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Fault Structural Complexity and Rupture Characteristics of the 2021 Maduo Earthquake

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Earthquake rupture processes, occurring across multiple spatial and temporal scales from surface to depth, reveal critical information about the nature of seismic events. Such insights are essential for understanding earthquake nucleation mechanisms, assessing seismic hazards, and interpreting regional tectonic deformation. Since the Cenozoic collision between the Indian and Eurasian plates, numerous large active fault systems around the Tibetan Plateau have been reactivated, resulting in frequent moderate to large earthquakes. The 2021 Maduo earthquake, the largest in China since the 2008 Wenchuan earthquake, occurred on the Jiangcuo Fault, a secondary fault within the northeastern Bayan Har block. This highlights the event's unique seismogenic context and complex rupture behavior.

In this study, we applied fractal dimension analysis of coseismic slip and used deep learning techniques to automatically identify surface ruptures from UAV imagery. Our results show that the spatial variation in rupture density, orientation, and style is strongly influenced by fault structural complexity. The densest surface ruptures are observed in the southeastern segment of the rupture zone, where the fault exhibits significant bending and supershear rupture characteristics. In contrast, regions with relatively simpler fault geometries exhibit sparser rupture patterns. Geophysical and geodetic inversion results indicate that the structural complexity of the Jiangcuo Fault extends from surface traces into the seismogenic depth, generating heterogeneous stress accumulations (asperities and barriers) that modulate the rupture process. Dynamic rupture modeling further demonstrates the critical role of fault segmentation, tectonic prestress, and geometric irregularities in controlling rupture evolution.

Future work will focus on the dynamic rupture simulation of the 2001 Kokoxili earthquake, aiming to explore its rupture characteristics and the associated dynamic interactions with surrounding fault systems. These efforts will contribute to a more comprehensive understanding of rupture behavior within the complex fault networks of the Tibetan Plateau.

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