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Are existing models adequate to describe the source dimensions of small, shallow earthquakes?

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We estimate and comment on the source characteristics of 20, small in magnitude (1.5 < M < 2.1), shallow earthquakes recorded beneath the Açu reservoir in NE Brazil. The Açu earthquakes are triggered by small changes in the pore water pressure, estimated as less than 0.5 MPa. The small station spacing and the very low-attenuation, Precambrian basement rock allowed for the collection of a unique data set consisting of 286 recorded earthquakes of duration magnitudes up to M = 2.1 and enabled location of the earthquakes with uncertainties less than 20 meters. Such data can provide invaluable information on the evolution of seismicity and permeability within the geosphere, a topic with great significance in engineering applications, e.g., geological nuclear waste disposal, geothermal energy exploitation etc. One of the most significant parameters to be defined in such applications is the rock mass healing times. This is often achieved by detecting collocated microearthquakes and analysing the time lag between occurrence times, making the estimation of the source dimensions one of the most important aspects of the analysis.

We compute the spectra of the individual waveforms of the largest recorded events and determine a corner frequency for each earthquake. Brune's circular model is then applied to estimate the source radius. At a second step, we calculate the stress drops. Our results indicate radii and stress drops with values ranging between 40 m to 70 m and 25 to 90 MPa, respectively. In a previous study of the six largest earthquakes in the same data set, the EGF method was used and the obtained values for the source radii and stress drops were of the same order of magnitude, after correction for the method.

The values of the stress drops we obtain are significantly higher than the values of large tectonic earthquakes or the values obtained from studies of induced seismicity elsewhere that have used the same model as in this study. Although this is a case of intraplate earthquakes and thus higher values for the stress drop are expected, the triggering mechanism (pore pressure diffusion) of the Açu earthquakes does not justify such values. Results could reflect the formation of fractures in intact rock rather than frictional failure. Such high values of stress drop with such small triggering pressure changes make it difficult to explain how these microearthquakes occur within a few days or even hours after each other. In the case of collocated events, this requires an exceptionally rapid healing process. An argument could be that the rock is highly heterogeneous and anisotropic and the high values of the stress drop describe the stress at a very localised level. However, this contradicts the main assumption of the model used, i.e. the existence of an infinite, homogeneous, isotropic elastic medium where the rupture takes place instantly inside a circle of a specific radius.

The description of the earthquake source still remains a challenge in earthquake engineering and seismology. In this study we try to estimate boundaries of what the stress drop should be in the case of small, shallow induced earthquakes in order to be in agreement with the underlying physics and assess, for the first time, the error introduced by the simplifications of a source model.