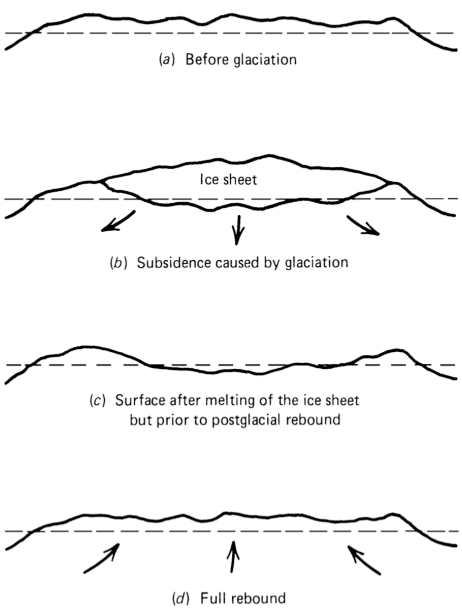
Mantle Viscosity and Post-Glacial Rebound

Post-glacial (or isostatic) rebound is an increase in elevation following the removal of an ice sheet. As ice sheets grow, their weight deforms the Earth's lithosphere downward. This forces the mantle to flow away from the region. When the ice sheet melts, the mantle flows back, and elevation increases. The magnitude and rate of subsidence and rebound depends on ***mantle viscosity***.

(T&S Figure 6.14)



At steady state the magnitude of lithospheric deformation is linearly dependent on ice sheet of thickness *H*, proportional to the ratio between ice and mantle density:

$$w_m = \frac{\rho_{ice}}{\rho_{mantle}} H$$

(Tarasov and Peltier, 1997)

Surface displacement decreases exponentially with time as the mantle flows from regions of elevated topography to regions of depressed topography:

$$w = w_m exp\left(\frac{-t}{\tau}\right)$$

(T&S Equation 6.104)

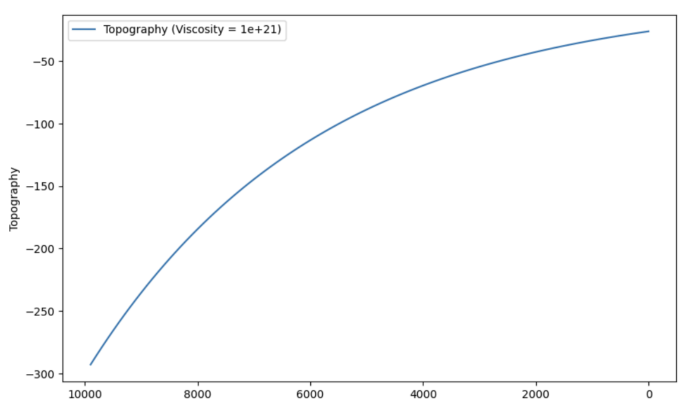
Where τ, the characteristic time of relaxation is:

$$\tau = \frac{4\pi\mu}{g\lambda\rho_{mantle}}$$

(T&S Equation 6.105)

For mantle viscosity μ, gravitational acceleration g, and characteristic wavelength λ, where $\lambda >> w_m$. We assume the mantle acts as a viscous fluid beneath the solid lithosphere.

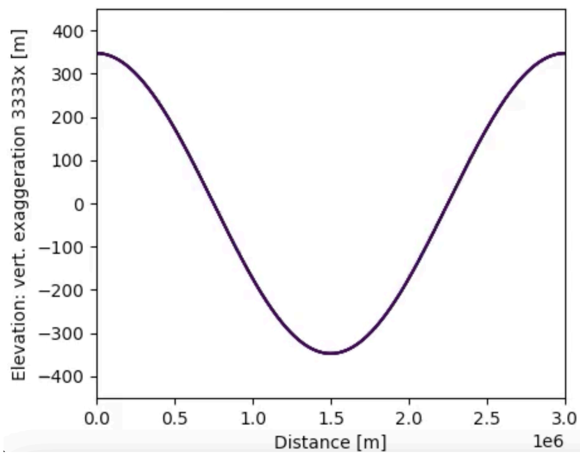
Below is a graph showing the elevation of a single point after an initial displacement of ~300m 10,000 years ago, with a mantle viscosity of $\mu=10^{21}$ kg/ms. **What would the graph look like if the mantle viscosity was $\mu=10^{22}$ kg/ms or $\mu=10^{20}$ kg/ms, assuming every other parameter stayed the same?**



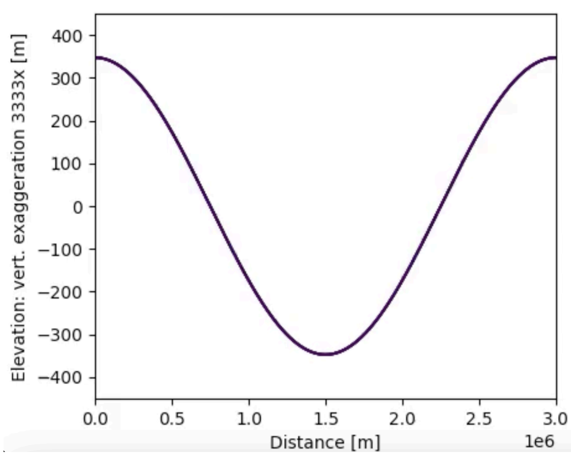
If we assume that the topographic profile can be represented by a sine wave, then the surface displacement w_x across the profile x over time can be modeled by the equation:

$$w_x = \cos\left(\frac{\pi x}{\bar{x}}\right) \cdot w_m \exp\left(\frac{-t}{\tau}\right)$$

The following topographic profile shows a region that has been displaced by a mass of ice. **What would the profile look like at t = 2000, t = 6000, t = 10000, and t = 14000 years after the unloading of the ice sheet? What is the direction of fluid flow in this system?**



What would the initial displacement profile look like if the thickness of ice decreased or increased by 50%?



How might a real system vary from this simplified model?