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The ICHESE report on the relationship between Hydrocarbon Exploration and the May 2012 earthquakes in the Emilia Region (Italy) and their consequences

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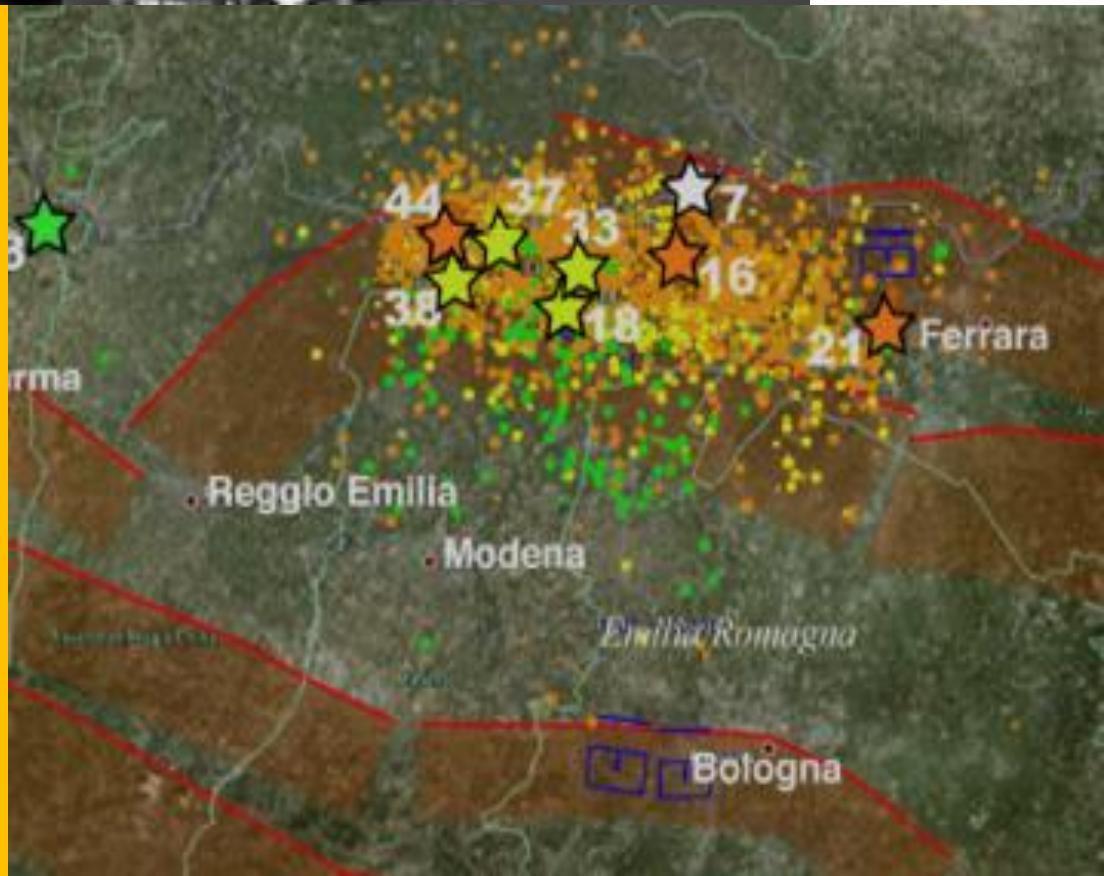
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# The Emilia Sequence (1)

A sequence of significant and devastating earthquakes (4 events > 5ML, with total collateral damage of c12 Billion Euros and great destruction of cultural heritage) occurred in the Emilia Romagna region of Northern Italy in May-June 2012.

**Damage to Cultural Heritage**

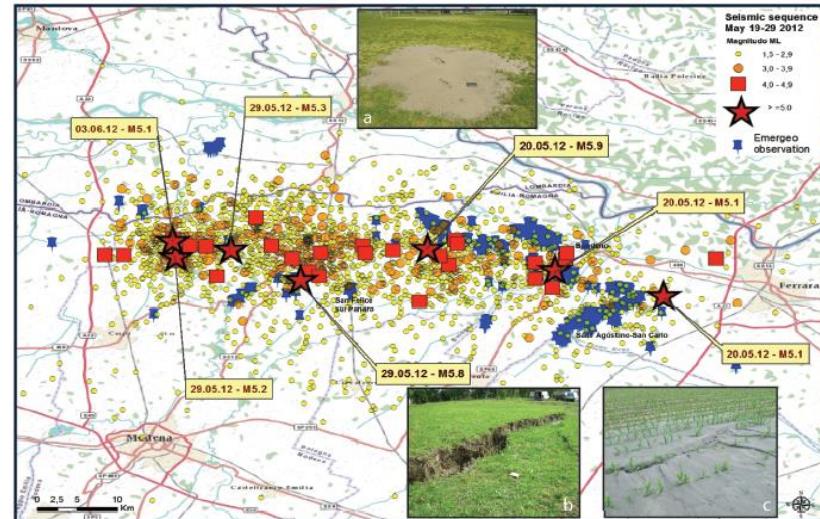
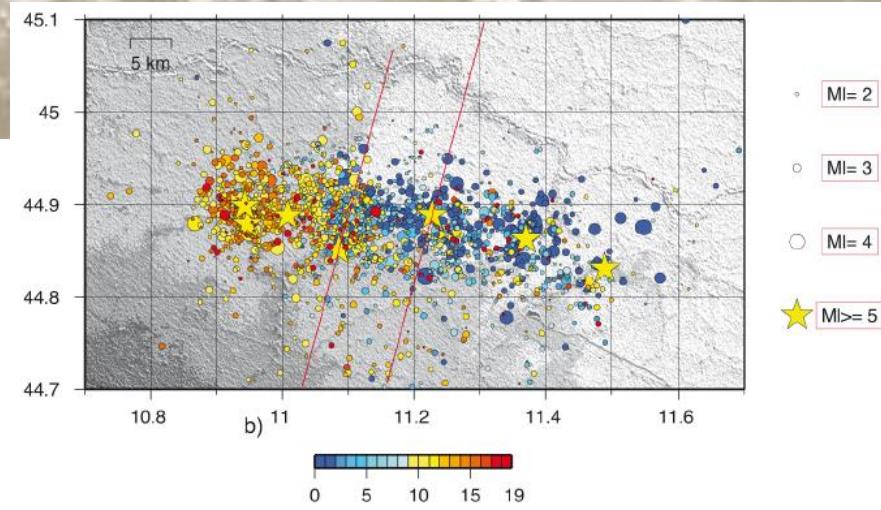
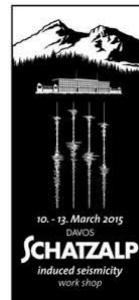
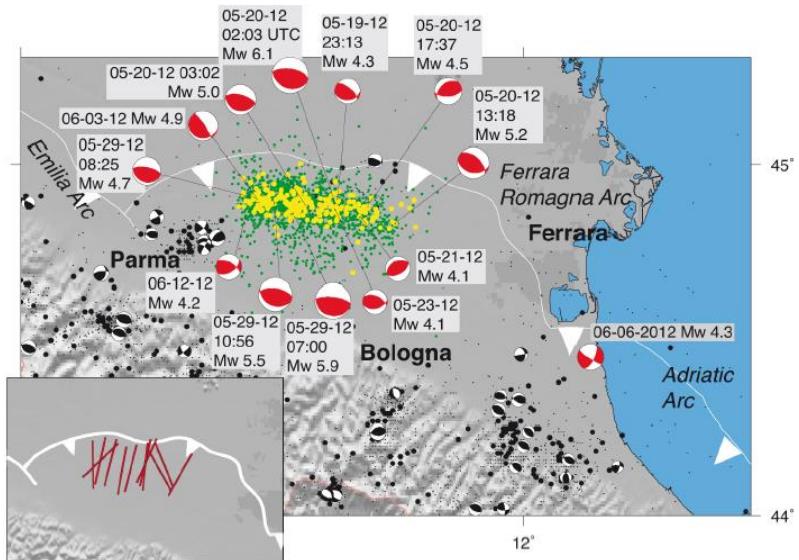


**Damage to Industrial Buildings**

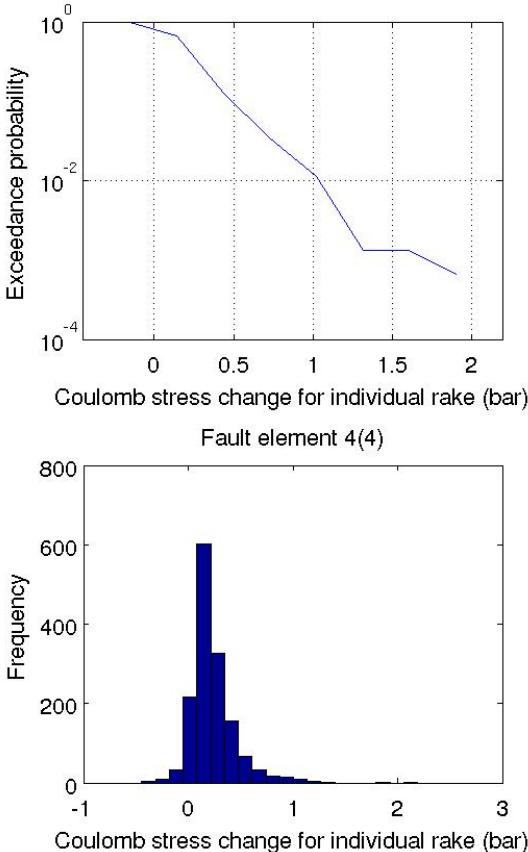


# The Emilia Sequence (2)

Focal mechanisms are of compressional type occurring along thrust faults with a dip of about  $45^\circ$ . These solutions are consistent with the seismotectonic environment of the earthquake, involving a complex system of blind thrust faults which accommodate motions at the WNW-ESE outer margin of the Northern Apennines.

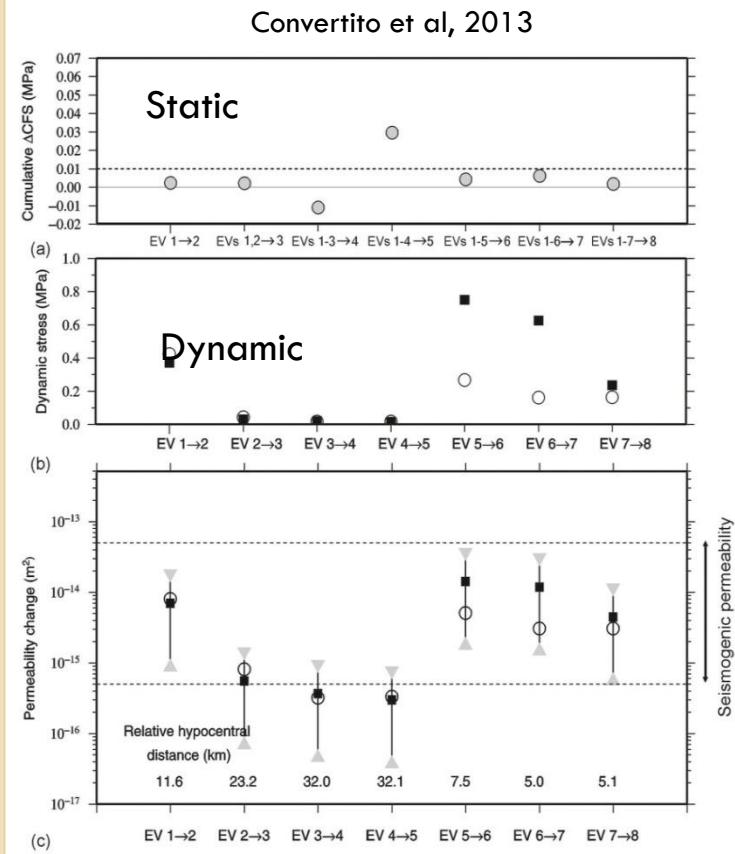


# The Emilia Sequence (3)



The estimate of the static stress variation for the Emilia 2012 sequence, indicates that the main shock of May 20 produced a positive stress transfer to the fault generating the May 29 earthquakes (in all cases the probability that  $CFF > 0$  is  $> 80\%$ ).

• Dynamic triggering might be the primary factor to explain the evolution of the 2012 Emilia seismic sequence. In fact, the authors observed a correlation between the locations of aftershocks and subsequent main events with: i) the peak dynamic strain fields; ii) the local change of the permeability



# The ICHESE Commission(1)

The Technical-Scientific Commission ICHESE was appointed on December 11, 2012 by the decree of Dr. Franco Gabrielli, Head of the Italian Department of Civil Protection of the Presidency of Council of Ministers, with the following questions:

- 1) *Is it possible that the seismic crisis in Emilia has been triggered by the recent researches at the Rivara site, particularly in the case of invasive research activities, such as deep drilling, fluid injections, etc.*
- 2) **"Is it possible that the Emilia seismic crisis has been triggered by activities for the exploitation and utilization of reservoirs carried out in recent times in the close neighborhood of the seismic sequence of 2012?".**



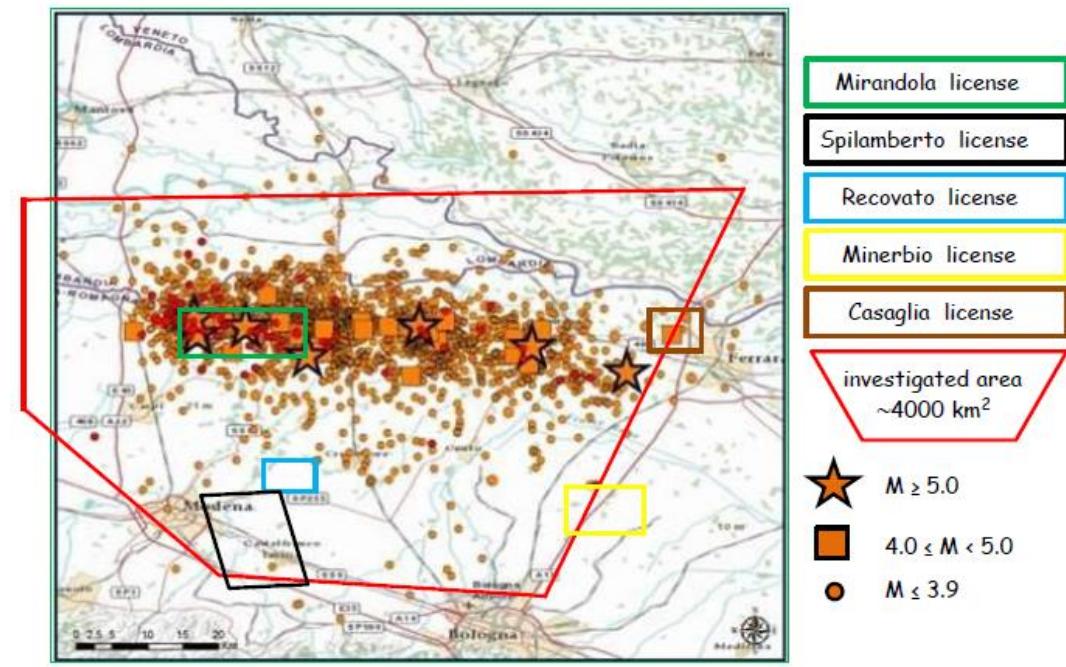
# The ICHESE Report (1)

Epicentral locations of the 2012 Emilia sequence in the period May 19-29, 2012 in proximity to five active licenses for hydrocarbon extraction and re-injection and geothermal energy. The study area is delineated by the red line.

The Commission decided to focus its attention on the nearest fields to the 2012 seismic activity: Mirandola and Casaglia.

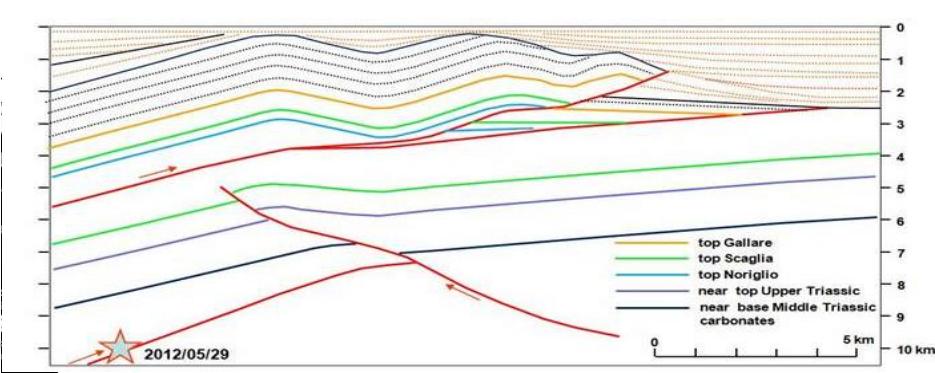
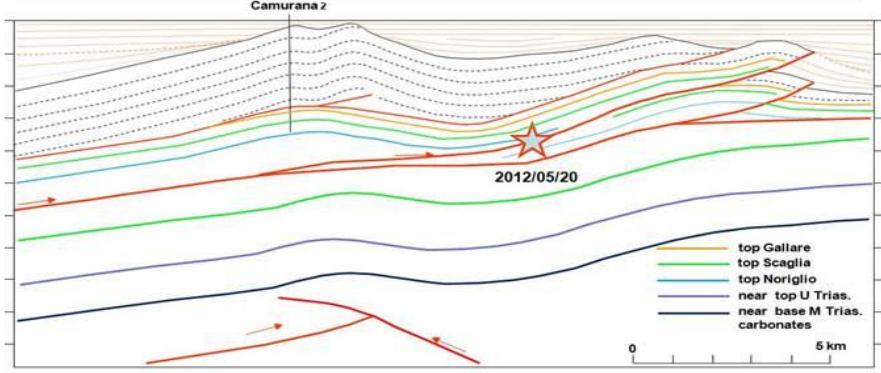
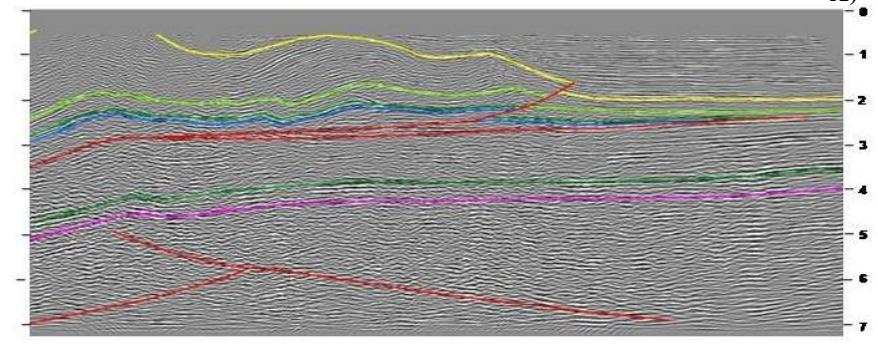
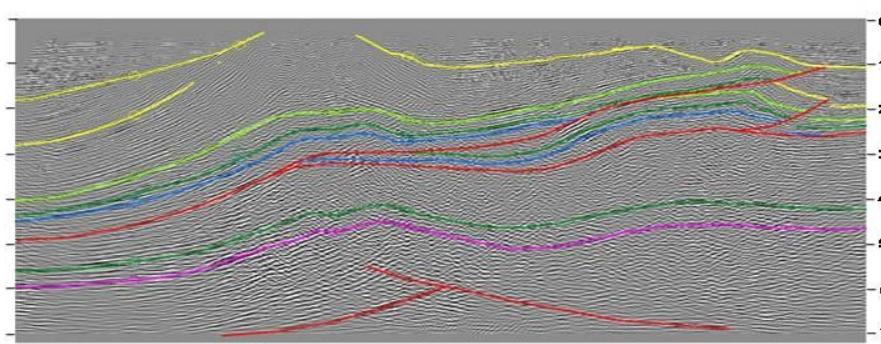
But the Cavone 14 well was the only site carrying out continuous waste-water injection before and during the 2012 seismicity.

Moreover, whereas the Cavone reservoir is located within Mesozoic carbonate formations and may be connected hydraulically to underlying thrust faults, the other reservoirs are in Plio-Pleistocene formations above some impervious units; consequently the connection with seismogenic structures is highly unlikely.



# The ICHESE Report (2)

Interpreted seismic lines (Two Way Reflection Time, TWT in seconds) across the Mirandola anticline and relative depth-converted sections (km) showing the probable causative faults of the 20<sup>th</sup> May and 29<sup>th</sup> May seismic events.



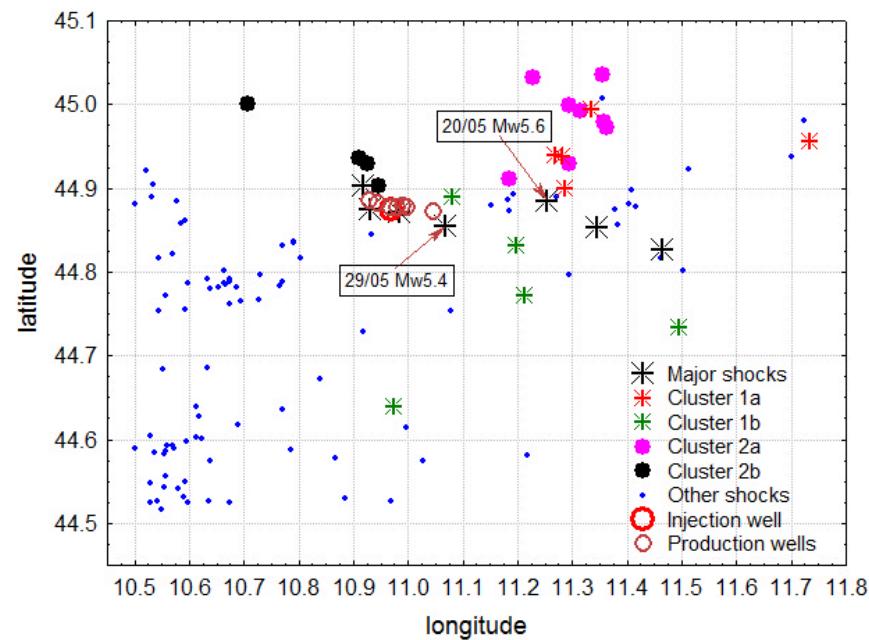
# The ICHESE Report (4)

## Catalogue

120 events in the magnitude range from 1.3 to 4.1ML, May 1<sup>st</sup>, 2005 to May 19<sup>th</sup>, 2012 (INGV) + 7 events M5+, from May-June 2012

## Considering that:

- the event occurrence process is non-Poissonian;
- magnitude distribution changes with time (expressed by changes in b-value with time);
- event rate is not constant and it increased considerably in the last year before the seismic crisis;
- Time-space clustering analysis shows strong connection between 22 events from the studied catalog and seven major shocks. 18 of these events occurred within one year before E-20 major shock and constitute more than half of the events that occurred in that year.

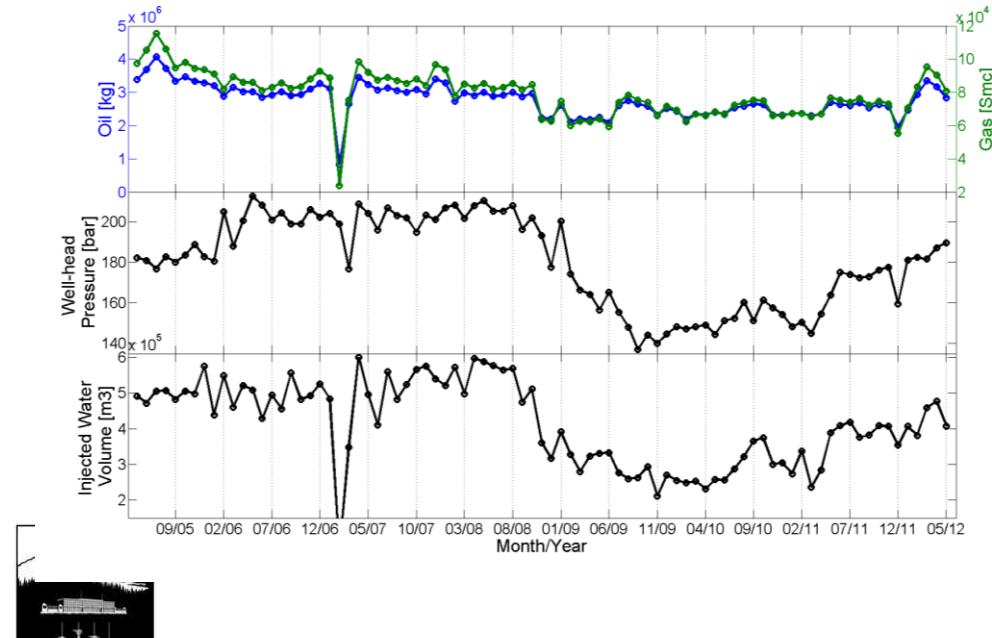


***The studied seismic sequences, at least from the middle of 2008, was in part connected with the subsequent major shock sequence.***

# The ICHESE Report (5)

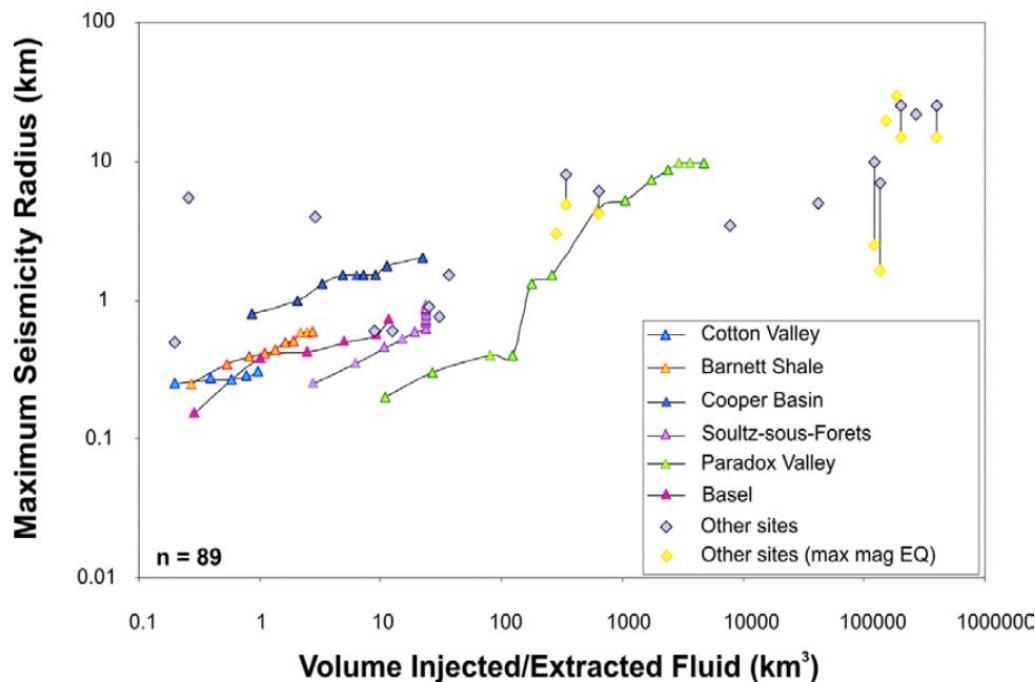
## FLUCTUATING PATTERN

- Simultaneous changes from increasing trend to decreasing trend of monthly extracted and injected volumes of fluid and of the well-head pressures occurred twice. These occurred between 09/2008 and 11/2008 and in 11/2010 and these variations were not correlated with changes in the seismicity.
- A rapid trend change from decreasing to increasing of all the production parameters occurred in April-May 2011, and is statistically correlated with an increase both in number and energy of earthquakes.



*These observations indicate that the last pre-May 20 seismic activity and the May 20 main event are statistically correlated with an increase of extraction and injection activity at Cavone.*

# The ICHESE Report (6)



Maximum radius of induced seismicity from the injection well plotted against the cumulative volume of fluid injected at different stages of injection for six sites. Also plotted are an additional 16 sites where only the total injected volumes and the final maximum radius are reported (Table 4). Data for Cotton Valley and Barnett Shale are from Shapiro and Dinske (2009); Cooper Basin from Baisch et al., (2009a); Basel from Ladner and Haring (2009); Paradox Valley from Ake et al., (2005), and; Soultz-sous-Forêts from Baisch et al. (2009b).

# The ICHESE Report (7)

- The low and negative static stress change generated by the depletion of the reservoir, may argue in favour of a tectonic origin of the whole earthquake sequence.
- The small, positive coseismic stress transferred from the May 20 events to the May 29 faults may explain the second phase of seismicity.
- **However, there are statistical correlations between the increase of seismic activity before the May 20 2012 event and the increase of production parameters since April/May 2011.**

*This means that it cannot be ruled out that the combined anthropogenic actions of extraction and injection of fluids in a tectonically active region may have contributed, adding a minute additional load, to the activation of a pre-stressed fault system, already close to the conditions required to produce a significant earthquake.*

# The ICHESE Report (8)

It is highly unlikely that the activities of hydrocarbon exploitation at Mirandola have produced sufficient stress change to generate an ‘induced’ seismic event.

While it cannot constitute proof, the current state of knowledge and all the processed and interpreted information does not allow the ruling out of the possibility that the actions involved in hydrocarbon exploitation in the Mirandola field may have contributed to ‘trigger’ the Emilia seismic activity.

Therefore in order to build a physical model that supports the statistical analysis it would be necessary to have an image as complete as possible of the dynamics of fluids in the reservoir and in the surrounding rocks.

# The ICHESE Report (9)

After excluding the possible influence of the production activity at four of the five active sites in the study area, (2 hydrocarbon fields, Recovato and Spilamberto, one gas storage field Minerbio, one geothermal field, Casaglia), on the basis of the state of current knowledge, the Commission declared that (ICHESE, 2014):

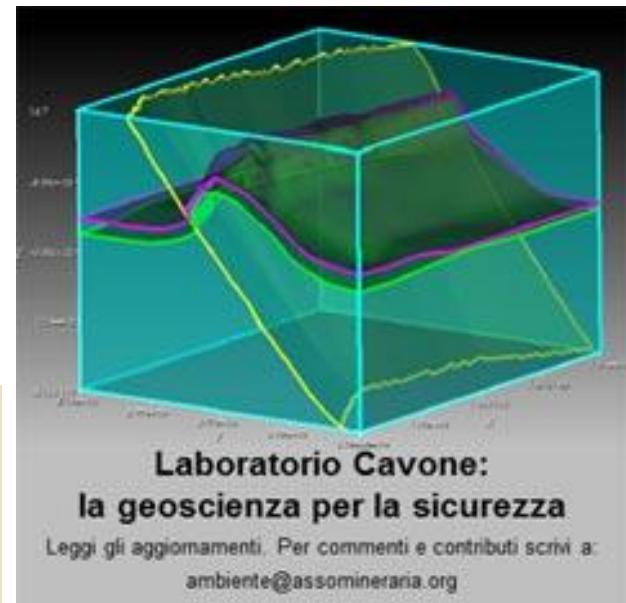
“ [...] the current state of knowledge and all the processed and interpreted information does not allow the ruling out of the possibility that the actions involved in hydrocarbon exploitation in the Mirandola field may have contributed to ‘**trigger**’ the Emilia seismic activity”.



# Consequences (1)

□ Applying the “**precautionary principle**” the Emilia Romagna region halted production in the Cavone (Mirandola fields) and it became a laboratory site (“Laboratorio Cavone”, <http://labcavone.it/>).

While the ICHESE report certainly indicated the possibility of a relation between seismicity and hydrocarbon activity, it did not encourage the application of this principle in this indiscriminate manner.



# Consequences (2)

ICHESE recommended the implementation of **monitoring systems** around hydrocarbon fields located in such tectonically active areas.

On **27 February 2014**, a working group was constituted to define guidelines for the monitoring of hydrocarbon exploitation and storage activities in Italy, in terms of **seismicity, pore pressure and soil deformation**.

The guidelines were issued on **24 November 2014** (<http://unmig.sviluppoeconomico.gov.it/unmig/agenda/dettaglionotizia.asp?id=238>) and will be gradually implemented to a pilot case.



# Consequences (3)

- Guidelines were delivered to all regional governments and the oil/gas companies active in the Italian territory.
- On the 12th of March a Decree Law will be delivered.
- The Decree states that all active oil/gas fields should be monitored adopting such guidelines.



# Conclusions

Although some controversial opinions were expressed in the scientific community regarding the conclusions of the ICHESE Commission, there is a consensus that it represents a **useful first step** in answering the concern of communities about the risks associated to anthropogenic activities.

