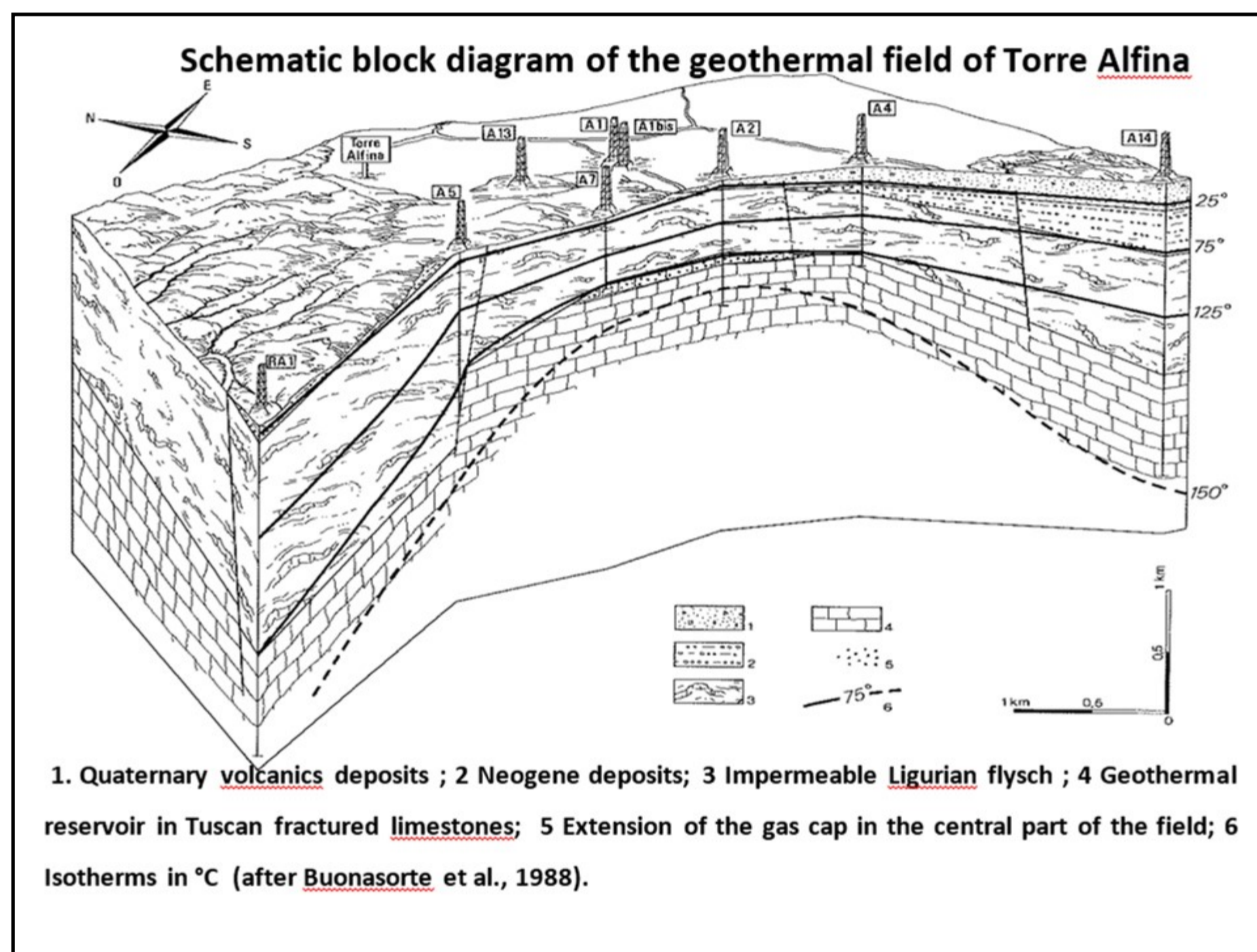


Environmental pre-exploitation monitoring of Torre Alfina geothermal system (Central Italy)

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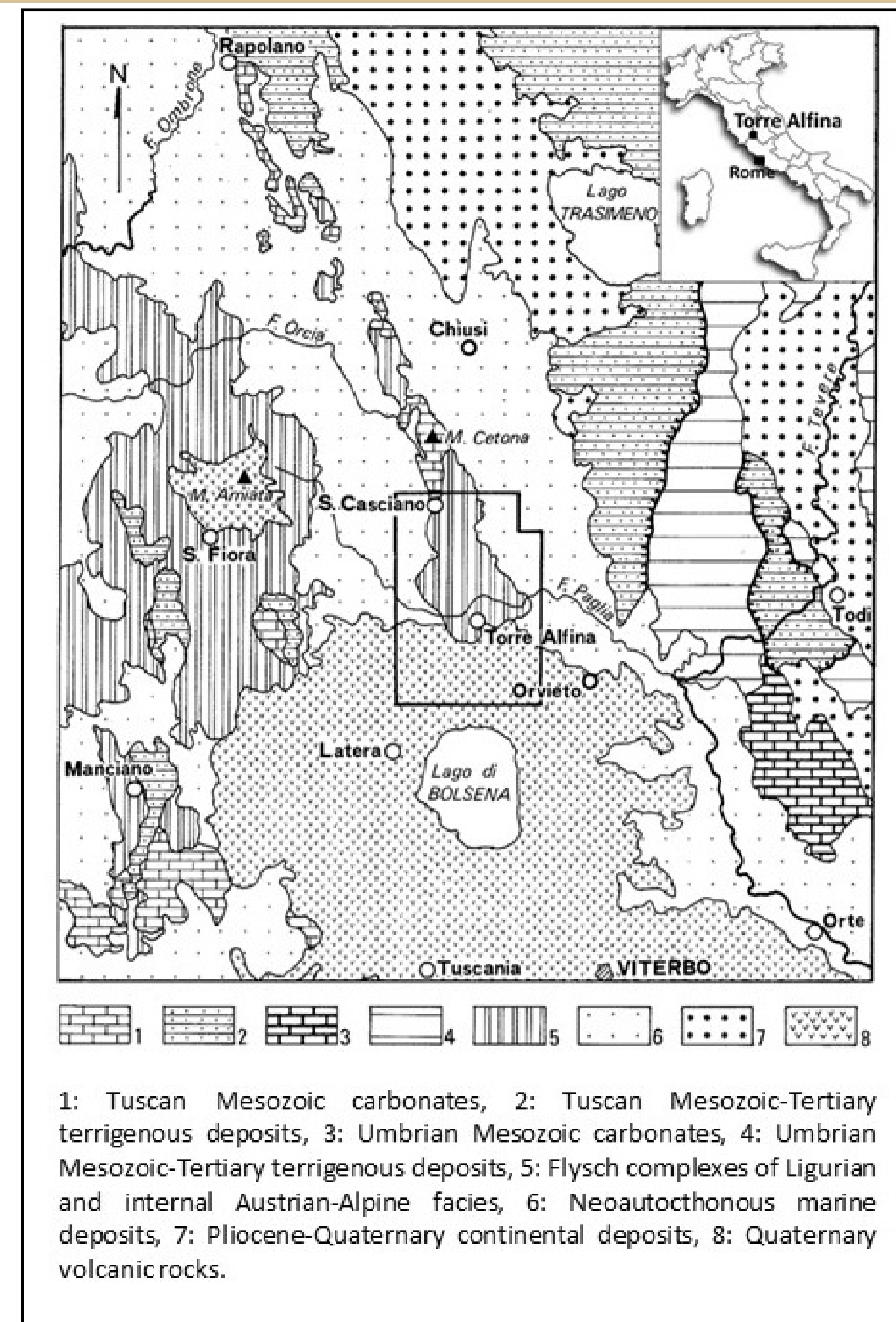
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An interesting project of geothermal pilot plant, with no-gas emission in atmosphere, has been submitted for approval in the medium-enthalpy geothermal field of Torre Alfina. This prompted us to develop a geochemical and geophysical monitoring of the area with the aim of establishing a background information to recognize anomalous gas emission, induced seismicity and subsidence, possibly related to the field exploitation. The exploration conducted by Enel in the years '70-'80, including the drilling of 9 deep wells, has shown the existence of a medium-enthalpy geothermal field in the Torre Alfina zone, in central Italy. The area has been affected by a very complex geological evolution during the Neogene. It was affected by the Quaternary volcanism of the Tyrrhenian margin which, reached its climax between 0.6 and 0.3 Ma. The present stress field around Quaternary volcanoes of central Italy has a NE to ENE direction of extension, in agreement with the alignment of Quaternary volcanoes and earthquake fault plane solutions, with T axes preferentially oriented between NE and ENE.



The geothermal reservoir is located in fractured Mesozoic carbonate rocks of the Tuscan series, forming a structural high, whose top is located at 500-600 m depth. In the central area of the field, in the upper part of the reservoir, a gas cap is found consisting essentially of CO₂, which has long been exploited. The impermeable cover of the reservoir is provided by allochthonous Units of the Ligurian flysch. The surface of volcanic rocks host an important cold aquifer extensively exploited for civil uses.

The geothermal fluid contained in the reservoir is a medium enthalpy (T = 140 °C) hot water with TDS = 5000 ppm, containing about 2% by weight of dissolved CO₂. The CIRM Commission of the Ministry of Economic Development approved the work program of two geothermal pilot plants, each of 5 MWe included under Legislative Decree 22/2011, which released the use of ORC binary systems; total reinjection of the fluid extracted in the same reservoir, and no emission of fluid to the atmosphere. The most advanced project is Castel Giorgio in Umbria Region for which the Ministry of Environment approved the environmental compatibility.



Based on an agreement with the operator, the National Institute of Geophysics and Volcanology (INGV) must ensure the following monitoring of the project area:

- Geochemical Monitoring:** periodic monitoring of soil CO₂ flux in the proximity of wells to be drilled in order to ensure that no abnormal gas emission will occur during drilling and exploitation; monitoring of CO₂ and H₂S air concentrations at the ORC plant and well heads; chemical monitoring of the water mass to check for possible contamination by geothermal fluid.
- Geophysical Monitoring:** installation and management of a local seismic network for monitoring ante-operam seismicity, which the aim of recognize and study the possible future seismicity induced by fluid extraction or re-injection (the first 6 stations with 3 components are operating from May 2014); monitoring of possible subsidence through a network of GPS sensor and InSAR satellite monitoring (the system will be activated in autumn 2015).

The microseismic network

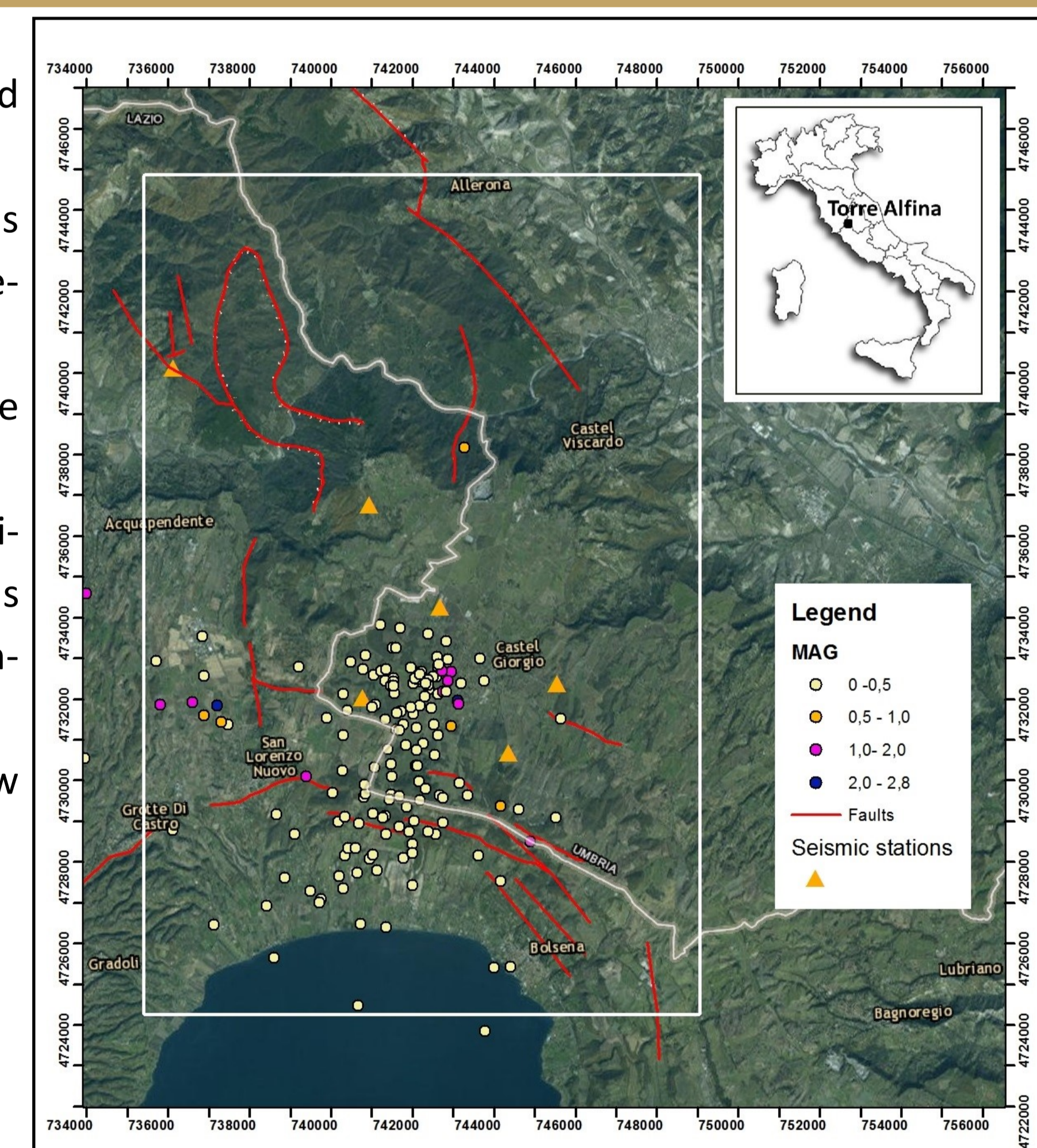
The microseismic network of Castel Giorgio -Torre Alfina, was designed to study both the natural seismicity of the area and the possible seismicity associated with geothermal fluid extraction and reinjection.

Seismic monitoring began in May 2014, with the installation of the three component seismic station of "Torraccia". Subsequently the seismic network has been expanded to six three components stations. The network geometry is such to have a spacing between the stations reduced to 3-4 km in the area corresponding to the geothermal reservoir, and wider moving away from the geothermal area.

For the transduction of the seismic signal a SS-20 sensor has been adopted with three components (N-S, E-W and vertical), short-period (2 Hz) with a usable band 0.1-250Hz. The SS-20 sensor, coupled to the digitizer SL06 / C3, an analog - digital 24-bit, is based on the Linux operating system.

During the period May - December 2014, in a preliminary study, almost 200 earthquakes have been located within the geothermal area. The maximum magnitude observed in this period was M_L=2.8, with a location just a few km west of the geothermal area. Most earthquakes have M_L ≤ 1.0. In fact, these area has been subject to a seismicity which manifests itself mainly with the characters more typical of volcanic and geothermal areas: low hypocenters depth and temporal earthquakes distribution in "swarms".

Based on the data obtained by INGV catalogues historical seismic activity, more resentful in the area, are related to: Civita di Bagnoreggio (1695) with M_w 5.67 ± 0.25; Acquapendente (1755, 1920, 1924) with M_w 4.50; Castel Giorgio (1957) with M_w 4.93 ± 0.21.



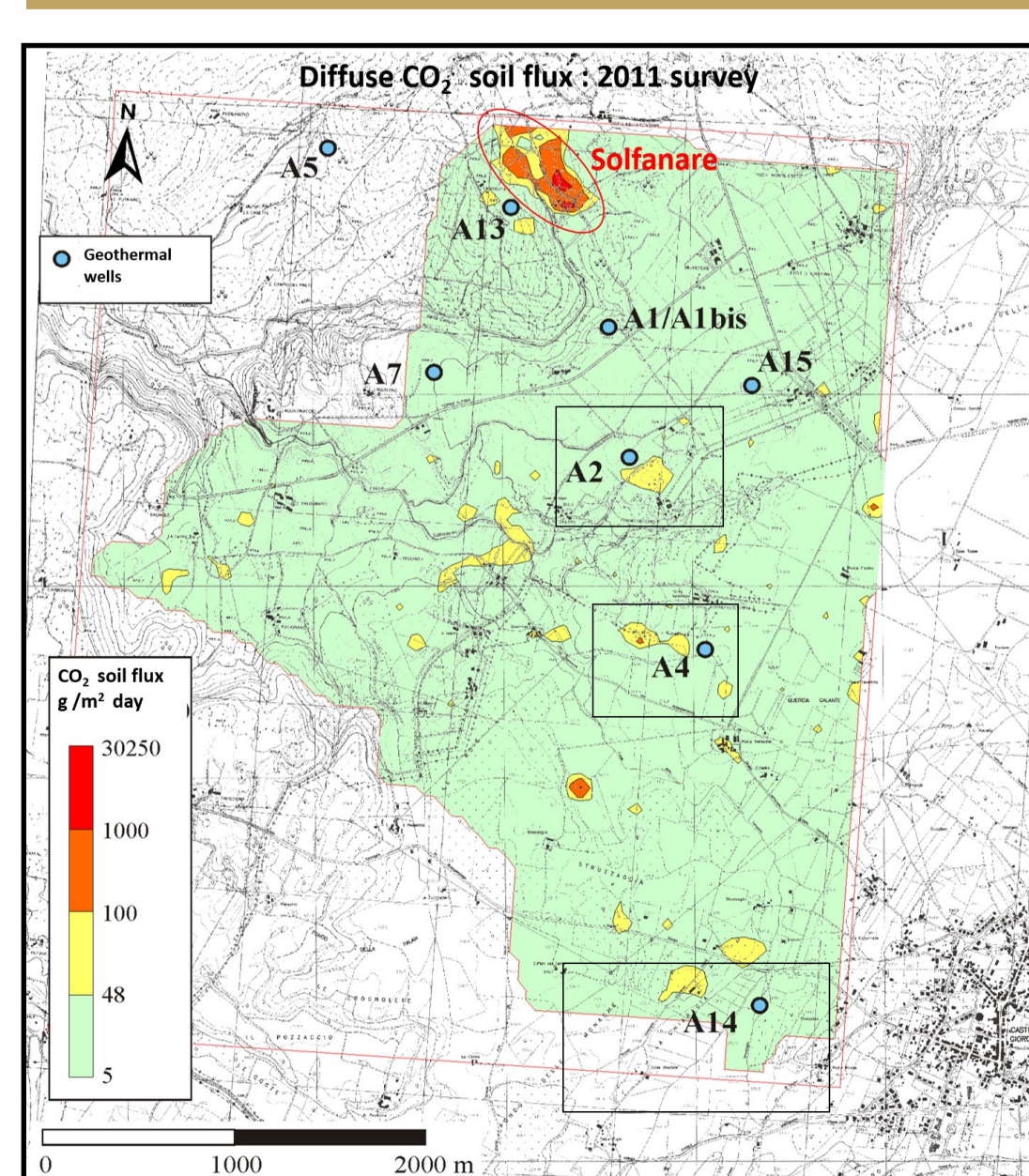
Gas geochemistry of Torre Alfina geothermal wells and Torre Alfina and Latera emissions

In the Torre Alfina geothermal area, there is only one gas manifestation, called "Solfanare", located at North of Torre Alfina. The chemical and isotopic composition of the gas emitted is shown in table 1 where for comparison are also reported data from Enel geothermal wells and those of the gas manifestation of the nearby area of Latera. The dominant gas is CO₂ whereas CH₄ content is low compared to the high enthalpy geothermal fields of Tuscany. The helium isotopic composition of Torre Alfina is the same of that of Latera and despite its relatively low values (R / Ra = 0.34 to 0.44) suggests a likely source of mantle (or magma) metasomatized in subduction process.

Sample	Date	H ₂	H ₂	N ₂	O ₂	CH ₄	CO ₂	H ₂ S	³ Ar	⁴ He/ ³ He	R/Ra	δ ¹³ C CO ₂	δ ¹³ C CH ₄	
	date	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm		‰ vs. PDB	‰ vs. PDB	
Solfanare														
TASa*	01-08-2012	7.0	247	0.84	0.16	0.16	98.43	700*	-	-	-	21.6	0.37	1.3
TAa*	23-4-2013	5.34	-	1.24	0.18	0.18	98.6	650*	-	-	-	-	-	-
TAa*	25-9-2013	5.01	bdl	1.2	0.14	0.15	97.8	730*	88.9	27.2	0.36	1.2	-11	
TAa*	25-9-2013	4.96	bdl	0.9	0.05	0.15	98.3	750*	39.0	32.0	0.36	-	-	
Geothermal wells														
TA1*	11-6-1973	-	bdl	1.31	trace	0.15	98.5	trace	-	-	-	-	-	
TA1*	27-8-1973	-	trace	1.53	trace	0.21	98.3	bdl	-	-	-	-	-	
TA1*	18-4-1974	-	bdl	1.65	bdl	0.19	98.1	bdl	-	-	-	-	-	
TA1-ba*	20-5-1974	-	trace	1.24	trace	0.18	98.6	trace	-	-	-	-	-	
TA1-ba*	2-7-1974	-	bdl	1.09	bdl	0.14	98.8	trace	-	-	-	-	-	
TA7*	7-7-1975	-	trace	0.89	trace	0.13	98.8	520	-	-	-	-	-	
TA7*	12-2-1976	-	trace	0.91	bdl	0.14	98.9	850	-	-	-	-	-	
TA13*	10-11-1999	4.0	96	1.0	-	0.20	98.8	-	40.0	0.41	1.3	-	-	
Latera														
Parasole P4	13	1.0	1.35	-	0.10	97.75	91*	82	61.0	0.48	1.31	-	-	
Parasole P4	6.13	9.5	0.93	-	0.10	96.60	4750*	8.41	88	0.44	1.53	-	-	

Source of data: a) this work; b) Buonasorte et al., 1988; c) Martelli (2002); *H₂S measured on the field with Dräger XAM 7000

Monitoring of CO₂ soil degassing: first results



In summer 2011, a first wide survey of soil CO₂ flux was carried out at Torre Alfina (1336 measurements over 12.6 km² by accumulation chamber). The resulting CO₂ map (see figure) shows that CO₂ emission is very low in most of the investigate area and even in the proximity of wells (A1, A7, A13), i.e. above the gas cap, remaining mostly at values below the threshold established background to 48 g /m² day. CO₂ soil flux anomalies are found only in the proximity of "Solfanare" area where geothermal gases upraise through a NW-SE fault.

Six target areas for regular monitoring of soil CO₂ flux from the soil has been identified and reoccupied 7 times from April 2013 to June 2015 (with an almost seasonal frequency). All measured values are always within the background threshold, as shown in the log-probability plot in figure. Three populations may be recognized with slightly increasing values that characterize the different soil types of the investigated area, respectively not vegetated, plowed and vegetated.

The lack of soil CO₂ flux, established with three years of study, show the efficacy of the impermeable layer upon the cap rock and represent an important background information.

