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Micro-Seismic Monitoring of UGS

THE "COLLALTO" SEISMIC NETWORK

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Background

Underground Gas Storage is playing an increasing role in European gas markets in order to match supply and demand of gas and to ensure the security of gas supplies. In addition, despite the persisting economic crisis and consequent reduction of gas demand, during the last years, storage operators are requested to offer a wide range of services to allow optimization of delivery system and to ensure a reliable supply of gas. This trend is, perhaps, even more marked in Italy considering the strong dependence on this energy source.

Lately, in this country, storages, and E&P business generally, are "under popular investigation" after the Emilia Romagna earthquake in May 2012 because of the suspicion that tremors may have been triggered by storage activities in that area.

Therefore, following the increasing demand for safety and information by the population living around storages, Edison Stoccaggio entrusted O.G.S. (National Institute of Oceanography and Experimental Geophysics), an Italian public research institute, with the task of developing Collalto Seismic Network (RSC - Rete Sismica di Collalto) in order to obtain a high-quality service and to provide transparent information and public data as well.

The RSC has been operating since January 2012.Based on the first three years (2012-2014) of data monitoring, the RSC detects all earthquakes down to about a local magnitude of 0.0 in the area surrounding the reservoir; thus it is a very effective solution of recognizing possible seismicity phenomena induced by storage activities and allowing the storage Operator to promptly activate proper actions to face the above mentioned phenomena before any consequence for the environment and safety of the people living around the storage.

Aim

In 2008, during the licensing of the extension for the Collalto plant, Edison Stoccaggio signed an agreement with the town of Susegana in order to consolidate the good relationship with the local authorities. In the agreement monitoring of natural and human-induced seismicity was identified as an effective tool of ensuring safe operations of the storage (ex "Marzano law" 239/2004 – Environmental compensations).

The Collalto micro-seismic network (RSC) was developed in order to achieve two main aims:

- introduce technical innovations that allow the acknowledgement of a possible presence of micro-seismicity induced by storage activities, before this phenomenon could trigger any natural seismicity potentially detrimental for the safety of the population living around the storage or for the environment.
- introduce managerial innovations such as full transparency of data and information, in order to support public acceptance of this kind of installations and to enhance collective climate of safety and security around the storage.

As shown in the following paragraphs of this report, the technical criteria adopted and the managing procedures introduced by Edison Stoccaggio in the Collalto experience, have anticipated the conclusions of "Ichese Commission" issued in February 2014 and they have been an example for the "Guidelines" issued by Development Ministry in November 2014.

"Collalto" field and "Collalto" area

Collalto storage is one of eleven underground gas storages presently in operation in Italy.

All these storages are "conventional storages" namely they are natural gas reservoirs located in the Po plain or Alpine/Appeninic foreland and most of them have been operating since mid-20th century.

The Collalto field is located in the North-East Alpine foreland, near the Piave river (municipality of Susegana (Tv).

It has been operating since 1980s as a production field and since 1994 as a storage field; at present the production is nearly finished.

The reservoir consists of sandstones carbonate more or less clayey.

There are seven hydraulically separated mineralized levels (pools), named "A, B, …, G" where the "pool A" is the most deep (about 1500 mt ground level).

"Pool A" and "pool E" were turned into storage given that they are the most important in terms of capacity, in fact they represent about the 80% of the total capacity of the reservoir.

The two storage levels are managed into the limits of their original pressures which are 165 barg (BHP) for the "pool A" and 146 barg (BHP) "pool E" respectively.

Concerning the natural seismicity classification, the area is classified as "zone II" on a scale from IV to I where I is the most dangerous area, according to Italian legislation. (see fig 1)

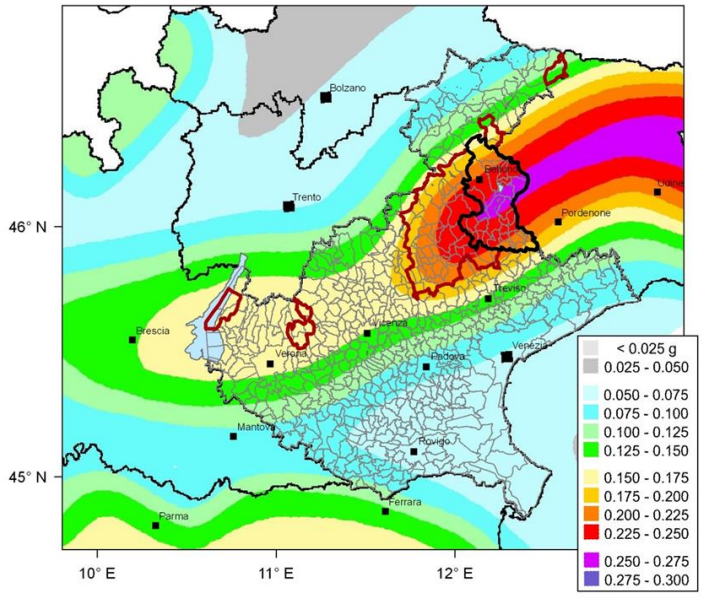

Fig. 1 Seismic hazard map

Collalto Seismic Network

The Collalto seismic network (RSC) has been operating since January 2012. Based on the first years (2012-2014) of monitoring data, the RSC detects all earthquakes down to about a local magnitude of 0.0 in the area surrounding the reservoir.

To obtain these effective results, ten broad-band and high-dynamics stations have been installed around the reservoir of Collalto.

The configuration of the RSC seismometric stations is more dense around the reservoir, where the distance among the stations is about 3 Km, whereas the distance among the stations becomes greater gradually away from the reservoir

This solution allows the definition of two different acknowledgement areas (see fig 2):

- the smaller area, is focused around the reservoir and it is the more sensitive in order to detect possible micro-seismicity induced by the reservoir;
- the bigger area is, also, suitable to detect the natural seismicity of the area.

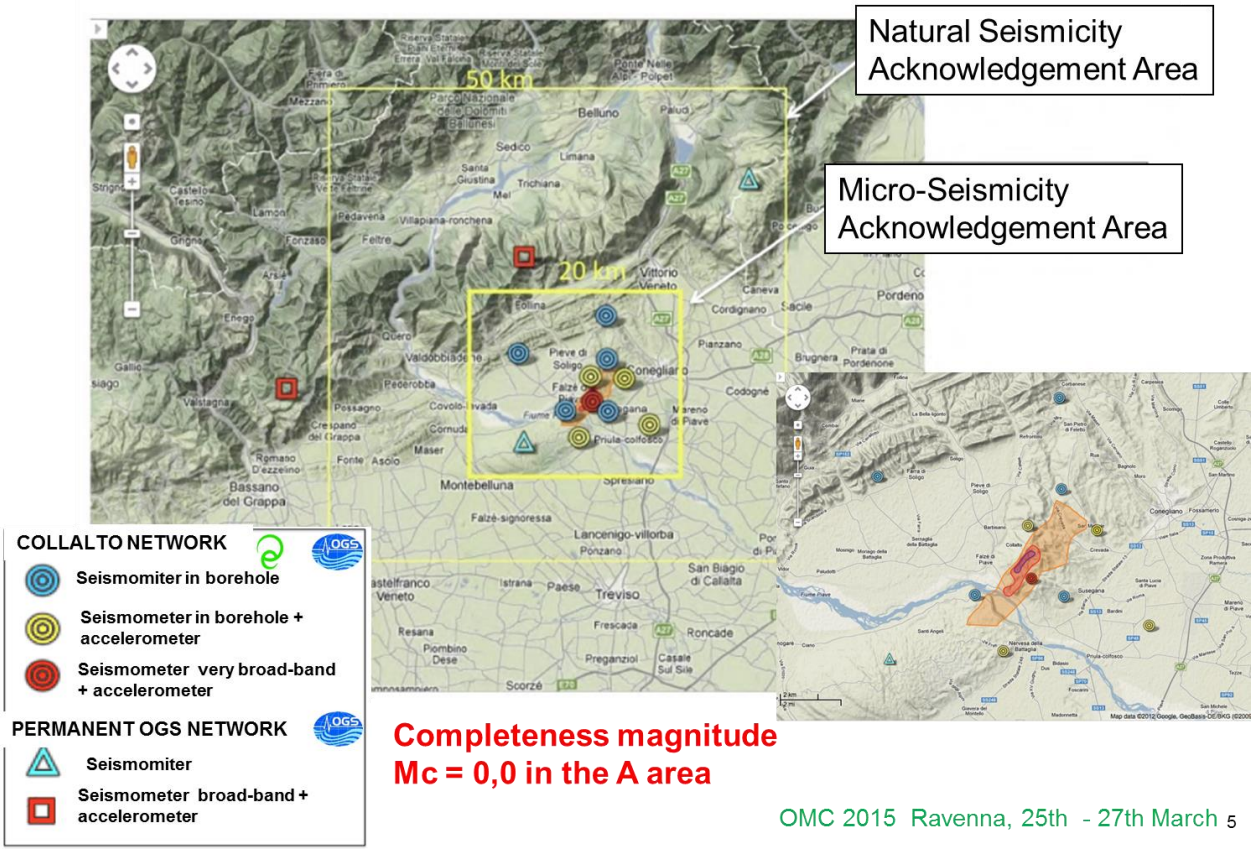

Fig 2 Acknowledgement areas

Moreover, as shown in fig. 3, RSC is gradually integrated with the regional seismic network operated by OGS to achieve the best results in terms of high quality of data.

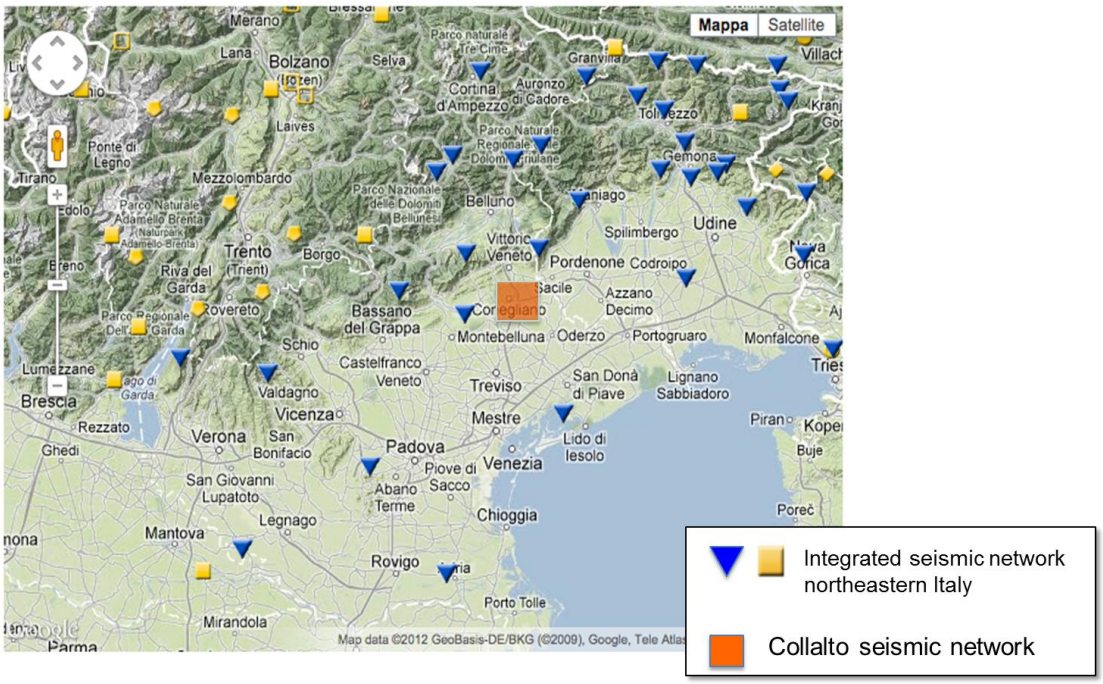

Fig 3: Seisimc Network operated by OGS in the NE of Italy

In order to reduce the background seismic noise and to improve the signal/noise ratio, all seismometric sensors have been installed into boreholes. The depth of the boreholes varies from about 14 m up to 40 m, with the exception of site ED01, located in the plain of the Piave river at the bottom of a 155 m deep well.

The features of the 10 stations are summarized in tab. 1

Tab 1 Characteristics of the 10 seismic stations

Station ID	Kind of seismometer	Station ID	Kind of seismometer
ED01	broad-band stations located in a deep well	ED06	very broad-band and high-dynamics station
ED02	broad-band stations	ED07	broad-band and high-dynamics stations
ED03	broad-band stations	ED08	broad-band and high-dynamics stations
ED04	broad-band stations	ED09	broad-band stations
ED05	broad-band and high-dynamics stations	ED10	broad-band stations

All stations are equipped with data tele-transmission devices and GPS antenna, for accurate real-time data acquisition.

Due to real time data acquisition, it is possible to carry out a real time visual inspection with the monitors installed in O.G.S. Headquarters.

Fig 4: Real time acquisition by monitors in O.G.S.

If there are any events near the reservoir considered "interesting events", a semi-automatic off-line analysis is carried out by the O.G.S. personnel. This manual adjustment is done in order to achieve the necessary accuracy in terms of localization and magnitude of the event given that these features are fundamental in establishing possible correlation with the storage activities.

Transparency of data and information

The most important innovation of the RSC is not technical but rather managerial.

Edison Stoccaggio decided to entrust an Italian public research institute with the task of developing and managing this micro-seismic monitoring network because we strongly believe that an independent scientific institution offers the necessary guarantees to reassure the stakeholders about the reliability of the information related to the monitoring.

Consequently, it provides the storage Operator with a powerful and essential tool in order to demonstrate, by facts, that the operations are implemented safely.

In addition Edison Stoccaggio decided to make an open-access repository of data and publications available to the public.

Edison Stoccaggio was, and still is, the only Company in Italy to make such choices in order to:

- face false information, false beliefs or manipulations;
- support public acceptance of this kind of installations;

- Enhance a climate of collective safety and security around the storage;

All data are freely available at the following web site:

rete-collalto.crs.inogs.it

Finally we organized public meetings with the population living around the storage to present the results and to promote a public debate about this sensitive topic.

The managing procedures introduced by Edison Stoccaggio in the Collalto experience, are in full compliance with the "best practice" set in the "Guidelines" ("*Indirizzi e linee guida per il monitoraggio della sismicità,…omissis…, nell'ambito delle attività antropiche"*) issued by the Italian Development Ministry recently in November 2014.

Results of three years of monitoring

The figure below are shows three years of monitoring (from January 2012 to October 2014);

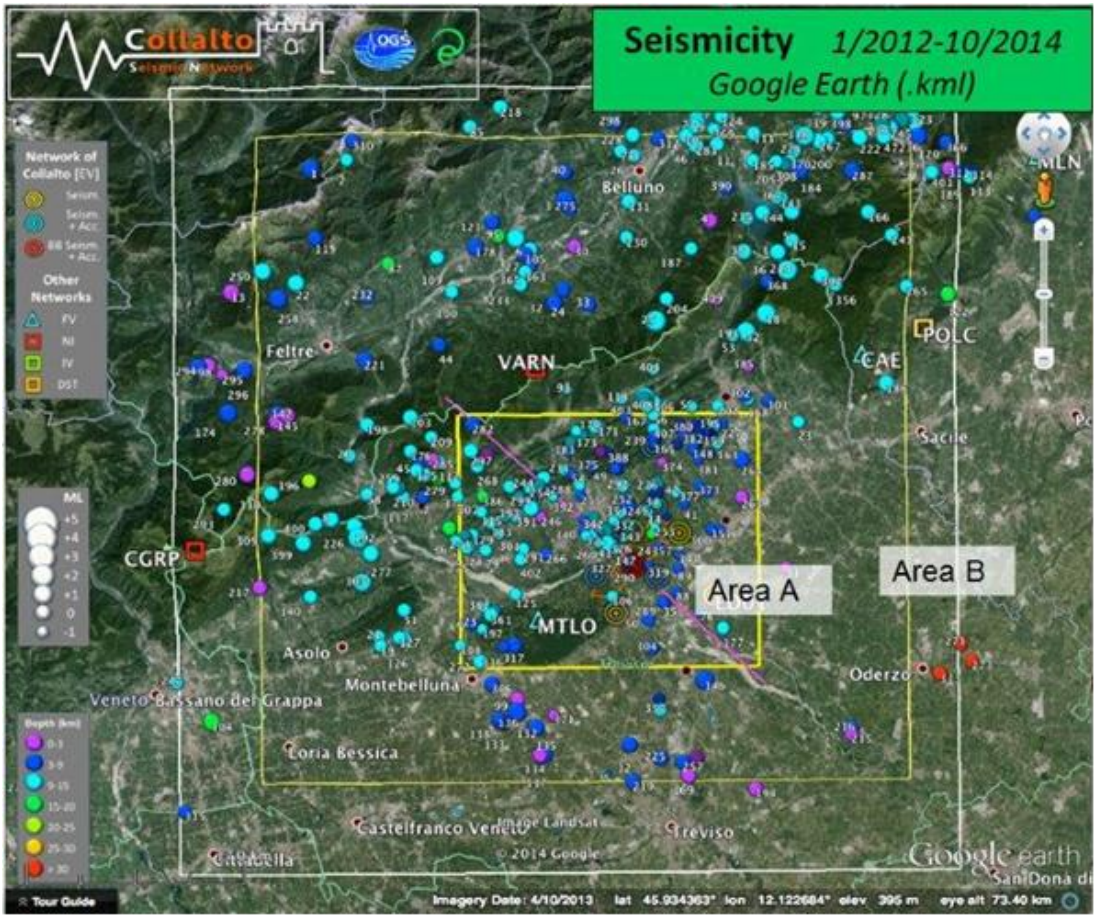

Fig 5: Events detected in about three years of monitoring

In this period RSC has detected 239 events localized in the "Area B" with a local magnitude between -0,4 and 2,9.

The have been 190 events localized in the "Area A" with a local magnitude between -0,8 and 1,3.

It is useful to specify that a phenomenon is classified as "event", in the automatic detection system of RSC, if it is detected by at least three micro-seismic stations.

In this figure it is possible to notice that the seismicity is not equally distributed in the area, but that events are located along the direction from SE to NW.

The reason of this distribution is clearly shown in fig. 6, where, in the same area, tectonic faults known in literature were represented. The box on top represents the section AA' indicated by the red line; in this section it is evident that all the events draw a shape very similar to the above mentioned faults.

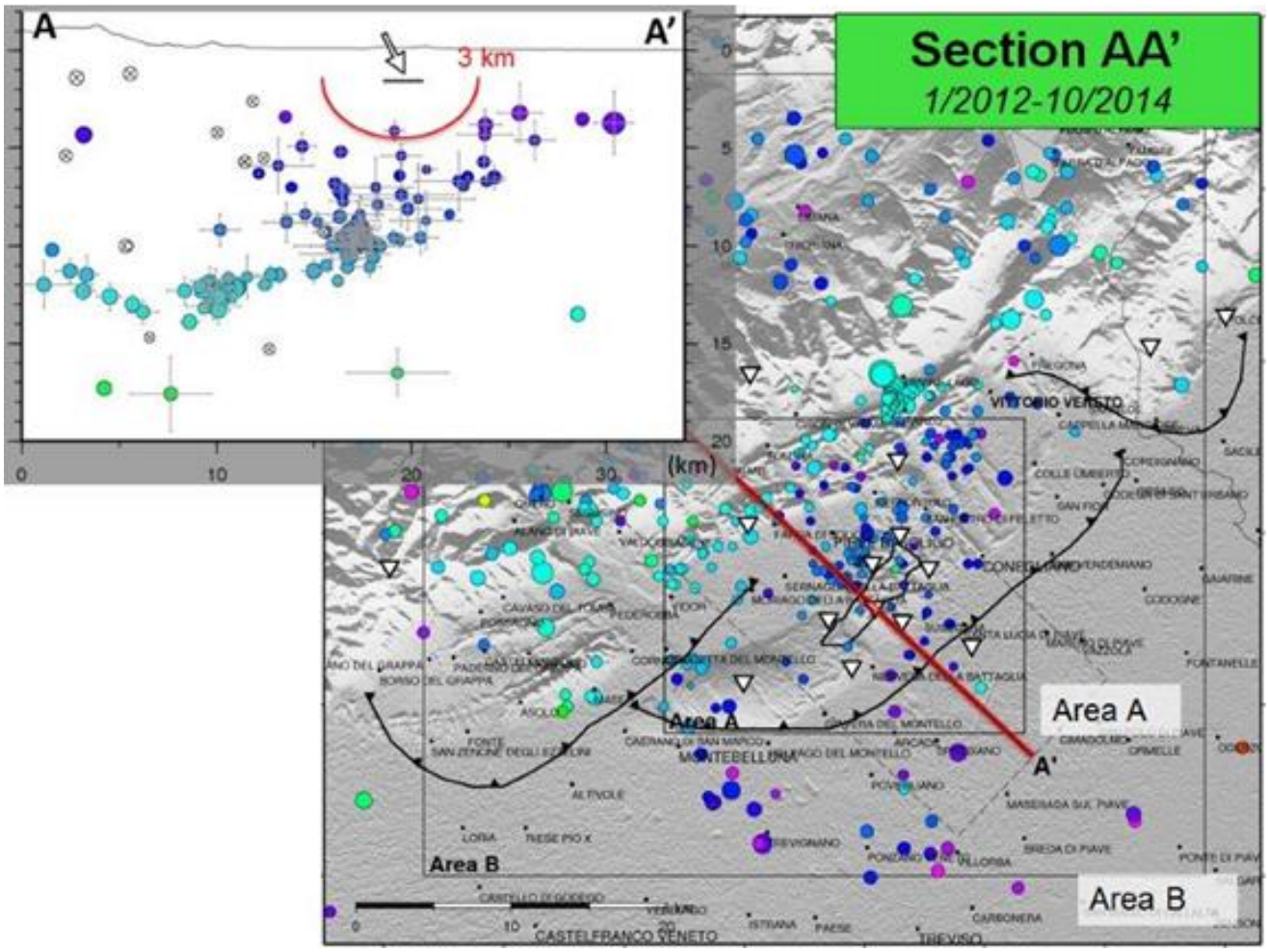

Fig 6: Events detected in the area – Section

Moreover, in this section, the reservoir is represented as a black segment and a red semi-circle around the black segment indicates the distance, in depth, of 3 Km from the reservoir; it is possible to notice that no event has been localized inside this red semi-circle. The event on the border is less than 3 Km deep in section, but the distance from the reservoir is more than 5 Km if we consider a plan view.

According to the above mentioned Italian "Guidelines" issued by the Development Ministry, the absence of micro-seismicity around 3 Km from the reservoir represents a revealing clue in order to exclude any correlation with the storage activities.

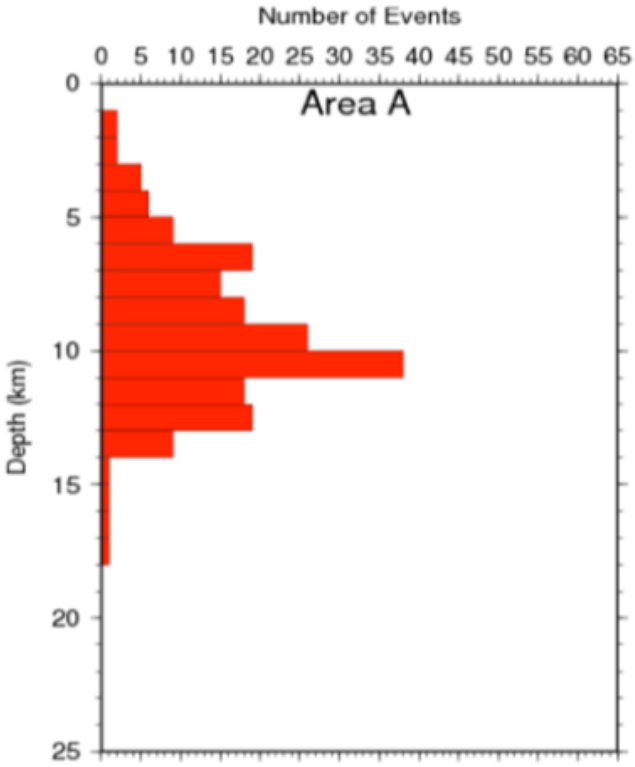

Fig 7: Depth and distance of the events

Fig. 7 shows the depth of the events in the "A area", most of the events are localized about at depth of 10 Km; that is the depth of the above mentioned faults of the area.

The following fig. 8 shows the comparison between the pressures of the reservoir and the flow rate of the gas injected/withdrawn in/from the reservoir, with seismicity rate, that is the number of the events in a given period.

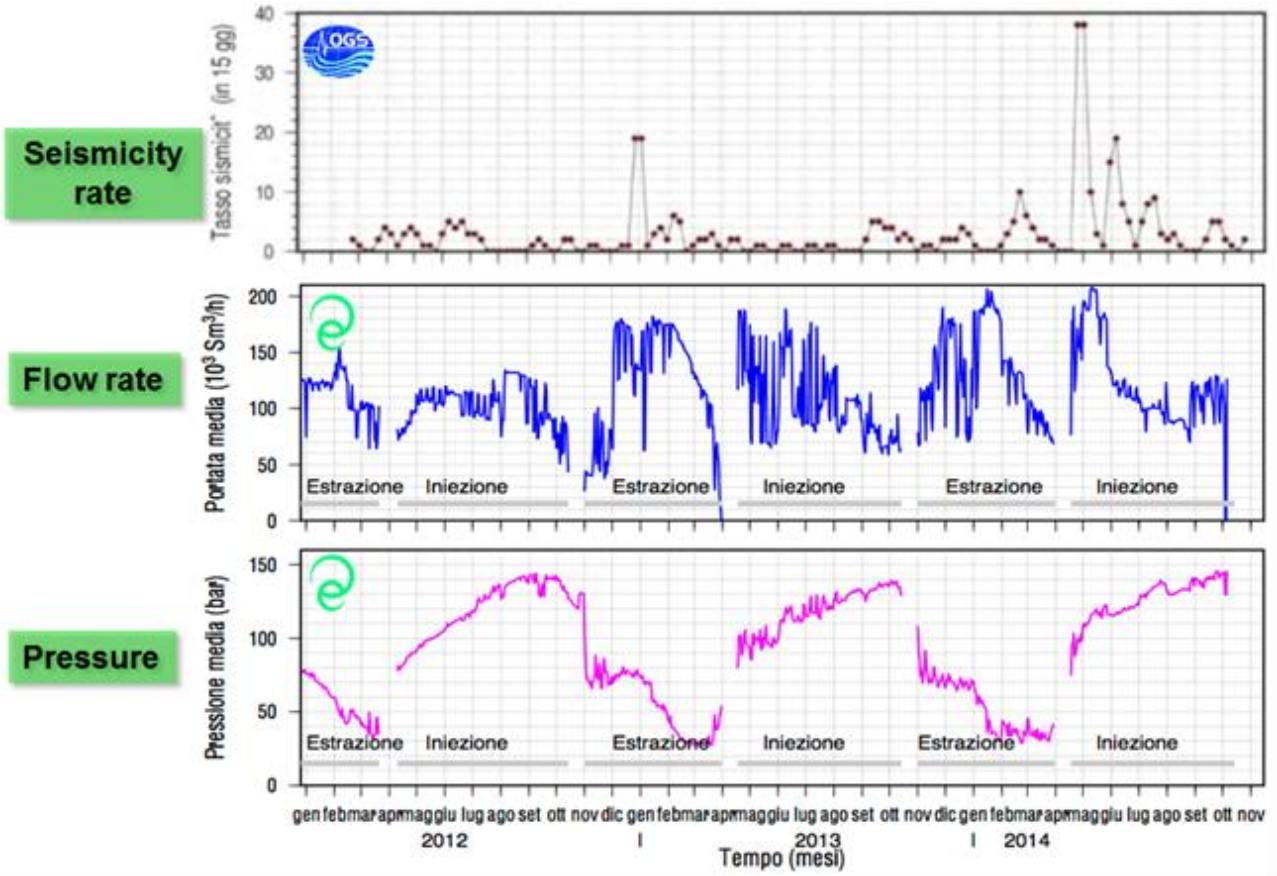

Fig 8: Comparison between seismicity rate and the pressure/flow rate

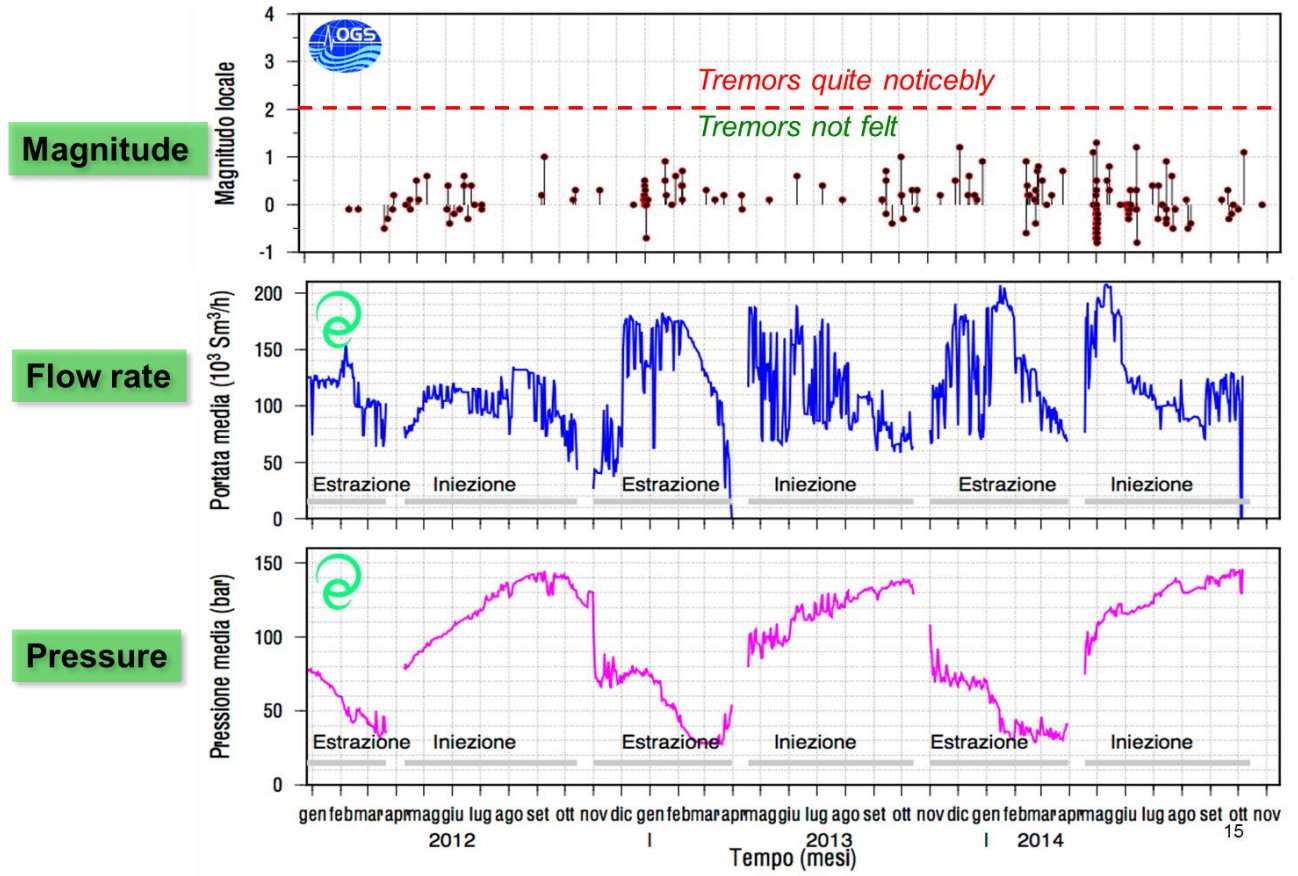

Fig 9: Comparison between magnitude and the pressure/flow rate

Fig 9 shows the comparison between the pressures of the reservoir and the flow rate of the gas injected/withdrawn in/from the reservoir, with local magnitude of the events.

Observing both figures, it is clear that there is no correlation between seismicity detected and the storage activities given that the micro-seismicity detected does not follow the trend of the displacement of the fluid into the reservoir.

Finally, another evidence of the absence of correlation is given by **Gutenberg-Richter law**.

The Gutenberg–Richter law expresses the relationship between the magnitude and total number of earthquakes in a given region and period of time.

This law states that the ratio between the number of large and small earthquakes (named "b parameter") is close to 1 in case of a seismically active region (natural seismicity).

This means, for example, that if the "b" parameter is exactly equal to 1, then for a given quake of magnitude 4.0 there will be 10 quakes of magnitude 3.0 and 100 quakes of magnitude 2.0 and so on.

The events detected by the RSC are sufficient to calculate the relationship magnitude - frequency of Gutenberg-Richter for the Collalto area.

The above relationship is shown in fig. 9; it is possible to notice that the slope b of the segment that approximates and describes the distribution magnitude-frequency, is about 1 as in case of natural seismicity.

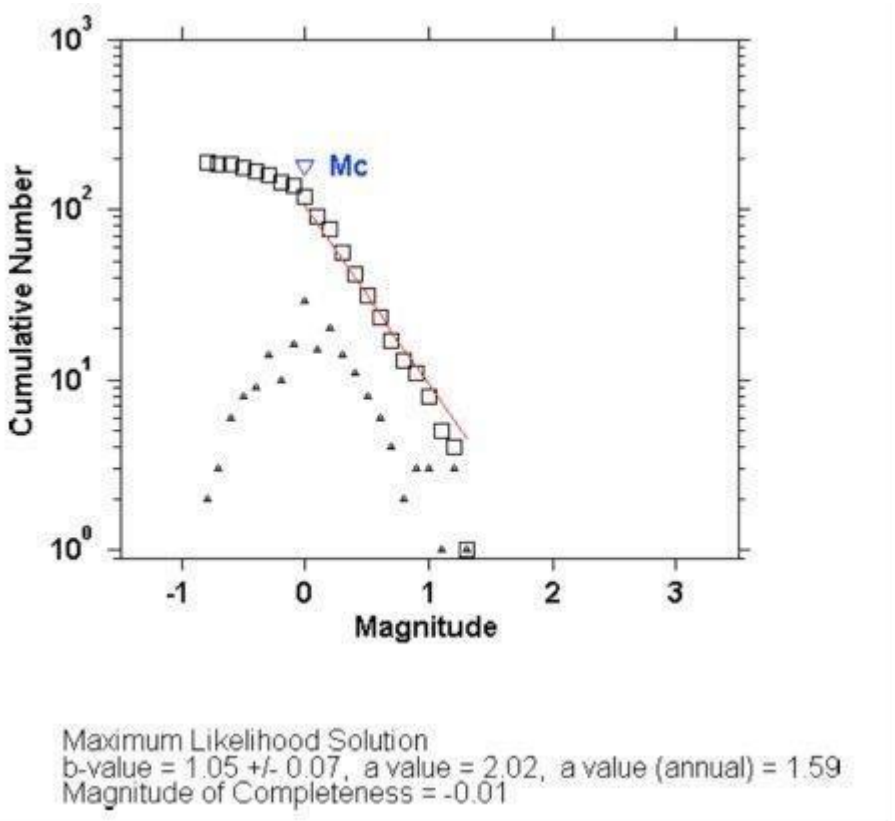

Fig 10: Relationship magnitude – frequency of Gutenberg Richter

In conclusion, it is scientifically accepted, that, unlike natural seismicity, induced seismicity is an evolutionary phenomenon.

In other words it starts around the area of anthropic activity and, following the displacement of the fluid into deep formations, it appears at greater distances gradually.

Nowadays there are not consolidated methodologies of recognizing certainly and promptly the correlation between injection/withdrawal activities and micro-seismicity around the reservoir; nevertheless the Collalto experience shows that manifestation of some of the

following phenomena gives us a significant evidence of understanding whether we are in presence of potential correlation:

- Clusterization of the events near the stress source;
- Increase in number of phenomena in a time unit;
- Correlation with the pressure/flow-rate trends of the fluid injected/withdrawn;
- Variation of the "b parameter" of the Gutenberg-Richter law (ratio between the number of large and small earthquakes);

As shown in this paragraph none of the above mentioned phenomena was observed in Collalto area.

It is therefore possible to conclude that the three years of monitoring allow to demonstrate objectively that micro-seismicity detected is to be considered natural seismicity.

Modus Operandi

Even though Collalto monitoring excludes any anthropic seismicity in the area up to now, it is fair to define the procedures to be carried out, the parties involved in, and their responsibilities in case of potential presence of induced seismicity.

For the above reasons, in April 2014, Edison Stoccaggio has promoted and signed an agreement about "who does what" with "Regione Veneto" and O.G.S., despite the absence of "Guide Lines" recognized by Italian legislation.

The agreement clearly and openly defines the criteria adopted for data analysis, the procedures to be activated, the attention/action thresholds and the responsibilities of the parties involved in seismic monitoring.

The above was considered both in case of normal operations and in case of an emergency due to an induced seismicity by a storage field.

The procedures to be implemented in case of "normal seismic signals" are:

1. Automatic **real time** data processing and **visual inspection** by monitors installed in O.G.S. Headquarters;
2. **Semi-automatic off-line analysis** + manual adjustment (on weekly and monthly basis);
3. **Reports** to Veneto Region containing data detected and reservoir/plant operating data (on semi-annual basis).

In case of "**anomalous seismic signals**" namely in case of signals that are suspected to be related to the storage operations, given that there are one or more clues described in the previous paragraph, the procedures to be implemented are**:**

a. OGS immediately notifies Edison Stoccaggio of this anomaly;
b. Edison Stoccaggio provide all useful information to allow OGS to evaluate the origins of this anomaly and the potential correlations with the storage activities;
c. Edison Stoccaggio informs Veneto Region and the Ministry of the Development;
d. Furthermore, in case of proven correlation, Edison Stoccaggio immediately activates the actions to face this phenomenon properly.

NOTE CONCORDATE TRA OGS, SEZIONE GEOLOGIA E GEORISORSE DELLA REGIONE VENETO E EDISON STOCCAGGIO S.P.A. SULLE MODALITA' DI GESTIONE DEL MONITORAGGIO SISMICO PRESSO LO STOCCAGGIO DI GAS NATURALE DI COLLALTO

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Nel presente documento si riassumono alcune note sulle le modalità con cui viene effettuata l'attività di monitoraggio sismico con la Rete Sismica di Collalto e alcune indicazioni per un ulteriore sviluppo delle modalità di gestione dei dati al fine di:

1. garantire la possibilità di controllo da parte della Regione Veneto sul monitoraggio sismico dell'attività di stoccaggio del gas svolta da Edison Stoccaggio s.p.a. a Collalto, così come previsto dalle prescrizioni ministeriali;
2. rispondere alle esigenze della Regione Veneto per quanto riguarda il monitoraggio sismico regionale per le finalità di Protezione Civile;
3. utilizzare il monitoraggio sismico effettuato con la Rete Sismica di Collalto per prevenire eventuali fenomeni di sismicità indotta.

...omissis...

scientifico in aggiunta ai rapporti semestrali.

24/03/2014

Enrico Priolo, OGS *Alberto Baglioni, Regione Veneto*

Gaetano Annunziata, Edison Stoccaggio s.p.a. *Enrico Schiavon, Regione Veneto*

Fig 1: Agreement among Edison Stoccaggio, Veneto and O.G.S.

It is important to point out that this agreement has anticipated and has been an example for the Italian Development Ministry that issued, in November 2014, the guidelines about technical characteristics and best practice to be adopted regarding the management of these kinds of networks.

Conclusions

In conclusion, RSC represents an important example regarding the best way of approaching a sensitive and delicate subject like the potential correlation between storages and seismic activity.

In fact the Collalto monitoring experience has shown that:

- ✓ Micro-seismic monitoring is an effective solution of recognizing a possible seismicity phenomena induced by storage activities. In addition, it allows the storage Operator to promptly activate proper actions to face the above mentioned phenomena
- ✓ It is necessary for the monitoring network to allow acknowledgment of both strong earthquakes and micro-seismicity with completeness magnitude about 0 in order to carry out proper analysis concerning the anthropic seismicity.
- ✓ The first 3 monitoring years of RSC show that no correlation has been detected between local seismicity and the operations of Collalto storage field.
- ✓ The seismic monitoring of Collalto field is managed by a public institute. This choice is appropriate for ensuring and demonstrating objectively safe operations in the storage and in E&P generally.
- ✓ An open-access repository of data and publications should be made available to public in order to fulfil rising demand for transparency and information by stakeholders, chiefly by the population living around these kind of plants.
- ✓ An agreement among all parties (i.e. competent authorities, company and independent institute) should be signed in order to properly and promptly activate actions to cope with any potential phenomenon of induced seismicity.

Acknowledgements

We would like to thank the Municipality of Susegana especially the former Mayor G. Montesel and the present Mayor V. Scarpa since they have shown that the main goal of their mandate, i.e. the protection of rights and interests of their citizens, is not in contrast with the development of mining activities, if these activities are managed in the full respect of the environment and in a safe way.

Finally we would like to thank all the colleagues in O.G.S. and all the colleagues in Edison Stoccaggio that took part in this project. Each of them has been essential in solving technical issues and/or in contributing to the definition of the management procedures of the network in absence of guidelines in Italian legislation.

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