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Modelling of fluid injection into a frictional weakening dilatant fault

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Governing equations

- Elasticity (Linear elastic & isotropic)

$$\tau(x,t) = \tau_o - \frac{G}{2\pi\cdot(1-\nu)} \int_{a_-(t)}^{a_+(t)} \frac{\partial \delta(s,t)}{\partial s} \frac{ds}{x-s}, \qquad |x| < a$$

- Shear weakening Mohr-Coulomb criterion

$$\tau(x,t) \leq f(\delta)(\sigma_o - p_o - p(x,t))$$

- Width averaged fluid mass conservation in the fault (with const. permeability k_f)

$$w_h c_f \frac{\partial p}{\partial t} + \frac{\partial w_h}{\partial t} - \frac{\partial}{\partial x}\left(\frac{w_h k_f}{\mu}\frac{\partial p}{\partial x}\right) = 0$$

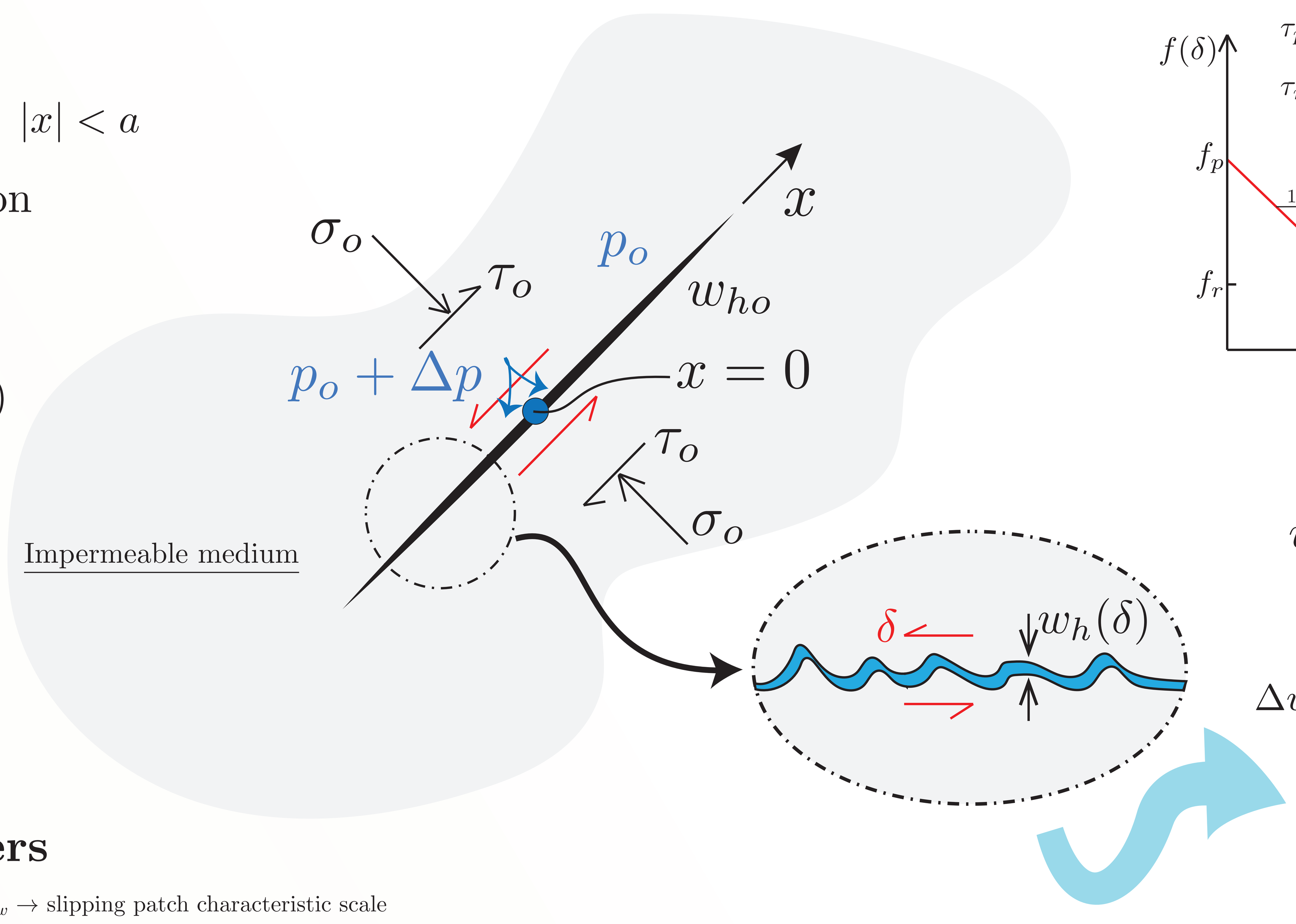
- Boundary condition

$$p(x=0,t) = p_o + \Delta p$$

- Initial condition

$$\frac{\tau_o}{\tau_p} < 1 \longrightarrow \text{No slip}$$

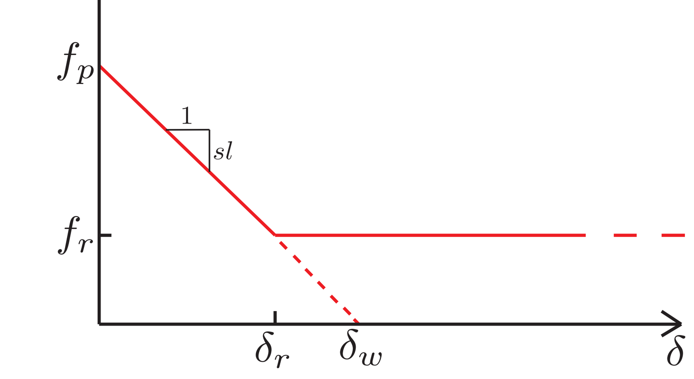
Model



Friction weakening law

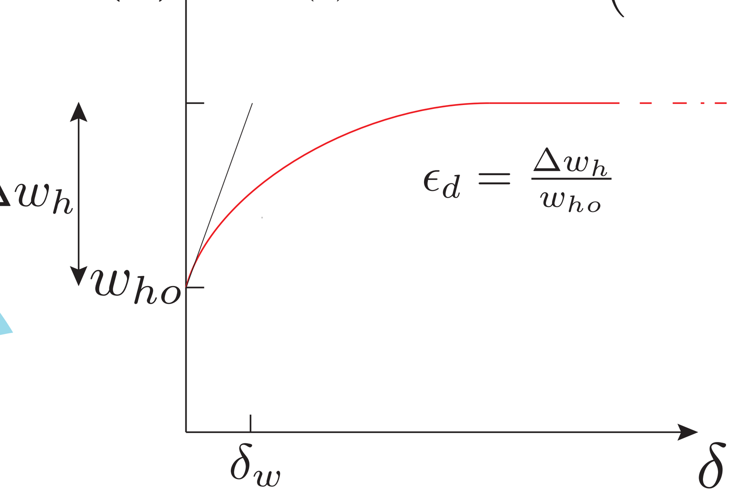
$\tau_p = f_p(\sigma_o - p_o) \rightarrow$ Ambient peak strength

$\tau_r = f_r(\sigma_o - p_o) \rightarrow$ Ambient residual strength



Dilatancy law

$$w_h(\delta) = w_{ho} + \Delta w_h\left(1 - e^{-\frac{\delta}{\delta_w}}\right)$$



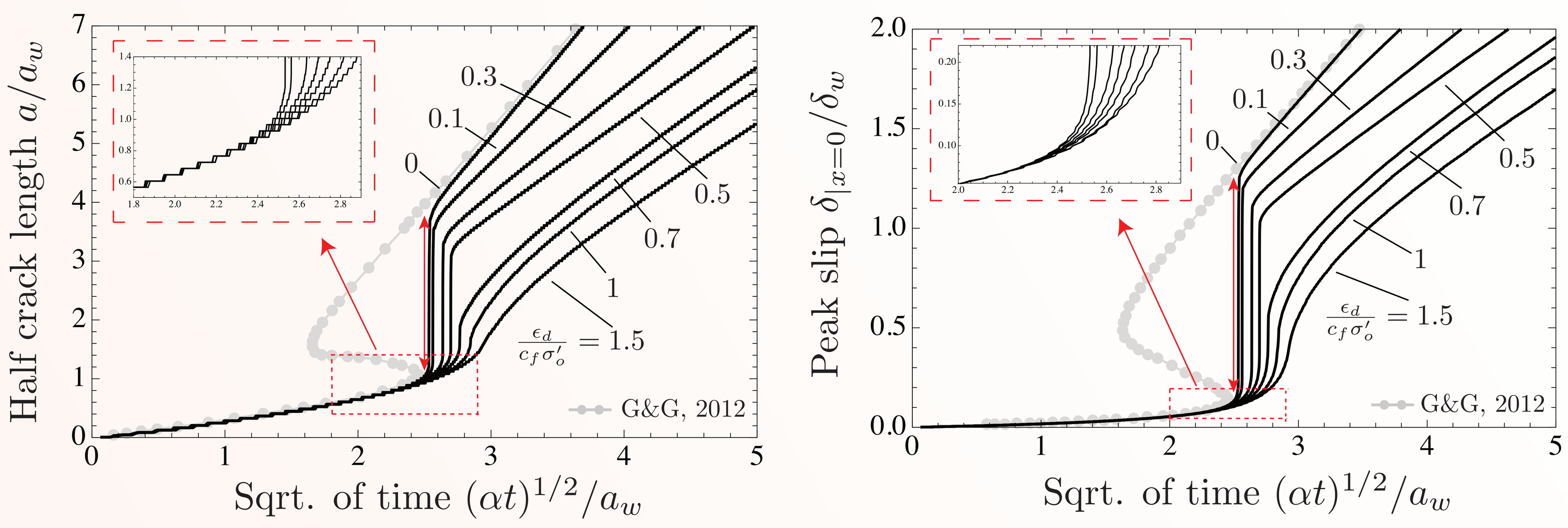
Dimensionless governing parameters

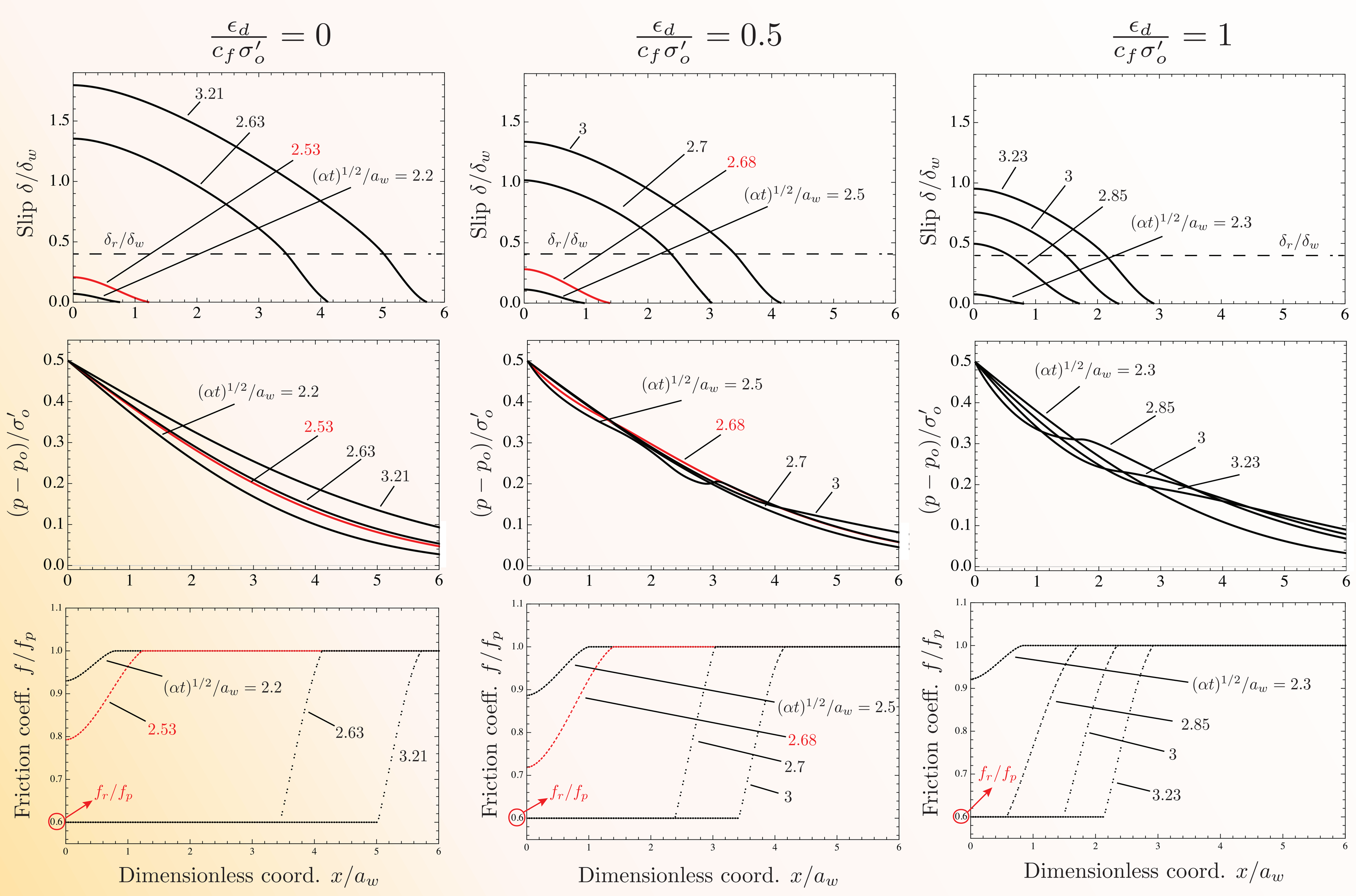
$$\frac{\tau_o}{\tau_p}, \frac{\Delta p}{\sigma'_o}, \frac{f_r}{f_p}, \frac{\sqrt{\alpha t}}{a_w}, \frac{\epsilon_d}{c_f \sigma'_o} \longrightarrow$$

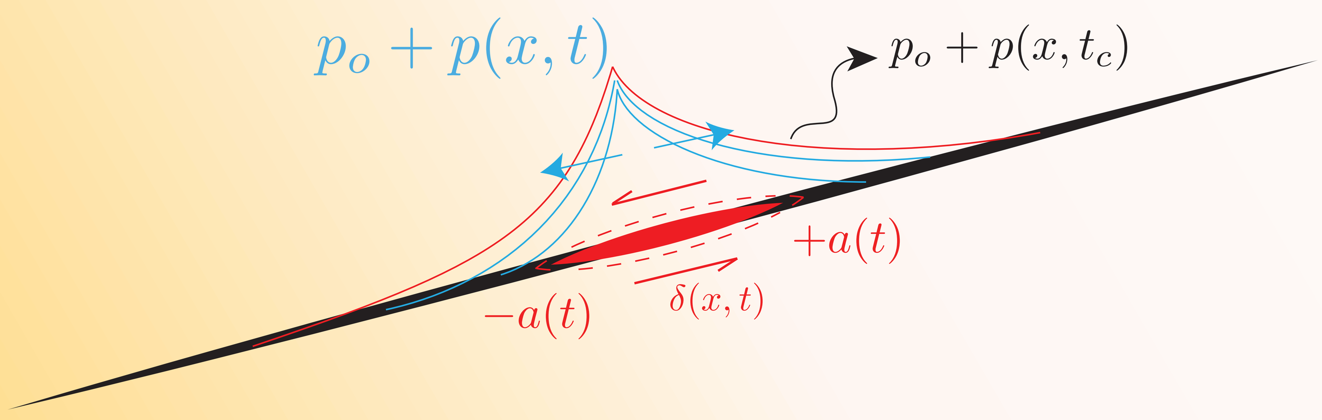
- $a_w = \frac{G}{\tau_p(1-\nu)}\delta_w \rightarrow$ slipping patch characteristic scale
- $\alpha = \frac{k_f}{c_f \mu} \rightarrow$ fault diffusivity
- $\sigma'_o = \sigma_o - p_o \rightarrow$ ambient normal effective stress

Ultimately stable fault $\tau_o < \tau_r$

Moderate overpressure: $\Delta p/\sigma'_o = 0.5$

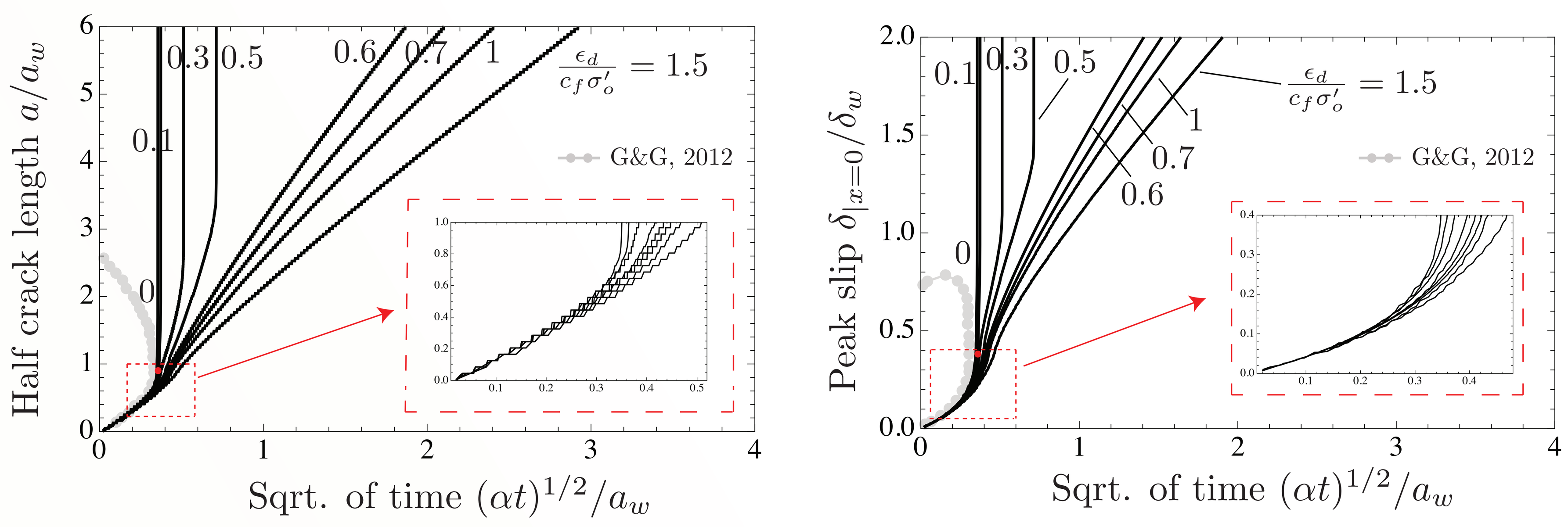


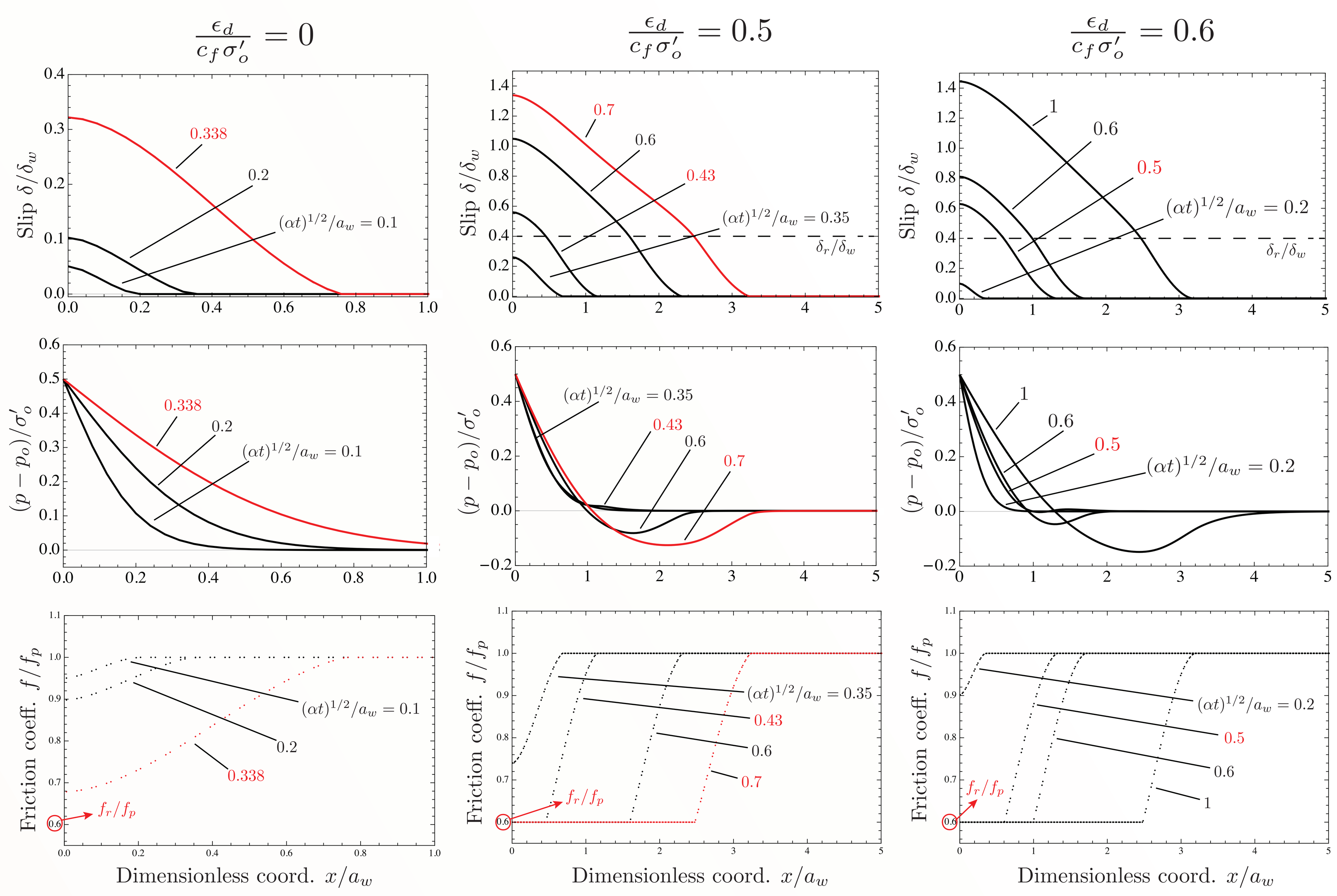


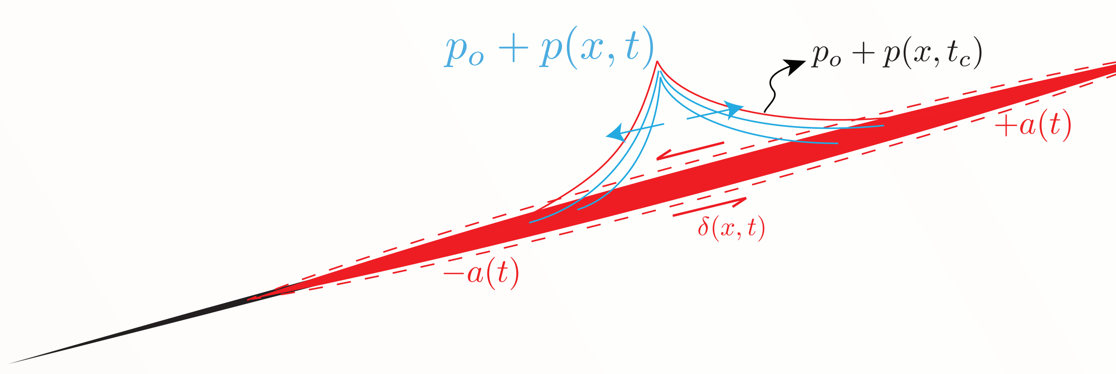


Unstable fault $\tau_o > \tau_r$

Moderate overpressure: $\Delta p/\sigma'_o = 0.5$







References

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Conclusions

- For non-dilatant case, our results match perfectly the semi-analytical results of G&G (2012) [1].
- The fluid driven shear crack propagation depends on both weakening of friction coefficient and loading conditions.
- For an ultimately stable fault, the shear crack is well inside the pressurized region at nucleation time. On the other hand, in a fault that is about to fail (i.e unstable fault), the shear crack is ahead the pore pressure profile at nucleation time.
- Dilatancy directly affects the slip propagation during high slip rate.
- Weak dilatancy effect in a fault with constant permeability delays the onset of instability (i.e diverging slip rate) as a small zone of shear crack is affected by the residual strength of the fault under undrained condition.
- High distant fault (with constant permeability) never exhibits dynamic instabilities.