (jeweils 20-Euro-Behandlung kostet 70 Euro, eine Öffnung-Behandlung 55 Euro).

DIE ANTRIN THERME

Im Herzen der Bucht, 100 Meter oberhalb des Strandes, liegt „Antin“, die 2004 Jahre alte Thermalbad, entstand aus dem Kalkstein. Es gibt Wasserfälle, natürliche Saunen und die 10-Grad-Quelle, die dem Berg entspringt.

DIE BUCHT

Angela Merkel schaut auf der Sommerreise in Ischia. Im Hintergrund der Insel, oberhalb der Maronti-Bucht, liegt die 2,5 Kilometer lange Kanaltal-Quelle, einer der schönsten der Insel, erstreckt sich von der Punta delle Vigorelle bis zum Kap Sant'Angelo.



DER NESSUNO DOLLER
„Nessuno“ ist ein kleines Dorf, das in der Bucht liegt. Es ist ein Ort, der sich in der Bucht befindet und der sich in der Bucht befindet.

Angela Merkel und ihr Mann Joachim Sauer besuchen am Osterurlaub am Meerort. Über ihre Osterurlauben sagt die Kanzlerin: „Wir verbringen unseren Urlaub gewöhnlich in der Natur als in der Stadt. Wir haben eine tolle Landschaft.“



DIE MARGHERITA VILLA
Die „Villa Margherita“ befindet sich unterhalb der Straße an der Insel, was aus der Fata Morgana die Maronti-Bucht zeigt. Die Angela Merkel und Joachim Sauer von Ischia. Die Villa ist ein Ort, der sich in der Bucht befindet und der sich in der Bucht befindet.



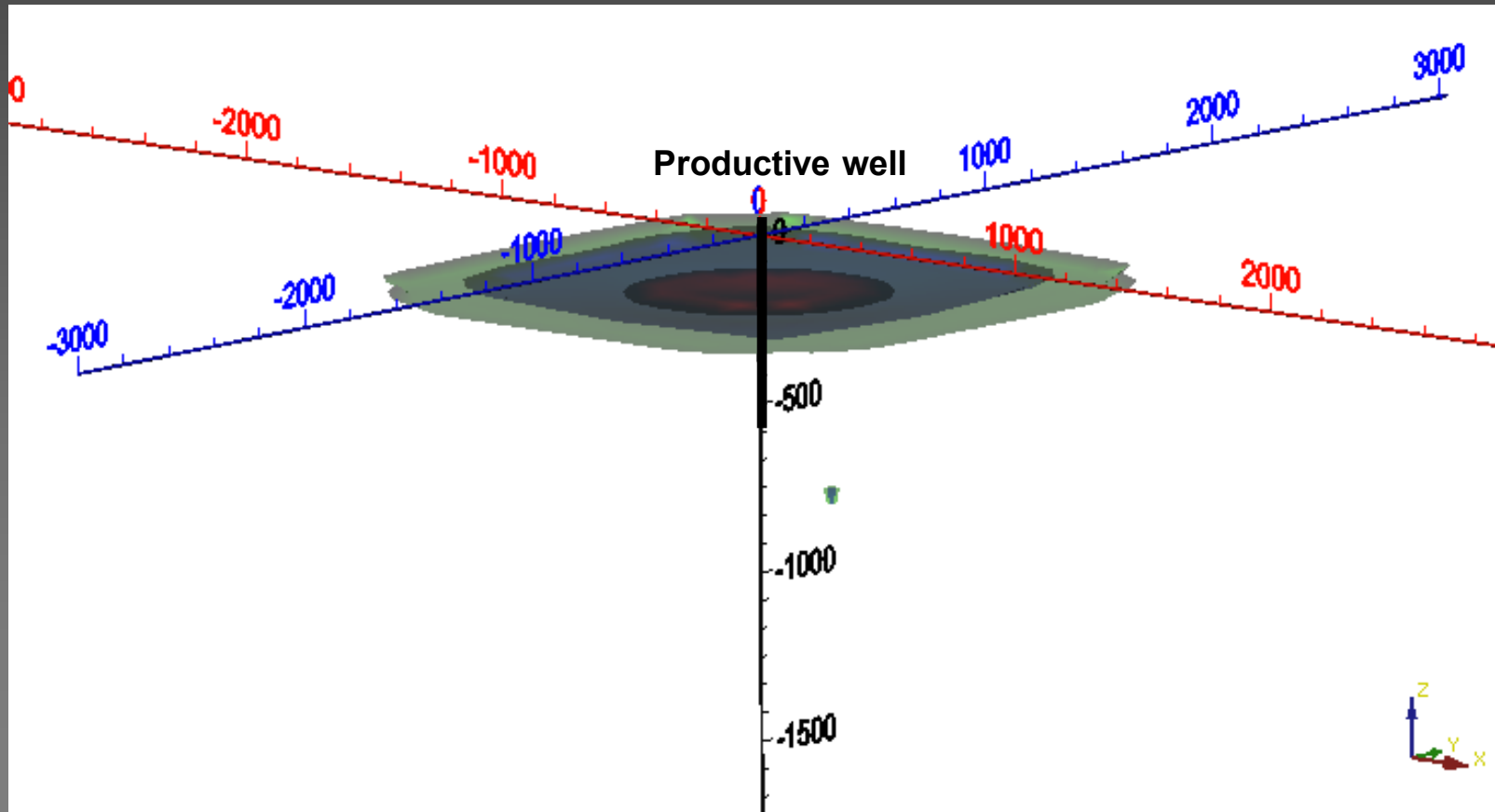
DAS FISCHEREI MUSEUM
Das Fischereimuseum ist ein Ort, der sich in der Bucht befindet und der sich in der Bucht befindet.



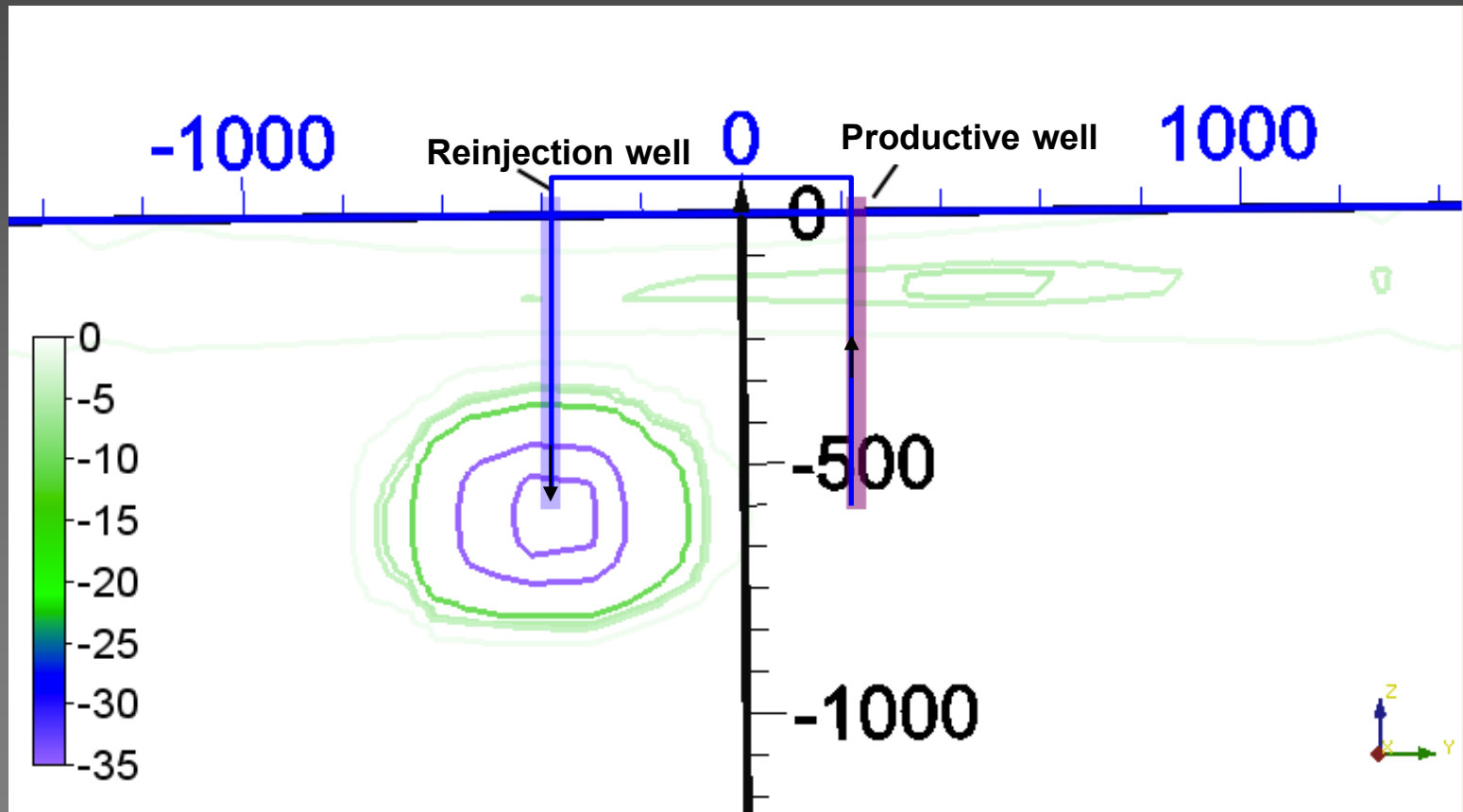
DAS FISCHEREI MUSEUM
Das Fischereimuseum ist ein Ort, der sich in der Bucht befindet und der sich in der Bucht befindet.



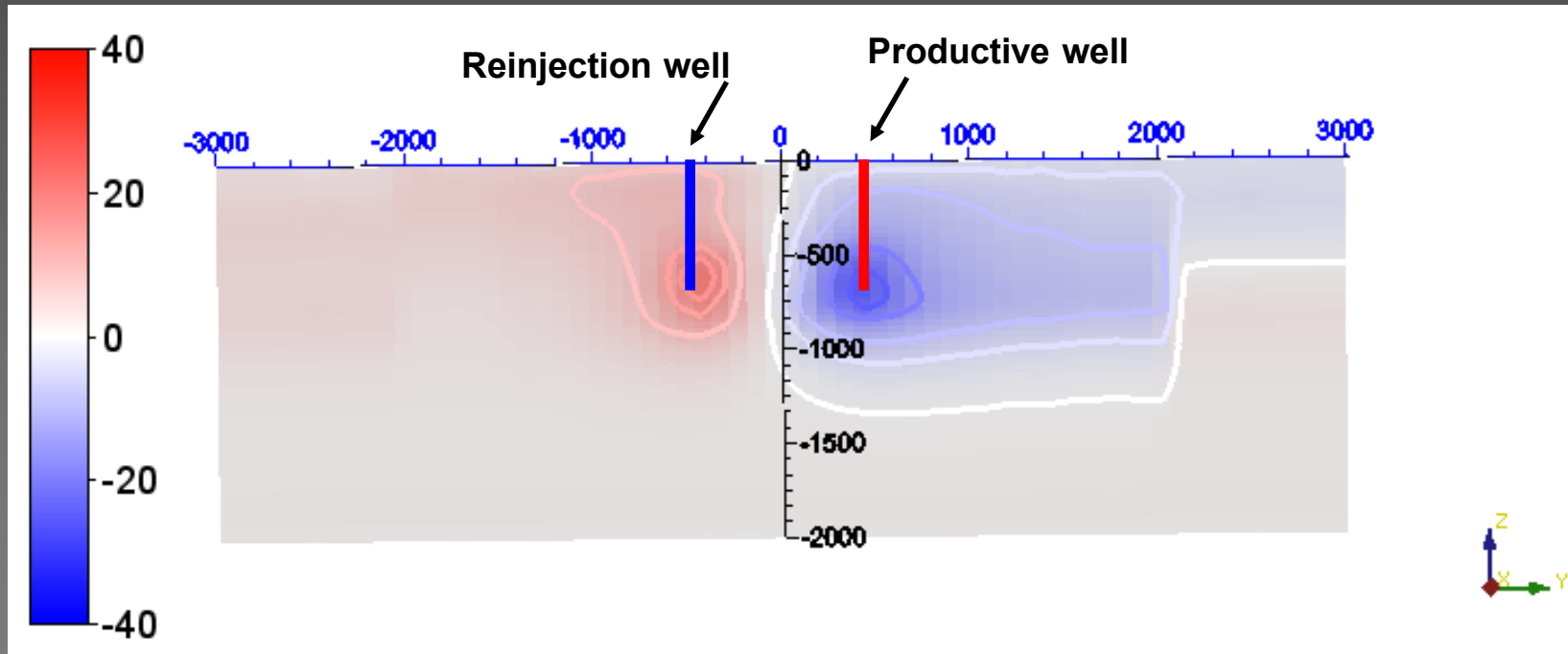
DT after 30 years around the productive well (3D)



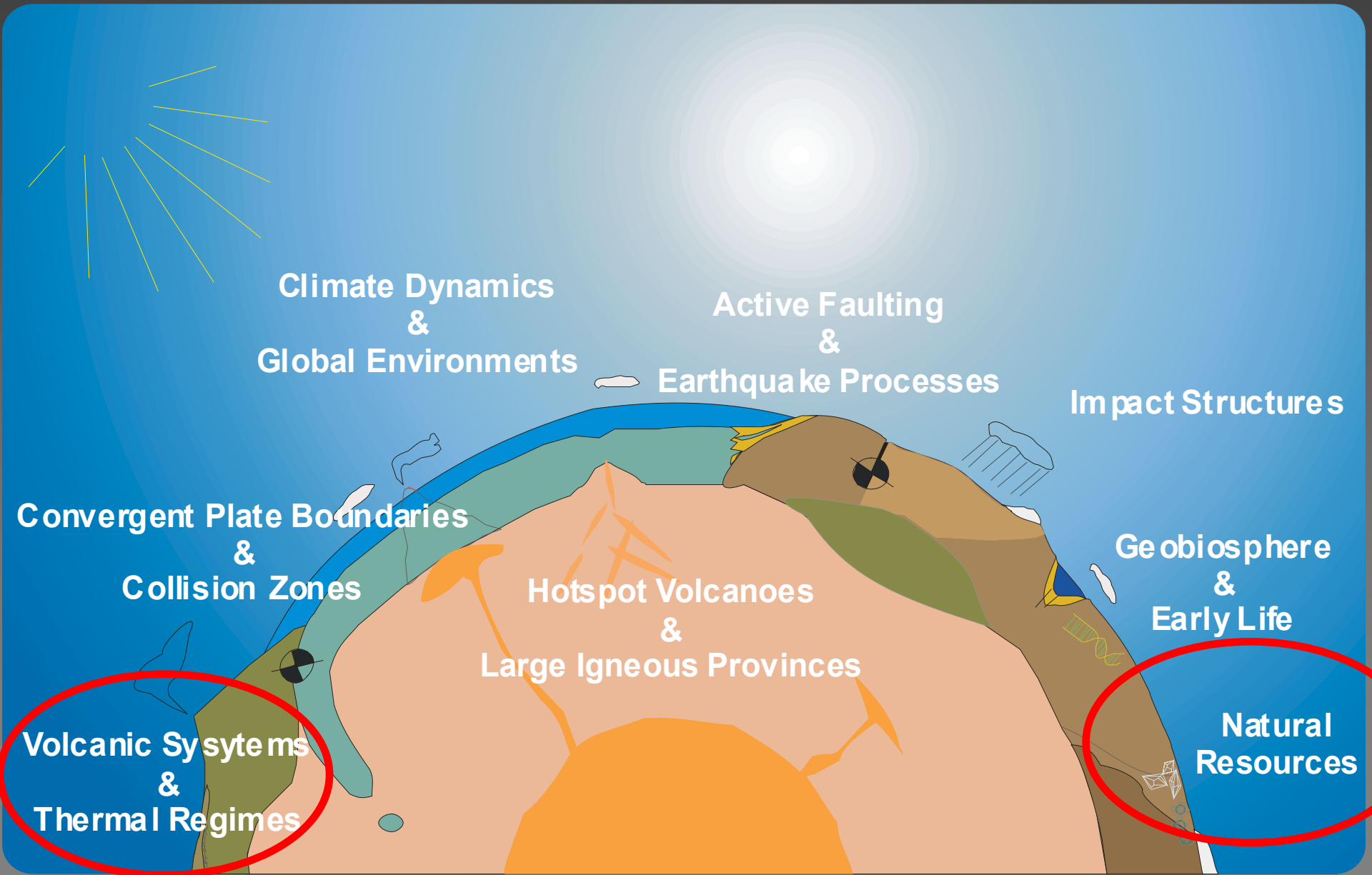
DT after 30 years around the productive and reinjection wells



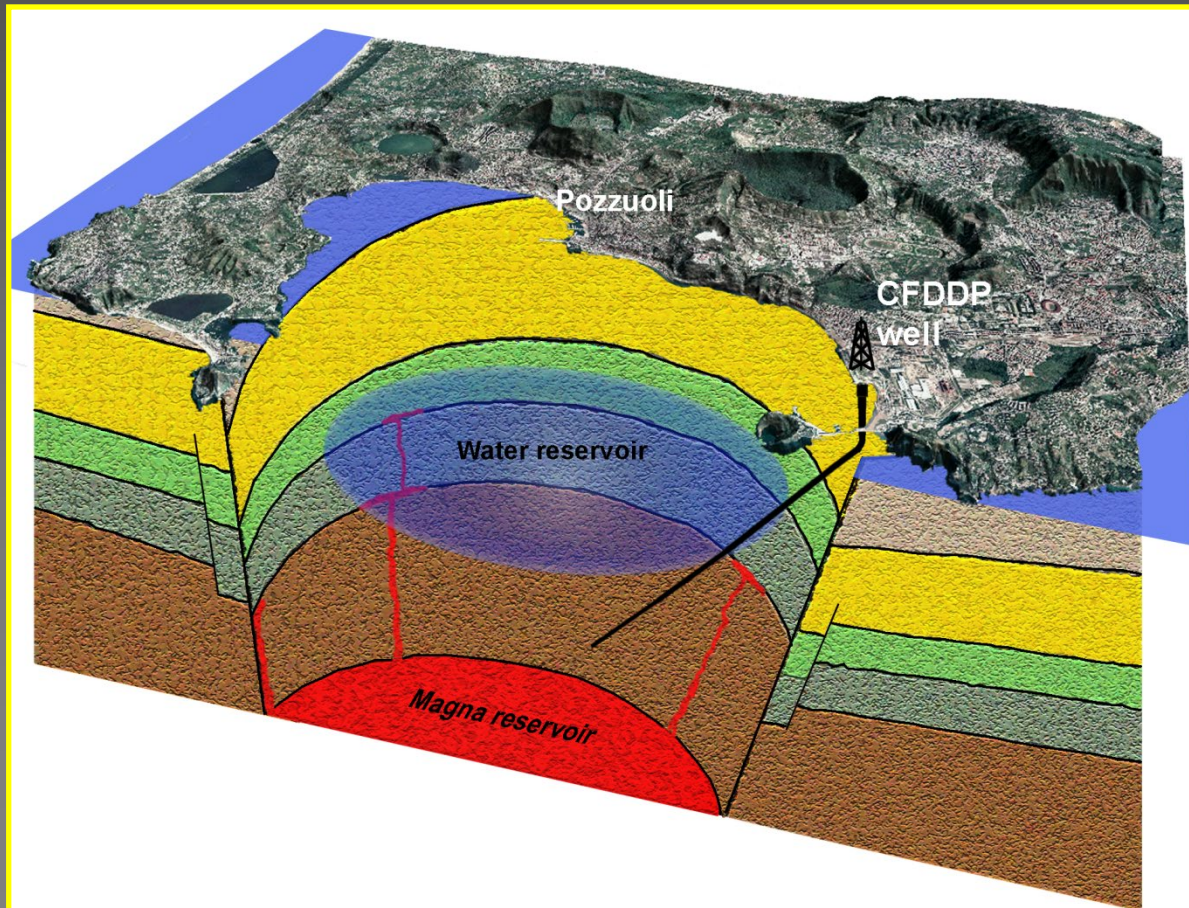
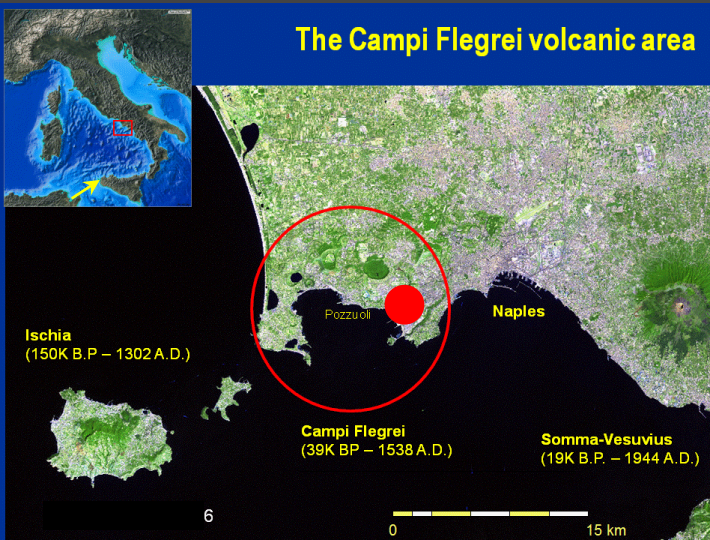
DP (bar) after 30 years around both the productive and reinjection wells



Campi Flegrei Deep Drilling Project (CFDDP) and themes of the ICDP International Continental Scientific Drilling Program



CFDDP: pilot hole (500 m deep) concluded in December 2012



The drilling site (December 2012)

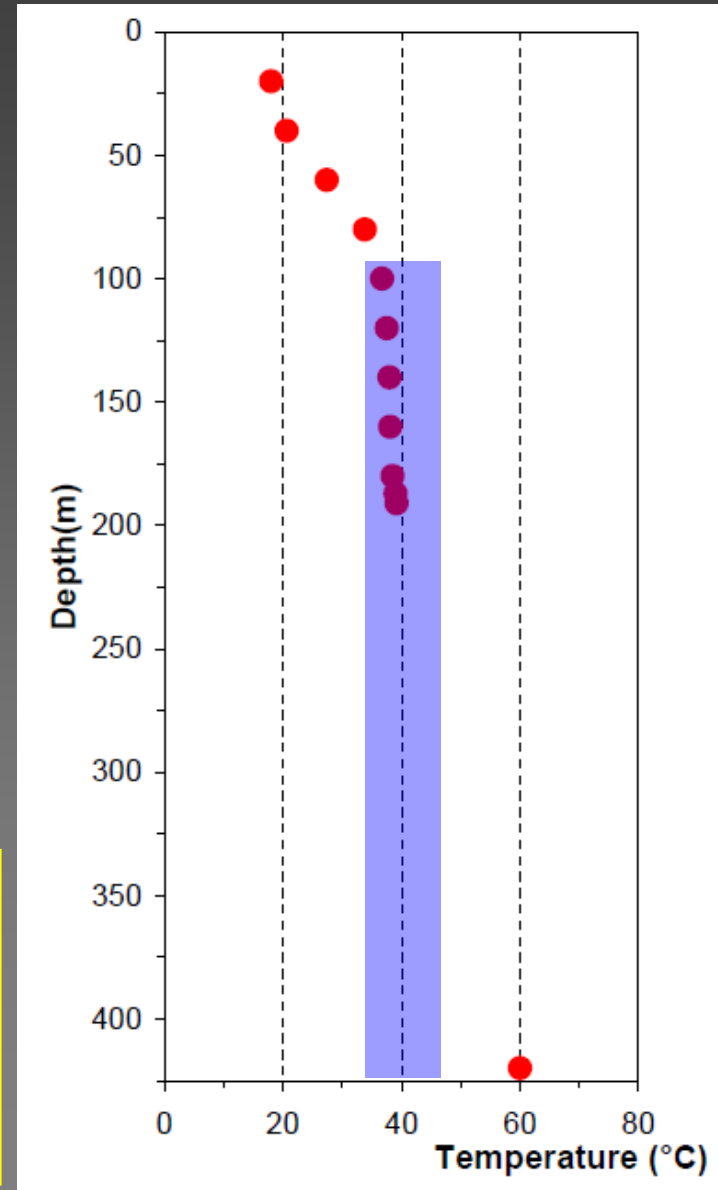




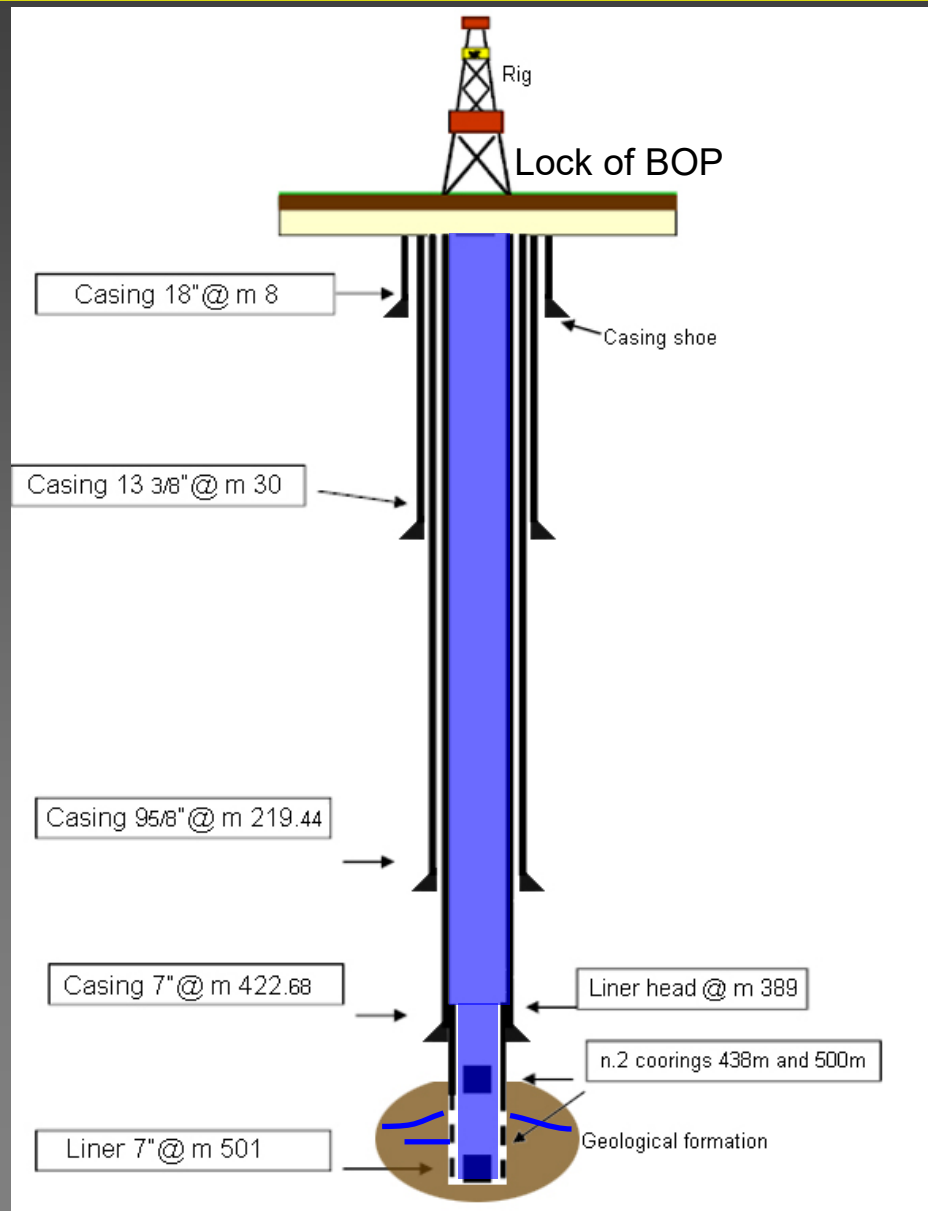
CFDDP drilling



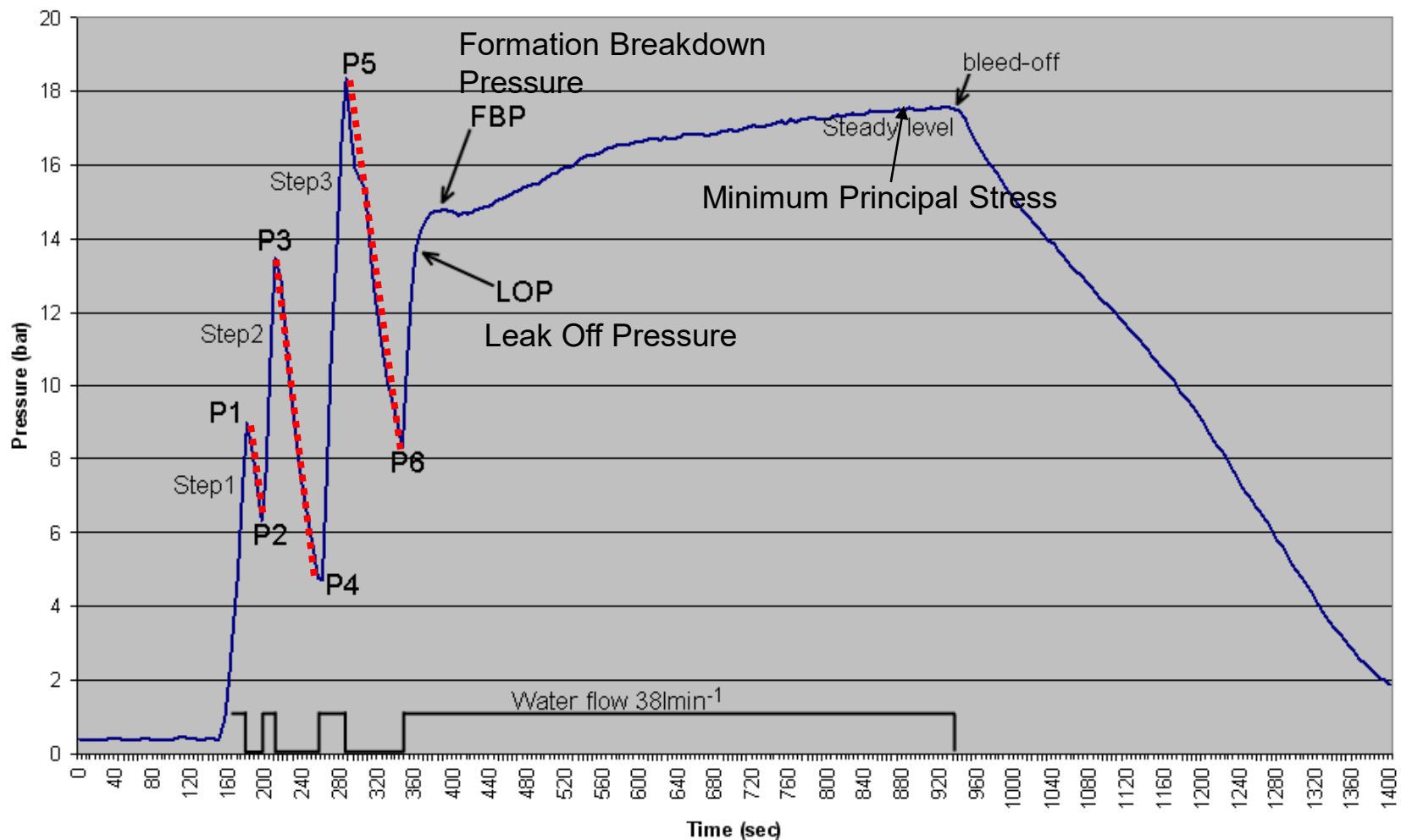
Measured temperatures



Leak-off Test for estimation of *in-situ* permeability and minimum principal stress

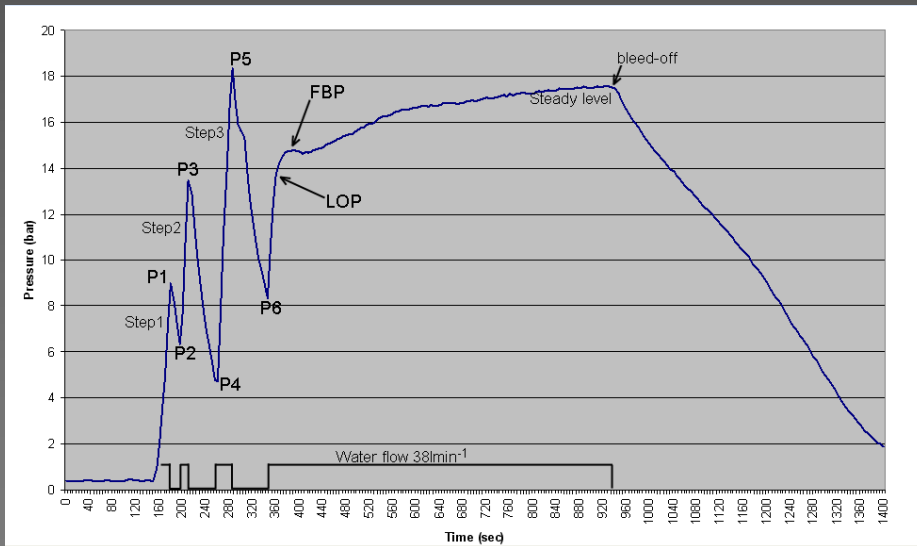


Leak-off Test for estimation of *in-situ* permeability and minimum principal stress



Leak-off Test for estimation of *in-situ* permeability and minimum principal stress

Step 1						Step 2						Step 3					
P ₁	P ₂	h ₁	h ₂	t ₂ -t ₁	ΔP ₁₋₂	P ₃	P ₄	h ₁	h ₂	t ₂ -t ₁	ΔP ₃₋₄	P ₅	P ₆	h ₁	h ₂	t ₂ -t ₁	ΔP ₅₋₆
8.9	6.3	90	63	15	2.6	12.8	4.7	120.8	40.7	45	8	18.3	8.3	183	83	60	10



$$K = \frac{A}{F \cdot (t_2 - t_1)} \cdot \ln \frac{h_1}{h_2}$$

$$F = \frac{3 \cdot \pi \cdot L}{\ln \left(1.5 \frac{L}{D} + \sqrt{1 + \left(1.5 \frac{L}{D} \right)^2} \right)}$$

Step	K (m/s)	k (m ²)	Δk (m ²)
1	4.3 * 10 ⁻⁶	4.3 * 10 ⁻¹³	±0.1 * 10 ⁻¹³
2	4 * 10 ⁻⁶	4 * 10 ⁻¹³	±2 * 10 ⁻¹³
3	2 * 10 ⁻⁶	2 * 10 ⁻¹³	±5 * 10 ⁻¹³

Next Steps:

Environmental Impact Assessment for power plants at Ischia and Campi Flegrei (final approval of MISE);

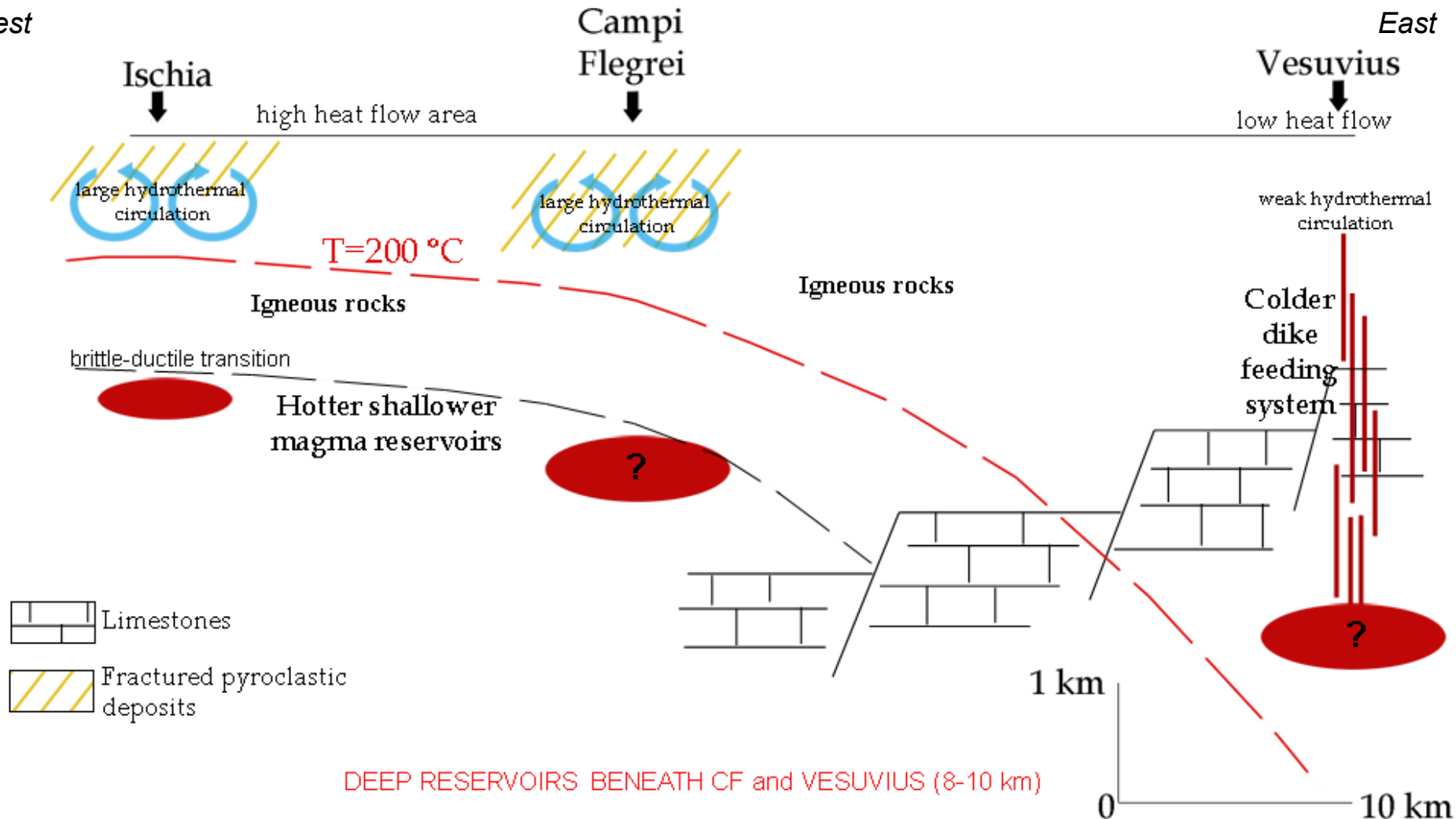
Deep drilling CFDDP (3.5 km) rocks and fluids parameters evaluation for deeper geothermal system;

Evaluation of best models of geothermal exploitation of highly urbanized contest (sustainability and environmental impact).

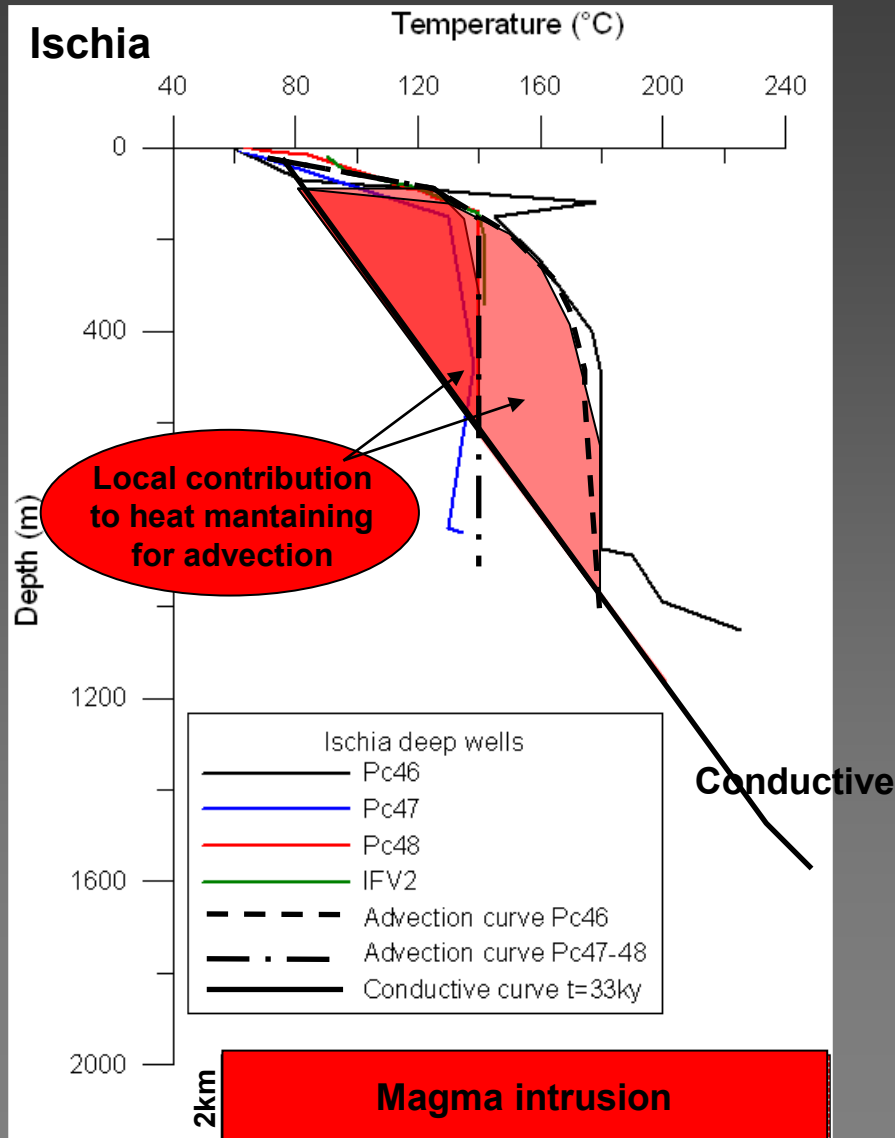
Thanks for your attention!



Temperatures and heat transport



Temperatures and heat transport



Conduction

$$T_{(y,t)} = \frac{Q}{2\rho c \sqrt{\pi k t}} e^{-y^2/4kt} \quad (1)$$

(one-dimensional solution)

Advection

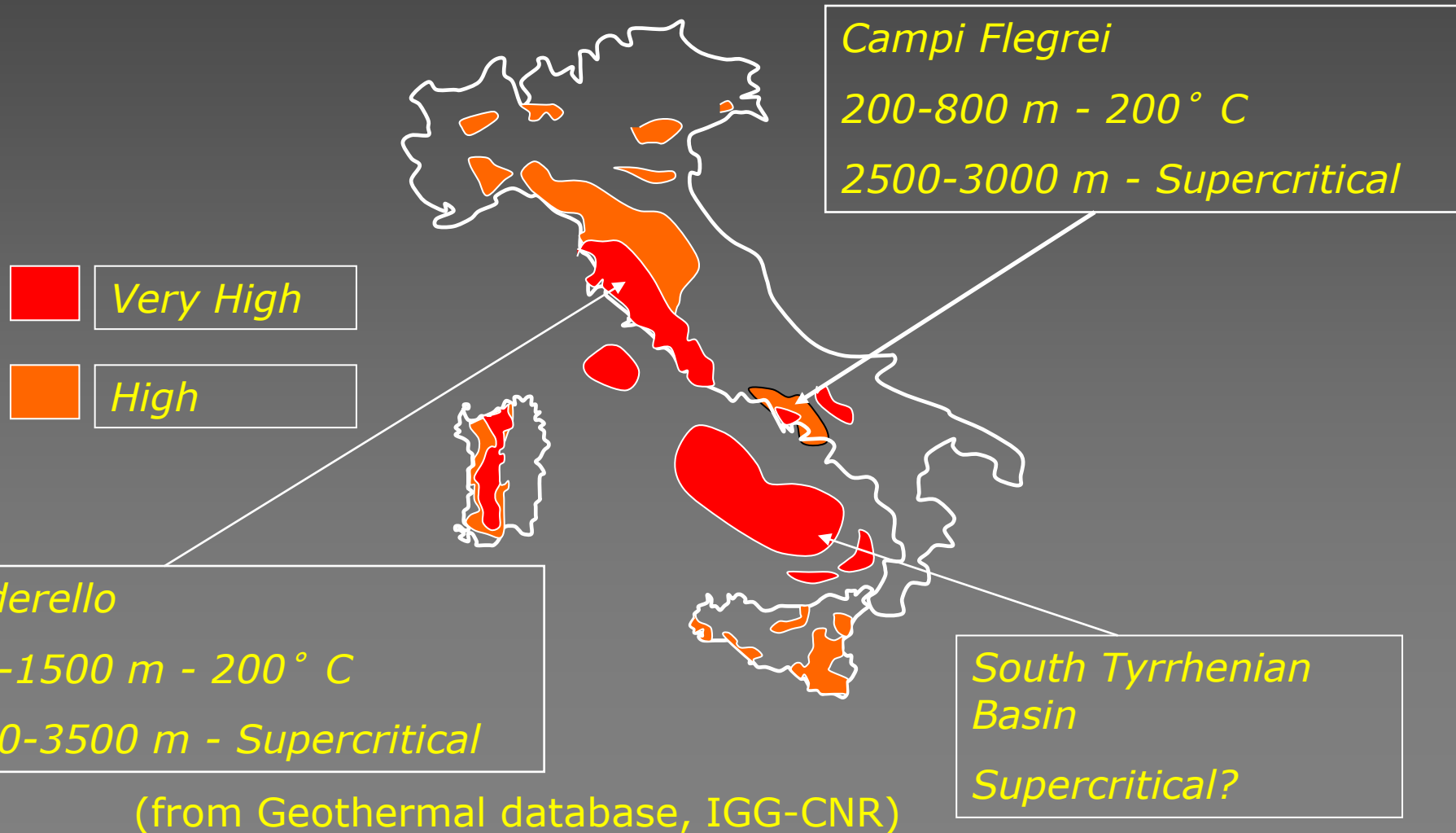
(Turcotte and Schubert, 2001)

$$T = T_r - (T_r - T_0) \cdot \exp\left(-\frac{\rho_f c_f v}{\lambda} y\right) \quad (2)$$

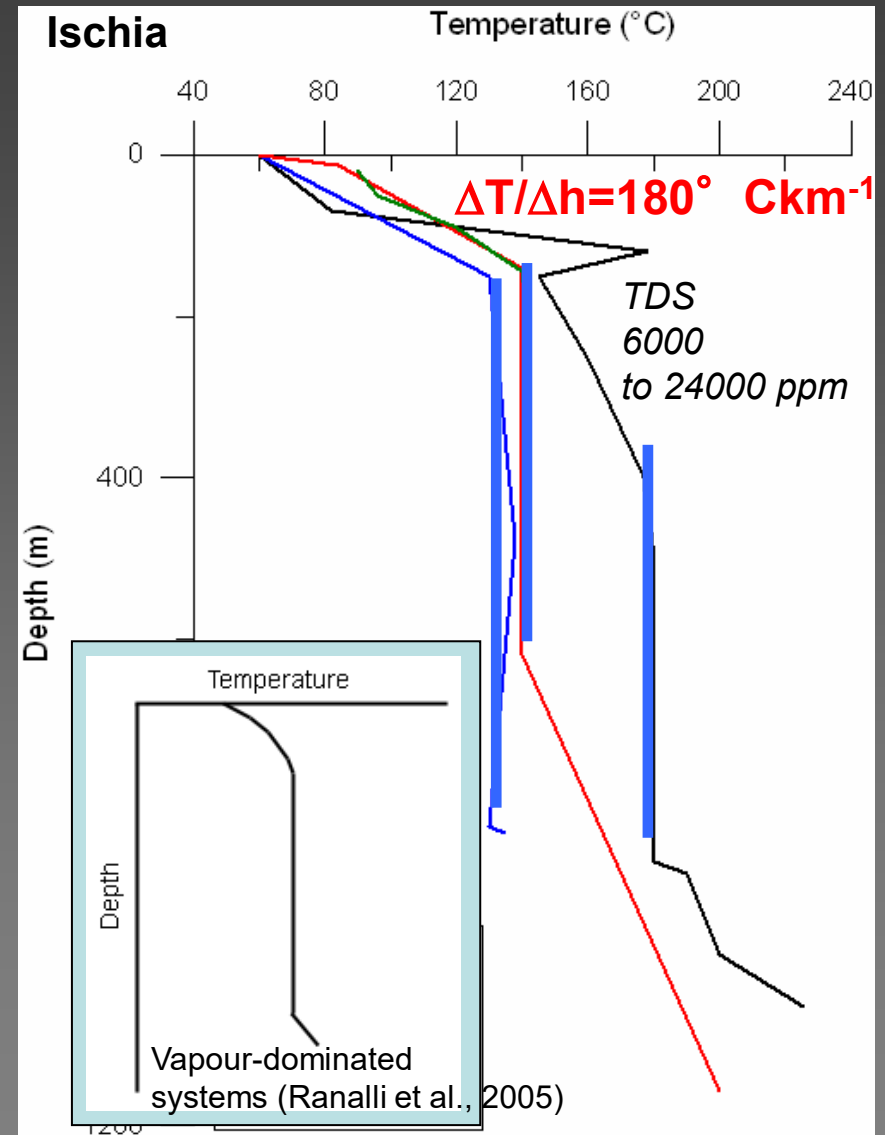
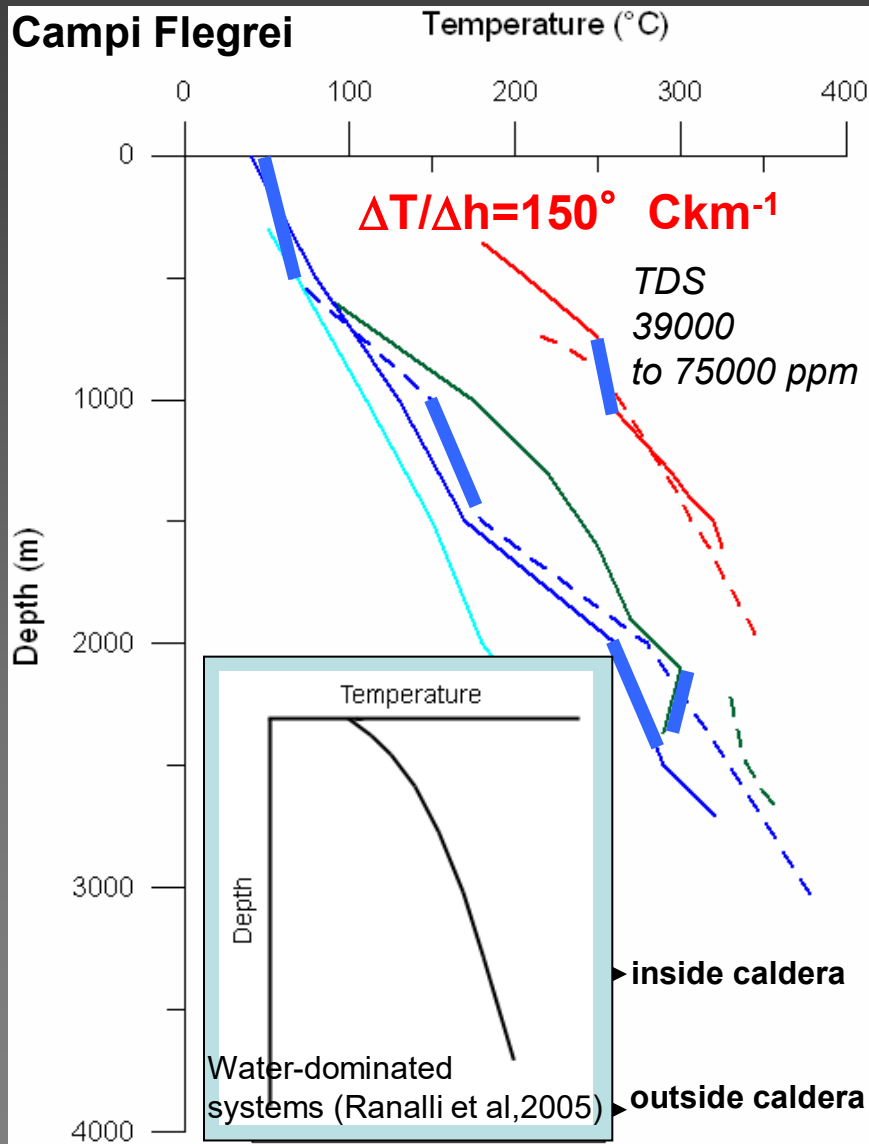
(one-dimensional solution in a porous media)

Q = heat content, $6 \cdot 10^{12} \text{Jm}^{-2}$
 k = thermal diffusivity, $1 \text{mm}^2 \text{s}^{-1}$
 λ = thermal conductivity, $3.35 \text{Wm}^{-1} \text{ } ^\circ \text{C}^{-1}$
 ρ = rocks density (average), 2300Kg m^{-3}
 ρ_f = fluids density, 1000kg m^{-3}
 c = magma specific heat, $1 \text{kJ kg}^{-1} \text{K}^{-1}$
 c_f = fluids specific heat, $4.815 \text{J kg}^{-1} \text{K}^{-1}$
 T_r = geoth reservoir temperature, $140\text{-}180 \text{ } ^\circ \text{C}$
 T_0 = surface temperature, $60 \text{ } ^\circ \text{C}$
 t = time, 33ky
 y = depth, down to 900 m
 v = Darcy velocity porous media, $6.7 \cdot 10^{-8} \text{ms}^{-1}$

Areas with high geothermal gradient in Italy



Temperatures of Phlegreans district





Data from AGIP-ENEL (1987) during productive tests (Campi Flegrei)

Temperature at well head: min 150° C, max 250° C;

Average flow rate: 55kgs⁻¹;

Specific heat of geothermal fluid: 3kJkg⁻¹K⁻¹ (T=180° C);

Density: 1.08kg l⁻¹ (con T=180° C);

Salinity: 30.000 TDS (ppm)in the reservoir (T=247° C, depth 500-900m);

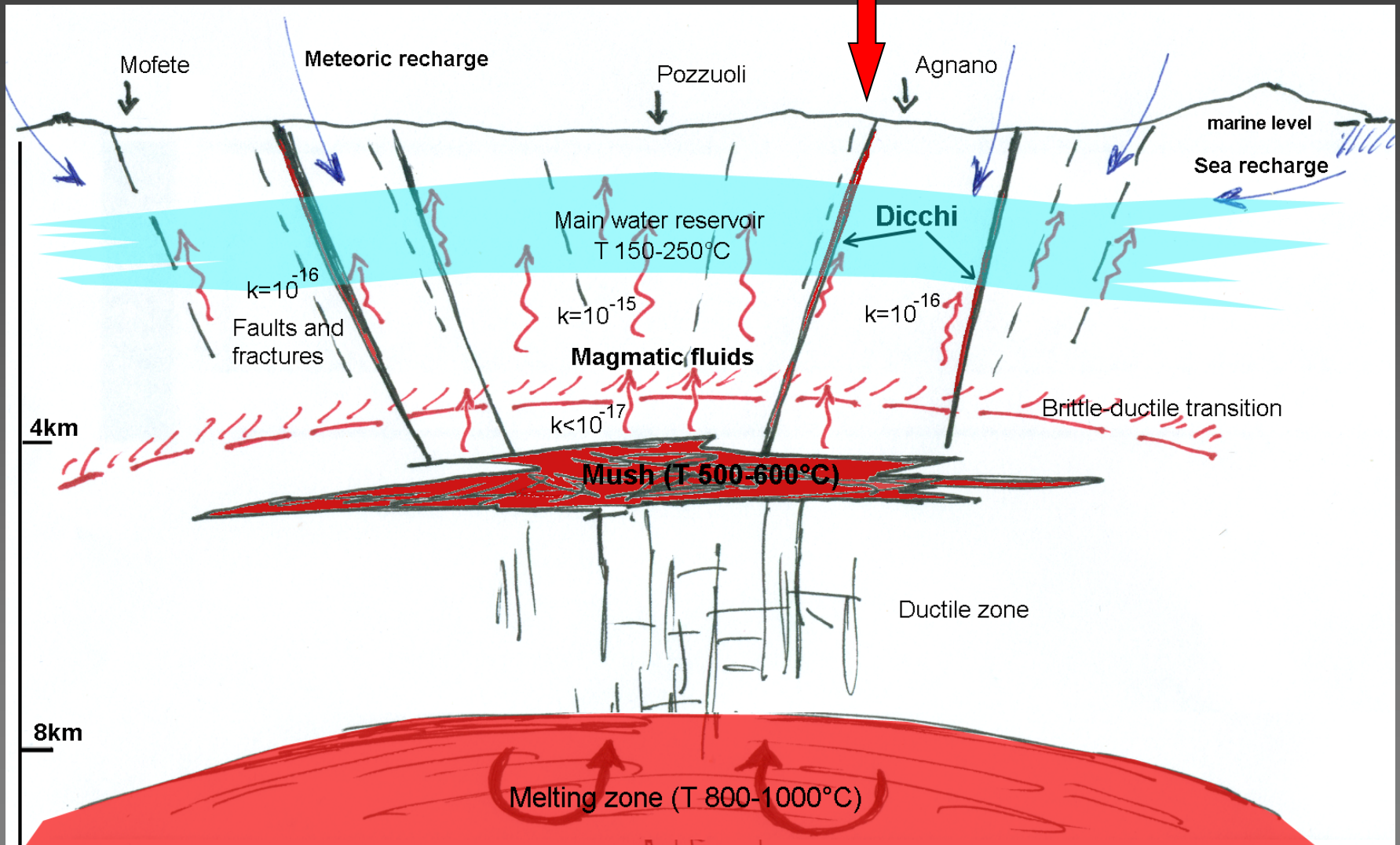
Vapor phase: 30-40%;

Not condensable gases <2% weight;

Well head pressure: 8bar.

5MW geothermal power plant

Campi Flegrei



Conceptual model of geothermal reservoir of caldera