

# **Georesources: technical framework, chances and risks**

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My presentation covers

- ✓ Energy Strategy 2050
- ✓ Induced seismicity
- ✓ Basel 2006 and St.Gallen 2013: earthquakes and geothermal energy
- ✓ Emilia 2012: earthquakes and hydrocarbon extraction
- ✓ L'Aquila 2009: earthquake, trial and sentence

# The induced seismicity challenge for future energy supply

- ✓ US, 2000: after 30 years, industry succeeds in drilling horizontally and fracking deep, thin rock layers to extract shale-gas; 180'000 wells were drilled in 10 years, restarting the US economy; seismicity associated to the re-injection of waste water exceeds natural seismicity 100 times
- ✓ Groningen, 2013: Induced seismicity induced by the largest on-shore gas field in Holland threatens cities and may force lower extraction rates, with significant impact on Dutch GDP and Shell/NAM
- ✓ Basel, 2006, and St.Gallen, 2013: Induced seismicity leads to a virtual halt of deep geothermal energy mining in Switzerland
- ✓ Blackpool, 2012: Felt seismicity in the UK stops hydro-fracking
- ✓ Emilia, 2012: 14 BEuros damage and 24 casualties from a sequence of M5-6 earthquakes, possibly associated to hydrocarbon extraction
- ✓ Valencia, 2013: the EU-sponsored Castor offshore gas storage field is halted after producing earthquakes during the first fill
- ✓ Lorca, 2011: largest damaging quake in decades in Spain associated with long-term ground-water extraction

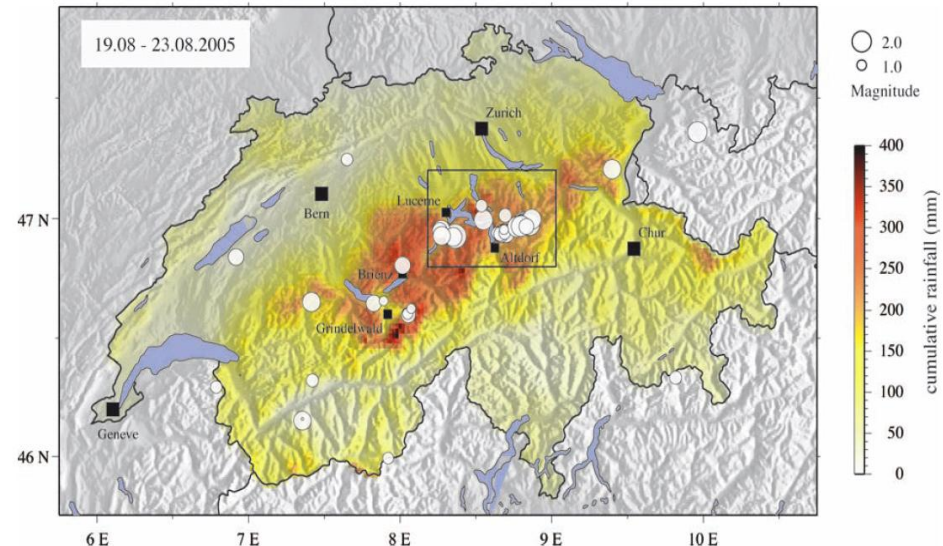
# Challenge: induced seismicity in Switzerland

Induced seismicity is well known in Switzerland. In recent years, it has been associated to the NEAT tunnel excavation, the DHM Basel and St.Gallen projects, heavy rain and the loading/unloading of large dams.

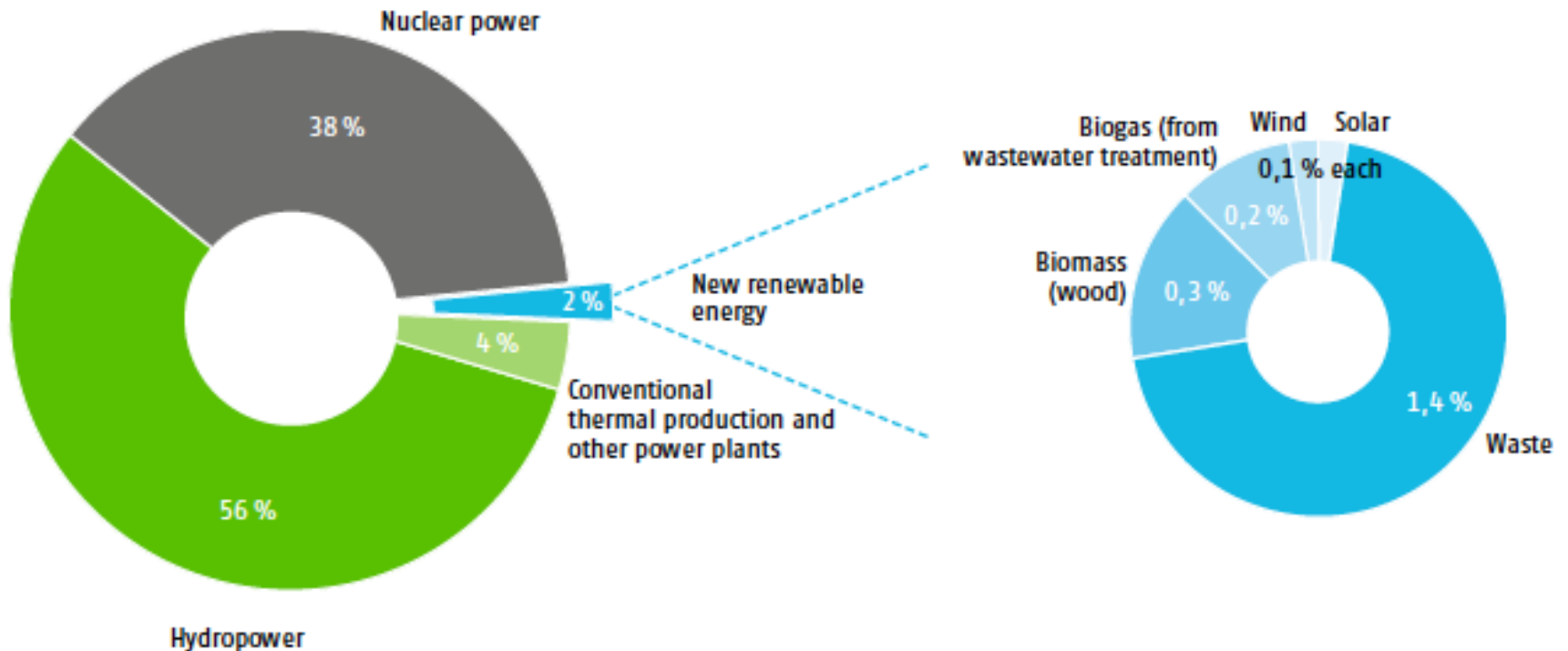
DHMB, 2006



NEAT, 2007

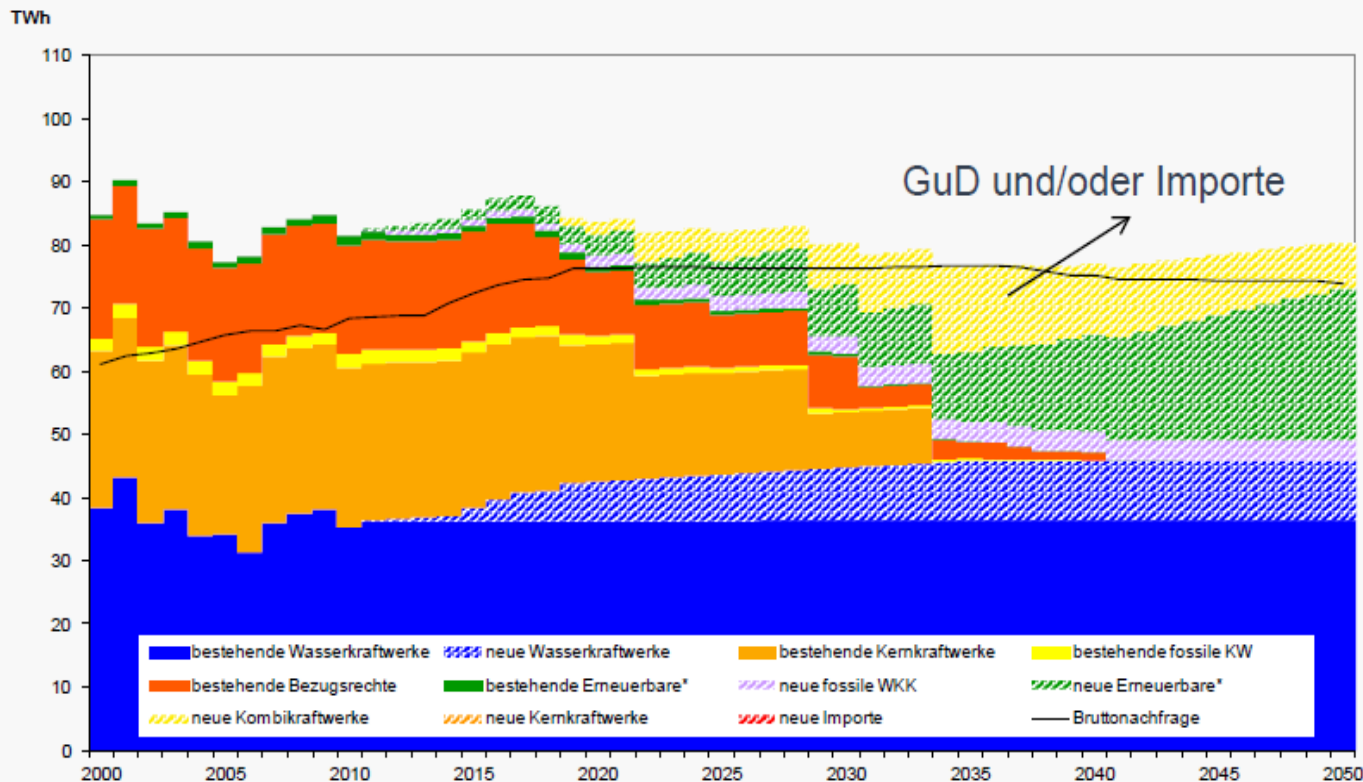


## Supply of Electricity: today



Today's renewable energy supply in Switzerland (heat+electricity) is less than 2% of the total supply. Switzerland expects a massive increase of renewable energies.

# Energy Strategy 2050



- ✓ Switzerland 2050: 9 mil population, 2% GDP yearly increase, electricity-based mobility, same electricity consumption as today
- ✓ Reduce demand via energy efficiency & savings
- ✓ Increase hydropower (10%), new renewables, Combined Heat & Power
- ✓ Meet greenhouse gas emissions targets
- ✓ Geothermal electricity: from 0 TWh in (2011) to 4.4+ TWh (2050; 5-10%)



# Deep heat mining

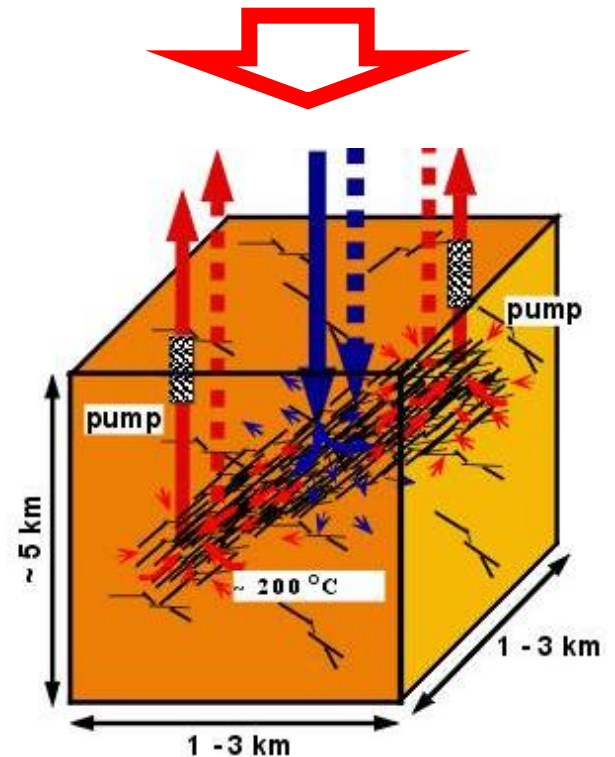
The heat flow is too small to be directly used. To extract the deep heat, we need to reach hot rocks or water.

In volcanic areas these can be found close to the surface, in other areas deep wells are required to exchange heat at depth.

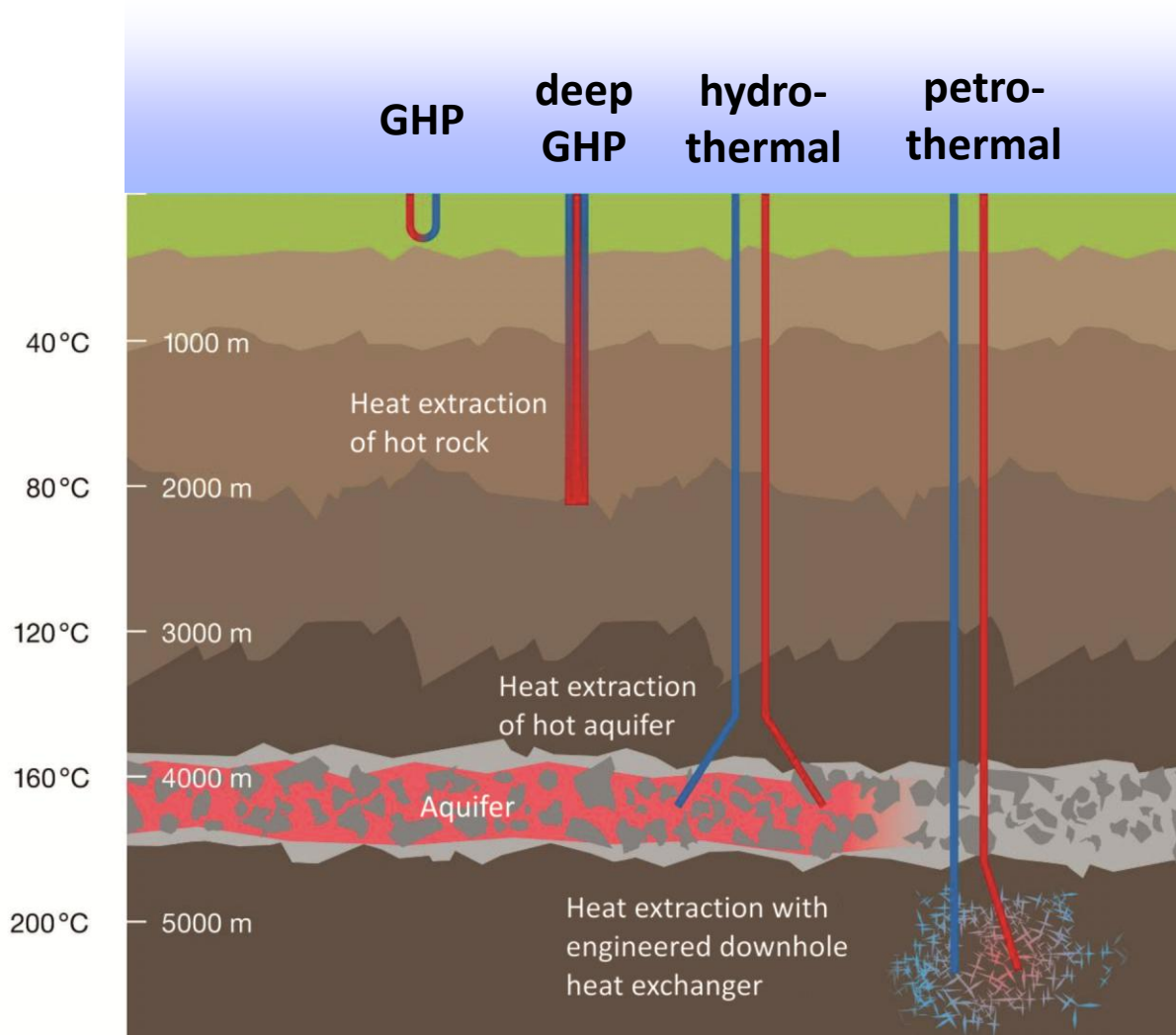
How much energy can be extracted ?

Cooling 1 cubic km of 200° C hot granite by 20° C could deliver heat sufficient to generate >10 Mwe for 20 years.

To extract this heat, we need to create a deep reservoir.



# Geothermal reservoirs



In a deep hydrothermal system, hot water is extracted from an open natural aquifer/structure.

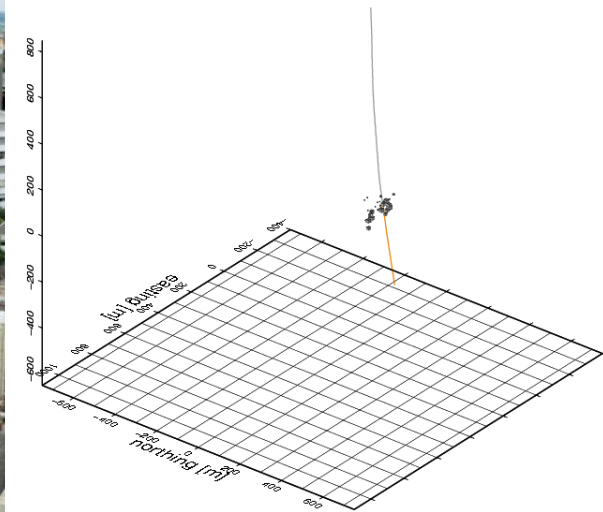
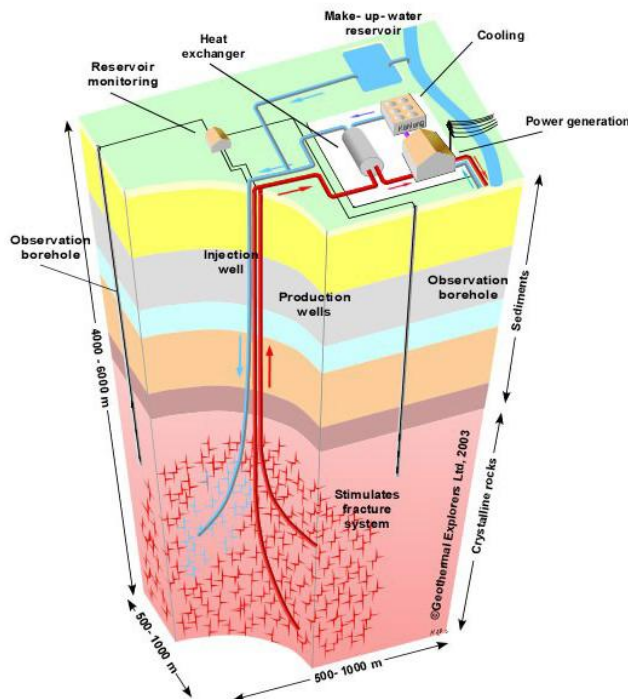
In an Engineered Geothermal System (EGS), deep impermeable rock is fractured by pressurized water, to allow water circulation.

Temperatures of  $>180^{\circ}\text{C}$  are required to produce significant electricity.



# Basel 2006

Mechanical stimulation in EGS and deep hydrothermal systems may induce earthquakes felt or producing damage at the surface. In 2006, induced seismicity in Basel during the EGS stimulation reached magnitude 3.4 and the project was abandoned.



# Basel 2006

- **Main Stimulation:**

**2 - 8 Dec. 2006**

$$V_{\max} = 11'570 \text{ m}^3 ; P_{\max} = 29,6 \text{ MPa}; Q_{\max} = 55 \text{ l/s}$$

- **Microseismicity:**

~15'000 detected / 3'555 located EQs.

Eq. rate increases with  $P_{WH}$  ( $R_{\max} \sim 200 \text{ Eq/h}$ )

lense shaped cloud ( $\sim 1 \times 0.5 \text{ km}$ )

growing away from injection point

- **Large magnitude events ( $M_L > 2.5$ )**

**8 Dec. 2006 3:06  $M_L 2.6$**

4:04 reduction of Q: 55 l/s  $\rightarrow$  30 l/s

11:34 stop of injection and shut-in

**8 Dec. 2006 15:46  $M_L 2.7$**

**8 Dec. 2006 16:48  $M_L 3.4$**

~18:40 bleed-off of well

**until 21 Mar. 2007, 4  $M_L > 3.4$**

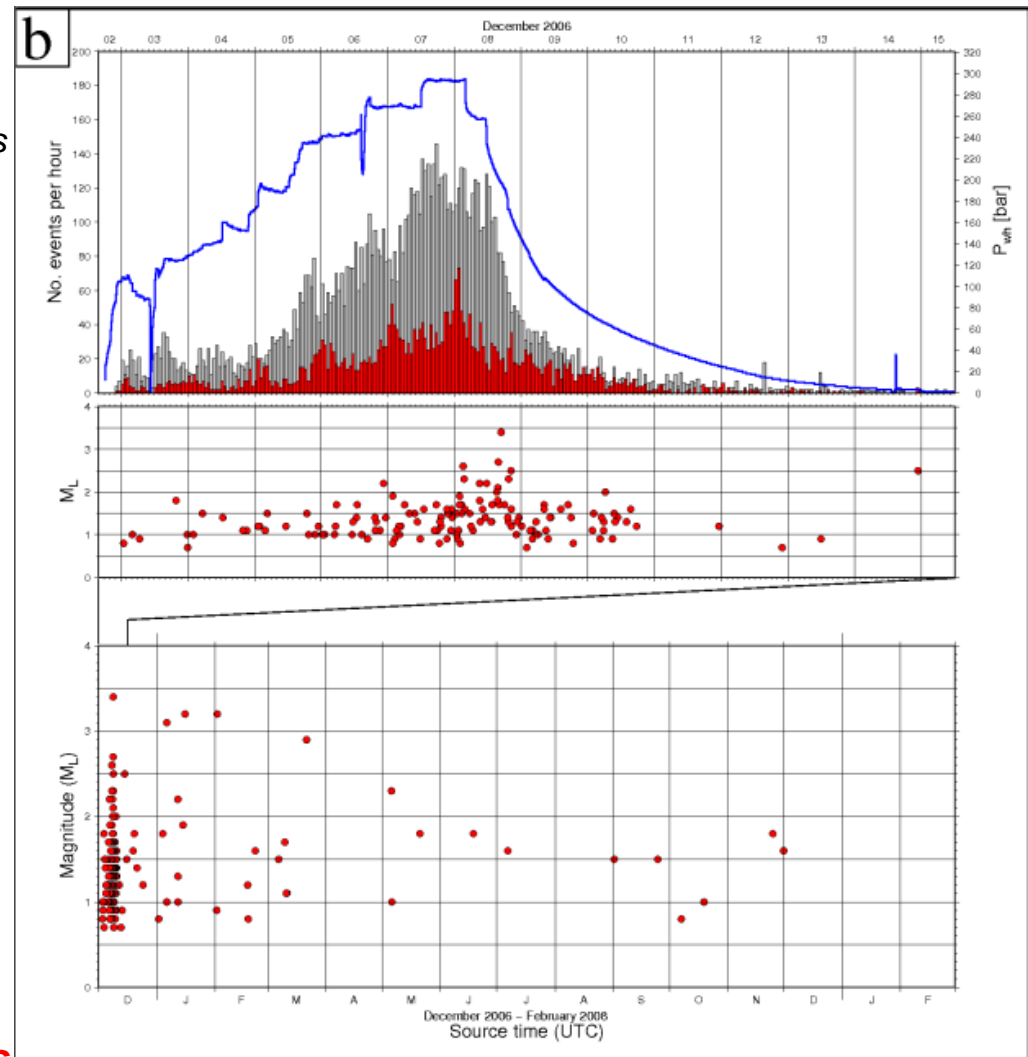
- **Macroseismic consequences**

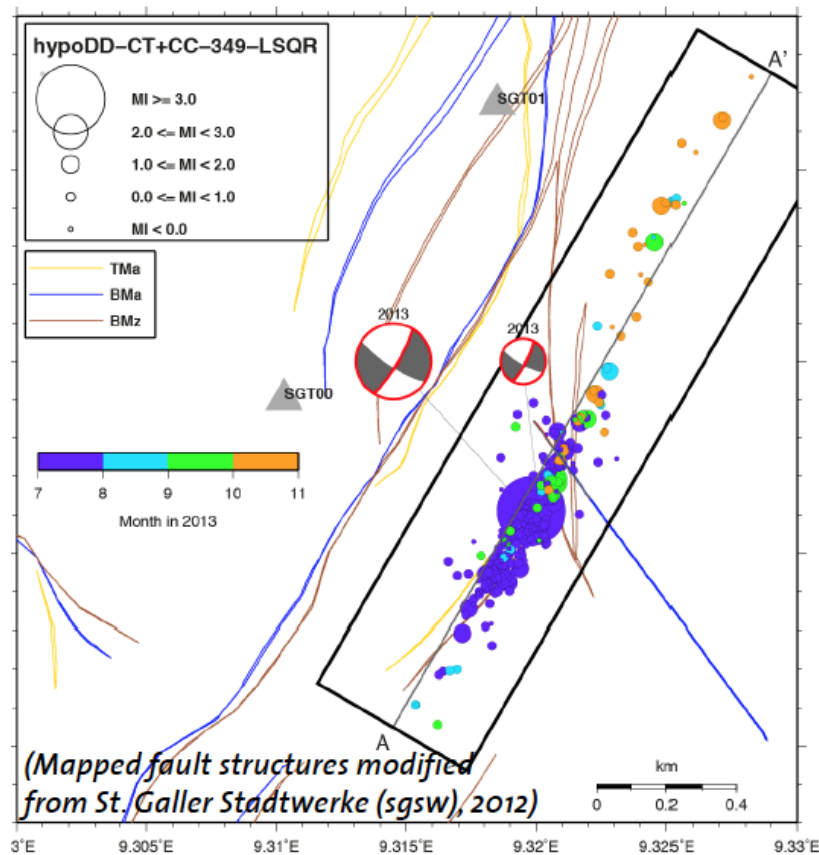
strongly felt, slight non-structural damage

~2500 insurance claims (9 million CHF paid)

> **Project terminated 10.12.2009**

> **Seismicity back to normal in 7-20 yrs**





The DGE project in St.Gallen targeted a fault system imaged from the surface, to construct a hydro-thermal heat exchanger at 4.5 km depth.

The fault started producing quakes during the first stimulation phase.

A phase of acidification was followed by an unexpected gas release. To kill the gas escape, an emergency high-pressure mud injection was executed, which in turn activated the fault with a M3.5 event. The events are partly located on an unmapped fault.

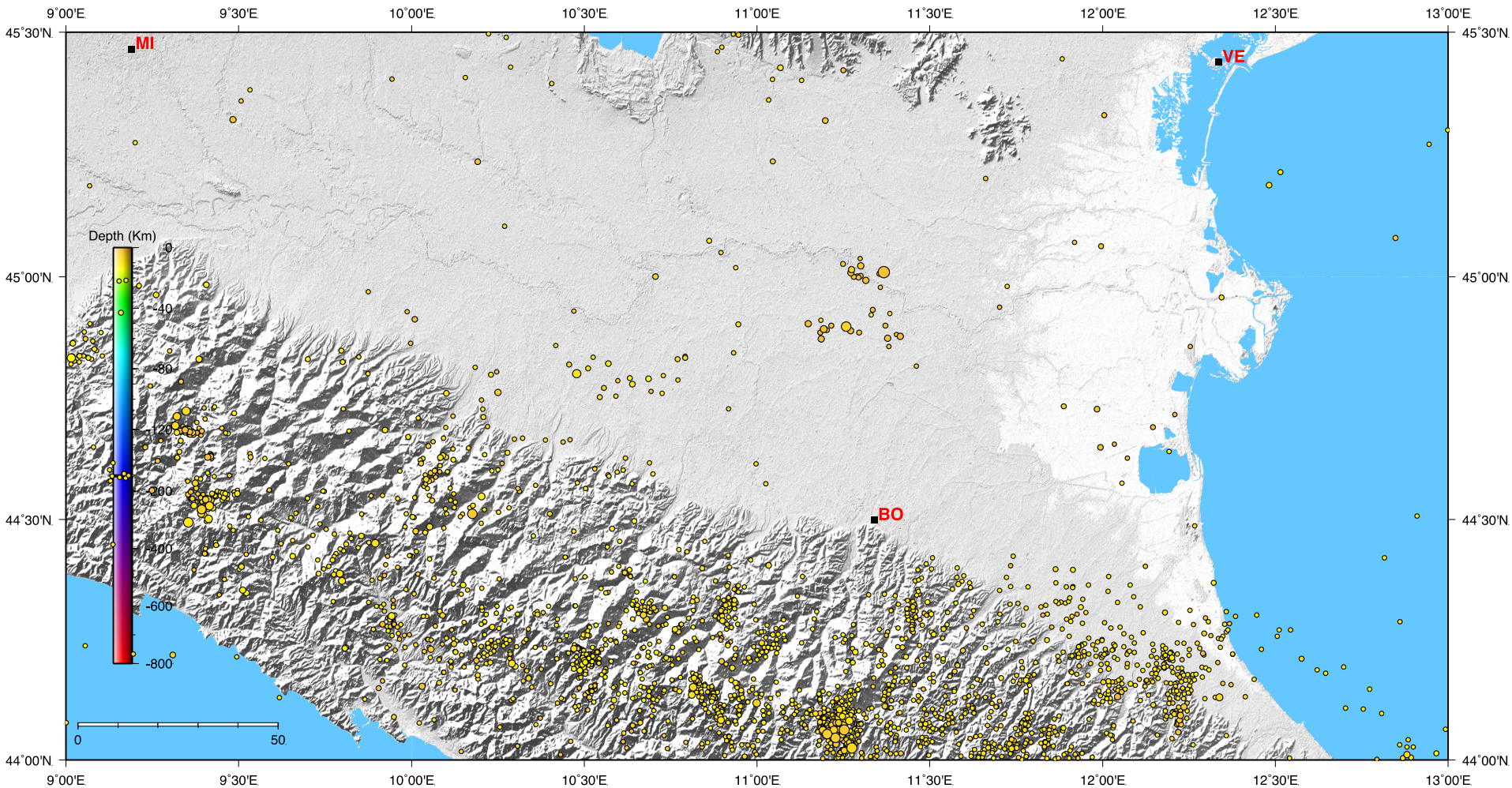
The Canton halted future DGE exploitation and authorized gas extraction.

## Lessons learned

- ✓ No off-the-shelf technology → we need R&D, together with industry, SFOE and a large international effort, focusing on resource imaging, modeling, reservoir engineering, long-term operations, risk assessment
- ✓ We need to develop dynamic monitoring and traffic light systems to condition extraction parameters depending on the response of the reservoir, to reduce the occurrence of induced seismicity
- ✓ Water is not readily available and not easily found → we need to bring from the surface the water we need and engineer the reservoir (EGS)
- ✓ Our ability to map the deep underground is limited → we need to account for surprises
- ✓ We need to minimize risk → stay away from cities and built environment
- ✓ Zero risk does not exist (as in most energy technologies)
- ✓ No short-term answers → Energy Strategy 2050
- ✓ We sit on an unlimited reserve of energy → excellent prospects !



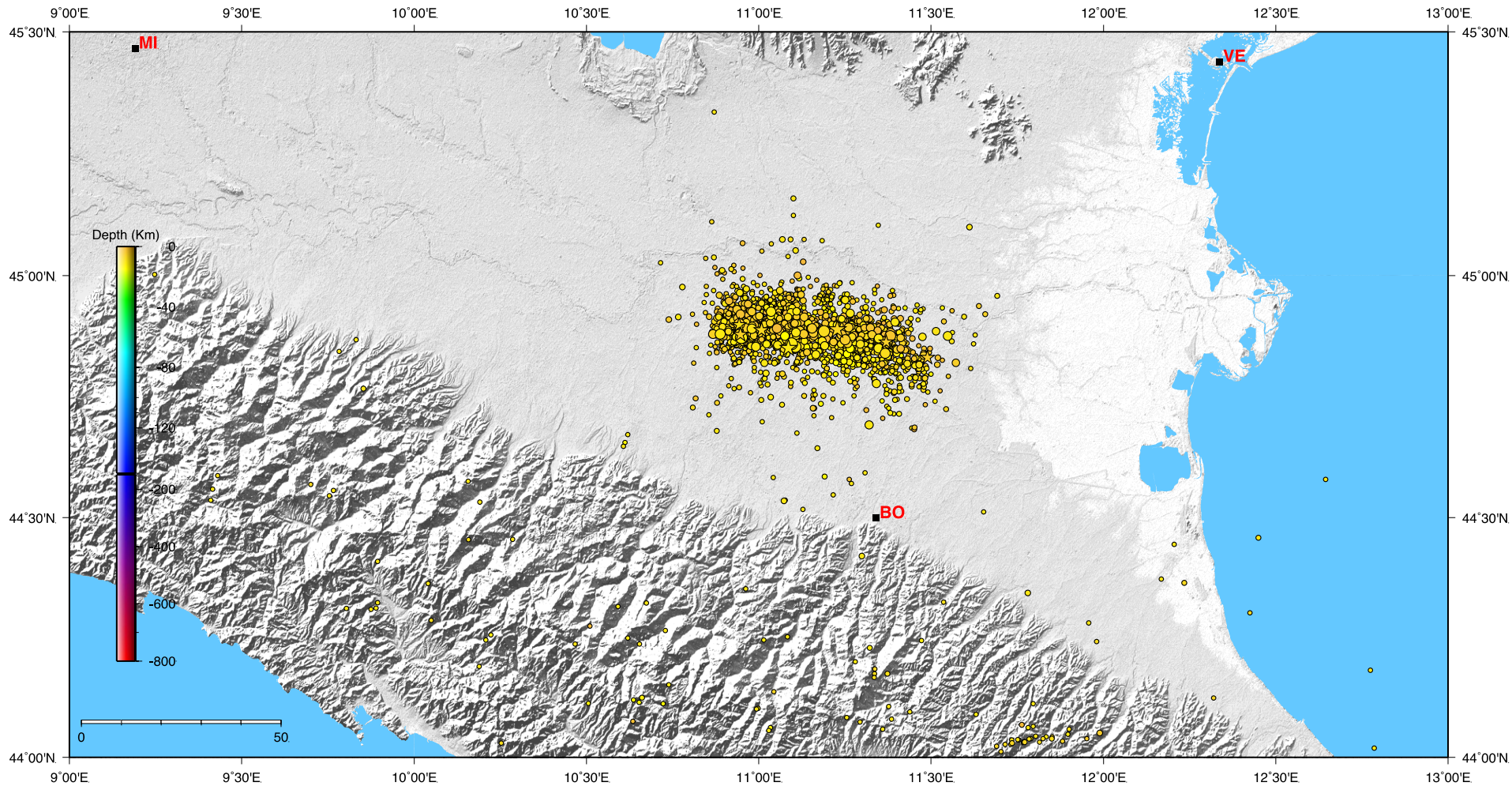
# Seismicity of Emilia, 2012



Database ISIDE INGVD, 5 years before May 20, 2012



# Seismicity of Emilia, 2012



Database ISIDE INGV, 6 months starting May 20, 2012

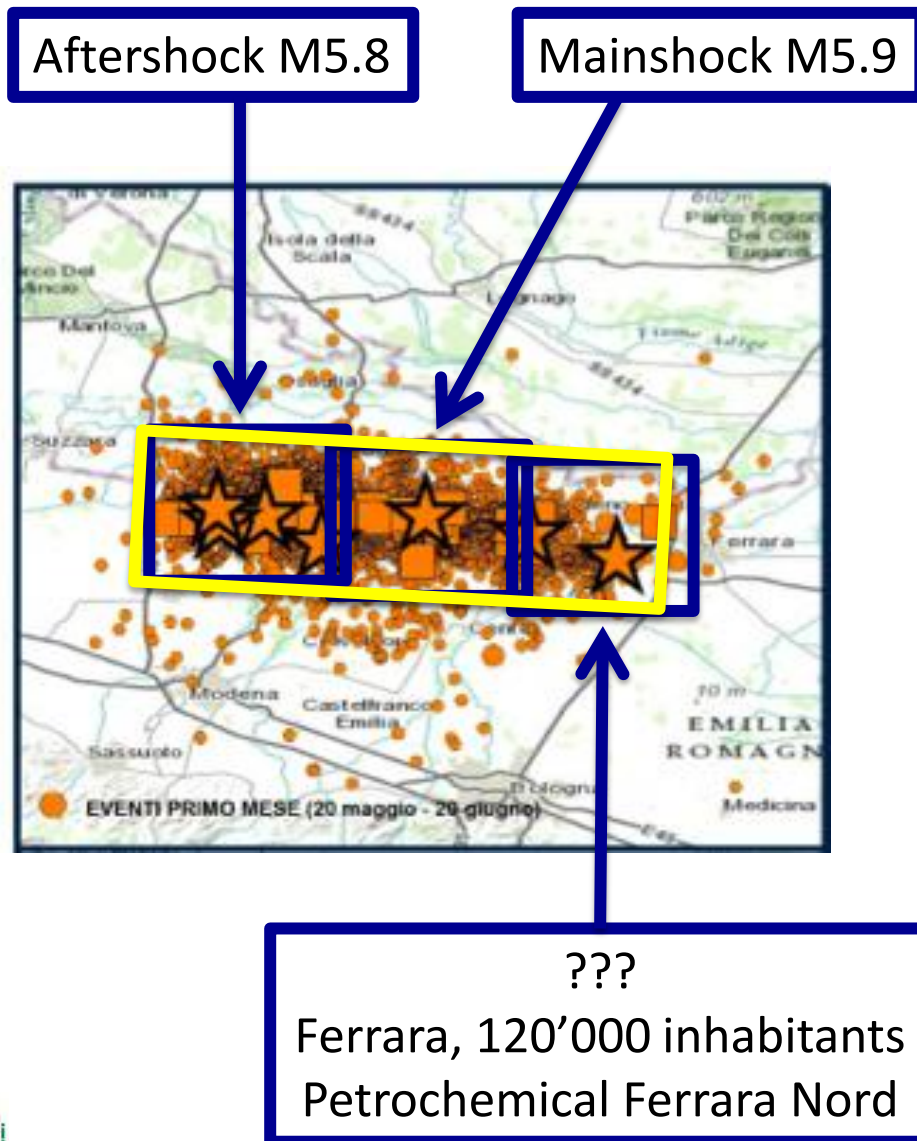


# Seismicity of Emilia, 2012

- ✓ Strong amplification of ground shaking due to the sediment coverage
- ✓ Extensive damage to large structures (castles, churches) and non-critical pre-cast concrete industry buildings
- ✓ The region is a prime pole in Europe for medical technology and food industry
- ✓ Damage for 14 BEuro, 1% of Italian GDP
- ✓ The immediate priority was to restart industrial production, to minimize market loss



# Seismicity of Emilia, 2012



- ✓ Unusual aftershock sequence spread over 50 km – instead of 12-15 km as expected for a M5.9 – with five Mw5+ events in the first week. The May 29 M5.8 event broke the western part of the sequence.
- ✓ On June 5, the government called the Commission of High Risks to evaluate the situation. The CGR concludes that there is a “significant” probability that the sector to the East of the mainshock will be activated and possibly also internal sectors of the Apennines (Garfagnana) may be activated.

# Seismicity of Emilia, 2012

Two hours after the report was delivered, the DPC and CGR directors were called to an emergency meeting of the Italian national security council and the Italian government, with the Italian premier and council of ministers.

The government discussed for hours – specifically on the possibility of evacuating the city of Ferrara – and implemented five rapid measures:

- ✓ Restock the civil protection supplies
  - ✓ Increase the military and fire-fighters contingents in the area
  - ✓ Perform a rapid vulnerability mapping of the city of Ferrara
  - ✓ Extend the emergency period from 100 days to 1 year
  - ✓ Remove all stocks from the petro-chemical complex of Ferrara Nord
- Local authorities threatened to sue the CGR for procured alert, fearing a decrease in tourism and industry presence
  - Seismicity in the Emilia sequence has since decreased

# Sequence of events

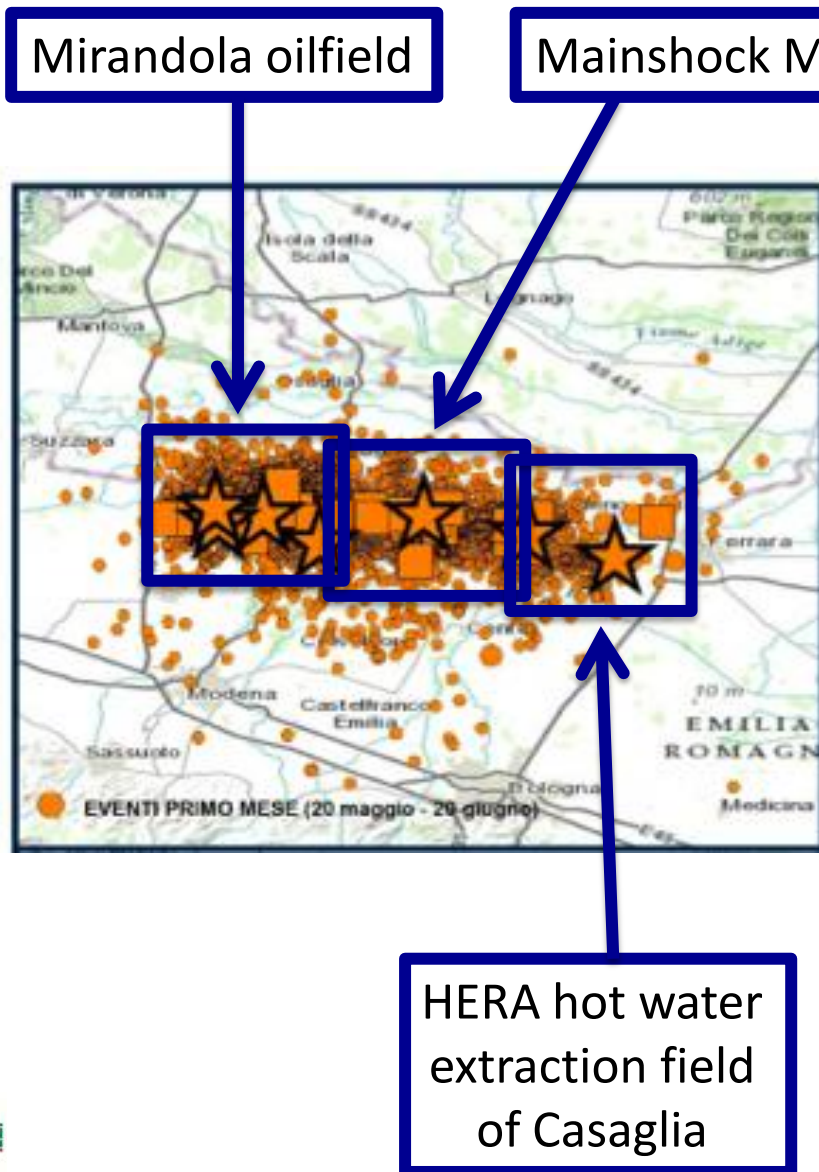
May 20, 2012	M5.9 mainshock
May 20-29	Extended area of strong aftershocks Informal communication INGV-CGR-DPC on possible extension of the sequence to the West and East
May 29	M5.8 second mainshock
June 5	meeting of the High Risks Commission
June 7	CGR report transmitted to Civil Protection
June 8	Measures implemented by Government, but no evacuation of Ferrara

- If the CGR meeting had taken place before the May 29 event, the successful “forecasting” would have likely led to the evacuation of Ferrara

# Seismicity of Garfagnana, 2013

- ✓ The Garfagnana Valley in the Italian Apennines has been hit by damaging earthquakes in the past. On January 23, 1985, following a M4.2 earthquake, the Civil Protection, fearing a larger earthquake, evacuated 100'000 people, including the main center of Castelnuovo.
  - ✓ Following the 2012 Emilia sequence, Garfagnana had been highlighted by the CGR as a region of possible seismicity re-activation, and local authorities had been “informed/alerted” by DPC.
  - ✓ On Jan 25, 2013, a M4.8 event hit Garfagnana, without significant damage.
  - ✓ On Jan 30, following an aftershock of M3.3, the INGV notification to DPC included the statement *“in the next hours more earthquakes could happen SW of the main shock, and may hit Castelnuovo”*
- During the night, 20'000 people were evacuated by the local mayors; the emergency lasted 24 hours.

# Seismicity of Emilia, 2012: possible role of induced seismicity ?



- ✓ The seismicity area to the West of the mainshock overlaps the Mirandola oilfield
- ✓ The seismicity area to the East of the mainshock overlaps the HERA hot water extraction field of Casaglia, serving the Ferrara district heating grid (400 m<sup>3</sup>/hr)



# Hydrocarbon resources in Italy

## GAS

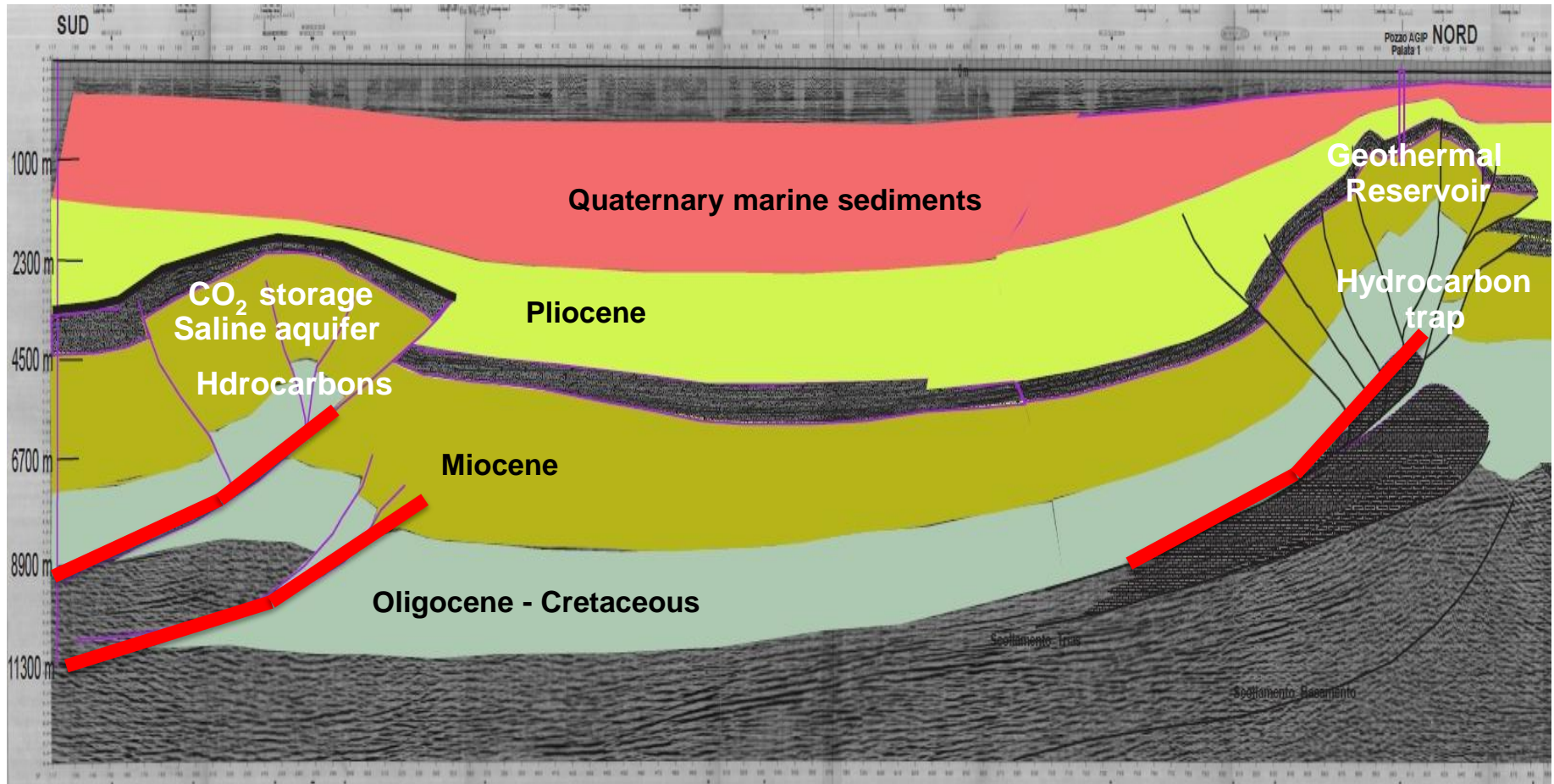


## OLIO

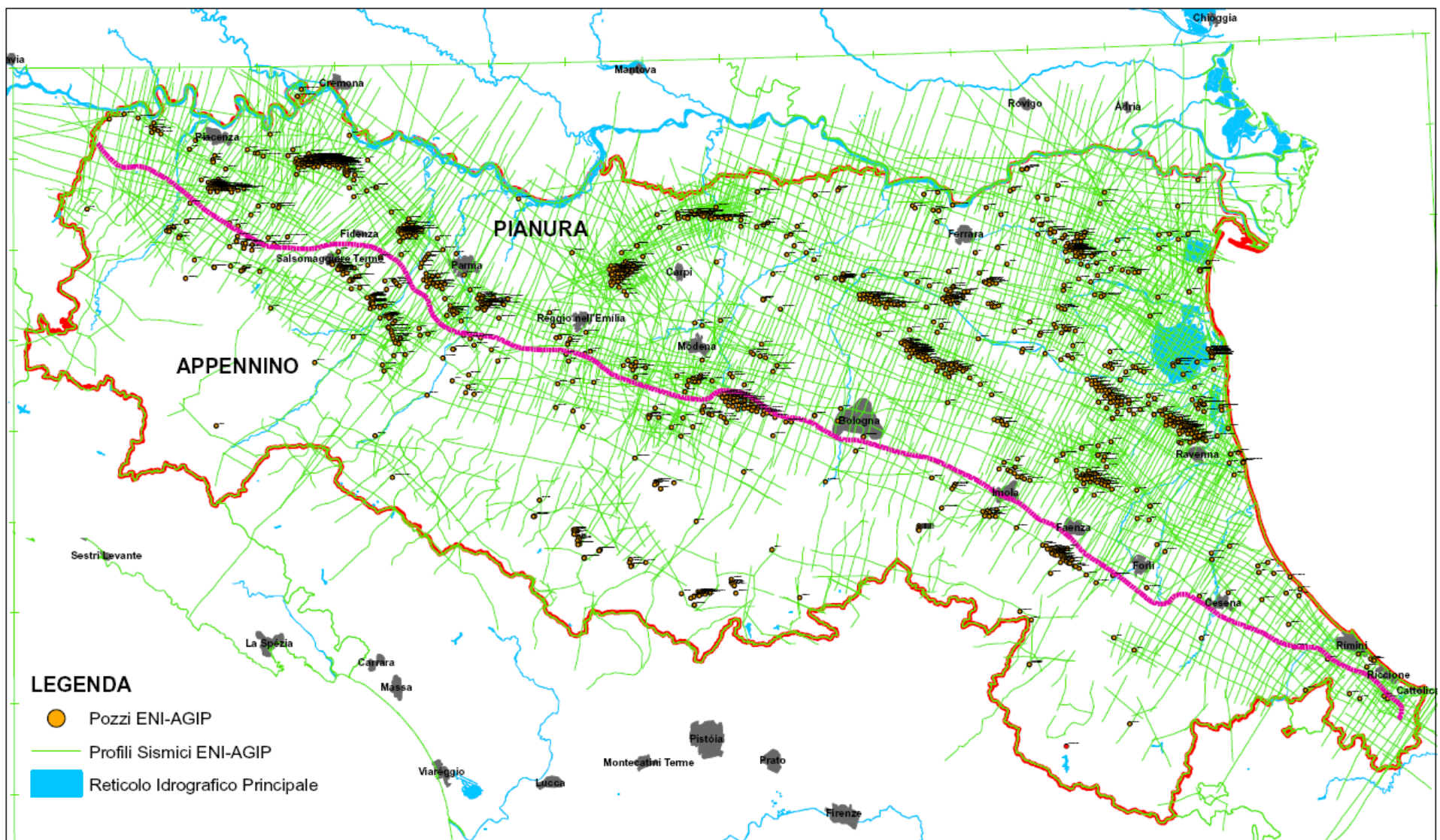


Italy has the largest hydrocarbon resources and production in Southern Europe, with reserves of 1840 MB of oil and 30 Tft<sup>3</sup> of gas and production of 43.2 MB/yr oil (75% in Val d' Agri) and 340 Bft<sup>3</sup> gas (mostly in the Adriatic).

The compressive fronts of the Apennines form traps for hydrocarbons and are the target areas for gas and CO<sub>2</sub> storage sites and for the extraction of deep geothermal energy







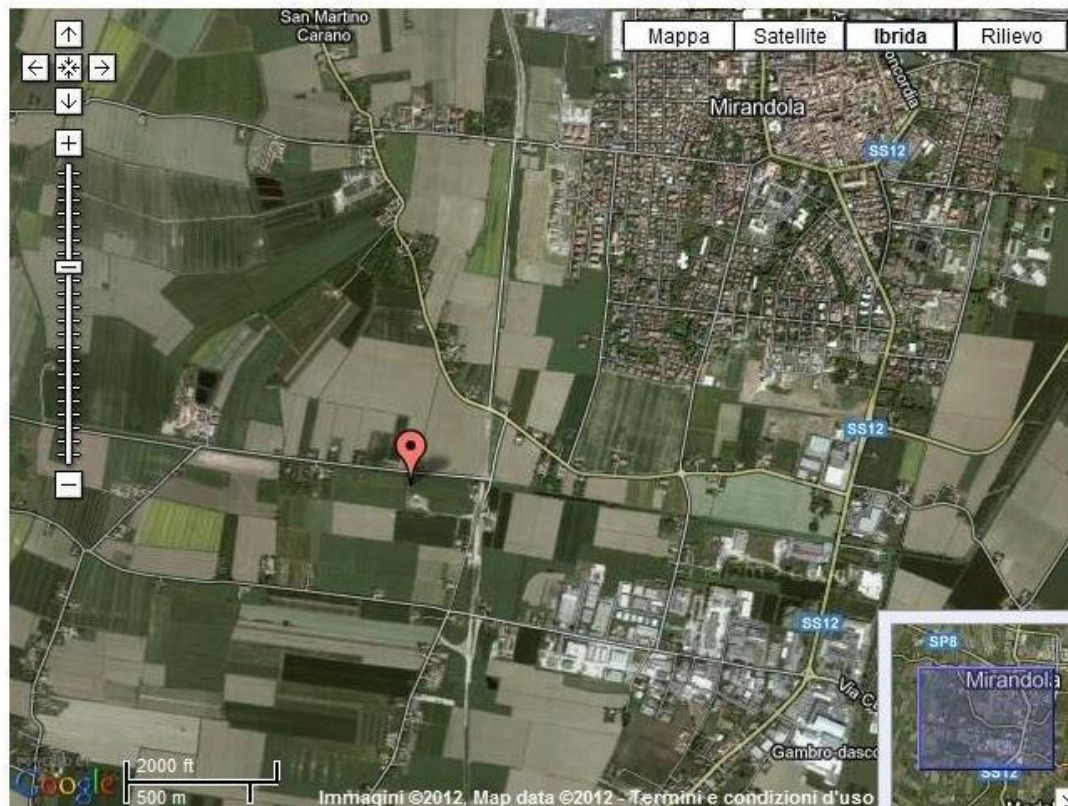


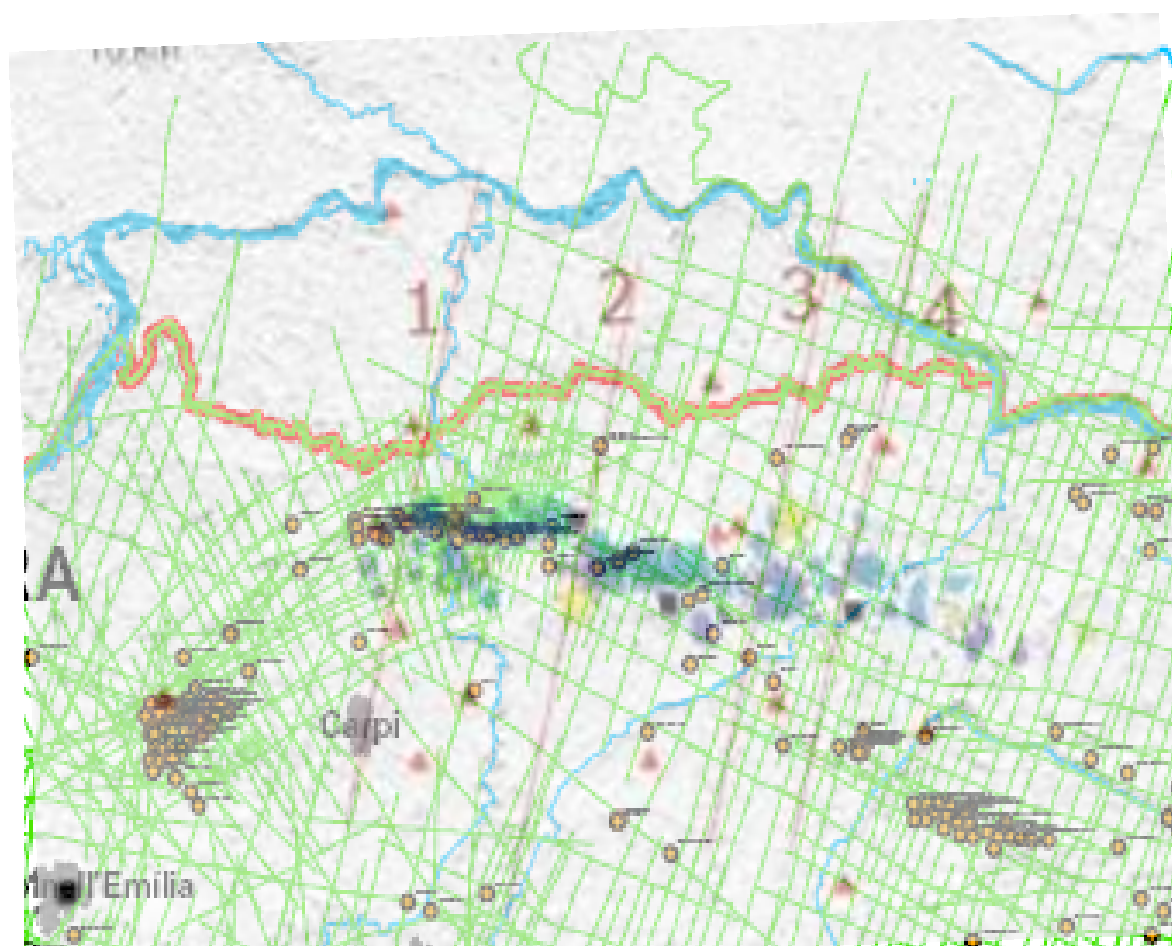
# Cavone-Mirandola oilfield

UBICAZIONE DEL POZZO

**S.GIACOMO 001**

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## Situation today

- ✓ The Italian Civil Protection nominated an international commission to evaluate if hydrocarbon extraction might have influenced or induced the seismic sequence in Italy: the ICHESE concluded that a direct triggering cannot be proven but it cannot also be excluded.
- ✓ In the past 50 years, four main sequences with Mw5-6 occurred on the external thrust faults, in addition to the M5.9 Emilia mainshock: Caviaga, 1951, M5.4; Ancona 1972, M5.4; Correggio, 1987-2000, M4.8; Emilia, 2012, M5.9-5.8
- ✓ Industry (ENI), authorities (MISE), the Civil Protection, the High Risk Commission and the main research institutes (INGV, OGS) are focusing efforts to understand the physical process, the associated hazard and risk profile and the possible consequences. In case of positive finding, MISE considers halting on-shore hydrocarbons extraction in Italy.



# The L'Aquila M 6.2 earthquake, April 6, 2009

- ✓ L'Aquila is located in a very active area of the Central Apennines, with past earthquakes reaching M7; the last such events hit L'Aquila in 1703 and Avezzano in 1915, SE of L'Aquila, causing 30'000 casualties and total destruction.
- ✓ A seismic sequence started below L'Aquila in late 2008, with increasing magnitude and frequency; a damaging shock of Mw 4.2 occurred on March 30, 2009.
- ✓ On April 6, 2009, the Mw 6.2 mainshock struck.



# The L'Aquila Mw 6.2 earthquake, April 6, 2009

- ✓ The shock caused significant damage, 309 deaths and over 2'000 seriously injured people in the city and nearby villages (Onna, Paganica). Over 90'000 people were evacuated.
- ✓ Over 1'000 classified historical buildings have been seriously damaged; the reconstruction is very slowly starting, owing to the difficulty of retrofitting historical buildings according to the severe restrictions imposed by the present building code, resulting in public anger and migration of population.



## L'Aquila trial: trial and sentence

Following the March 30 M4.2 event, on March 31 the High Risks Commission (CGR) met in L'Aquila. The seven seismologists, engineers and public officers participating in the CGR meeting of March 31 were sued by the families of the victims.

In the trial, the prosecutor argued that:

- I. a direct causal link can be established between the reassuring message communicated to the media after the CGR meeting and the death of 37 people that changed their habits as consequence of that message
- II. the reassuring message can be ascribed to the *negligence, carelessness and incompetence* of the seven scientists and engineers, who in different capacities and responsibilities failed in *their duty to society of conducting a proper risk evaluation and of providing a clear, correct and complete information*, failing to evaluate all the information available to the scientific community, as expected by their function, resulting in manslaughter

➤ The judge confirmed these motivations and sentenced the seven scientists to six years in jail and a first compensation fine of over 10M\$.

## L'Aquila trial: public reaction

This court case presents unpleasant and possibly incorrect aspects – the feeling of summary justice, the risk of political contamination, scientists used as scapegoats – and sets in any case an important precedent:

- ✓ The international reaction of the scientific community was very forceful, arguing that Italy is putting again science on trial (i.e. Galileo).
- ✓ In Italy, many scientists agreed but many others argued that this freedom is not challenged in L'Aquila, what is challenged is the responsibility of scientists serving in advisory roles for the government.
- ✓ With few exceptions, the Italian Government, Parliament, public opinion and media argued that scientists should take their responsibility and engage in advisory roles for the government, and should be prepared to pay for serious misconduct, as doctors and engineers do.

➤ The appeal trial will start this fall.

# Conclusions

- ✓ We need to develop our underground resources, and this will be possible only if we learn to control the risk of induced seismicity
- ✓ Deep Geothermal Energy is a pillar of the Energy Strategy 2050
- ✓ Our present tools and knowledge are insufficient to provide operational forecasts of hazards and seismic activity
- ✓ The DGE projects in Basel, Zurich and St.Gallen provide very important data for better understanding and future application
- ✓ Roles and responsibilities of all parties in case of induced seismicity are not yet regulated
- ✓ We need appropriate language and procedures to pass scientific information and its uncertainties to the public, authorities and decision makers
- ✓ We are learning ...

## Questions for you

- ✓ What happens if your house is built according to the most recent norms and collapses during an earthquake killing your family ? Who is responsible ? The regulator/authorities for choosing a too low protection level ? The scientists approving the map because their model were not good enough ?
- ✓ What happens if we discover today that an energy technology – e.g. oil extraction – used for the past 80 years produces an important earthquake risk which we did not account for ? Who is responsible ? The industry for the peril posed to the population ? The regulator/authorities for licensing the activity without proper risk assessment ? The scientists for not doing accurate work ? If we cannot prove or exclude the risk, should we stop in any case all extractions ?
- ✓ As the state of stress in the Basel underground is now perturbed with respect to the normal earthquake cycle, who will be responsible when the next Basel quake comes ?
- ✓ ....