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Transient cnoidal waves explain the formation and geometry of fault damage zones

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The spatial footprint of a brittle fault is usually dominated by a wide area of deformation bands and fractures surrounding a narrow, highly deformed fault core. This diffuse damage zone relates to the deformation history of a fault, including its seismicity, and has a significant impact on flow and mechanical properties of faulted rock. Here, we propose a new mechanical model for damage-zone formation. It builds on a novel mathematical theory postulating fundamental material instabilities in solids with internal mass transfer associated with volumetric deformation due to elastoviscoplastic p-waves termed cnoidal waves. We show that transient cnoidal waves triggered by fault slip events can explain the characteristic distribution and extent of deformation bands and fractures within natural fault damage zones. Our model suggests that an overpressure wave propagating away from the slipping fault and the material properties of the host rock control damage-zone geometry. Hence, cnoidal-wave theory may open a new chapter for predicting seismicity, material and geometrical properties as well as the location of brittle faults.