District Heating and Direct Uses: the Grado Geothermal Pilot Project

UNIVERSITÀ
DEGLI STUDI DI TRIESTE

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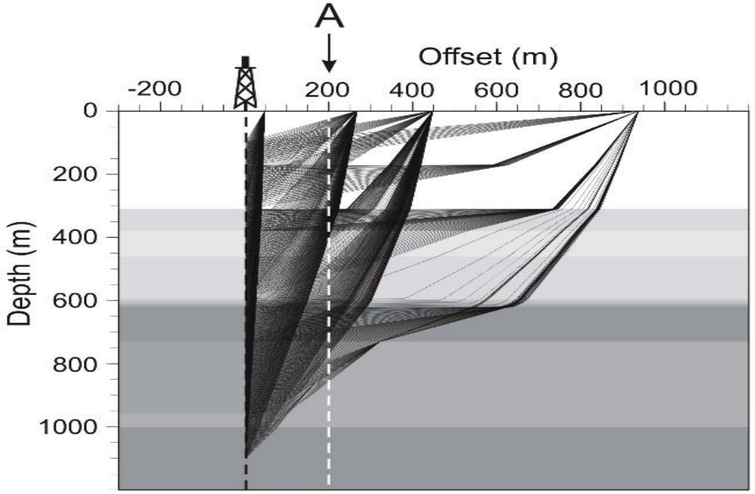
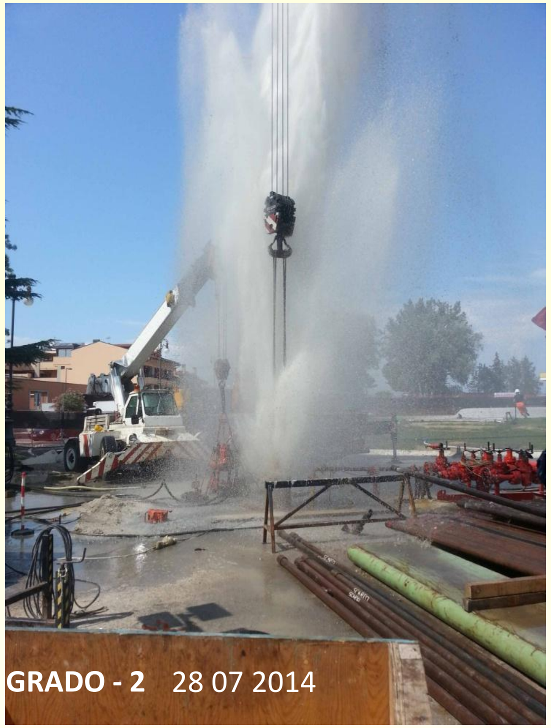




UNIONE
GEOTERMICA
ITALIANA

International School on Geothermal Development, ICTP Miramare, Trieste

(December 07-12, 2015)

International Geothermal Association

Grado Geothermal Pilot Project: Expertise Network and Acknowledgments

- ✓ **European Union** for providing 77 % of total funding to the Project, through **DOCUP-2 and POR-FESR Programs**
- ✓ **FVG Region - Geological Survey** and **Grado Municipality** for Project funding, support and coordination
- ✓ **Grado city and inhabitants** for their patience and comprehension,
- ✓ **Dept. of Engineering and Architecture and Dept. of Mathematics and Geosciences**
- ✓ **Drilling companies Fratelli Perazzoli** and **SIME Drilling,** *for completion Grado-1 and Grado-2 wells,* and **Impresa Cicuttin**, responsible for the DH network deployment
- ✓ **OGS crew** for geophysical data acquisition and processing
- ✓ **E. Castelli**, Project design, work and operations director for both Grado-1 and Grado-2 wells + **Idrostudi, Trieste**
- ✓ **R. Petrini** for isotopic analysis and interpretation
- ✓ **Students, PhDs and several University and free lance experts** for cooperation and support in drilling and data analysis

Della Vedova et al., 2015, World Geothermal Congress, Melbourne

Adri-Jo Geothermal Platform: http://www.fondazioneinternazionale.org/geothermalPlatform.php)

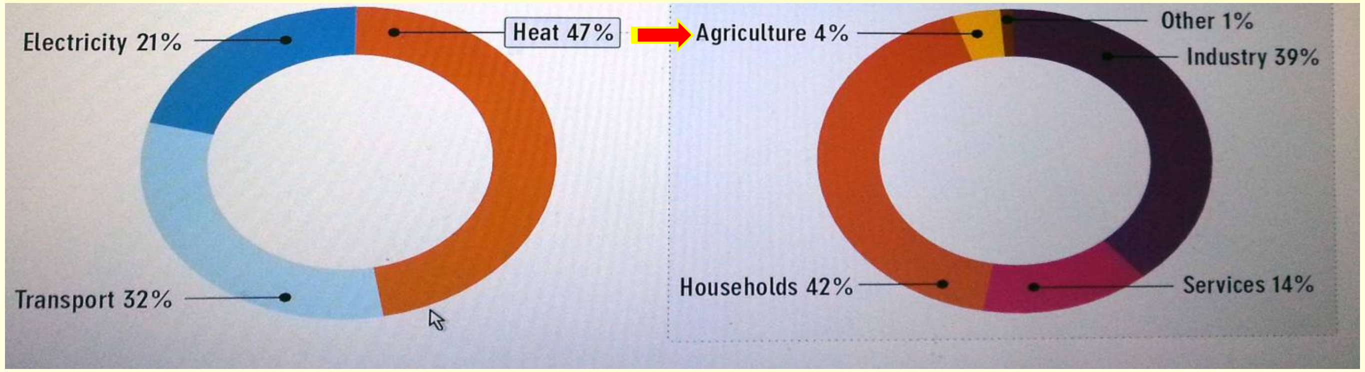
Outline

- ❑ Geothermal Potential for Direct Uses
- ❑ Grado District Heating (DH) Geothermal Pilot Project
- ❑ Geological and Geophysical Reservoir Characterization
- ❑ Reserves Assessment, Geothermal Doublet + DH Completion
- ❑ Challenges of Geothermal Projects & concluding Remarks

Renewable Heating & Cooling
European Technology Platform

Strategic Research and Innovation Agenda for Renewable Heating & Cooling

Final Energy and Heat Use by EU 27 (2011)



Most important aims by 2020

- ➢ Significantly reduce the cost of RHC technologies (for geothermal: reduce exploration, drilling costs & geologic risk)
- ➢ Enhance RHC system performance and reliability
- ➢ Reduce RHC system payback time

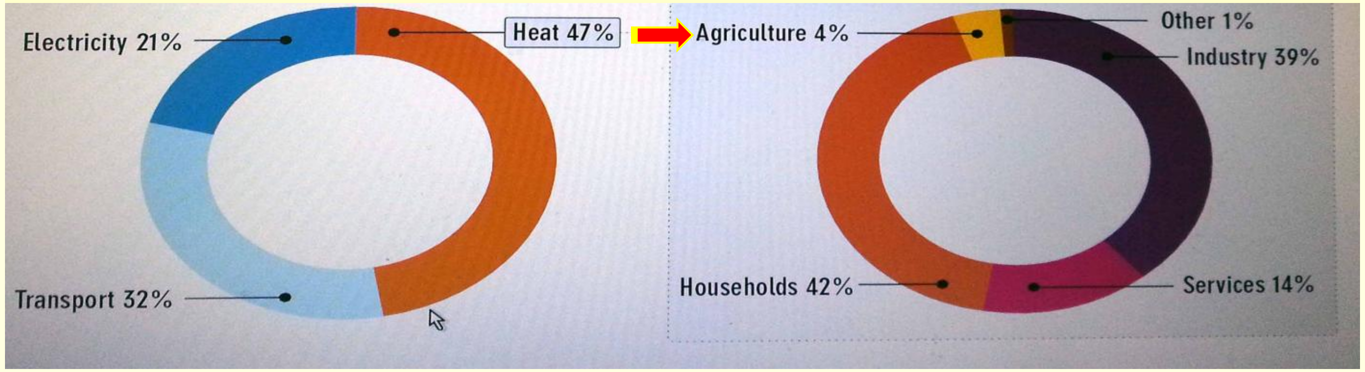
Geothermal Energy

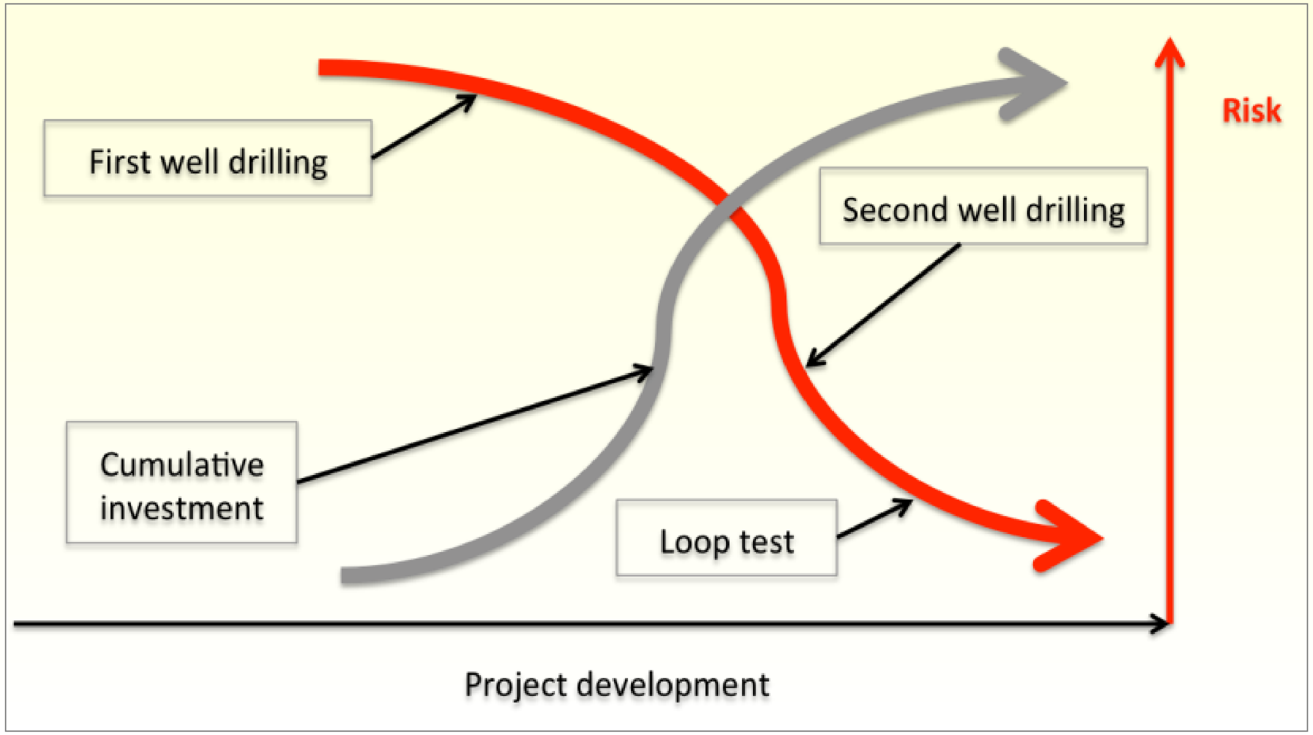
- *Clean*
- *Renewable*
- *Sustainable*
- *Anywhere…*
- *Round the clock !*
- *Excellent for base-load*

RHC Renewable Heating & Cooling
European Technology Platform

Strategic Research and Innovation Agenda for Renewable Heating & Cooling

Final Energy and Heat Use by EU 27 (2011)





Geothermal Energy

- *Clean*
- *Renewable*
- *Sustainable*
- *Anywhere…*
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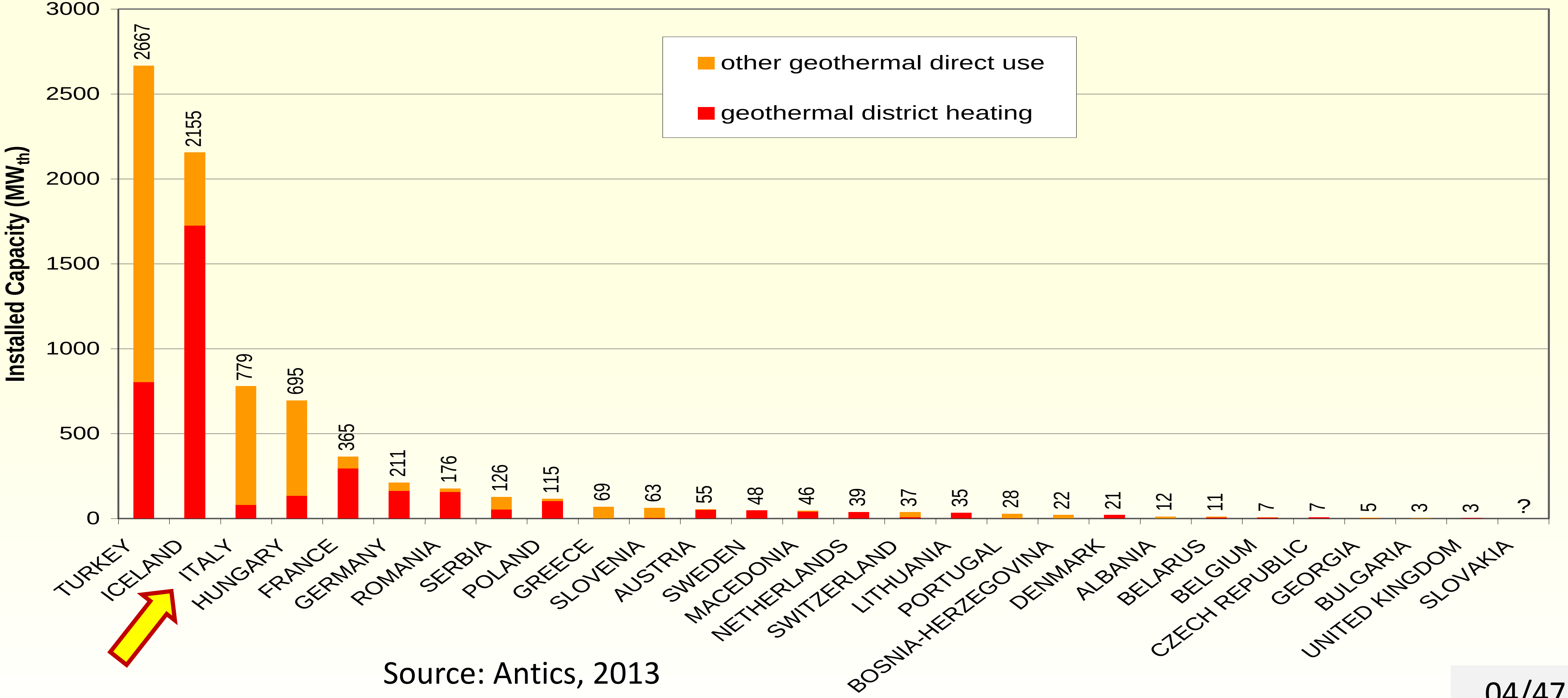
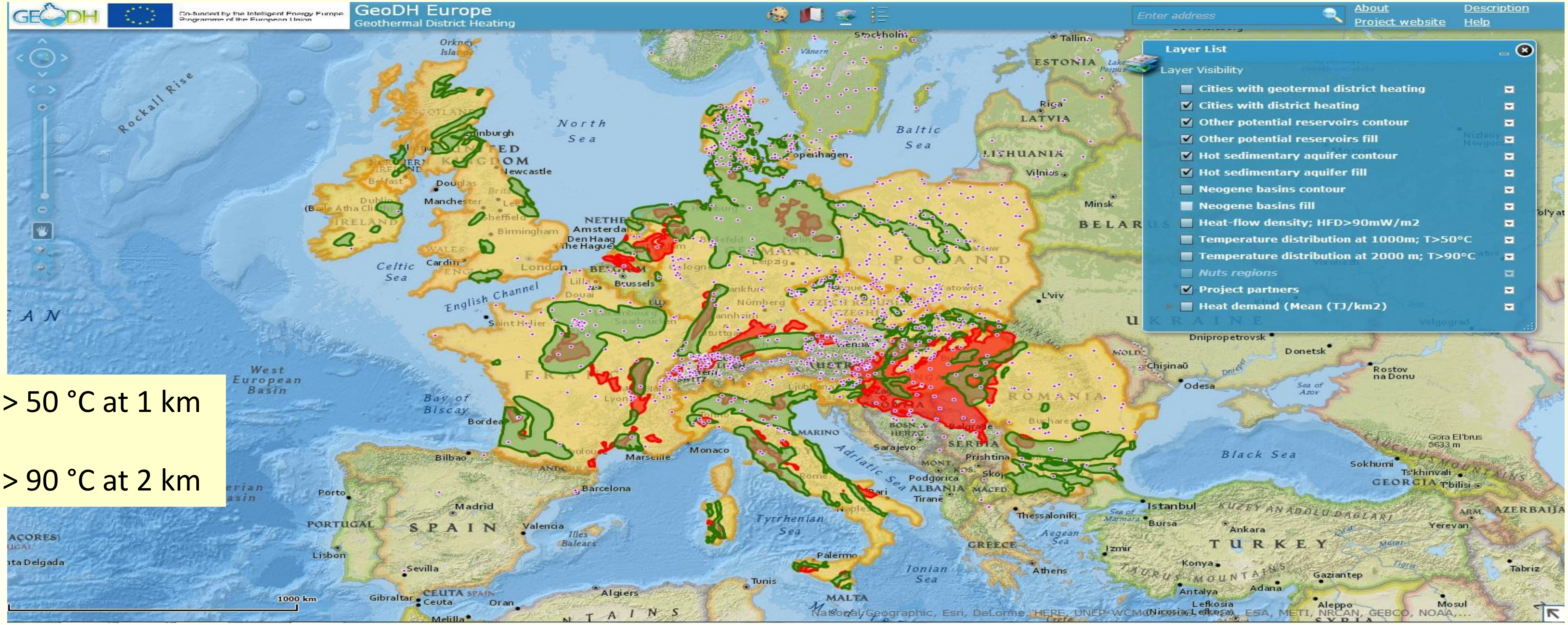
GEOTHERMAL DIRECT USES IN EUROPE

INSTALLED CAPACITY 2012 & SHARE OF GEOTHERMAL DISTRICT HEATING
(*after EGC 2013 Country updated Reports*)



Source: Antics, 2013

Geothermal District Heating Potential in Europe



Layer List

Layer Visibility

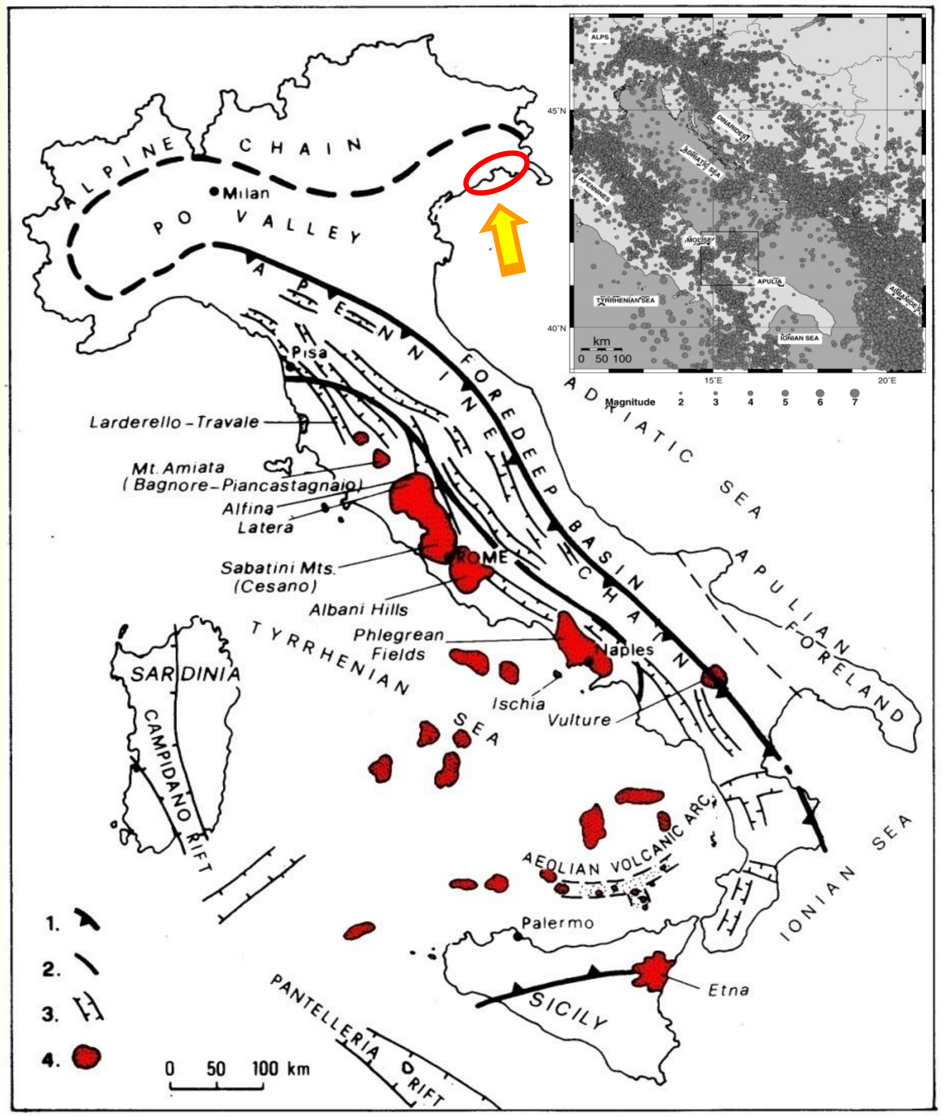
- ☐ Cities with geotermal district heating
- ☑ Cities with district heating
- ☑ Other potential reservoirs contour
- ☑ Other potential reservoirs fill
- ☑ Hot sedimentary aquifer contour
- ☑ Hot sedimentary aquifer fill
- ☐ Neogene basins contour
- ☐ Neogene basins fill
- ☐ Heat-flow density; HFD>90mW/m2
- ☐ Temperature distribution at 1000m; T>50°C
- ☐ Temperature distribution at 2000 m; T>90°C
- ☐ *Nuts regions*
- ☑ Project partners
- ☐ Heat demand (Mean (TJ/km2)

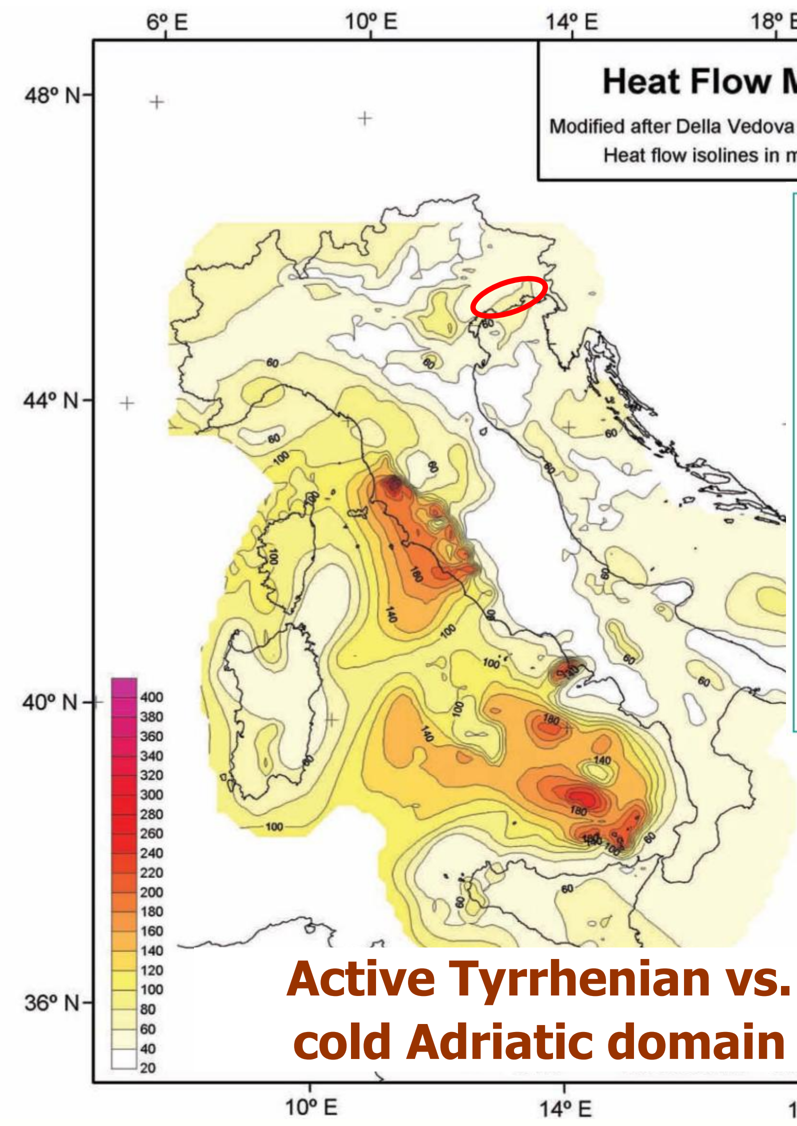
🟩 > 50 °C at 1 km

🟥 > 90 °C at 2 km

Over 25% of the EU population lives in areas directly suitable for Geothermal District Heating, ensuring security of supply (source EGEC)

Hf Map & Adriatic Foreland





Heat Flow Map

Modified after Della Vedova et alii (2001)

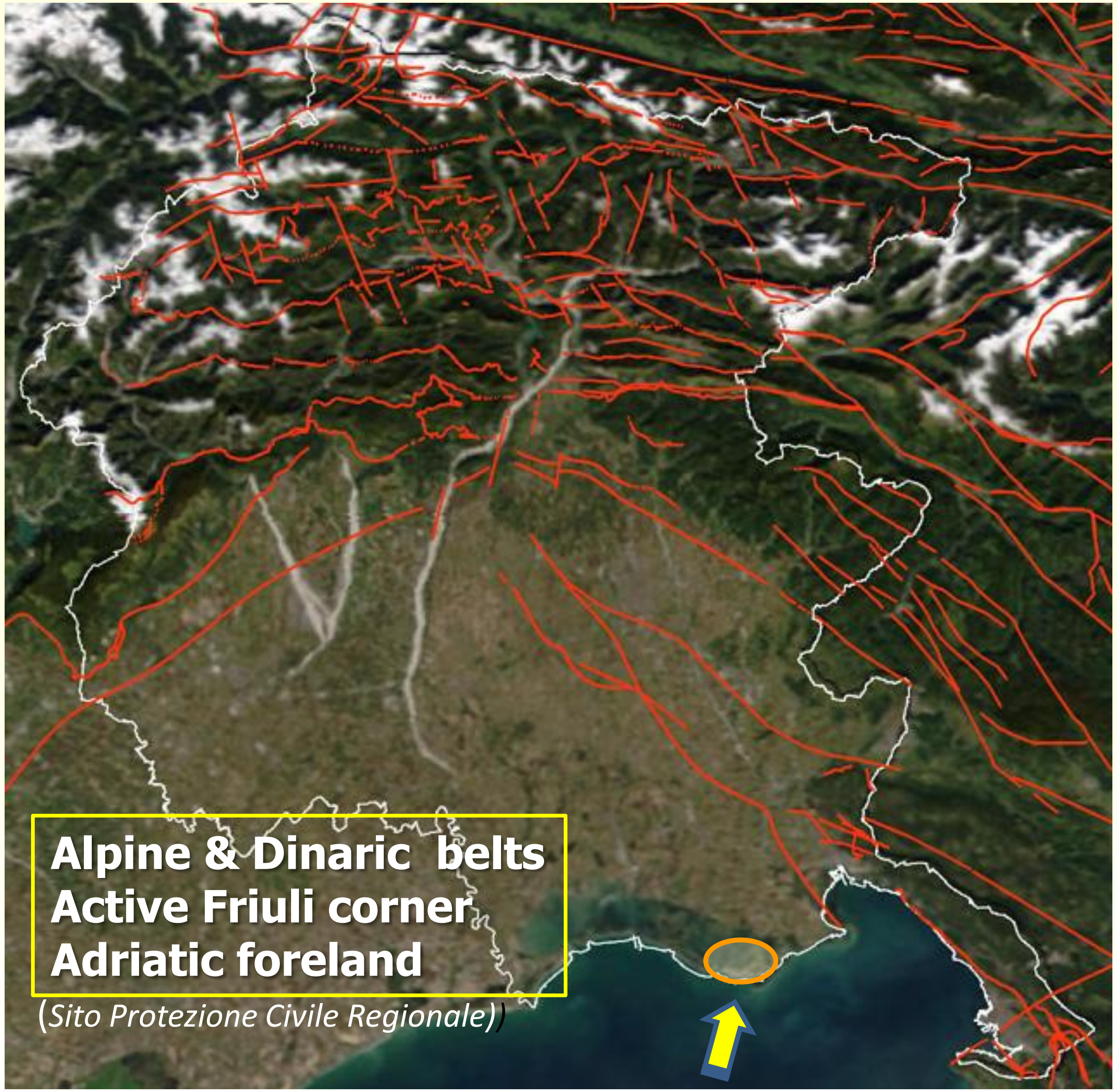
Heat flow isolines in mW/m2

Active Tyrrhenian vs. cold Adriatic domain

EUROPEAN GEODYNAMIC SETTINGS

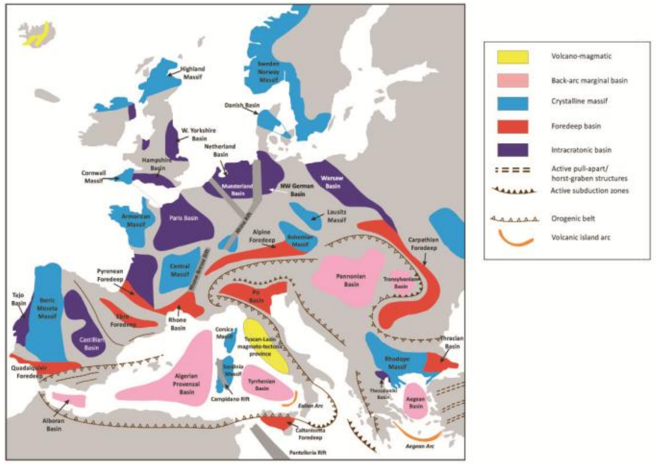
(after C. Sommaruga)

Hf Map & Adriatic Foreland



Alpine & Dinaric belts
Active Friuli corner
Adriatic foreland

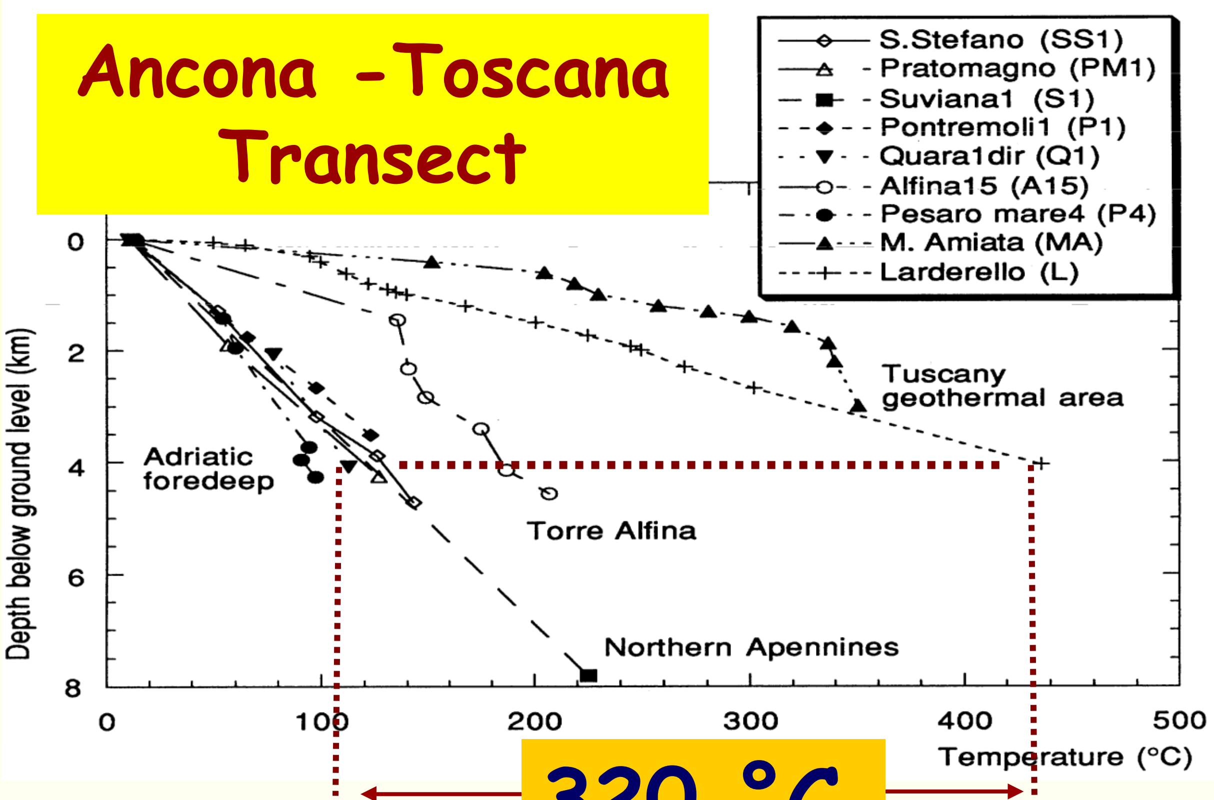
(*Sito Protezione Civile Regionale*))



EUROPEAN GEODYNAMIC SETTINGS
(after C. Sommaruga)

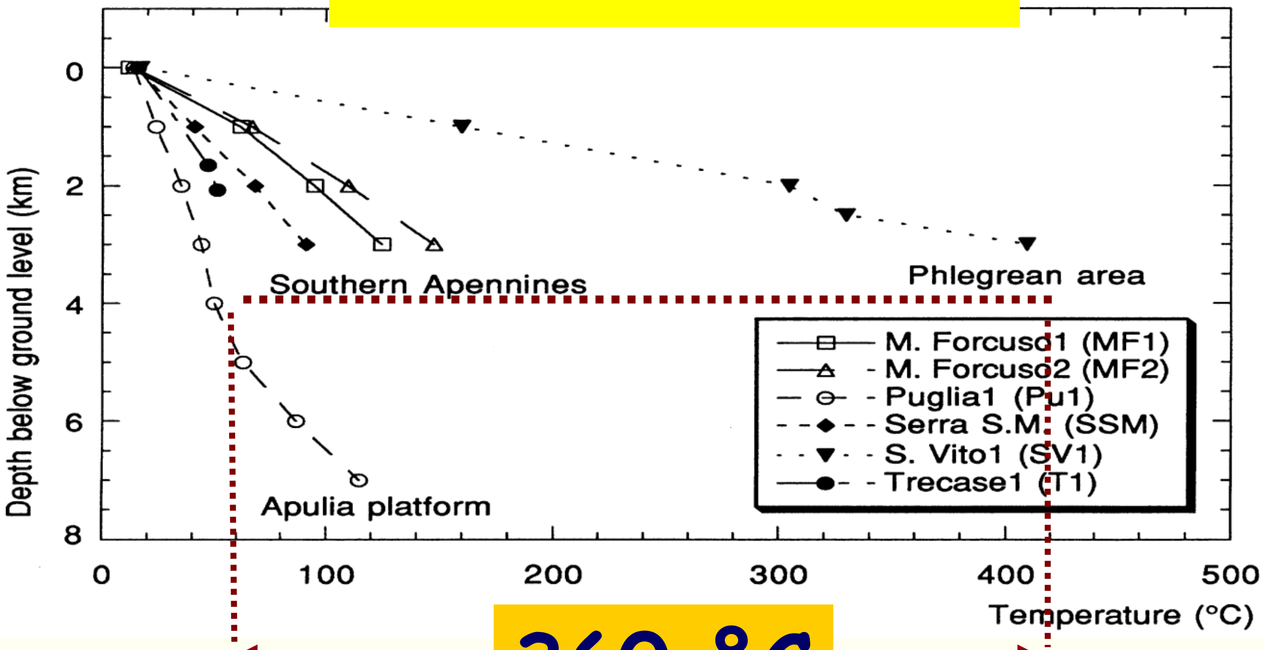
Thyrrenian vs. Adriatic Domain

Ancona -Toscana Transect



320 °C

Gargano - Napoli Transect



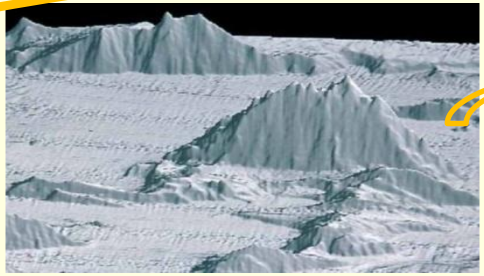
360 °C

Large difference in heat input from the Mantle!

Shallow water resources <200 m (red and orange patterns)

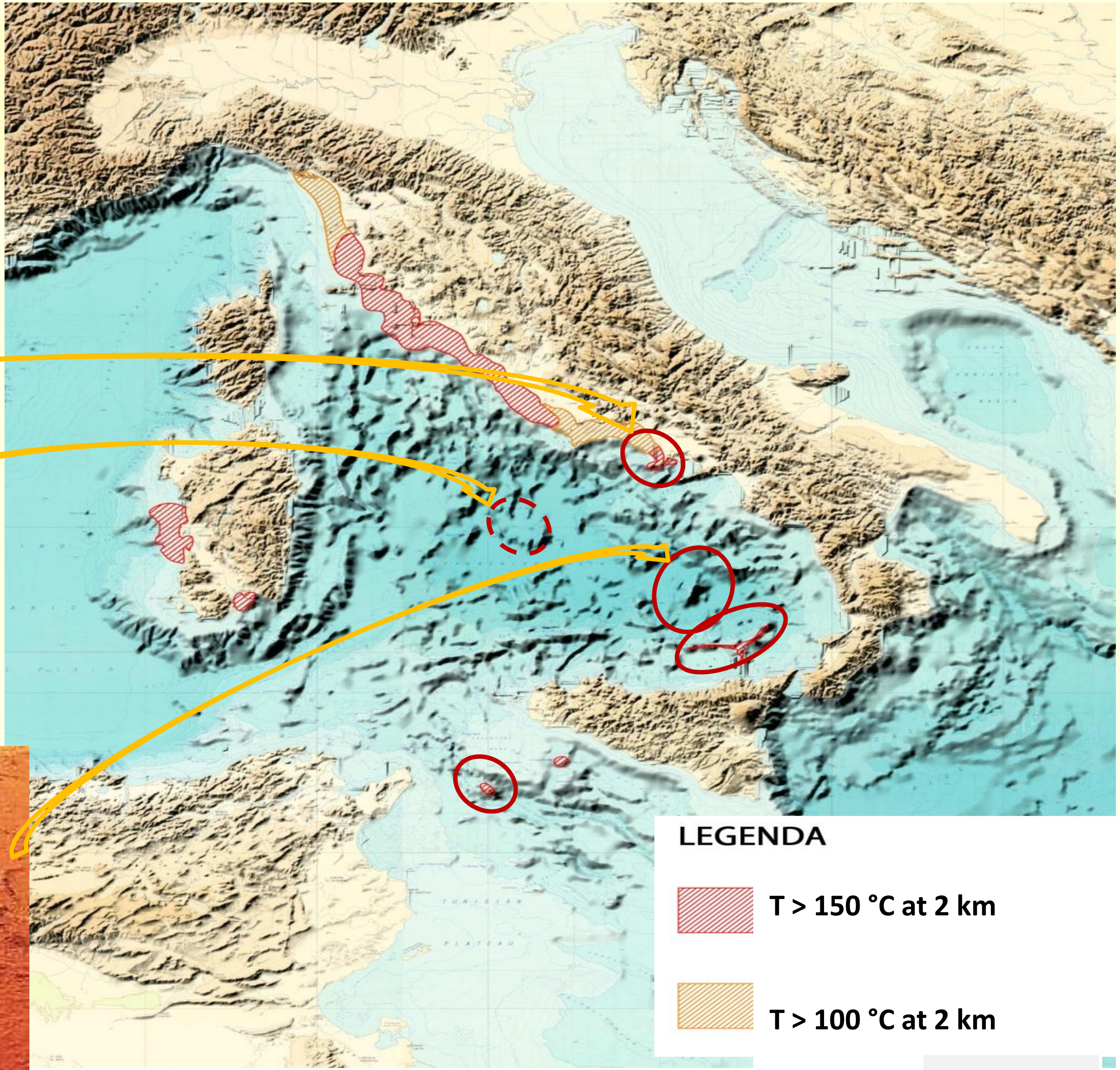
Deep resources (circles)

Vavilov SMt.



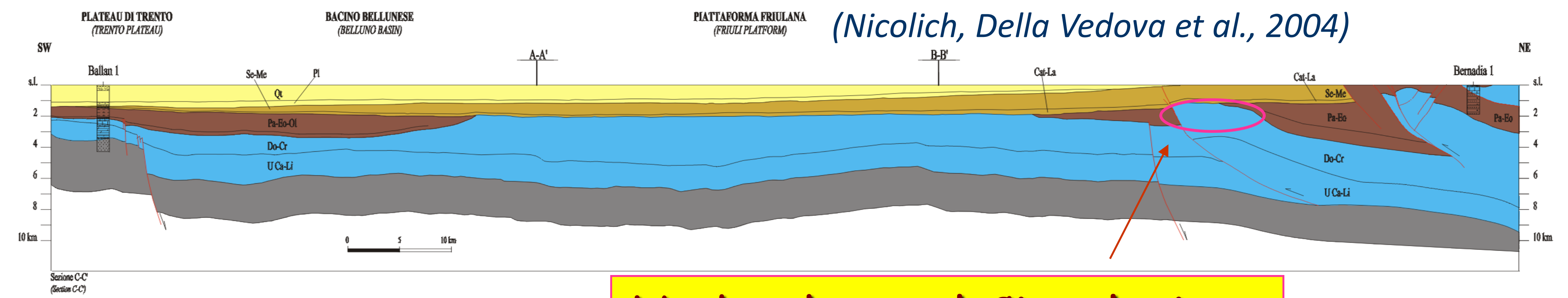
Campi Flegrei Deep Drilling Project

Marsili SMt.



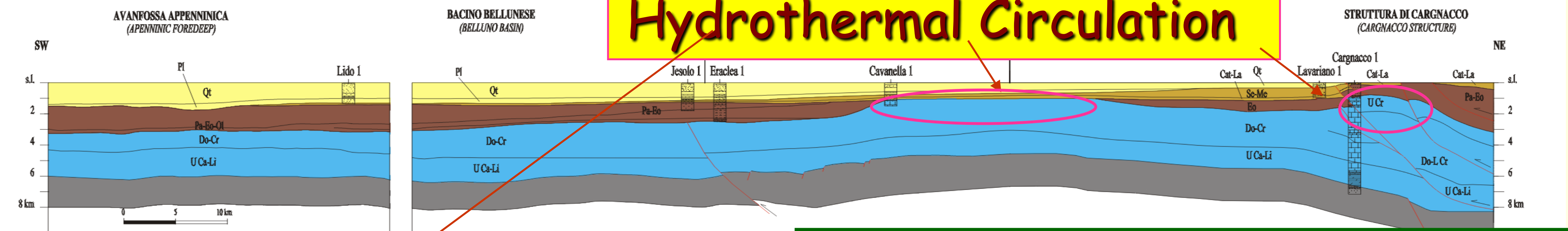
Adriatic Mesozoic Platform

(Nicolich, Della Vedova et al., 2004)

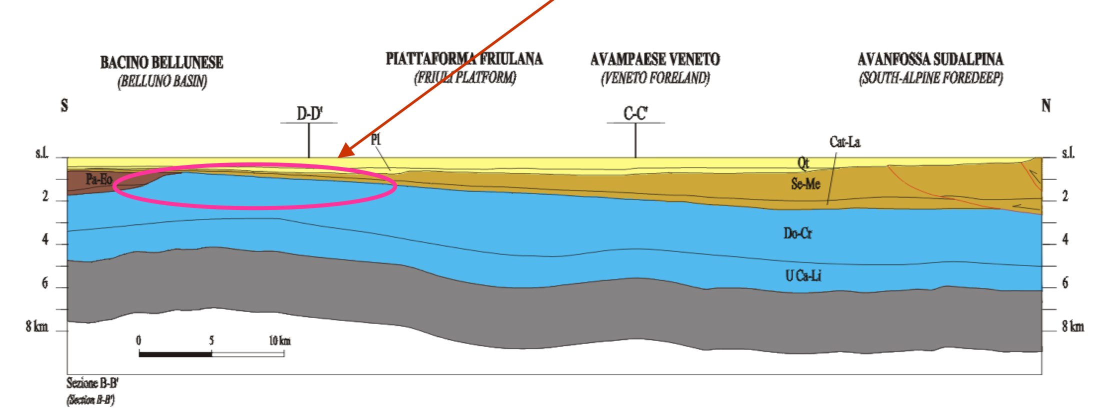


C –C'

Hydrothermal Circulation



D –D'

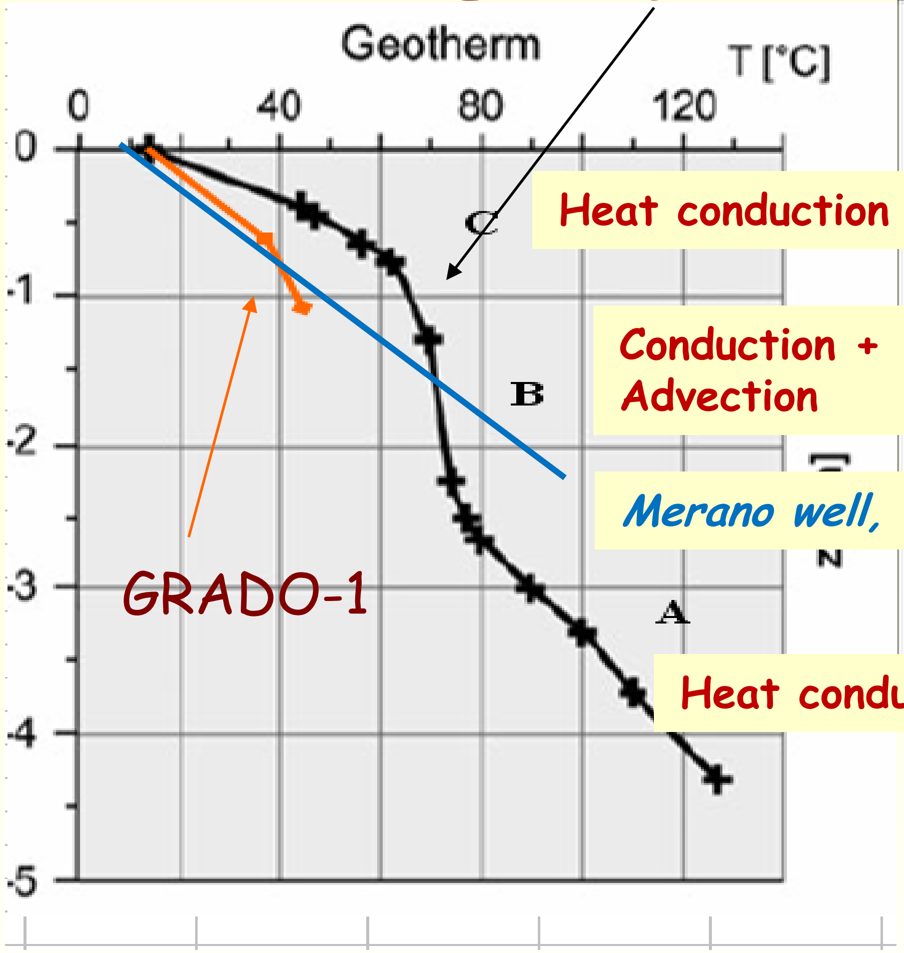


B –B'


Map to Top of Mesozoic carbonates

2-D Geothermal model

CESAROLO-1



Heat conduction

Conduction + Advection

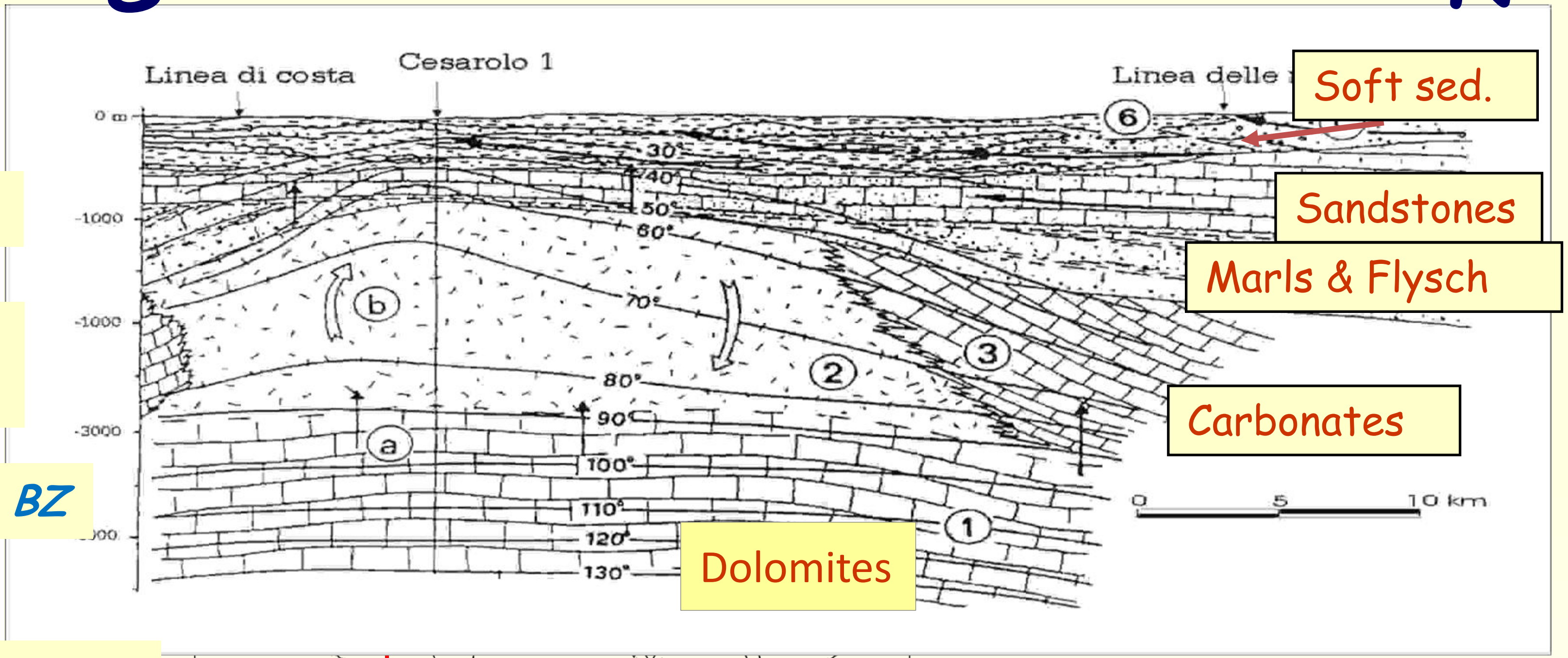
Merano well, BZ

Heat conduction

GRADO-1

S

N



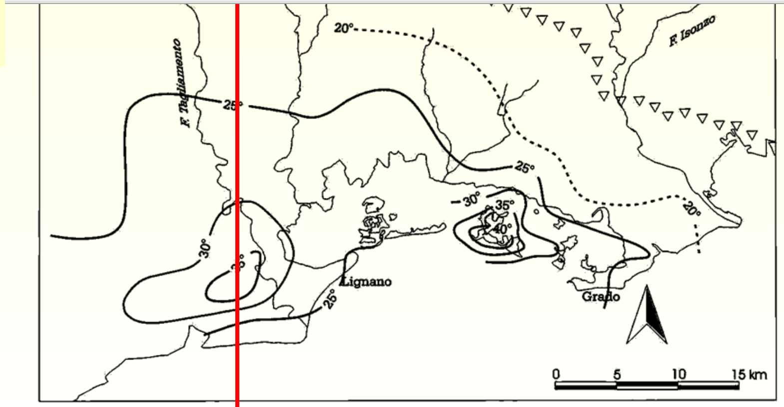
Soft sed.

Sandstones

Marls & Flysch

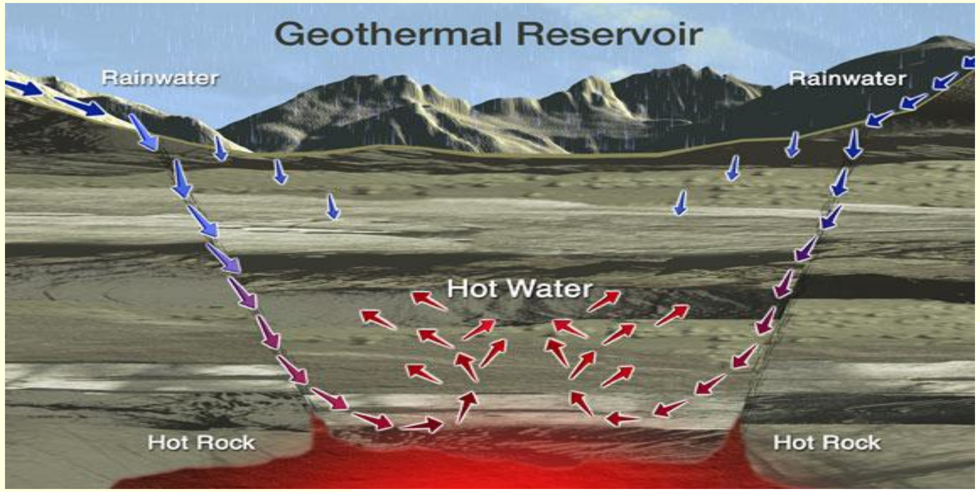
Carbonates

Dolomites

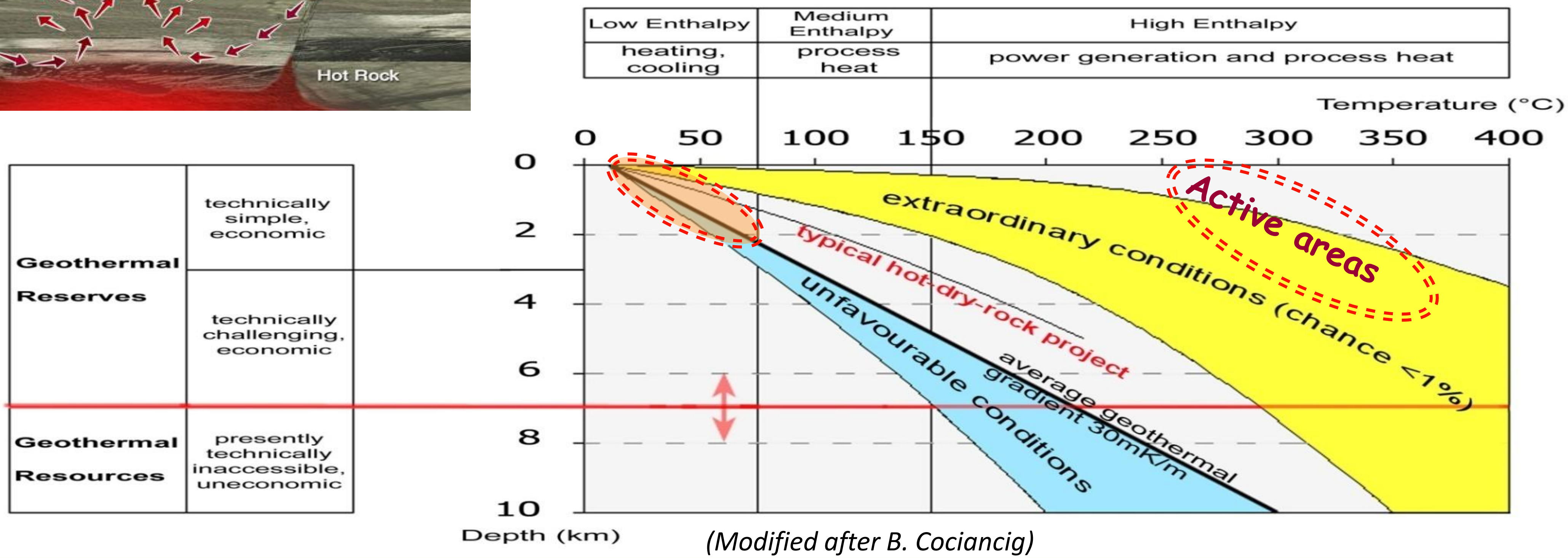


Distribuzione delle temperature (°C) a 300 m di profondità (Calore et. al., 1995).

Geothermal Resources & Reserves



- Heat potential is enormous
- Available at shallow depth in active areas
- Constant source and largely renewable



(Modified after B. Cociancig)

Outline

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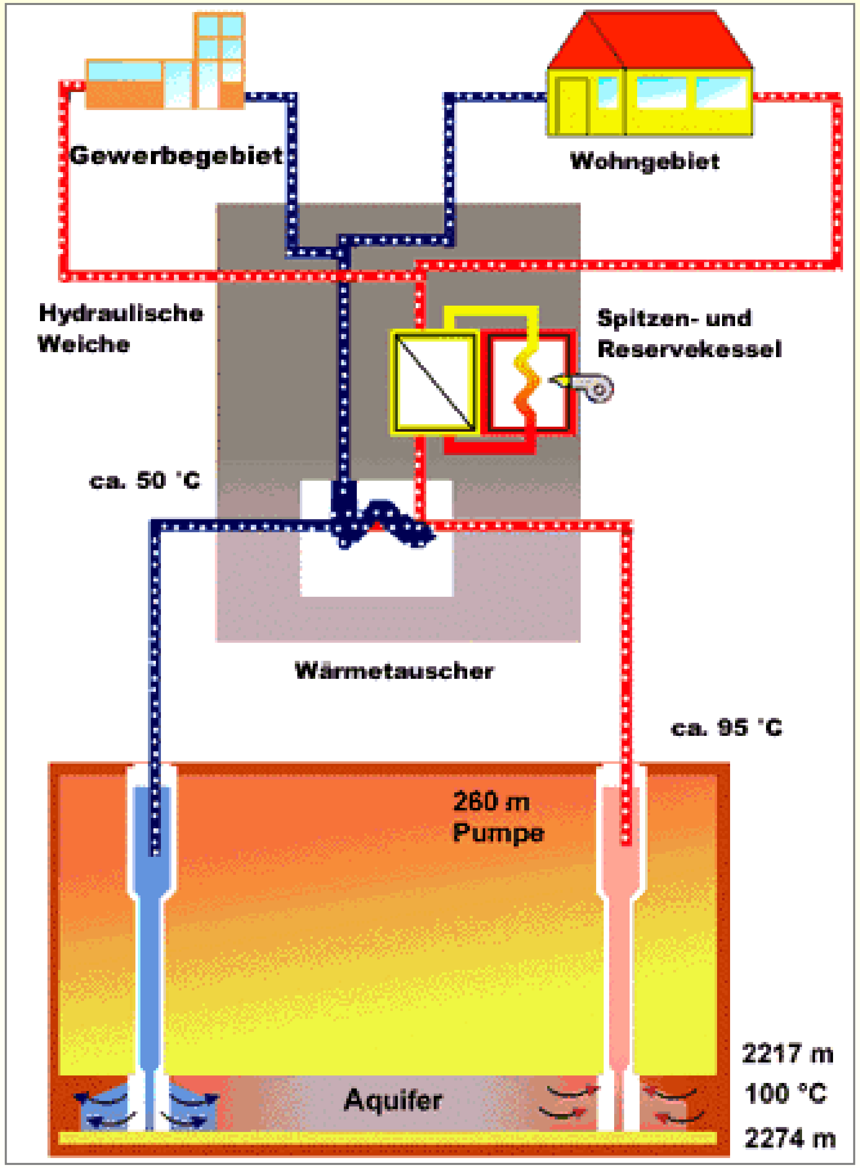
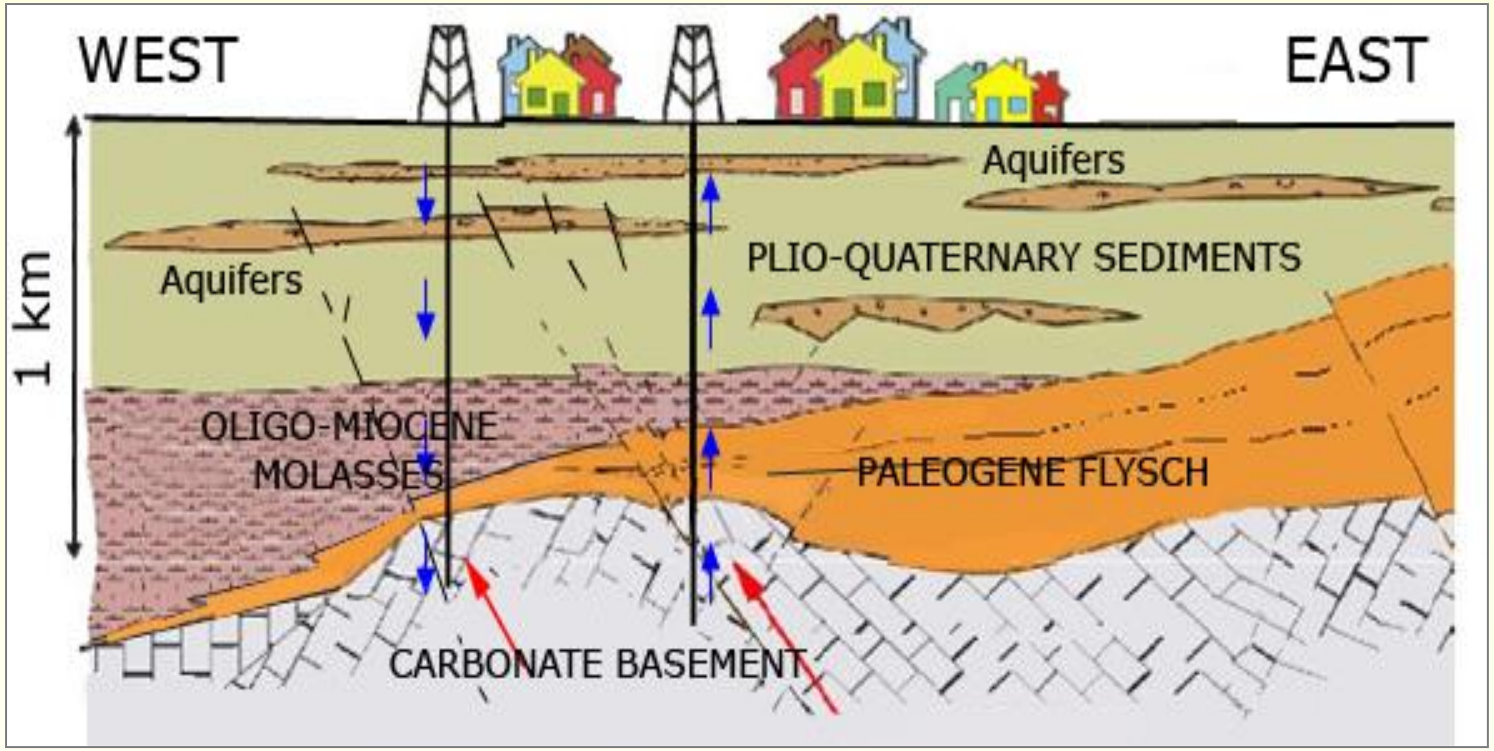
RFVG calls for geothermal applications within POR FESR 2007-2013 (EU Funding: 77% of admissible costs to beneficiary public administrations)

RFVG Calls	Submitted Proposals (N)	Funded Projects (N)	Initial budgets		StartedProjects (N)
			Admissible costs (€)	Contribution (€)	
Borehole Heat Exchangers + HPs (1)	23	14 (Pontebba)	3.957.237,35	2.656.157,59	10
Geoth. Resources beyond 700 m	2	1 (Grado 2)	2.495.999,20	1.921.920,00	1
Geoth. Resources up to 700 m (1)	3	2	481.932,40	371.087,95	1
Borehole Heat Exchangers + HPs (2)	9	6	1.511.786,12	1.164.075,31	5
Geoth. Resources up to 700 m (2)	2	1	636.548,49	490.142,34	1
Total	39	24	**9.083.504,56**	**6.603.383,19**	18

Grado Geothermal DH Pilot Project





Grado Geothermal DH Pilot Project

Phase 1 (2002-2008, 2.5 M€):

- **Implementing Party**: Regione Autonoma FVG (Italy)
- **Goal**: Assess geothermal resource
- **Method**: Geology & Geophysics and exploration drilling
- **Scientific Partner**: Trieste University
- **Funding**: European Union, National and Regional Administrations

Phase 2 (2010-2014, 2.5 M€):

- **Implementing Party**: Grado Municipality (Gorizia province)
- **Goal**: Design and realize the geothermal doublet
- **Method**: G&G, 2nd borehole, reservoir characterization, DH network
- **Scientific Partner**: Trieste University and OGS Trieste
- **Funding**: European Union, National and Grado Municipality

Project Motivation

- Assess the geothermal potential of the buried Adriatic carbonate platform
- Characterize the geothermal reservoir
- Evaluate sustainability and impacts for long term utilizations
- Demonstrate economic feasibility of geothermal doublets in Adriatic cold areas
- Replicate geothermal doublets in other favourable areas

Geothermal Pilot Project Structure (2004-2015)

Project Phase/ Structure	Integrated Methodology	Results	Main Risks
Exploration and well location	Seismic reflection, VSP, Gravity, Geology, wells	Geologic model, reservoir structures, faults location	High geologic and exploration risk
Reservoir characterization	Drilling, well logs, pumping tests, geochemistry,thermo-fluid dynamic modeling	Geothermal potential assessment, wells interconnection	High drilling risk, reservoir properties and geologic risks
Well completion & DH network	Casing, cementing, shallow tunnelling, DH pipes & pumps, heat exchangers	Completion of main DH network, connecting 4-6 Public buildings	Moderate development and construction risk
Operational	Management and optimization	Higher efficiency and lower payback time	Low operational risk

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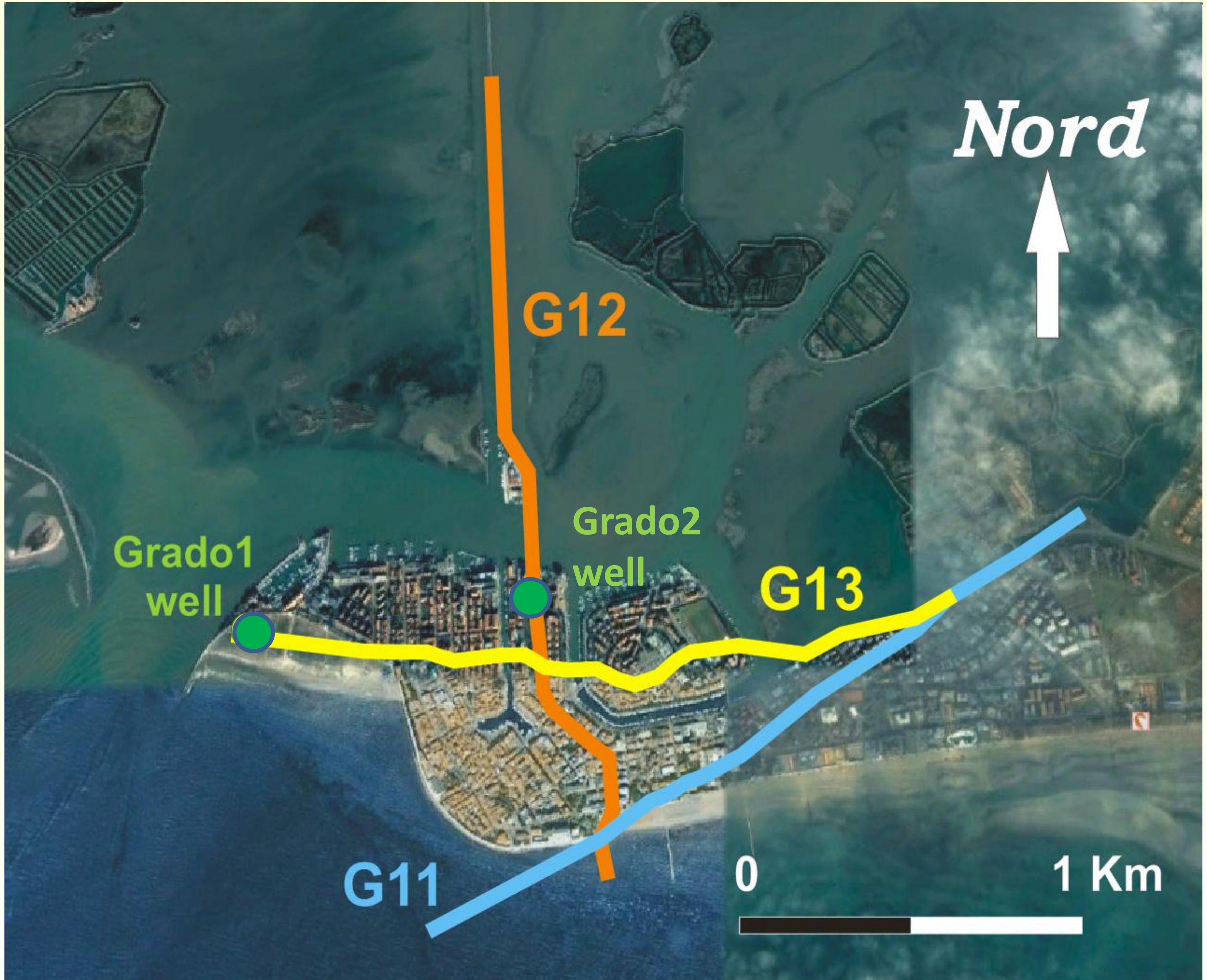
Data And Results

- 7 **Reflection Seismic Profiles** (about 12 km) and 4 **Multi-offset VSPs**
- **Gravity data** (229 new measurements + 97 available data)
- Two **geothermal boreholes** (1100 and 1200 m deep), one km apart
- Borehole **geophysical logging** in the carbonate reservoir of the two wells
- **Pumping tests and monitoring** and **Geochemical measurements**
- Thermofluid-dynamics **modelling** (still in progress)
- Geothermal model, **potential assessment and sustainability**

Della Vedova et al., EGC 2013; Della Vedova et al., WGC 2015
Poletto et al., EGC 2013; Poletto et al., WGC 2015

Surface reflection seismic layout to locate Grado 2

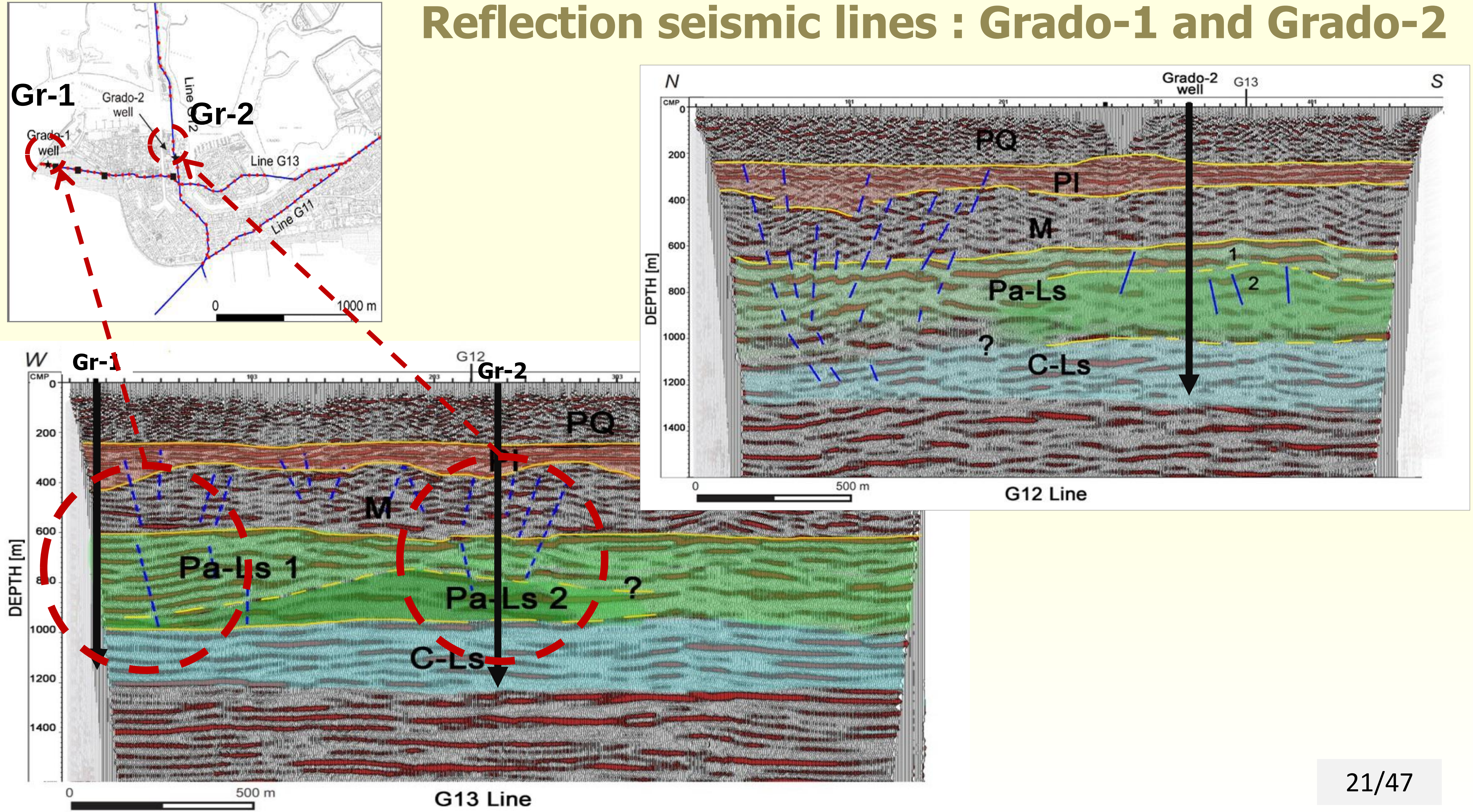


Surface seismic acquisition parameters

	G11	G12	G13
Seismic source:	Hydrapulse	Hydrapulse	Minivib (18 s, 8 – 200 Hz)
Sensors:	geophone (6x10 Hz) and hydrophone		
Intertrace:		10 m	
Shot interval:		20 m	
Layout:		fixed spread	
Channels:	236	256	174
Length:	2350 m	2550 m	1730 m
Sampling rate:		1 ms	
Data length:	4 s	4 s	22 s

Surface seismic acquisition parameters

Reflection seismic lines : Grado-1 and Grado-2



Borehole seismic in Grado-1 well

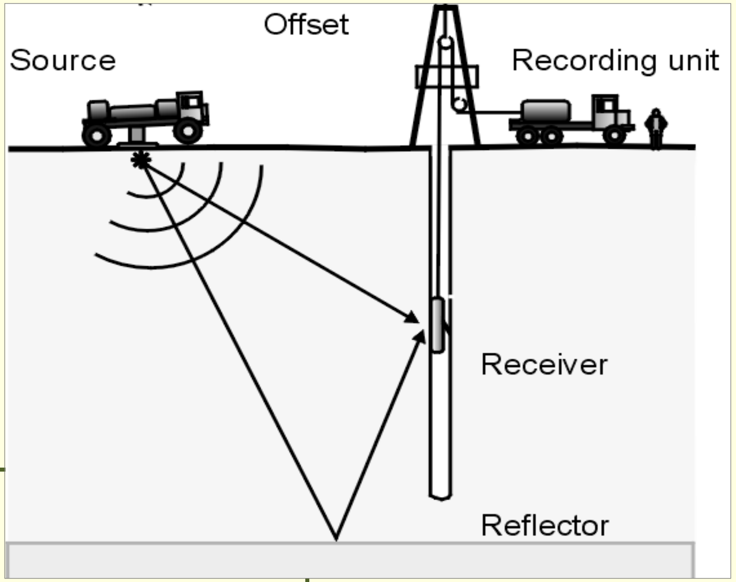
Concept of Vertical Seismic Profile (VSP)

4 VSPs: 1 near offset + 3 offset VSP

OBJECTIVES

- Characterize reservoir eastward of Grado 1
- Bridge logging data to MCS reflection
- Improve geology by numerical modelling

Borehole seismic in Grado-1 well



Concept of Vertical Seismic Profile (VSP)

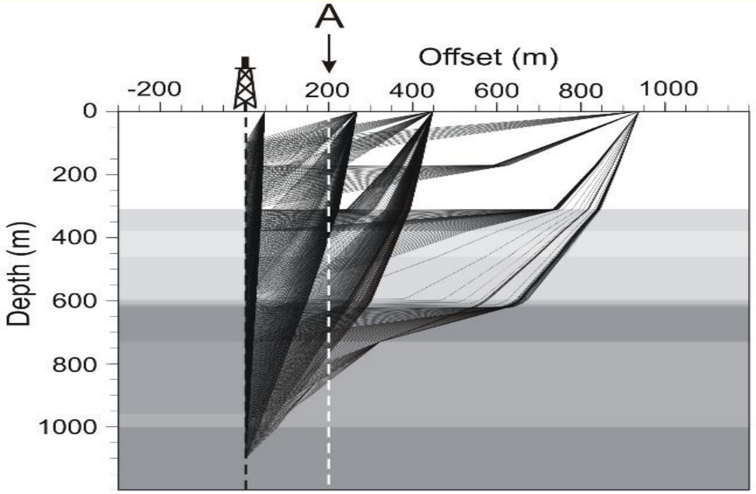
4 VSPs: 1 near offset + 3 offset VSP

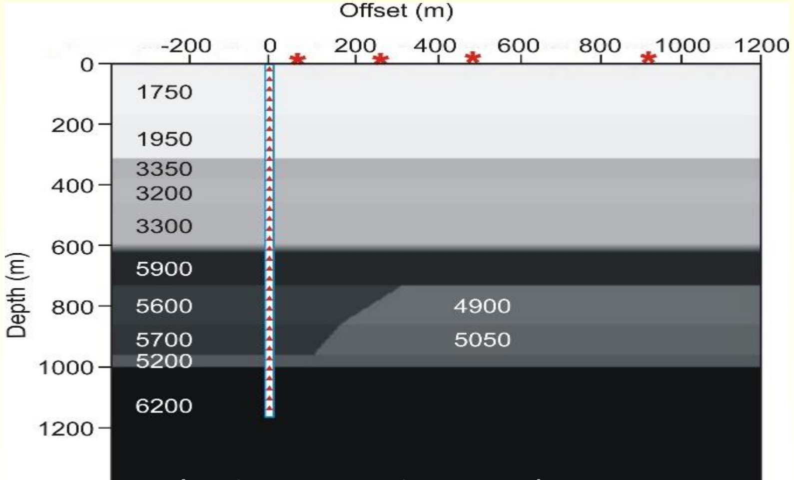
Well depth :	1.1 km
Seismic source:	Hydrapulse
Borehole sensors:	3 C geophone (Avalon)
Surface sensors:	geophone (10 Hz)
Offset:	44 m, 266 m, 449 m, 939 m
Depth intervals:	5 m (near offset), 10 – 20 m (medium-far offsets)
Depth levels no.:	186, 91, 90, 51
Sampling rate:	0.5 ms
Data length:	4 s

OBJECTIVES

- Characterize reservoir eastward of Grado 1
- Bridge logging data to MCS reflection
- Improve geology by numerical modelling

VSP data



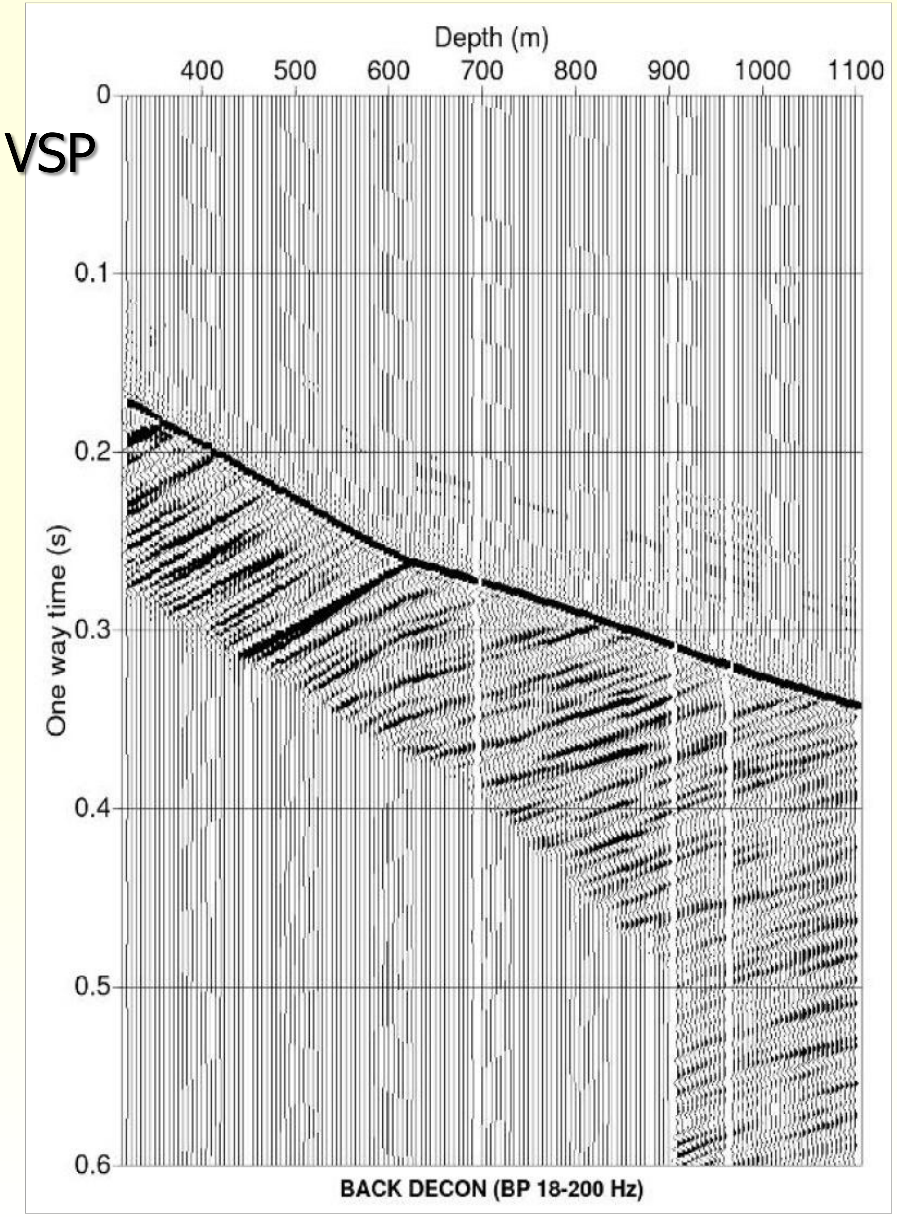


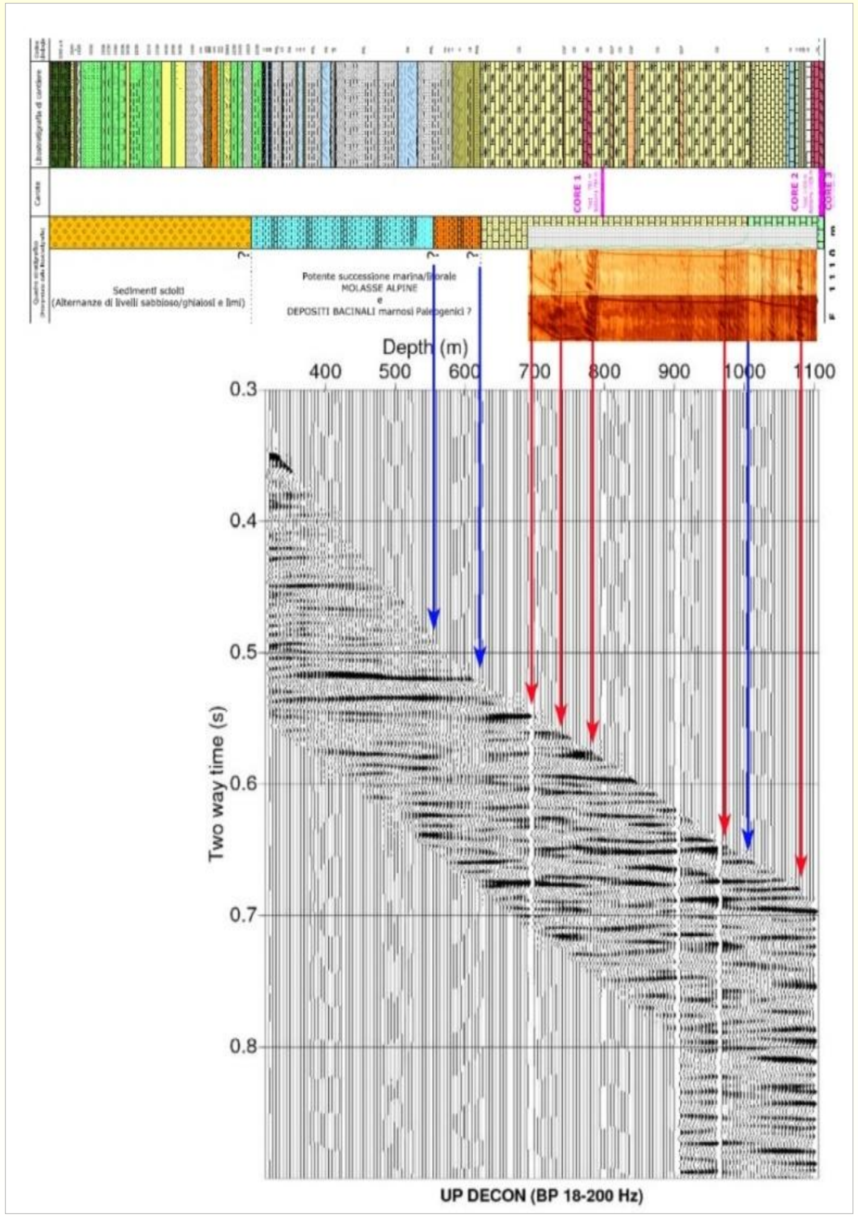
(Poletto et al., 2013)

VSP reflectivity and well results

NEAR-OFFSET VSP
VERTICAL
COMPONENT

Bandwidth
up to 200 Hz





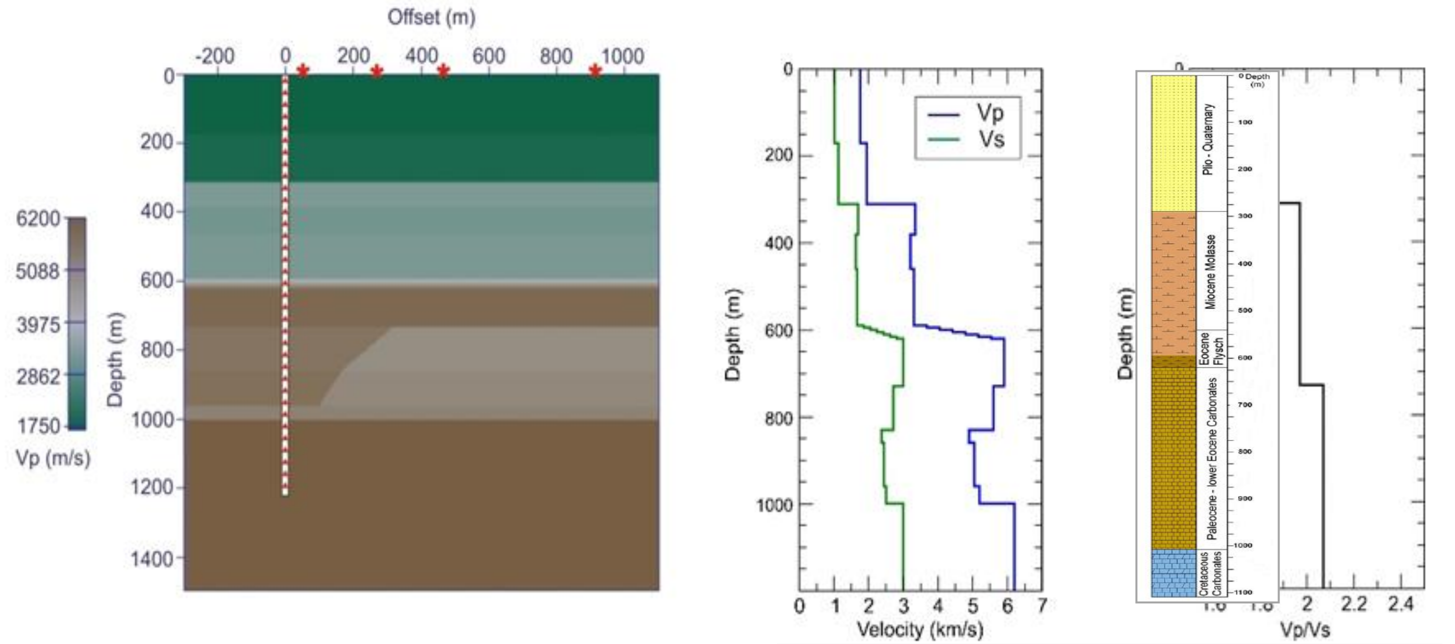
GRADO-1
STRATIGRAPHY
and

CBIL LOG

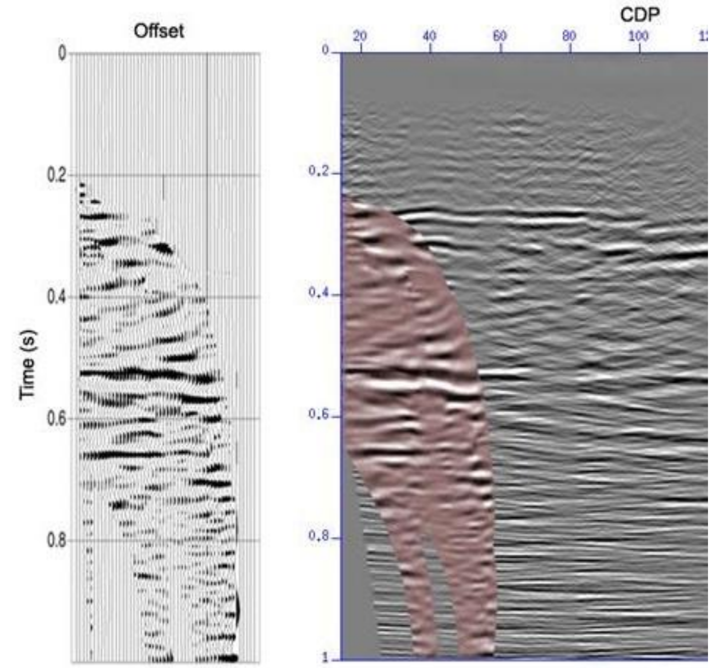
TWT
deconvolved
up-going after
wave separation
showing
interpretation of
interfaces (blue)
and *sloping*
fractures (red)

Lateral changes and Vp/Vs analysis

Modelling direct and converted P and S waves, including anisotropy and attenuation, allowed to **calibrate local velocity** and tune a model showing **lateral changes** in the reservoir

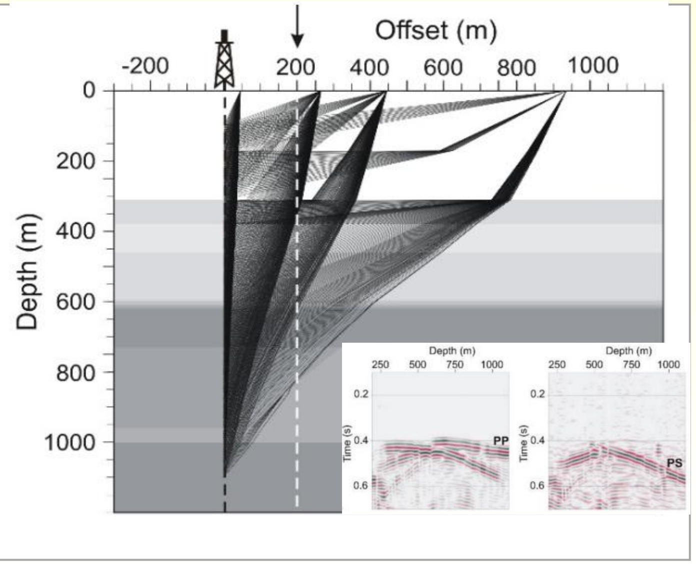


P and S velocity profiles 200 m East of Grado-1



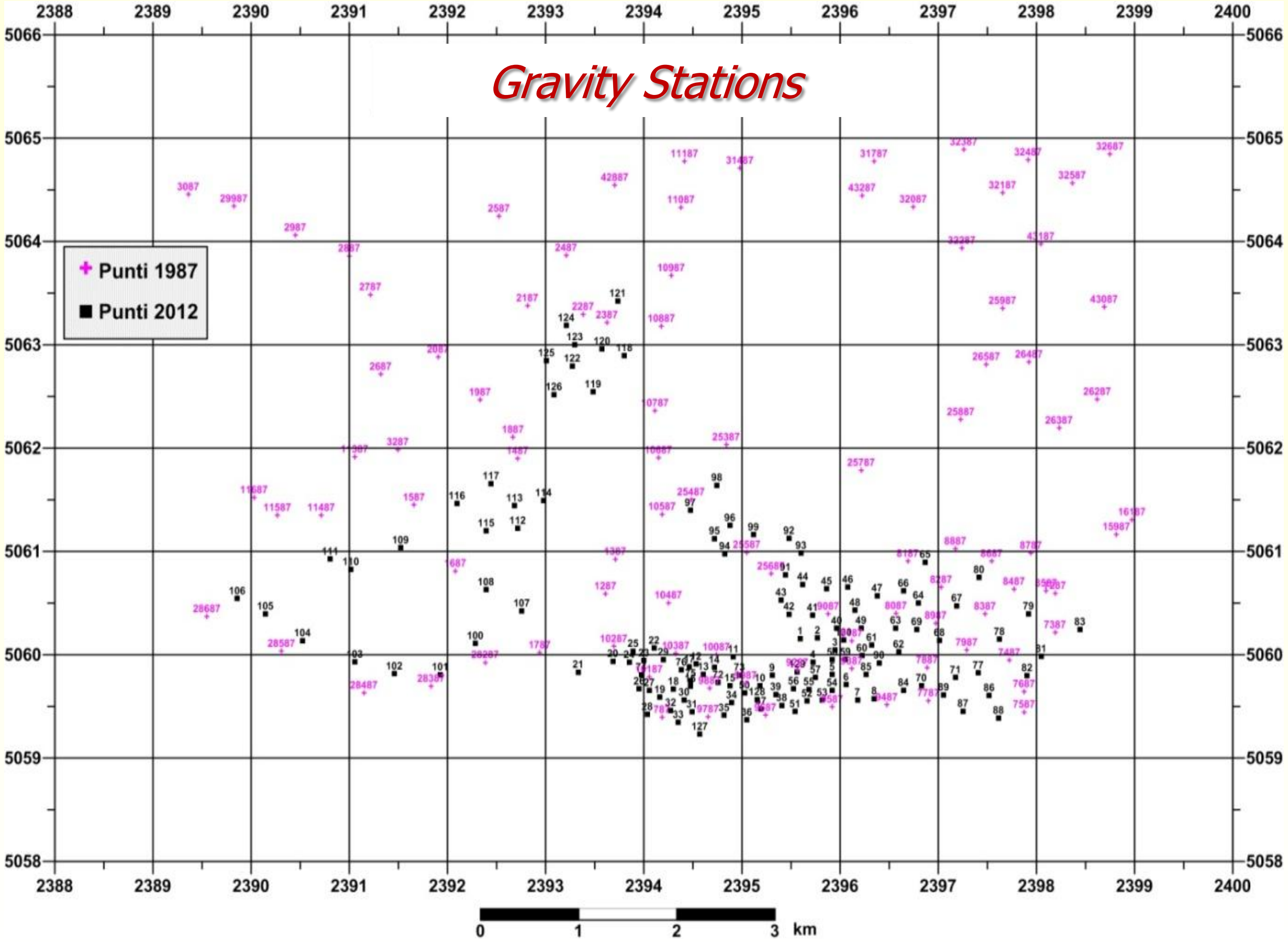
Multioffset VSP time migrated data superimposed on MCS G13 passing through the well

Raypaths of transmitted PP arrivals through the limestone interface at 600 m depth, helping to locate velocity changes

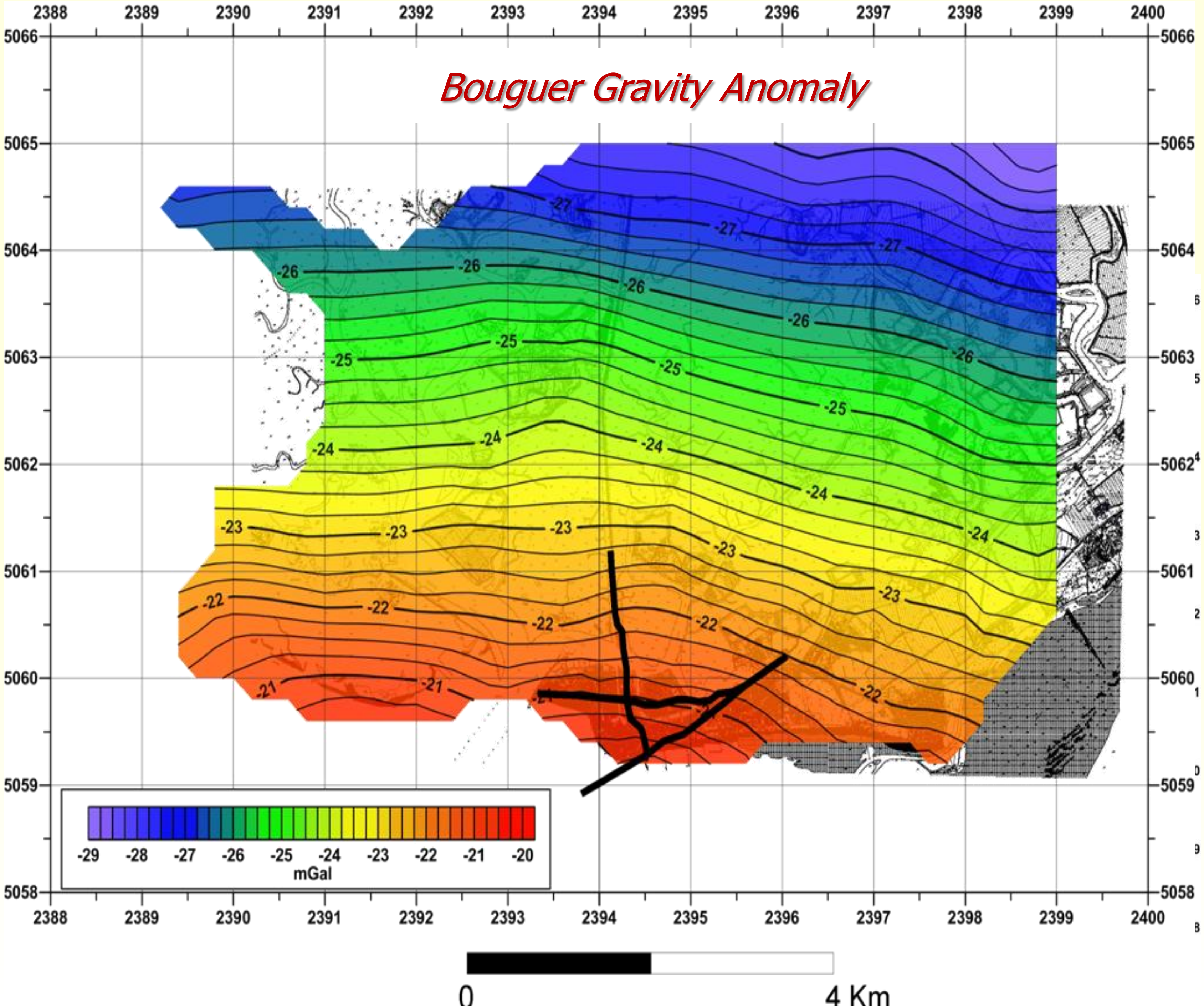


Gravity data Acquisition

LaCoste & Romberg model D
229 new measurements
Integration with previous measurements (1987)

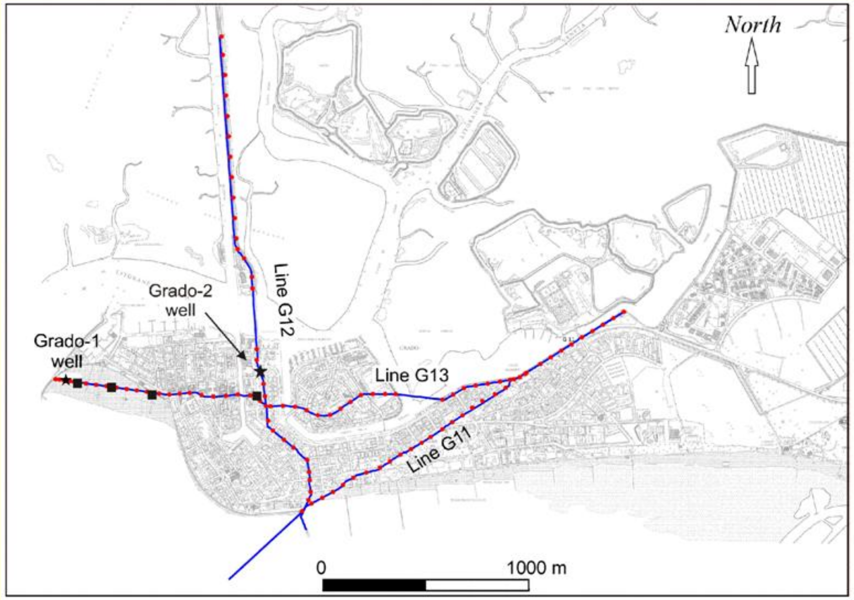


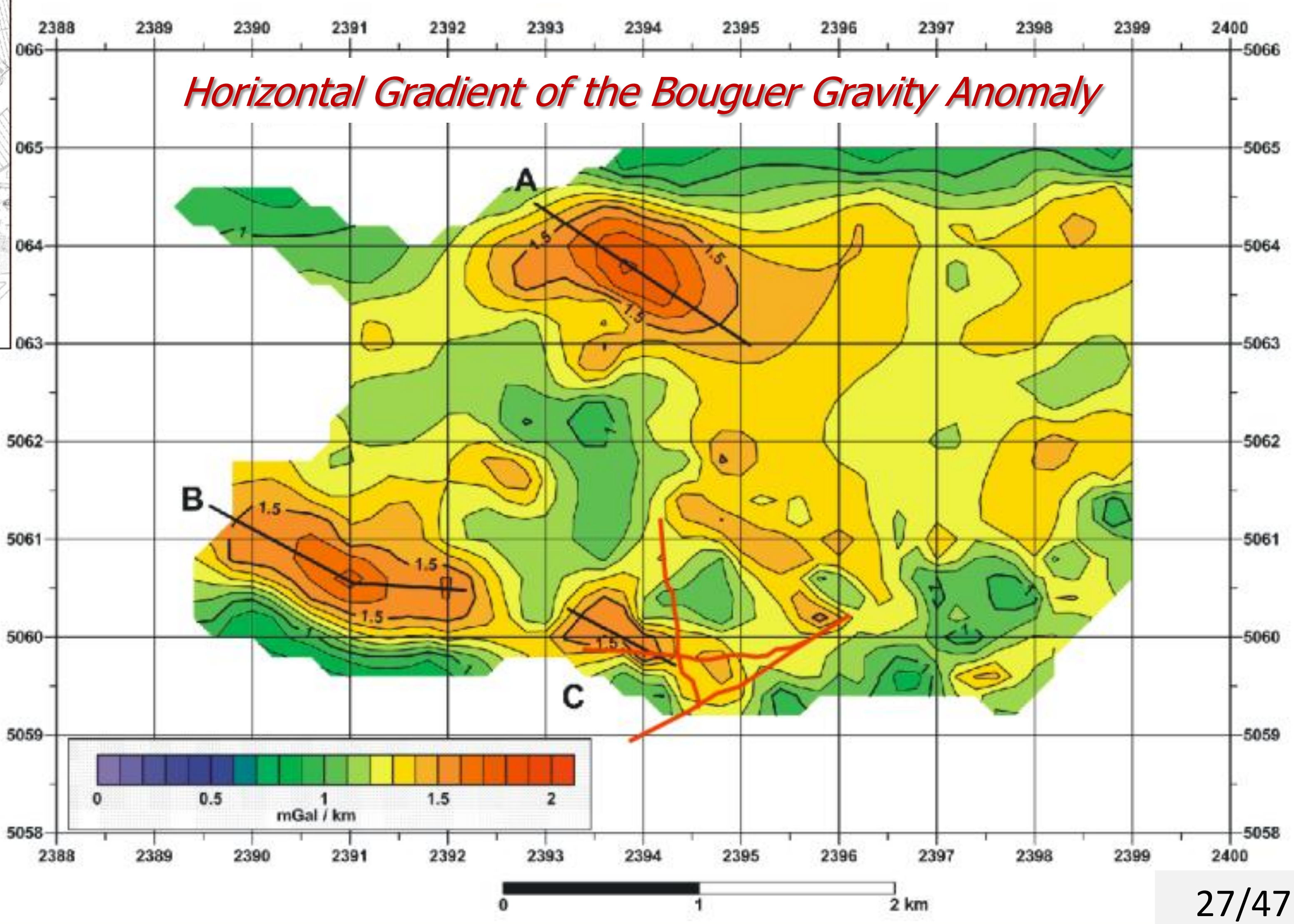
Carbonate platform culmination to the south



Carbonate platform culmination to the south

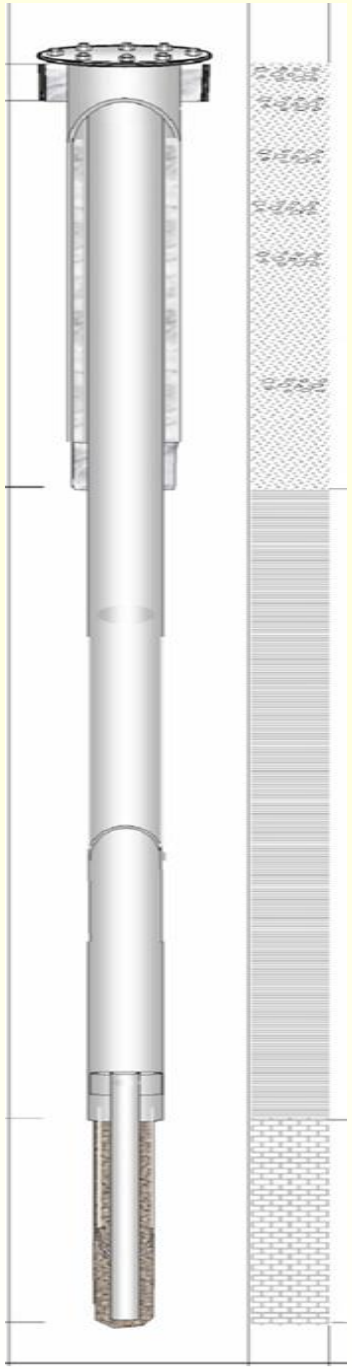
Joint data interpretation




Horizontal Gradient of the Bouguer Gravity Anomaly

Lateral changes in mass distribution at the bedrock interface, reflecting tectonic and stress regime orientation of the Dinaric far deformation front

GRADO 2 Drilling …..



0-30 m: surface casing 24”

30-272 m:
17” 1/2 rock bit, casing 13” 3/8, cemented

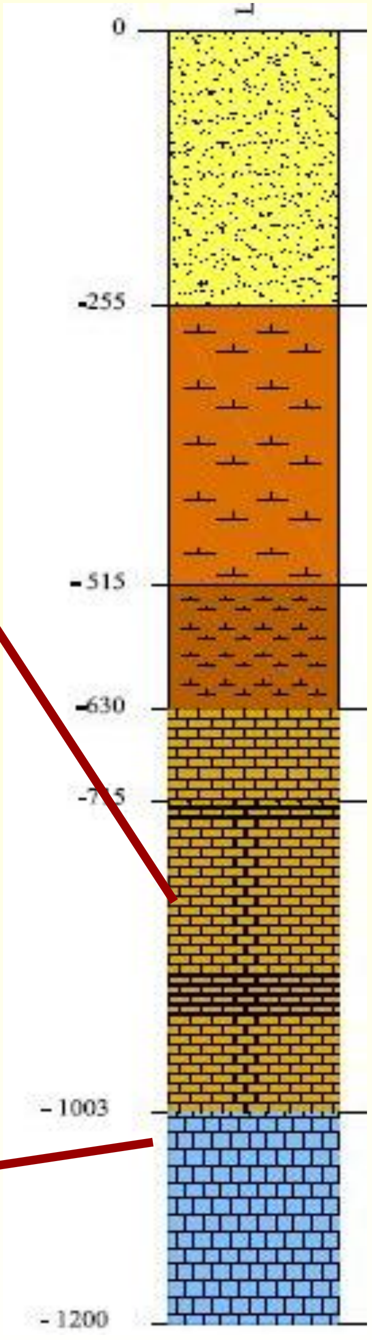
272-675 m:
12” ¼ rock bit,
casing 9” 5/8, cemented

675 – 1100/1200 m:
8” ½ PDB rock bit

Grado LITHOLOGY

Core 1: 791 m
Paleogene
Limestones

CORE 2: 1005 m
Aurisina Cretaceous
Limestones

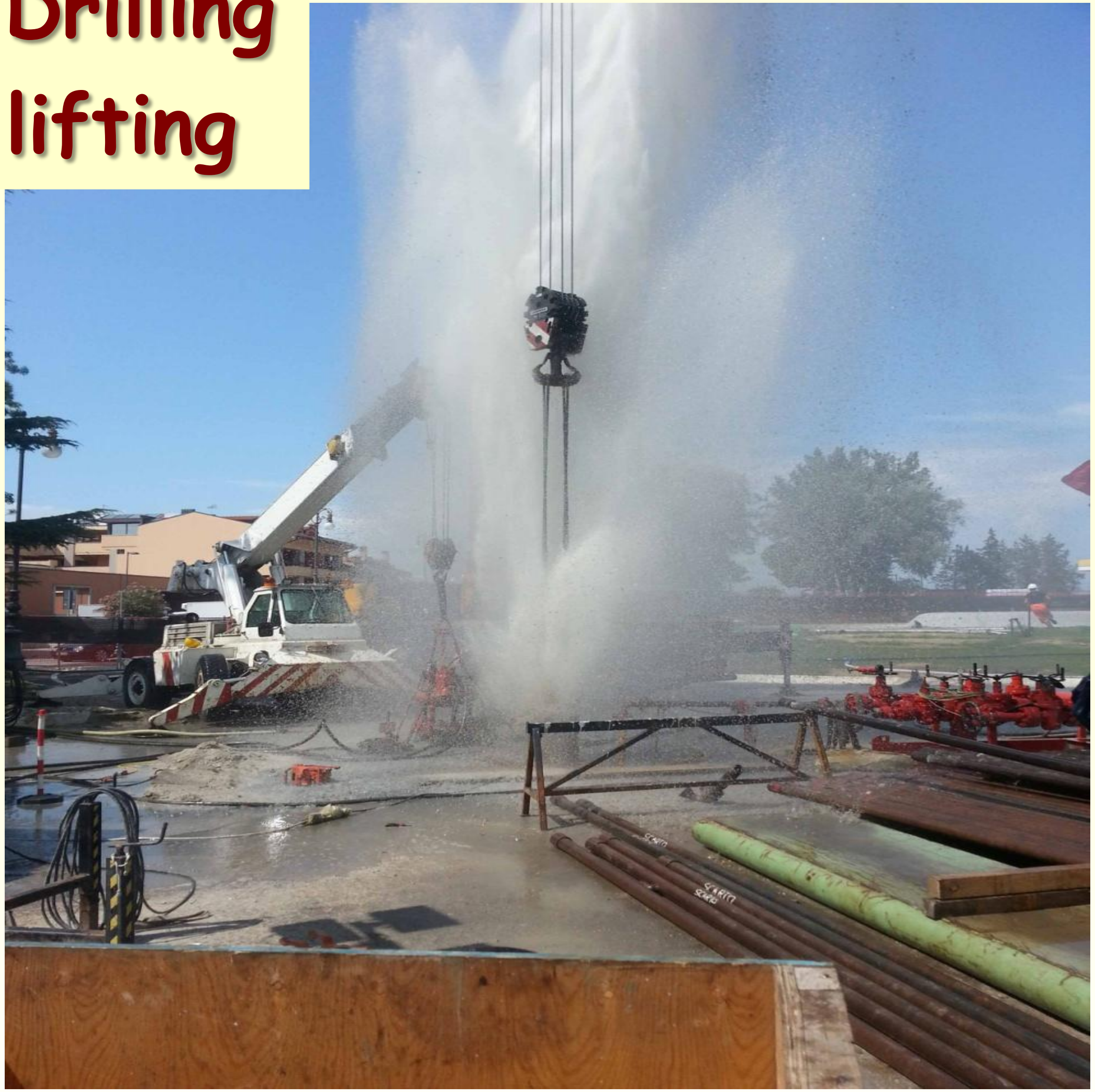


0-255 m
Plio-Quaternary
sediments

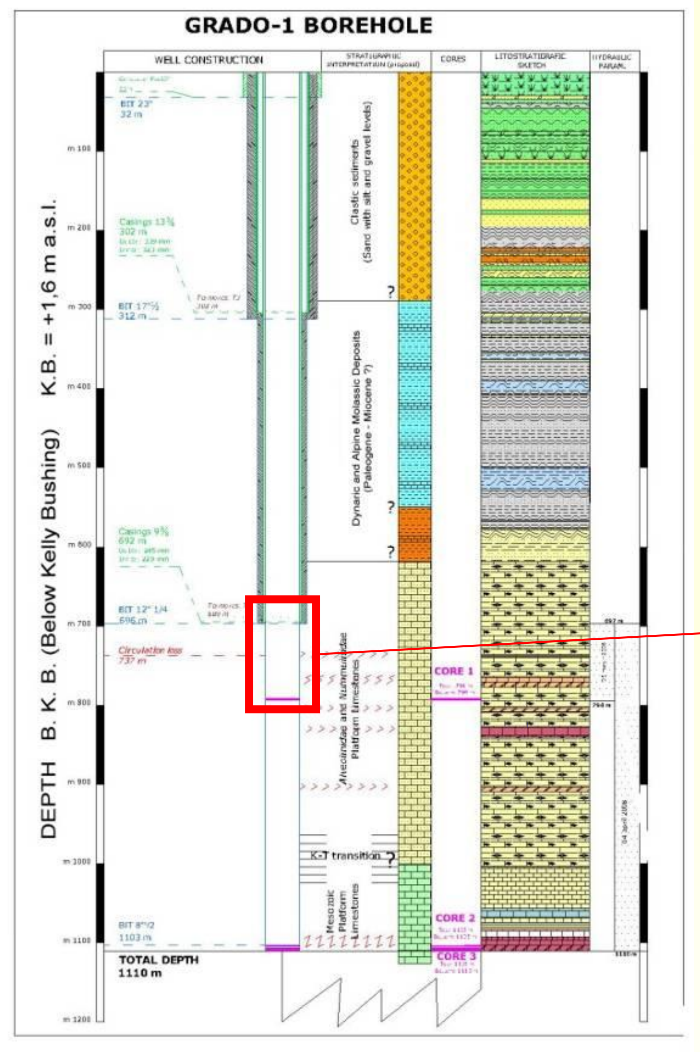
255-630 m
Miocene marls
and sandstones

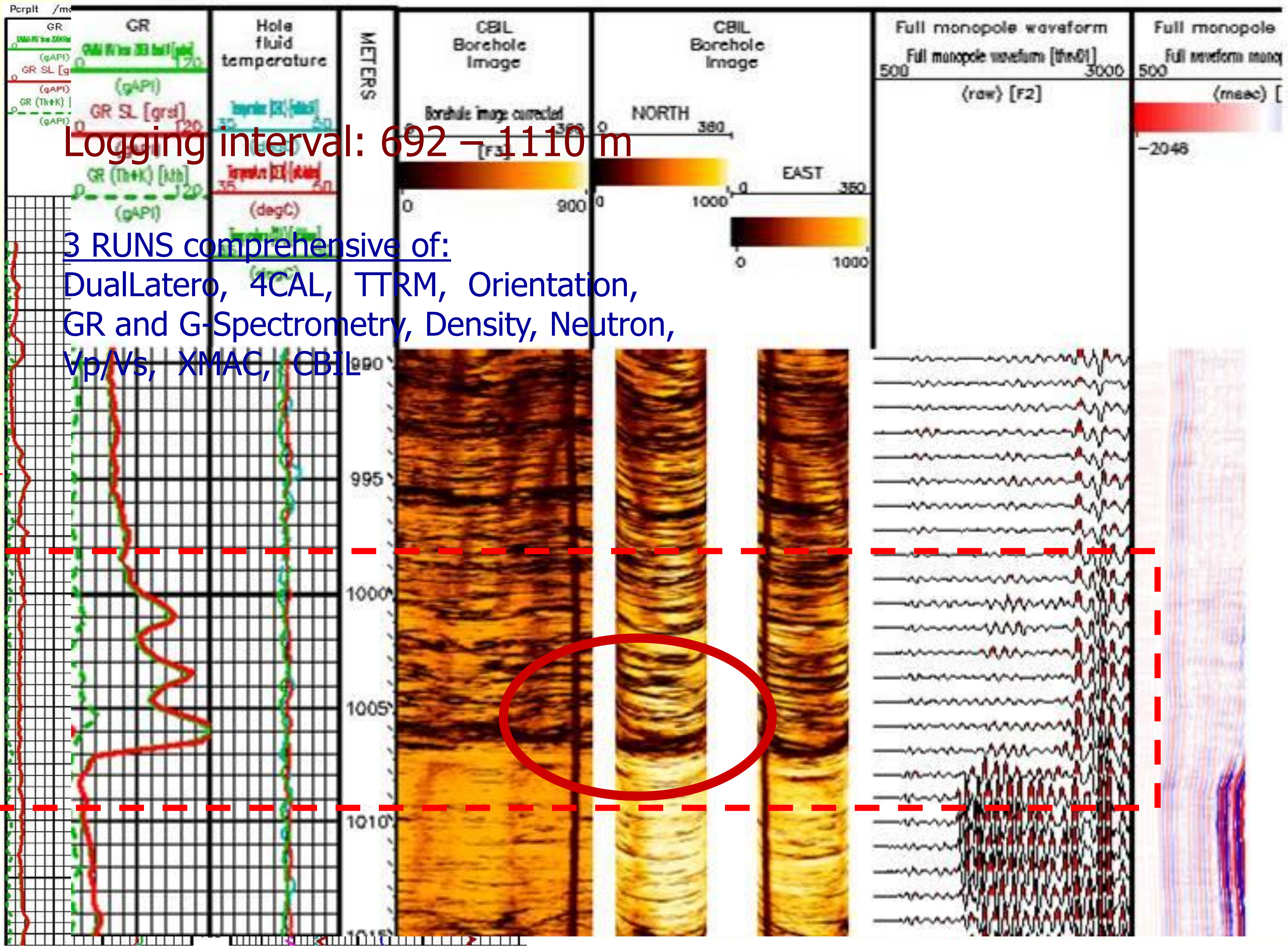
630-1200 m
Paleogene and Mesozoic
limestones, geothermal
reservoir

Grado 2 Drilling and air lifting



Grado-1: Geophysical Logs





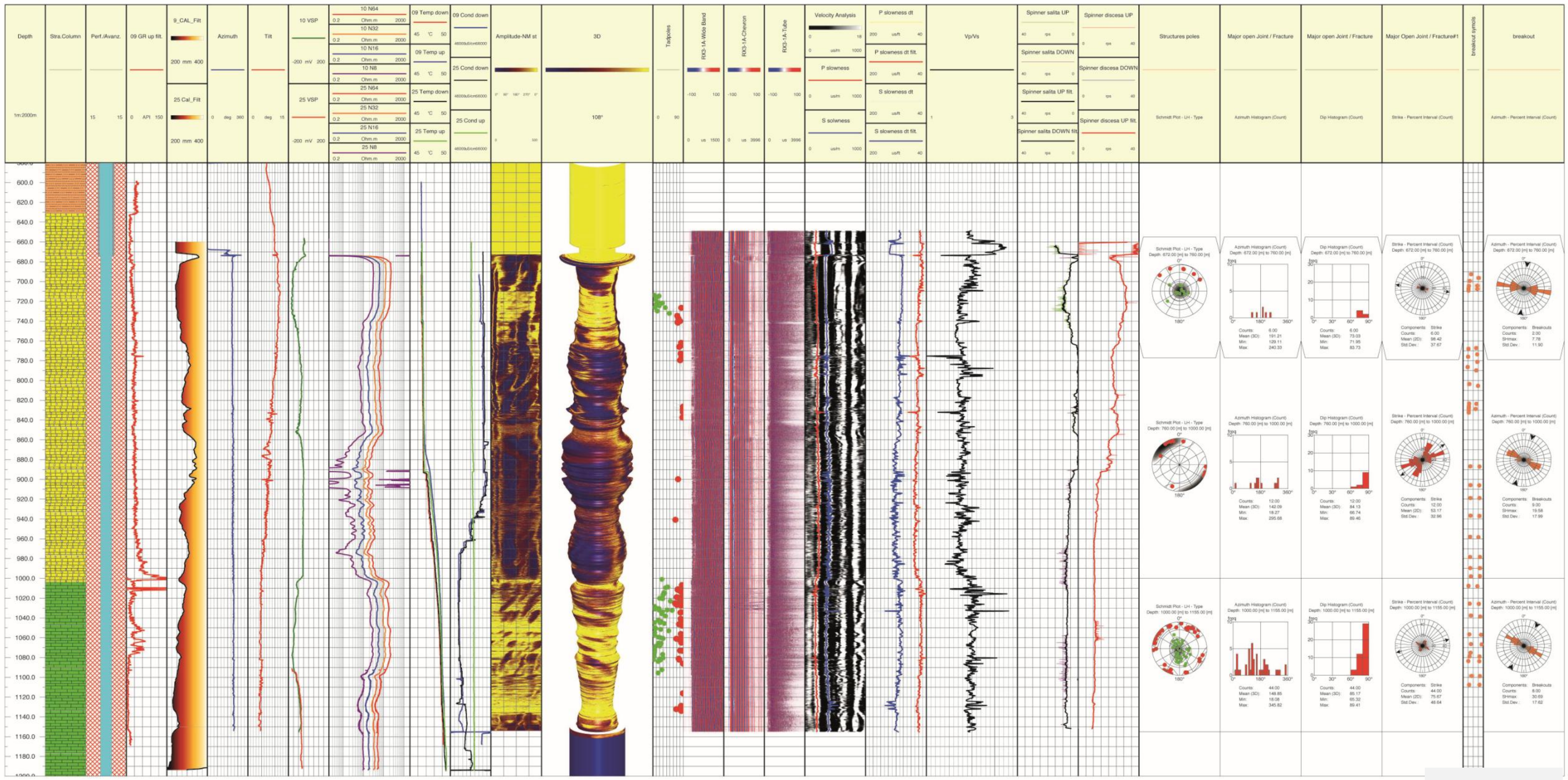
Logging interval: 692 – 1110 m

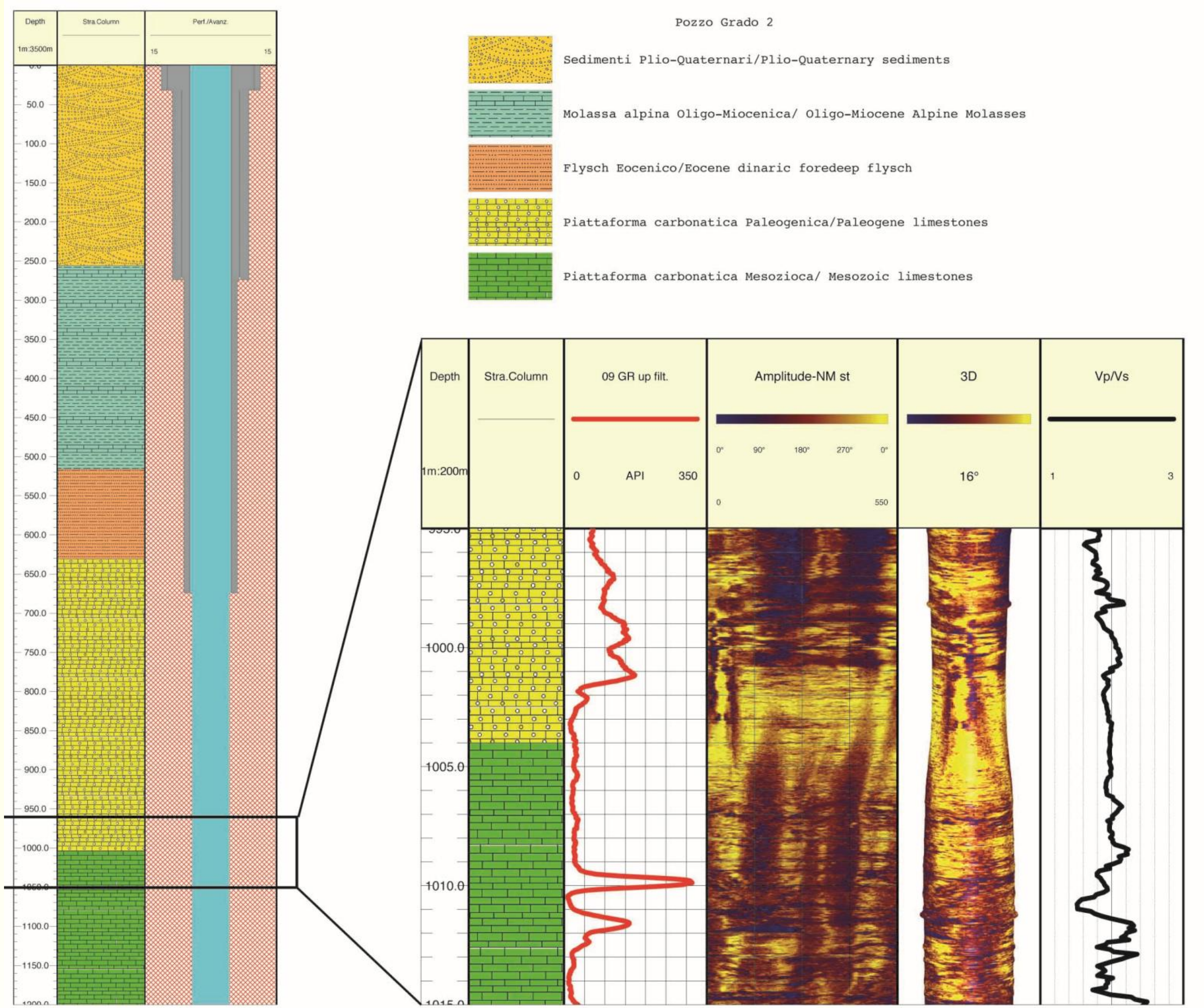
3 RUNS comprehensive of:

DualLatero, 4CAL, TTRM, Orientation, GR and G-Spectrometry, Density, Neutron, Vp/Vs, XMAC, CBIL

Fluids circulation in fractures

Grado-2: Geophysical Logs



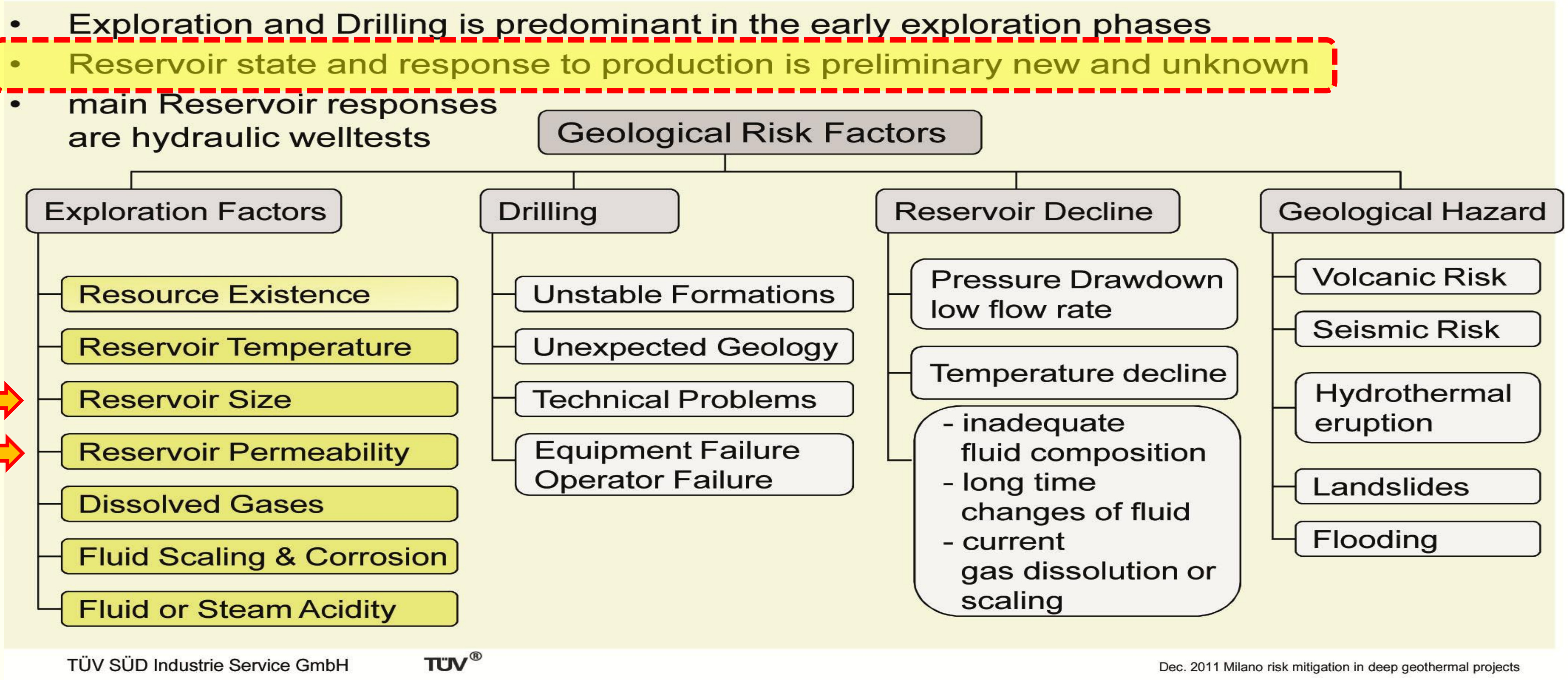

Pozzo Grado 2
Sedimenti Plio-Quaternari/Plio-Quaternary sediments
Molassa alpina Oligo-Miocenica/ Oligo-Miocene Alpine Molasses
Flysch Eocenico/Eocene dinaric foredeep flysch
Piattaforma carbonatica Paleogenica/Paleogene limestones
Piattaforma carbonatica Mesozioca/ Mesozoic limestones
Depth
1m:3500m
Stra.Column
Perf./Avanz.
15
15
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
550.0
600.0
650.0
700.0
750.0
800.0
850.0
900.0
950.0
1000.0
1050.0
1100.0
1150.0
1200.0
Depth
1m:200m
Stra.Column
09 GR up filt.
0
API
350
Amplitude-NM st
0°
90°
180°
270°
0°
0
550
3D
16°
Vp/Vs
1
3
1000.0
1005.0
1010.0
1015.0

Grado 2 acidizing + liner deployment

Outline

- ❑ Geothermal Potential for Direct Uses
- ❑ Grado District Heating (DH) Geothermal Pilot Project
- ❑ Geological and Geophysical Reservoir Characterization
- ❑ Reserves Assessment, Geothermal Doublet + DH Completion
- ❑ Challenges of Geothermal Projects & concluding Remarks

GEOTHERMAL POTENTIAL: GEOLOGICAL RISK STRUCTURE



- Exploration and Drilling is predominant in the early exploration phases
- Reservoir state and response to production is preliminary new and unknown
- main Reservoir responses are hydraulic welltests

Geological Risk Factors

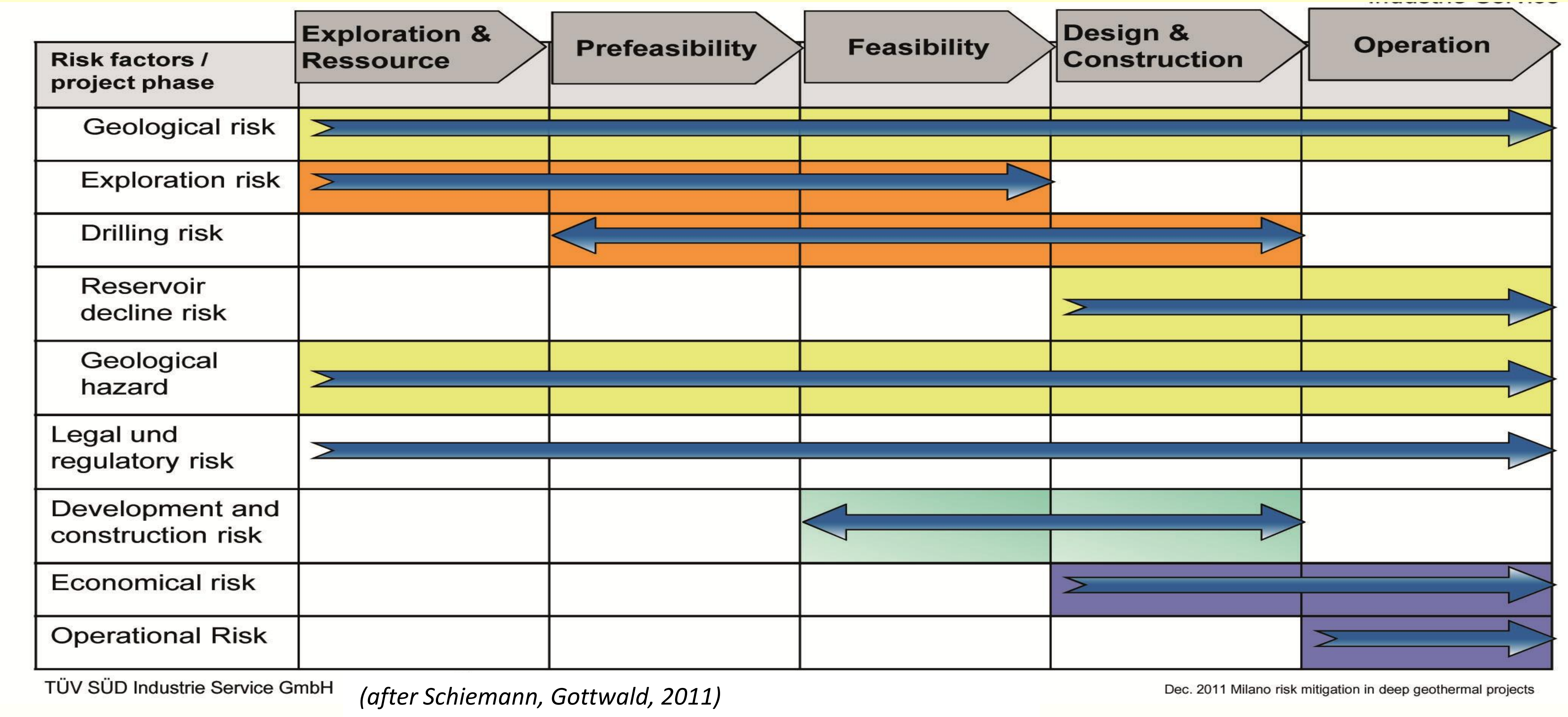
- **Exploration Factors**
  - Resource Existence
  - Reservoir Temperature
  - Reservoir Size
  - Reservoir Permeability
  - Dissolved Gases
  - Fluid Scaling & Corrosion
  - Fluid or Steam Acidity
- **Drilling**
  - Unstable Formations
  - Unexpected Geology
  - Technical Problems
  - Equipment Failure Operator Failure
- **Reservoir Decline**
  - Pressure Drawdown low flow rate
  - Temperature decline
  - - inadequate fluid composition
    - long time changes of fluid
    - current gas dissolution or scaling
- **Geological Hazard**
  - Volcanic Risk
  - Seismic Risk
  - Hydrothermal eruption
  - Landslides
  - Flooding

TÜV SÜD Industrie Service GmbH TÜV®

Dec. 2011 Milano risk mitigation in deep geothermal projects

Natural hydrothermal systems do not require fracking → NO INDUCED SESMICITY!

GEOTHERMAL PROJECT RISK STRUCTURE



Risk factors / project phase	Exploration & Ressource	Prefeasibility	Feasibility	Design & Construction	Operation
Geological risk	→	→	→	→	→
Exploration risk	→	→	→		
Drilling risk		↔	↔	↔	
Reservoir decline risk				→	→
Geological hazard	→	→	→	→	→
Legal und regulatory risk	→	→	→	→	→
Development and construction risk			↔	↔	
Economical risk				→	→
Operational Risk					→

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(after Schiemann, Gottwald, 2011)

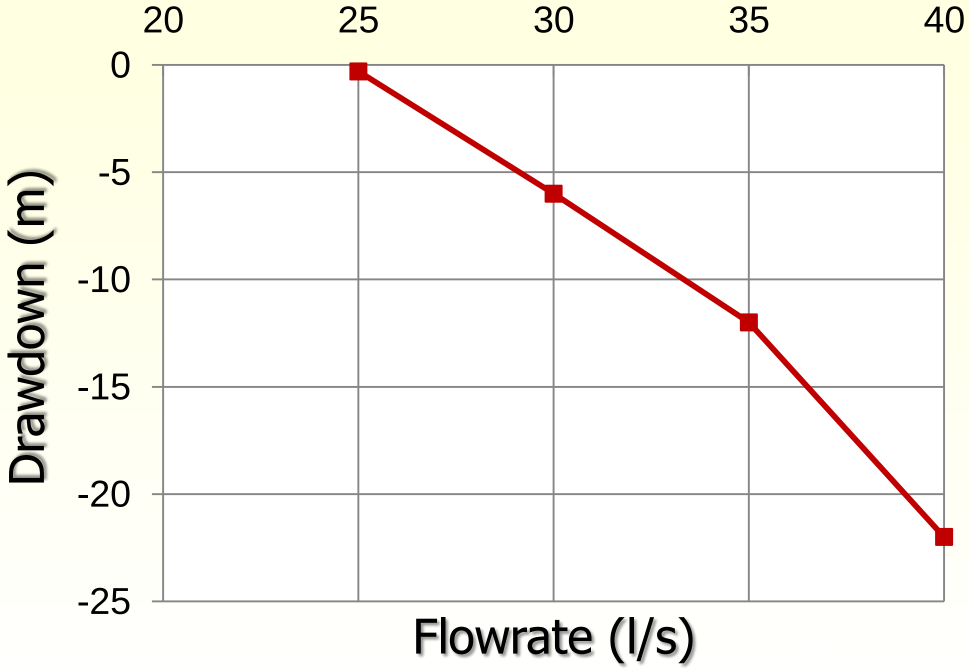
Dec. 2011 Milano risk mitigation in deep geothermal projects

Geothermal Reservoir Potential Assessment

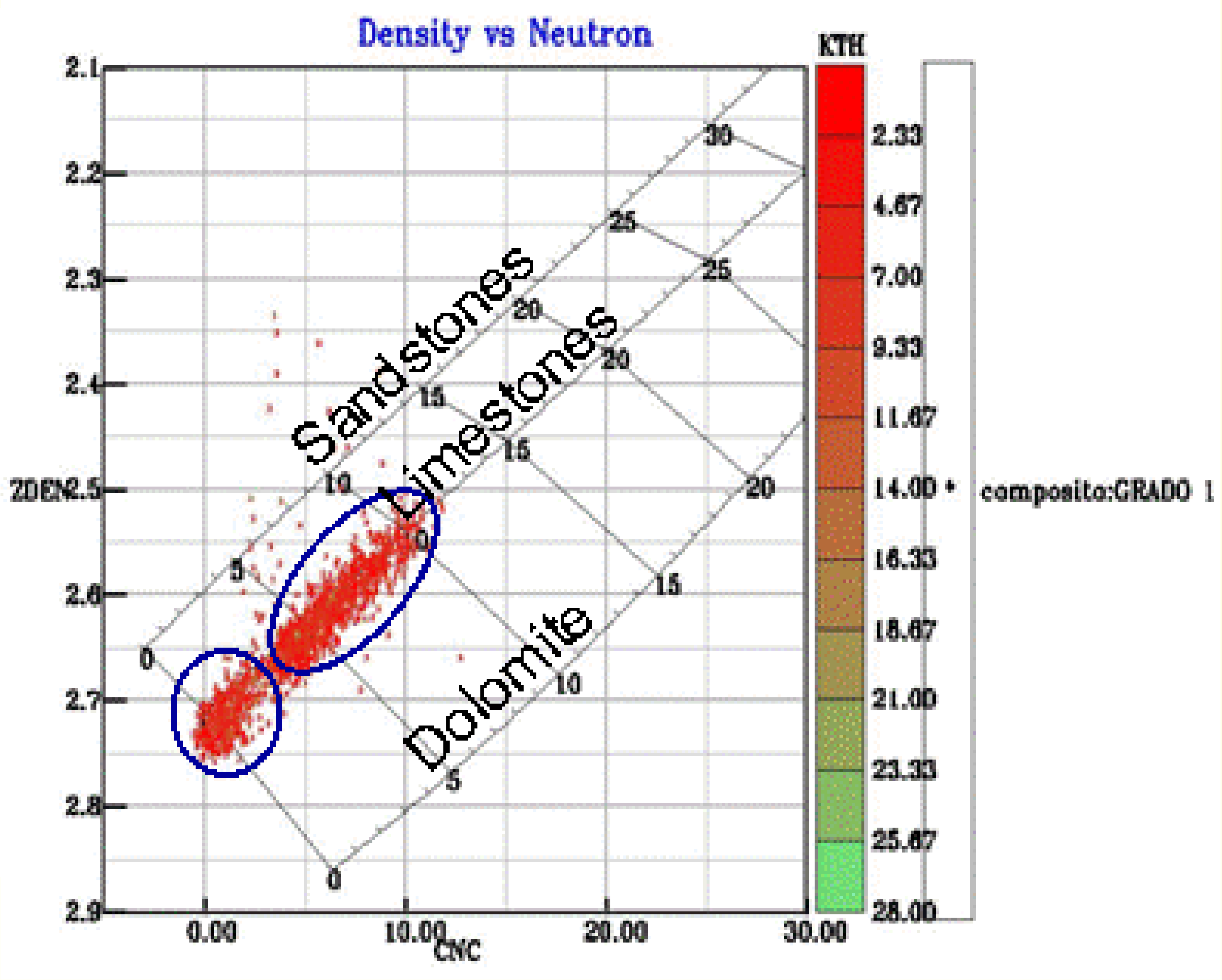
Artesian outflow:	27,2 l/s (~100 ton/h), 240 KPa
Water temperature:	49 °C
Salinity:	30 g/l (fossil seawater, 10 Ma)
Thermal power:	2,3 MW

(assuming 20 °C as useful DT)

With 35 l/s (~126 ton/h):
Thermal power → > 3 MW



Geothermal Reservoir: Size Estimate



Area	≈ 50 km^2
Thickness	1,5-2 km
Volume Reservoir	*75-100 km^3*

Estimated Effective Porosity	
85%	n_e < 1-2 %
10%	n_e = 2 - 4 %
5%	n_e = 8 - 10 %

Rough volume of **moving geothermal waters = 0,6 km^3** (6 x 10^8 m^3)
(corresponding on average to a volume of 6x10^6 m^3 for each km^3 of reservoir)

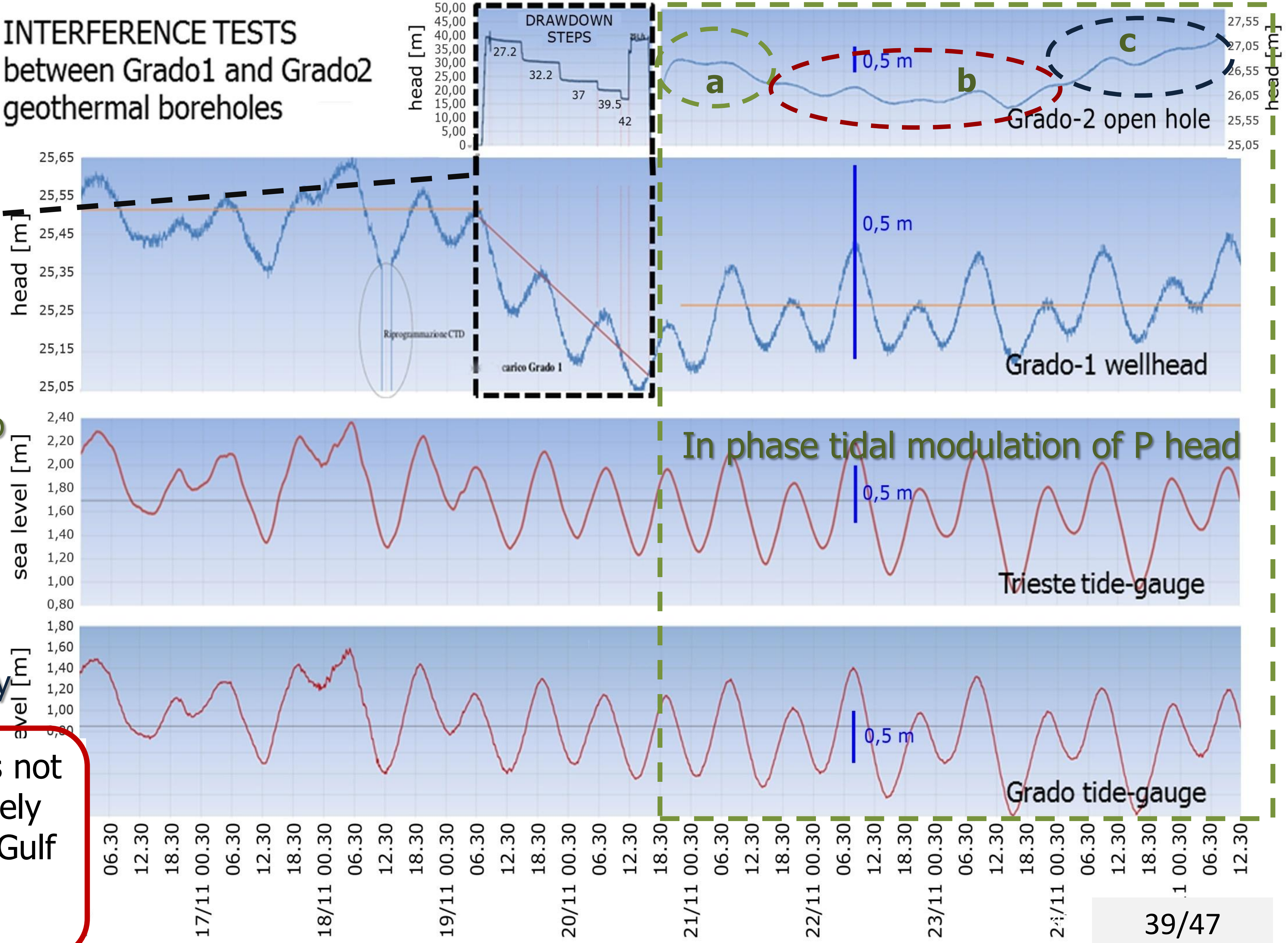
Pumping Tests

- ✓ Grado-2: pumping
- ✓ Grado-1: monitoring
- ✓ NO Re-Injection

a) Quick partial recovery following pumping stop (good T nearby?)

b) 2 days of NO recovery (no efficient recharge)

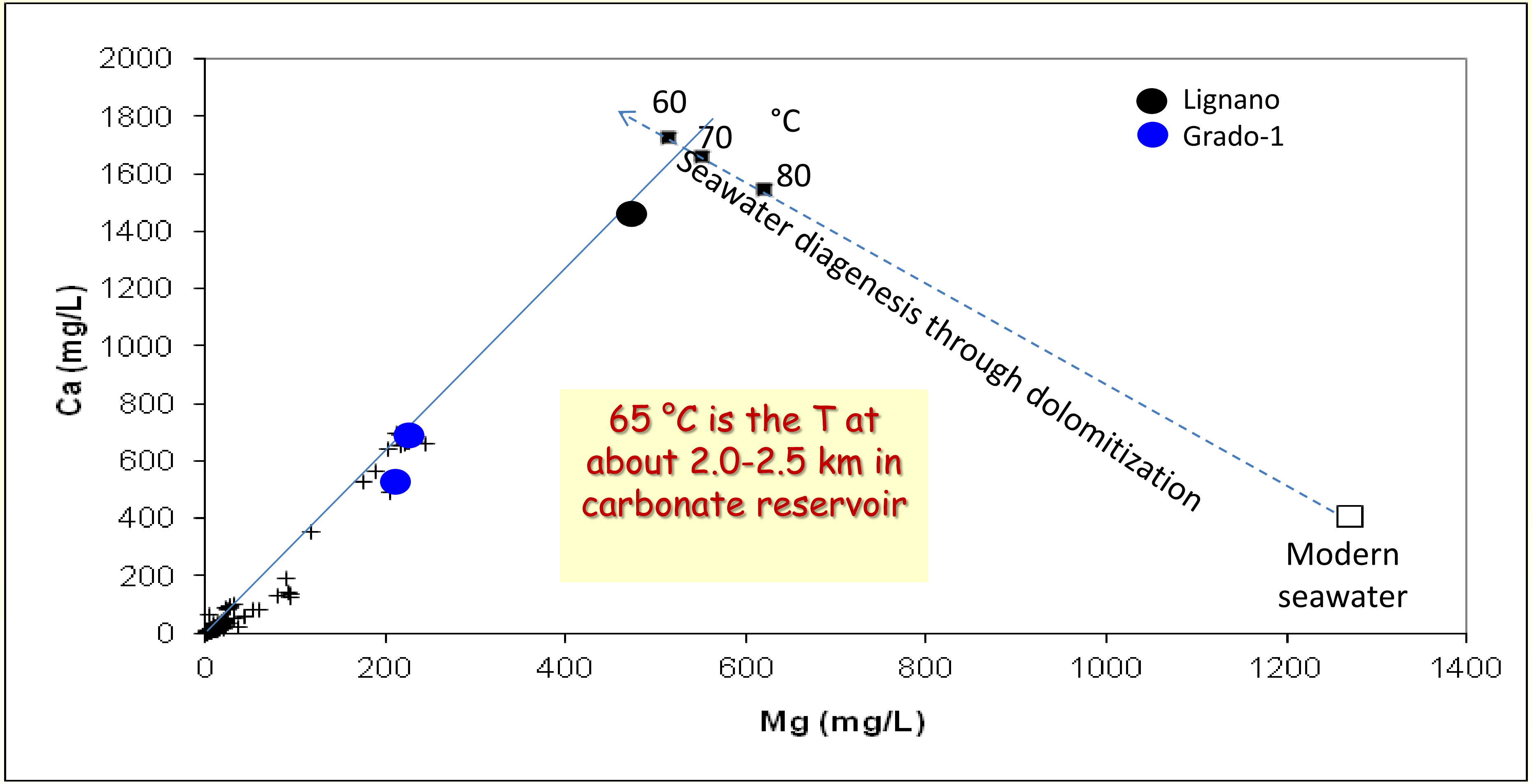
c) Delayed partial recovery



INTERFERENCE TESTS between Grado1 and Grado2 geothermal boreholes

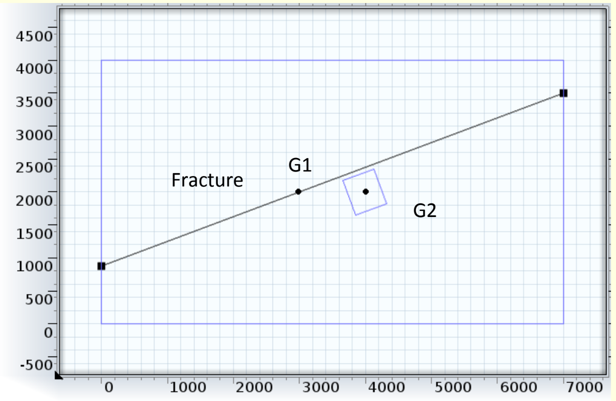
Reservoir recharge seems not very efficient, though likely connected to the Trieste Gulf by low permeability network of fractures

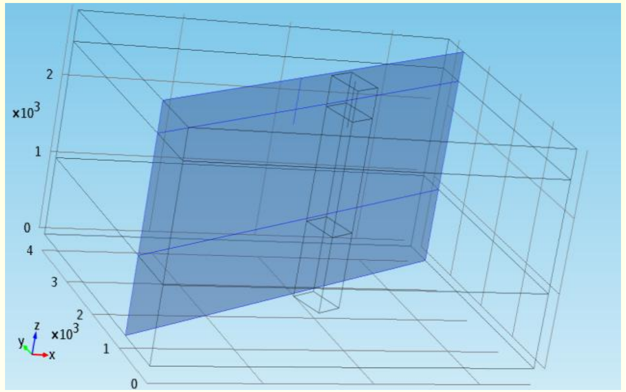
Estimate of the deep reservoir temperature

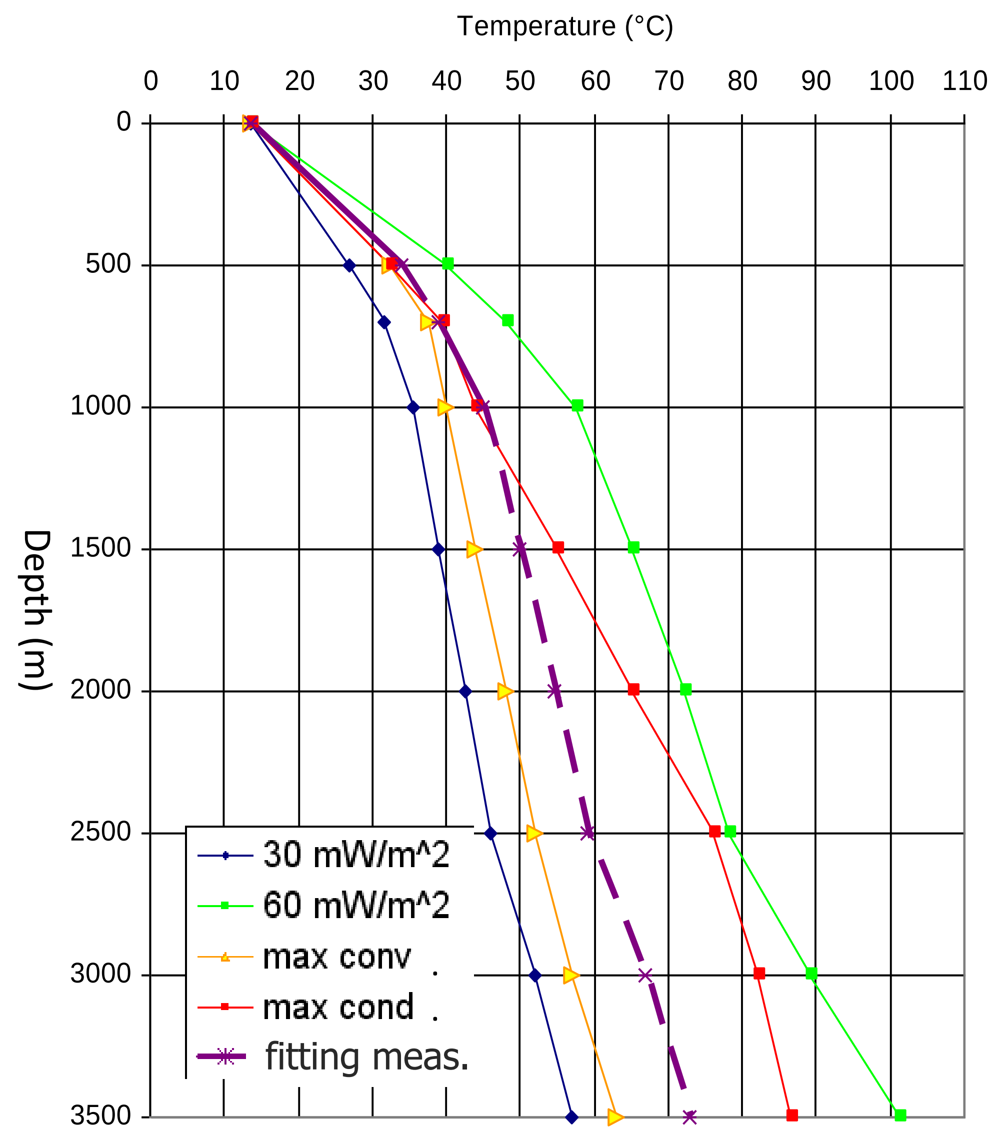


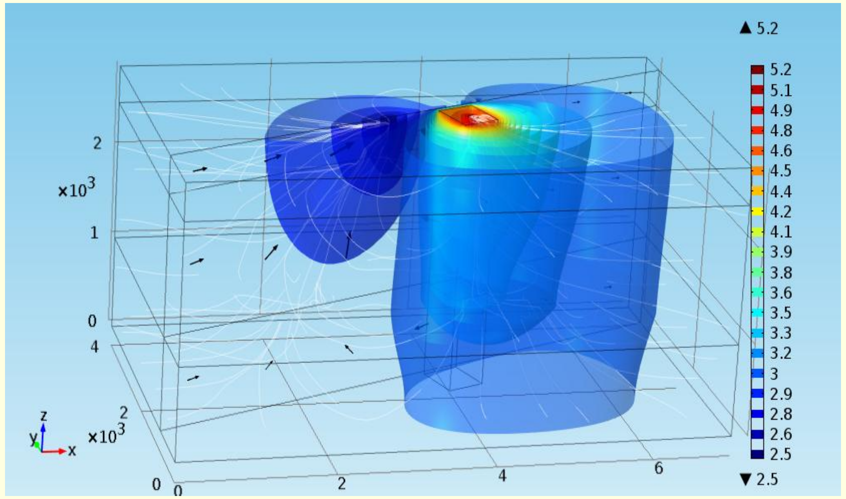
65 °C is the T at about 2.0-2.5 km in carbonate reservoir

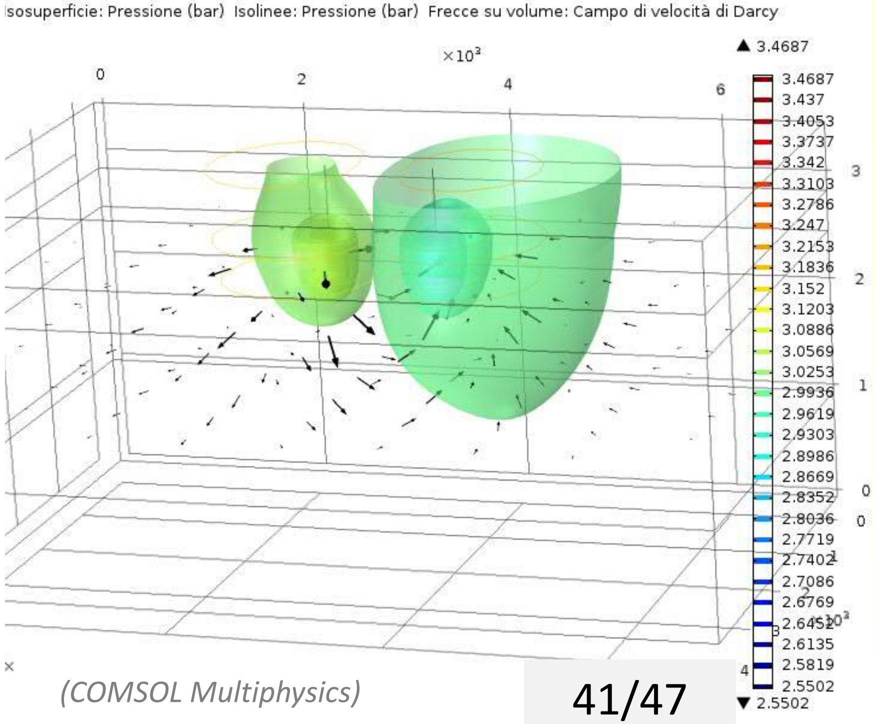
Geothermal Reservoir: Numerical Modeling





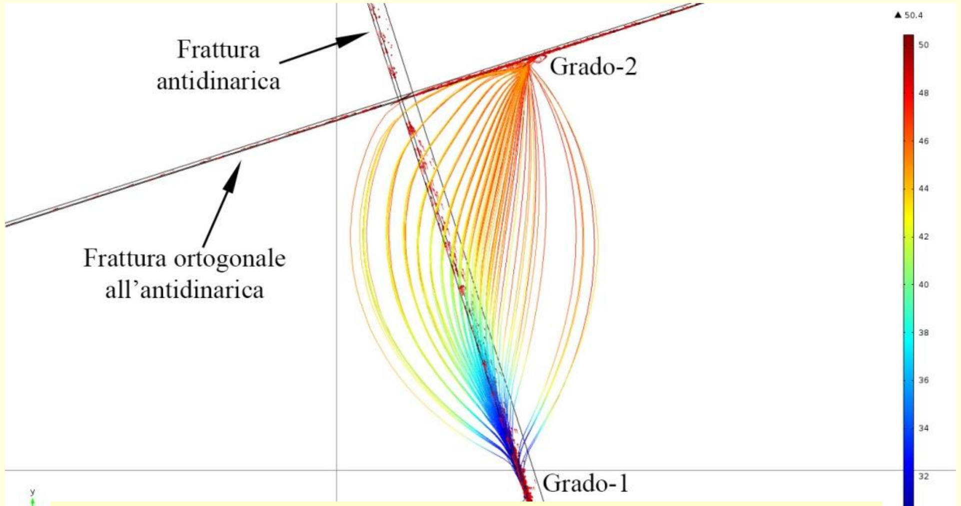




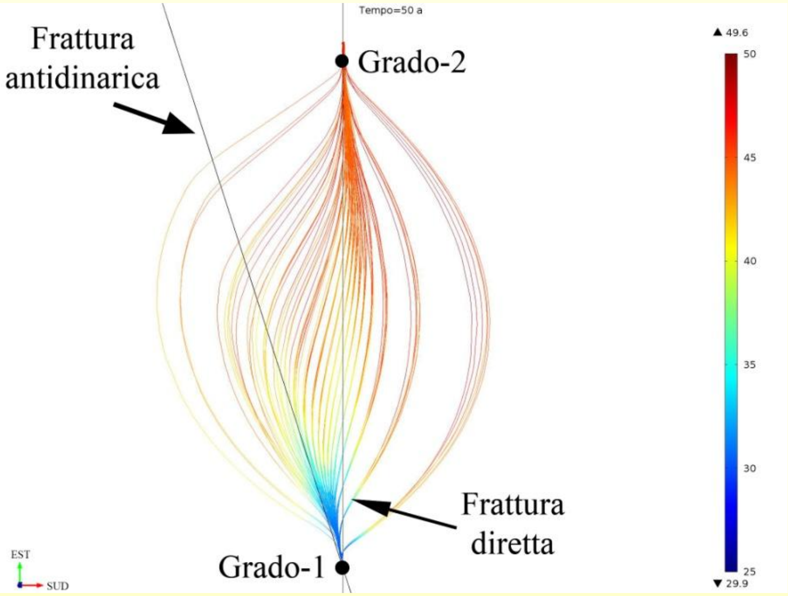


(COMSOL Multiphysics)

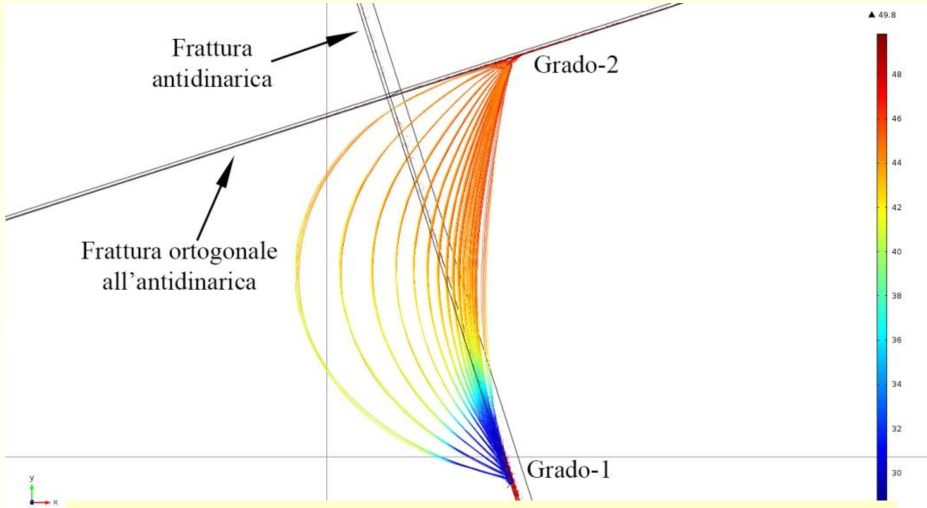
Fractured Geothermal Reservoir



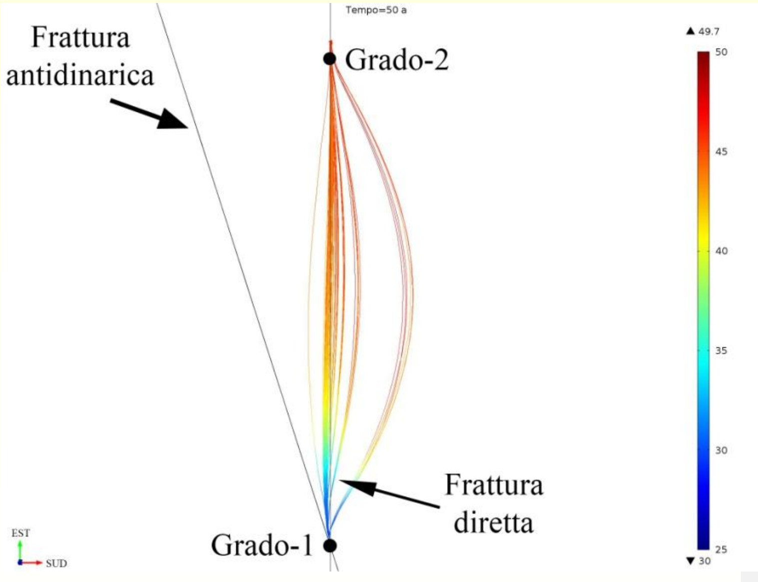
K_m=10 mD; K_f=1000 mD; 108 ton/h; 50 a



K_m=10 mD; K_f=1000 mD; 108 ton/h; 50 a



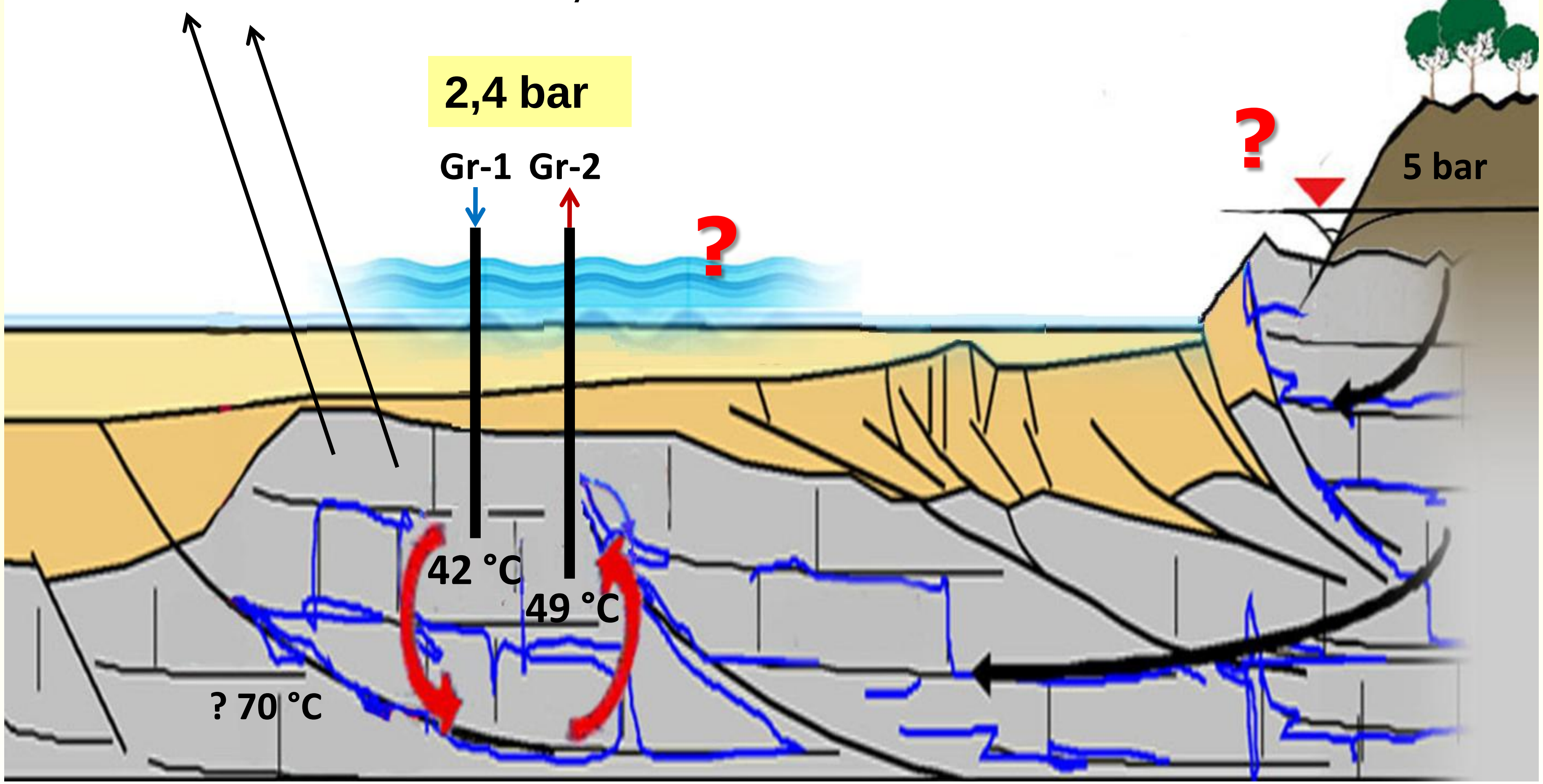
K_m=10 mD; K_f=100 mD; 108 ton/h; 50 a



K_m=10 mD; K_f=100 mD; 108 ton/h; 50 a

Geothermal Reservoir: CONCEPTUAL MODEL

Miocene fossil seawater (10 Ma)
Artesian reservoir modulated by the sea tides, with NO GOOD RECHARGE
Re-injection required



Horizontal Directional Drilling under the port canal

Network will link 6 public buildings

Completion of DH pilot system and Distribution Network

5 Millions Euros:
- ✓ Project design,
- ✓ 2 exploration geophysical campaigns;
- ✓ Drilling – completion - development of production and re-injection wells;
- ✓ Hydraulic tests, corings and geophysical logging;
- ✓ Realization of district heating network + heat exchangers

- Started in 1st phase
- Completed in 2014 with horizontal directional drilling and shallow tunneling connecting Grado-1 and 2
- Serving public buildings (school gym, catering institute, conference hall, library)

- ➢ Planned connections are in progress
- ➢ Further connections (municipality edifice, junior high school, …) and long lasting uses can be fostered

Grado DH Results and Perspectives

- We characterized a small portion of the **buried N-Adriatic carbonate platform**
- The **integrated geophysical approach** allowed to:
  - ✓ Assess the reservoir geological structures, extension and recharge
  - ✓ Locate the two wells of geothermal doublet within the same reservoir
  - ✓ Identify sub-vertical fault systems interconnecting the doublet
- **Geothermal potential is** ***2.5–3.0 MW_{th}*** (available energy ***20.000-25.000 MWh***)
- **Two km of DH network** was realized connecting **6 public buildings**
- DH *capacity factor now is 0,20 ONLY* (2 MW x 12 h x 6 months = 4320 MWh)
- Need to **optimize management, increase capacity factor** to increase return on investment
- Next work: reservoir and thermo-fluid dynamic modelling, extend DH network, evaluate sustainability and impacts in operational conditions
- **Message**: ***other geothermal doublets can be realized in cold Adriatic areas***

Challenges of DH Geothermal projects & Concluding Remarks

- DH systems must locate in areas with *good geothermal potential*
- They require geophysics → to *reduce risk by best well location and orientation*
- Producing wells must hydraulically connect with injection wells →*permeability*
- *Impacts Assessment*: resource, subsidence, aquifers mixing, induced seismicity
- *Complex surface facilities:* pumping, piping, monitoring and remote control
- *High Capex*, especially if drilling is unsuccessful or needs deep wells
- Management optimization → *energy saving, efficiency, lowest impacts*
- Technology R&D → *Enhancing RHC system performance and reliability*

Geothermal Systems Guidelines 1

Geothermal Resources Oriented

- Find out areas with good geothermal/hydrothermal potential (**T, k**)
- Carry out geological and geophysical surveys to identify structures, stress regime, fractures orientation, … (**locate wells**)
- Characterize resource and assess its geothermal potential (**drilling**)
- **Temp., depth and drilling costs** are critical design parameters
- **Recharge** is critical for sustainable open-loop systems
- Carefully design geothermal systems: **reduce geological risk to limit financial risk**
- **Integrate** locally **available RES** and conventional …..
- **Monitor and optimize the performance**

Geothermal Systems Guidelines 2

Environment oriented

- Check campatibility with Urban Development Plan, avoid protected/excluded areas (unstable areas, polluted stes, archeologic and military areas, …)
- Carefully evaluate geologic impacts (subsidence, flooding, landslides, …) at various time scales
- Assess environmental hazards: depletion of water resource, aquifers recharge, flooding, potential contamination, subsidence, ….)
- → **total re-injection**

Geothermal systems guidelines 3

Regulatory framework

- Obtain authorization, permits (drilling, pumping and reinjection of water)
- Maintain distance from permit/property boundaries
- Stimulate competition among enterprises
- Check for incentives and supporting measures
- …..

Thanks for your attention!

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http://www.fondazioneinternazionale.org/geothermalPlatform.php

UNIONE GEOTERMICA ITALIANA

Gruppo Nazionale di Geofisica della Terra Solida Nov. 18, 2015 Trieste

International Geothermal Association

Open Loop System

High efficiency and limited investment

Water resources in peri-Adriatic Areas

a) Surface water bodies (canals, rivers, basins, sea, …): estimated T range 10-22 °C
b) Drainage waters from tunnels in mountain areas: 8-40 °C
c) Artesian wells: 13-18 °C
d) Shallow unconfined aquifers (50-100 m): 8-14 °C
e) Hydrothermal waters from new or existing wells : 12-30 °C
f) Low T deep aquifers : 30-90 °C

OPEN LOOP PONTEBBA ICE RINK PLANT

Groundwater source → 2 production wells D1 + D2

Water discharge → 1 re-injection well R

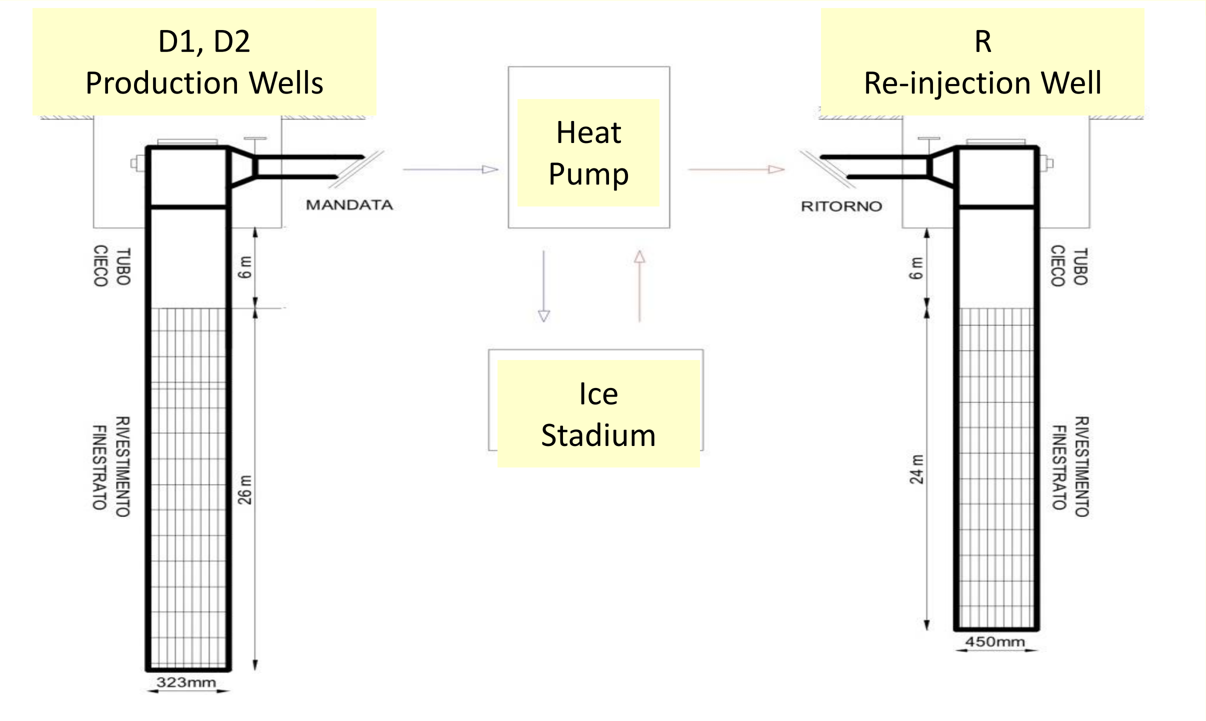
Old Pontebba Ice Rink plant

- 700 kW HP with R-22 refrigerant
- Cooling tower

New Pontebba Ice Rink Plant (2012)

- New Geothermal Heat Pump system (3 wells)
- 2 Ammonia HPs, 750 kW tot. installed capacity
- Heating and cooling of additional units
- 40 % average savings during first 2 seasons

Production and re-injection wells


D1, D2
Production Wells

Heat
Pump

R
Re-injection Well

Ice
Stadium

- Grounwater temperature 8,5 – 9,0 °C
- Cooling/heating power: 600-700 kW
- Production rate 50 l/s (20 + 30 from D1 & D2)
- Max. temperature difference = 3 °C

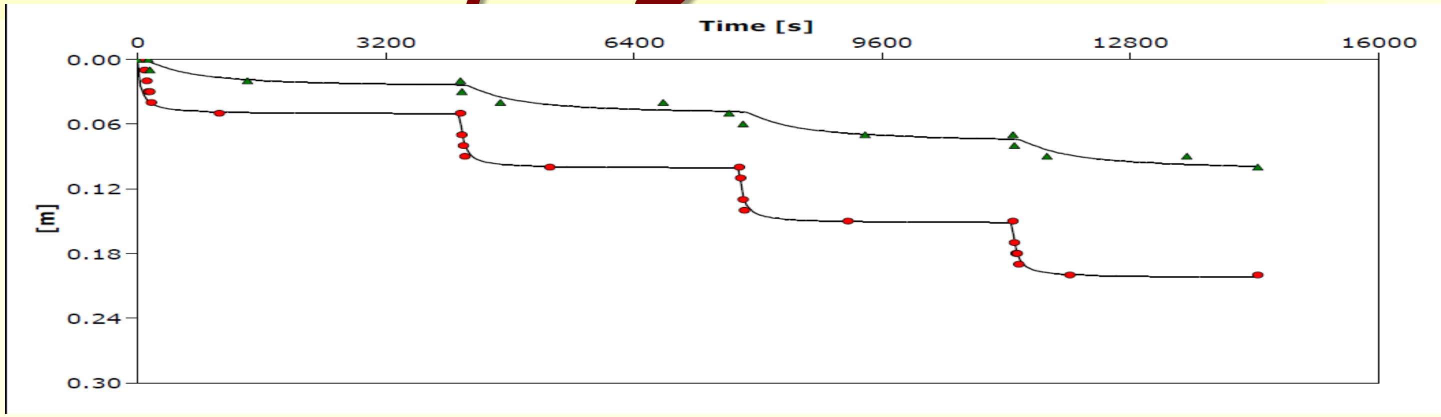
D1 e D2 production

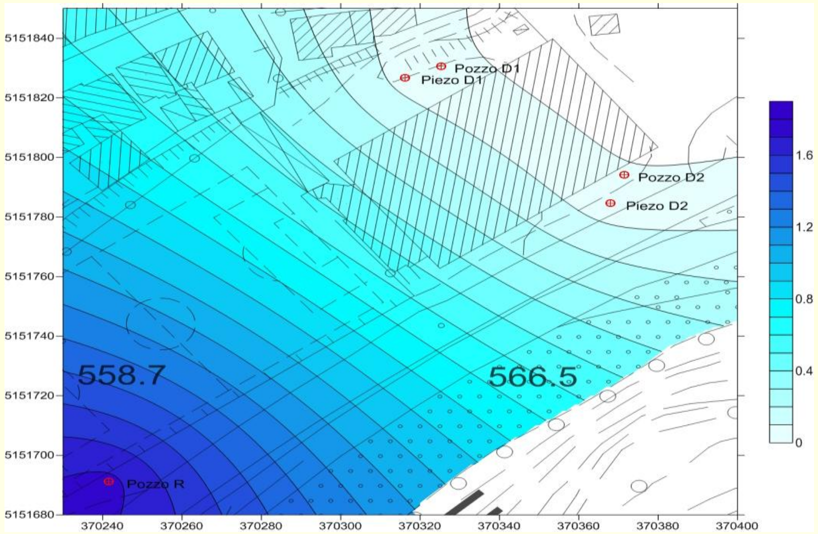
- 32 m deep, 13" 3/8 casing, 8 mm
- Screen from 6 to 32 m

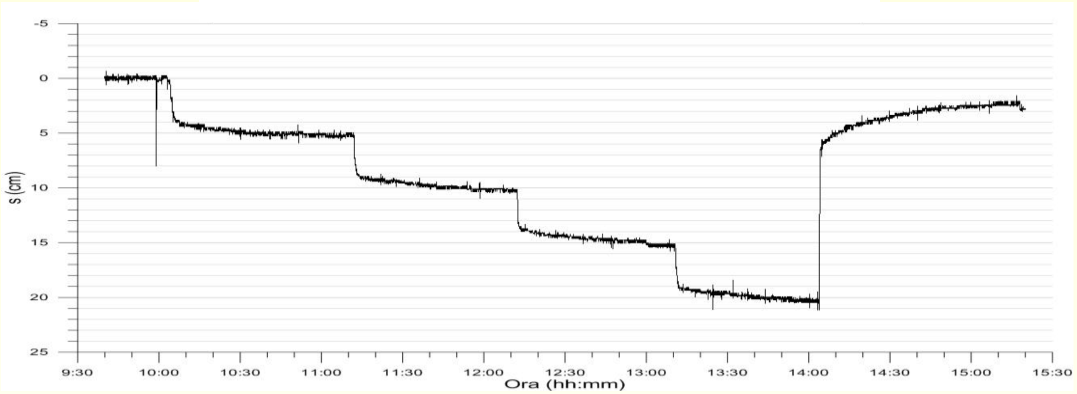
R re-injection

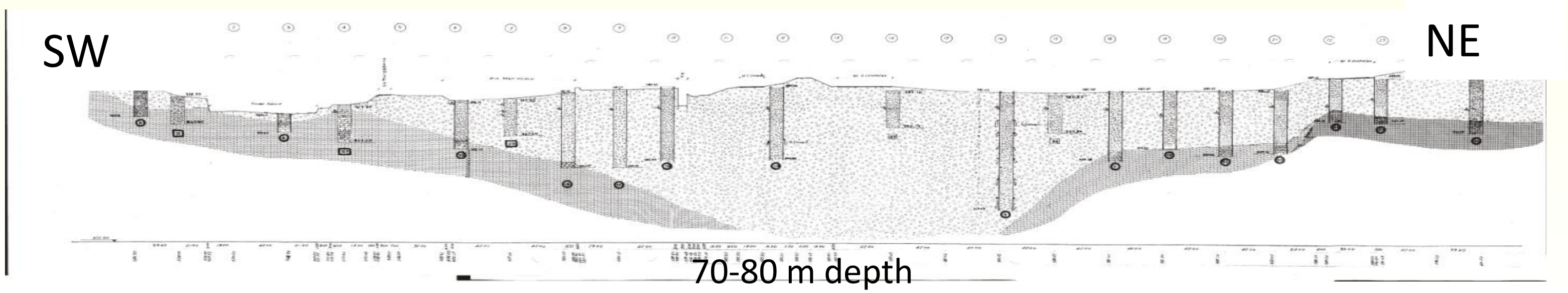
- 30 m deep, 18" casing, 9 mm
- Screen from 6 to 30 m

Step Drawdown Pumping Tests



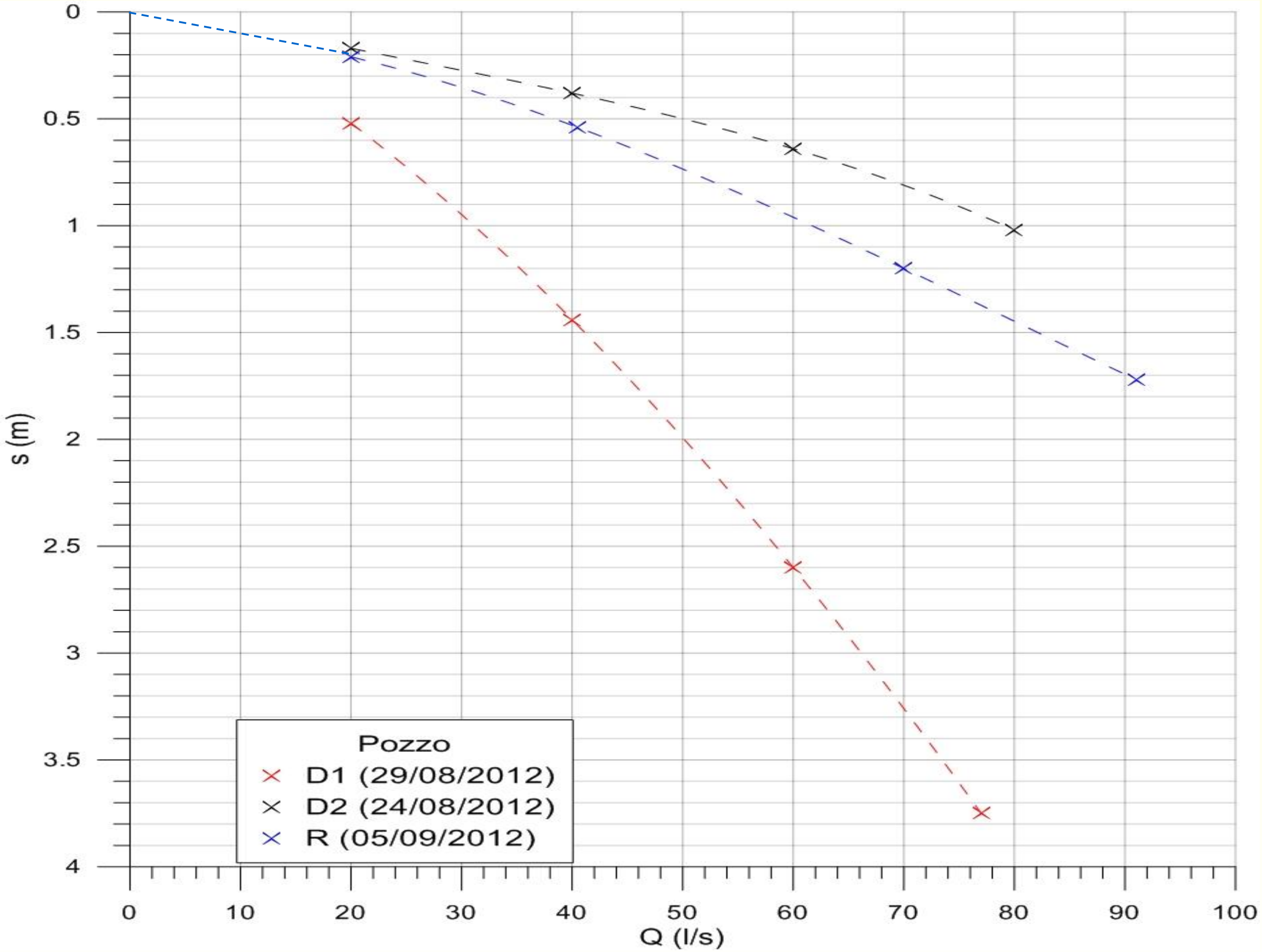


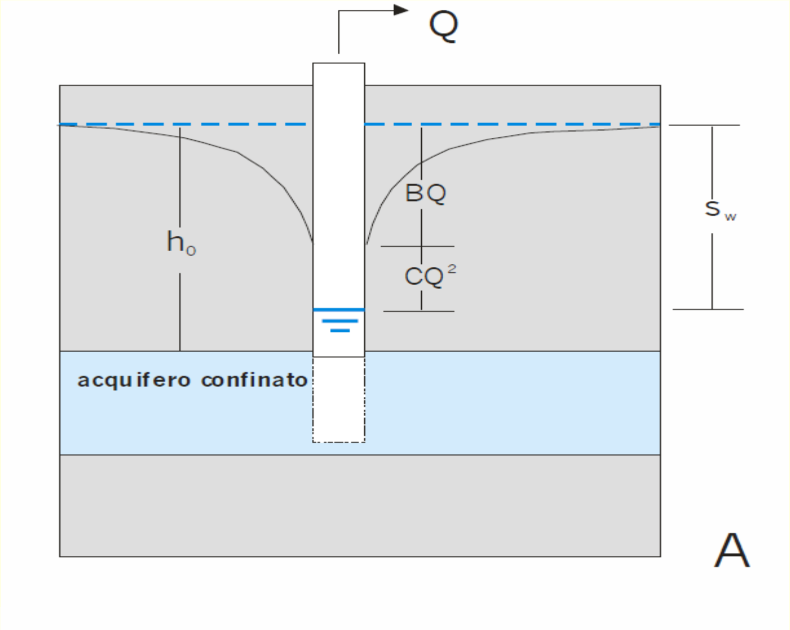




70-80 m depth

Pumping Tests Drawdown Curve



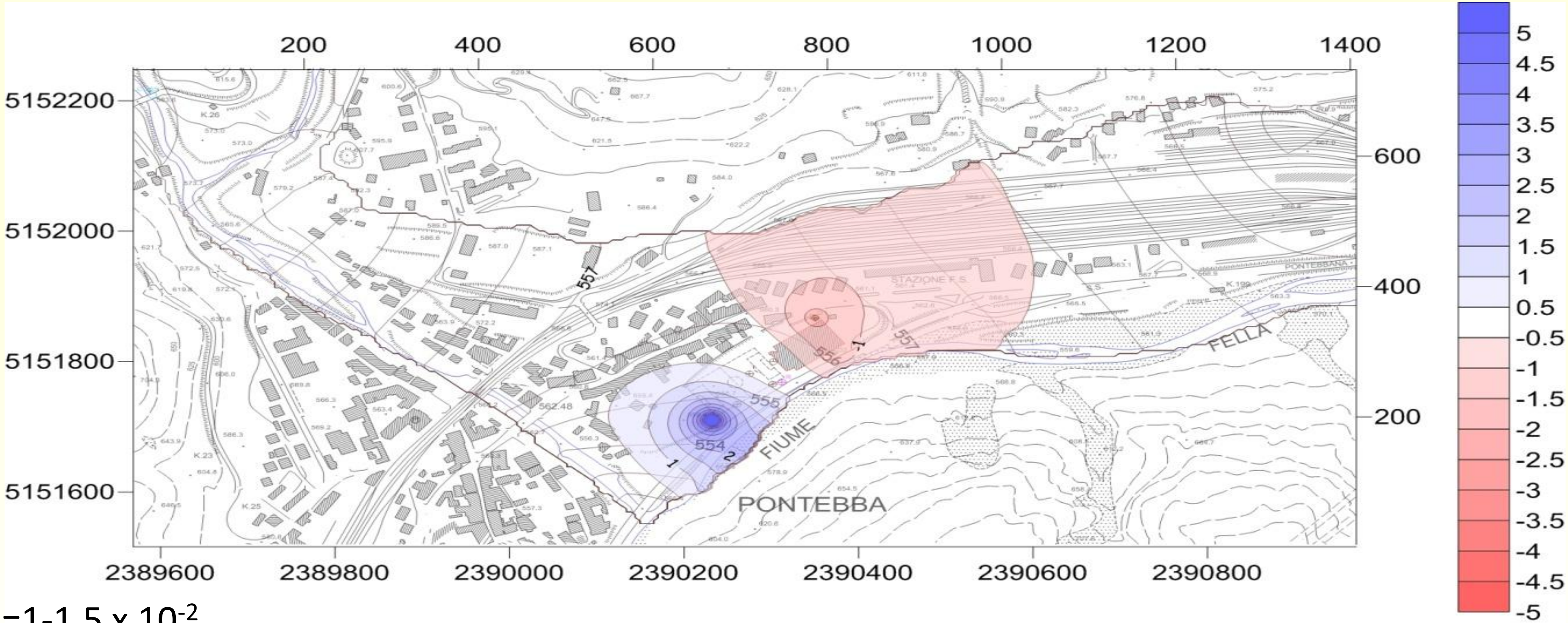


$$s_w = BQ + CQ^2$$

Production rates:
D2= 40 l/s
D1 = 25 l/s

Pontebba Ice Rink
Impact assessment on groundwater resource by max. pumping rate in dry season

D1+D2=72 l/s
R=72 l/s
K=1×10^{-3} m/s, $K_{Fella} = 1 \times 10^{-5}$ m/s



i=1-1.5 x 10^{-2}

Seawater Heat Pumps for the Requalification of the Trieste water-front