How does topography control shallow geological processes?

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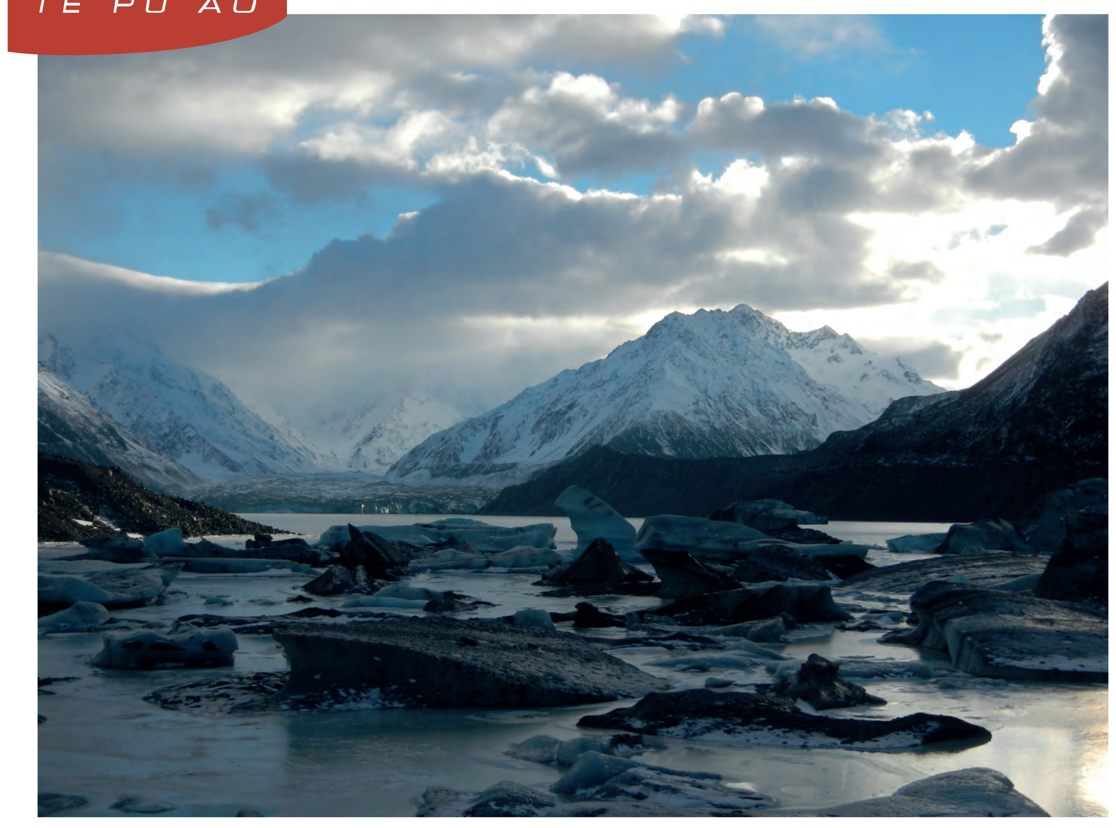


Progress toward improved application of conceptual and numerical models of crustal evolution models to higher spatial and temporal frequencies has revealed considerable inconsistencies in the predictive powers of current models, especially at the near surface. Here we focus on how topography, at the scale of ridges and valleys, feeds back into the 3D stress and strain fields and related parameters. A new formulation, the Failure Earth Response Model (FERM), which unifies the description of tectonic and geomorphic forcings within a single framework, allows us to gather stresses generated by far field tectonics processes, topography and surface processes into a single stress state for every point.

See keynote talk: Koons: Unifying Tectonics & Surface Processes in Geodynamics.

FERM is constructed on the two, basic assumptions about the three-dimensional stress state and rheological memory:

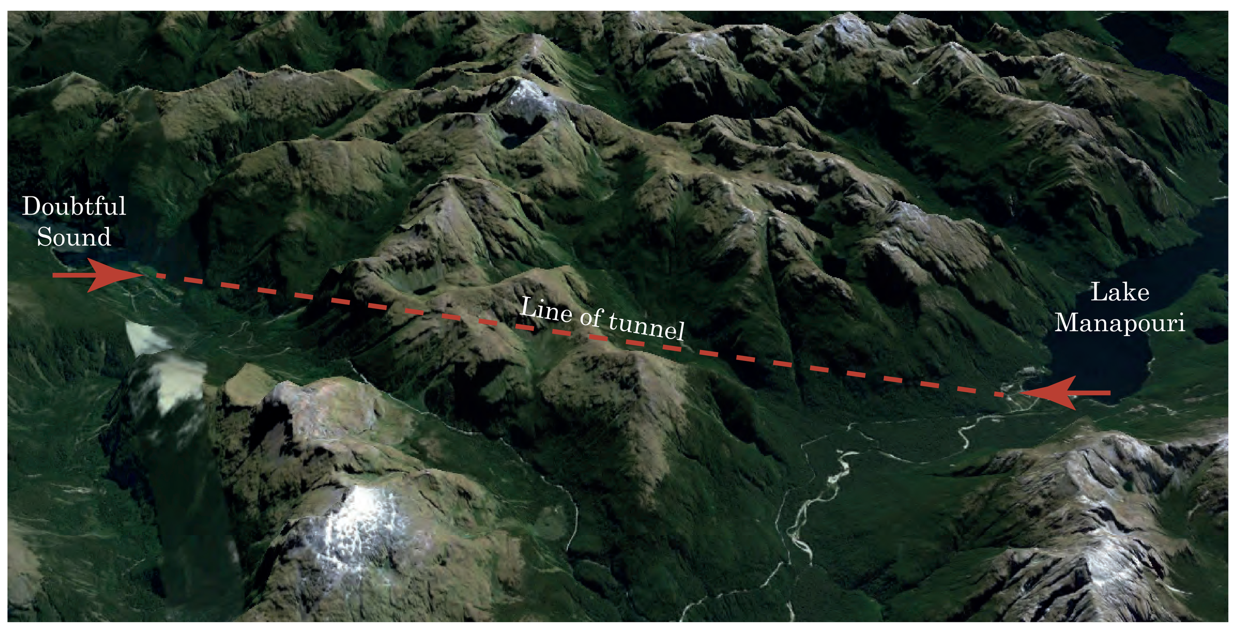
I) Material displacement, whether tectonic or geomorphic in origin, at or below Earth's surface, is driven by local forces overcoming local resistance, and

II) Large displacements, whether tectonic or geomorphic in origin, irreversibly alter Earth material properties enhancing a long term strain memory mapped into the topography.

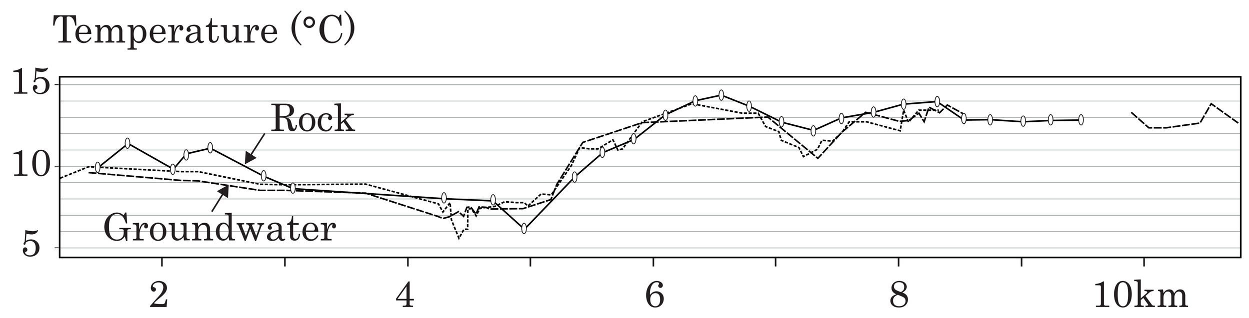
Using FERM we can explicitly consider the contribution that pore pressure fluctuations, seismic accelerations, fault damage and large storm events make toward the rock mass failing using examples from the Southern Alps of New Zealand.

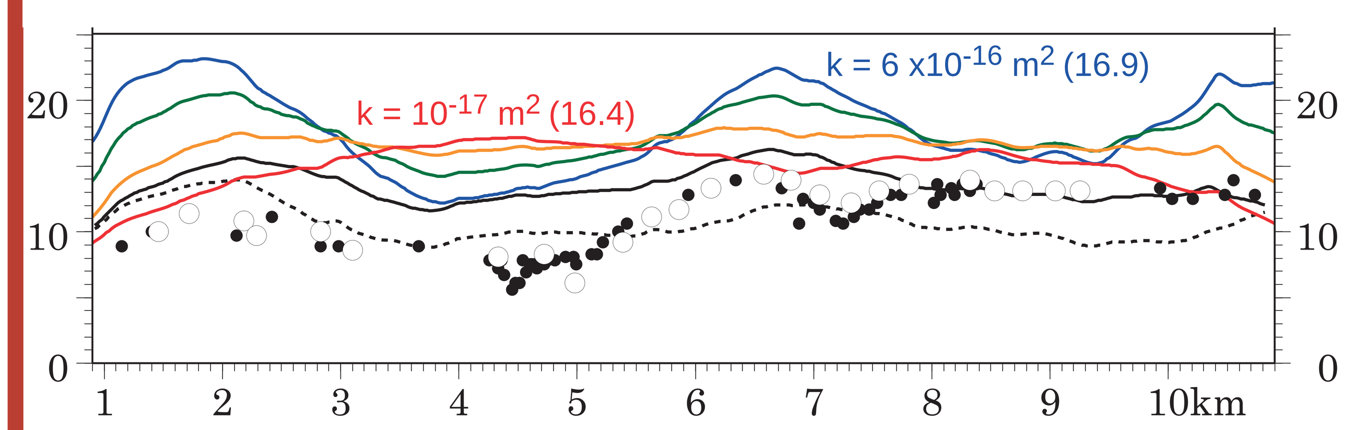
Manapouri tunnel, Fiordland, New Zealand: High permeability correlates with topographically driven proximity to failure.

Upton and Sutherland, EPSL, 389, 176-187, 2014

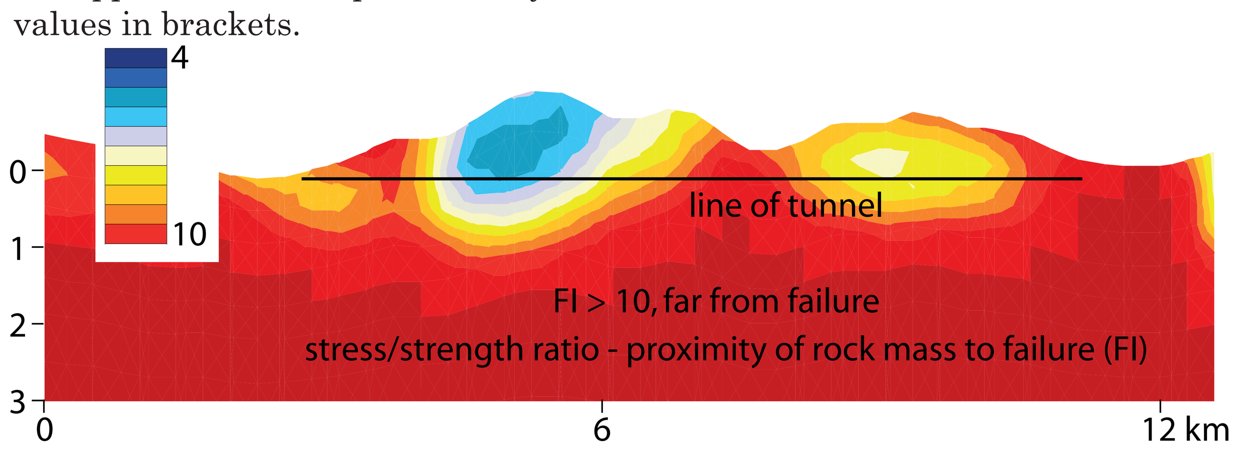


The tunnel passes beneath ~1km of relief. The temperatures in the tunnel (below) are almost isothermal with the coolest temperatuers observed beneath the highest topography - implying an advective regime.

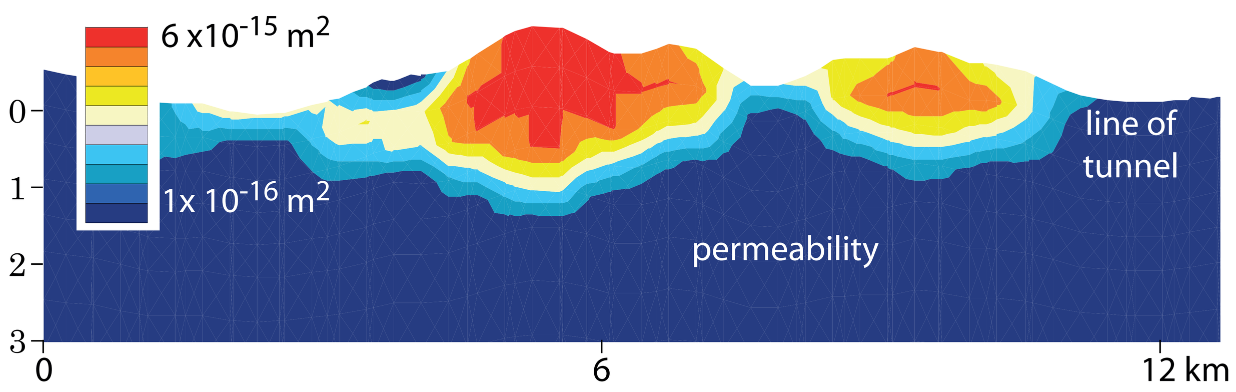




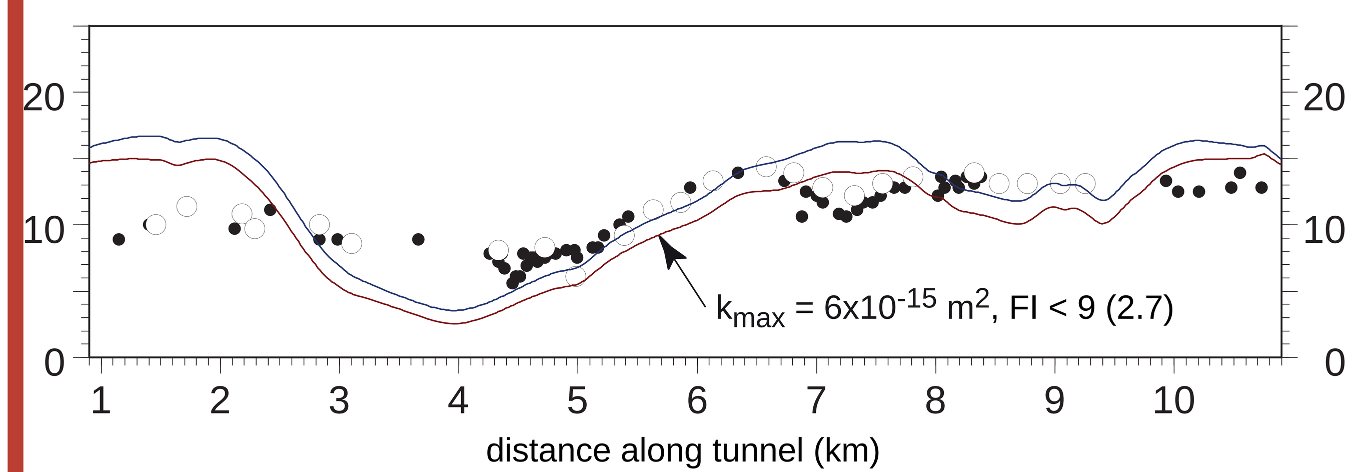
Model temperatures for uniform permeability (k) values (colours). High k predicts low temperature beneath the highest topography but temperatures beneath the valleys are much to high. The best results come from models with a stepped horizontal permeability structure (black and dashed). RMS misfit values in brackets.



Proximity of the rock mass to failure (FI – failure index) along the line of the tunnel. 1 = failure, >10 rock is far from failure.

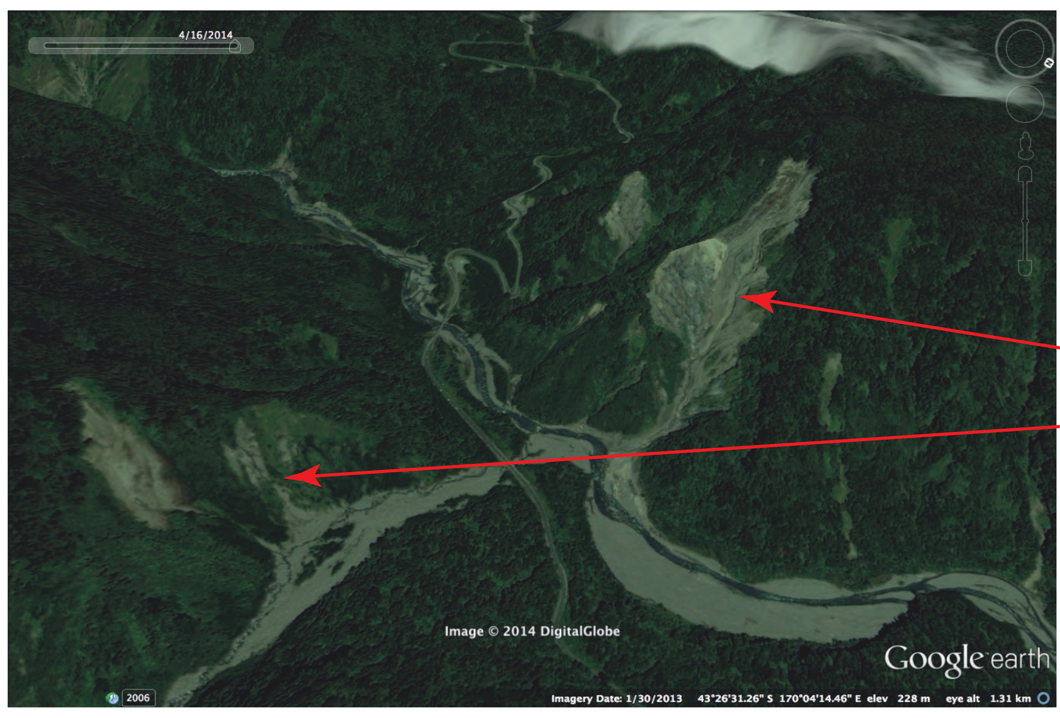


Permeability calculated from the proximity to failure such that if FI < 9, k = 6 × 10^{-15} m^2.

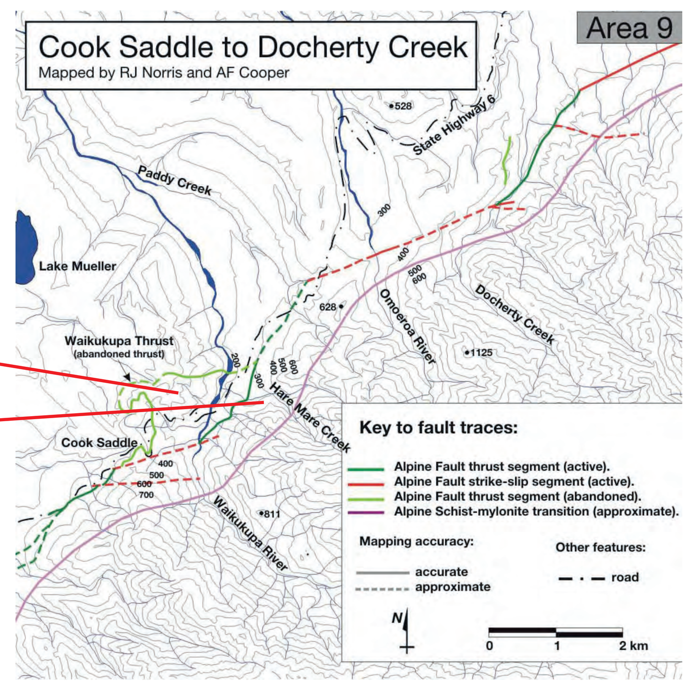


Model results: Red – if FI < 9, k = 6 × 10^{-15} m^2 ; blue – if FI < 9, k = 5 × 10^{-15} m^2 . Measured values are also shown, open circles = rock temperature, filled circles = groundwater temperature. RMS misfit values in brackets.

FERM model of the Akpine Fault at Hare Mare Creek and the Waikukupa River

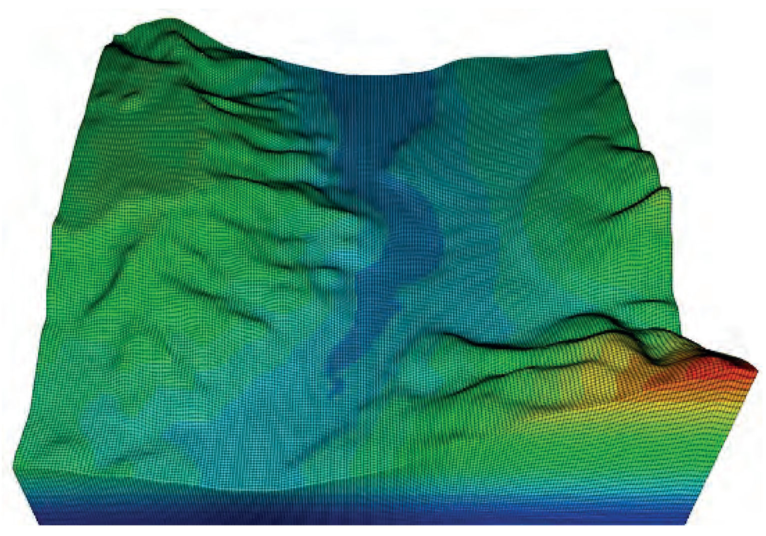


Google Earth image of our study area. Erosion is forming a rapidly downcutting gully where the weak rocks of the Alpine Fault are exposed. The relief here is high enough for topographic stresses to be all that are required for these rocks to reach failure.

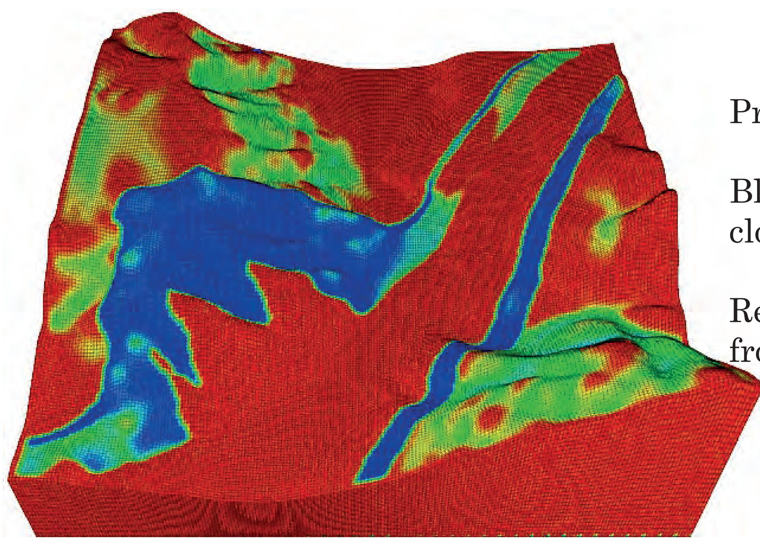


Norris and Cooper (****), website address

Geology map showing the active and abandoned traces of the Alpine Fault and the approximate location of the mylonite/schist transition.



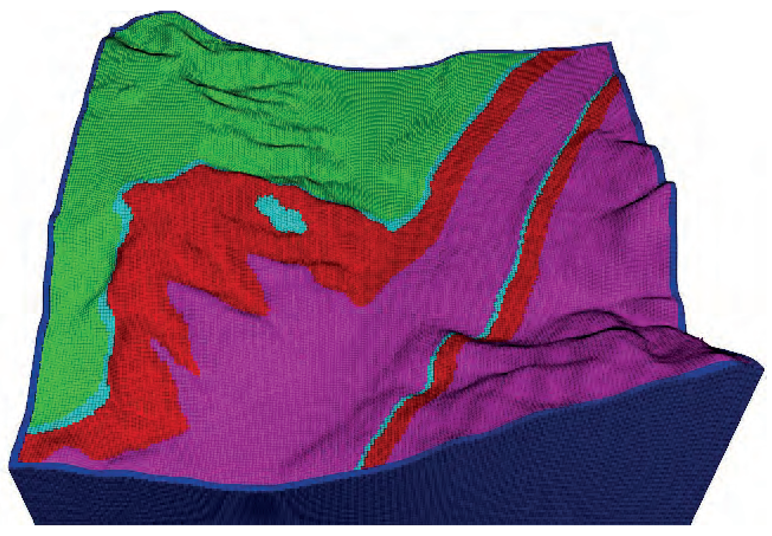
3D model of Hare Mare Creek and Waikukupa River



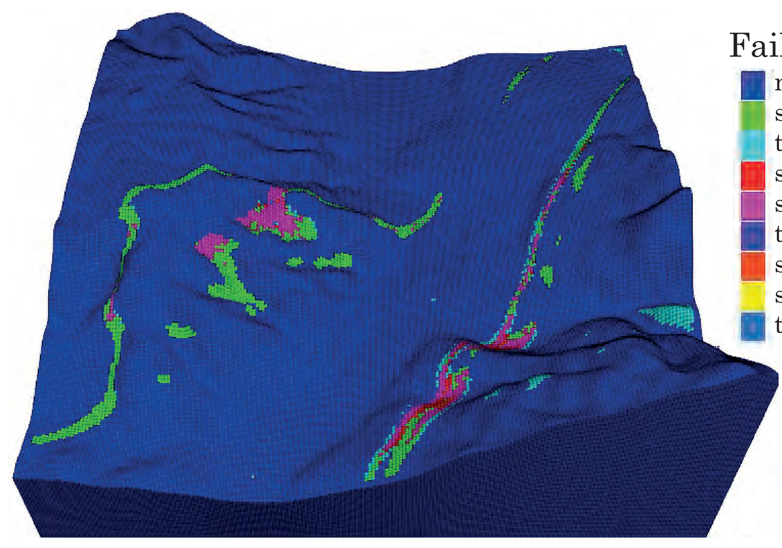
Proximity to failure:

Blue - rocks are at or very close to failure

Red - rocks are very far from failure

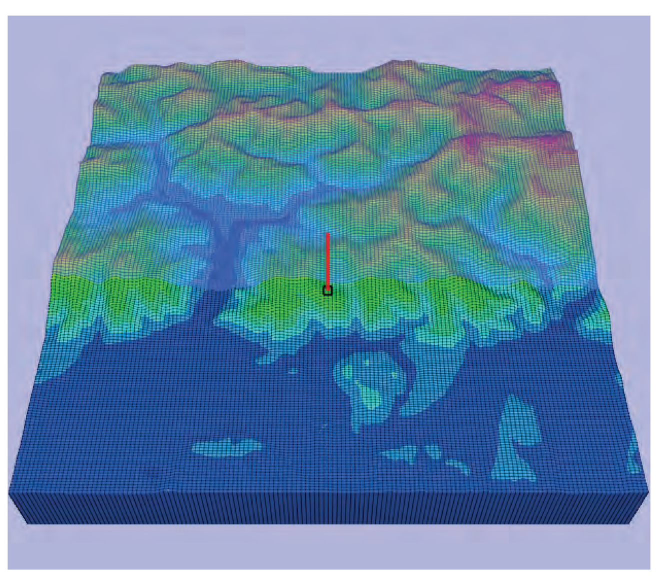


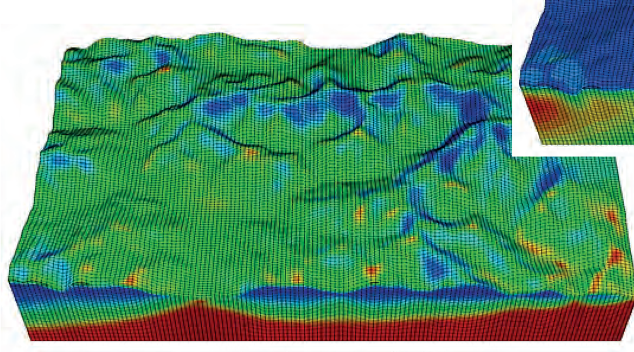
Geology: Green: West of Fault, cohesion = 5e6 Pa
Blue: Fault gouge, cohesion = 1e5 Pa
Red: Cataclasites, cohesion = 1e6 Pa
Purple: Mylonites, cohesion = 1e7 Pa



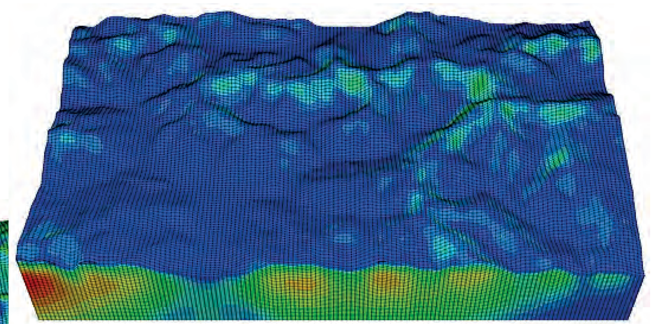
Failure state:
- none
- shear-past
- tension-past
- shear - past, tension - past
- shear - now, tension - past
- tension -now, tension - past
- shear - n, shear - p, tension - p
- shear - n, tension - p
- tension - n, shear - p, tension - p

Topographic stresses Whataroa Valley - site of the Deep Fault Drilling Project





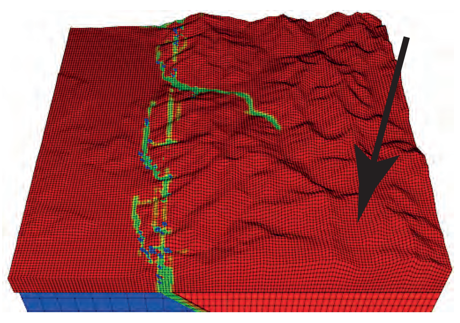
Proximity to failure:
red - far from, blue - close to



Effective shear stress

Partitioning of displacement in the near surface as a funtion of topography

Alpine Fault fixed below 2km, strain softening rheology, based on f reducting from 30° to 5°



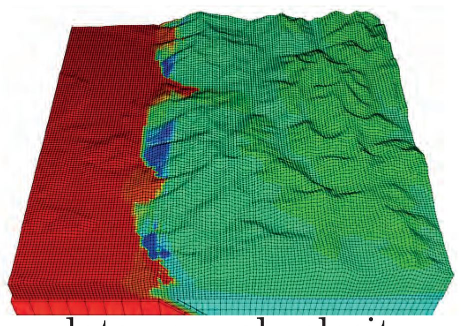


plate normal velocity

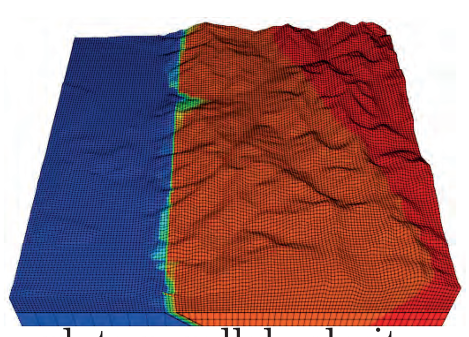


plate parallel velocity