HYDROQUAKES: A PILOT STUDY IN THE CENTRAL-SOUTHERN APENNINES FOR THE REALIZATION OF A HYDROGEOCHEMICAL MONITORING NETWORK FOR SEISMIC PRECURSORS AND OTHER SOCIETAL APPLICATIONS

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ABSTRACT

The aim of this work is to provide a methodology for the investigation of seismic precursors starting from hydrogeological, hydrogeochemical, and seismic study of the territory. Hydrological effects originated during the seismic cycle (particularly prior to and during strong earthquakes) have long been observed and documented, as they are among the most outstanding coseismic phenomena that can be even observed over great distances. Moreover, since a few decades, geochemical changes of groundwater prior to intermediate and/or strong (Mw ≥ 5.0) earthquakes have started to be a concrete hope and, at the same time, a big scientific and technological challenge for geoscientists working in the field of seismic precursors. Deformation and stress perturbation during the seismic cycle can cause changes in deep fluid migration eventually leading to changes in shallower groundwater circulation and geochemistry. As monitoring sites, we identified the Sulmona and Matese areas in the central-southern Apennines. These two areas were affected in the past by Mw > 5.5 earthquakes. Each study area includes 5-6 monitored springs and boreholes. Groundwaters are mainly calcium-bicarbonate type or secondarily sulphate-calcium-bicarbonate type. Continuous monitoring and monthly sampling of the two study areas started in December 2017, although in the Sulmona area they had already started in 2014 for a previous project, whose results have been published in previous papers. In an attempt to identify potential seismic precursors, we carried out, for each monitored spring, analyses of major and trace elements and analyses of isotopes of the water molecule, boron, and strontium. During these years of monitoring (2018-2019), there were no high magnitude earthquakes. The three seismic events with the highest magnitude were indeed the 2019 Collelongo (Mw 4.1, January 1st), Balsorano (Mw 4.4, November 7th), and San Leucio del Sannio (Mw 3.9, December 16th) earthquakes. The most interesting result is that these earthquakes (except Collelongo) were not substantially preceded by hydrogeochemical anomalies. This evidence suggests that this type of pre-seismic anomalies could arise substantially only with intermediate and strong earthquakes (Mw ≥ 5.0); however, it is also true that the Collelongo earthquake, which occurred on a very large Apennine normal fault (the fault that generated the great Avezzano earthquake of 1915, Mw 7.0) at great depths (16-17 km), was preceded by very weak hydrogeochemical anomalies of Li, B, and Sr in most monitored springs. These weak anomalies could be related to pre-seismic breakages at great crustal depths along a very large fault. We also describe the monitoring stations as well as the used instrumentations, procedures, and analyses. We propose some preliminary results that emphasize the importance of collecting data from a widespread network of monitoring stations over a seismic territory and for long time. HydroQuakes provides new evidence for the importance of building a national hydrogeochemical network for the identification of seismic precursors. Future possible implementations as well as further societal uses for such a network are also addressed. The HydroQuakes Project is funded by Fondazione ANIA to CNR-IGAG.

MONTHLY SAMPLING, IN SITU MEASUREMENTS, AND REMOTE CONTROL

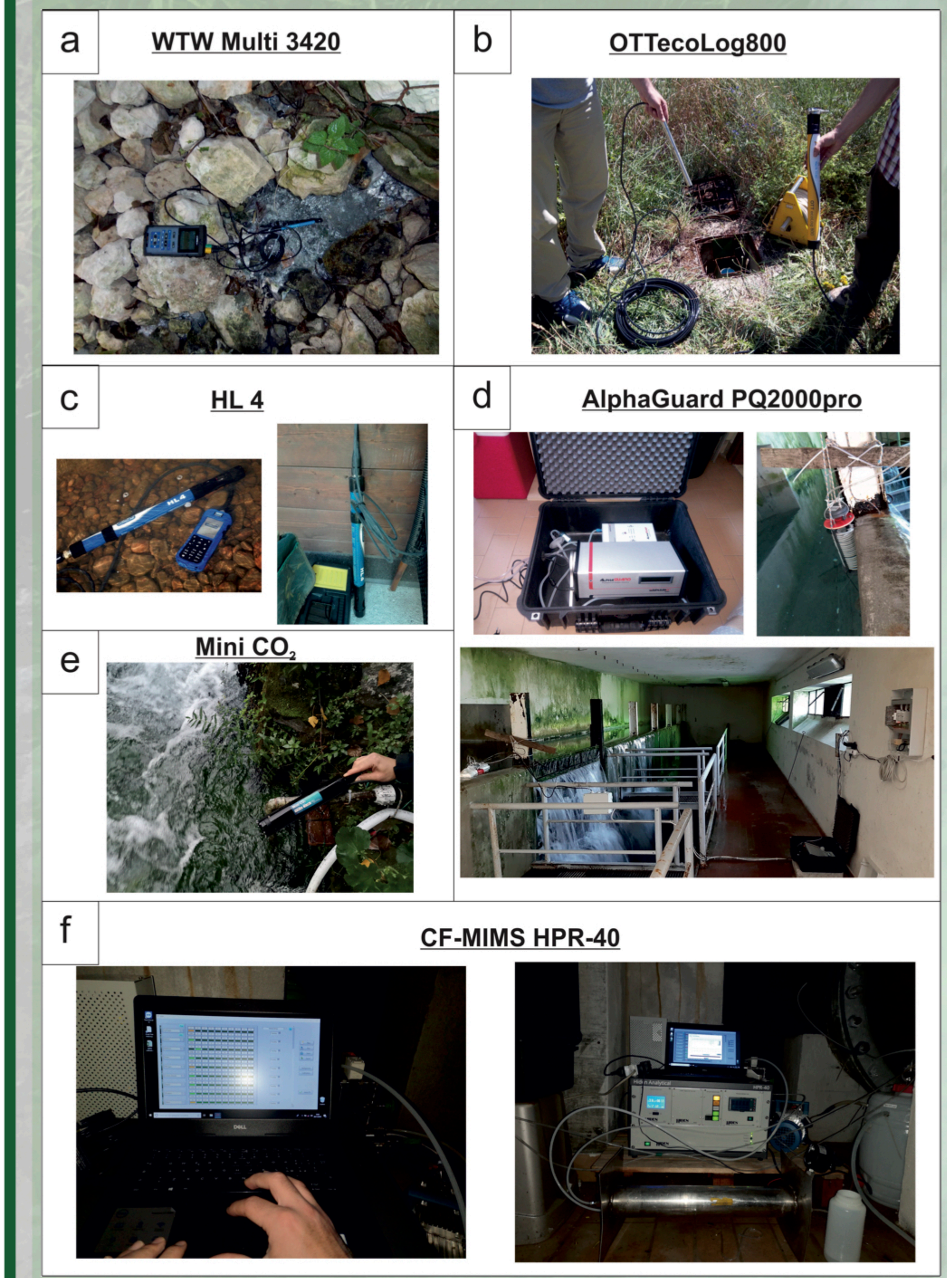

Fig. 3 - Probes installed in monitoring stations

Each month, we in-situ-measure temperature, pH, and electrical conductivity (EC) (Fig. 3a).

Each month, we collect samples for the analyses of:
- major and minor elements,
- δ^2H and $\delta^{18}O$.

Sporadically, we collect samples for the analyses of:
- $\delta^{11}B$,
- $^{87}Sr/^{86}Sr$,
- $\delta^{13}C$.

In some stations, we installed:
- 2 probes for measurement of temperature, groundwater level, pH, dissolved oxygen, and electrical conductivity (OttEcolog800 by Hydromet, Fig. 3b; Hydroloab HL4 by Hydromet, Fig. 3c) at the borehole PF 60.3 and Grassano spring;
- 3 probes for dissolved radon measurement (AlphaGUARD Model PQ2000PRO by Saphymo, Fig. 3d) at the Giardino, Bojano, and Grassano springs;
- 2 probes for dissolved CO_2 measurement (Mini CO_2 by Pro-Oceanus, Fig. 3e) at the Giardino and Grassano springs;
- 1 spectrometer for continuous measurement of Hydrogen, Nitrogen, Neon, Oxygen, Argon, Carbon Dioxide, Helium, Methane, and Krypton dissolved gases (Continuous Flow Membrane Inlet Mass Spectrometer, CF-MIMS by Hiden, Fig. 3f) at the Bojano spring.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

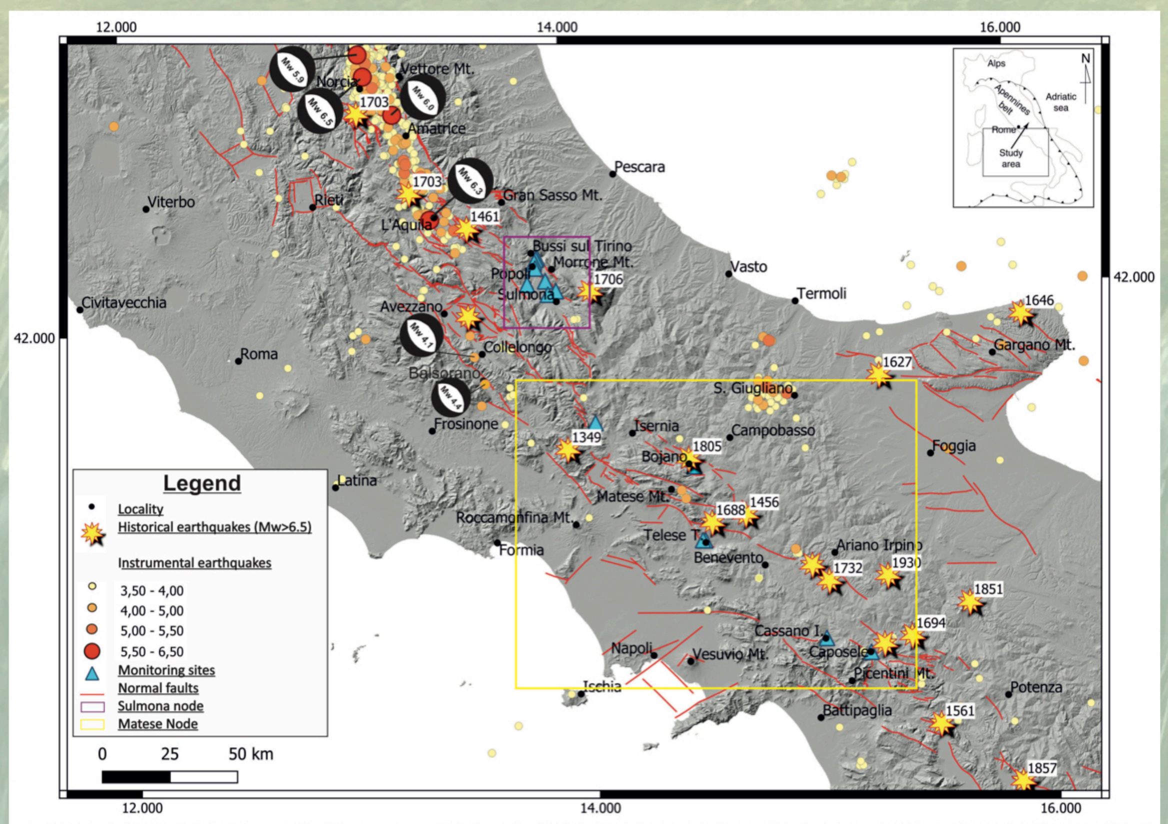

Fig. 1 - Geological setting. Location of the well and springs monitored and analyzed in this work.

The Sulmona area (Fig. 1) is located between the Gran Sasso and the Mt. Morrone carbonate aquifers. The carbonate aquifers host regional groundwater flow and feed springs located at ridge piedmonts, which frequently correspond to active normal faults.This deep contribution is increased by active faults and related deep rock deformation (Petitta et al., 2011, 2015; Fiorillo et al., 2015; Barberio et al., 2017, 2018).

The Matese massif (Fig. 1) is an important carbonate aquifer formed by a Meso-Cenozoic (mainly Cretaceous) carbonate succession about 2000 metres thick (Civita, 1973; Celico, 1978, 1983). The Matese massif is bounded at the edges by flysch deposits that come into contact with the massif itself through normal and thrust faults.In this area, waters are mainly of calcium bicarbonate type. Very important for hydrogeological purposes is the epigean and hypogeal karst phenomena, strongly developed and able to determine the widespread presence of feeding ratios between surface runoff and groundwater (Ruggiero, 1926; Lambiase and Ruggiero, 1980; Santo, 1991).

THE NETWORK NODES

Each monitoring node of the HydroQuakes project include a set (5-6 in each node) of monitored springs and boreholes. We chose the two nodes (Sulmona and Matese) of the HydroQuakes project on the basis of seismological and hydrogeological reasons.

The predominant water type of the monitored springs is calcium – bicarbonate, with some more mineralized springs that are calcic sulphate – calcium – bicarbonate waters (Fig. 2).

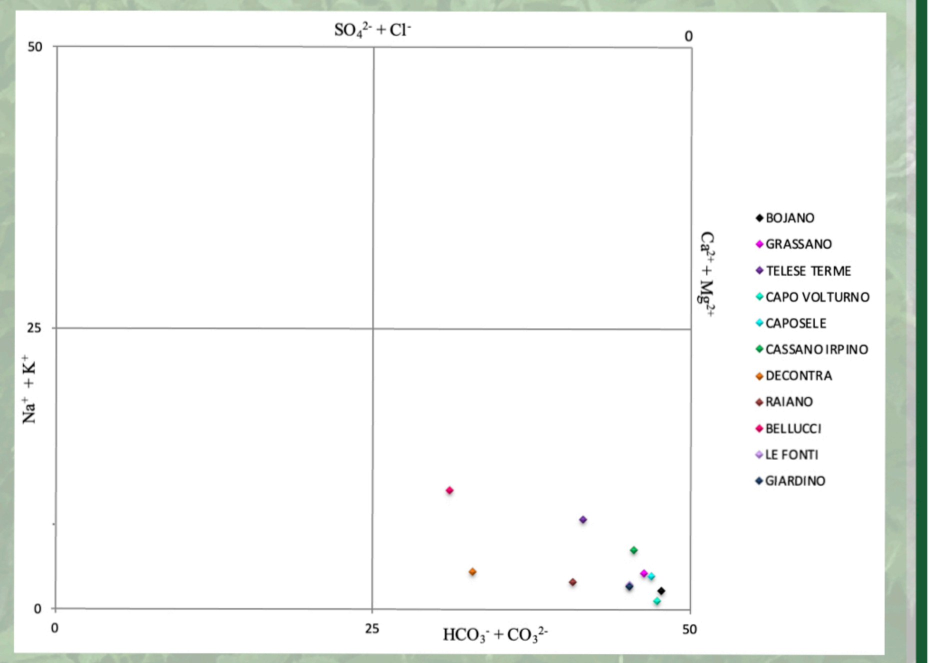

Fig. 2 - Chebotarev's classification diagram for groundwater

RESULTS

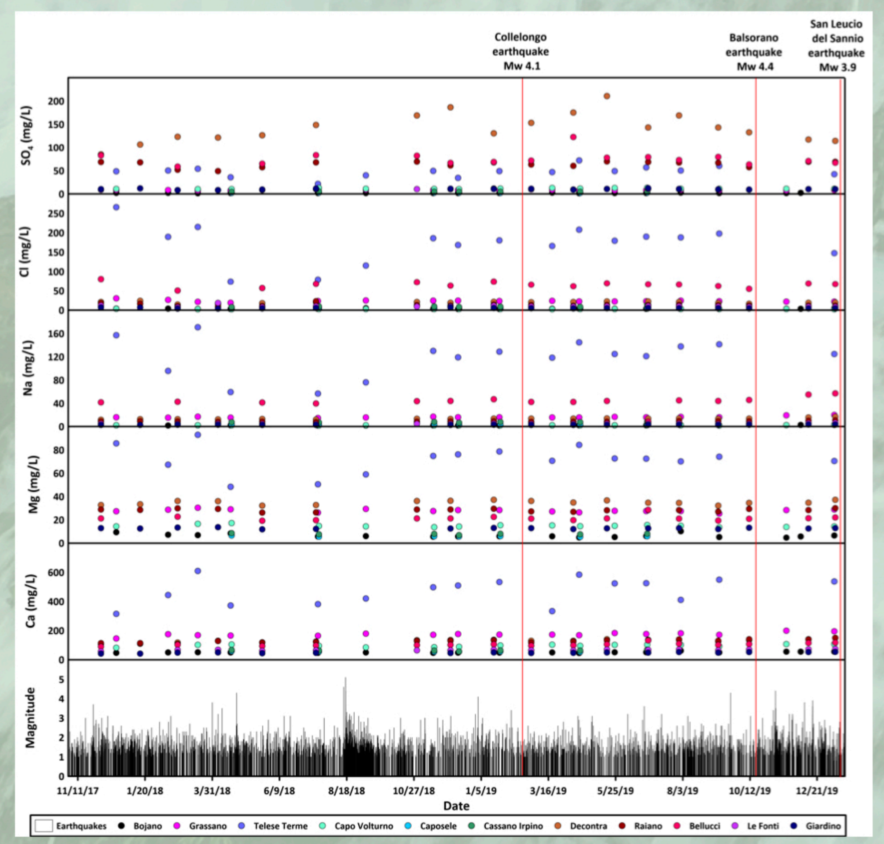

Fig. 4 - Time series of major elements

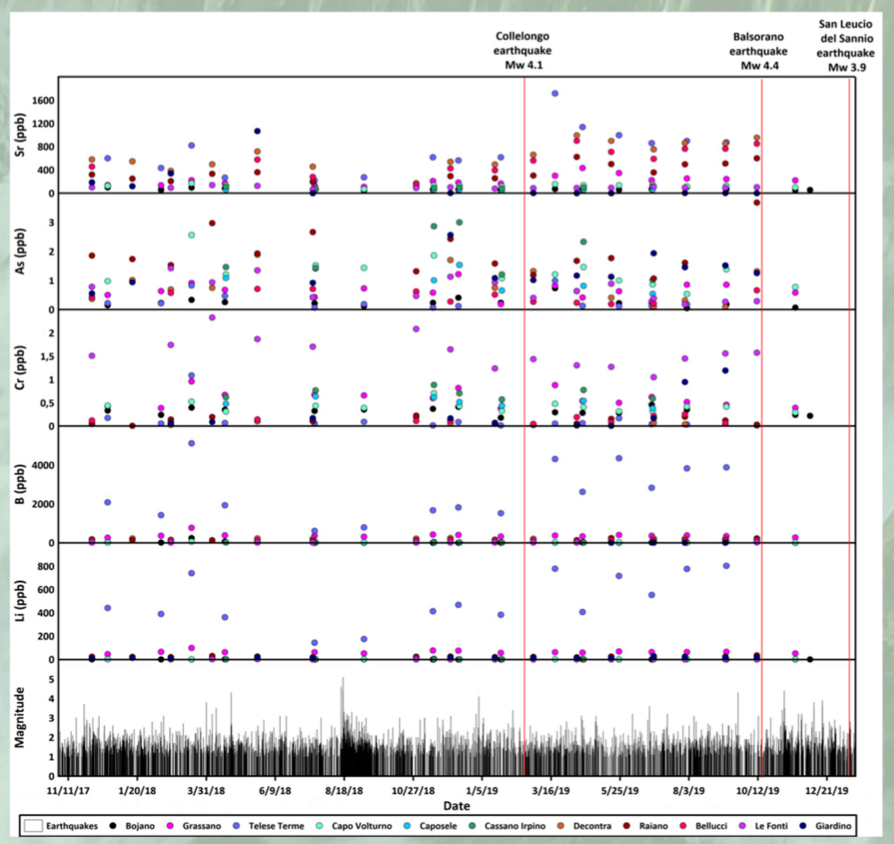

Fig. 5 - Time series of trace elements

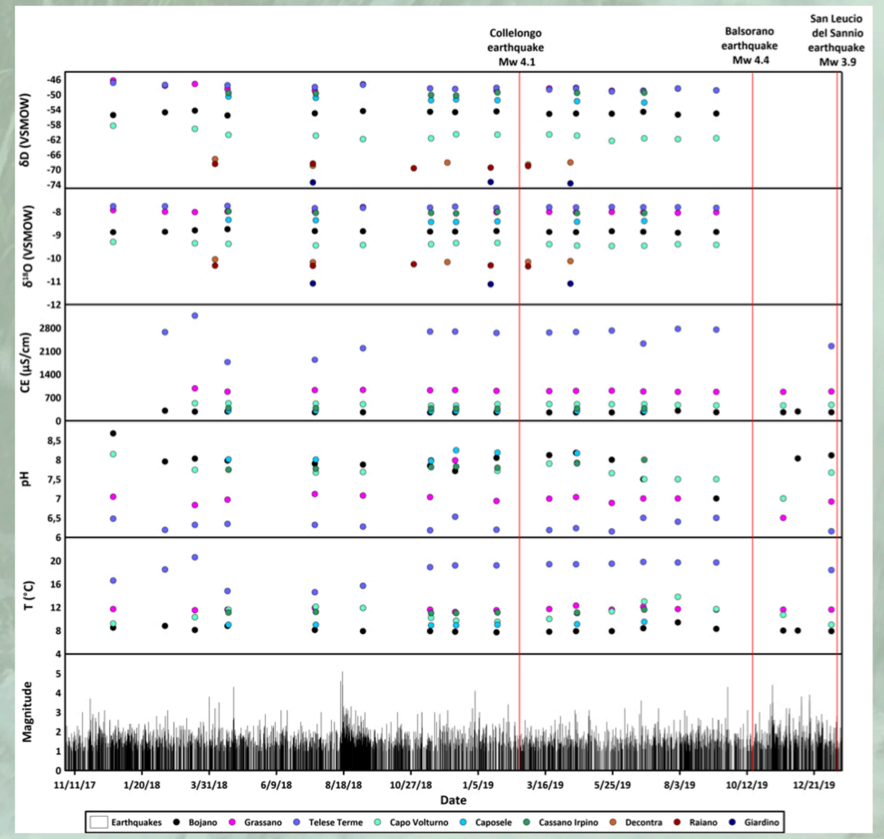

Fig. 6 - Time series of physico-chemical parameters and δ^2H and $\delta^{18}O$

From a hydrogeochemical point of view, the water of all springs have shown to have a substantial invariability over time of the elements analyzed during the years of monitoring (December 2017 – December 2019) (Figs. 4-5-6).

During these years of monitoring, there were no high magnitude earthquakes. The three seismic events with the highest magnitude were indeed the 2019 Collelongo (Mw 4.1, January 1st), Balsorano (Mw 4.4, November 7th), and San Leucio del Sannio (Mw 3.9, December 16th) earthquakes.

In November 2018, two months before the Collelongo earthquake, small increases were recorded in concentrations of Li, B and Sr in all springs except Caposele and Cassano Irpino; in the spring Le Fonti there was an increase only in the concentration of strontium (Fig.5).

DISCUSSION

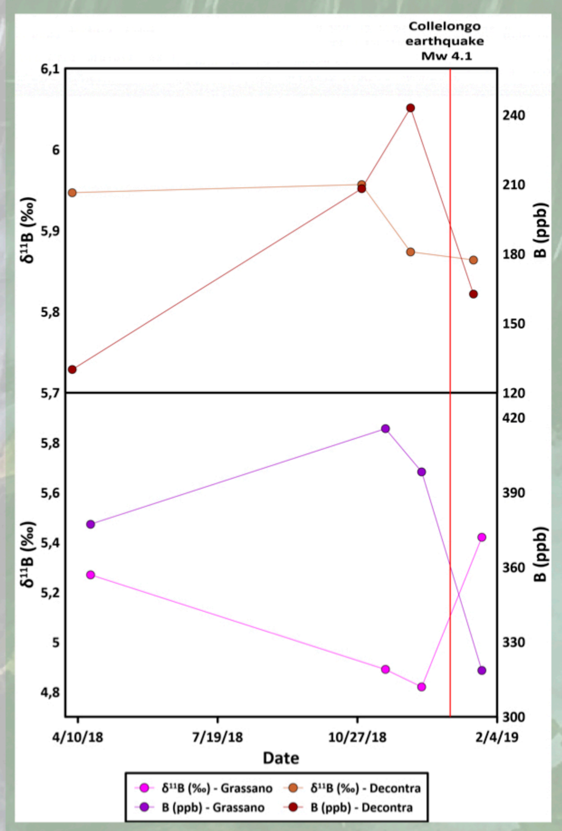

Fig.7 Time series of $\delta^{11}B$ and B concentration

In November 2018, two months before the Collelongo earthquake (1st January 2019), we recorded an increase in the concentration of Boron and a corresponding decrease in the $\delta^{11}B$ isotope (Fig.7). The following month the concentration of boron began to decrease, returning to the usual concentration values after the earthquake of January 1st, while the value of $\delta^{11}B$ tends to increase after the earthquake. These results show the simultaneous boron concentration increase and boron isotope ratio decrease prior to the seismic events, may be related to desorption from mineral surfaces.

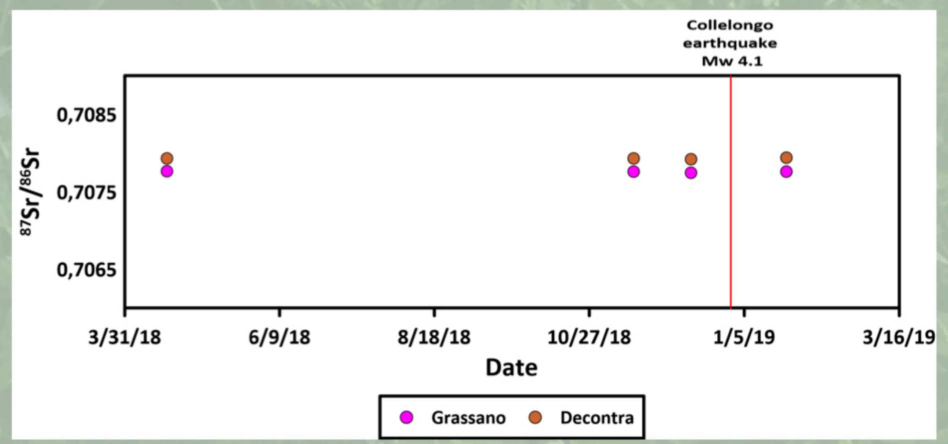

Fig.8 Time series of $^{87}Sr/^{86}Sr$

The results of the isotopes of strontium (Fig. 8) show minimal differences, at the limit of the measurement error. This indicates that the isotopic signature of strontium is always the same and that therefore the circuit has not changed but that there may have been different water-rock exchanges.

CONCLUSION

In these two years of monitoring we have, therefore, recorded some small signal but that is not defined enough because inside the typical seasonal variations of the monitored springs. This result allows us to say that we cannot record hydrogeochemical seismic precursors for earthquakes of less than Mw < 5.

Since September 2019 the following probes, AlphaGUARD, Mini CO2 and CF-MIMS, are connected to an on-line acquisition system developed by Digimatic s.r.l. (http://www.digimatic.it/Home.html). The system allows the operators to display and download all acquired data in real-time.

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