Seismicity in the geothermal area of Mt. Amiata Volcano (Italy)

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Located in the inner sector of the Northern Apennines (southern Tuscany), Mt. Amiata is a quaternary volcano that was active in between 0.3 My and 0.19 My b.p.. It now hosts a water-dominated geothermal field which is being exploited for the production of electric power since the early 1960s. Historical records report at least ten moderate (M < 5.3), yet damaging earthquakes, occurred well before the geothermal exploitation started. Nonetheless, public concern is rapidly raising due to the possibility that the geothermal production processes (i.e., vapor extraction and re-injection of condensates back into the subsurface) provoke stress perturbations that may trigger earthquakes. A critical issue thus consists in discerning whether seismicity is related to the exploitation of the geothermal resource, rather than to the natural tectonic stresses at the site. Here, we report data from a temporary seismic network operated at Mt Amiata during the 2016-2019 time span. We obtained precise, absolute locations using a non-linear probabilistic location procedure and a minimum-misfit, 1-D velocity model specifically derived for the area. Complementary information on the velocity structure was also derived from the inversion of the surface-wave group- and phase-velocity dispersion curves, as obtained from frequency-time analysis (FTAN) of regional earthquakes and noise correlation functions, respectively. Our catalog amounts to more than 1000 earthquakes, with a completeness magnitude of about 0.4. The improvement in earthquake detection with respect to the catalog from the national monitoring program is of the order of 1 magnitude unit. Hypocenters are clustered within a few, distinct focal volumes, two of which closely correspond to the productive fields. Most hypocenters are shallower than 5km, getting deeper as the distance from the geothermal areas increases. Overall, the lower bound of hypocentral depths follows the K-horizon, a regional-scale seismic reflector inferred to mark the upper limit of the brittle-to-ductile transition and, possibly, the top of the Pleistocene granitic intrusions. Throughout the observation period, the largest magnitude observed within the geothermal area is ML=2.9 (ML=2.1 in the national catalog); 95% of the earthquakes have magnitudes lower than 1. Earthquakes occur at a rather constant rate of less than 1 event/day, occasionally interspersed by short-duration (1-3 days), swarm-like bursts accounting for tens of earthquakes that do not exhibit any clear mainshock-aftershock sequence. The scaling relationships of the catalog are examined by computing clustering in the magnitude-distance-time space domains. The background and stationary components have similar relevance (55% and 45%, respectively), thus not resulting diagnostic about the principal driving mechanism of the observed seismicity. Although the proximity between the main focal volumes and production areas would suggest that geothermal exploitation plays a major role in the earthquake-generation process, the
lack of any industrial data prevents from inferring any causative relationship between the two phenomena.