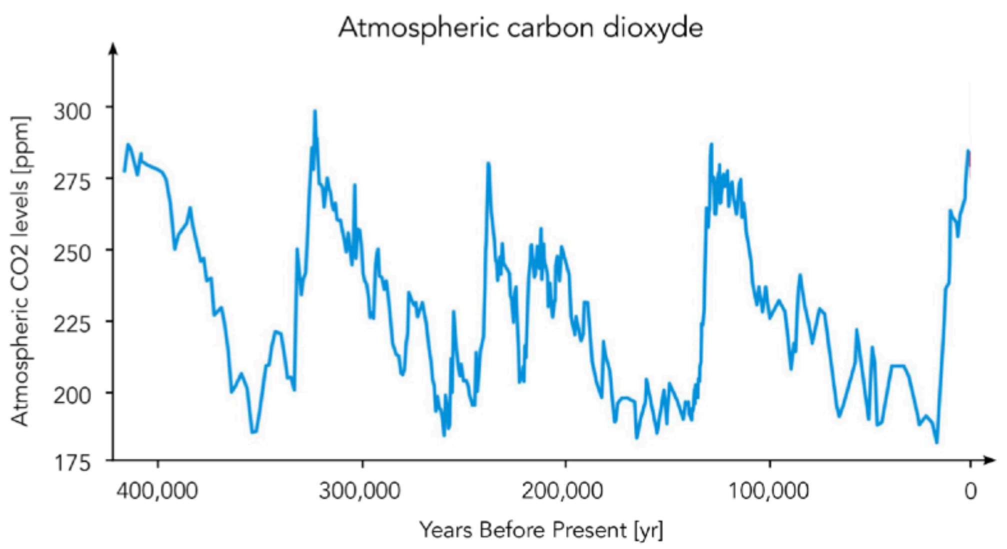
Modelling reactive two-phase flow: challenges and implications

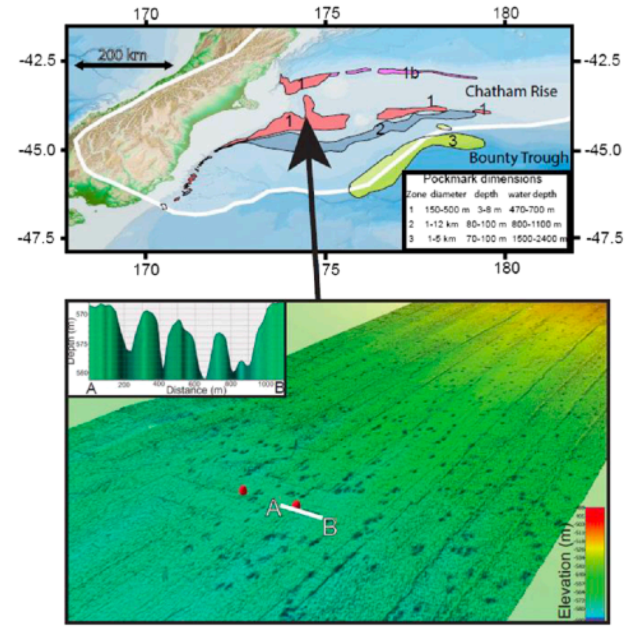
Andrey Frendak MSU
Yury Podladchikov UNIL
Ludovic Räss ETHZ

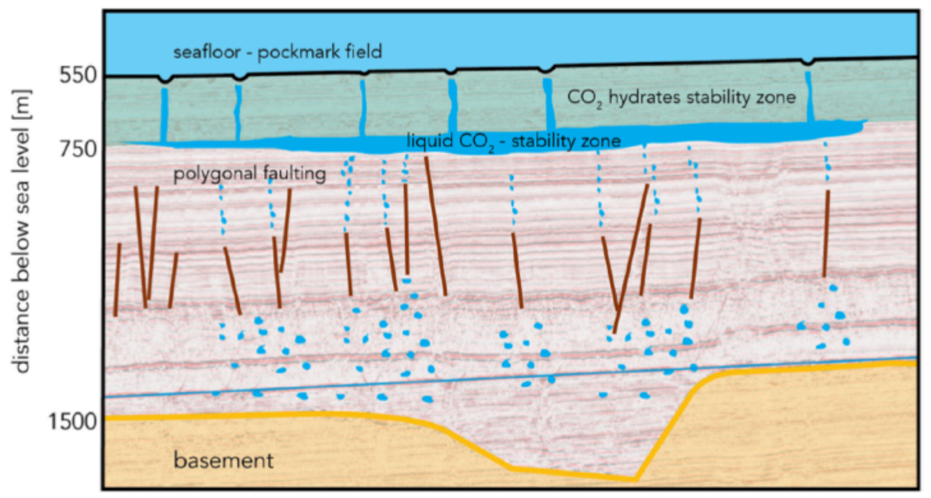
Atmospheric CO_2 variations from ice core records



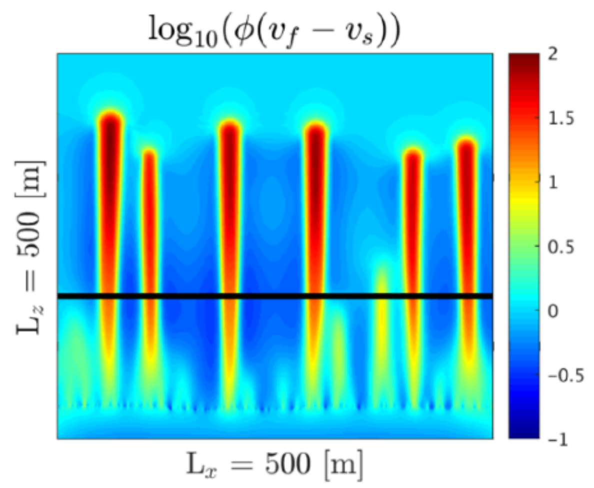
After Stott, pers. comm.

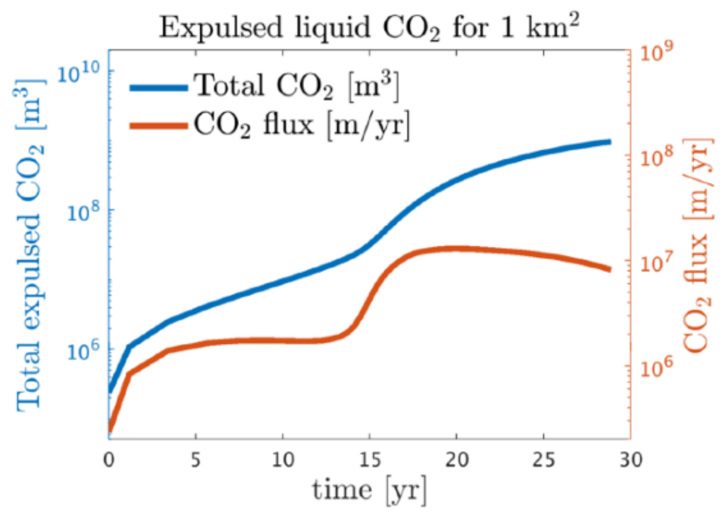
Understand the mechanisms responsible for CO_2 variations in "recent" geological times.





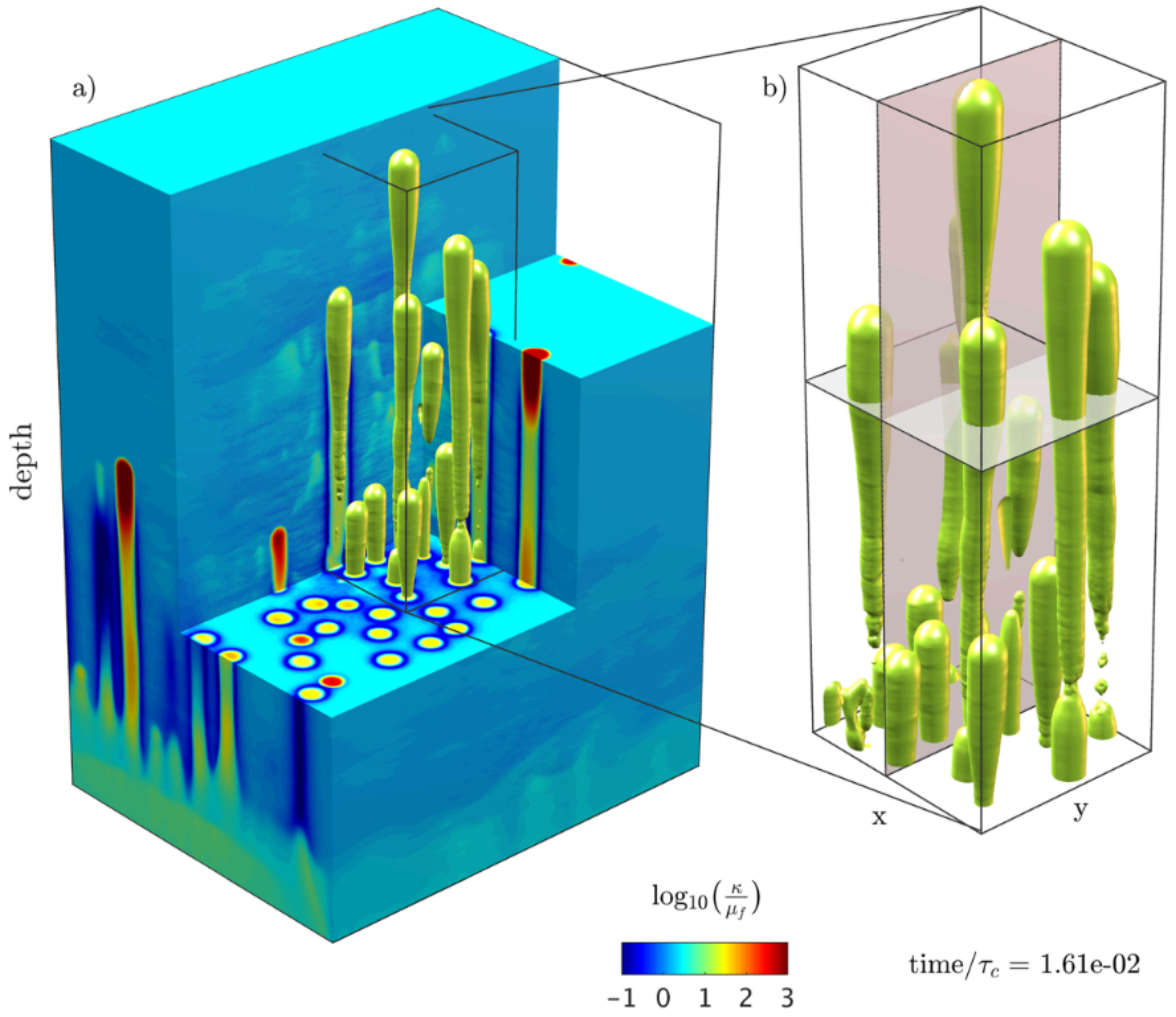
Stott et al., 2019





The hydro-mechanical model

HMC coupling



Räss et al., 2018

$$0 = \nabla_j(\bar{\tau}_{ij} - \bar{p}\delta_{ij}) - \bar{\rho}g_i \qquad \frac{\partial\phi}{\partial t} = (1-\phi)\nabla_k v_k$$

$$0 = \nabla_k v_k + \frac{\bar{p} - p^f}{\eta_\phi(1-\phi)} \qquad \eta_\phi = f(\phi, \bar{p}, p^f, \dot{\epsilon}_{II})$$

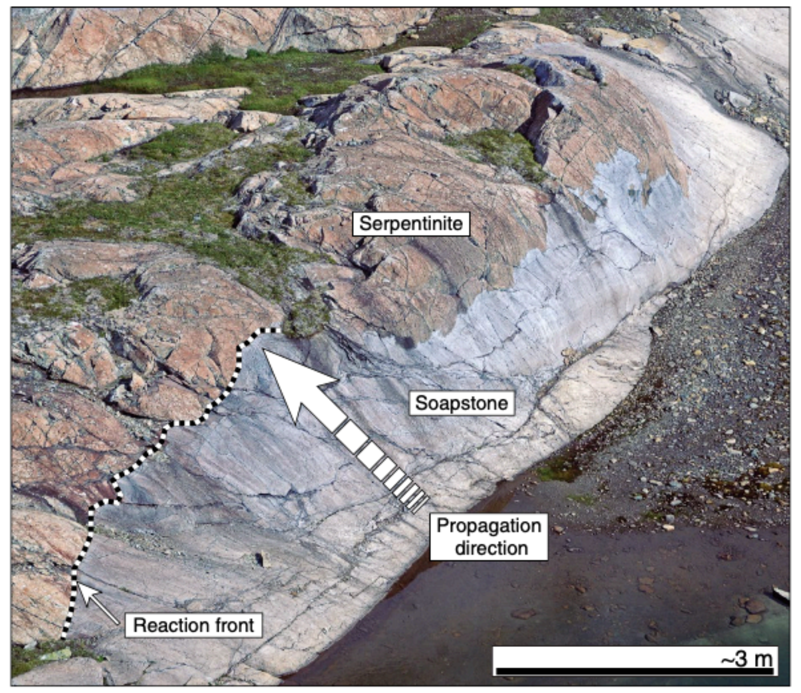
$$0 = \nabla_k q_k^D - \frac{\bar{p} - p^f}{\eta_\phi(1-\phi)} \qquad \mu = f(\phi, \dot{\epsilon}_{II})$$

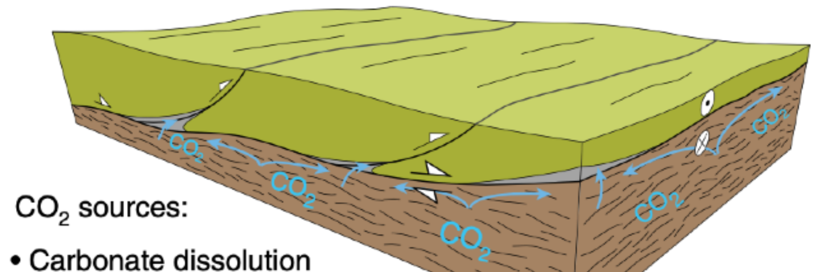
$$k_\phi = k_0(\phi/\phi_0)^3$$

$$q_i^D = -k_\phi(\nabla_i p_i^f + \rho^f g_i)$$

$$\frac{1}{G}\frac{\partial\bar{\tau}_{ij}}{\partial t} + \frac{\bar{\tau}_{ij}}{\mu_s} = \nabla_i v_j + \nabla_j v_i - \frac{2}{3}\delta_{ij}\nabla_k v_k$$

The hydro-chemical model

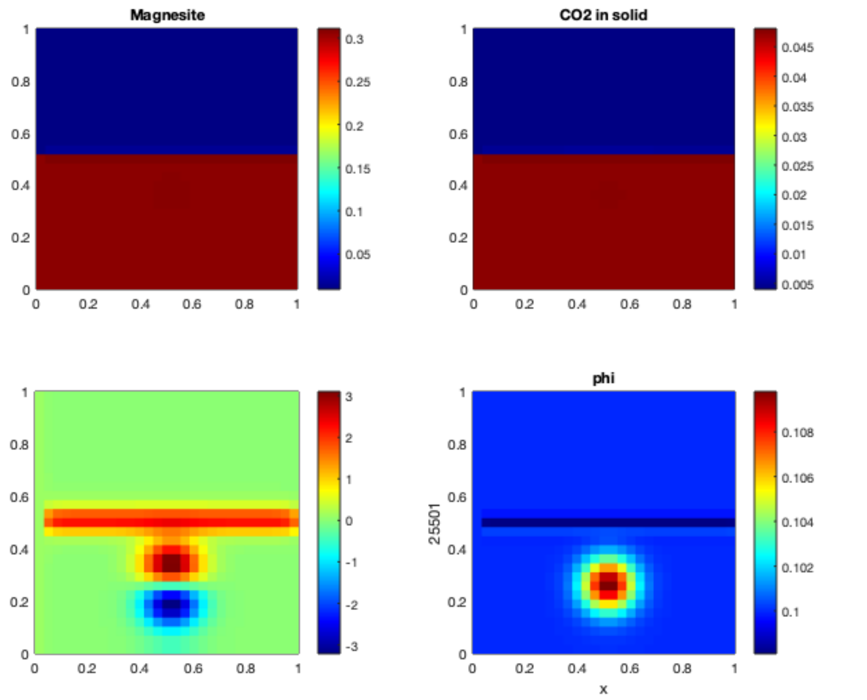




CO_2 sources:

- Carbonate dissolution
- Increased pore-fluid production
- Thermally induced carbonate breakdown

Beinlich et al., 2021 Nature Geo



$$\rho_f = \rho_f(T, P_f, C_f^{CO_2})$$

$$\rho_s = \rho_s(T, P_f, C_f^{CO_2})$$

$$C_s^m = C_s^m(T, P_f, C_f^{CO_2})$$

$$C_s^{CO_2} = C_s^{CO_2}(T, P_f, C_f^{CO_2})$$

$$\frac{\partial}{\partial t}\left(\rho_f \phi C_f^{CO_2} + \rho_s(1-\phi)C_s^{CO_2}\right) - \nabla\left(\rho_f \phi C_f^{CO_2} \frac{k\phi^3}{\mu_f}(\nabla P_f + \rho_f \mathbf{g})\right) = \nabla\left(\rho_f \phi D_f^{CO_2} \nabla C_f^{CO_2}\right)$$

$$\frac{\partial}{\partial t}\left(\rho_s\left(1 - C_s^m\right)(1-\phi)\right) = 0$$

$$\frac{\partial}{\partial t}\left(\rho_f\phi + \rho_s(1-\phi)\right) = \nabla\left(\rho_f \frac{k\phi^3}{\mu_f}(\nabla P_f + \rho_f \mathbf{g})\right)$$

Some details

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How geologic processes affect the carbon flux from/to the oceans on glacial timescales ?

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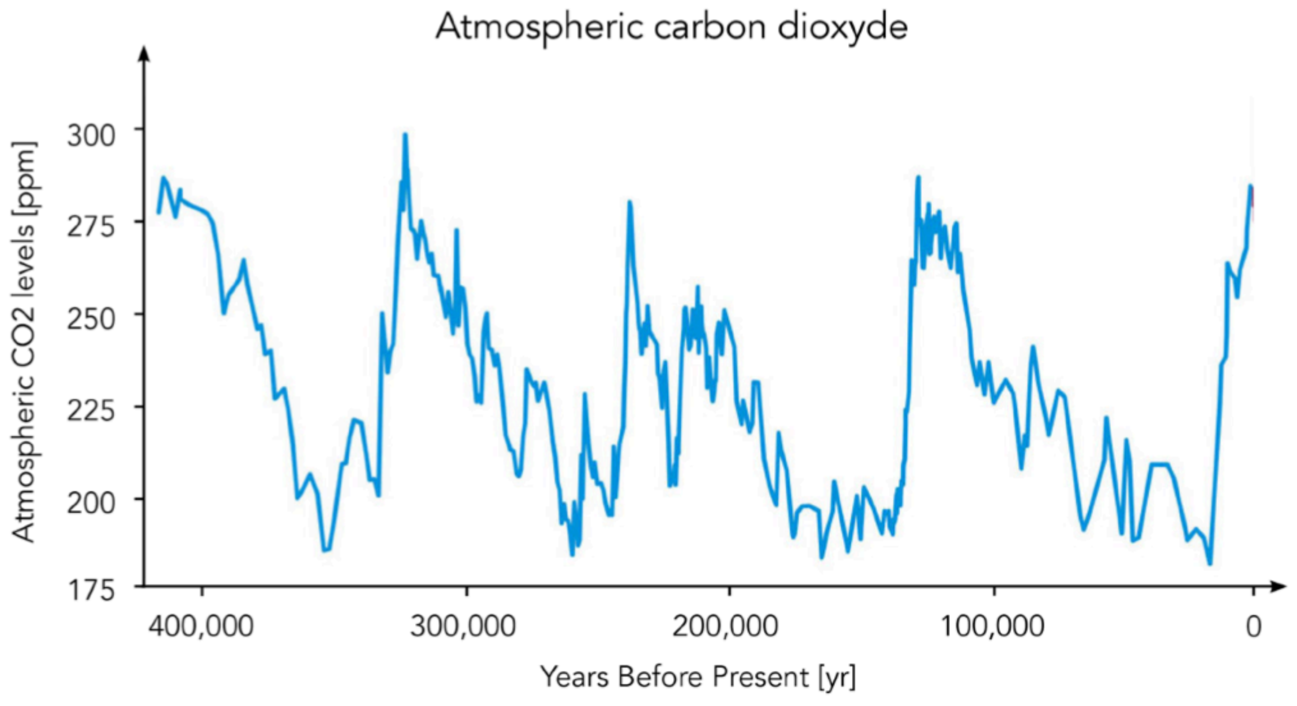
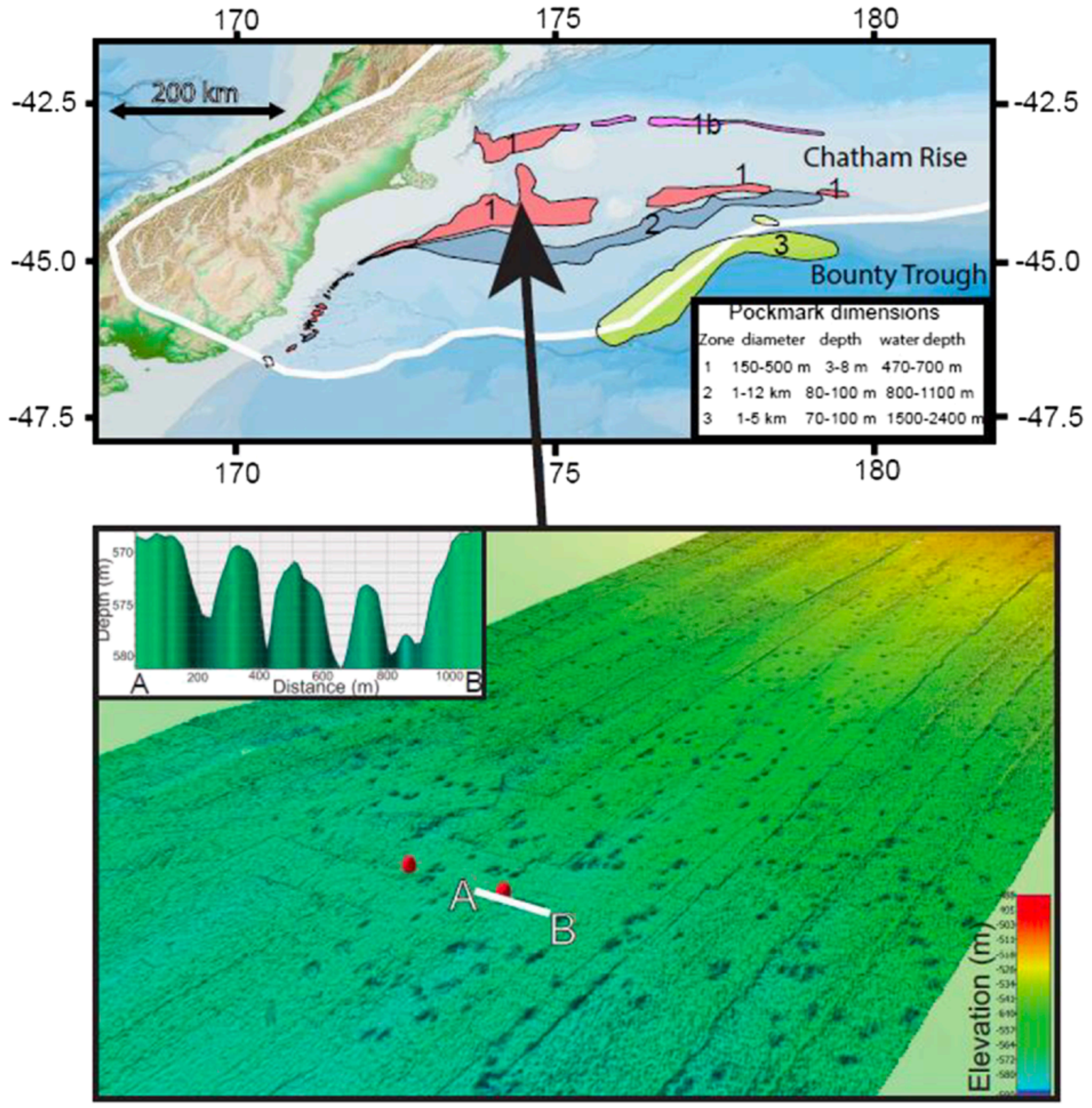


After Stott, pers. comm.

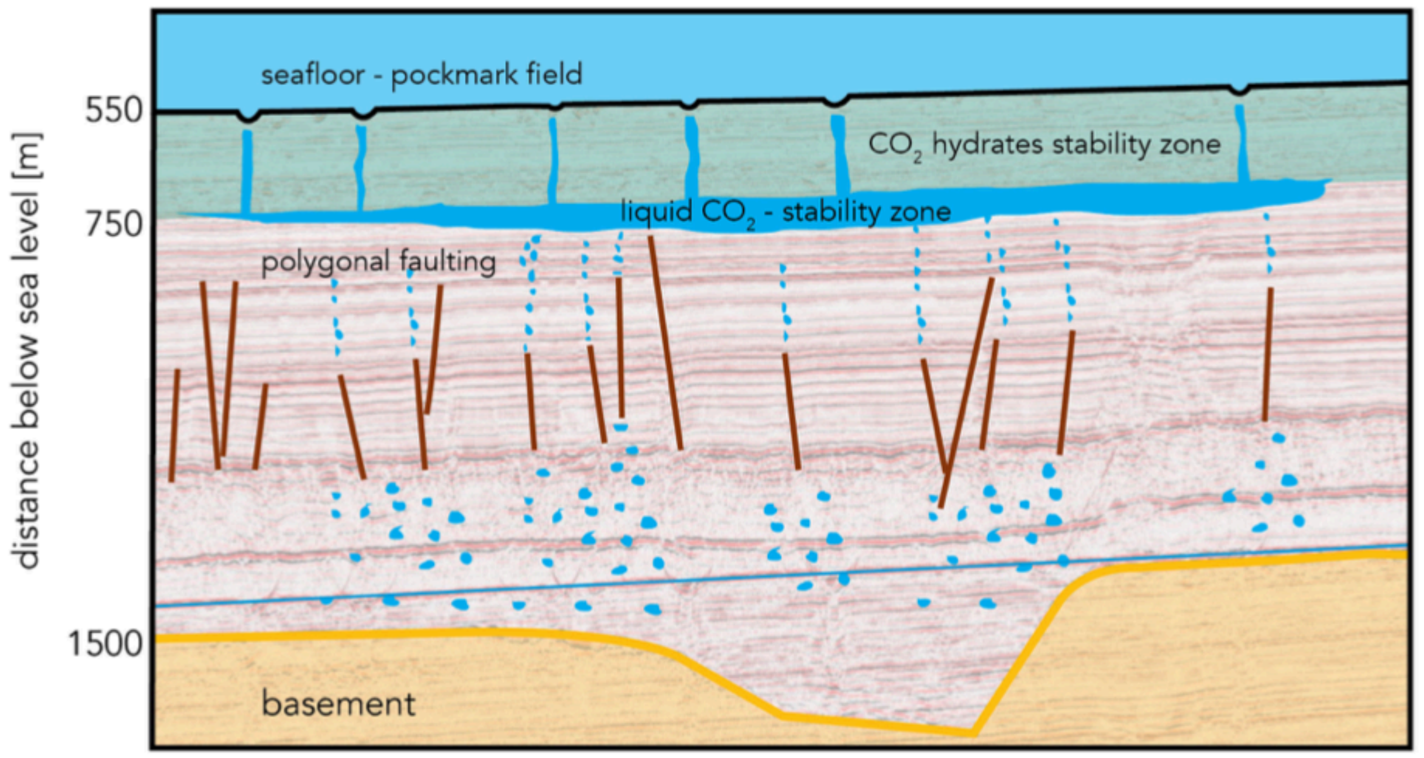
Ice core records show a significant response of Earth's climate to variations in atmospheric CO_2 concentrations.

Pockmark field offshore New Zealand



Stott et al., 2019

Potential flow pathways



Deep CO_2 leaking through polygonal fault system and accumulating beneath the hydrate «seal».

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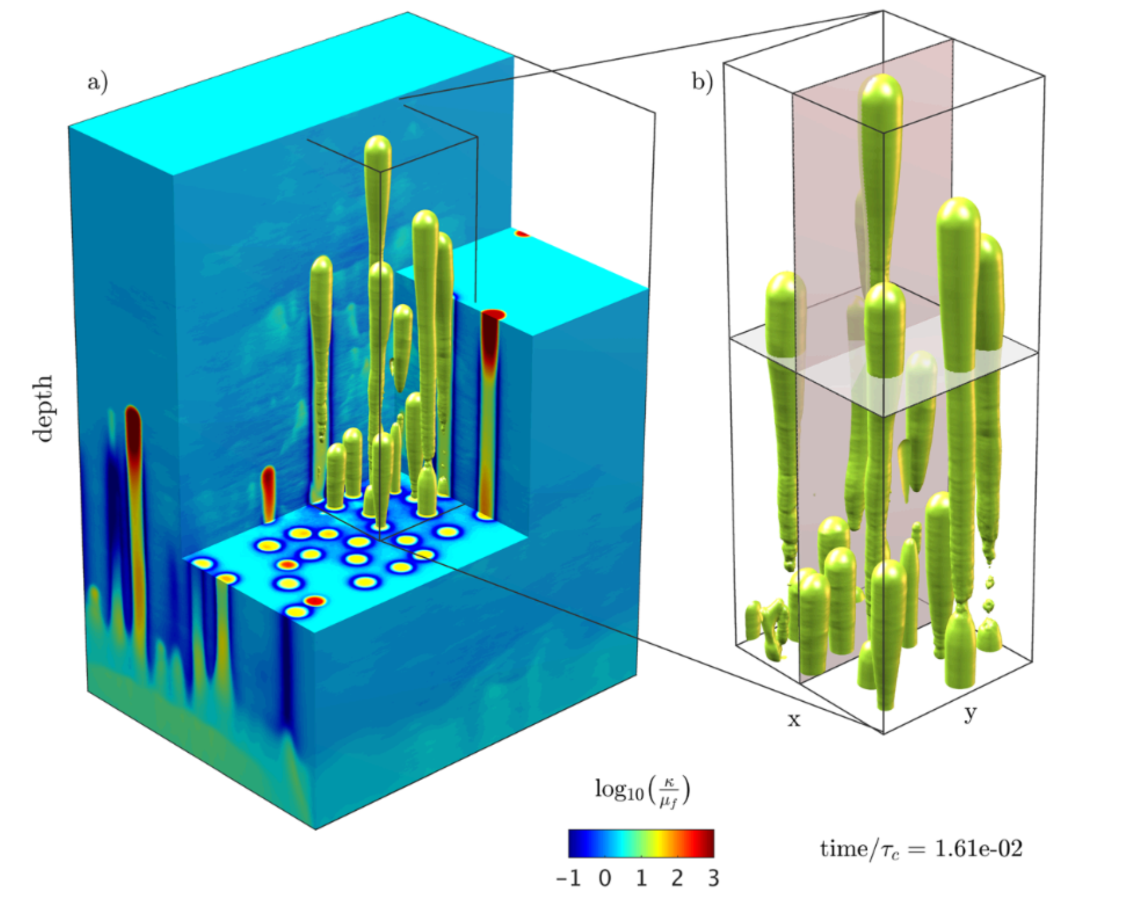
The hydro-mechanical model



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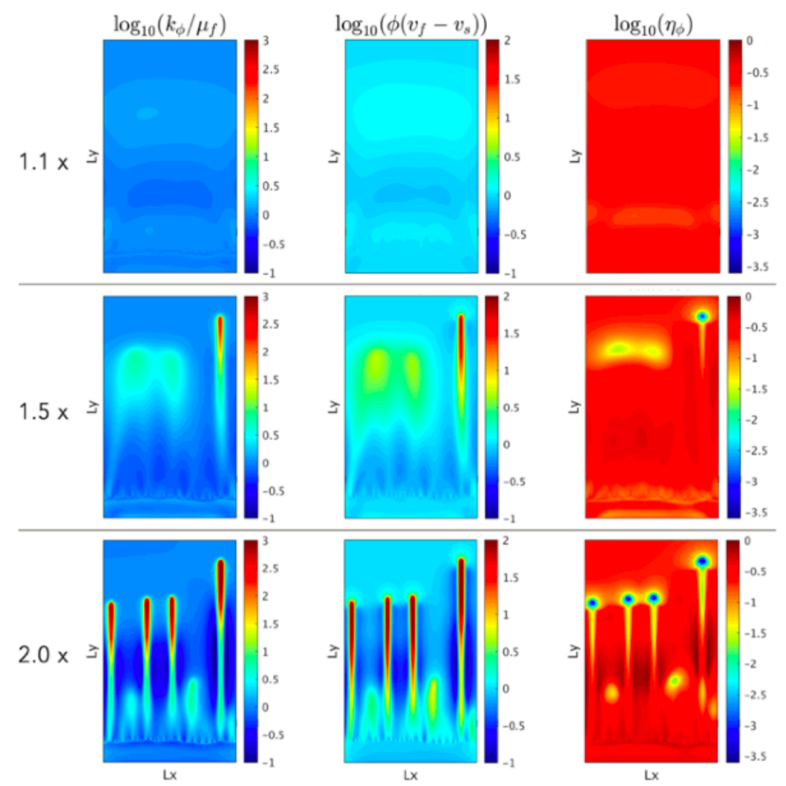
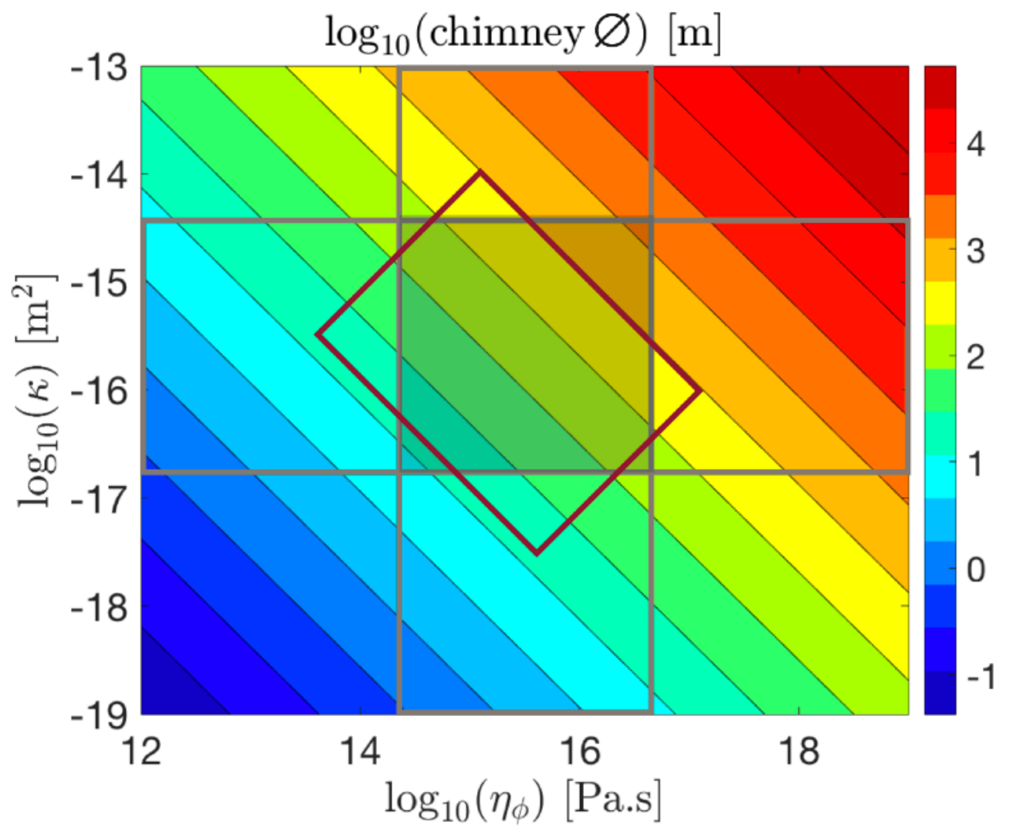
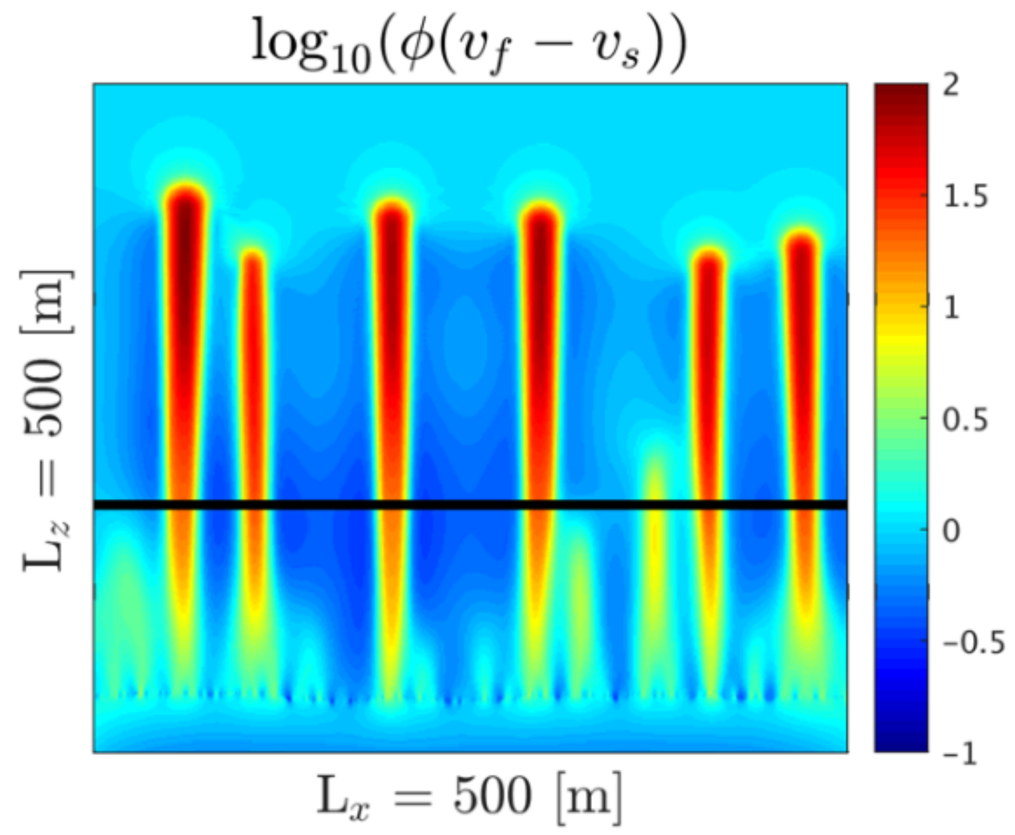
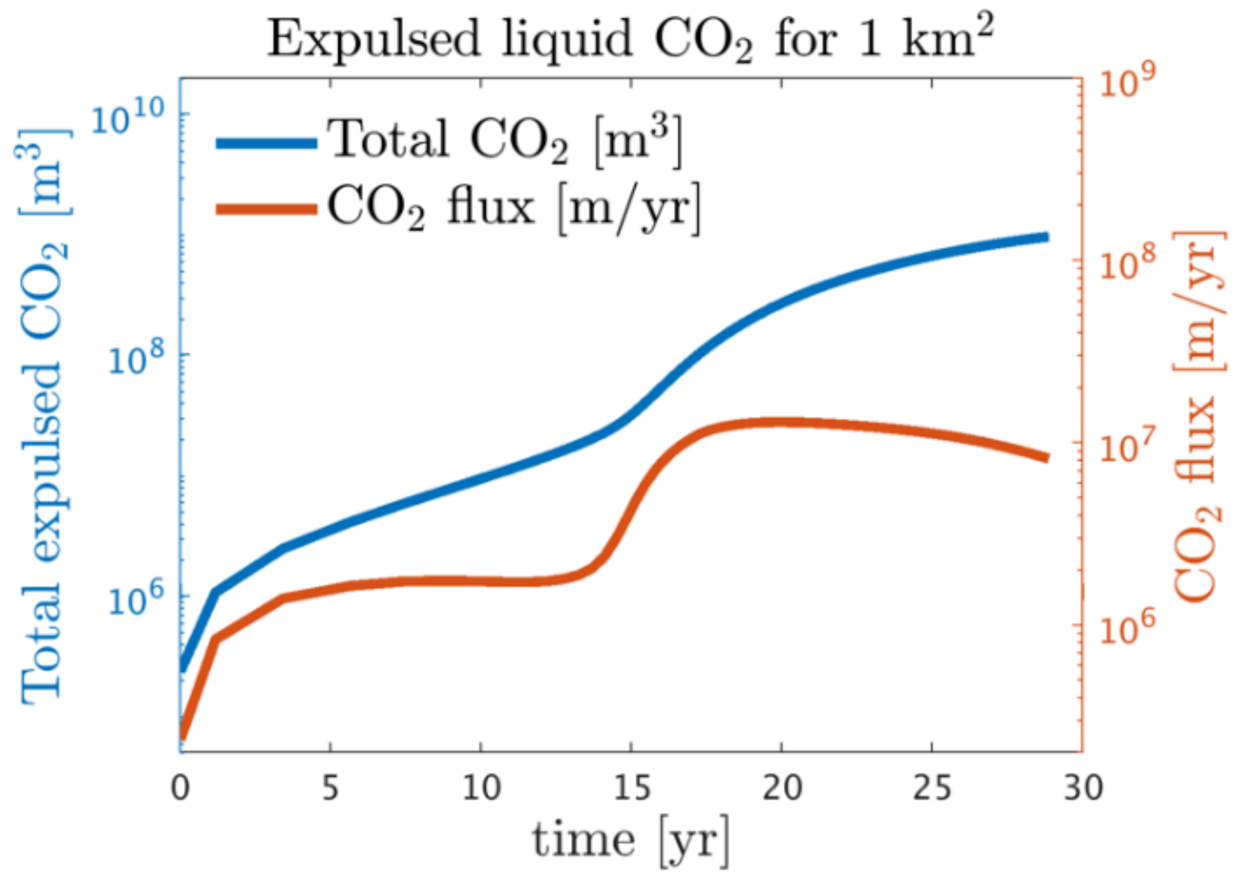
Chimney size and CO_2 flux predictions









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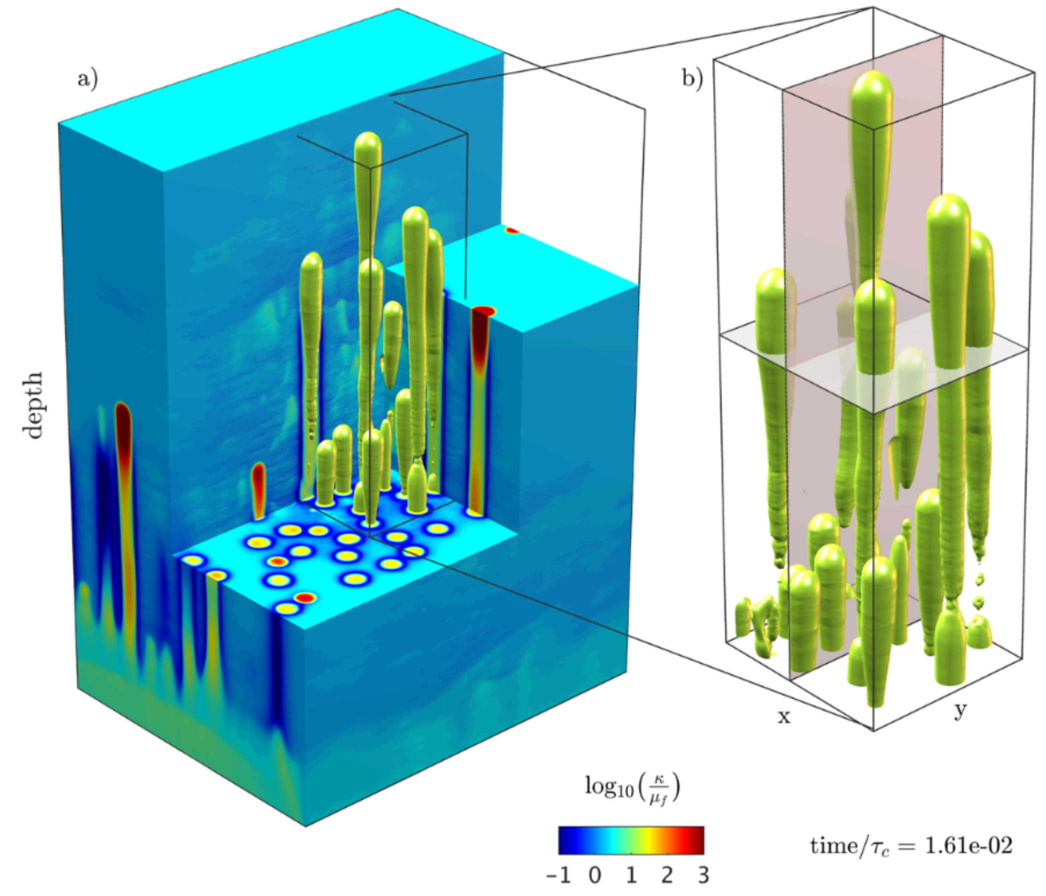

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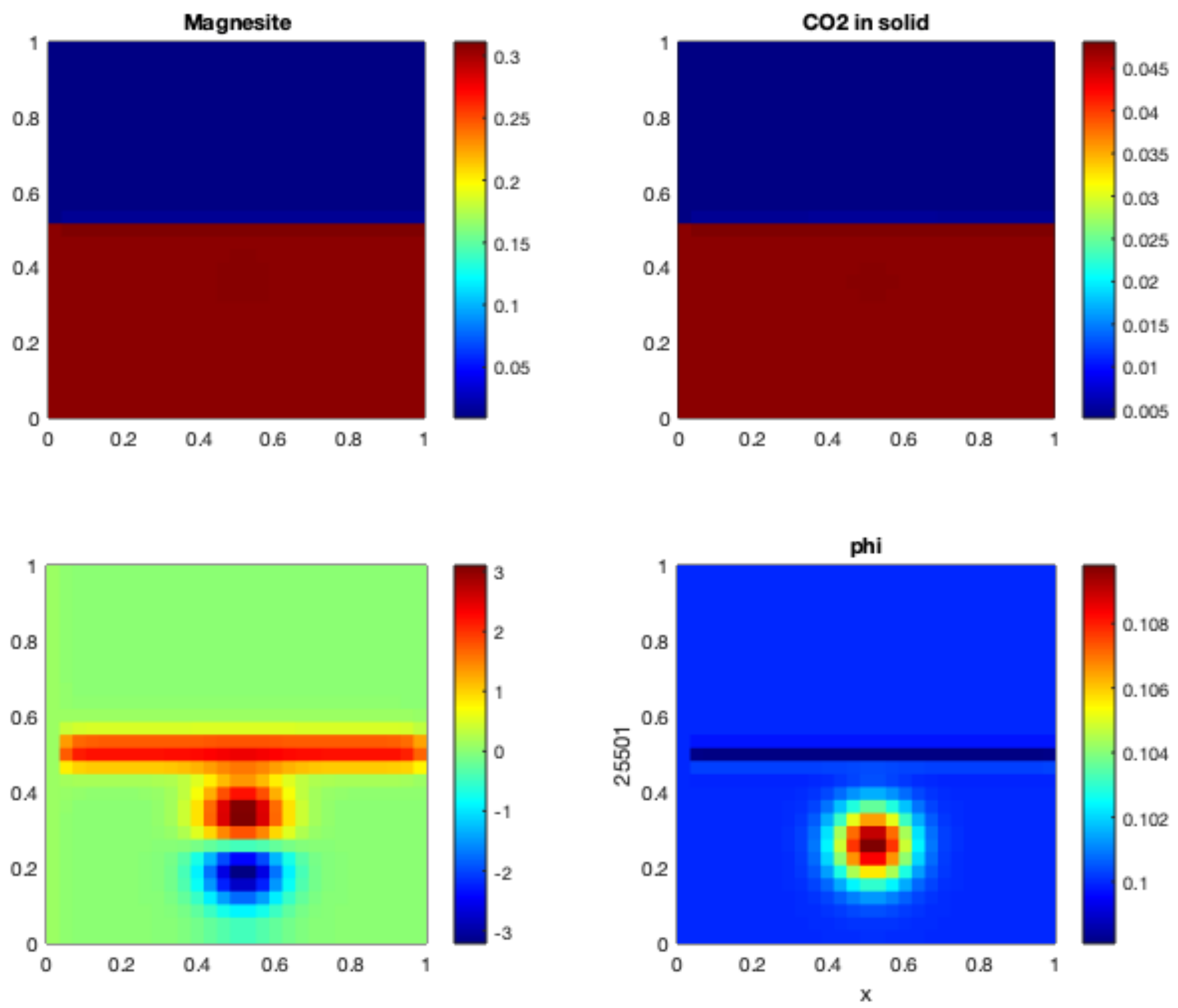
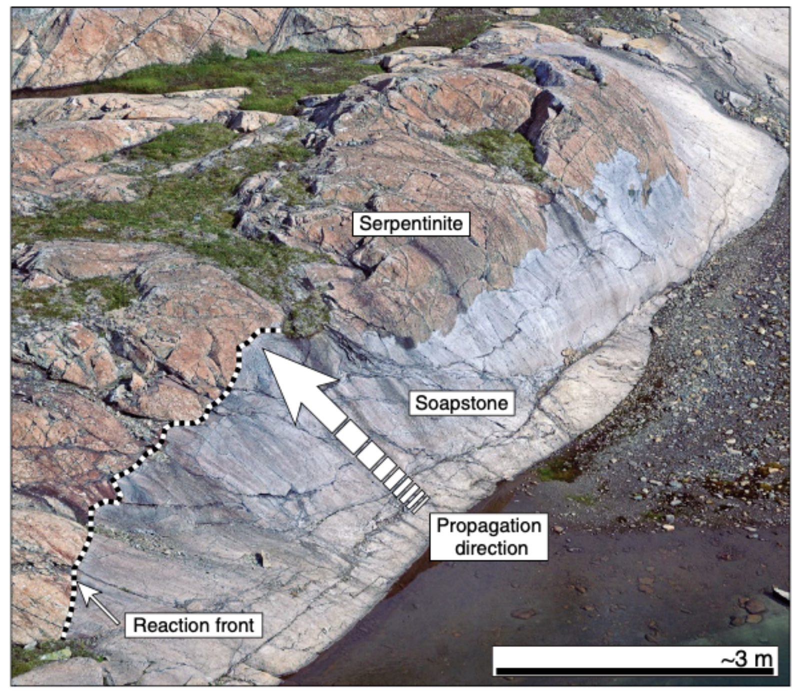
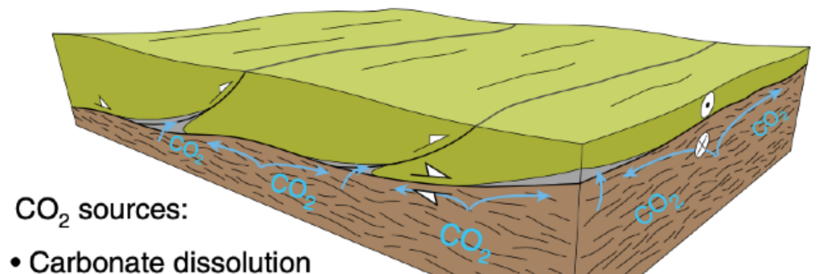


The reactive flow model





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