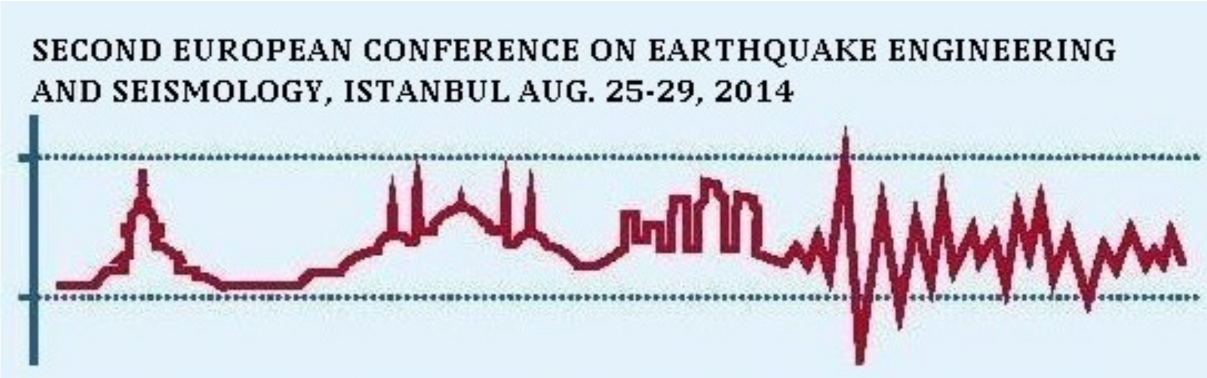

SEISMICITY AT THE LARDERELLO-TRAVALE GEOTHERMAL FIELD (ITALY).

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One of the most uncertain aspects of energy production at geothermal fields is the potential for the induction of earthquakes from extraction of hot fluids and injection of wastewater back into the subsurface. Induced seismicity is perceived as a problem in most communities near geothermal fields, and even small events (M~2) have raised residents' concern related to both damage from single events and their cumulative effects. Proper geophysical studies, seismic monitoring and engineering controls can be applied to enable the safe and economic implementation of the geothermal energy production cycle; however, a major issue exists in case the geothermal plant is located in a tectonically-active region. Under that circumstance, a primary need consists in discerning whether the detected seismicity is related to the energy production cycle, rather than to a 'natural' background activity at the site.

Located in central Tuscany, Italy, the Larderello-Travale Geothermal field (LTGF) is the oldest geothermal power plant of the world. The whole geothermal area is about 400 km2 and has a production of more than 1000 kg/s of super-heated steam, with a running capacity of about 700 MW. The area is seismically active; analysis of historical seismicity indicates that the maximum intensity was observed in the Travale zone in 1724, with an earthquake of 7 - 8 Mercalli scale (Batini et al., 1985). Recent seismicity is of low to moderate intensity with earthquakes characterized by magnitudes generally lower than 4. Reinjection at LTGF began in the late 1970's; early studies (Batini et al., 1985) indicate that injection and seismicity rates are positively correlated, while maximum magnitudes generally decrease as the rate of injection increases.

In this communication we report the results from a seismological study conducted at LGTF using a dense deployment of broad-band instruments. The experiment had the main goal of gathering high-quality data for an area still poorly known, mainly due to the lack of public seismic recordings. Following this objective, we also aim at deriving different observables which can provide constraints on the driving mechanisms of the recorded seismicity, and at investigating robustness and resolving capabilities of passive seismological methods toward the characterization of the rock medium hosting the geothermal reservoir. During the May 2012-May 2013 time interval we recorded more than 1800 earthquakes, 70% of which were located accurately after manual picking and using a 1-D model derived specifically. Large part of the seismicity is concentrated in the SE sector of the area, where most of the deep geothermal production wells are located; hypocentral depths are confined within the shallowest 10 km of crust (Figure 1).

Additional investigations are currently ongoing, and they concern: (1) Anisotropy. Measurements of S-wave polarization azimuths and delay time are conducted using an automatic procedure (Piccinini et al., 2013); results indicate that LTGF is characterized by a marked anisotropy,

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which induces significant splitting of the recorded shear waves. Polarization angles exhibit a complex pattern, characterized by marked spatial and temporal variability; the correlation with major large-scale crustal heterogeneities and the regional stress field is not obvious (Fig. 2). (2) Clustering.

Overall, LTGF is characterized by a moderate (~5 events/day) seismicity rate. Nonetheless, there are periods in which bursts of earthquakes occur accounting for hundreds of events tightly clustered in space (few hundreds of meters) and time (generally a few hours). For eight of these clusters, we exploit waveform similarity and use a matched-filter procedure for deriving complete catalogs which are subsequently analysed in terms of temporal evolution and magnitude distributions.

For several of the identified clusters, the recurrence times deviate significantly from what predicted by Omori's law (Fig. 3), and the temporal evolution of amplitudes does not recall a typical mainshock-aftershock sequence. Though preliminary, these results indicate promising directions for the quantitative monitoring of seismicity associated with an active geothermal field located in a tectonically-active region, and for the identification of parameters which may help in discriminating the actual origin of those earthquakes.

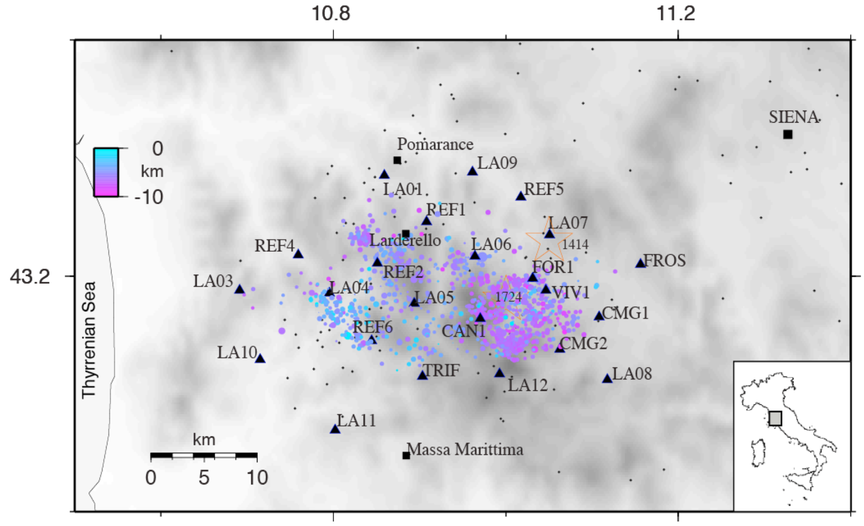

Figure 1. Map of LTGF with station position (triangles) and event location (dots). Epicenters are colour-coded according to the corresponding depth, following the color scale at the top left. The inset at the bottom right marks the location of LTGF with respect to Italy.

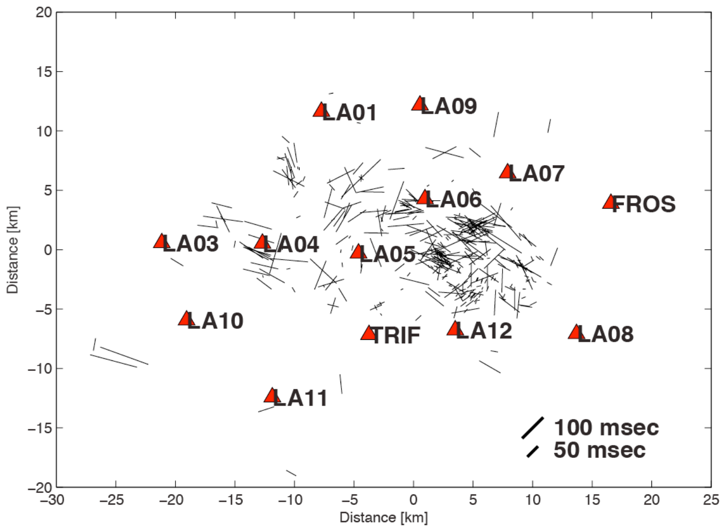

Figure 2. Distribution of the fast-wave polarization azimuths derived from shear-wave-splitting analysis. The length of the vectors is proportional to the delay time.

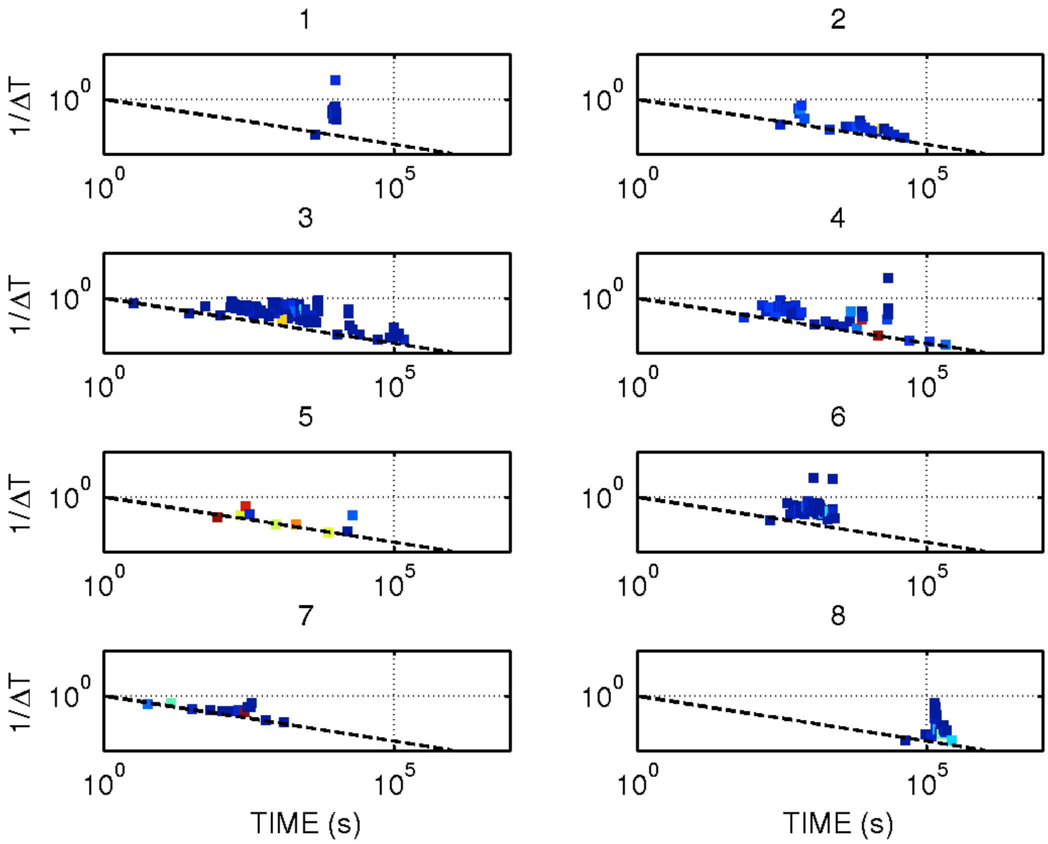

Figure 3. Amplitude and inter-event times for the 8 analysed seismicity bursts. For each burst, the reciprocal (1/DT) inter-event times are plotted against the time of occurrence; the normalized amplitudes of individual events are indicated by different colors, with amplitude increasing from cooler (blue) to warmer (yellow) tones. Dashed lines indicate the trends predicted by Omori's law.

REFERENCES

Batini, F., Console, R., Luongo, G., 1985. Seismological study of Larderello-Travale geothermal area. *Geothermics* 14 (2–3), 255–272.

Piccinini, D., M. Pastori, and M. Marghieriti (2013) "ANISOMAT+: An automatic tool to retrieve seismic anisotropy from local earthquakes", *Comput. Geosci.*, 56, 62–68, ISSN 0098–3004, doi:10.1016/j.cageo.2013.01.012.