Summary – Shapes, geoid, topography

• How do we measure shape/topography?
  – GPS, altimetry, stereo, photoclinometry, limb profiles, shadows

• What is topography referenced to?
  – Usually the geoid (an equipotential)
  – Sometimes a simple ellipsoid (Venus, Mercury)

• What controls the global shape of a planet/satellite? What does that shape tell us?
  – Rotation rate, density, (rigidity)
  – Fluid planet $f \sim \Omega^2 a/2g$  Satellite $f \sim 5\Omega^2 a/g$

• What does shorter-wavelength topography tell us?
  – Hypsometry, roughness, elastic thickness?
Summary – Rheology

• Definitions: Stress, strain and strength
  – strength = maximum stress supported, $\sigma = F/A$, $\varepsilon = \Delta L/L$

• How do materials respond to stresses?: elastic, brittle and viscous behaviour
  – Elastic $\sigma = E\varepsilon$
  – Brittle $\tau = c + f\sigma$
  – Viscous $\sigma = \eta \frac{d\varepsilon}{dt}$

• What loads does topography impose?
  – $\sigma \sim 1/3 \rho gh$

• Elastic, viscous and brittle support of topography
  – Flexure, $\alpha = (4D/\Delta \rho g)^{1/4}$
  – Viscous relaxation and dynamic support
  – Role of yield stress $Y$ and friction coefficient $f$ in controlling topography on large and small bodies, respectively
Summary – Tectonics

• Sources of stress
  – Shape changes, loading/curvature

• Ductile response – folding, boudinage, diapirism
  – Failure of elastic buckling instability analysis

• Brittle response – faulting
  – Byerlee’s law
  – Andersonian fault mechanics ($f=0.6$ implies $\theta=60^\circ$)
  – Normal, thrust, strike-slip faulting

• Tectonics across the solar system
Summary - Volcanism

• How and why are melts generated?
  – Increase in mantle potential temperature; or
  – Reduction in solidus temperature (e.g. water); or
  – Thinning of the lithosphere

• How do melts ascend towards the surface?
  – Initially via porous flow through partially-molten rock
  – Later by flow in macroscopic fractures (dikes)

• What controls the style of eruption?
  – Magma viscosity, volatile content, environmental effects

• What controls the morphology of surface volcanic features?
  – Volcano morphology controlled mainly by viscosity
  – Flow characteristics can be used to determine material properties

• How does volcanism affect planetary evolution?
  – Advection of heat; sequestration of heat-producing elements
Summary – Impact cratering

• Why and how do impacts happen?
  – Impact velocity, comets vs. asteroids

• Crater morphology
  – Simple, complex, peak-ring, multi-ring

• Cratering and ejecta mechanics
  – Contact, compression, excavation, relaxation

• Scaling of crater dimensions
  – Strength vs. gravity, melting

• Cratered landscapes
  – Saturation, modification, secondaries, chronology

• Planetary Effects
Useful Equations

\[ v_{esc} = \sqrt{\frac{2GM}{R}} = \sqrt{2gR} \]

\[ P_{\text{max}} \approx \rho v_i^2 \]

\[ D \approx \left( \frac{\rho_p}{\rho_t} \right)^{1/4} L^{3/4} \left( \frac{v_i^2}{g} \right)^{1/4} \]

\[ s_{\text{max}} = \frac{v_{ej}^2}{g} \]
Summary – Mass Movements

• Downhill creep is diffusive: \( \frac{\partial z}{\partial t} = K \frac{\partial^2 z}{\partial x^2} \)

• Resistance to sliding depends on pore pressure:
  \[ \sigma_s = c + (\sigma_n - p) \tan \phi \]

• Angle of repose is independent of gravity

• Effective friction coefficient of long-runout landslides is very low
Summary - Wind

• Sediment transport
  – Initiation of motion – friction velocity $v^*$, threshold grain size $d_t$, turbulence and viscosity
  – Sinking - terminal velocity
  – Motion of sand-grains – saltation, sand flux, dune motion

\[ d_t \approx 10 \left[ \frac{\eta^2}{\rho_f (\rho_s - \rho_f) g} \right]^{1/3} \]

\[ q_s = C \frac{\rho_f v^*^3}{g} \]

\[ v = \sqrt{\frac{4 (\rho_s - \rho_f) dg}{3 \rho_f C_D}} \]

\[ v^* \approx 3.5 \frac{\eta}{\rho_f d_t} \]

• Aeolian landforms and what they tell us
Summary – Ice & Sublimation

• Ice rheology
  – Non-Newtonian \( \dot{\varepsilon} = \frac{\partial u}{\partial z} = A \sigma^n \)

• Glaciers & ice sheets
  – Cold-based vs. warm-based
  – Erosional & depositional features

• Ice in the subsurface
  – Polygons, ice wedges, thermal wave, neutron data

• Sublimation
  – Albedo-lag feedbacks
    \[ \frac{dh}{dt} = \frac{P_{\text{vap}}}{\rho} \sqrt{(\mu / 2\pi RT)} \]
Summary – “Water”

- Surface flow
  - Water discharge rates
  - Sediment transport – initiation, mechanisms, rates

\[ u^* = \sqrt{gh \sin \alpha} \quad u^*_{\text{crit}} = \left( \frac{\rho_s - \rho_f}{\rho_f} \right)^{1/2} (gd)^{1/2} \theta^{1/2} \]

- Channels – braided vs. meandering
- Fluvial landscapes