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Detecting the preparatory phase of induced earthquakes at The Geysers (California) using K-means clustering

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The generation of strong earthquakes is a long-debated problem in seismology, and its importance is increased by the possible implications for earthquake forecasting. It is hypothesized that the earthquake generation processes are anticipated by several phenomena occurring within a nucleation region. These phenomena, also defined as preparatory processes, load stress on the fault leading it to reach a critical state. In this paper, we investigate the seismicity preceding 19 moderate (Mw≥3.5) earthquakes at The Geysers, Northern California, aiming to verify the existence of a preparatory phase before their occurrence. We apply an unsupervised K-means clustering technique to analyze time-series of physics-related features extracted from catalog information and estimated for events occurred before the mainshocks. Specifically, we study the temporal evolution of the b-value from the Gutenberg-Richter (b), the magnitude of completeness (Mc), the fractal dimension (Dc), the inter-event time (dt), and the moment rate (M_r). Our analysis shows the existence of a common preparatory phase for 11 events, plus other 5 events for which we can guess a preparatory phase but with different characteristics of previous ones, indicating different possible activation behavior. The duration of the preparatory process ranges between about 16 hours and 4 days. We find that the retrieved preparatory process involves a decrease of b, Mc, and Dc, and an increase of M_r, as found by many authors. Finally, we show a clear correlation between events showing a preparation phase and the location of injection's wells, suggesting an important role of fluids in the preparatory process.