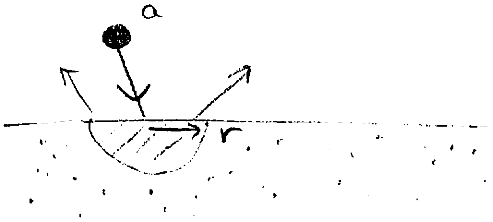
Surfaces - Crater Counts

DJ

2011.5.22

We possess useful age-crater data only for a few places on the Moon. Crater counts provide a measure of relative ages + sometimes (people hope) absolute ages.

① Crater size vs projectile size



Two limits:

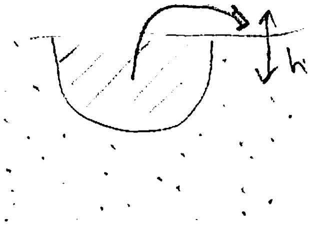
⊛ Energy scaling - impact energy is used to vaporize + communite rock.

$$E = \frac{1}{2} m_p v^2$$

$$E = \underbrace{\frac{2}{3}\pi \rho r^3}_{\text{hemispherical crater}} \overset{\text{J kg}^{-1}}{L}$$

← energy/mass to vaporize/comminute rock.

⊛ Gravity scaling - energy is used to lift material out of the crater



$$E = \frac{2}{3}\pi \rho r^3 h g \; ; \text{ with } h \sim r \text{ for a hemisphere}$$

$$= \frac{2}{3}\pi \rho r^4 g$$

Energy scaling $\quad E \propto r^3 \rightarrow r \propto E^{1/3}$

Gravity scaling $\quad E \propto r^4 g \rightarrow r \propto \left(\frac{E}{g}\right)^{1/4}$

Obviously, V also plays a large role.

For sun-orbiting projectiles, $V \sim \frac{30}{\sqrt{R_{AU}}}\ \mathrm{km\,s^{-1}}$

[eg: $V \sim 30\ \mathrm{km\,s^{-1}}$ @ 1AU, $V \sim 5\ \mathrm{km\,s^{-1}}$ @ 30AU]

eg. Earth, take $V = 30\ \mathrm{km\,s^{-1}}$,

Grav Scaling $\quad \cancel{\tfrac{2}{3}\pi}\rho_p a^3 V^2 = \cancel{\tfrac{2}{3}\pi}\rho r^4 g$

$$a \sim \left[\frac{\rho}{\rho_p}\frac{g}{V^2}\right]^{1/3} r^{4/3}$$

if $\rho = \rho_p$, $g = 10\ \mathrm{m\,s^{-2}}$, $V = 30\ \mathrm{km\,s^{-1}}$, $r = 1\ \mathrm{km}$

$$a \sim \left[\frac{10}{(3\times10^4)^2}\right]^{1/3} r^{4/3}$$

$$a \sim 10^{-8/3} \cdot 10^4 \sim 50\ \mathrm{m}$$

(eg: Meteor crater Az made by ~ 50 m scale projectile]

Actual scaling is very complicated but this is ~ right.

- With the projectile vs. crater scaling understood, we can relate crater production functions to projectile diameter distributions.

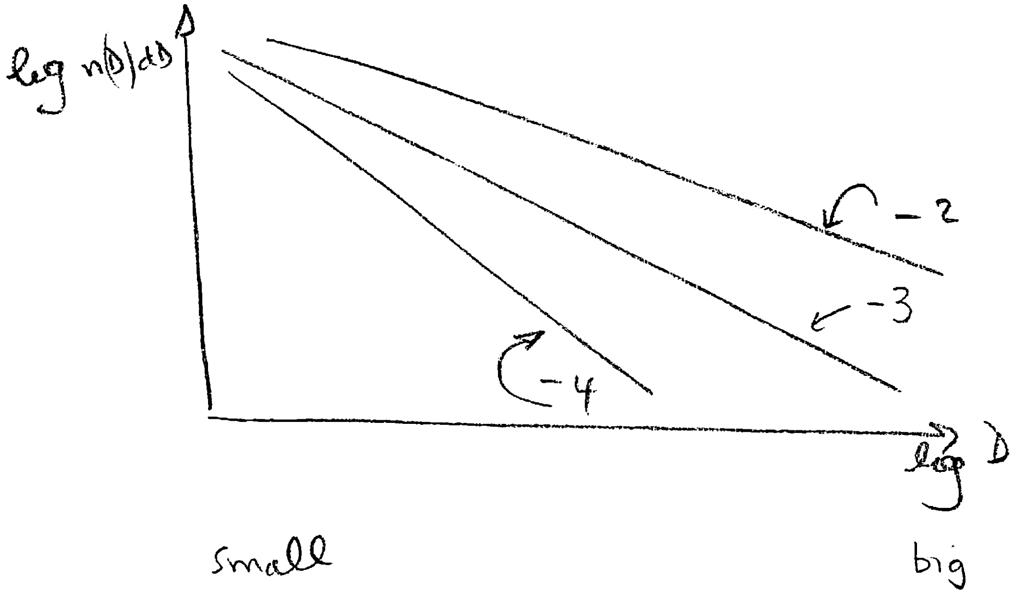
Crater size distributions are wide, w/ many small craters for every large one. Suggests use of power laws, although they are not actually power laws.

$n(D)\,dD$ = # crater with diameter in range $D \rightarrow D + dD$

This is a <u>differential</u> power law distribution

$$n(D)\,dD \equiv \Gamma D^{-q} dD \qquad \Gamma, q \text{ constants}$$

$\Gamma \propto$ total # craters, q - measure of size distribution.

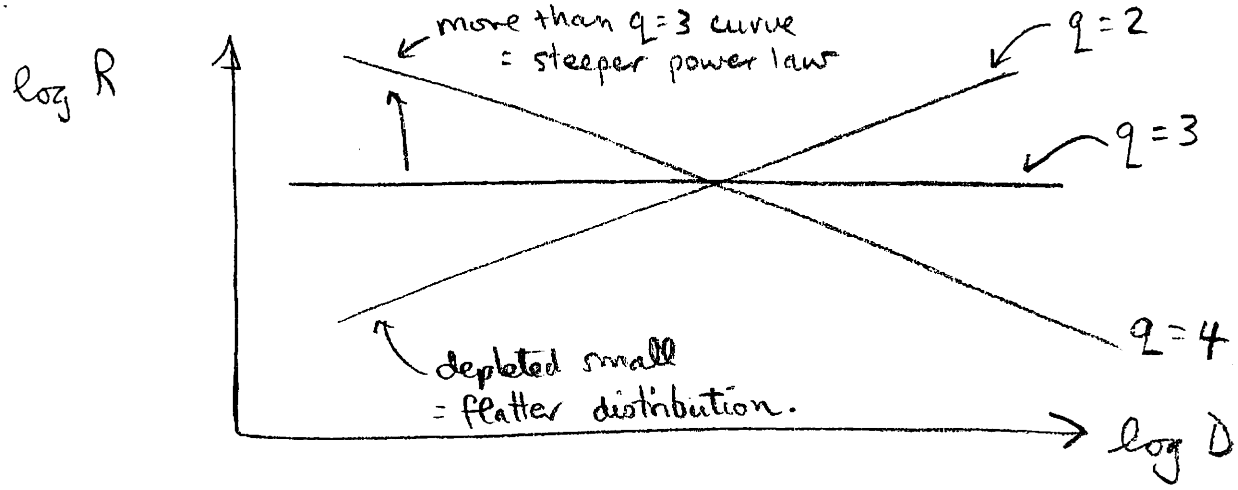


Convention is to use "R-plots" = "relative-plots" which are

$$\text{measured} \quad \frac{n(D)\,dD}{\Gamma D^{-3}\,dD}$$

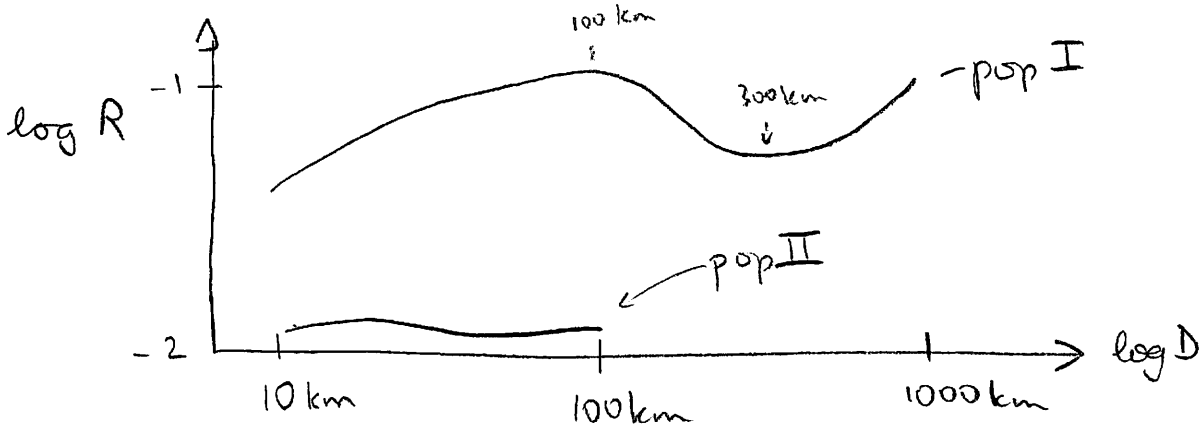
eg: actual $n(D)\,dD$ vs D has slope -3

but R-plot has slope $-3+3=0$



Empirically, crater distributions are usually within ±1 of slope 0 on an R-plot.

Highlands of Moon Define "Population I"



Lowlands (lunar maria) define Population II

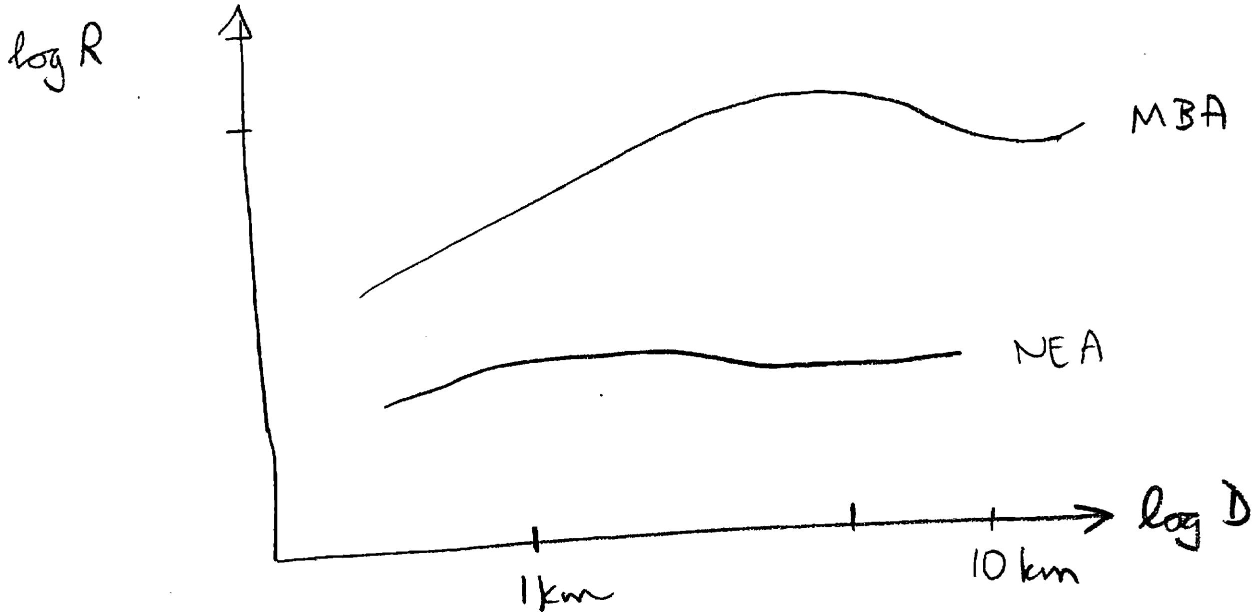
(*) $\boxed{\text{Pop I} \neq \text{Pop II}}$ in their R-plots.

Pop II = lower # craters/area at a given size

and

consistent w/ R ~ flat → q ~ 3.

There distributions can be compared with the size distributions of solar system projectile populations.



The main belt asteroids MBA resemble scaled-down Pop I (OK, because $a/D \geqslant 10$ ... 10 km projectile makes a few 100 km diam crater).

The Near Earth Asteroids (NEA) resemble the Pop II, but smaller

∴ Suggests that Pop I result from size-independent clearing of main-belt and

Pop II results from (more recent) size dependent escape population = NEAs.

NEA $\neq$ MBA perhaps because of size-dependent Yarkovski effect, responsible for destabilizing asteroids in a size dependent way.

⊙ $N(D)dD$ for comets not well known + subject to strong evolutionary effects.

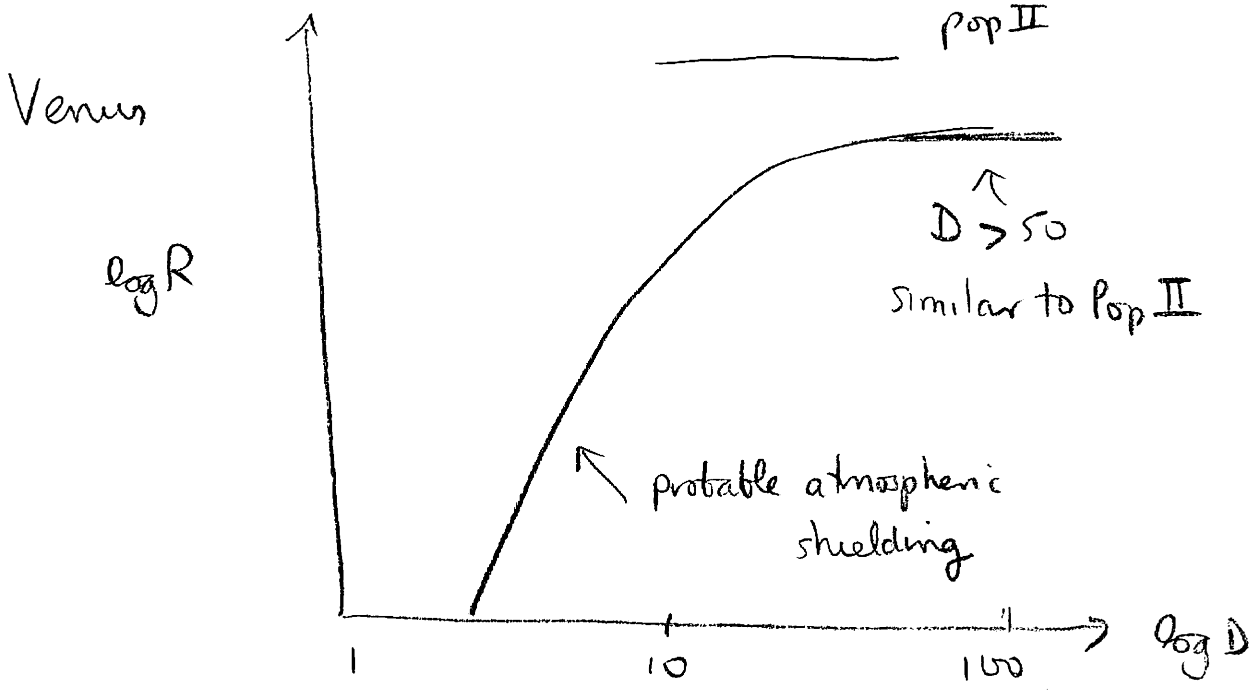
⊙ $N(D)dD \propto D^{-4.0\pm0.3} dD$ for Kuiper belt and $D \gtrsim 50$km. This is too steep to match Lunar craters but the $D < 50$km are more relevant and q may be smaller there. Not yet clear what's going on.

Present belief: highlands = Pop I = MBA projectiles destabilized by dynamics (maybe Late Heavy Bombardment)

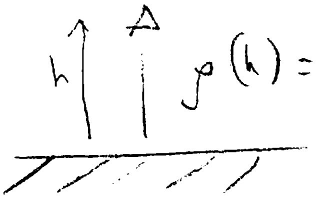
Lowlands = Pop II = rain of Yarkovski destabilized objects from MB

Some comets must also hit – contribution unclear.

Other Surfaces



Atmospheric Shielding



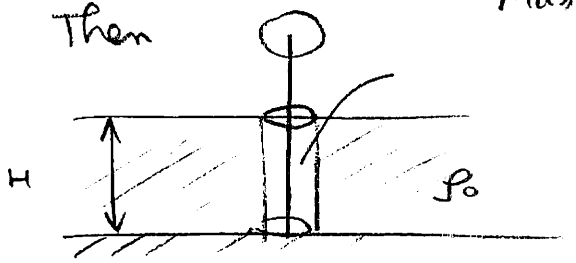
$\rho(h) = \rho_0 \exp\left(-\frac{h}{H}\right)$

$H = \frac{kT}{\mu m_H g}$ = scale height

$H \sim 10$ km for ⊕ & most planets

Very roughly, approximate atmosphere as a slab of density ρ_0, thickness H.

Then



Mass intercepted by projectile of radius a is $\underbrace{\pi a^2 H}_{\text{Volume}} \rho_0 \; \boxed{\text{kg}}$

Expect strong decelleration of projectile when

$$\cancel{\tfrac{4}{3}}\cancel{\pi}\rho_p a^{3} \leq \cancel{\pi}\cancel{a}^{2} H\rho_0$$

or $$\boxed{a \lesssim \frac{\rho_0}{\rho_p} . H}$$

eg: $\oplus$: $\rho_0 = 1\ \mathrm{kg\,m^{-3}}$, $H = 10^4\ \mathrm{m}$, $\rho_p \equiv 1000\ \mathrm{kg\,m^{-3}} \rightarrow$

$$a \lesssim 10\ \mathrm{m}$$

eg Venus $\rho_0 \sim 100\ \mathrm{kg\,m^{-3}}$. $H = 10^4\ \mathrm{m}$, $\rho_p \equiv 1000\ \mathrm{kg\,m^{-3}}$

$$a \lesssim 1000\ \mathrm{m}$$

Venus atmosphere so dense that it can slow down or stop km-sized projectiles

Assume gravity scaling, than crater size expected from $a = 1\,\mathrm{km}$ projectile is roughly

$$r^4 \sim \frac{\rho_p}{\rho}\,\frac{a^3 v^2}{g} \sim \frac{1 .\ 10^9 .\ (4\times10^4)^2}{10}$$

$r^4 \sim 16 \times 10^{16}$

$r \sim 2 \times 10^4 = 20\,km$

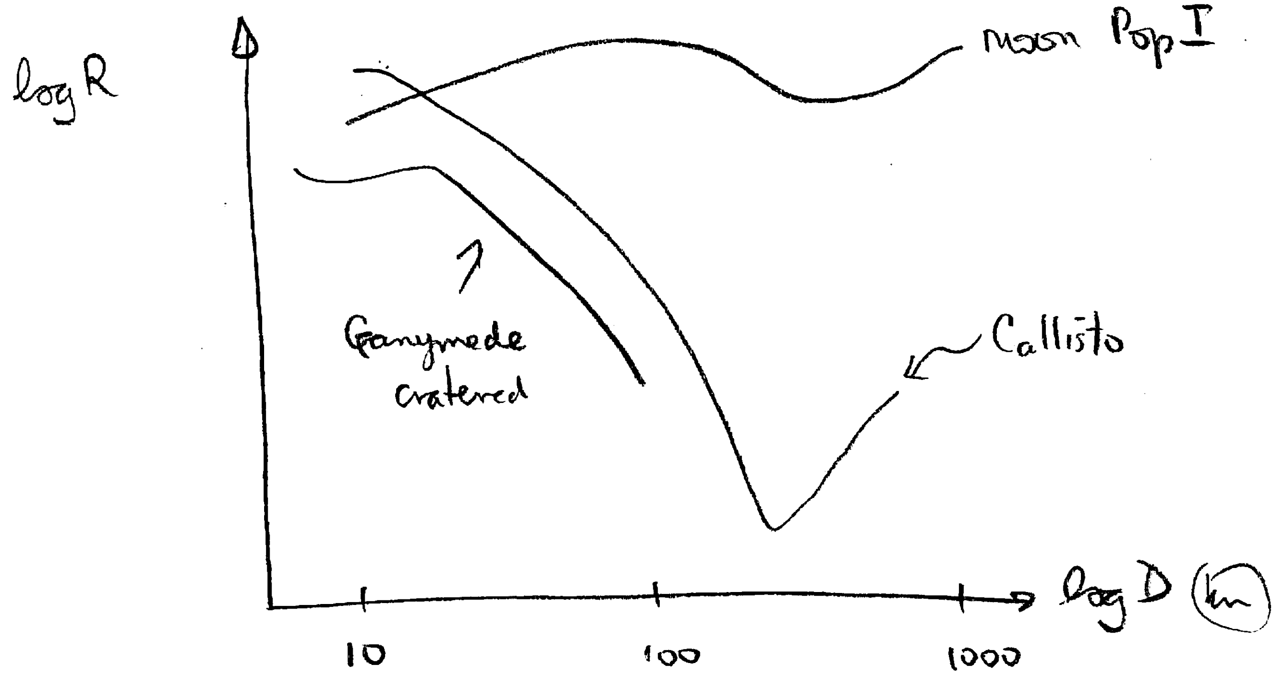
$\underline{D = 2r = 40\,km}$

= Consistent with R-plot + atmospheric shielding.

Expect many more Tunguska-style atmospheric explosions on Venus than on ⊕.

Expect shielding also on Titan ($P_0 \sim 1.5\,bar$)

Icy Satellites - Ganymede + Callisto



⊙ Large craters on G+C appear depleted - maybe effect of ice rheology.

⊙ Even @ small sizes, R-plots for G+C not like lunar populations

→ no evidence from R-plots that same projectile populations struck inner + outer solar system surfaces

⇒ no basis for age-dating outer solar system using crater counts.