a) \[ \sigma = \frac{P}{A} \]

b) \[ \frac{dh}{dt} = \frac{\rho_0 \sqrt{\frac{M}{2\pi I_2}}}{\theta s} = 1.2 \times 10^{-5} \text{m/s} \]

so \( t = \frac{D}{2} \approx 0.94 \text{ days} \).  

c) \( \gamma = \frac{N}{PSD} \)

Also \( \gamma \) is larger when sample deeper mantle, which is likely to be less viscous (more rapid relaxation).

d) \[ t \sim \frac{d^2}{K} \Rightarrow K \sim \frac{d^2}{T} \sim \frac{30^2}{(10 \times 10^3)^2} \sim 0.09 \text{ m}^2/\text{yr} \).  

e) Small particles are stuck in the viscous boundary layer where forces are small, large particles are too heavy to move. In between is a "sweet spot."  

f) \[ \kappa = \left( \frac{E_T e^3}{3(1-e^2) \rho y} \right)^{1/4} \]

\( \kappa \approx 3 \text{ km} \Rightarrow T_e \approx 0.3 \text{ km} \).  

g) Large boulders are found at the edge of the rain channel. They are transported less readily than fine-grained material which subsequently erodes away.  

h) Large asteroids are unfurled and will fly apart if they spin too fast. Smaller asteroids can be maintained together by mutual attraction.

i) Either the rocks are buckling viscously (not elastically) at high temperatures. Or new are born, weak layers allowing elastic buckling to happen.  

j) Titan - lowest gravity of all four.  

2 a) $\delta w = u w = \frac{\delta \rho w^3}{8 \pi}$

b) $\delta w = u h$. 

c) $u = \frac{\rho \delta h^2 \sin \alpha}{\pi}$

d) $t = \frac{h^2}{K} \quad L = ut = \frac{uh^2}{K}$. 

e) $\delta \rho \delta h^3 = \rho \delta h^3 \sin \alpha$ \quad \therefore $w^3 = \frac{\rho}{\delta \rho} \sin \alpha \cdot h^3$ 

f) $\Delta \rho \uparrow h \uparrow$ because magma is coming out of the ground fast.
$p \uparrow h \uparrow$ because the downhill speed increases.
$\alpha \uparrow h \uparrow$ same as for $p$. 

(3).

g) Because it controls the ascent and the descent speed. 

3 a) $\frac{D}{2}$ 

$\text{mass} = \rho \frac{2}{3} \pi \left(\frac{D}{2}\right)^3$

potential energy $= mg \frac{D}{2} = \frac{2}{3} \pi \rho \left(\frac{D}{2}\right)^4 g$

b) $ke = \frac{1}{2} m v^2 = \frac{1}{2} \left(\frac{4}{3} \pi \left(\frac{D}{2}\right)^3\right) \rho v^2$. 

c) $\frac{8 \pi \rho \frac{D^4}{16}}{g} = 2 \frac{\pi}{3} \frac{L^3}{18} \rho v^2 \quad \therefore D^4 = 2 \frac{L^3 \rho v^2}{g}$

d) $\text{volume} = \frac{2}{3} \pi \left(\frac{L}{2}\right)^3 \rho v^2 = M \text{mol} \frac{L_H}{L_H}$

$\therefore \text{volume} = \frac{2}{3} \pi f \left(\frac{L}{2}\right)^3 \frac{v^2}{L_H}$. 

e) $\text{melt volume scales as} \quad L^3$

$\text{crust volume scales as} \quad D^3 = L^{9/4}$

So melt volume is a larger fraction of large crusts (larger $L$).

f) $D \sim \frac{1}{9^{1/4}} \quad \text{so the larger crust would be a factor of } 1.87 \text{ larger.}$

g) S.C. fraction scales with $\frac{1}{9}$ so diameter on Mars is six times larger. 

h) Same (because bulk velocities are the same).
4. a) normal stress \( \sigma_{ij} \sim p g R \) ①  
   b) max shear stress \( \sigma_{ij} \sim f \rho g R \) ①  
   c) max shear stress \( \sigma_{ij} \sim p g h \) ①  
   d) \( p g h \sim f \rho g R \Rightarrow \frac{h}{R} \sim f \) ①  
   e) \( g = \frac{GM}{R^2} \approx \frac{\pi}{3} \frac{R^2}{R^2} = \frac{G}{3} \rho g R \), \( \Rightarrow \sigma_{ij} \sim \frac{4}{3} \pi G \rho g R \) ①  
   f) \( Y = \frac{4}{3} \pi G \rho g R \), \( \Rightarrow \frac{3Y}{4\pi G \rho g R} = \frac{h}{R} \) ②  
   g)  
   h) \( \frac{3Y}{4\pi G \rho g R^2} = f \Rightarrow R = \frac{122h}{f} \) ②  

5. a) \( \frac{\partial \Delta h}{\partial t} = \frac{\partial h}{\partial t} = \frac{\Delta h}{\partial t} = \frac{\partial h}{\partial t} \) ①  
   b) small dunes travel faster. They outpace the big dune shape; thus they get caught in the "wind-shadow" and stop, so that big dunes eat little dunes. ②  
   c) Modification timescale = \( \frac{L}{V_d} = \frac{L \Delta h}{V_d} = \frac{\Delta h}{V_d} \) ①  
   d) \( Q_s = \frac{C \rho g V_d^3}{g} = 2800 \text{ m}^3 \text{s}^{-1} \)  
   e) \( t = \frac{\Delta h}{Q_s} = 363 \text{ s} \) ①  
   f) Velocities this high must be very rare. ①  
   g) Gravity is lower. Atmospheric density is higher. ②  
   h) If there are multiple wind directions, the dune orientation is giving some kind of averaged answer. ②  

6. a) normal stress \( \sigma_{ij} \sim p g h \cos 30^\circ \)  
   \[ \frac{52 \text{ kPa}}{\text{ }} \] ②
b) \( \text{shear stress} = f \sigma n = 31 \text{kPa} \)  

c) \( \text{shear stress} = \rho gh \sin 30^\circ = 30 \text{kPa} \). \( \text{It will not move} \).  

d) \( \theta = \tan^{-1} \left( \frac{h}{w} \right) = 31^\circ \)  

e) \( \theta \)  

f) \( \tau \sim \frac{d^2}{d \xi^2} \Rightarrow K \sim \frac{d^2}{d \xi^2} \sim 0.9 \text{m}^2 \text{s}^{-1} \)  

g) \( K = \frac{h^2}{\rho n} \Delta P \Rightarrow h = \frac{K \rho n}{\Delta P} = 9 \times 10^{-8} \text{m} \)  

h) The static pressure would both be lower. 
So the pressure change required to initiate motion would be lower.  

7 a) \( \rho g (h - z) \sin \alpha \)  

b) \( \frac{du}{dt} = A (\rho g (h - z))^n \Rightarrow u = -A (\rho g)^n (h - z)^{n+1} + c \)  

c) \( \text{at } u = 0, z = 0 \Rightarrow 0 = -A (\rho g)^n h^{n+1} + c \Rightarrow c = A (\rho g)^n h^{n+1} \)  

\( \text{at } u = 0, z = 0 \Rightarrow 0 = -A (\rho g)^n h^{n+1} + c \Rightarrow c = A (\rho g)^n h^{n+1} \)  

d) \( \bar{u} = \frac{1}{h} \int_0^h u \, dz = \frac{C}{h} \int_0^h \left[ 1 - \left( 1 - \frac{z}{h} \right)^{n+1} \right] \, dz \)  

\[ = \frac{C}{h} \left[ \frac{z + h (1 - \frac{z}{h})^{n+2}}{n+2} \right]_0^h = \frac{C}{h} \left[ h + \frac{h}{n+2} \right] \]  

\[ = \frac{C}{h} \left[ (n+2)h - h \right] = \frac{C (n+1)}{h} \)  

e) Once the glacier thickness exceeds the ice yield strain, the glacier stops moving at the surface and begins moves laterally.  

f) \( V = \rho gh \Rightarrow h = \frac{500\nu}{\sigma} \)