Impacts and Cratering

- Dominates surface properties of most rocky bodies
- “Back of the envelope” calculation of the energy of an impact…
Formation of Impact Craters

- Impactor unperturbed by atmosphere
- Impact velocity ~ escape velocity (11 km s\(^{-1}\))
  - \(\rightarrow\) tens of meters in diameter
- Impact velocity > speed of sound in rocks \(\rightarrow\) impact forms a shock
  - Pressures \(~100\text{ times stress levels of rock} \rightarrow\) impact vaporizes rocks
- Shock velocity \(~10 \text{ km s}^{-1}\) \(\rightarrow\) much faster than local sound speed so shock imparts kinetic energy into vaporized rock

Contact/Compression

- Projectile stops 1-2 diameters into surface \(\rightarrow\) kinetic energy goes into shock wave \(\rightarrow\) tremendous pressures \(\rightarrow\) \(P \sim (1/2)\rho_0v^2\)
  - Peak shock pressures \(~1000\text{ kbar}; pressure of vaporization \sim 600\text{ kbar}\)
- Shock loses energy
  - Radial dilution \((1/r^2)\)
  - Heating/deformation of surface layer
  - Velocity drops to local sound speed – seismic wave transmitted through surface
- Can get melting at impact point
- Shock wave reflected back through projectile and it also gets vaporized
- Total time \(~\text{few seconds}\)
Excavation

- Shock wave imparts kinetic energy into vaporized debris → excavation of both projectile and impact zone (defined as radius at which shock velocity ~ sound speed (meters per second))
- Timescale is just a dynamical/crossing time (t = (D/g)^1/2)
- Crater size? D goes as E^1/3 → empirically, it looks like ~ 10 times diameter of projectile.
- Can get secondary craters from debris blown out by initial impact
- Large impacts → multiring basins (Mars, Mercury, Moon)

Craters

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Depth</th>
<th>Timescale</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>35m</td>
<td>2m</td>
<td>4yr</td>
<td>Small Earthquake</td>
</tr>
<tr>
<td>1km</td>
<td>50m</td>
<td>1600yr</td>
<td>Barringer Meteor Crater</td>
</tr>
<tr>
<td>7km</td>
<td>350m</td>
<td>51,000yr</td>
<td>9.6 mag earthquake</td>
</tr>
<tr>
<td>10km</td>
<td>500m</td>
<td>10^5 yr</td>
<td>Sweden</td>
</tr>
<tr>
<td>200km</td>
<td>10km</td>
<td>150 Myr</td>
<td>Largest craters/KT impactor</td>
</tr>
</tbody>
</table>
Crater Density

- number of craters km\(^{-2}\) vs diameter
- Saturation equilibrium – so many craters you just can’t tell….
  - Much of the lunar surface
  - Almost all of Mercury
  - Only Martian uplands
  - Venus, Earth not even close \(\rightarrow\) there is a cut-off in Venus’ distribution
- Calibrate with lunar surface rocks
- \(10^7\) times more small craters (100m) as there are large craters (500-1000 km)
Lavinia Planum Impact Craters

Note ejecta surrounding crater
“It’s the size of Texas, Mr. President”
- from yet another bad movie

- Comets – small, rocky/icy things \( \rightarrow \) 10s of km
- Asteroids – small, rocky things \( \rightarrow \) a few to 10s of km \( \rightarrow \)
the largest is the size of Texas (1000 km)
  - 100-300 NEAs known
- Close encounters…. 
  - Tunguska River in Siberia \( \rightarrow \) 30-50m meteorid exploded above
  ground \( \rightarrow \) flattened huge swath of forest

You make the catastrophe...

- Need high velocity
  - max velocity \( \sim \) 70 km s\(^{-1}\) (combine Earth’s orbital velocity plus
solar system escape velocity)
  - Earth-asteroid encounters \( \rightarrow \) 25 km s\(^{-1}\)
  - Earth-comet encounters \( \rightarrow \) 60 km s\(^{-1}\)
- Make it big…. 
  - \( E \sim mv^2 \rightarrow \) something 1000 km would wipe out the entire
western hemisphere, but let’s be realistic and go for \( \sim10\)m \( (10^{21} \text{ J}) \)
or \( \sim1 \) km \( (10^{23} \text{ J}) \)
  - One impact imparts more energy in a few seconds than
the Earth releases in a year via volcanism etc.
Processes at Work

- Impact cratering
- Weathering/erosion
- Conditions of the atmosphere
- Geological activity
  - Volcanic activity
  - Tectonics

Geological activity - Earth

- Volcanism
  - Shield volcanoes
    - Formed via a single plume
    - Hawaii – crustal plate moving over a hot spot
  - “cone” volcanoes
    - Formed over subduction zones
    - Cascade mountains, Mount Etna
- Earthquakes
  - At plate boundaries
- Plate tectonics
  - Mid-ocean ridges, mountain chains, moving continents, earthquakes, “ring of fire”, global resurfacing
Mercury

- Heavily cratered
- No volcanoes, no mountain chains, no plate boundaries, no continents $\rightarrow$ no recent tectonics
- Shrinking?
- Weak magnetic field
- Conclusion: one plate planet with no activity over the past several billion years; surface is shaped by impacts
Mercury, South Pole, Scarp displacement
Venus

- Lots of volcanic activity in the recent past
  - Characteristic feature is a “coronae” which is a circular structure like the caldera of a volcano but without the mountain to go with it

- Global resurfacing about 300 Myr ago
  - Crater density (number per km\(^2\))
  - We call this a “young” surface

- A couple of continent-like features

- No obvious plate boundaries
Venus Topography identified

- Lakshmi Planum
- Maxwell Montes
- ISHTAR TERRA
- Beta Regio
- Phoebe Regio
- Themis Regio
- LADA TERRA
- APHRODITE TERRA
- Artemis Chasma
- Atalanta Planitia
- Alpha Regio
- Aria Regio

© 2011 Brooks/Cole - Cengage Learning
Terrestrial Planet Surface Morphology

- Mars
  - Massive Shield Volcanoes
  - Huge Erosion Channels
  - Much cratering, much eroded
  - Polar Caps
Mars Orbiter Laser Altimeter Topographic Map

Sojourner at Yogi Seeds Fig 23-15)
9/29/09

“Evidence” for recent liquid flow

Floor of Newton Crater

MOC high resolution mosaic

SW Wall of Newton Crater
Let’s put it all together....

- Calculate the surface area to mass ratio ($km^2 \ g^{-1}$)
  - Moon: $5.16 \times 10^{-19}$
  - Mercury: $2.26 \times 10^{-19}$
  - Mars: $2.25 \times 10^{-19}$
  - Venus: $9.46 \times 10^{-20}$
  - Earth: $8.55 \times 10^{-20}$