ASTR 150

- **Homework 3** due following Monday (Sept 30th)
- No lecture next Wed/Fri
  - Good time to finish asteroid lab

- Last time: Solar System Formation 2
- Today: Impacts and the Earth

Music: *It's the End of the World As We Know It*– REM

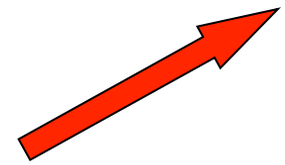
Air Brakes: Falling Through the Atmosphere

- Air causes resistance
- An object falling in the atmosphere will have gravity pulling downward, and air resistance pushing upward
- When the two cancel, the object reaches its maximum velocity, or its terminal velocity

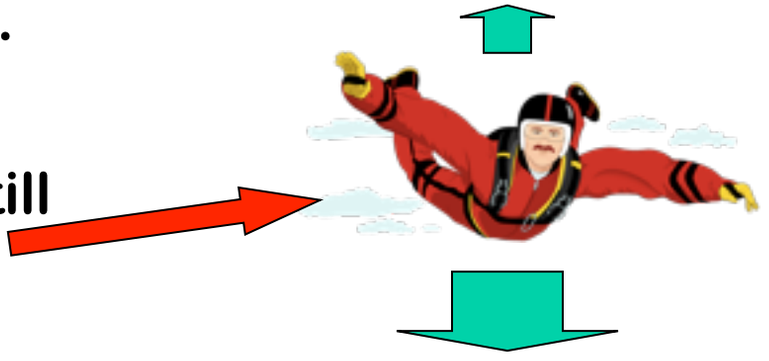
Terminal Velocity

Consider a skydiver:

1. At the start of the jump, no air resistance, so diver accelerates downwards, speed increasing.



2. As the speed increases, air resistance increases. Diver still accelerates, but less than before, speed still increasing.



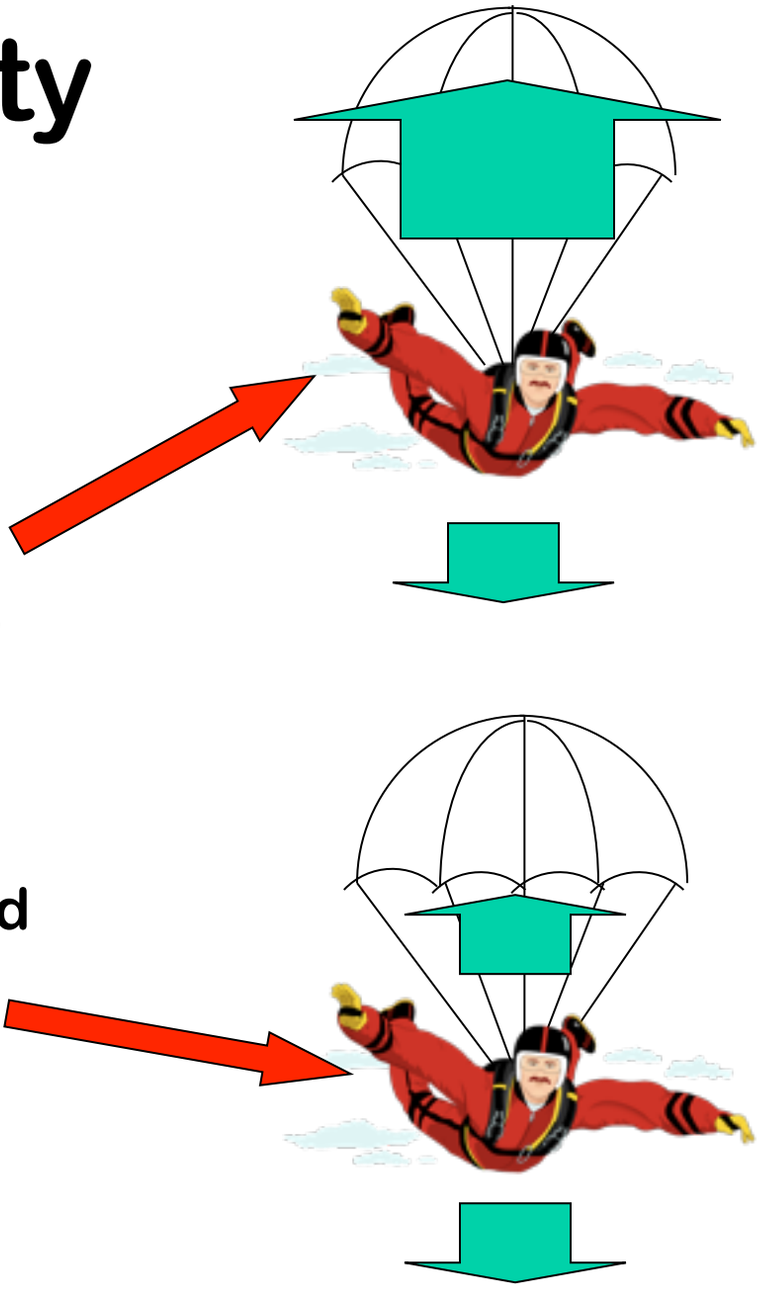
3. Air resistance increases until it equals the pull of gravity, and the diver no longer accelerates. The speed is at the terminal velocity.

Note, the air resistance depends on the speed of the object and its shape (surface area) - the greater the surface area the more air resistance!

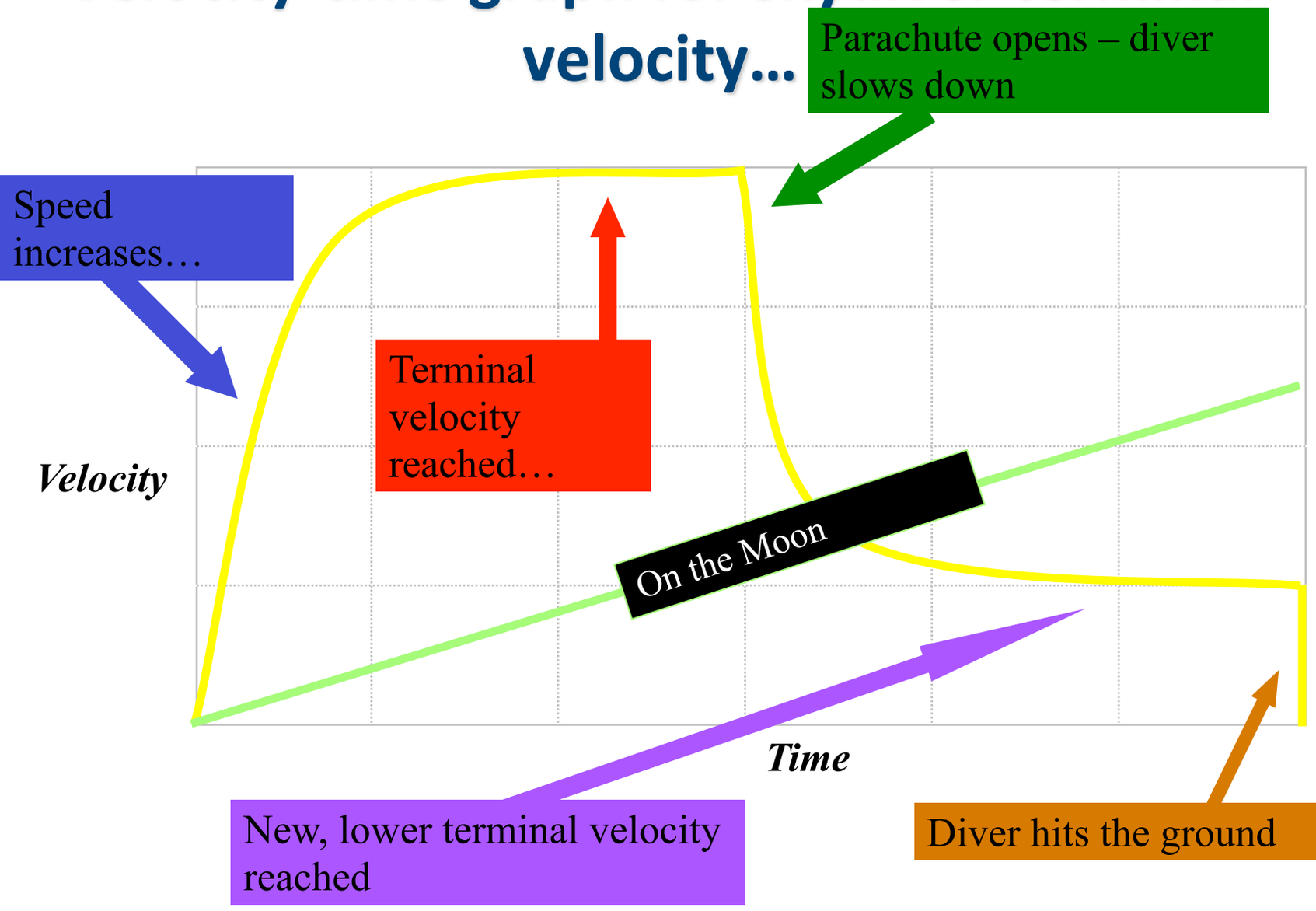
Terminal Velocity

Still considering a skydiver:

4. **When opening the parachute, shape changes, more air resistance, so diver decelerates, speed decreases**
5. **Because object is slowing down the air resistance decreases until it balances gravity. Diver has now reached a new, lower terminal velocity, allowing him to land safely.**



Velocity-time graph for skydiver terminal velocity…

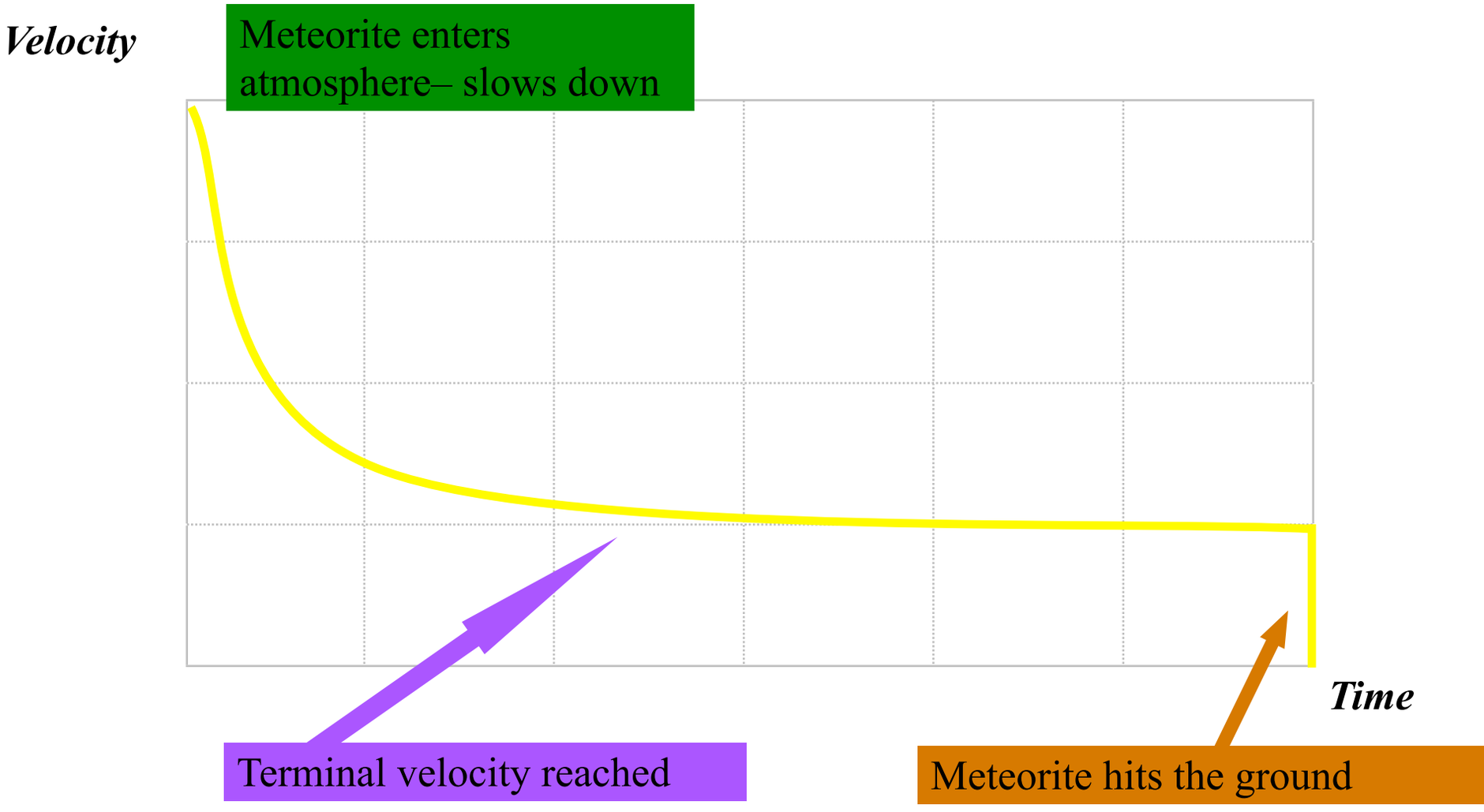


i>clicker question

Why would a skydiver not have a terminal velocity on the Moon?

A. No air.
B. No gravity.
C. No parachutes.
D. No time.
E. No weight.

Meteoroid terminal velocity graph



Up on Speed

- Terminal velocity depends on
  - Shape of the object
  - Mass of the object
  - Size of the object
- Rougher shape = lower terminal velocity
- More mass = higher terminal velocity
- Bigger size = lower terminal velocity

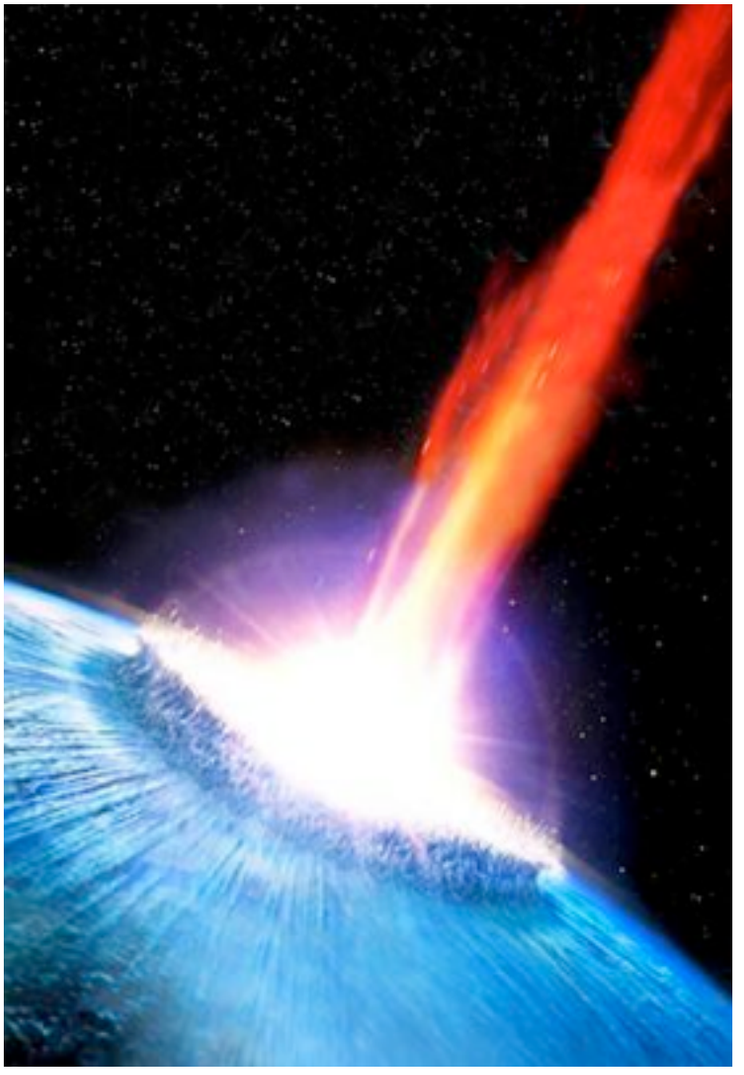
Rough Shape = more drag

Ramming Speed!

- Objects less than a few kilograms will burn up completely in the atmosphere
- Objects a few kg to 7000 kg will slow down due to the atmospheric drag
- These reach their terminal velocity – about 90-180 m/s (200-400 mph)

The Big One

- Objects ~9,000 kg will keep some of their initial velocity – impact at ~2-4 km/s
  - (1.5 miles per second!)
- Really big objects (~10^6 kg) won't be noticeably slowed,
  - impact at near their initial velocities (>11 km/s!)



Why does a meteor shine?

Meteroid compresses the air in front of it, called ram pressure

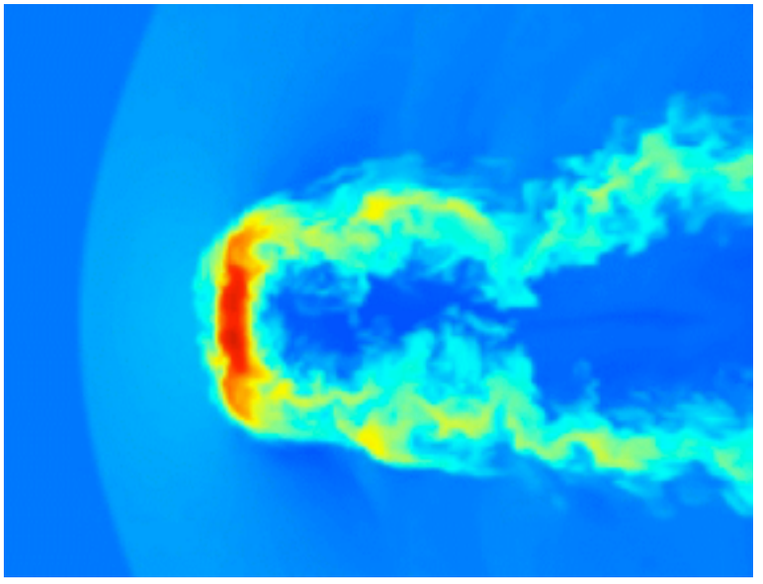
Rapid compression heats up the air, like quickly pumping up a bicycle tire

Hot air heats up the meteoroid

Why does a meteor shine?

Due to ram pressure, the outer layers of the object can melt or boil away, called **ablation**.

The meteor light you see is a combination of ablation and ionizing of the air by the extreme heat



It's a Drag

Atmospheric flight stresses an object

- **Newton III: meteor pushes on and compresses air**
- **but compressed air pushes back on meteor**

Large objects may break apart into many pieces at 11-27 km (7-17 miles) up

Causes an series of smaller meteorites on the ground.

Cool Touch

After the meteor reaches terminal velocity, the ram pressure is gone, and the lights go out.

Meteor cools off fast

Meteoroid has been in space for 4.5 billion years, so it is cold and the upper atmosphere is cold

- Small meteorites never hot
- Some meteorites found with frost on them!

Small meteorites do not start fires!

Sometimes newly fallen meteorites are actually covered in frost.
But they are never above ambient temperature.
You will not get burned.

What do meteorites look like?

Metetorite outside cooked during fall

New stony meteorites have a fusion (melted) crust – dark color.

Iron meteorites, a welded metal look

Older meteorites can be weathered, look like Earth rocks

But not always. It can wear away quickly, or the meteorite could have broken up after terminal velocity.

Why Does it Hurt So?

- It's really about the energy released
- Kinetic energy from motion:

$$KE = \frac{1}{2}Mv^2$$

- 250m asteroid impact at 20 km/s releases 1,000 MT of energy - 10x the largest nuclear weapon!

Meteoroids move at high speeds; small objects can cause significant damage

i>clicker Question

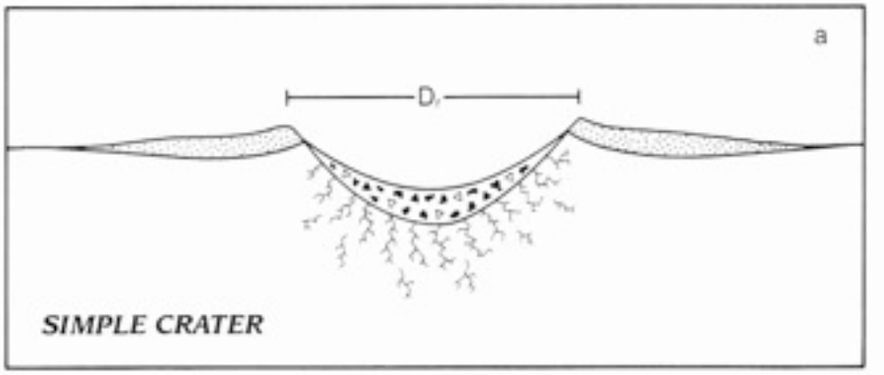
Which meteorite imparts the most energy?

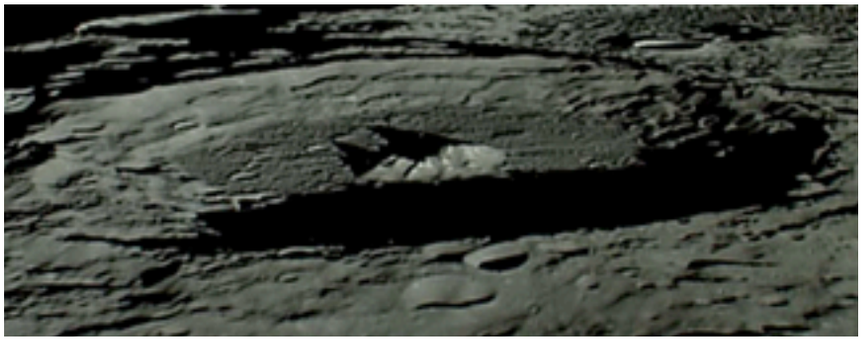
A. 1 kg moving at 100 km/hr
B. 1 kg moving at 200 km/hr
C. 2 kg moving at 100 km/hr
D. 100 kg moving at 10 km/hr
E. 100 kg moving at 1 km/hr

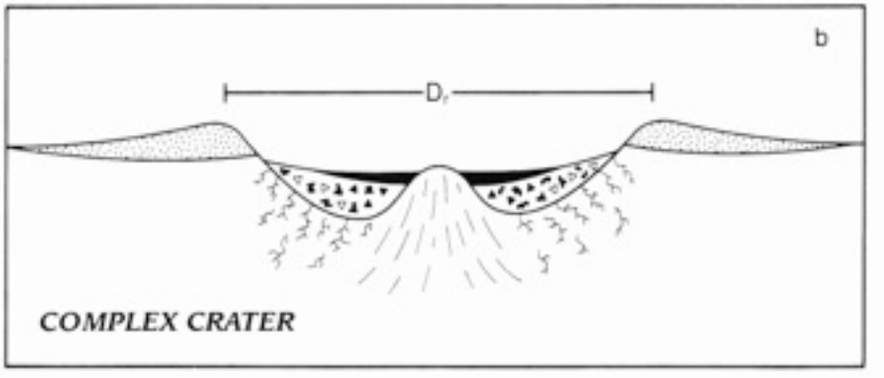
Hints: $1^2 = 1$, $2^2 = 4$, $10^2 = 100$, $100^2 = 10{,}000$, $200^2 = 40{,}000$

Answer B

Simple vs. Complex Craters

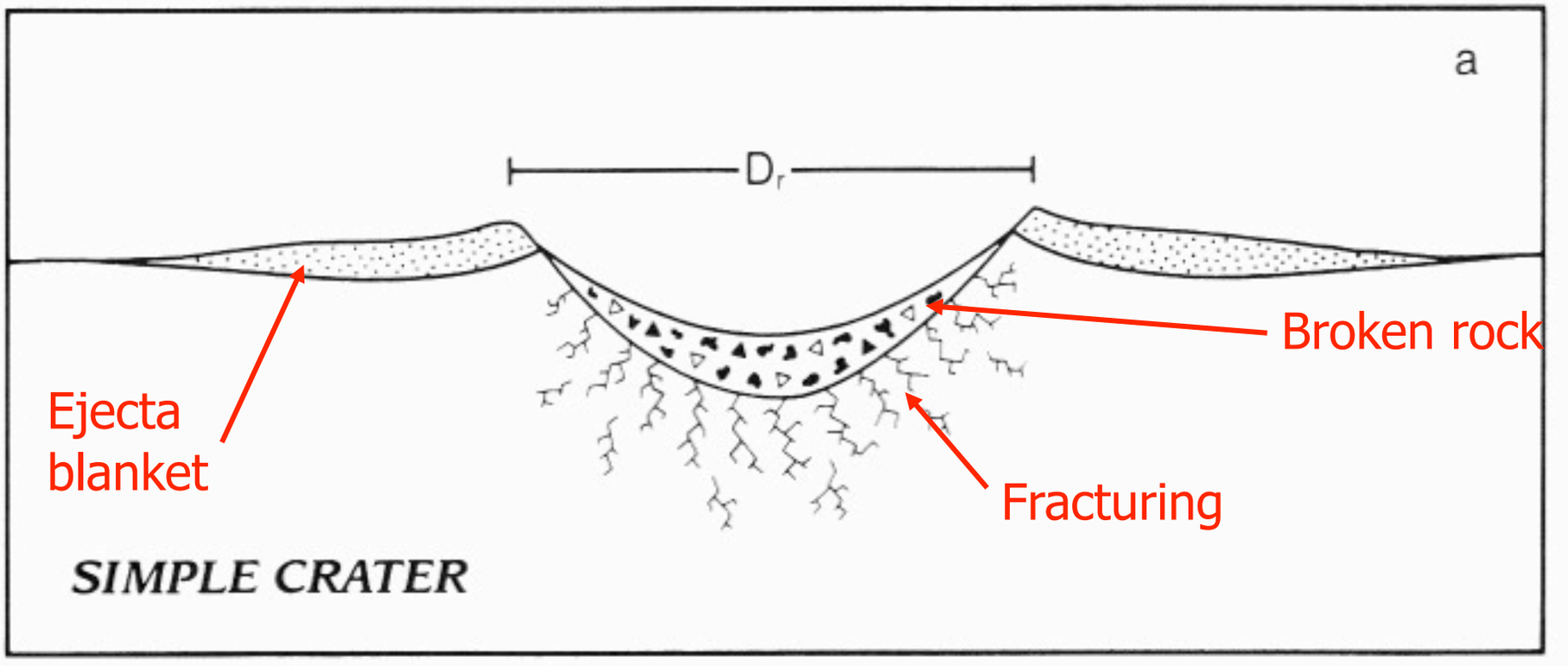






Simple craters are basically simple bowls
With time, the ejecta blanket outside the crater is eroded
Complex craters are generated by rebound of the central core
This core, as it decompresses, may melt

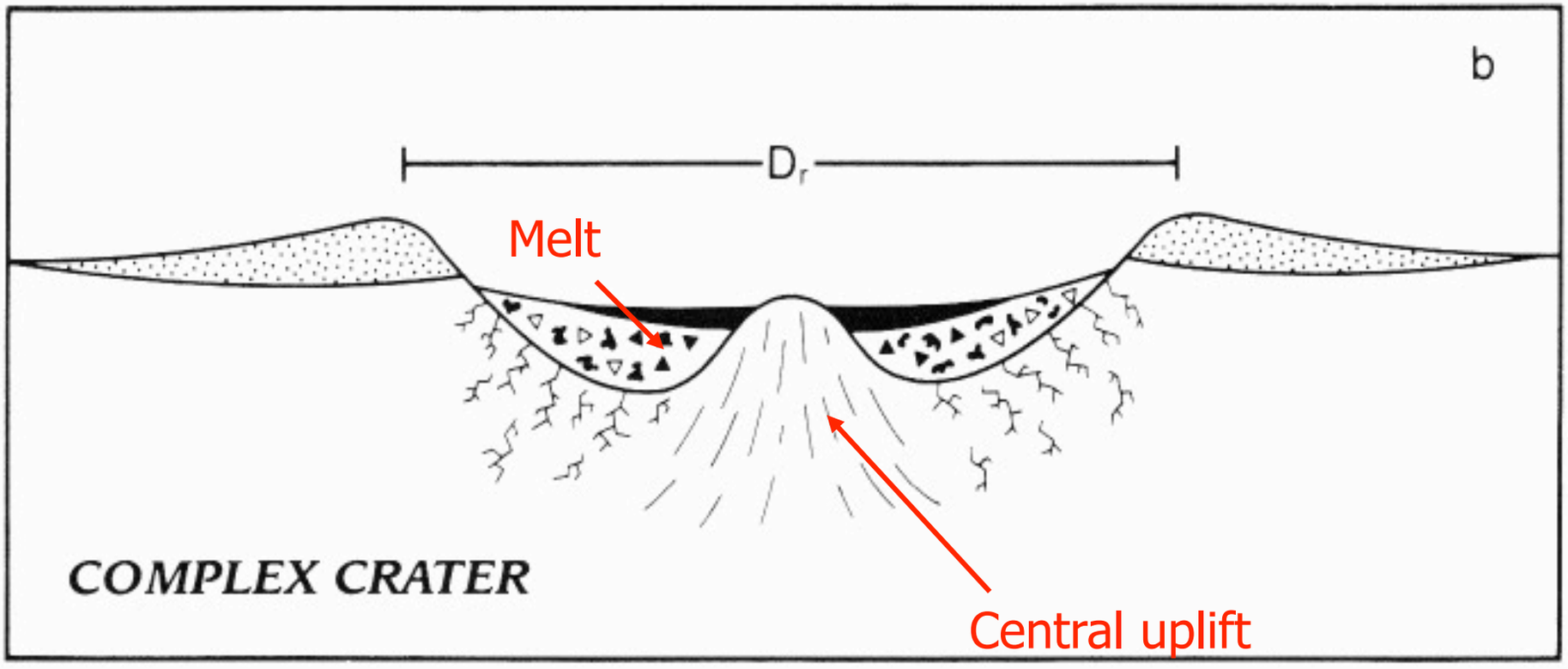
Simple craters



- Bowl structure
- 15-20 times diameter of impacting object
- All less than 1-2 miles across on Earth

With time, ejecta blanket is eroded

Complex craters

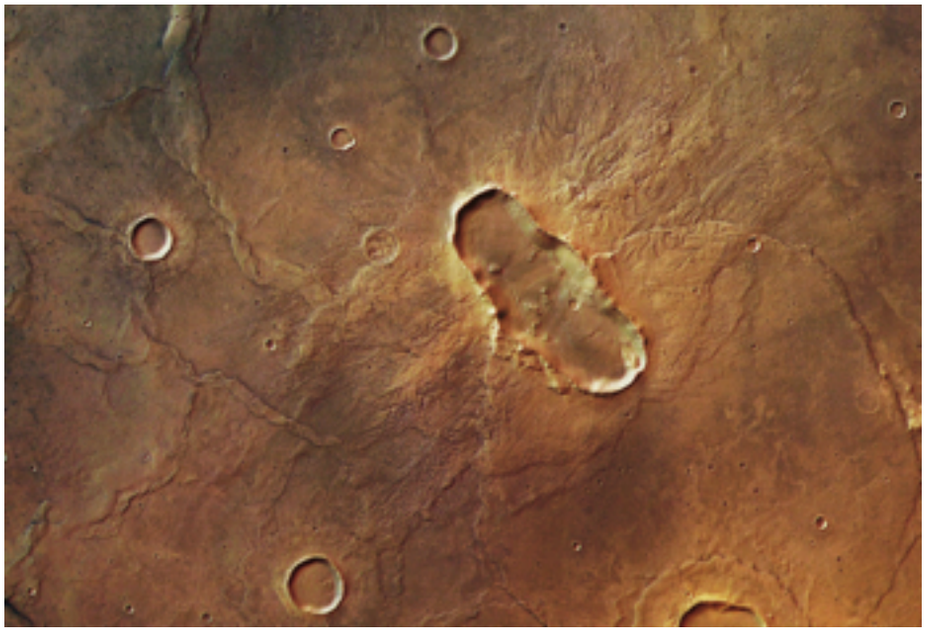


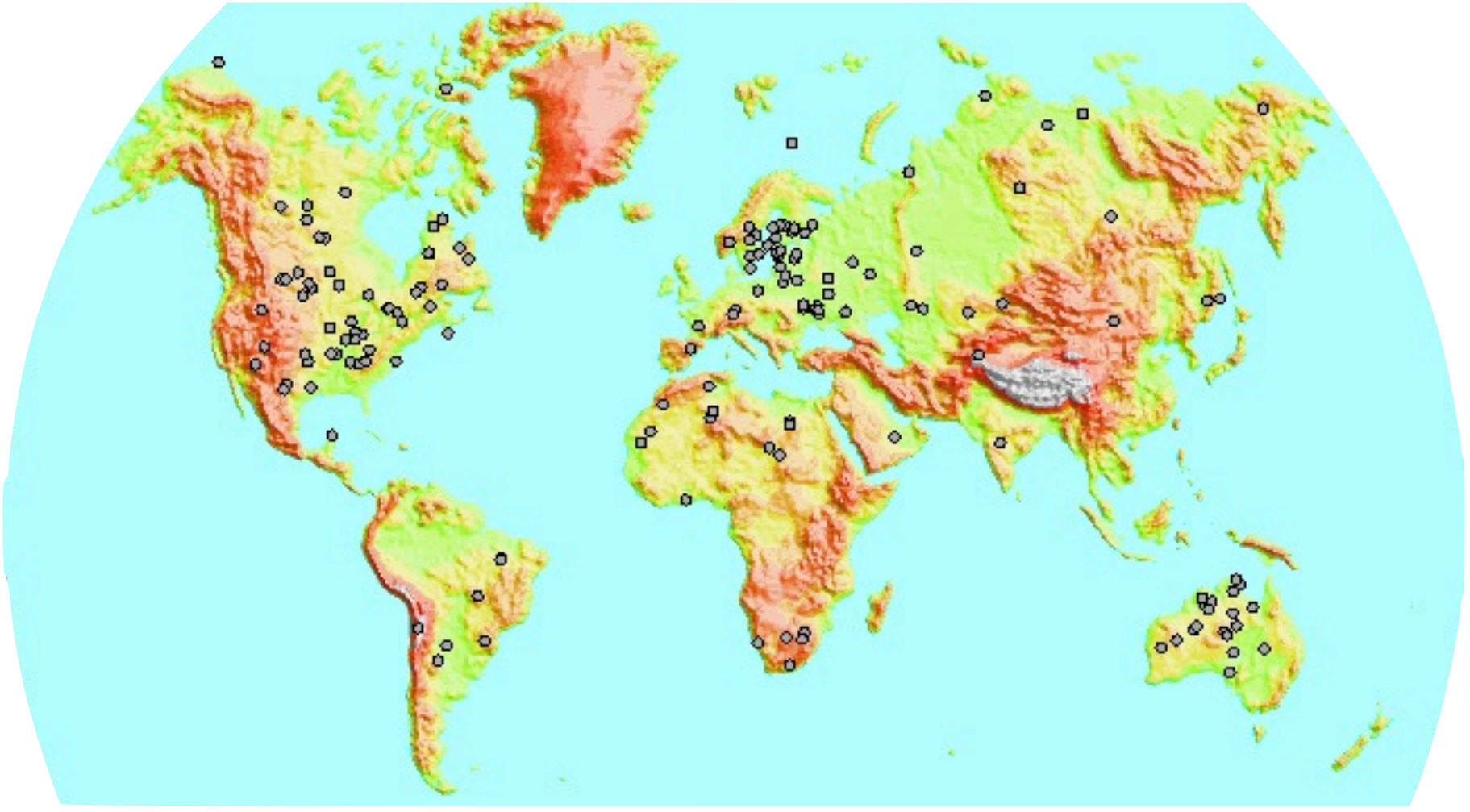
- Central peak, peak ring, or multiple rings
- Melt sheet generated
- About 10x impactor diameter
- Why the central peak? loss of overlying material -- less downward force (weight) -- central region “rebounds”

With time, ejecta blanket is eroded

Why are Craters Round?

- Impact vaporizes the impactor.
- Explosion!
- It's like dropping a bomb.
- This causes round craters.
- In rare cases, objects will hit with shallow, grazing impacts, creating oblong craters.

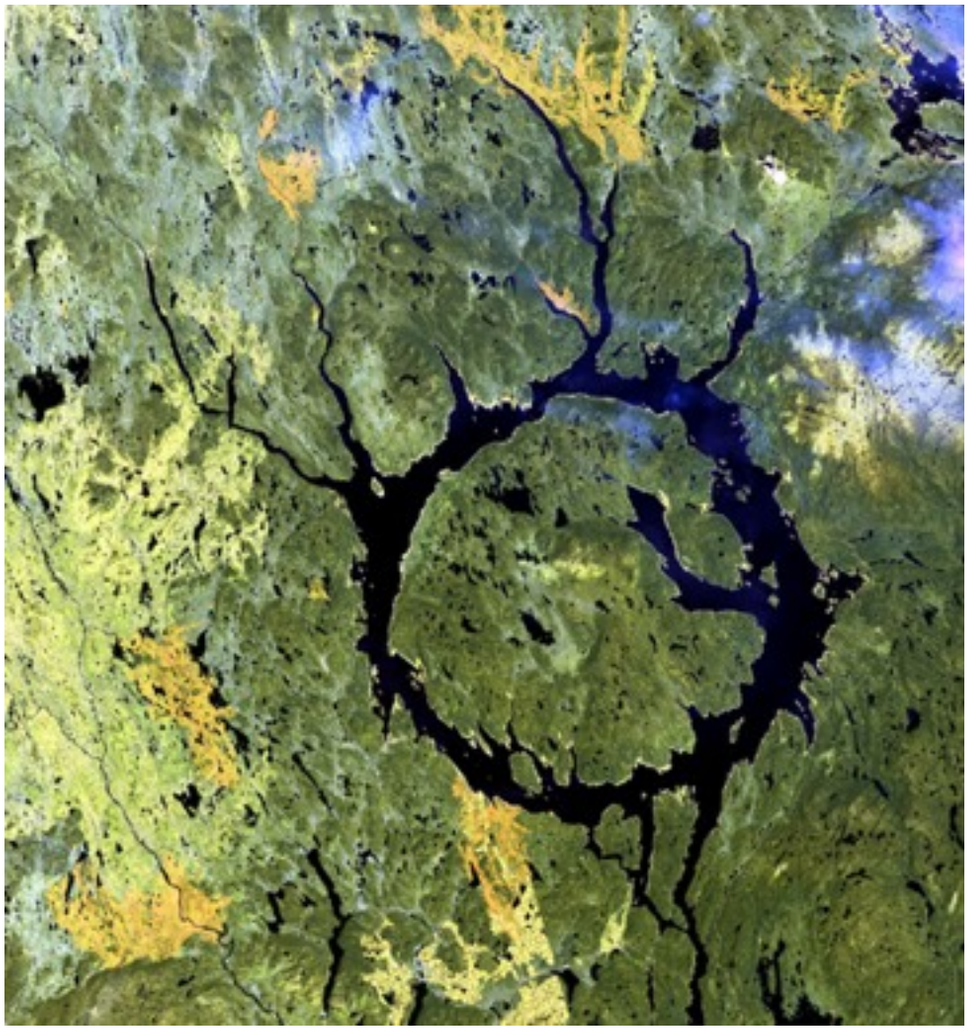




There are about 200 large, well-preserved impact craters worldwide…BUT…>>200 impact events during Earth's history

Earth's Craters

Manicouagan Crater in Quebec, Canada 100 km wide



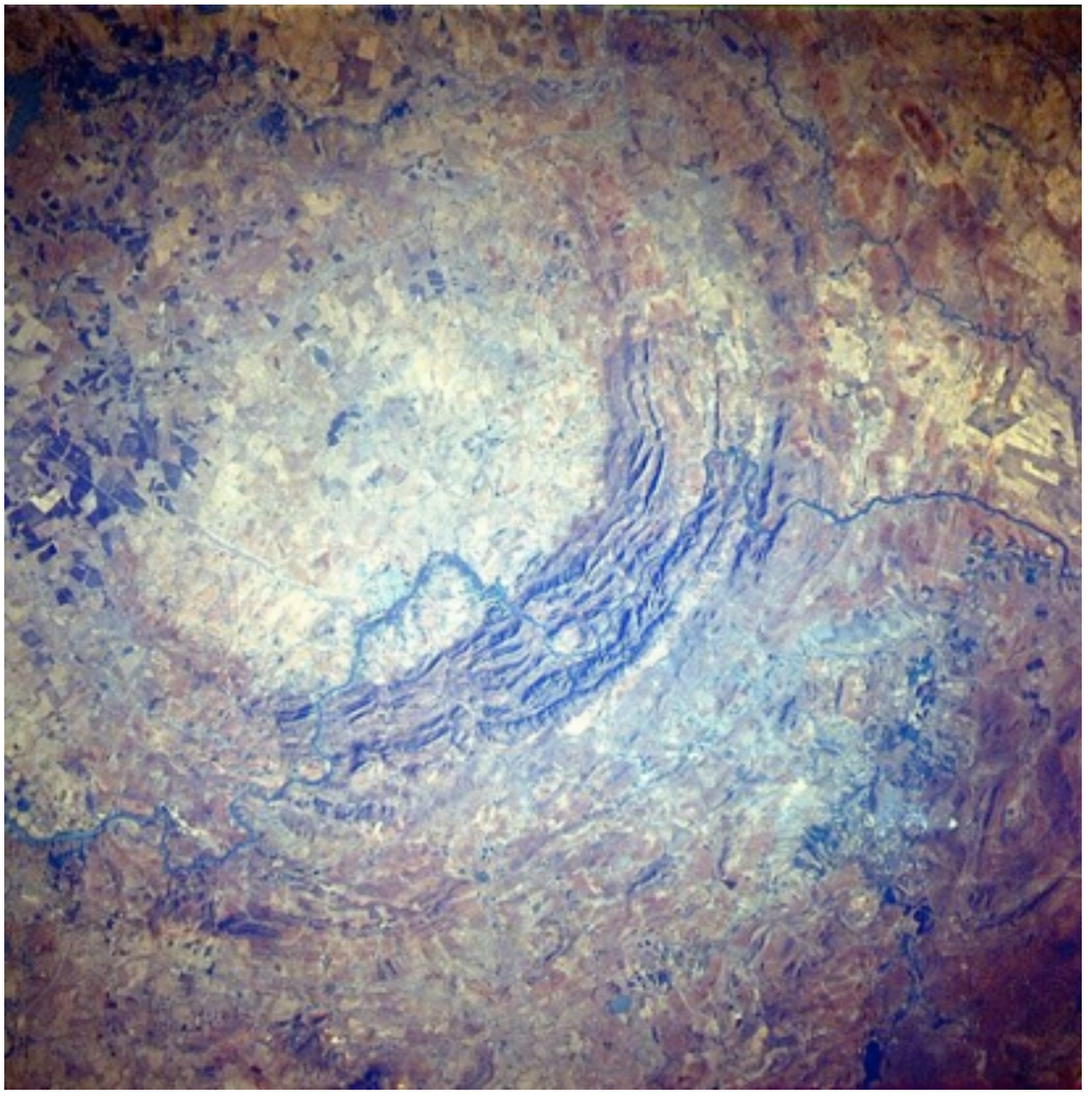
http://www.unb.ca/passc/ImpactDatabase/images/manicouagan.htm

A spectacular example of a complex crater
Original rim removed by erosion…current diameter is 100 km
Has an uplifted central core and outer rings, which are filled by a lake
Its age - 210 Ma - coincides approximately with a large extinction at the end of the Triassic period

Earth's Craters

- Clearwater Lakes in Quebec, Canada – 26 km wide (290 million years ago) from a double impact!
- Submerged central peak in smaller lake.

Vredefort Crater

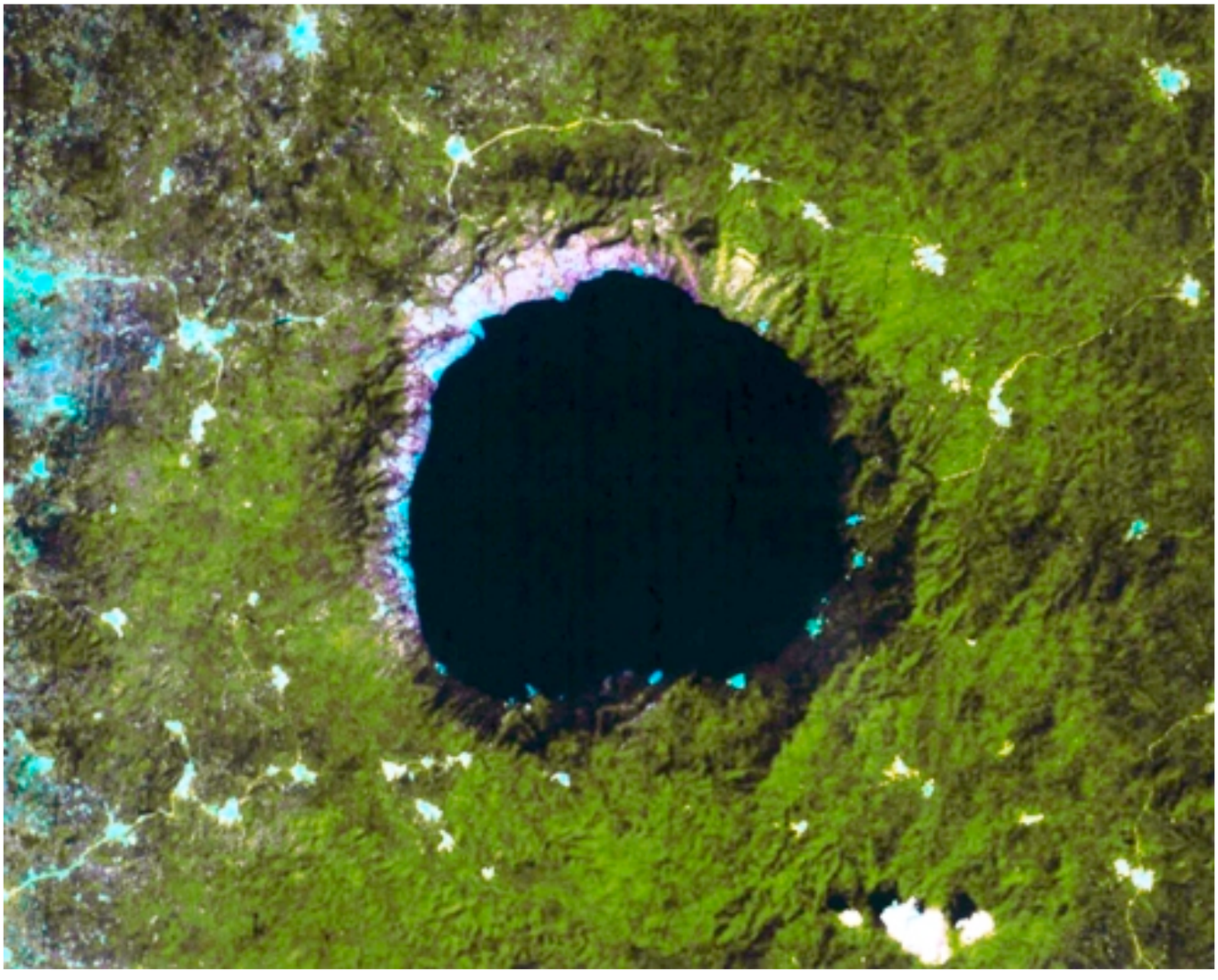


the largest and oldest known impact crater, Vredefort Crater, shown above, located in South Africa. It is approximately 250 kilometers in diameter and is thought to to be about two billion years old. The Vredefort Dome can be seen in this satellite image as a roughly circular pattern. What an impact that must have been!

Wolfe Creek crater (Kandimalal), Australia

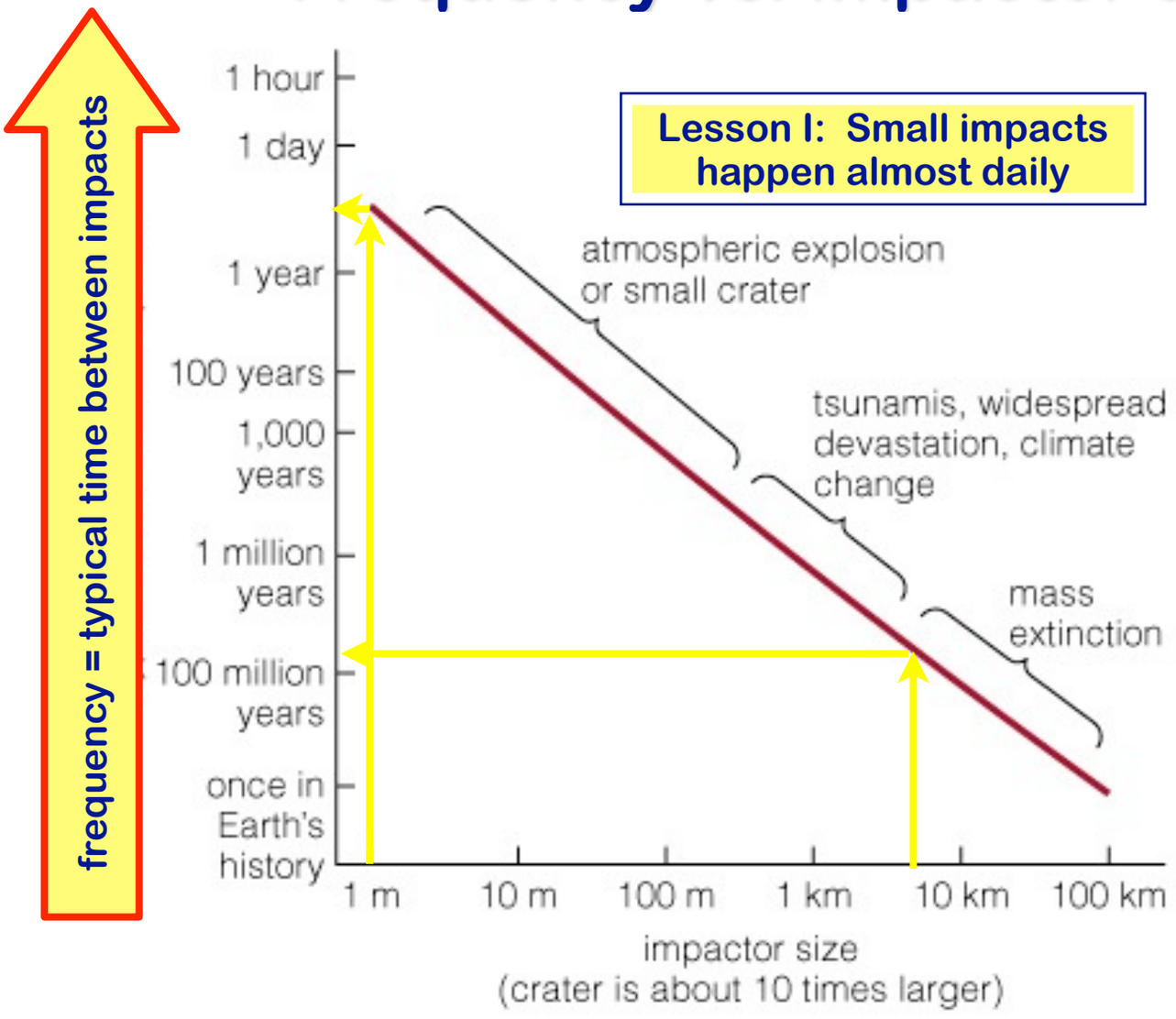
Another relatively well-preserved meteorite crater is found in the desert plains of north-central Australia. Wolfe Creek crater is thought to be about 300,000 years old and is 880 meters across and and about 60 meters deep. It's partially buried under the wind-blown sand of the region, and although the unusual landform was well-known to the locals, scientists didn't find the crater until 1947.

Bosumtwi Crater, Ghana



The last crater on our tour of impressive impact craters is this located in Ghana, Africa. It is about 10.5 km in diameter and about 1.3 million years old. The crater is filled almost entirely by water, creating Lake Bosumtwi. The lakebed is made of crystalline bedrocks.

Threat Assessment:
Frequency vs. impactor size



Lesson I: Small impacts happen almost daily

Lesson II: Impacts large enough to cause mass extinctions typically around 100 million yrs apart

Lesson III: life on Earth > 3000 million yrs: many dangerous impacts over that time!

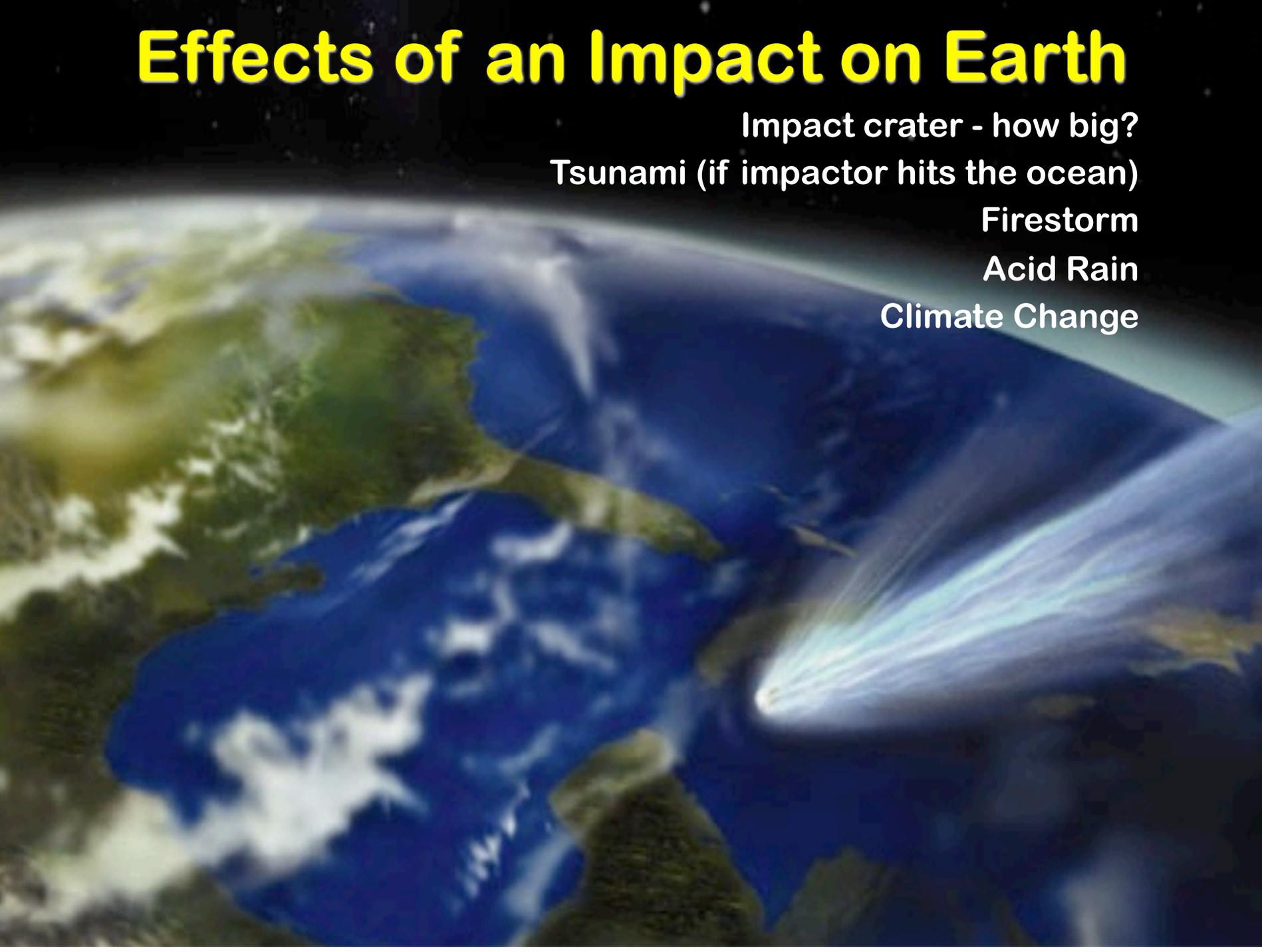
impactor size: gives idea of how much damage

Asteroids and comets have hit the Earth and continue to do so.
A major impact is only a matter of time: not IF but WHEN.
Major impacts are very rare.

Extinction level events ~ millions of years.
Major damage ~ tens-hundreds of years.

Impacts will certainly occur in the future, and while the chance of a major impact in our lifetimes is small, the effects could be devastating.

Effects of an Impact on Earth



Impact crater - how big?

Tsunami (if impactor hits the ocean)

Firestorm

Acid Rain

Climate Change

Death from Above?

Bad news:

- extinction-level impact essentially guaranteed during the > 3 billion year time life has been on Earth
- Killer Skies could (and did) play an essential role in biological evolution
- to make matters worse: impact rates are averages--individual events occur effectively randomly--can't predict next one based on average rate

Good news:

- over shorter timescales, extinction threat is very unlikely

  here: "short" = up to millions of years
- There has not been any evidence of anyone being killed by a meteorite.

  Although there are stories…
- But, there is evidence of people being hit!

Ann Elizabeth Hodges (Sylacauga, Alabama)

Nov 30th, 1954 2:46 pm, Ann was dozing on the couch, when a meteorite (8.5 lbs) crashed through the roof, bounced off a radio, and hit her on the side!

Mbale meteorite Uganda, 1992

Meteorite broke into many pieces, a small one of which (3 grams) hit a tree, then a young boy in the head.

http://home.wxs.nl/~terkuile/meteorites/mbale/mbale.html

Tunguska, Siberia: June 30, 1908

Estimated ~50 meters across meteoroid

Exploded 5-10 km above the surface

Blast energy ~15 MT

(Megatons TNT)

No confirmed impact crater

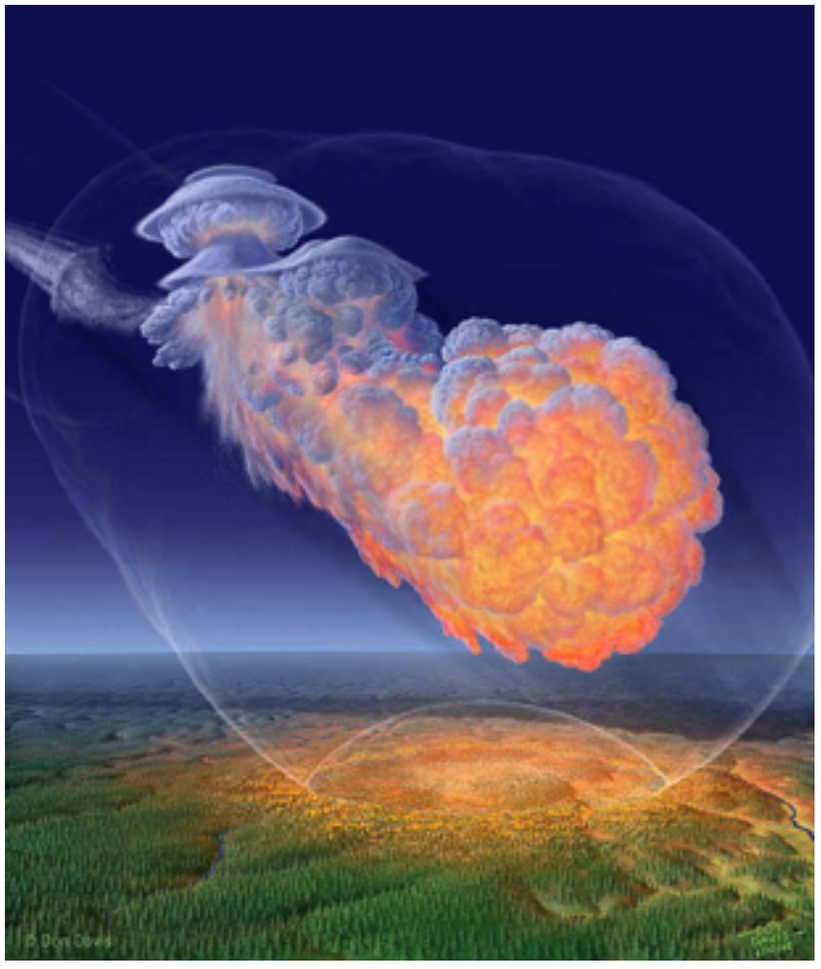
Location of the Tunguska impact

The meteor, which was an estimated sixty yards across, never actually touched down. The force of its entry—the compression and superheating of the air beneath it—caused it to explode some twenty-five thousand feet above the ground

There was a detonation with the combustive power of 10-20 megatons.

If the meteor had struck just five hours later, it would have exploded over St. Petersburg and annihilated every living thing in that glorious, baroque city

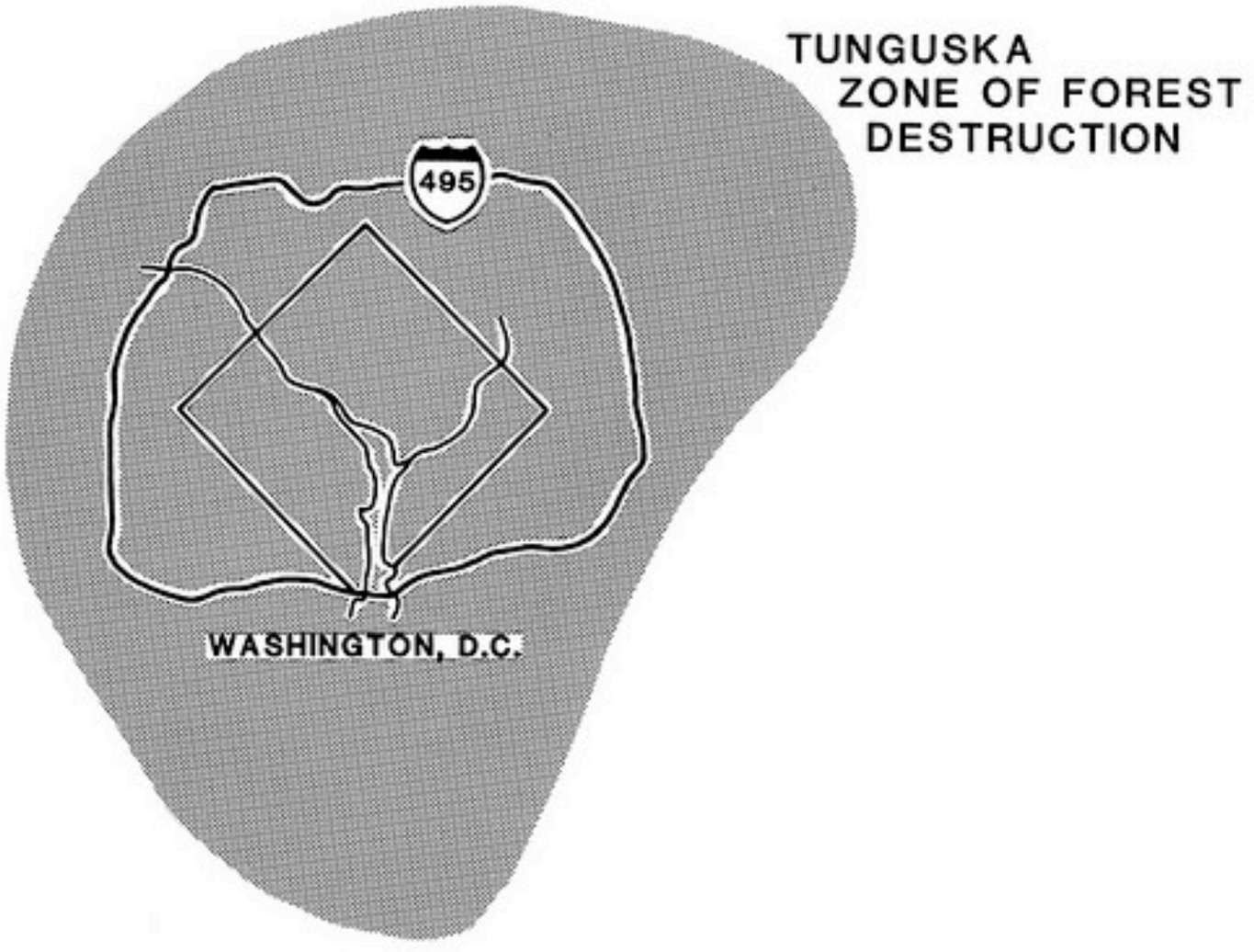
Artist's conception of Tunguska air blast



near Tunguska Ground Zero
19 years (!) after impact

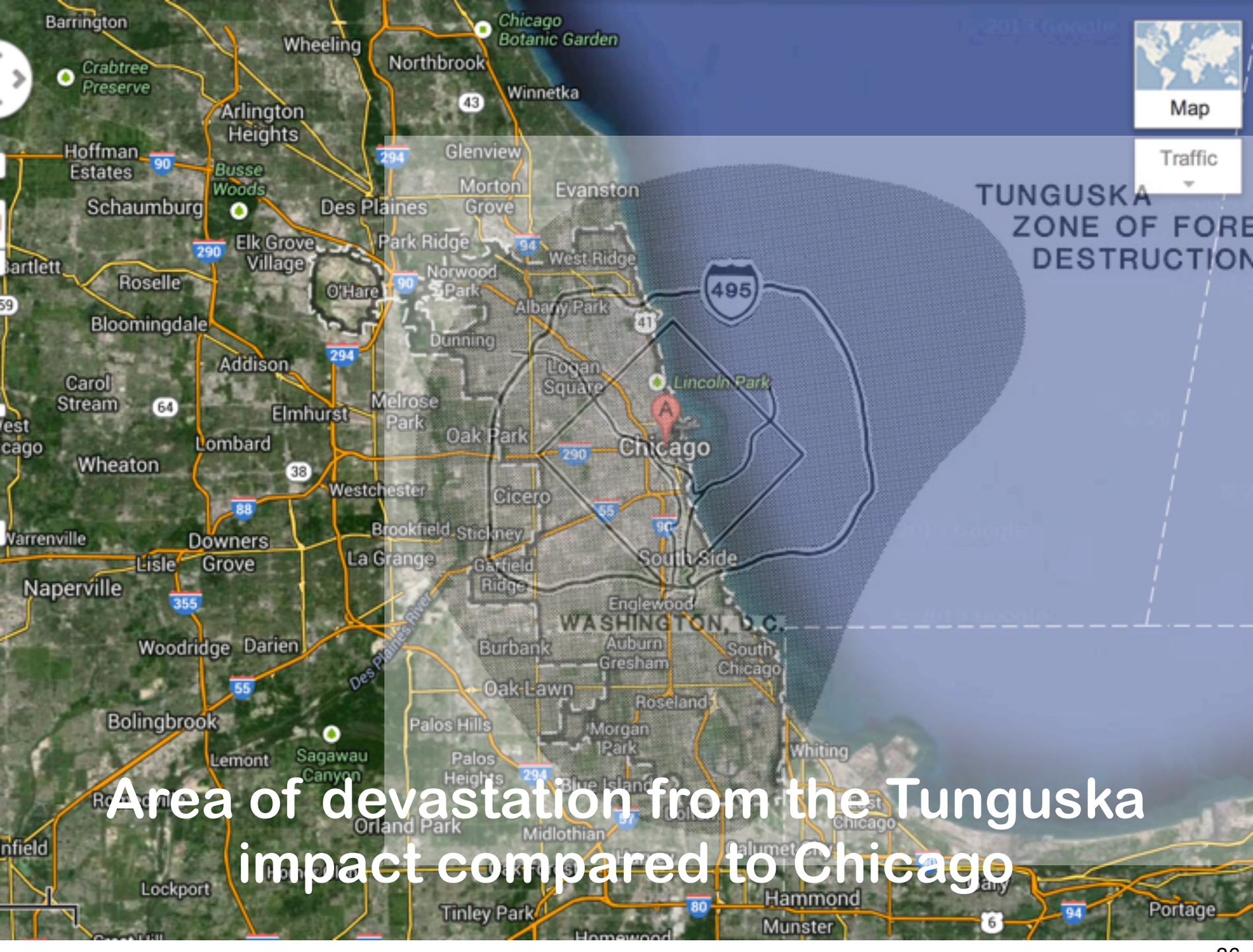
The explosion leveled 2,150 square km of forest - about 80 million trees!
Trees lay in radial ("spokes") pattern centered on ground zero

A group of herders camped 30km the blast site related they heard a great deal of noise and saw the forest burning around them, much of it devastated
One older man at about this distance was reportedly blown about forty feet into a tree, causing a compound fracture of his arm.
Hundreds of the herders' reindeer, in the general area around ground zero, were killed.
The first recorded expedition arrived at the scene more than a decade after the event.
To the explorers' surprise, no crater was to be found. There was instead around ground zero a vast zone (8 kilometers across) of trees scorched and devoid of branches, but standing upright. Those farther away had been partly scorched and knocked down in a direction away from the centre.



Area of devastation from the Tunguska impact compared to Washington DC

The Tunguska event flattened 2,150 square miles of trees
Asteroid strikes this size probably happen about once every hundred years. However, this is just an average. Just because we got hit once doesn't mean we're safe for another hundred years. Indeed, there was another Tunguska-class strike in the Brazilian rain forest on 13 August 1930



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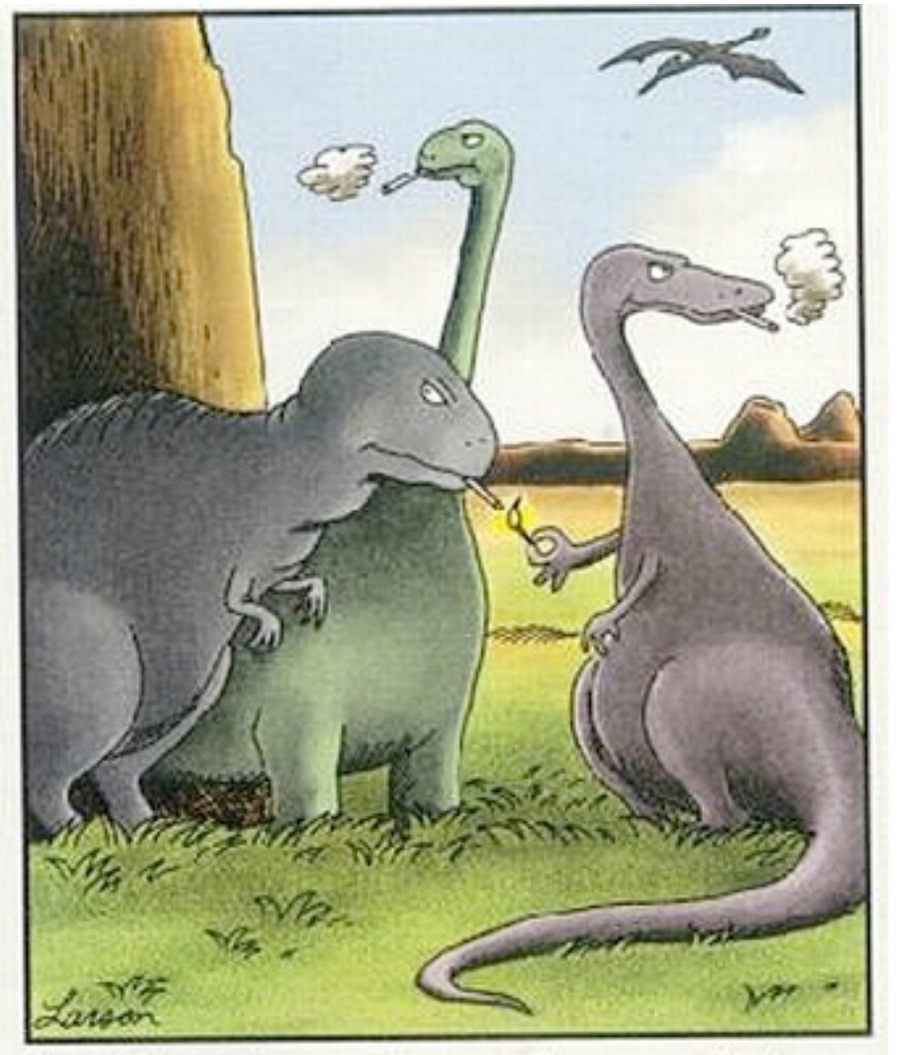
What Killed the Dinosaurs?

65 million years ago, 75-95% of all the species on Earth disappeared

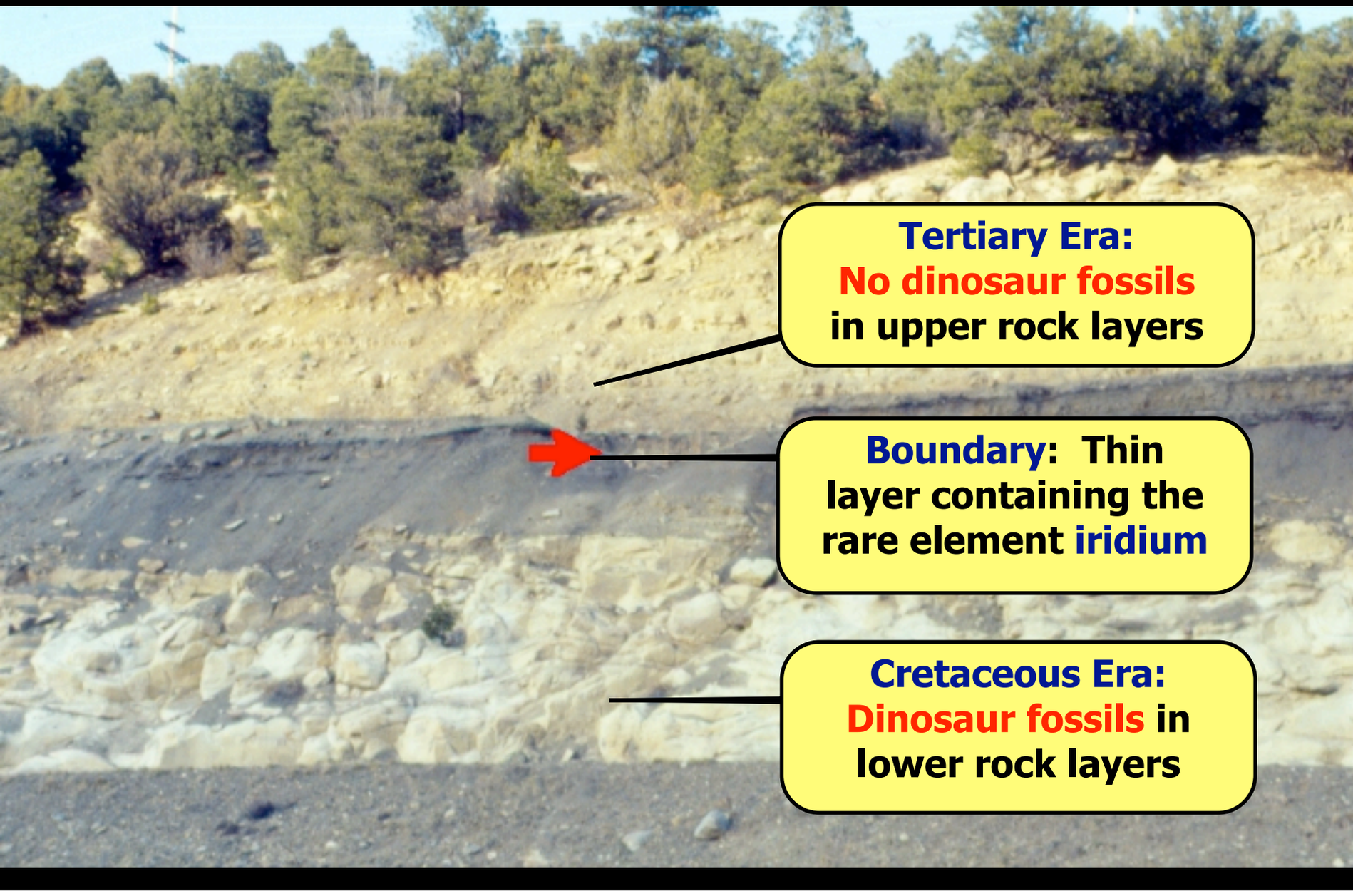
2nd largest known mass extinction in geological history

Was an asteroid collision to blame?



The real reason dinosaurs became extinct

Cretaceous-Tertiary (KT) Boundary



layer containing iridium also enriched in carbon - possibly soot from global fires

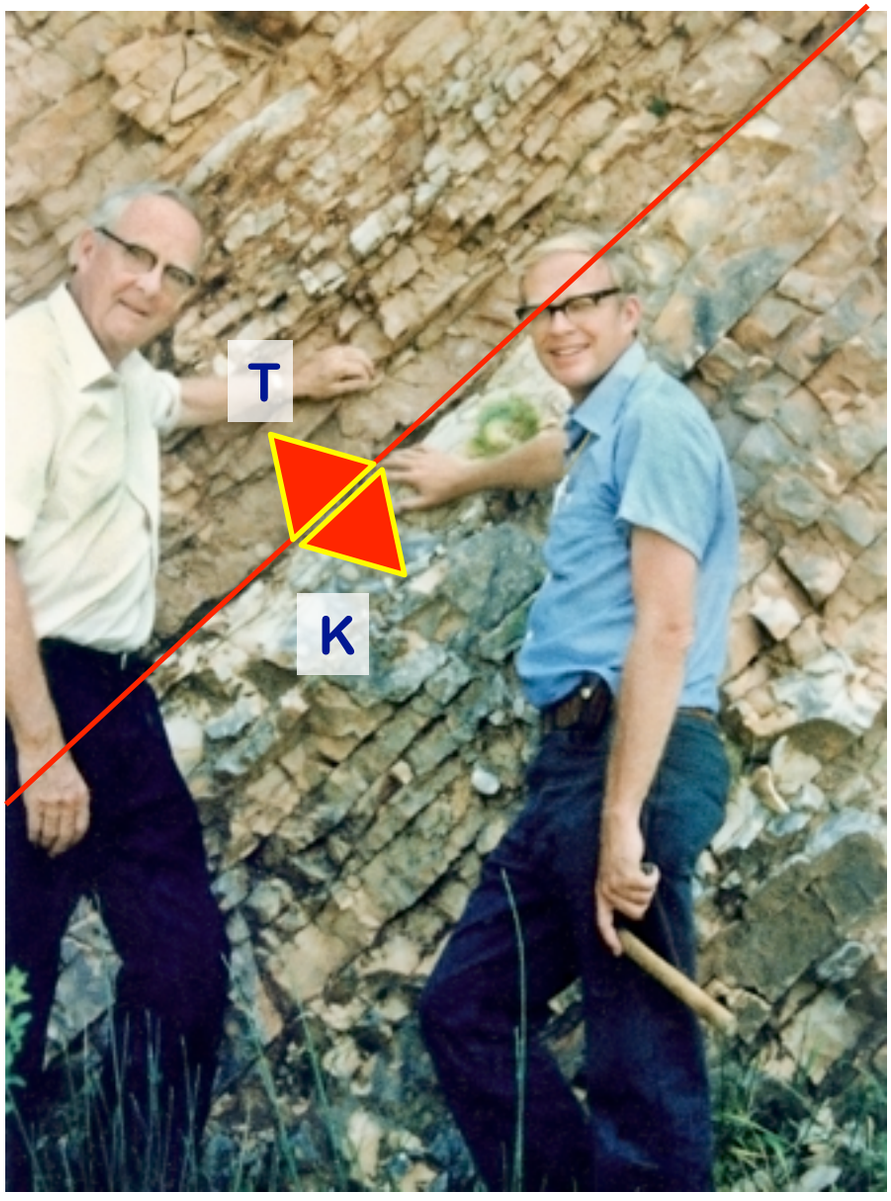
Iridium: Evidence of an Impact

In 1980, a worldwide layer of iridium was found

Laid down 65 million years ago

Iridium is an element that is very rare in Earth rocks, but is often found in meteorites!

The iridium layer - evidence of an impact 65 million years ago



Luis and Walter Alvarez: Dino CSI

http://newscenter.lbl.gov/feature-stories/2010/03/09/alvarez-theory-on-dinosaur/

K/T Boundary: Iridium Layer

http://www.nsf.gov/news/news_images.jsp?cntn_id=116480&org=NSF

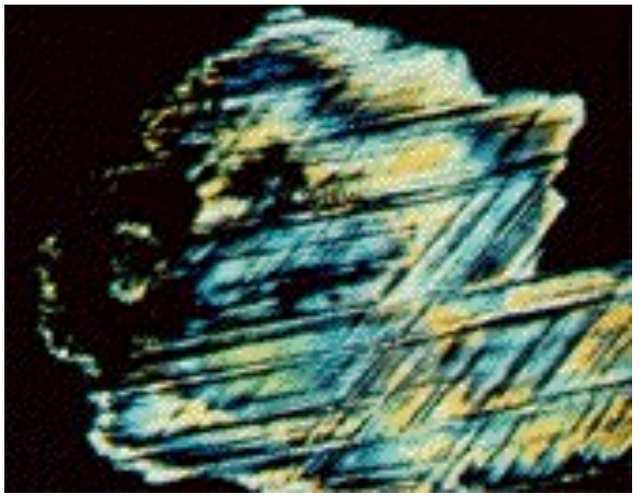
Other meteorite evidence

Spherules

- Melt droplets formed in the impact
- Dispersed globally

Shocked quartz

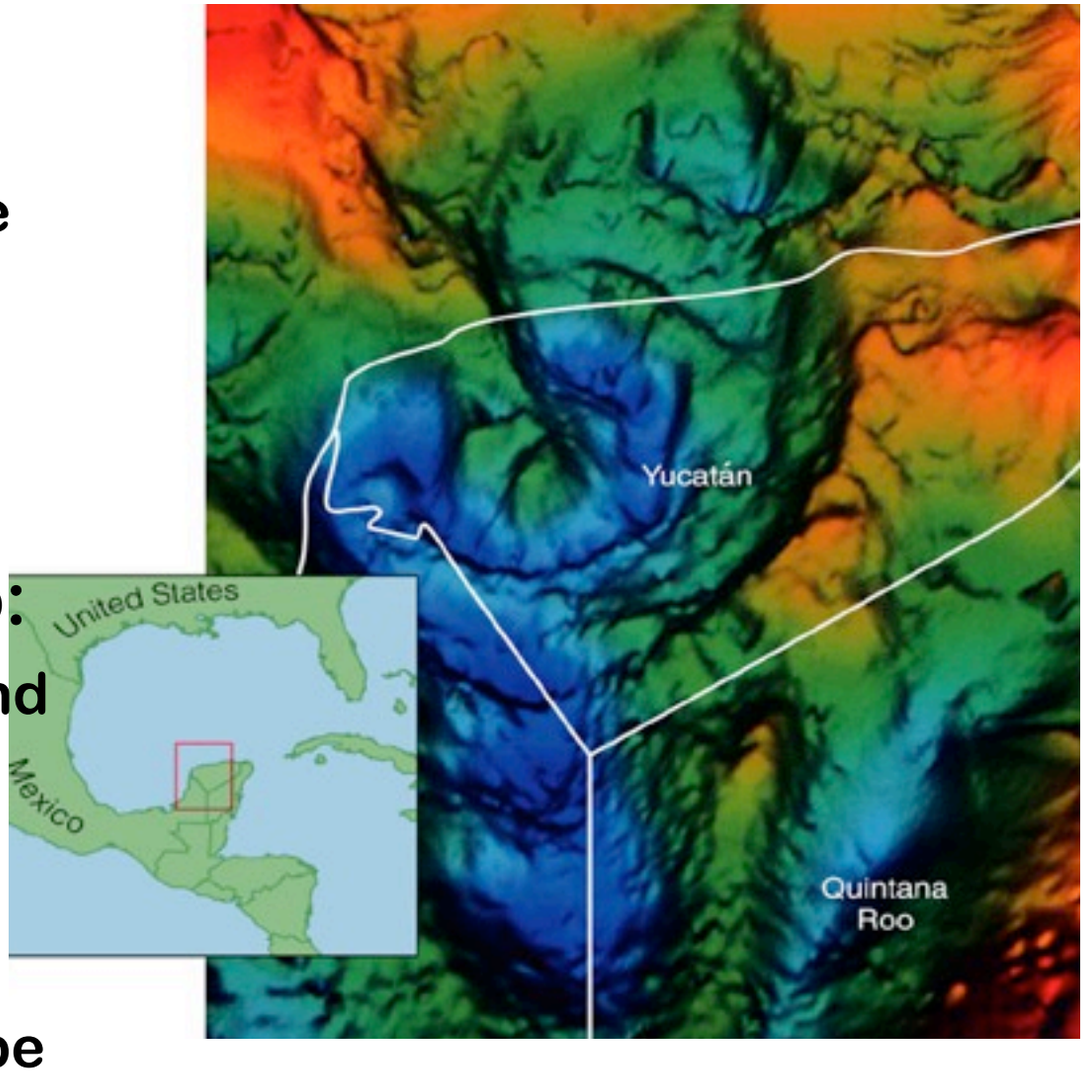
- Requires high pressures
- Often found near impact sites



Impact Site: The Chicxulub Crater

200 km diameter crater

- under the northwest corner of the Yucatan peninsula of Mexico
- centered on village of Chicxulub



beneath ground zero:

- glass = flash melted sand
- radioactive dating:
  65 million years old

From crater size:

- Impactor estimated to be 10 km across

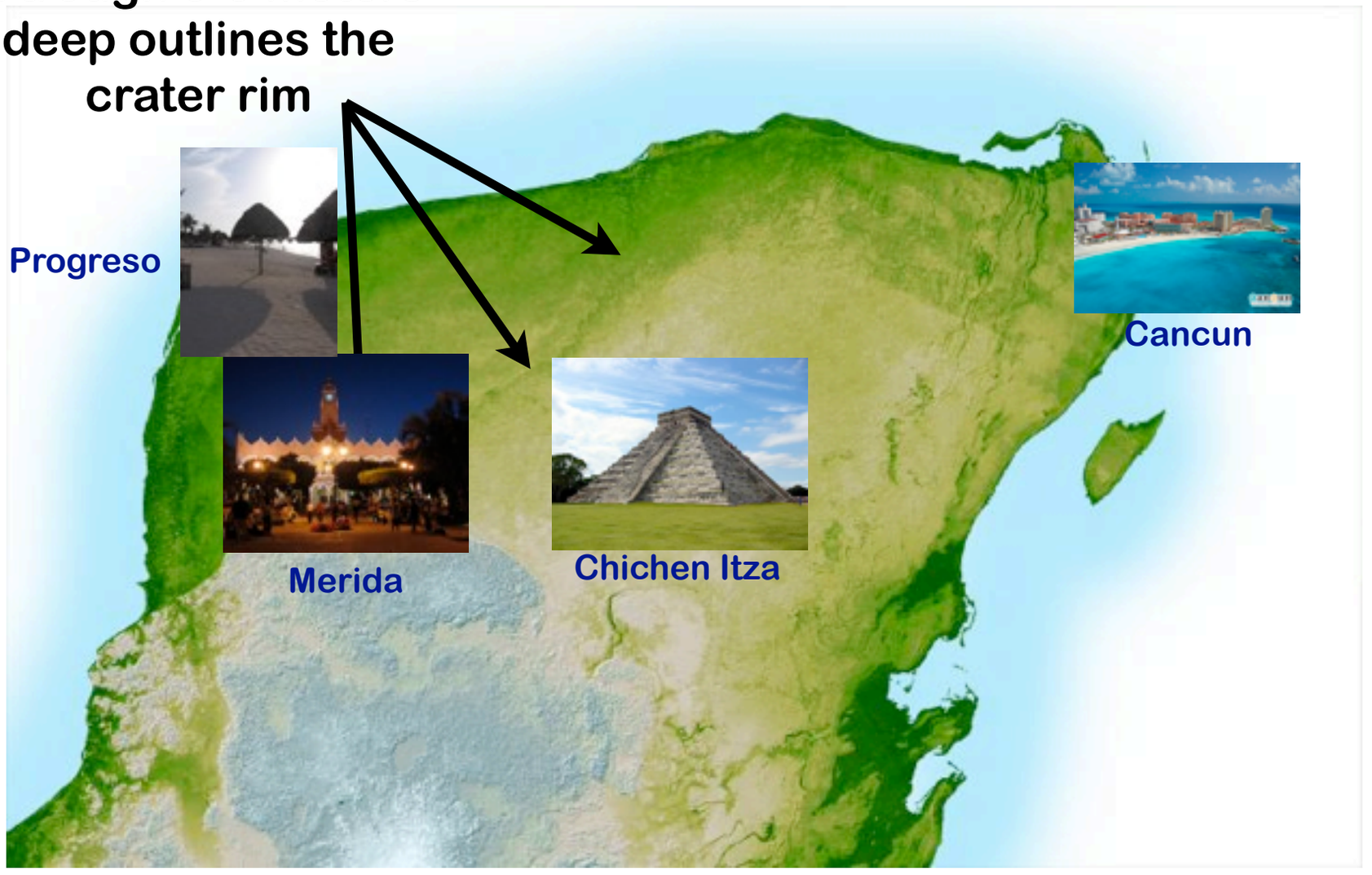
Map of variable gravity strength; white lines show the outlines of land masses and the Mexican regions.

Impactor estimated to be 10 km (6 miles) in diameter

Thousands of times more powerful than the entire world's nuclear arsenal!

100 times more powerful than the largest known volcanic eruption

A trough 3-5 meters deep outlines the crater rim



Today, the crater has <u>almost</u> completely eroded away

The Hammer of Doom

Likely KT impactor:

- Diameter: 10 km
- Composition: Rock

  though still not known if impactor was asteroid or comet
- Mass: 1.3 trillion tons
- Impact speed: 20 km/s

  = 45,000 mph

Impact!

- Punches a hole in the atmosphere
- Send large amounts of debris 100 km up
  - 10 trillion tons of material!
  - Debris rains back down around Earth
- If asteroid hits ocean, water recovering crater floor vaporizes to steam

Impact lofts debris to fall back to Earth

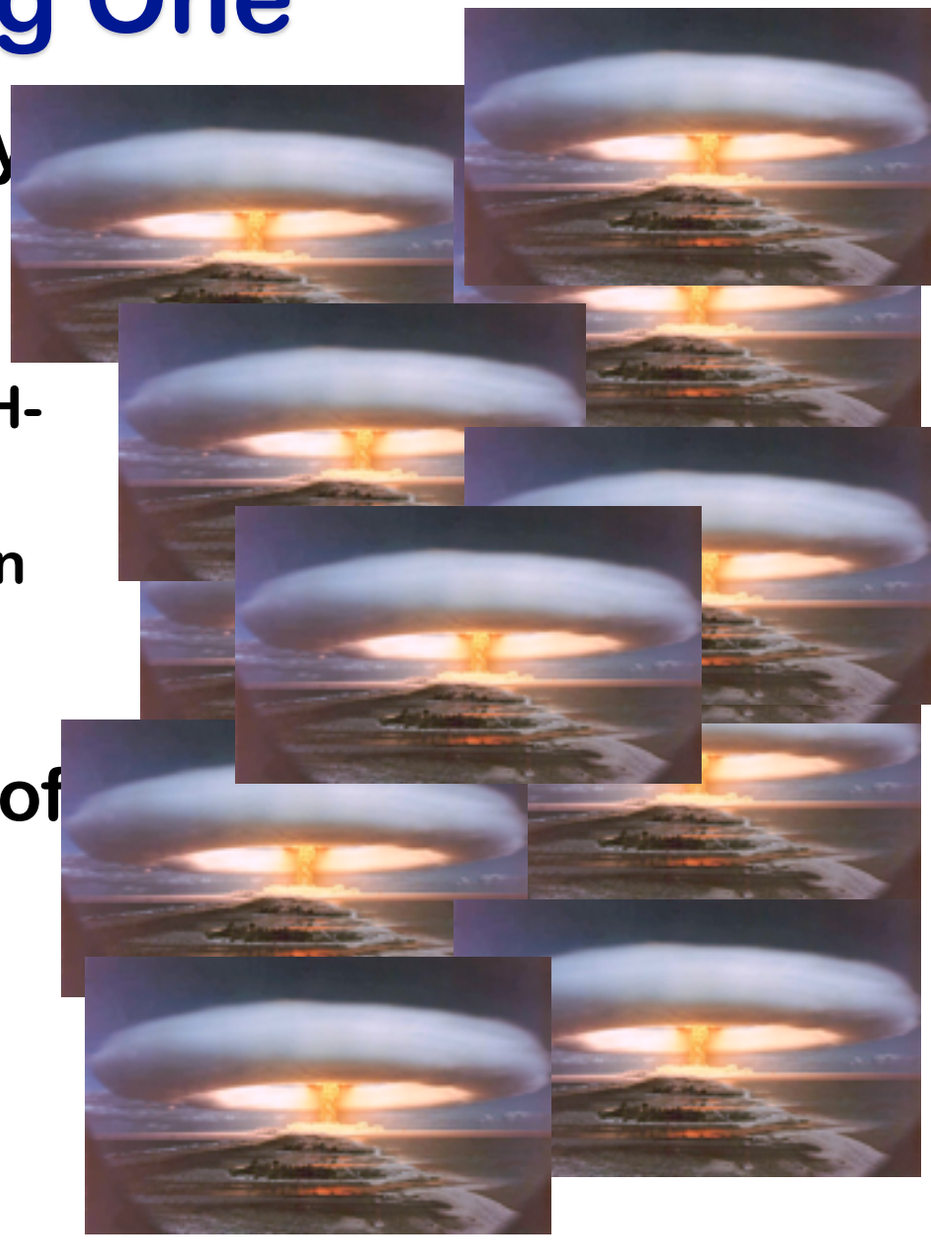
On its way to the impact, the asteroid pushes aside the air in front of it creating a hole in the atmosphere. The atmosphere above the impact site is removed for several tens of seconds. Before the surrounding air can rush back in to fill the gap, material from the impact: vaporized asteroid, crustal material, and ocean water (if it lands in the ocean), escapes through the hole and follows a ballistic flight back down.
Within two minutes after impact, about 10^5 cubic kilometers of ejecta (10^{13} tons) is lofted to about 100 kilometers. If the asteroid hits the ocean, the surrounding water returning over the the hot crater floor is vaporized (a large enough impact will break through to the hot lithosphere), sending more water vapor into the air as well as causing huge steam explosions that greatly compound the effect of the initial impact explosion.

The Big One

Impact Energy: capability to do damage
6×10^7 Megatons of TNT

- Equivalent to about a million H-bombs!
- Thousands of times more than the world's entire nuclear arsenal

Produces an earthquake of 12.4 magnitude

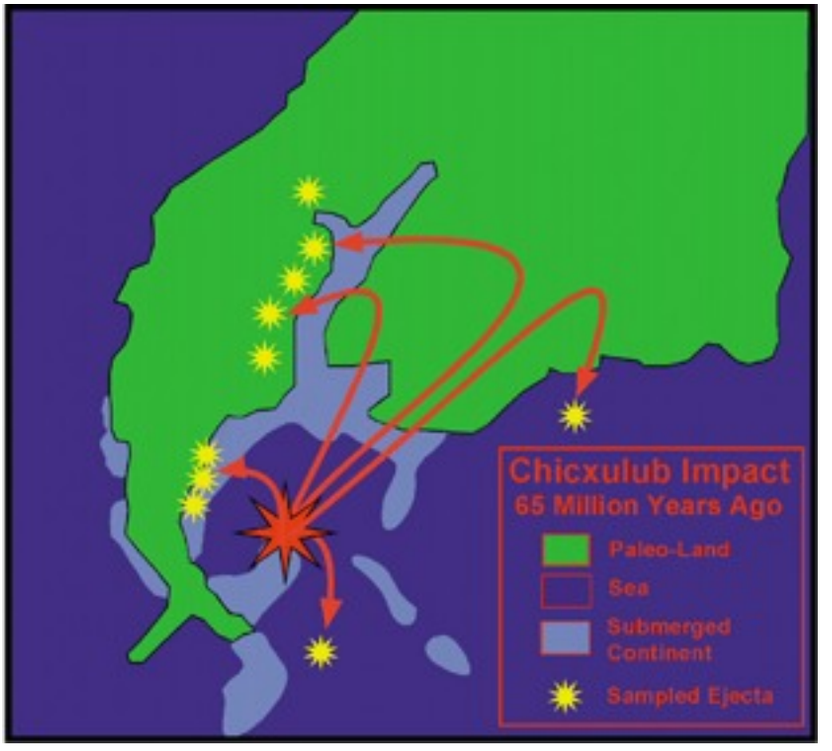


If the asteroid hits the ocean, it will create a tsunami

oceans cover about 75% of the Earth's surface, so it is likely the asteroid will hit an ocean
The amount of water in the ocean is nowhere near large enough to "cushion" the asteroid.
The asteroid will push the water aside and hit the ocean floor to create a large crater. The water pushed aside will form a huge tidal wave, a tsunami.

Chicxulub Impact

- At the time, shallow seas covered what is now the northern Yucatan Peninsula
- Tsunamis radiated out across the Gulf of Mexico
- Slammed into Central and North America



At the time, shallow seas covered what is now the northern yucatan peninsula
Tsunamis radiated out across the gulf of mexico

Deep Impact Again