What if?

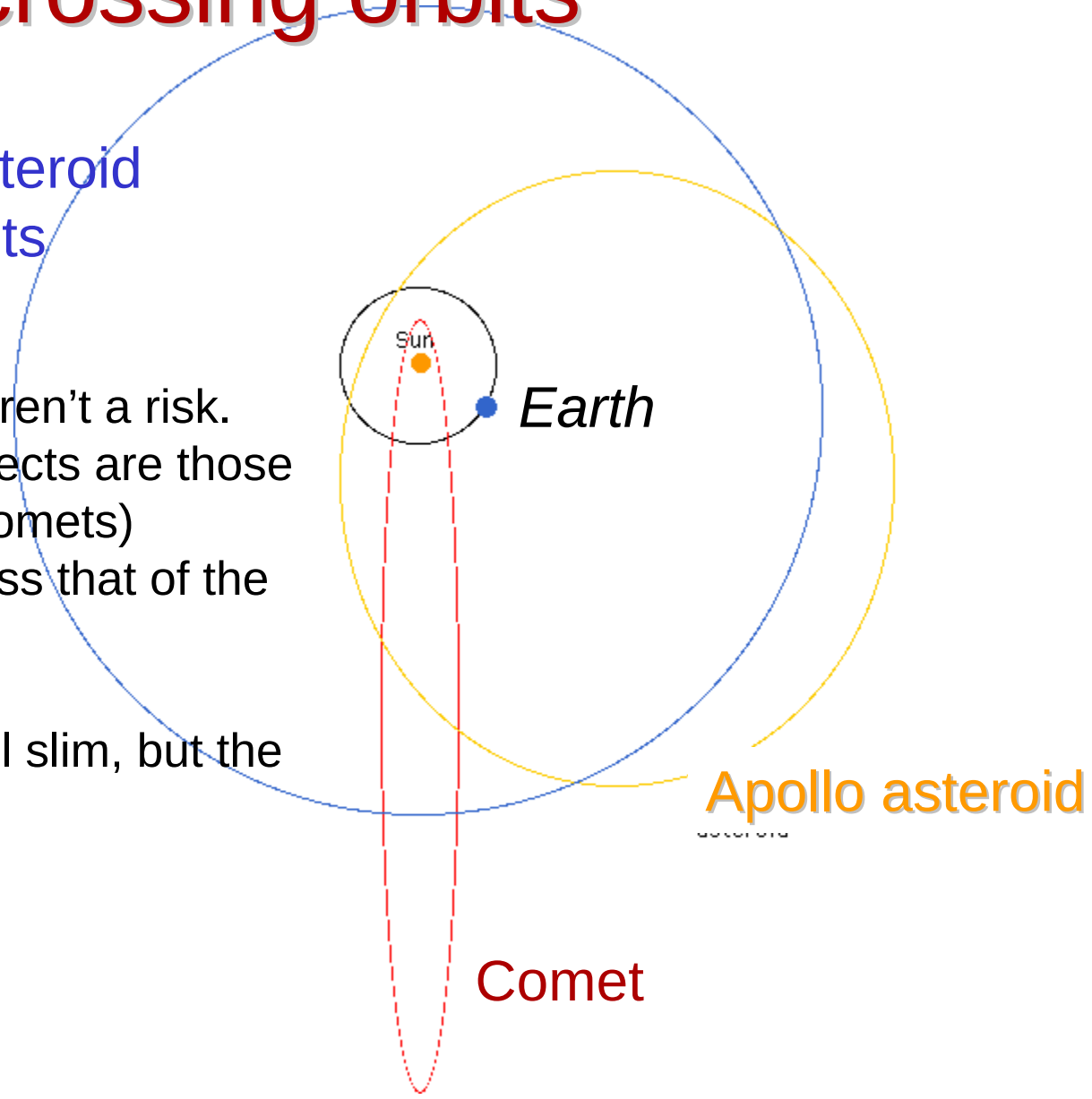
What happens during an impact?

- crater formation

Evidence for big impacts on Earth?

- Chicxulub

Things that can hit Earth have: "Earth-crossing orbits"

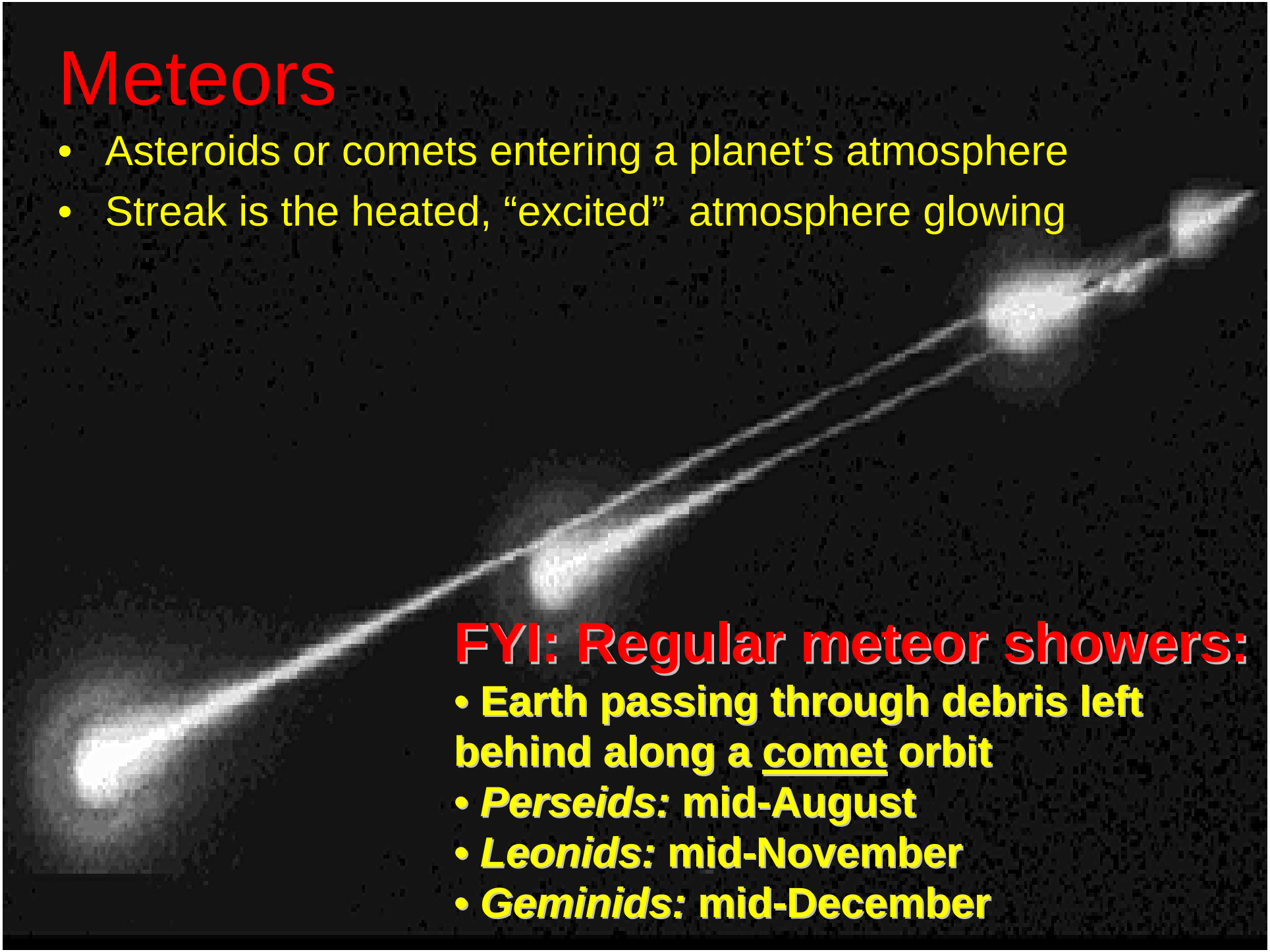


Most asteroids aren't a risk. The problem objects are those asteroids (and comets) whose orbits cross that of the Earth.

The odds are still slim, but the chance is there.

Meteors

- Asteroids or comets entering a planet's atmosphere
- Streak is the heated, "excited" atmosphere glowing



FYI: Regular meteor showers:

- **Earth passing through debris left behind along a comet orbit**
- ***Perseids:* mid-August**
- ***Leonids:* mid-November**
- ***Geminids:* mid-December**

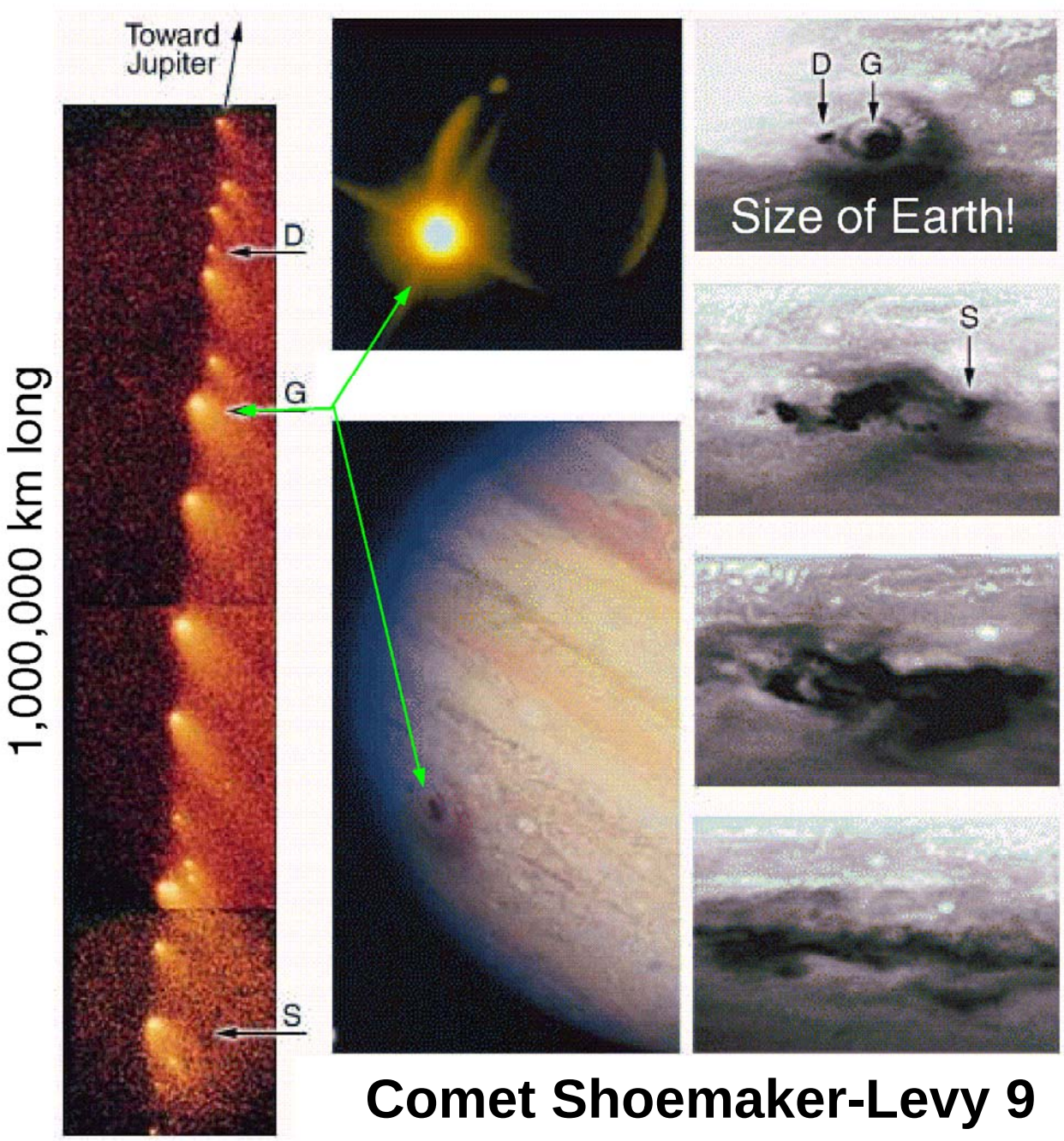
Do *large* meteors ever hit?

Is there any evidence of impacts in our solar system?

It happens… Comet impact with Jupiter in 1994!

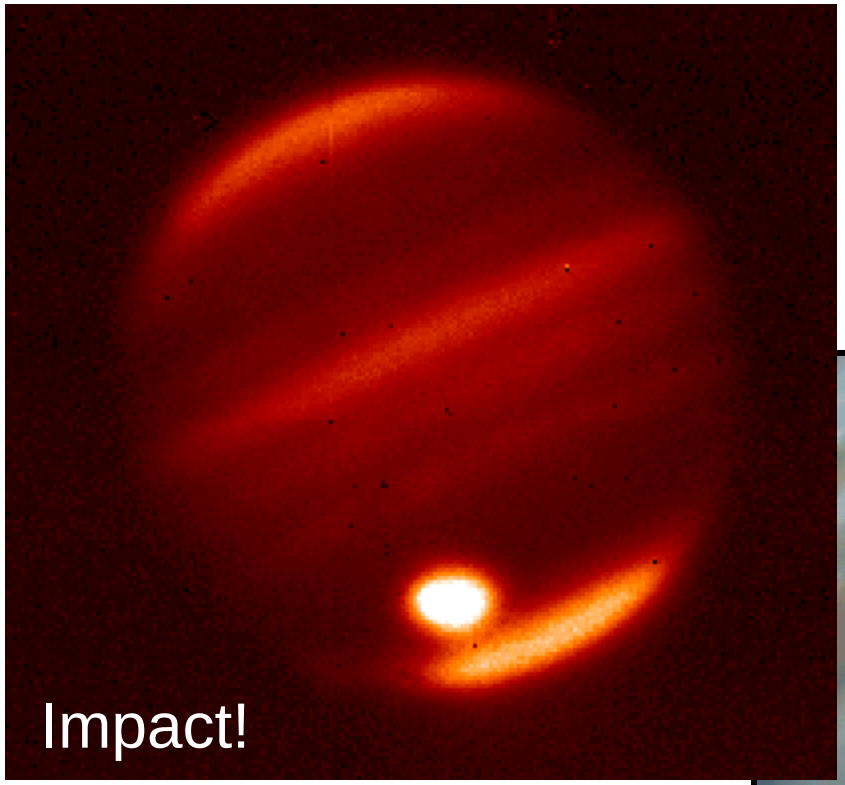
fragment size:
~1 km diameter

speed: ~60 km/s



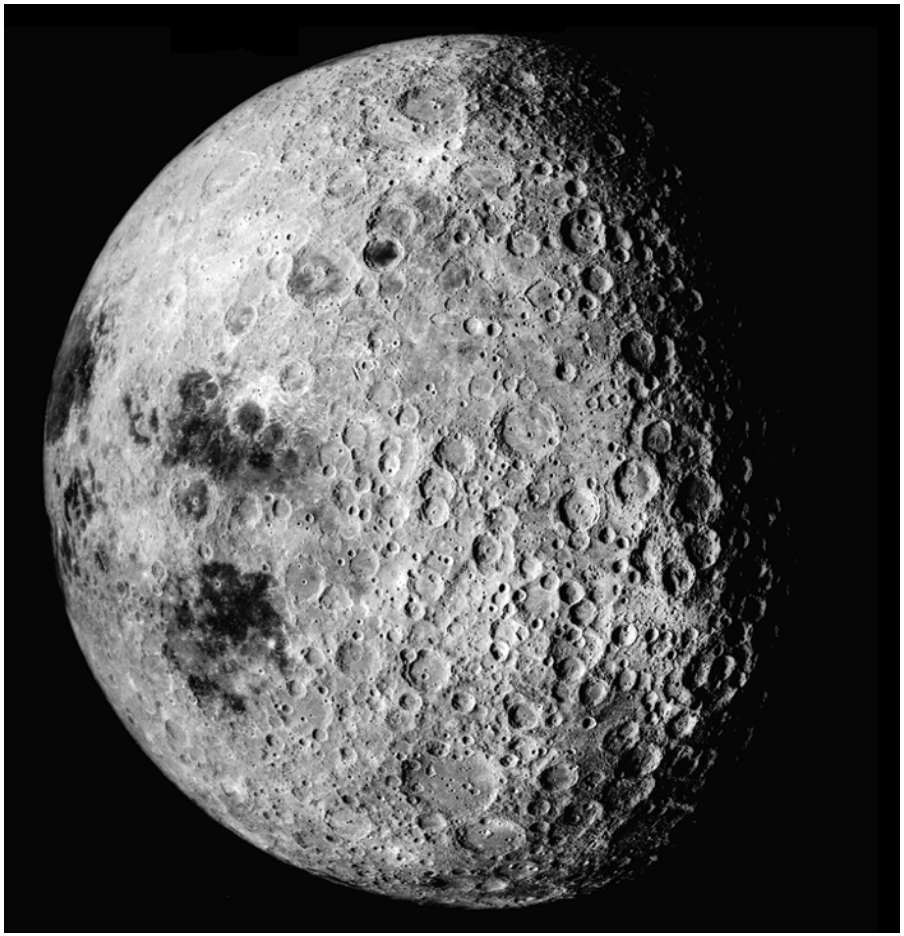
NASA photos, 1994

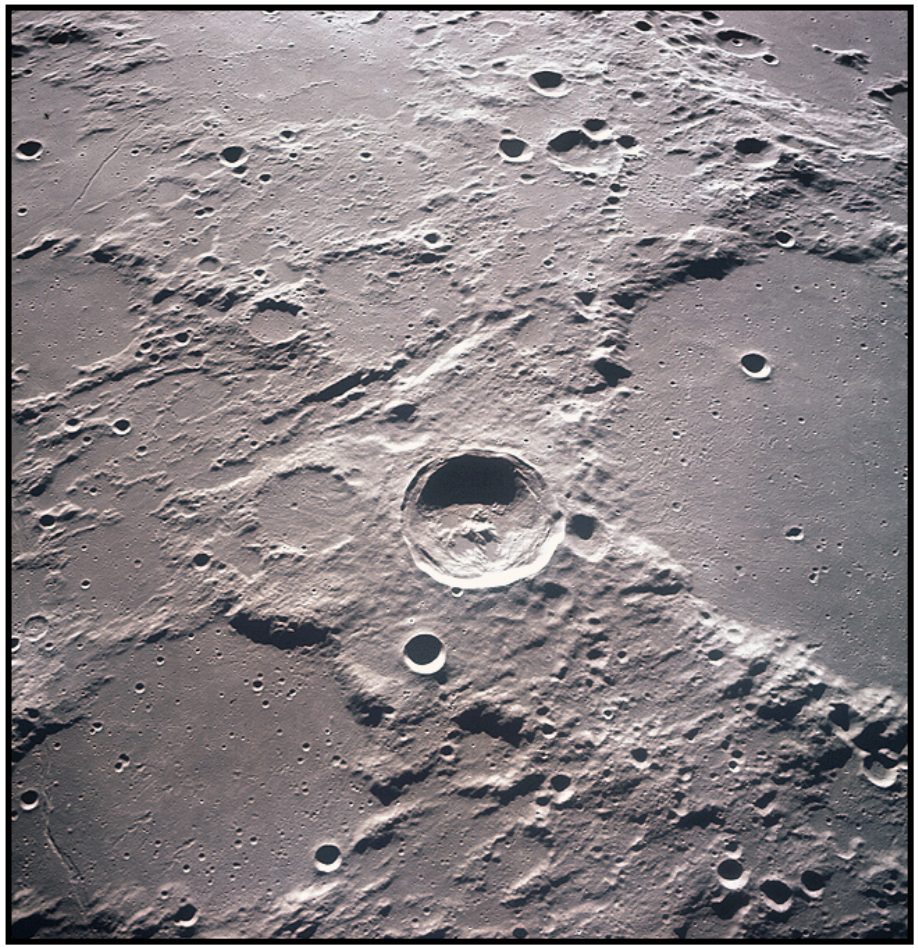
Comet Shoemaker-Levy 9


Impact!


Earth-sized scars lasted months

Evidence of other impacts?





Look at the other planets and moons (like ours)..

Any large impacts on Earth?

Meteor Crater, Barringer, Arizona
0.049 +/- 0.003 Ma
(49,000 +/- 3,000 years ago)

Impacts or volcanism…?

Although it seems obvious that the craters on the moon and on Earth are impact craters, many believed that they were volcanic in origin until the 1960s. Scientists believed that the atmosphere almost completely protected the Earth. Even most lunar craters were believed to be volcanic. Gene Shoemaker was working as a geologist studying craters produced by nuclear bombs in order to compare them with lunar craters (it was debated how many were impacts and how many were volcanic). He believed that some structures on Earth were also impact craters. The nuclear tests generated some very unique, characteristic melts and rock structures. In particular:

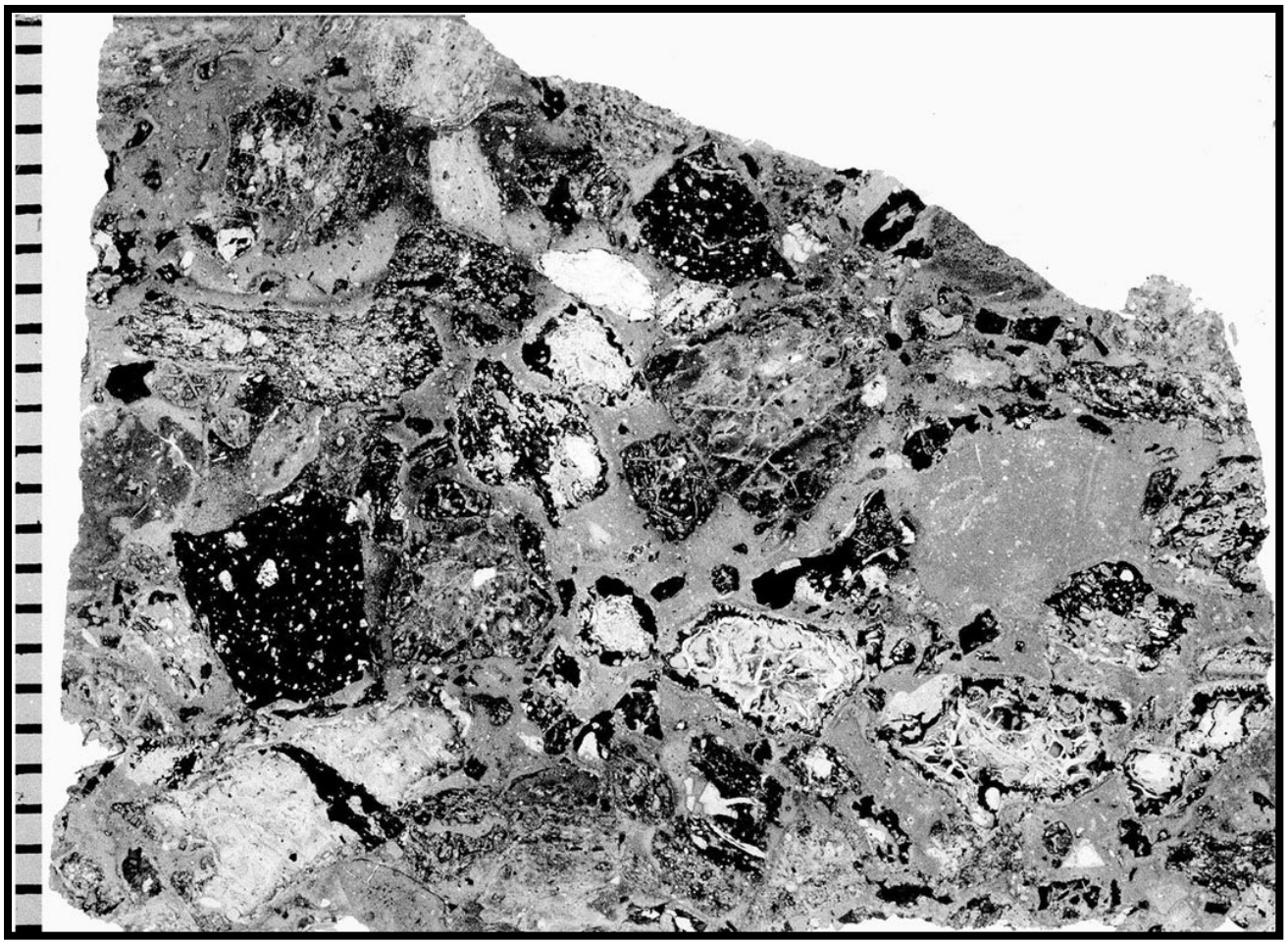
- A melt called suevite that holds broken, shattered rock together
- "shocked" quartz – a disturbed crystal structure formed by the blast's shock wave.

Both of these cannot be produced by a volcanic eruption or explosion.
Shoemaker and colleagues proved the Barringer Meteor crater was of impact origin. Soon after, he was holidaying in Germany and visited an area that was thought to be a gigantic caldera (Ries). At a town in the centre of the caldera, he visited the cathedral – and found it was built from suevite breccia! Things progressed rapidly from there and by the 1970's it was accepted that in fact the Earth (and the moon) were bombarded regularly by comets and asteroids.
In 1994, Shoemaker and his wife Carolyn co-discovered a comet (Shoemaker-Levy) that crashed into Jupiter – the biggest impact ever observed.

Characteristic rock types from impact shock

Suevite

- impact melt fusing rock fragments (breccia) together



Impact Craters in Canada

Sudbury, Ontario:

- Todd Bertuzzi's home
- 27% of world's nickel!
- M-type asteroid
  - 1850 +/- 3 Ma
  - 250 km crater (deformed)

The big nickel

Impact Craters in Canada

Sudbury, Ontario:

- 27 % of world's nickel
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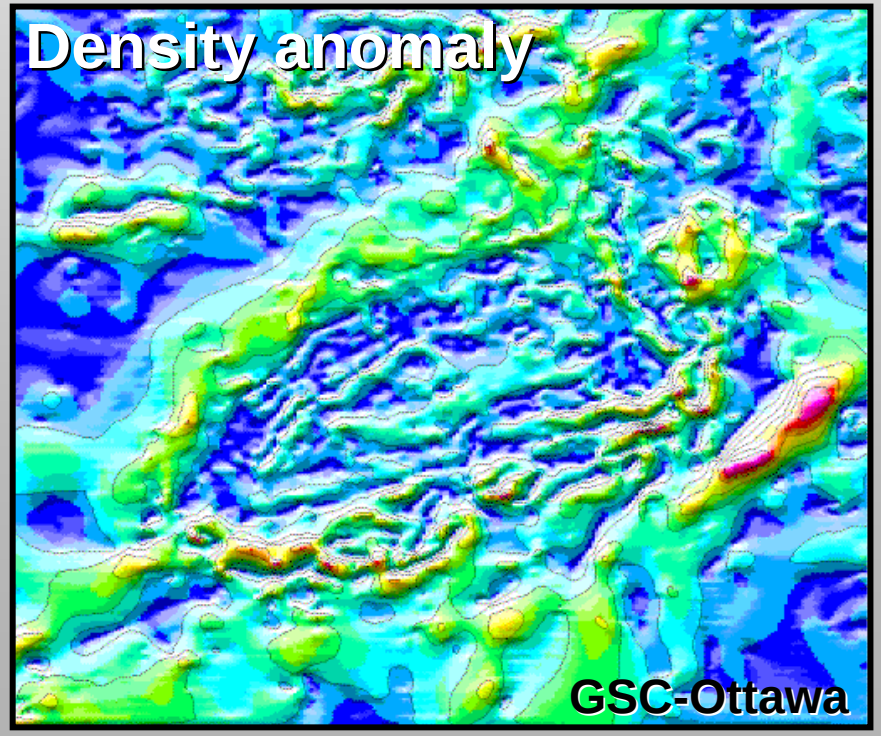
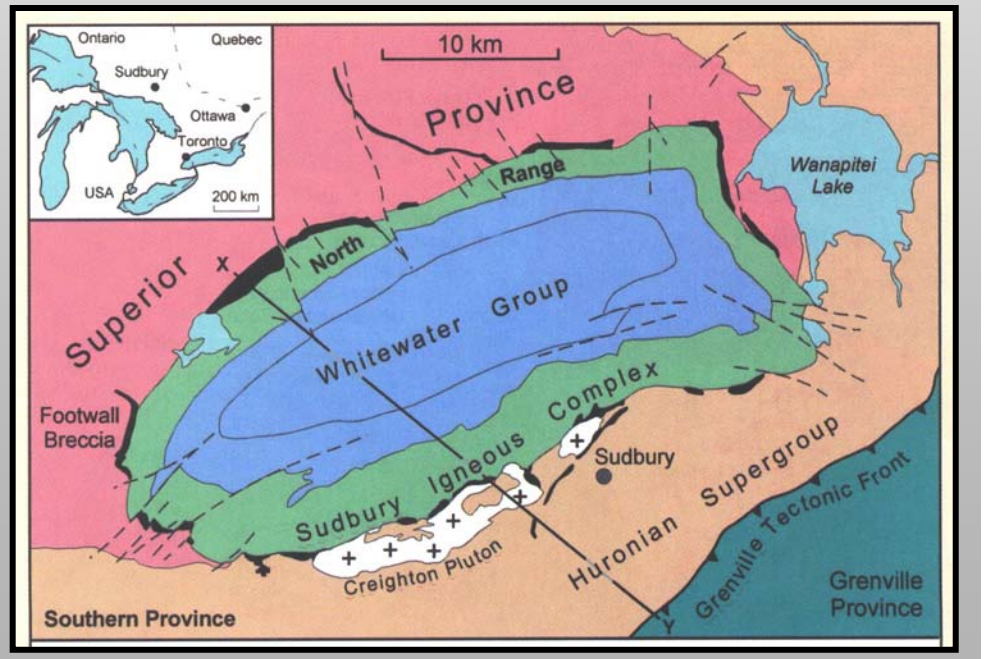
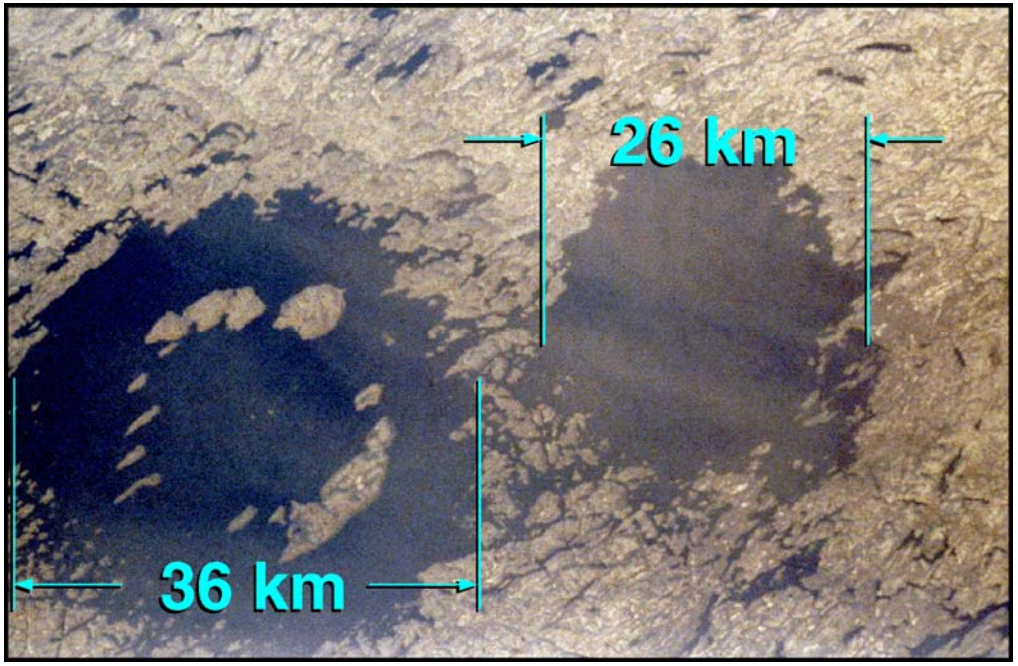


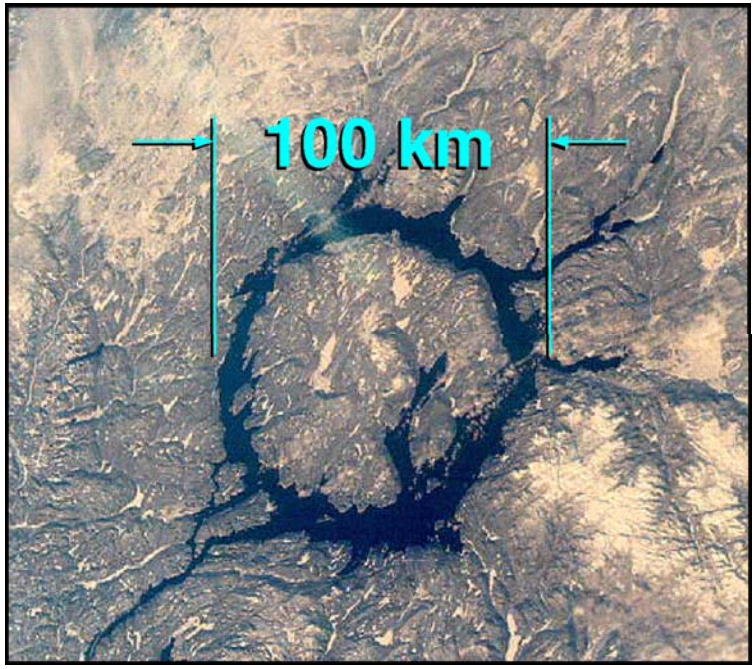


Plummer Box 20.1

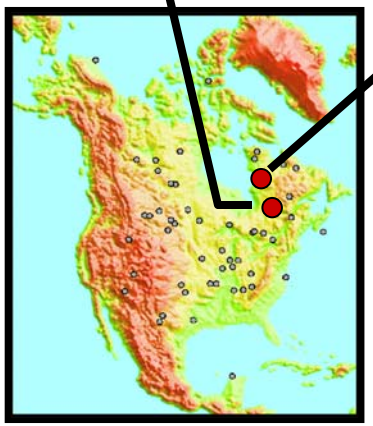
Impact Craters in Canada



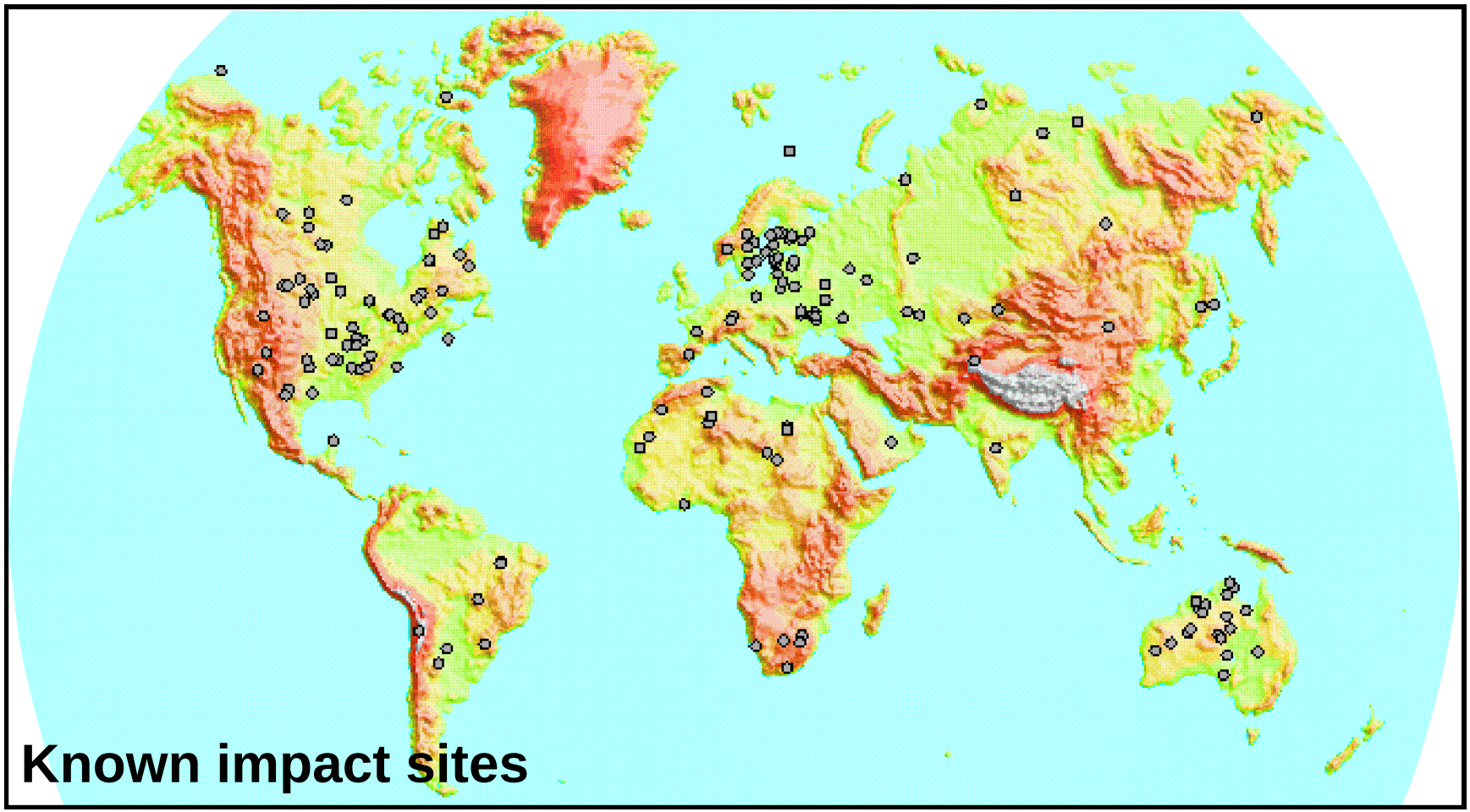
Clearwater, Quebec
(290 +/- 20 Ma)



Manicouagan, Quebec
(214 +/- 1 Ma)



Why so few impact craters on Earth?



Global Distribution

- **~170 craters (large impacts) have been discovered**

Why so few compared to the Moon or Mars?

Why so few impact craters on Earth?

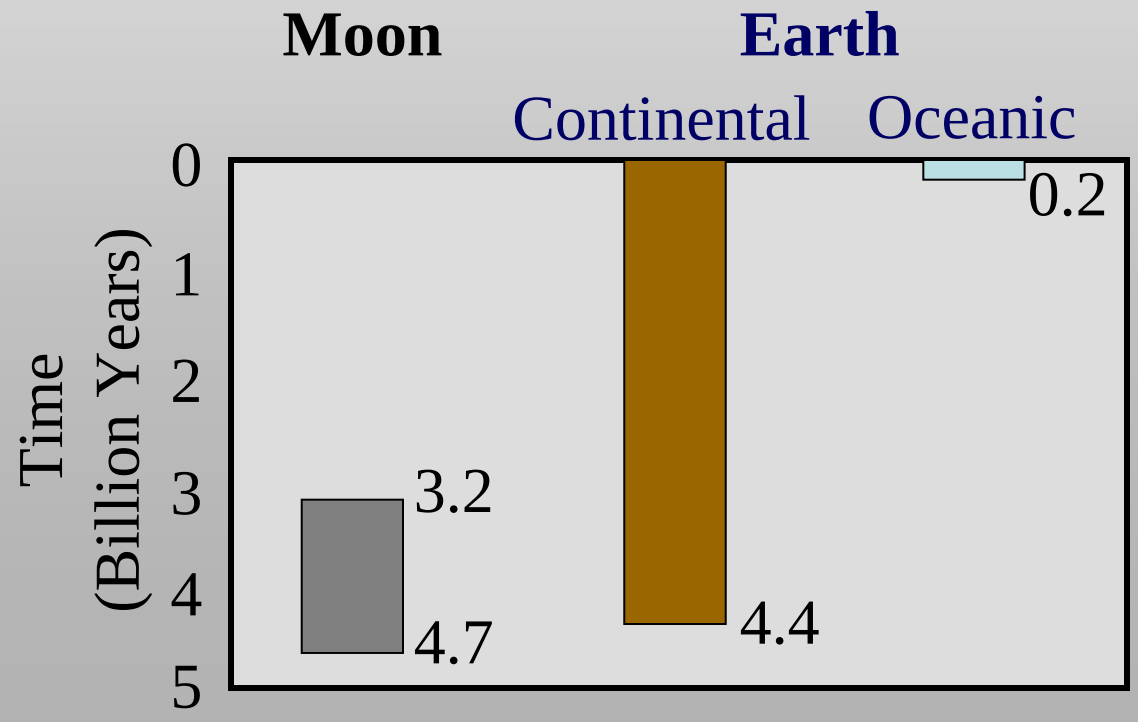
1) Atmosphere

a) ***shields*** against smaller meteors

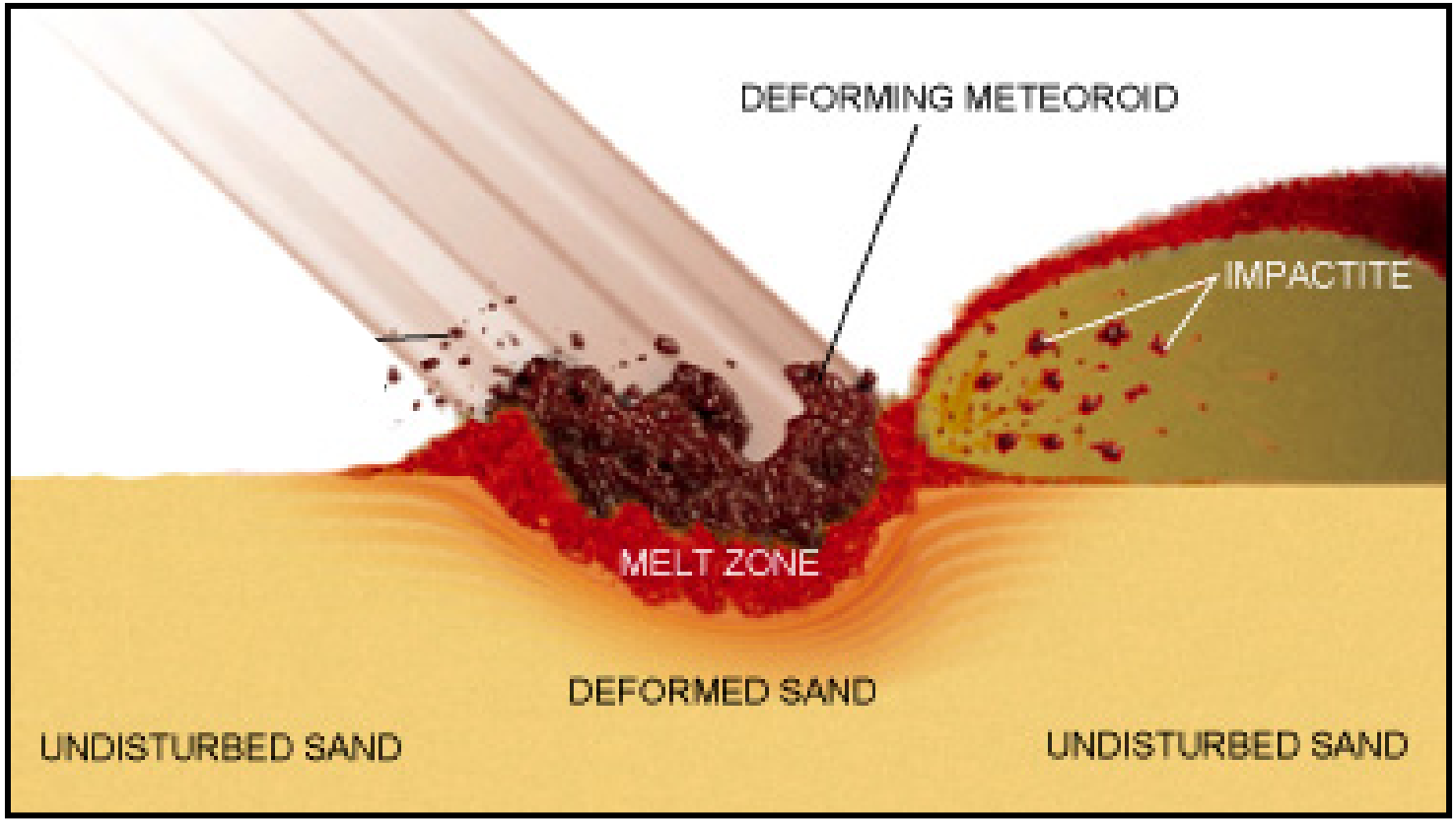
b) ***erosion*** of craters

2) Ocean covers 71% of surface area (hides impacts)

3) Age of rocks ⟸ **Plate Tectonics**



Crater Formation



Huge amount of energy released

- **heat** and **disruption**

Factoid: The Black Stone of Mecca is the physical goal of the Hajj pilgrimage. It is considered to be the Ka'bah's original cornerstone, laid by Abraham. Although not fully tested, it appears that the Black Stone is an impactite – a combination of meteorite and impact-melted sand!

How much energy is released?

Smallish asteroid:

radius = 1 km
density = 4000 kg/m^3
speed = 10 km/s
mass = density x volume
= 2 x 10^{13} kg

Approximate mass of humans on Earth
= (6 x 10^9 people) (50 kg/person)
= 3 x 10^{11} kg *(100 times less)*

The impactor has energy because it is moving:

Kinetic energy = 1/2 x mass x $(\text{speed})^2$
= 1/2 x (2 x 10^{13} kg) x (10000 m/s)^2
= 10^{21} Joules

Vancouver Power usage = 3.5 x 10^8 Joules/s
Small impact: energy used by Vancouver in **90,500 years**!

Asteroids versus Comets?

Asteroid:
radius = 10 km
density = 4000 - 7000 kg/m^3
speed = 10 km/s

Comet:
radius = 1 km
density = 100 kg/m^3
speed = 60 km/s

Kinetic energy = 1/2 x mass x (speed)^2

Mass-Velocity Tradeoff

So, both are nasty.
Asteroids can be large and dense but tend to move more slowly.
Comets are small and very low density, but they are moving very quickly when the pass the Earth.

Crater Structure: Simple to Complex

Crater changes with the size of the impact.

Not only the size of the crater but its structure.

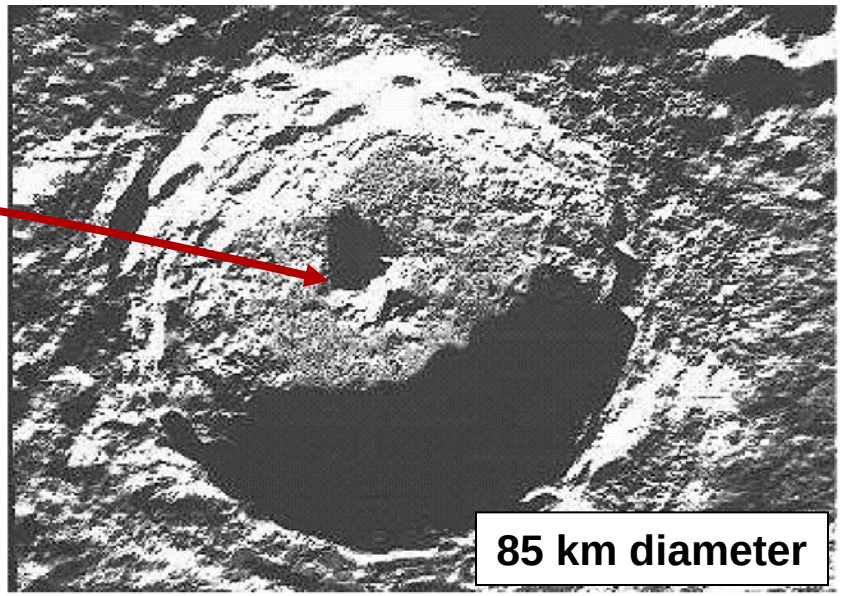
1) Simple crater:

- typically smaller (usually < 4 km diameter)
- filled with breccia, melt, melt droplets
- surrounded by ejecta blanket (including melt droplets)

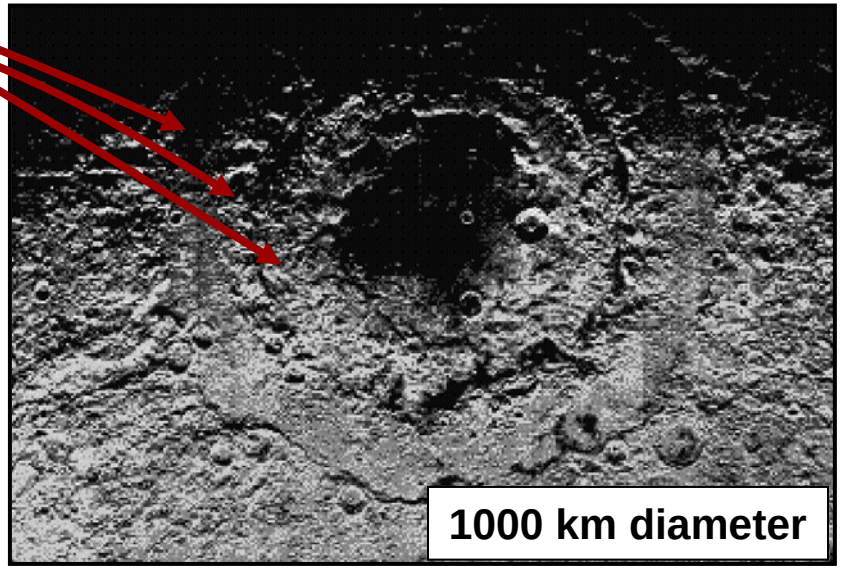
Crater Structure

Complex crater

- ***central peak***
  - peak formed by ***rebound*** of the depressed crater floor

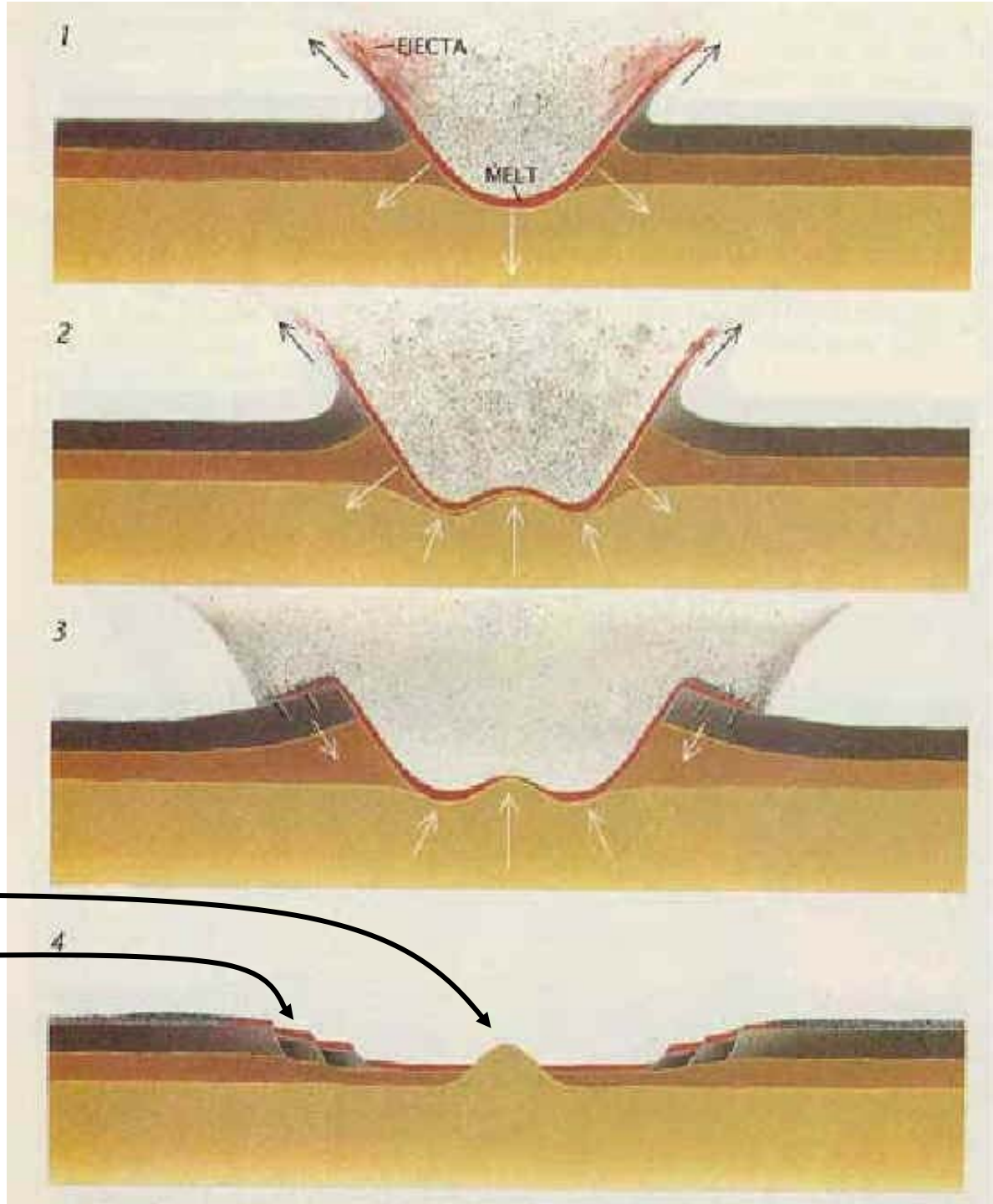


- ***multiple rings***
  - trough and peak rings formed by combination of rebound and slumping of crater floor
  - ***shock waves*** also generate thrust faults forming rings



Crater Structure

Complex crater



- ***central peak***
- ***multiple rings***

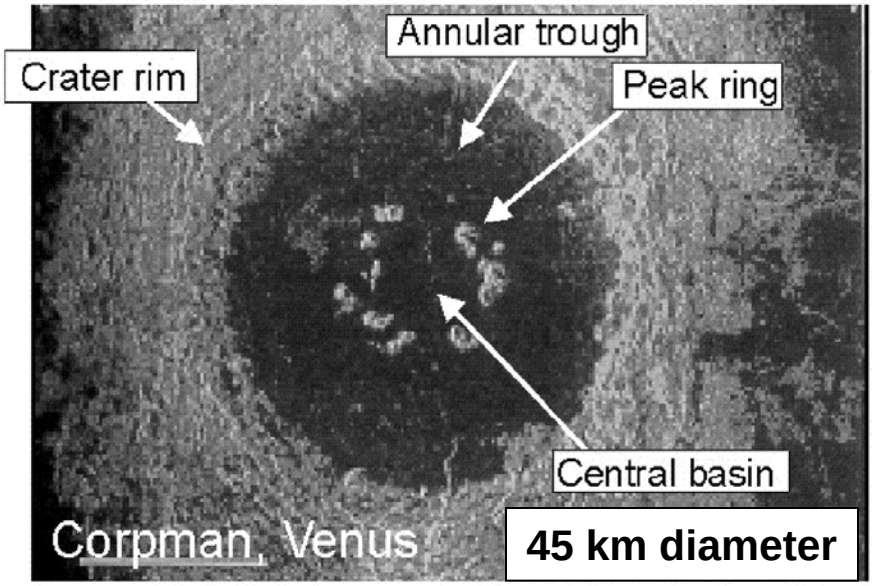
Scientific American, 1990

Crater Structure

2) Complex crater (Venus)

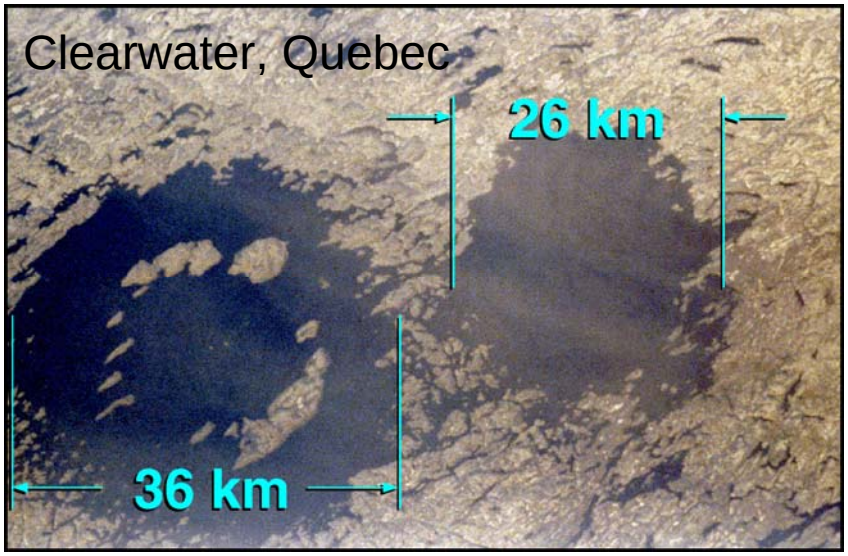
- Much larger
- ***central peak ring*** and ***annular trough***

These are 'rebound' features' that bulge up after the impact.



Complex crater (Quebec)

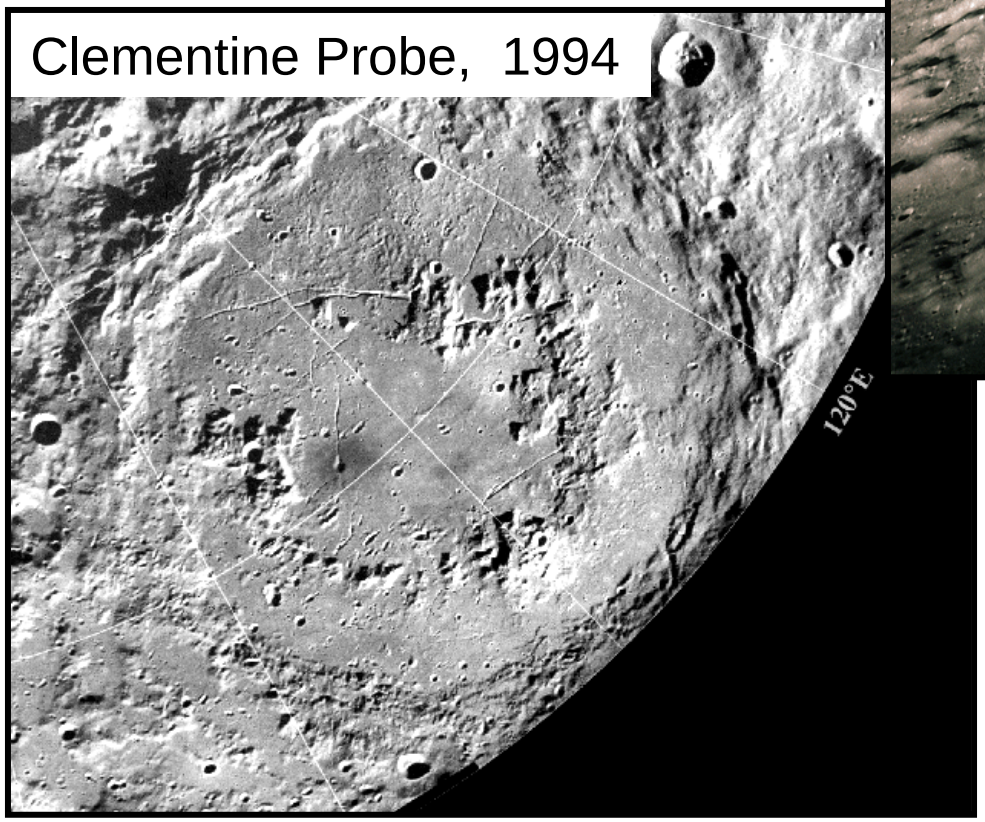
- ***central peak ring*** and ***annular trough***



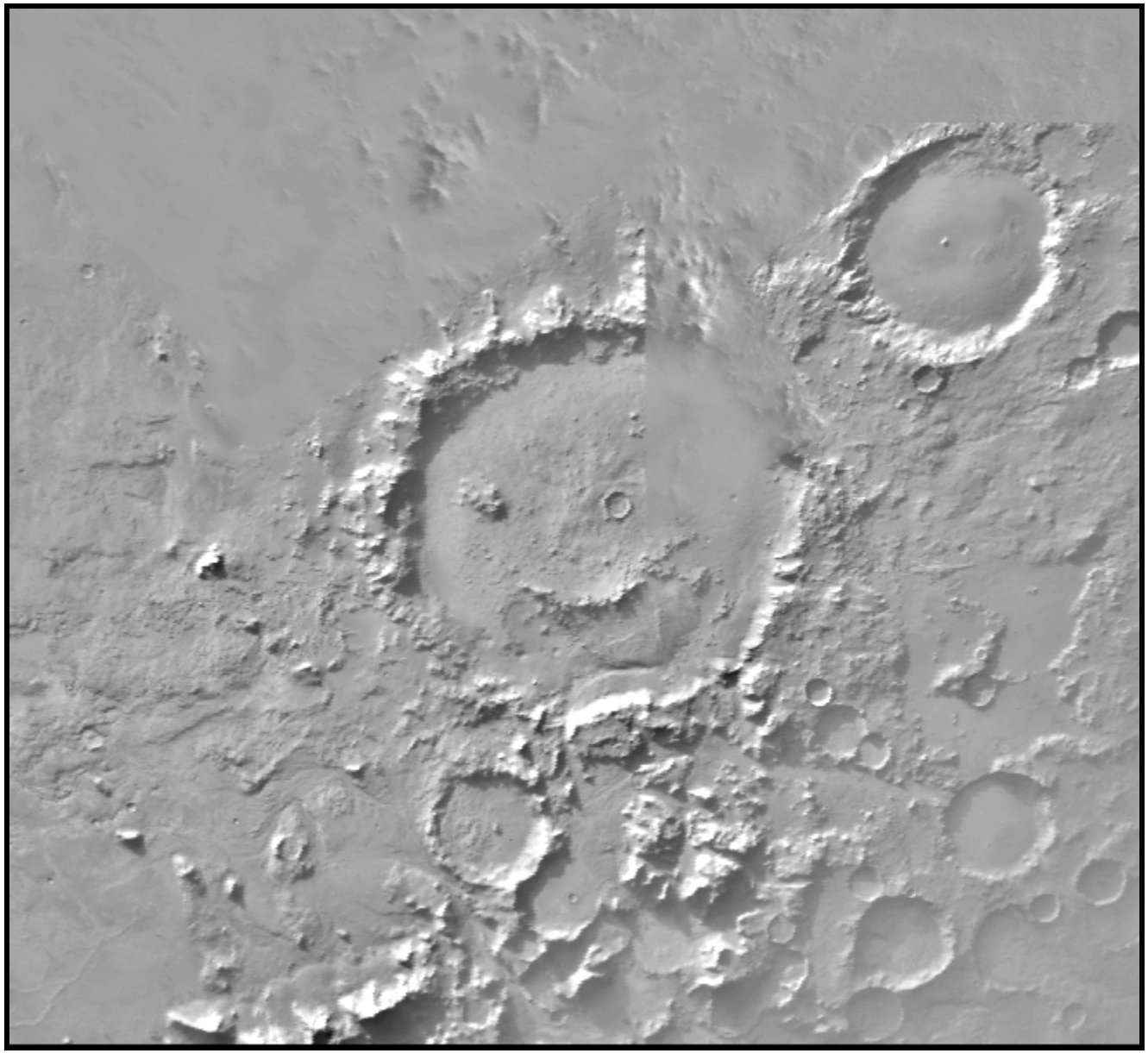
Lunar Craters

Simple to complex

Davy crater chain

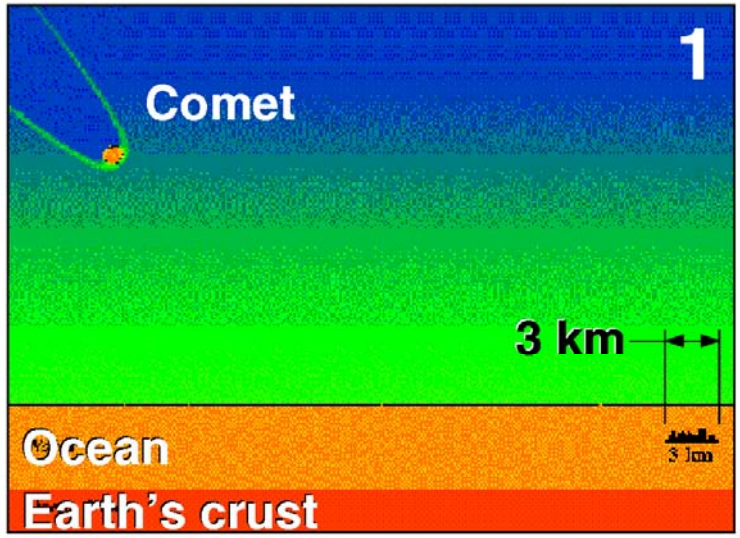


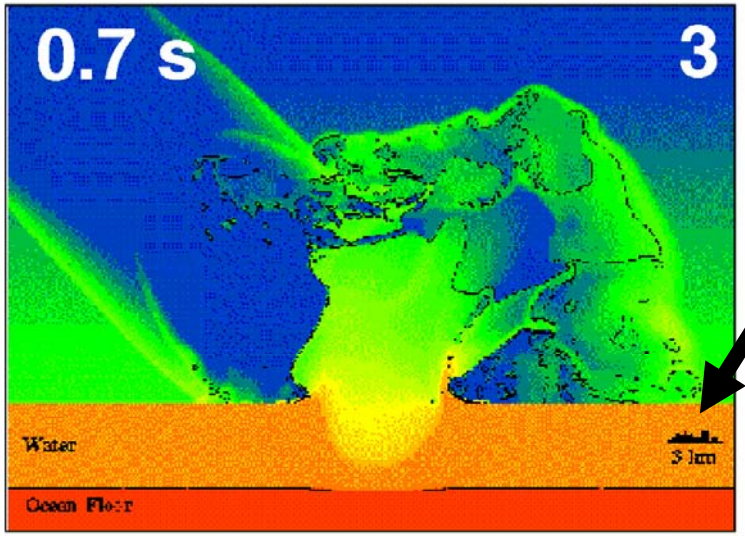
Schrodinger Impact Basin
(312 km diameter)



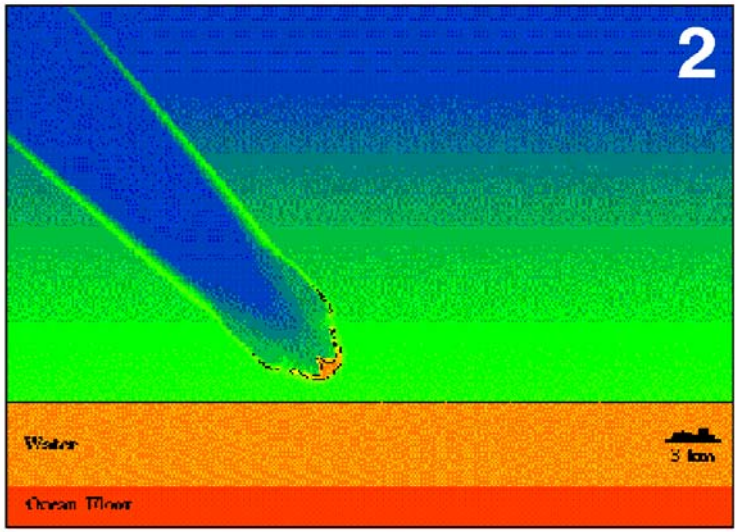
Don’t Worry, Be Happy Crater

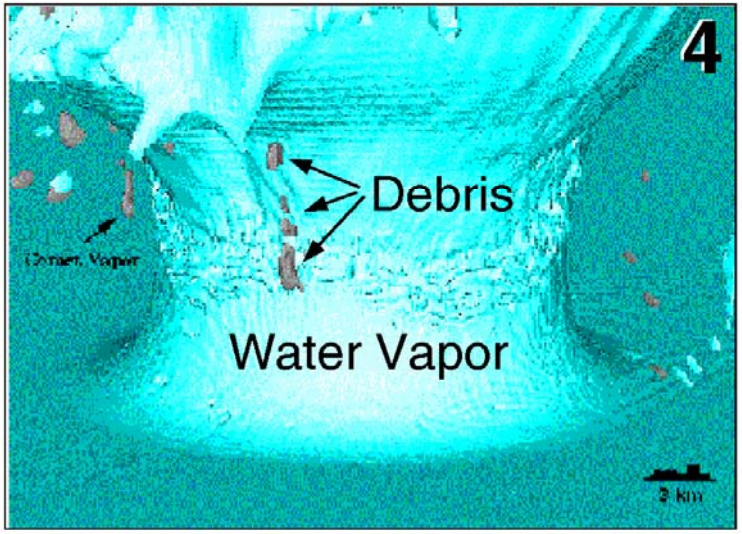
Impact with ocean and crust beneath





City for scale





Comet penetrates ocean (5 km deep) and craters the oceanic crust below. Water vaporized and globally distributed. Tsunami.

Sandia Labs: http://sherpa.sandia.gov/planet-impact/comet

How is the Earth affected by:

- meteor showers?
- small impacts?
- LARGE impacts?

- physical effects
- environmental effects
- cultural effects

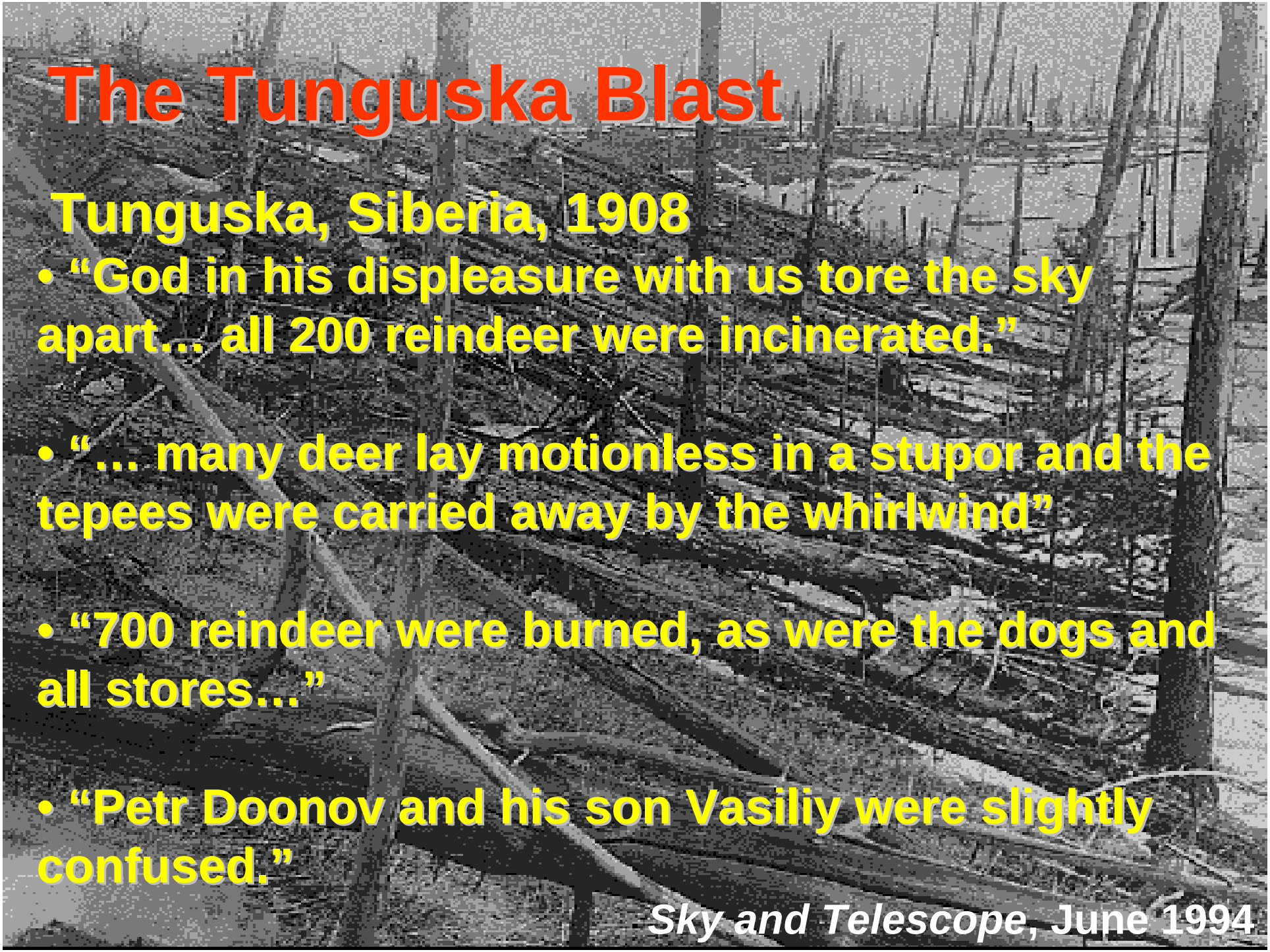
Historical Earth Impacts

Caruca River, Brazil (Amazon) [August 13, 1930]

- air blast
- 1/10 the size of Tunguska

Tunguska, Russia [11:30am, June 30, 1908]

- air blast of an S-type asteroid (meteorite)
  - diameter 60 m
  - exploded 8 km up in atmosphere
- explosive energy release = 15 x 10^6 tons of TNT
  - 1000 x Hiroshima
  - levelled 3100 km^3 of forest



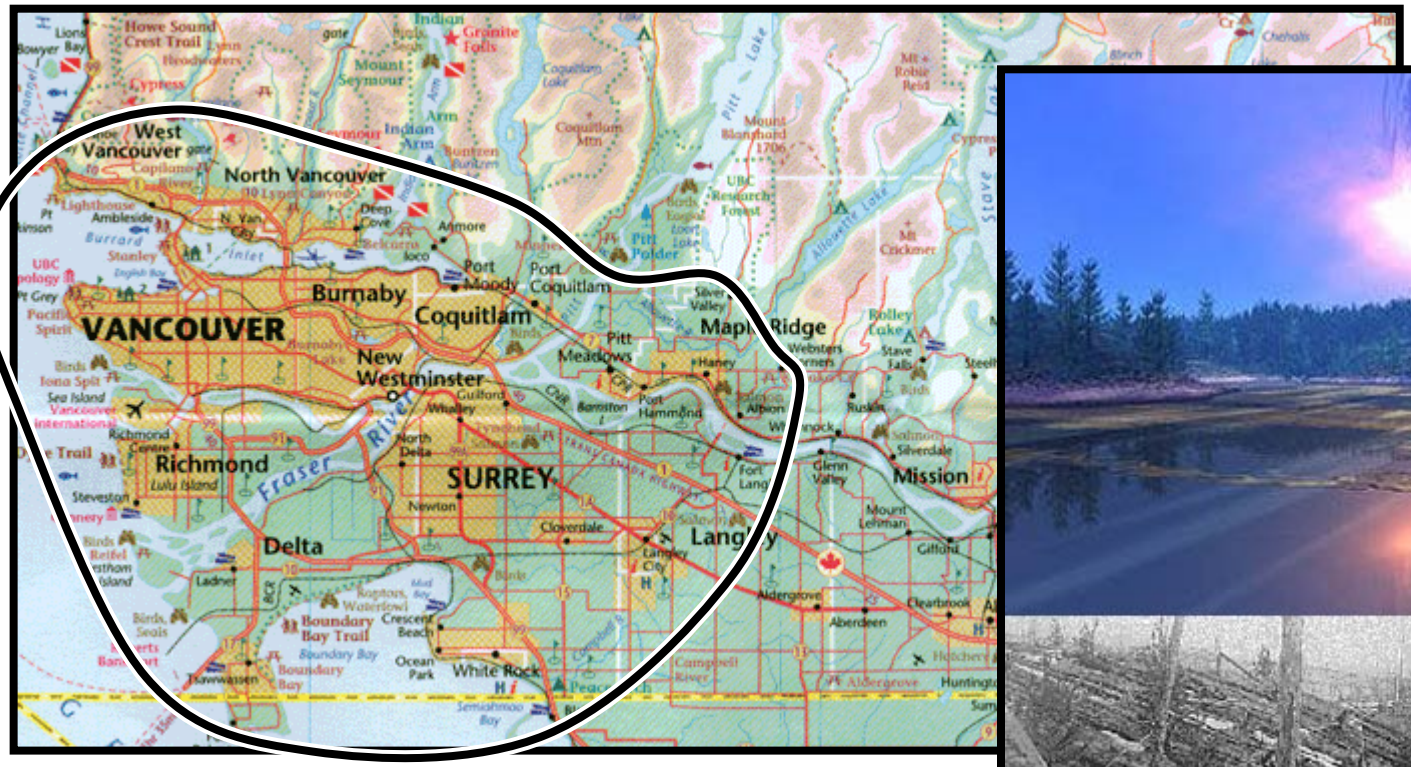
The Tunguska Blast

Tunguska, Siberia, 1908

- **"God in his displeasure with us tore the sky apart… all 200 reindeer were incinerated."**
- **"… many deer lay motionless in a stupor and the tepees were carried away by the whirlwind"**
- **"700 reindeer were burned, as were the dogs and all stores…"**
- **"Petr Doonov and his son Vasiliy were slightly confused."**

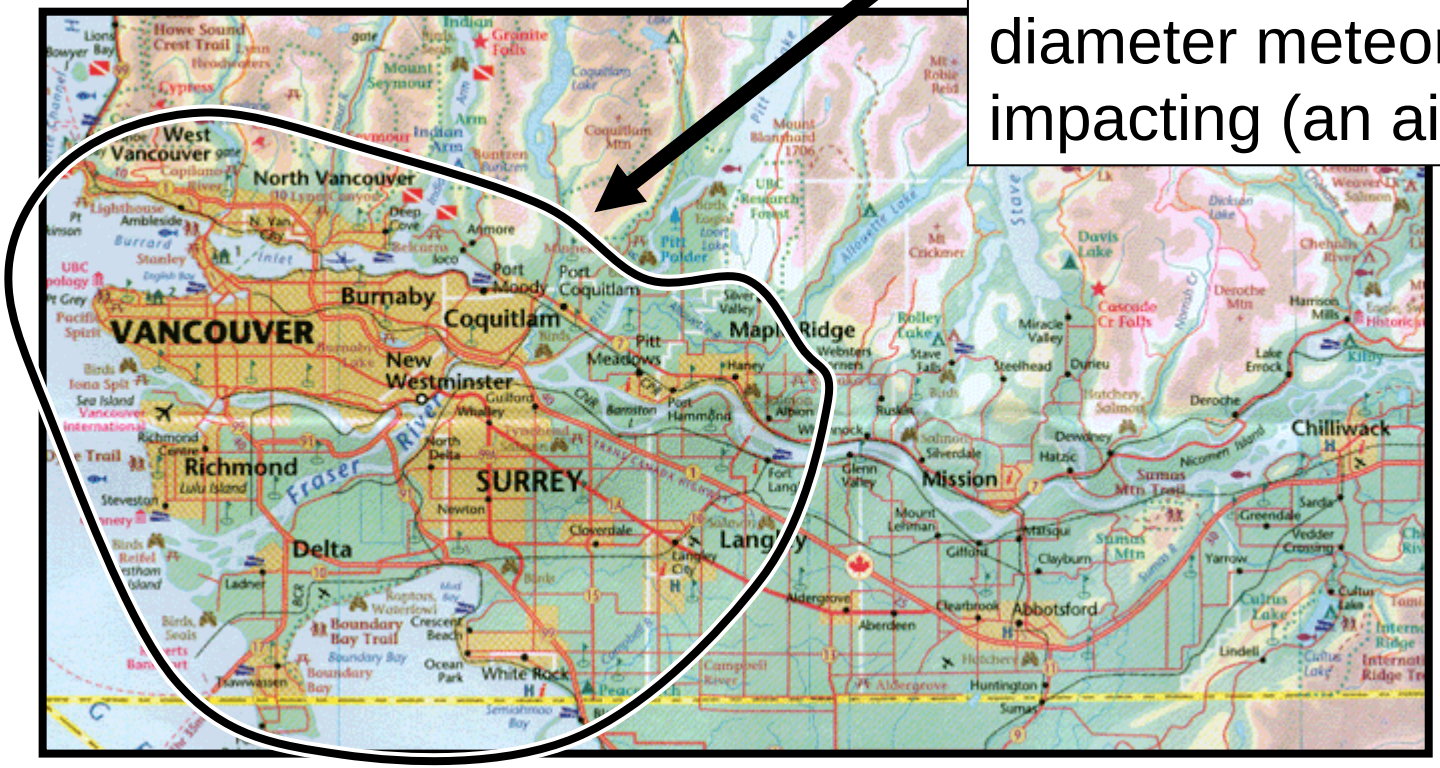
***Sky and Telescope*, June 1994**

The Tunguska Blast



Area of blowdown zone…

A bigger impact?

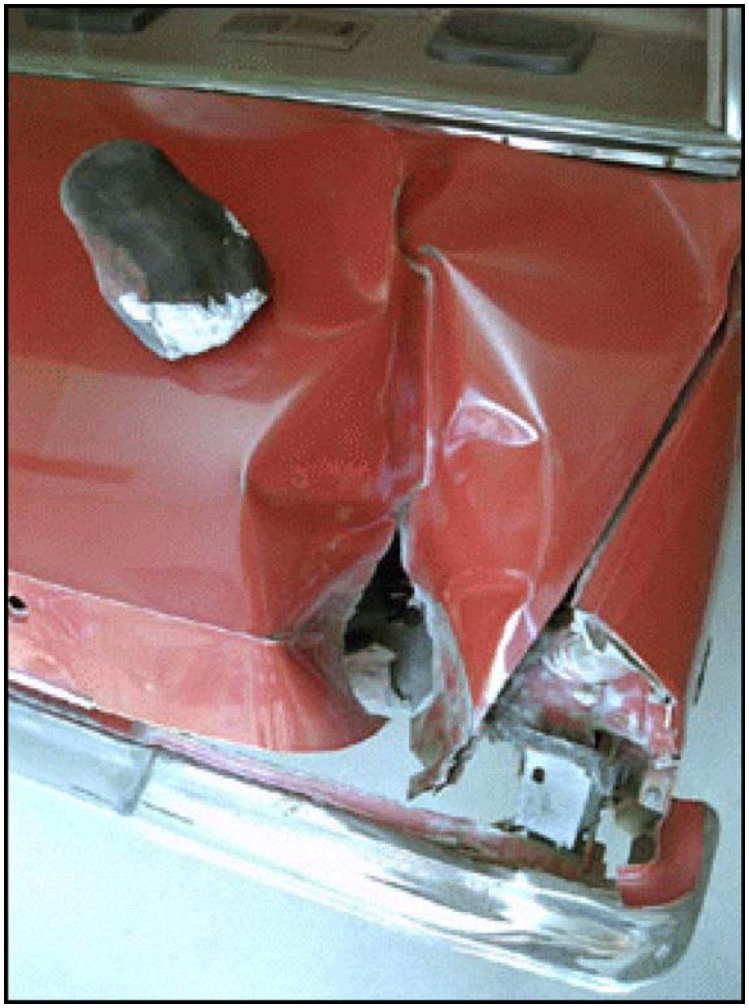


Blowdown zone for a 60m diameter meteorite not even impacting (an airblast)

If a 5 km diameter asteroid hit Vancouver at a typical speed:

- The initial crater would be about 60 km diameter
  - That would then slump, to form a final crater about 100 km
- *The blowdown radius would be about 450 km*
- The fireball zone would ignite things out to about 600 km!

What would ICBC do?



Peekskill Meteorite (New York, 1992)

- Michelle Knapp's Chev - post impact

See video clip on the website