Fundamentals of Planetary Science Homework 4

Student: 纪浩正, 12311405@mail.sustech.edu.cn

1 Briefly summarize and describe different types of planetary surface processes.

Planetary surface processes are driven by forces originating from either the planet's interior (**endogenic**) or external sources (**exogenic**). These processes shape landscapes through deformation, material transport, and erosion.

Endogenic Processes

- **Tectonics**: Driven by internal heat and mantle dynamics, tectonics involve crustal deformation from stresses like compression (shortening) and extension (stretching). Key features include:
  - Faults (brittle deformation, e.g., thrust faults)
  - Folds (ductile deformation, e.g., mountain ranges)
  - Rift valleys and graben systems (formed by crustal extension)
- **Volcanism**: Involves the ascent of magma from the interior to the surface via fissures (dikes) or eruptions. Effects include:
  - Lava flows, volcanic cones, and calderas
  - Heat and gas release, altering surface chemistry and atmospheres

Exogenic Processes

- **Impact Cratering**: Caused by collisions with asteroids, comets, or meteoroids. Types include:
  - Primary craters (direct impacts)
  - Secondary craters (formed by debris ejected from primary impacts)
- **Aeolian Processes**: Wind-driven erosion, transport, and deposition of sediment. Features include:
  - Abrasion landforms (e.g., yardangs, ventifacts)
  - Depositional landforms (e.g., sand dunes, loess plains)
- **Hydrological Processes**: Shaped by liquid water (or other fluids, like methane on Titan). Effects include:
  - Erosion (e.g., river valleys, canyons)
  - Sedimentation (e.g., deltas, alluvial fans)
  - Chemical interactions (e.g., dissolution, mineral precipitation)

2 Give a typical example of extensional tectonics and compressional tectonics respectively on planetary surfaces.

Extensional Tectonics: Valles Marineris (Mars)

- **Scale and Morphology**: Valles Marineris spans approximately 4,000 km in length, up to 200 km in width, and reaches depths of 7 km. It is the largest known graben system in the Solar System.
- **Fault Mechanics**: The canyon walls are bounded by high-angle normal faults, formed as the Martian crust stretched and thinned due to Tharsis-related uplift. This process reflects regional crustal extension.

Compressional Tectonics: Maxwell Montes (Venus)

- **Topography**: Maxwell Montes constitutes the highest mountain range on Venus, with peak elevations reaching 11.5 km above the mean planetary radius. It is centrally located within Ishtar Terra, a continent-sized highland region exhibiting anomalous crustal thickness.
- **Structural Style**: The mountain range displays a series of parallel ridges with 2–7 km spacing, interpreted as:
  - Fold-and-thrust belts formed by horizontal crustal shortening
  - Imbricated thrust faults accommodating crustal thickening

  This compressional architecture suggests large-scale convergence in Venus' lithosphere.

3 What are possible mechanisms to produce magmatic activities on planets. If magma has been generated in the interior of planets, derive the criterion under which the magma can reach the surface using a simplified 2-D model.

3.1 Possible Mechanisms

1. **Increase in potential temperature:** Thermal upwelling (plumes) or a hot mantle raise T above the melting temperature.
2. **Decompression melting:** Upwelling into regions of lower pressure causes adiabatic melting without extra heat.Solid-state phase transitions male melting more possible.
3. **Volatiles:** Addition of volatiles (H_2O, CO_2) lowers the melting temperature or solubility of water.

3.2 Criterion for Dike Ascent to the Surface

Assume a vertical dike of half-width w must rise a distance L through host rock before freezing. We compare its ascent timescale t_{ascent} to its cooling timescale t_{freeze}.

1. Maximum Ascent Velocity

Balancing buoyancy driving flow against viscous stresses gives

$$u_x = \frac{\Delta\rho\, g}{2\,\eta} x\,(\omega - x) \leq \frac{\Delta\rho\, g}{2\,\eta} \left(\frac{x + \omega - x}{2}\right)^2 = \frac{\Delta\rho\, g\, w^2}{8\,\eta} := u_{\max}$$

where

- $\Delta\rho = \rho_{\text{rock}} - \rho_{\text{magma}}$ is the density contrast,
- g is gravitational acceleration,
- η is the magma viscosity.

2. Cooling Timescales

$$t_{\text{ascent}} = \frac{L}{u_{\max}} = \frac{8\,\eta\,L}{\Delta\rho\,g\,w^2}$$

$$t_{\text{freeze}} = \frac{w^2}{k}$$

where k is the thermal diffusivity of the dike walls.

3. Eruption Criterion

Requiring $t_{\text{ascent}} < t_{\text{freeze}}$ yields

$$\frac{8\,\eta\,L}{\Delta\rho\,g\,w^2} < \frac{w^2}{k} \quad \Longrightarrow \quad w^4 > \frac{8\,\eta\,k\,L}{\Delta\rho\,g}$$

Hence the minimum dike width to erupt is

$$w_{\min} = \left(\frac{8\,\eta\,k\,L}{\Delta\rho\,g}\right)^{1/4}.$$

Equivalently, for a given w, the dike will reach the surface if

$$L < \frac{\Delta\rho\,g\,w^4}{8\,\eta\,k}.$$

4 Describe the principle of determining the age of Lunar surface based on spatial density of craters.

Relative Age

More older age, more severe crater degradation state, more weathered, more smoothed rims and less distinct. By superposition relationships: Older units are overlaid by younger ones.

Absolute Age Calibration

Returned lunar rock samples carry radioactive "clocks" that, when measured in the laboratory, yield an absolute age for their sampling site. By plotting those ages against the corresponding crater density $N(1)$, one constructs a chronology curve that can be applied across the Moon.

1. **Site Selection:** Choose the exact regions where samples were collected (e.g. Apollo landing sites), avoiding nearby bottom, and mountains.
2. **Secondary-Crater Masking:** Identify and exclude all obvious secondary craters. Measure the remaining usable area A.
3. **Crater Mapping:** Count every primary crater with diameter $D \geq D_0$ (e.g. $D_0 = 1$km) within the masked area and record their diameters.

4. **Density Calculation:** Compute the spatial density

$$N(D \geq D_0) \ = \ \frac{\text{number of craters with } D \geq D_0}{A} \quad \left[\text{craters/km}^2\right].$$

5. **Chronology Curve:** Plot each sample's radiometric age t versus its measured $N(1)$. Fit the points to derive the function $N(t)$. Thereafter, any terrain with a known $N(1)$ yields an absolute age by inverting $N(t)$.

5 What are Potential Evidences for Liquid Water on Present-Day Mars?

Obvious hydrological landforms on Mars: outflow channels, valley networks, lake basins, and deltas observed *in situ*.

Spectral evidence of hydrated salts in recurring slope lineae.

Temperature range from –80 °C to 30 °C, allowing water to exist as liquid or ice.

Subterranean lake: MARSIS radar on Mars Express detected a liquid water body beneath the south polar ice cap, marked by an anomalously high-reflectivity region.