
Tectonics Down Under: the mechanics of earthquakes and faulting driven by the ductile regime

K. Regenauer-Lieb[1],M. Veveakis[1,2], S. Alevizos[1], M. Hu[1], C. Schrank[3]and Thomas Poulet[2,1]
[1]School of Petroleum Engineering, UNSW, Kensington, NSW 2052, Australia.
[2]CSIRO Mineral Resources Flagship, PO Box 1130, Bentley, WA 6102, Australia
[3]Science and Engineering Faculty, Queensland University of Technology, Brisbane, QLD 4001, Australia

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The classical model for the mechanics of earthquakes is based on the assumption that seismogenic faults are controlled by the brittle crust and diffuse into their ductile roots [*Scholz*, 1990]. However, field observations challenge this simple view:rocks in the ductile realm can localize in unusually narrow shear planes, as thin as millimetres. Well-known examples include the exposed Glarus, McConnell and Naukluftcarbonate thrusts, which display tens of kilometres of displacements on such ultra-thin layers. Geological observations infer repeated slippage events, similar to episodic tremors observed in subduction zones like Cascadia in Canada and Hikurangi in New Zealand. In all of the above cases, deep fluid release reactions were found to be an important trigger of slow earthquakes in the ductile realm [*Poulet et al.*, 2014a; *Poulet et al.*, 2014b]. In contrast to their brittle counterparts, the periodicity and slip magnitude of these ductile events is a result of a material instability and not of a random geometric stress concentration.Therefore, ductile events are predictable provided that the material properties can be inverted from geological and geophysical observations.

This finding opens a new way for understanding the mechanics of faulting and earthquakes based on fundamental multiphysics mechanisms underpinning the time-dependent instability. The approach converges in the long time scale (quasi-static) limit to the classical continuum mechanics failure envelopes of the classical fault mechanics approach. However, being time-dependent, it predicts that the long-term strength of faults is not governed by cracking of the brittle crust (geometrically controlled stress build up in the brittle crust) but rather by creeping flow (energy feedbacks) leading to slow slip instabilities that are driven by geodynamic processes. These instabilities propagate upwards from the ductile regime into the top and rupture the brittle crust. We explicitly identify the role of elastic P-waves and S-waves in triggering instability [*Veveakis and Regenauer-Lieb*, 2015] and show applications of the unified “wave mechanics” approach [*Regenauer-Lieb et al.*, 2016] as a quantitative link between rate-controlled elasto-dynamic instabilities in the brittle field and creeping flow instabilities of the deep earthquake generator.

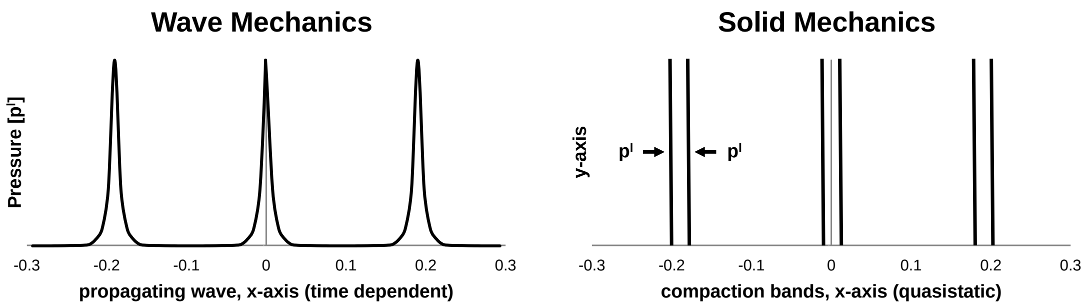

Figure 1 Duality of a *wave mechanics* (left panel) versus a *solid mechanics*(right panel) concept forelasto-visco-plastic P-wave instabilities. The time-dependent wave mechanics approach predicts material instabilities in the shape of a special form of propagating pressure (P)-waves that in the stationary limit are equivalent to compaction bands of solid mechanics.

References

[1] Poulet, T., E. Veveakis, M. Herwegh, T. Buckingham, and K. Regenauer-Lieb (2014a), Modeling episodic fluid-release events in the ductile carbonates of the Glarus thrust, Geophysical Research Letters, 41(20), 7121-7128.
[2] Poulet, T., E. Veveakis, K. Regenauer-Lieb, and D. A. Yuen (2014b), Thermo-Poro-Mechanics of chemically active creeping faults. 3: The role of Serpentinite in Episodic Tremor and Slip sequences, and transition to chaos, Journal of Geophysical Research: Solid Earth, 119(6), 4606–4625 doi:10.1002/2014JB011004.
[3] Regenauer-Lieb, K., T. Poulet, and E. Veveakis (2016), A novel wave-mechanics approach for fluid flow in unconventional resource, The Leading Edge, doi:10.1190/tle35010xxx.1.
[4] Scholz, C. H. (1990), The mechanics of earthquakes and faulting, 439 pp., Cambridge University Press.
[5] Veveakis, E., and Regenauer-Lieb (2015), Cnoidal Waves in Solids, Journal of Mechanics and Physics of Solids, 78, 231-248.