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Two-phase Damage Models of Magma- and Hydro-Fracturing

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Damage and fracturing in two-phase and porous flows are relevant for geological process such as magma fracturing during melt migration and hydro fracturing of crustal rocks for carbon sequestration and shale-gas recovery. These fracturing processes are associated with the propagation of a pore-generating damage front ahead of high-pressure fluid injection. We therefore examine the propagation of porous flow in a damageable matrix by applying the two-phase theory for compaction and damage proposed by Bercovici et al. [1]; Bercovici and Ricard [2]. The movement of the fluid and the solid is governed by the two-phase flow laws, while damage (void generation and micro-cracking) is treated by considering the generation of interfacial surface energy by deformational work. Calculations of one dimensional (1-D) flow of fluid migrating buoyantly through compacting and damageable matrix show that damage is mitigated in steady state largely because of pressure loss at the fluid front. However, in time-dependent flows, linear stability analysis shows that the propagation velocity of porosity waves is strongly dependent on damage. In the damage-free case porosity waves are dispersive in that wave-speed decreases with wavenumber (inverse wavelength); however with damage the dispersion flattens and beyond a critical damage reverses (the wave speed increases with wave number). Since normal dispersive behavior balances breaking in the nonlinear wave case, such reversed dispersion implies that damage has a profound effect in the nonlinear limit by facilitating wave front steepening and high-speed shocks. Nonlinear solitary wave solutions are obtained numerically and show that the transmission of porosity waves induce high stress and damage that can push the damage front forward. With damage the porosity waves sharpen and calculations suggest that they can transform from shape-conserving solitary waves into faster shock waves, which is also predicted by the linear theory. Such pulse-like shock waves may prove effective at promoting fluid migration through hydro- and magma fracturing.

References

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[2] Bercovici, D., and Y. Ricard (2003), Energetics of a two-phase model of lithospheric damage, shear localization and plate-boundary formation, Geophys. J. Intl., 152, 581–596.