Constructing the Solar System: A Smashing Success

Impact Earth:
Chicxulub and other terrestrial impacts

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Compton Lecture Series
Autumn 2012

Compton Lecture Series Schedule

1. 10/06/12 A Star is Born
2. 10/13/12 Making Planetesimals: The building blocks of planets
3. 10/20/12 *Guest Lecturer: Mac Cathles*
4. 10/27/12 Asteroids and Meteorites: Our eyes in the early Solar System
5. 11/03/12 Building the Planets
6. 11/10/12 When Asteroids Collide
7. 11/17/12 Making Things Hot: The thermal effects of collisions

   11/24/12 No lecture: Thanksgiving weekend
8. 12/01/12 Constructing the Moon

   12/08/12 No lecture: Physics with a Bang!
9. 12/15/12 Impact Earth: Chicxulub and other terrestrial impacts

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Part 1:

Lecture series summary ...

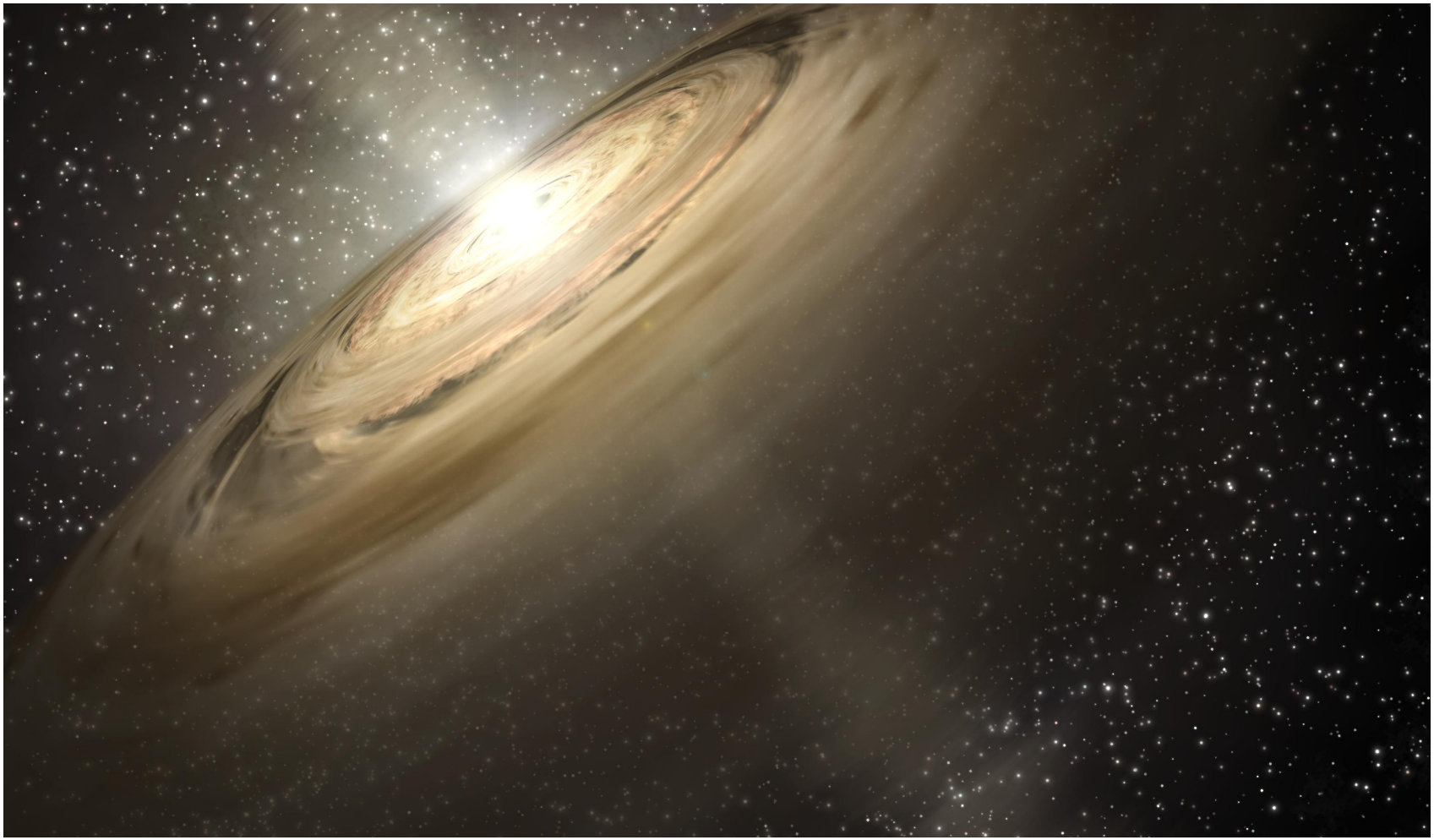

Image courtesy of NASA/JPL-Caltech

... A Smashing Success!

Cloud collapse

- Started from a nebula
- Small overdensity started contraction
- Cloud collapsed to form Sun

Carina Nebula

Image courtesy of NASA, ESA, N. Smith (University of California, Berkeley), and The Hubble Heritage Team (STScI/AURA)

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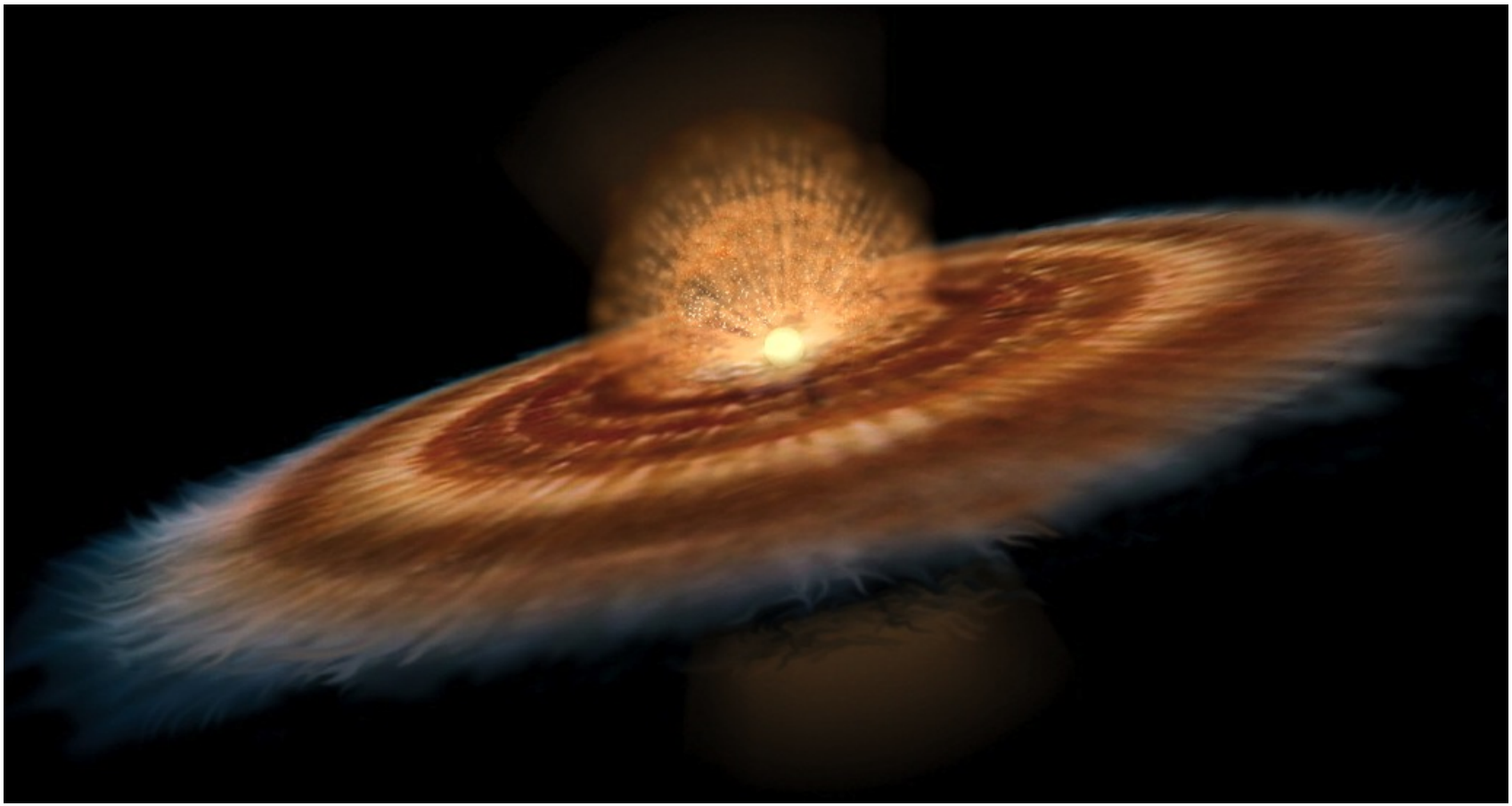
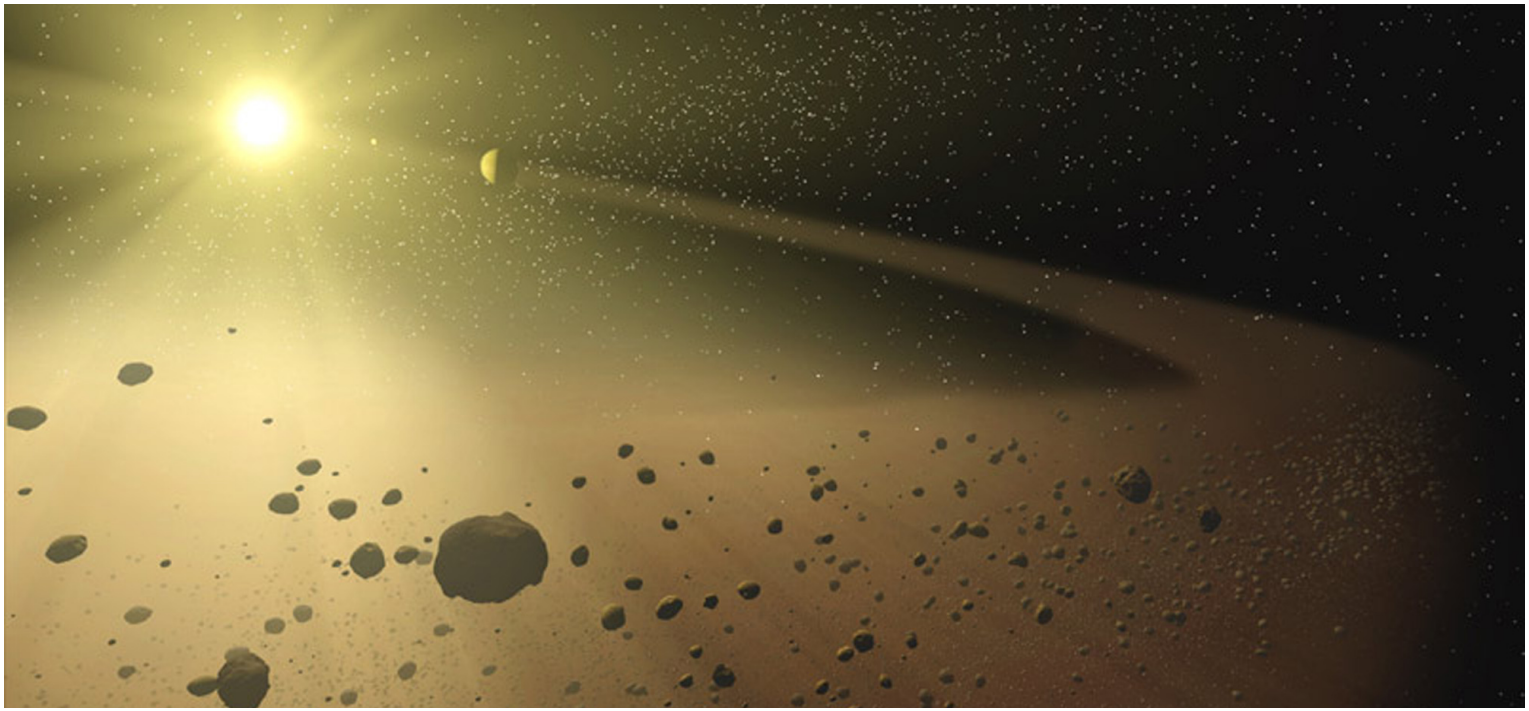


Image courtesy of Don Dixon/NASA

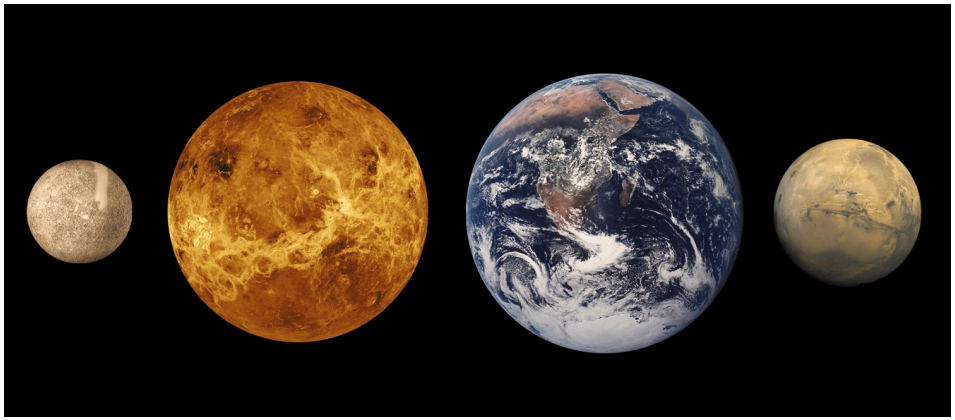
Planetesimals formed in the disk surrounding the Sun



Images courtesy of NASA/JPL-Caltech

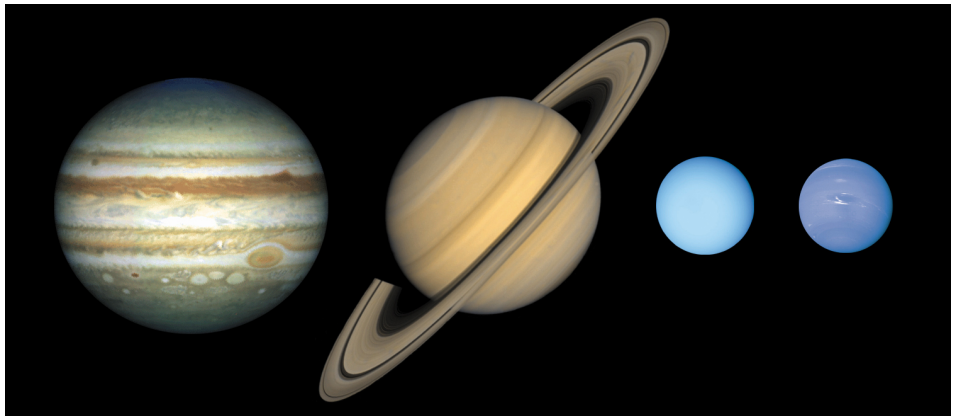
- Disk of gas and dust around the young Sun
- Low velocity collisions between dust particles
  - → Growth of meter-sized objects
- Collisions and/or gravitational instability
  - → Growth of planetesimals (km-scale)

Building the planets



- Further collisions between planetesimals
  - → Growth of terrestrial planets

- Extra mass and condensed ices at greater orbital distances
  - → Rapid growth of gas giants



Images courtesy of NASA

Moon formation

- Most likely scenario:
  - → Moon formed during collision between **Theia** and **Earth**

Image courtesy of NASA

Collisions were a vital process

- Collisions were vital for the growth of the planets and the formation of the Moon
- But, how else did collisions affect the Earth?

Image courtesy of Don Dixon/NASA

Part 2:

Paucity of Impacts Craters on Earth

Image courtesy of Shane Torgerson/Wikimedia Commons

Known impact craters on Earth

Why are there so few?

Image courtesy of Planetary and Space Science Centre, University of New Brunswick/NASA/Google

183 confirmed impact structures on Earth

Less craters on Earth than on other Solar System bodies

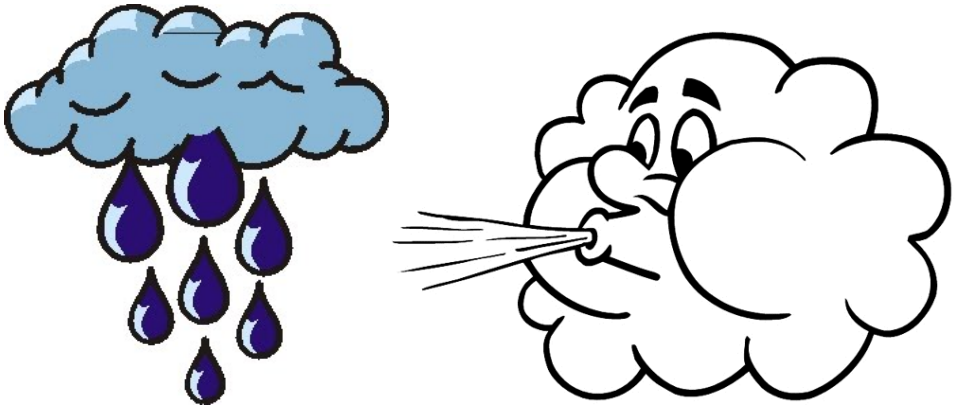
- Geologic processes remove craters over time
  - Weathering/erosion (wind/water)
  - Volcanism
  - Tectonics
- Atmosphere stops smaller projectiles from reaching surface
- Oceans prevent some craters from forming
- Selective searches — economic reasons

- The Moon? No!

Image courtesy of NASA

Image courtesy of Gregory H. Revera/Wikimedia Commons

Erosion



- Earth's atmosphere and water cycle unique among the planets
- Over time can remove surface evidence of craters
- Probably not a major effect

Volcanism

- Lava erupted from volcanoes can hide evidence of craters
- We can see this effect directly on Mars and the Moon
  - → Younger volcanic surfaces (e.g. Tharsis) exhibit fewer craters

Image courtesy of Getty Images/Tom Pfeiffer/VolcanoDiscovery

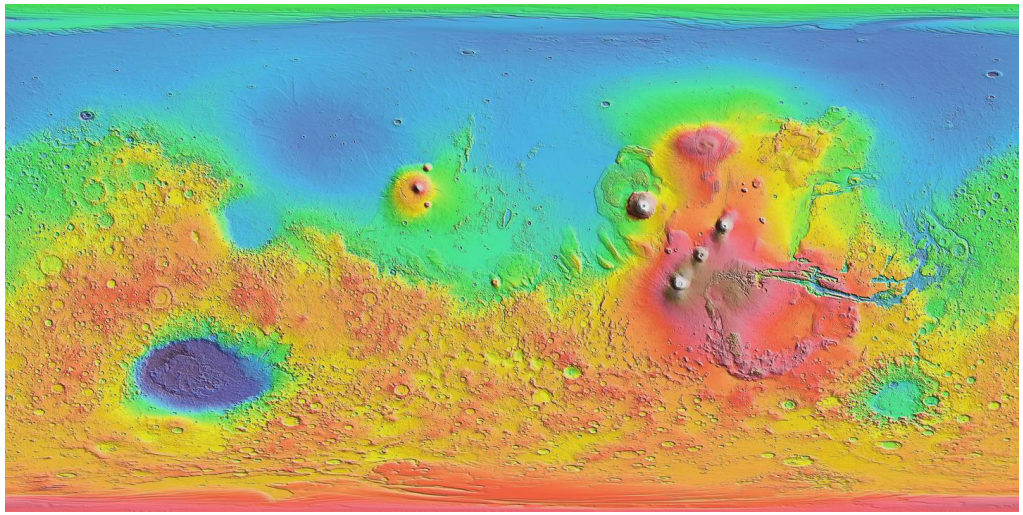


Image courtesy of NASA/MOLA Science Team

Tectonics

- Tectonic plates move around on the Earth's surface
- Older surfaces are recycled
- Only young craters are still visible
- Oldest sea floor is only ∼200 million years old

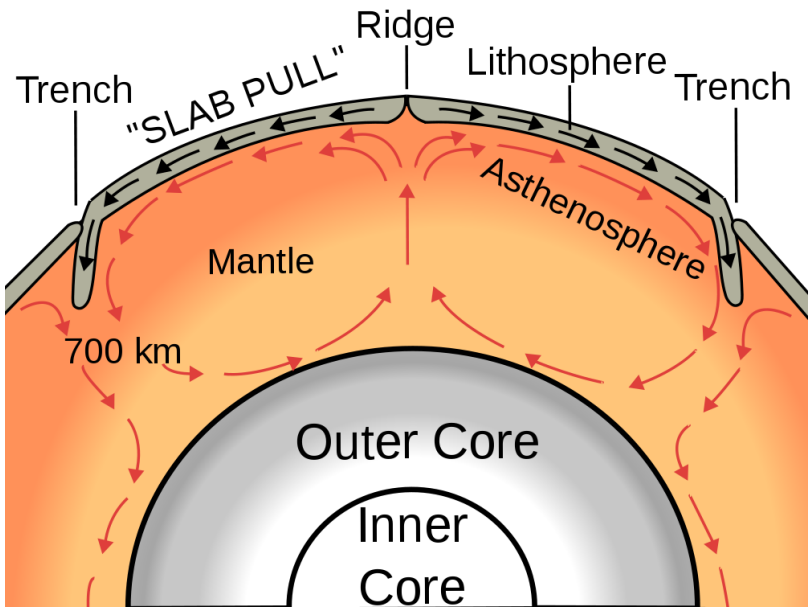


Image courtesy of NASA/USGS/Wikimedia Commons

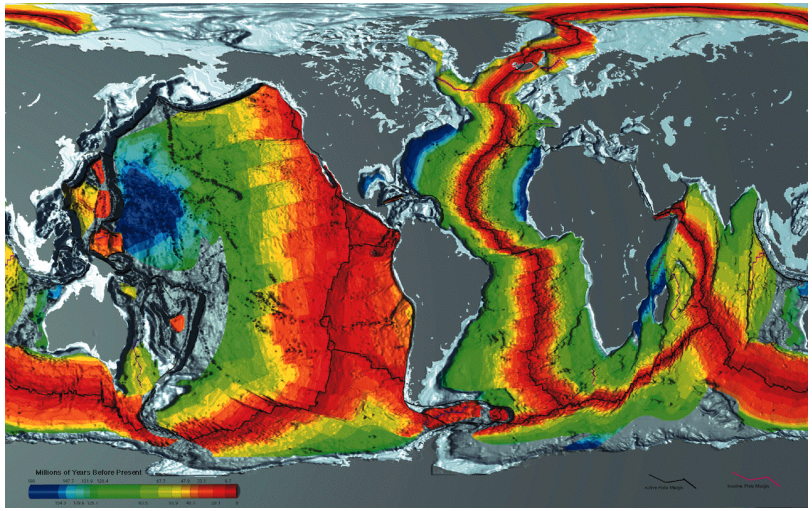


Image courtesy of NOAA

The atmosphere protects us from many smaller impacts

- Meteoroids are heated as the travel through the atmosphere
- But, what process causes this heating?

- Common misconception:
  - Friction with the air
- Actually:
  - High speed of meteoroid
  - Compresses air in front of it
    - → Ram pressure
  - Air is heated by pressure
  - This heats the meteoroid

Geminids meteor shower, two nights ago

Image courtesy of John Chumack

Image courtesy of Colin Legg

Tunguska event

Siberia, Russia: 7.14 am June 30, 1908

- Powerful explosion
- Believed to be an airburst from a meteoroid or comet
- 3 – 6 miles above the Earth's surface
- Flattened 80 million trees
- 830 square miles
- Largest impact event on Earth in recorded history
  - → 1000 times more powerful than Hiroshima

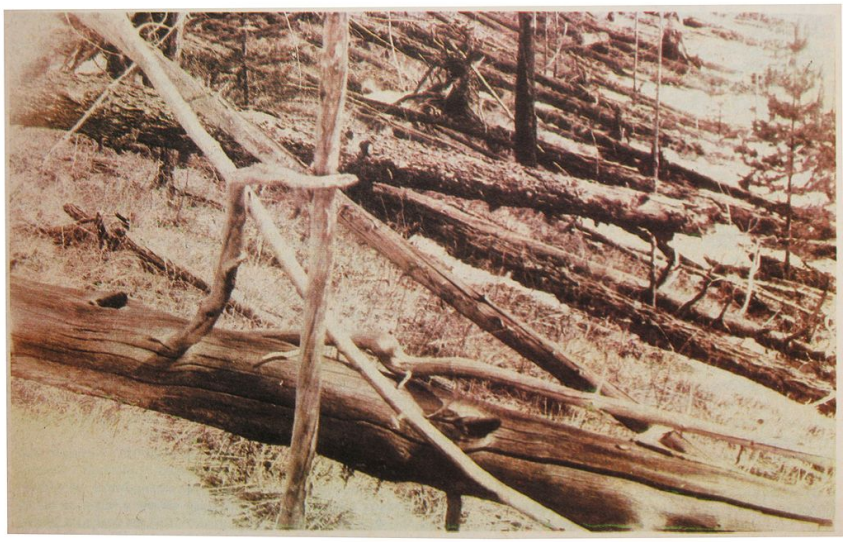


Image courtesy of Wikimdeia Commons/Vokrug Sveta (1931)

Oceans

- 70% surface covered by the oceans
- Only around 10% of craters thought to have formed in the oceans
  - 15–20 out of 183 known craters
  - Most have since moved onshore
  - Only 1 deep sea crater known
- What happens during an impact into the ocean?

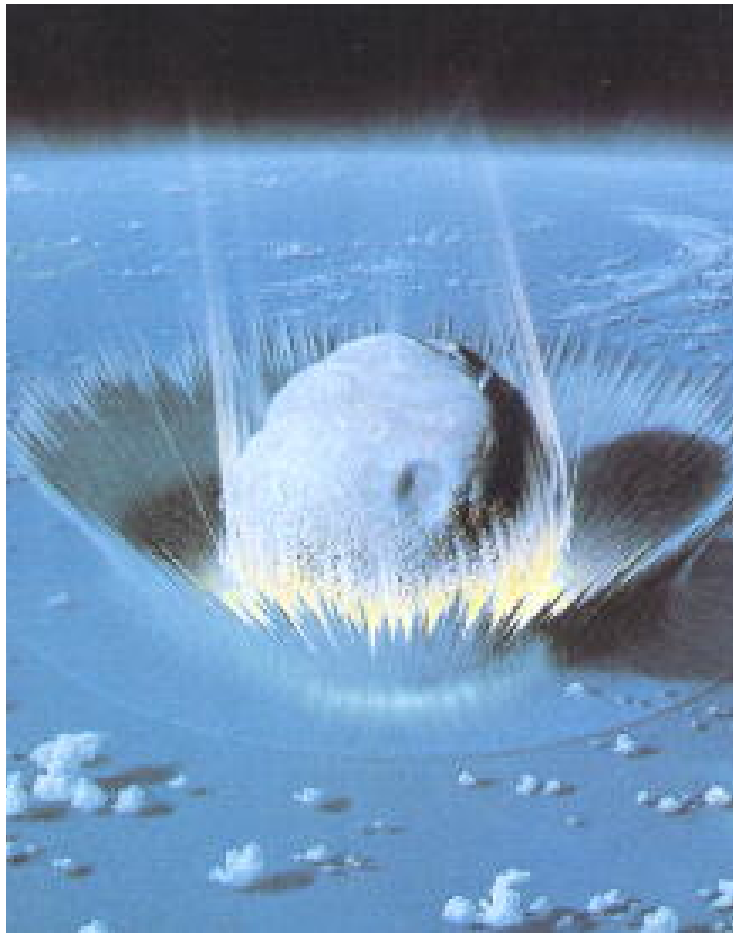
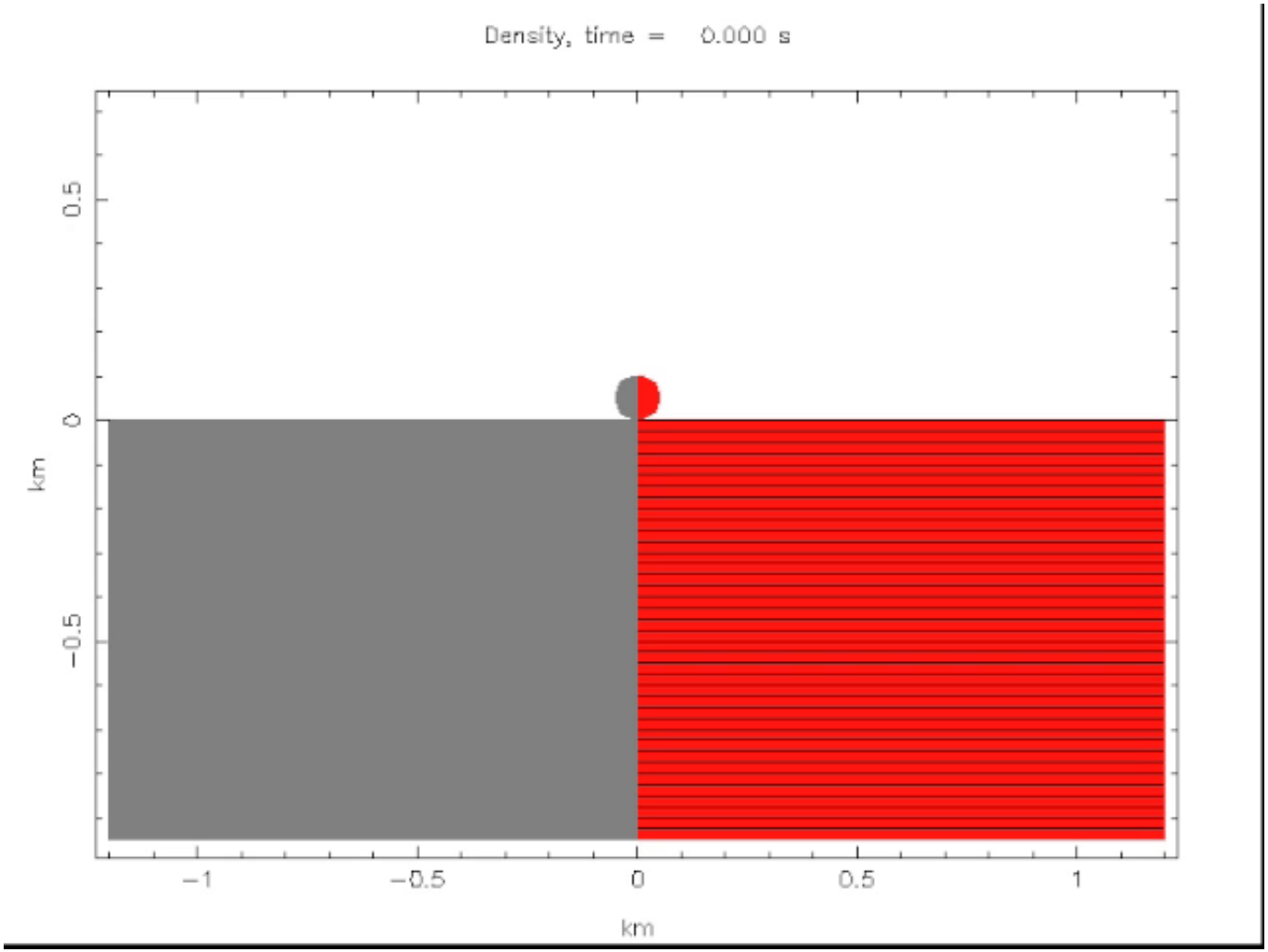


Image courtesy of Don Davis

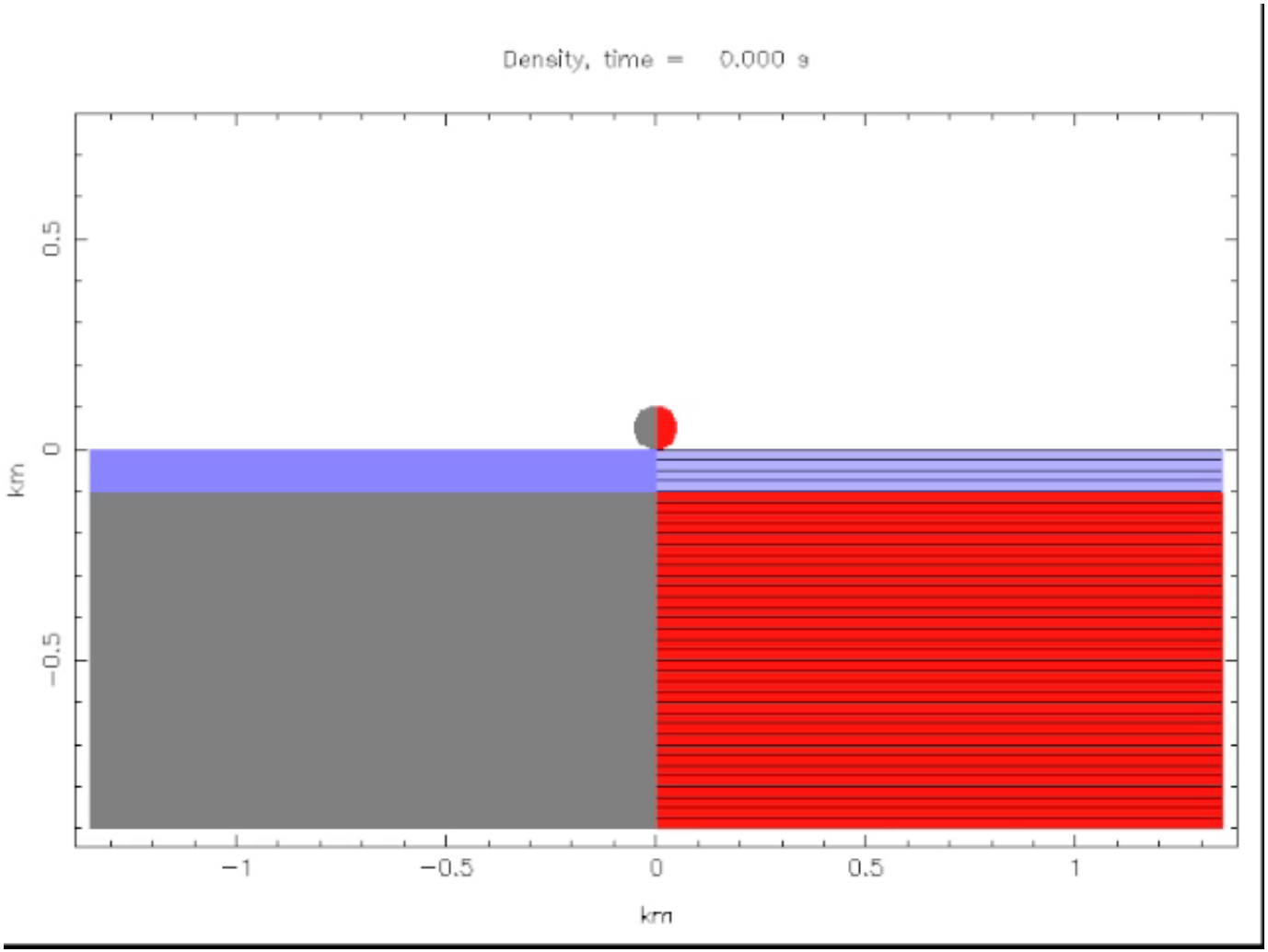
Impact on land
No water



This movie can be viewed online here:
http://geosci.uchicago.edu/~tdavison/comptonlectures/Lecture8_r0.mov

Impact in shallow sea

100 m water depth



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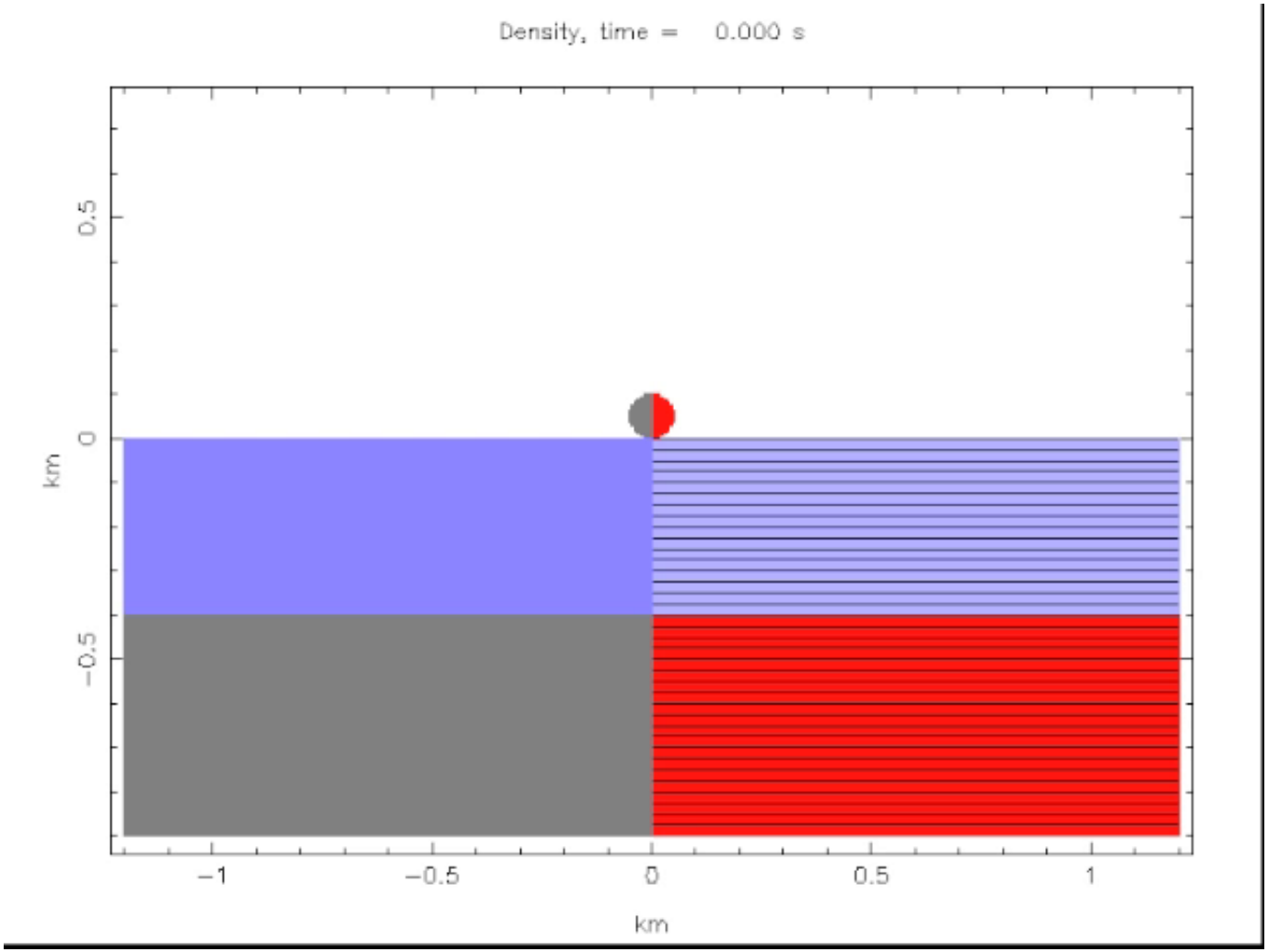
Impact into ocean

400 m water depth



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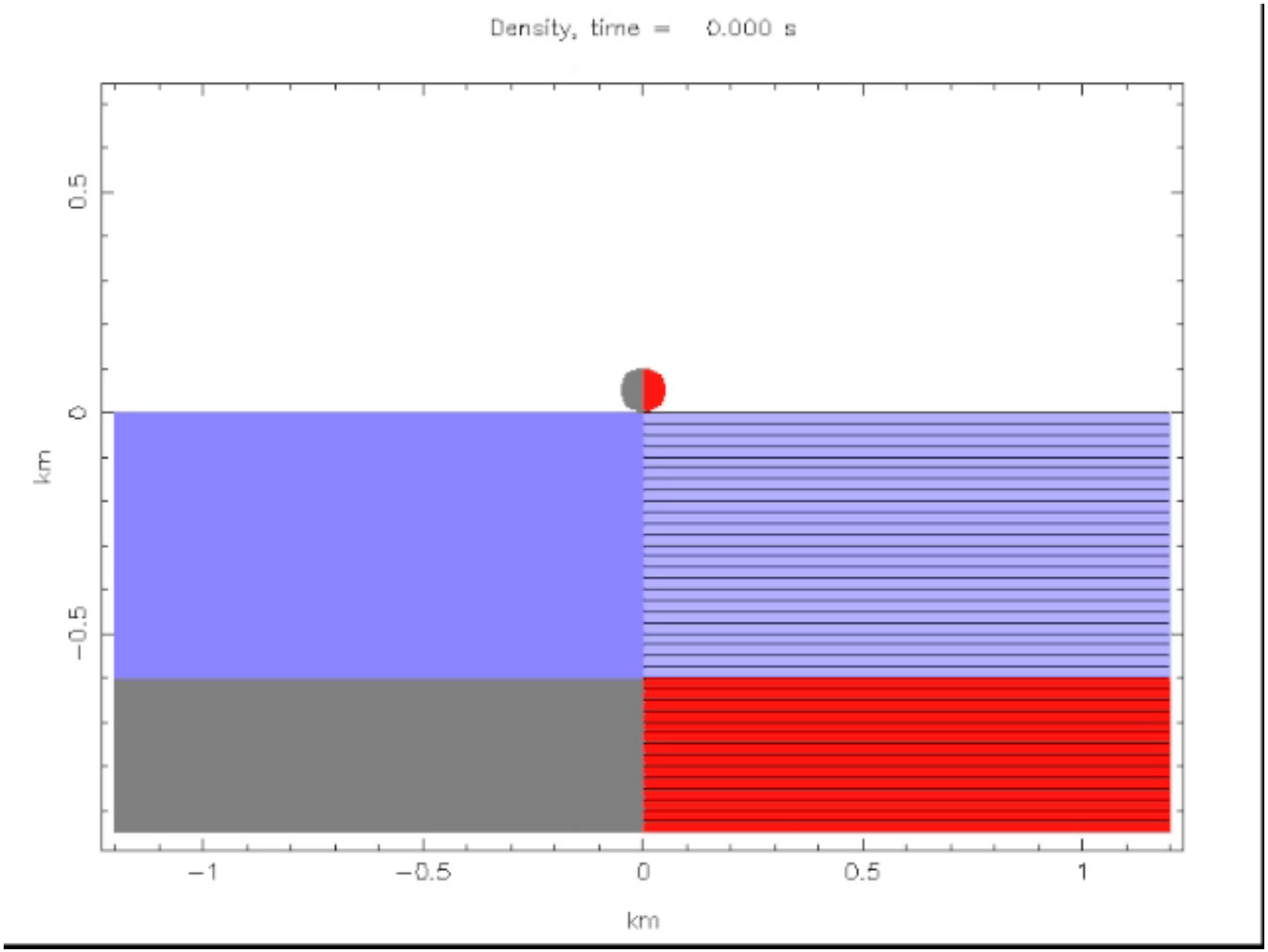
Impact into deep ocean

600 m water depth



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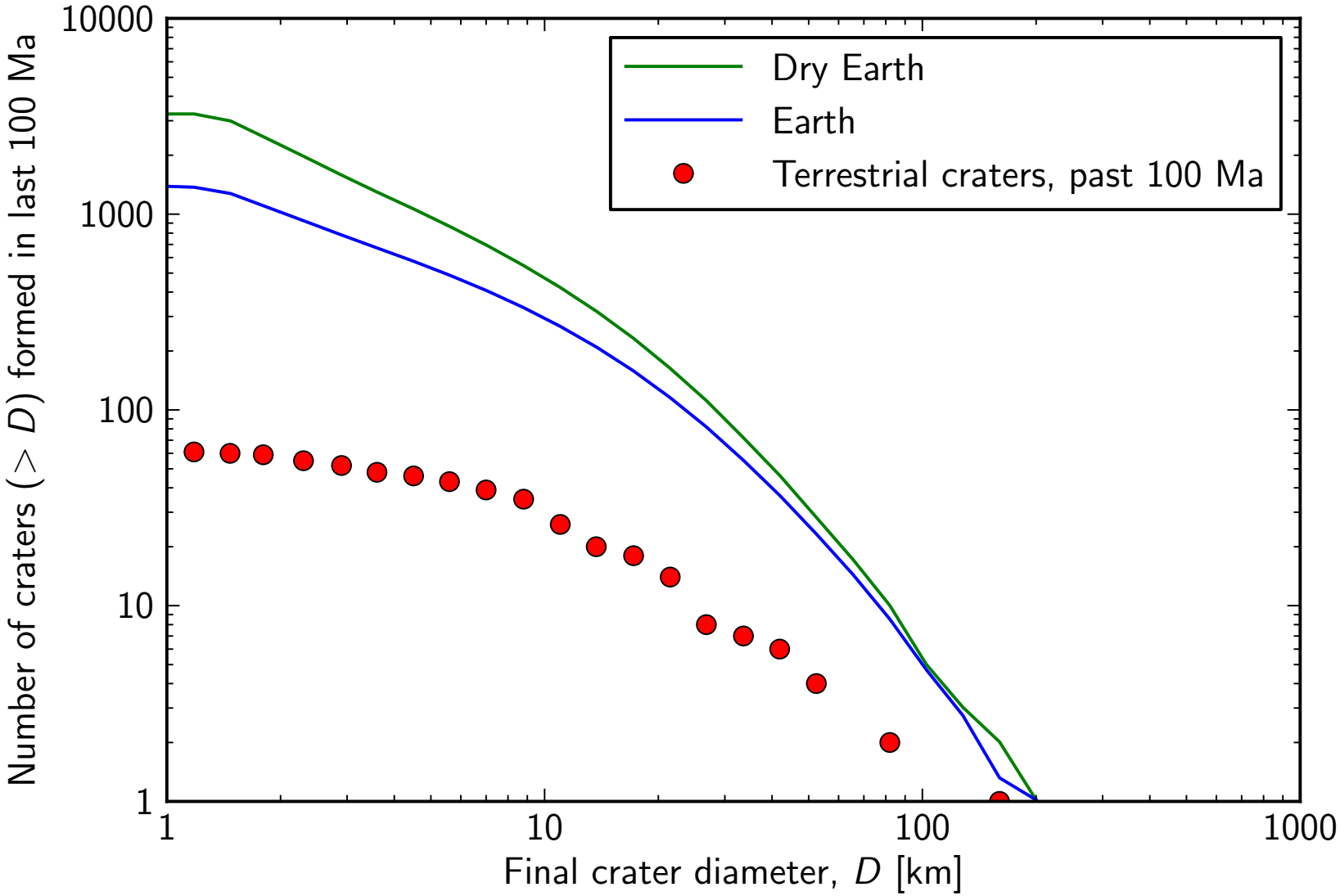
Filtering effect of oceans



Economic selectivity

- Most craters found in areas of intense geologic study
  - i.e. where the money is!
  - N. America, Europe and Australia

  → Many craters probably still to be found

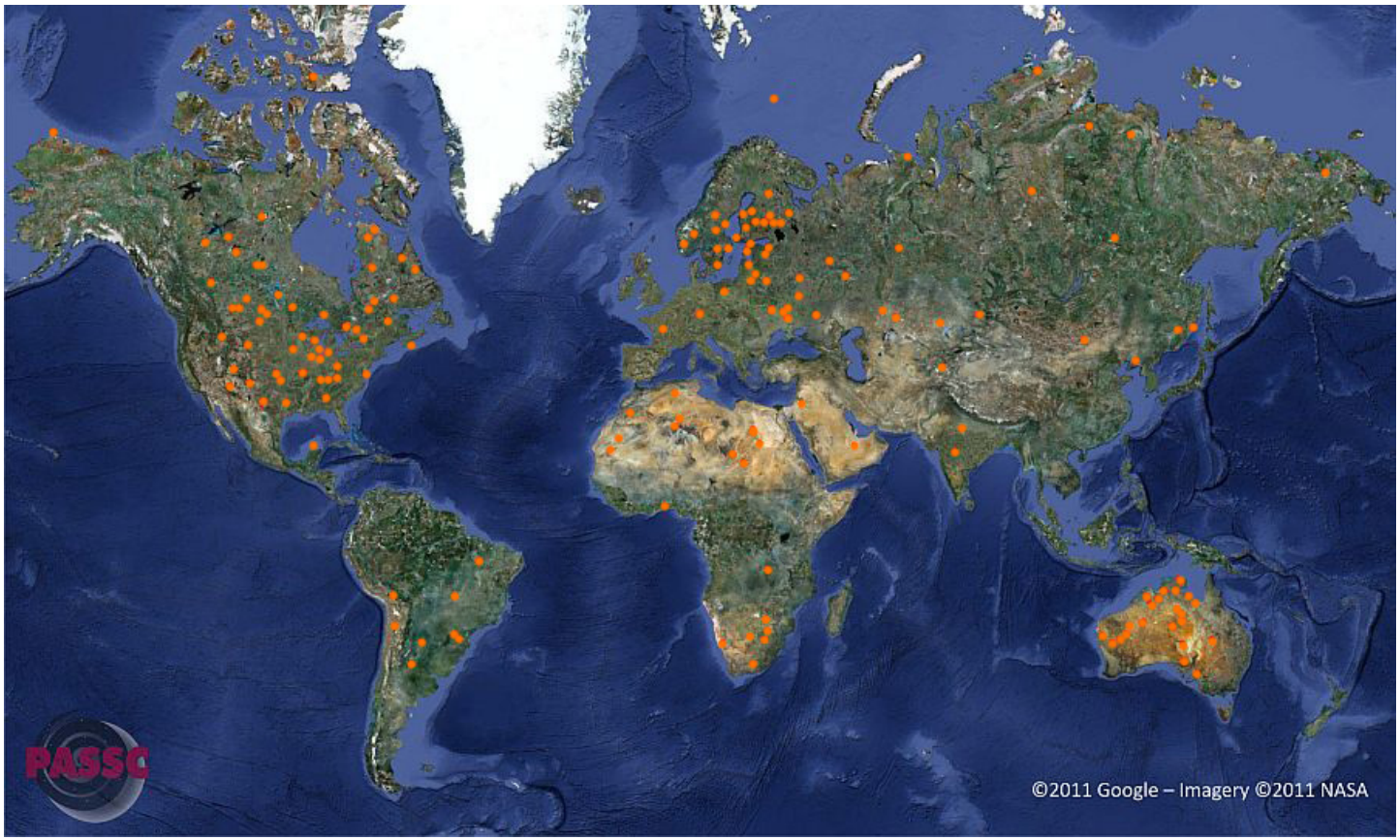


Image courtesy of Planetary and Space Science Centre, University of New Brunswick/NASA/Google

Part 3:

Impacts on Earth

Image courtesy of Don Dixon/NASA

Barringer Crater, Arizona (Meteor Crater)

1.2 km diameter; 50,000 years old

Image courtesy of Shane Torgerson/Wikimedia Commons

Carancas Crater, Peru

15 m diameter; Oct 15 2007

Image courtesy of P. Schultz, Brown University

Chesapeake Bay

85 km diameter; 35.5 million years old

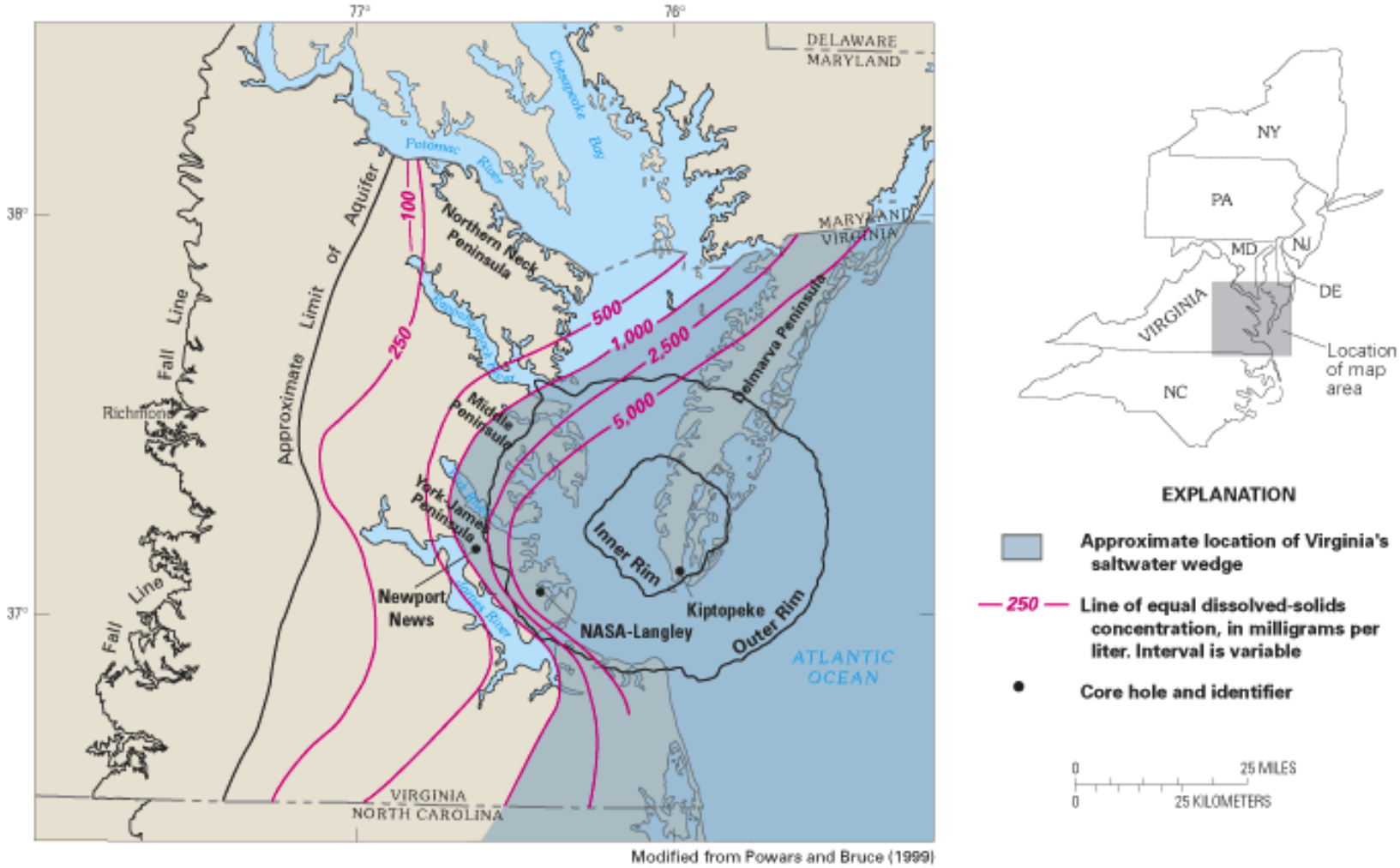


Image courtesy of Powers and Bruce (1999)/USGS

Manicouagan Crater, Canada

100 km diameter; 215 million years old

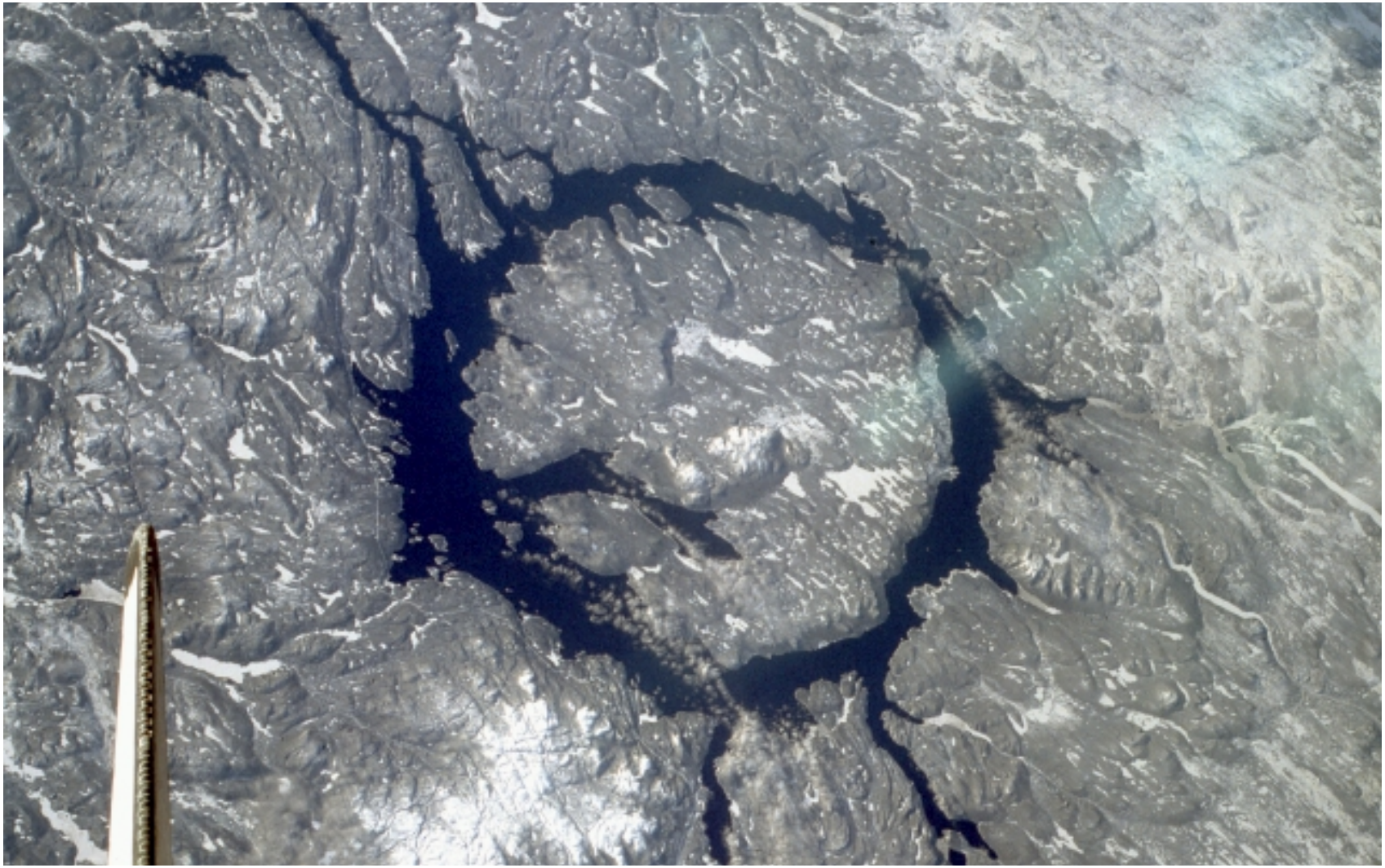


Image courtesy of Image Science & Analysis Laboratory, NASA Johnson Space Center

Part of a crater chain with Rochechouart and St. Martin craters

Vredefort Dome

250 – 300 km diameter; 2023 million years old

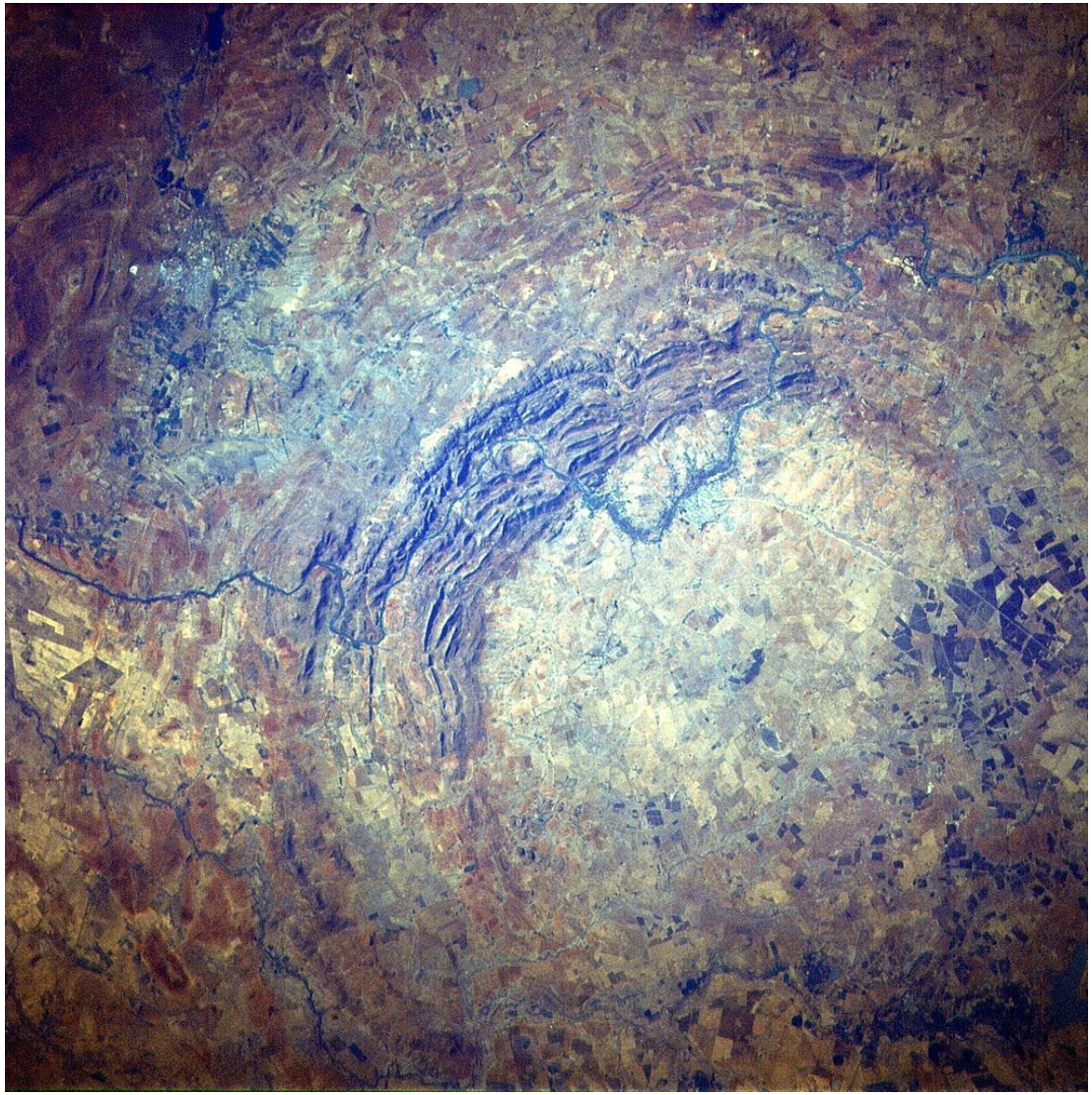


Image courtesy of NASA/Wikimedia Commons

Chicxulub

180 km diameter; 65.5 million years old

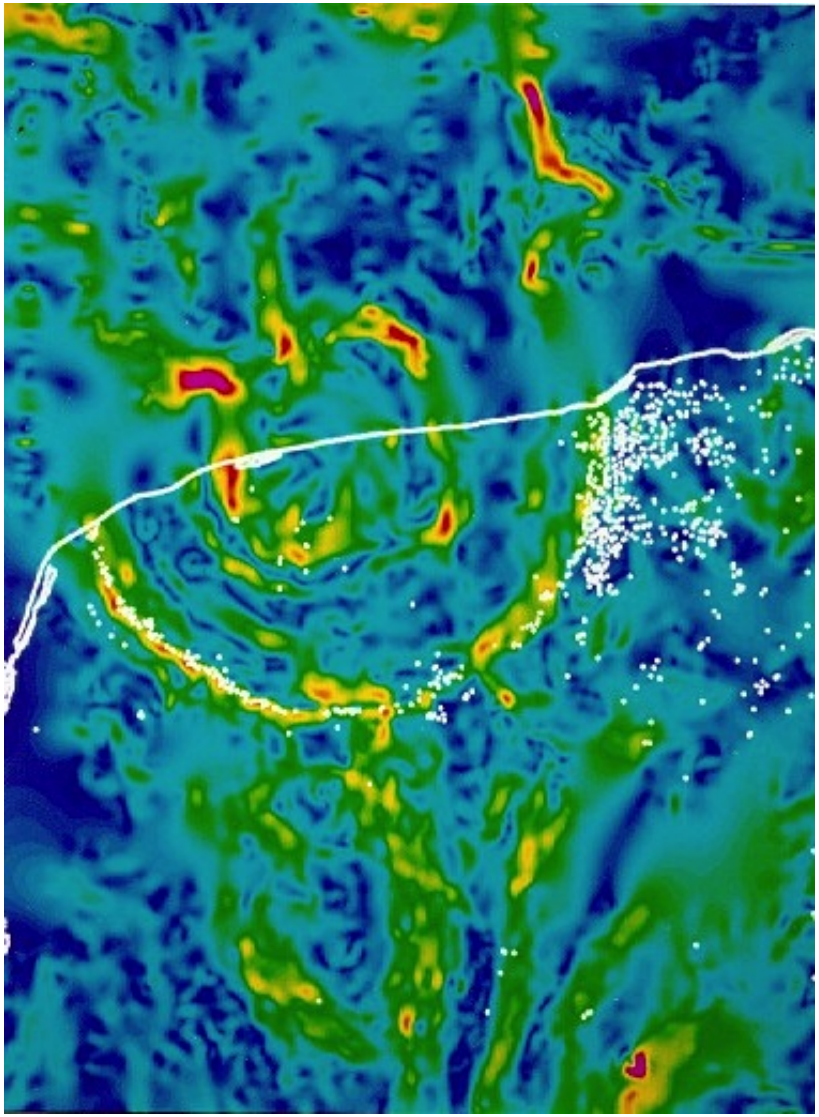


Image courtesy of the Geological Survey of Canada

- Bouguer gravity anomaly map
- Crater not exposed at surface
- Seismic surveys show it is buried 100's to 1000's meters deep
- Sits astride the Mexican coastline in the Yucatán Peninsula

K-Pg Extinction Event

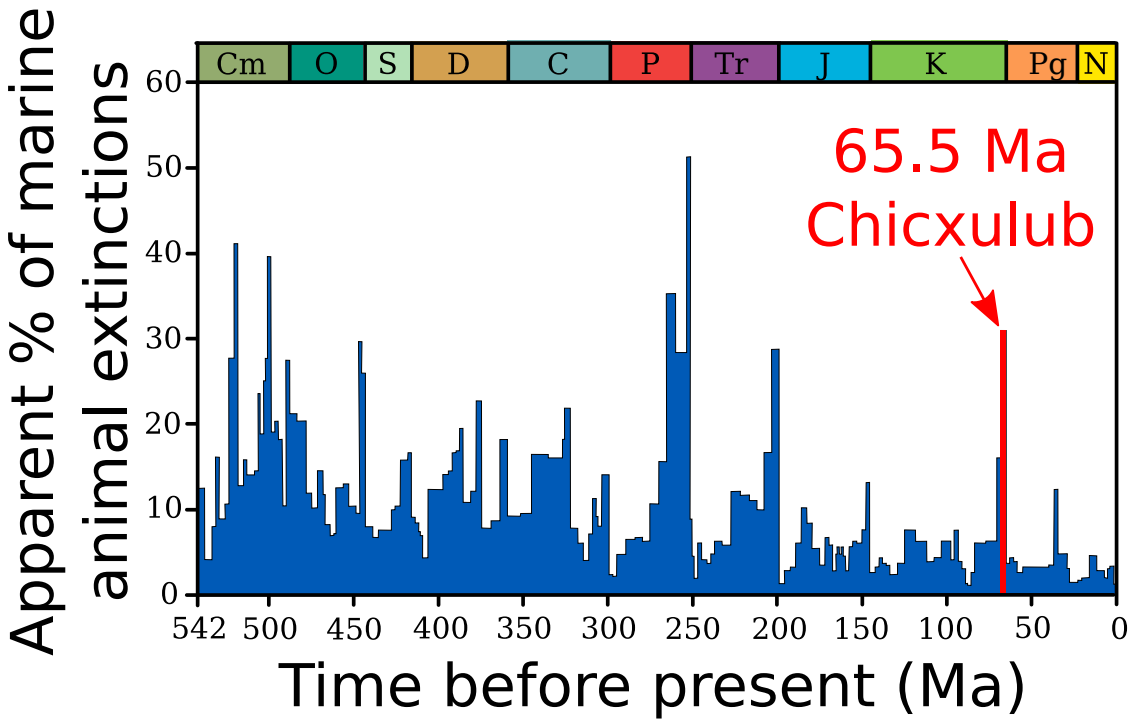


Image adapted from Wikimedia Commons

- 75% of all species became extinct
- All Non-avian dinosaurs included

How do we know the Chicxulub Crater caused the mass extinction?

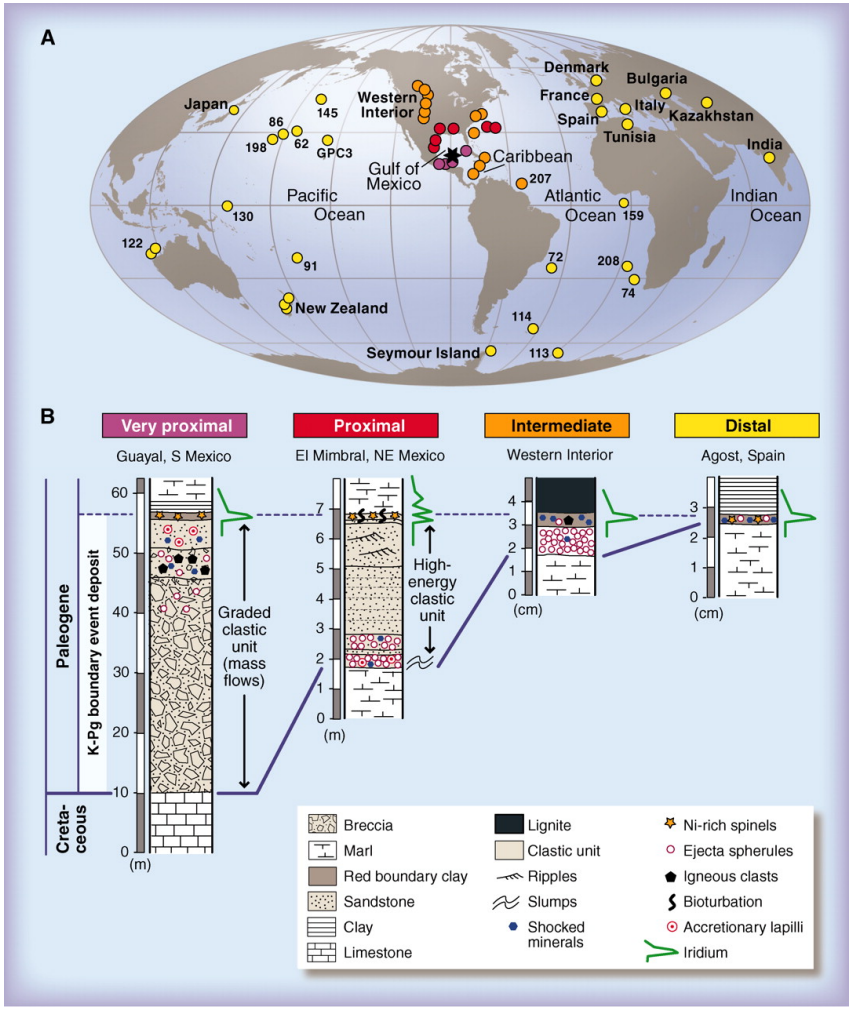


Image courtesy of Schulz et al (2010), *Science*

- Evidence around the globe of the impact event
- High-energy deposits found around the world
- Global layer rich in Iridium
  - → High concentrations in meteorites, low concentration in the Earth's crust

How do we know the Chicxulub Crater caused the mass extinction?

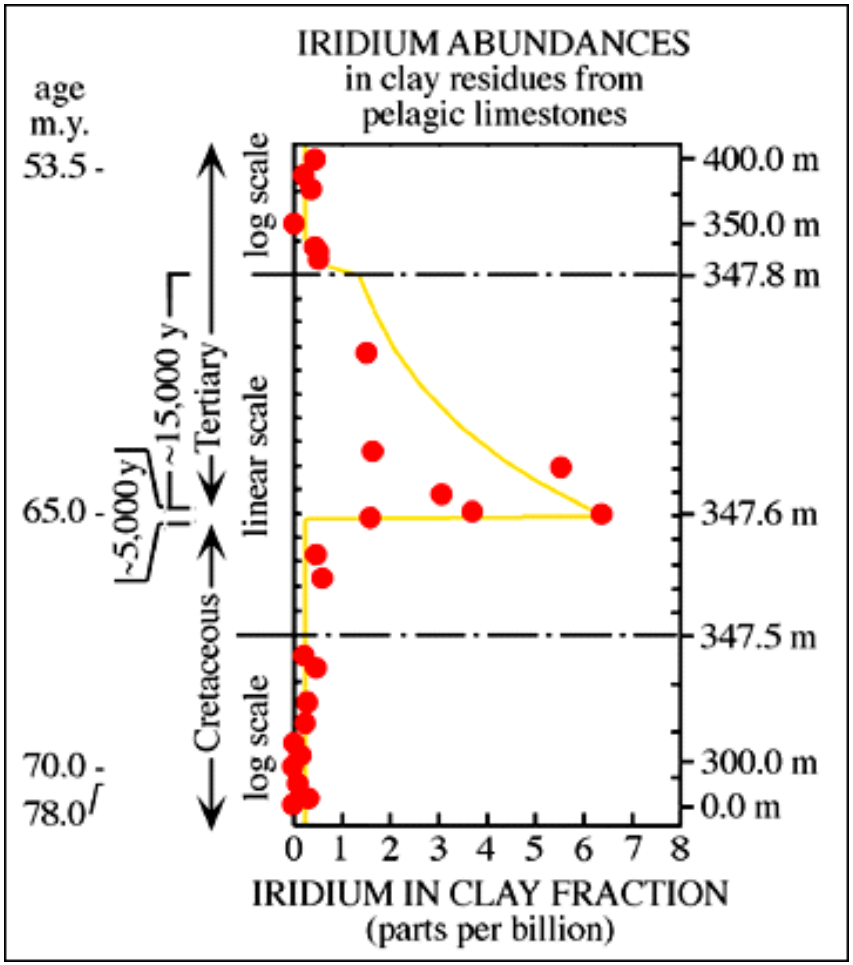


Image courtesy of P.E. Olsen / Alvarez et al. (1980), *Science*

- Evidence around the globe of the impact event
- High-energy deposits found around the world
- Global layer rich in Iridium
  - → High concentrations in meteorites, low concentration in the Earth's crust
- Effects of impact felt around the world

Impactor estimated to have been 10 km in diameter

What are the effects of an impact like this?

Images courtesy of Don Davis

- Magnitude > 11 earthquakes
- Tsunamis
- Ejected material distributed globally
  - i.e. iridium rich, high-energy layer
  - Dust cloud — blocked out sunlight for < 1 year
  - Sulfuric acid aerosols < 10 years — reduced sunlight by 10 – 20 %
  - Infrared radiation on re-entry to atmosphere
    - $\rightarrow$ Kill exposed creatures and start global wildfires

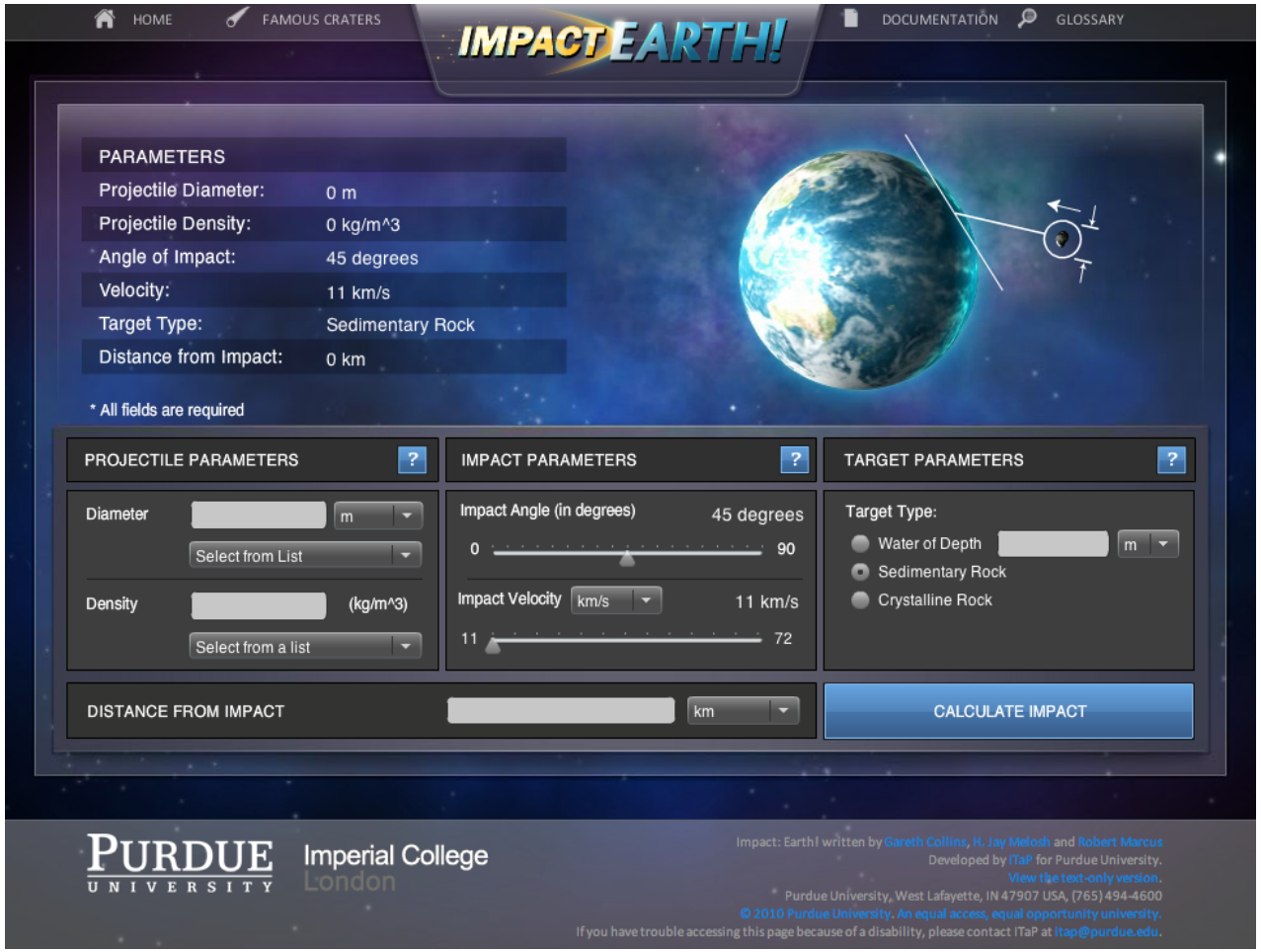
$\rightarrow$ Extinctions!

Part 4:

Collateral effects of impacts on Earth

Image courtesy of Don Dixon/NASA

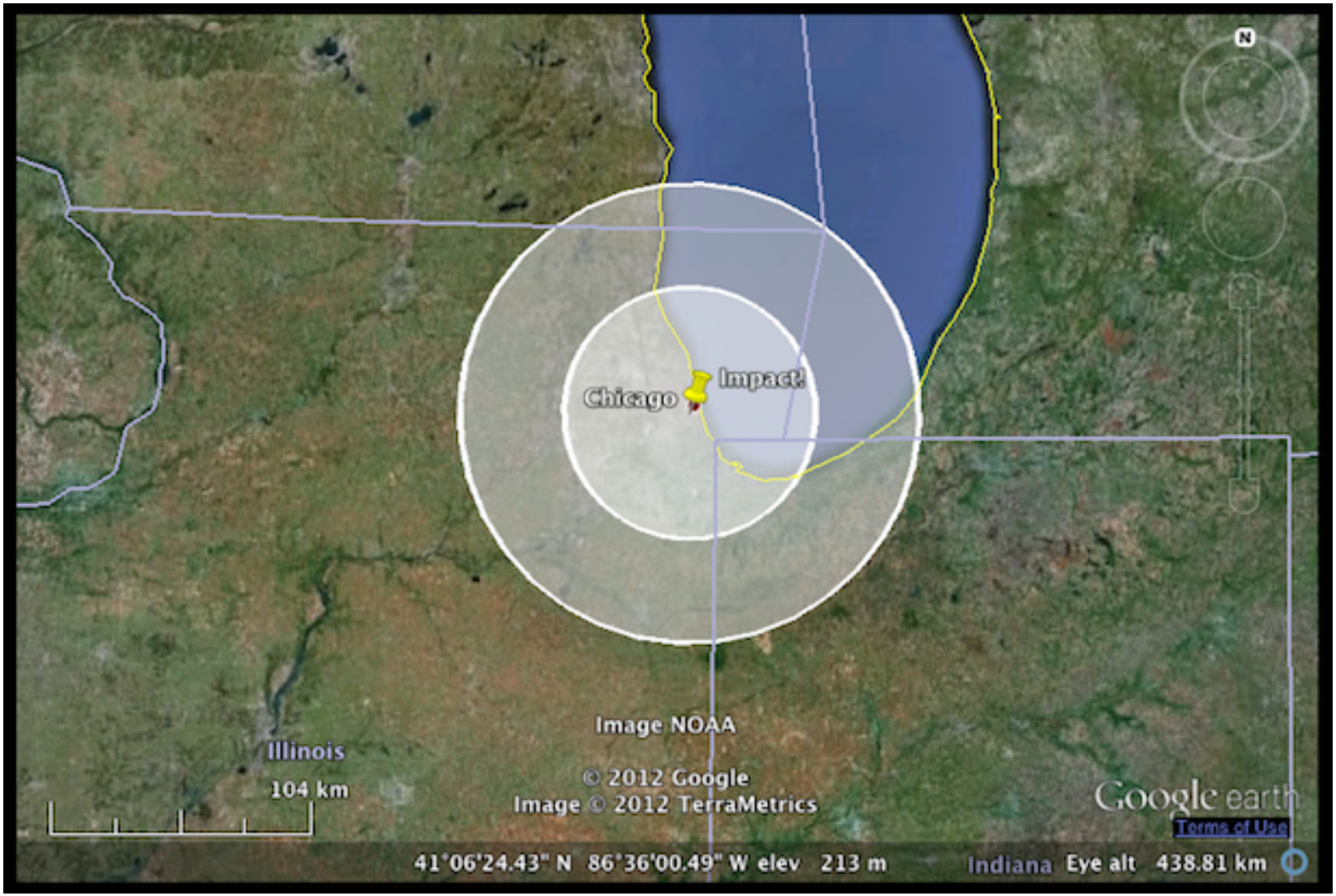
Impact Earth! web calculator



http://www.purdue.edu/impactearth

Go and try it out yourselves!

Also, Google maps version



http://impact.ese.ic.ac.uk/ImpactEffectsMap

How frequent are big impacts

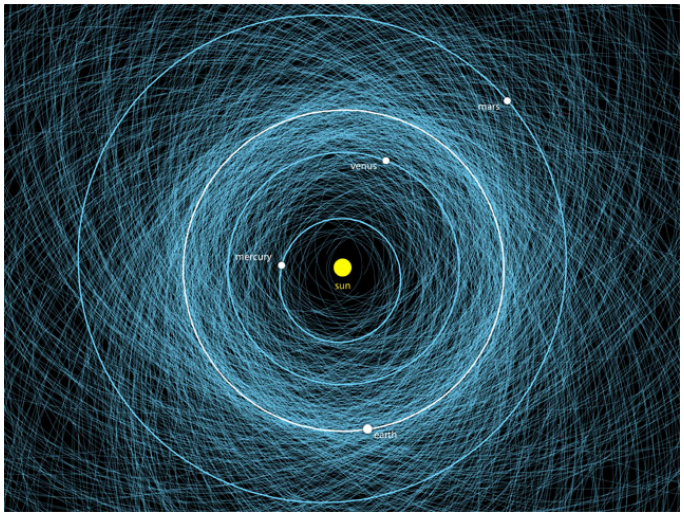
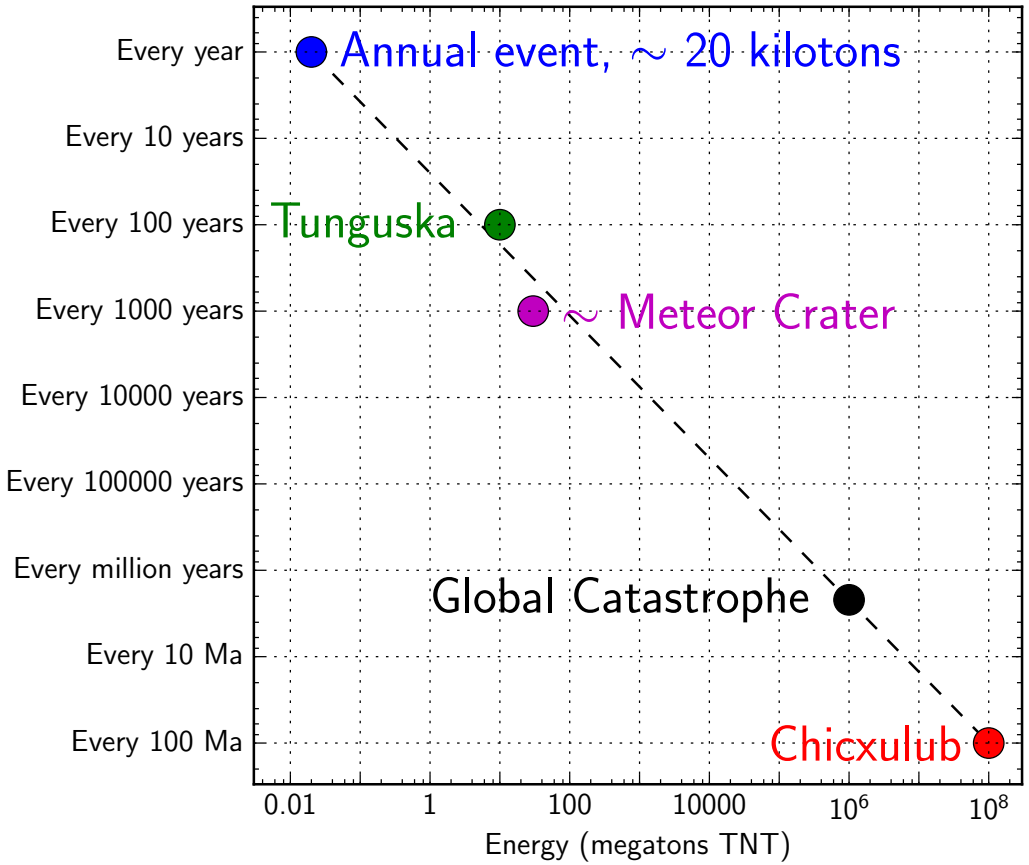


Image courtesy of Paul Chodas/NASA/JPL

Image courtesy of David A.Hardy/Photo Researchers

Currently know of 1360
potentially hazardous objects



What can we do if there is a serious threat?

- Several possible asteroid deflection strategies
- Best strategy depends on how long we have
- If long enough, only need to change the orbital speed by a few cm / year
  1. Nuclear Bomb
  2. Kinetic Impact
  3. Gravity Tractor (0.22 μm/s/day)
  4. Focussed Solar Energy

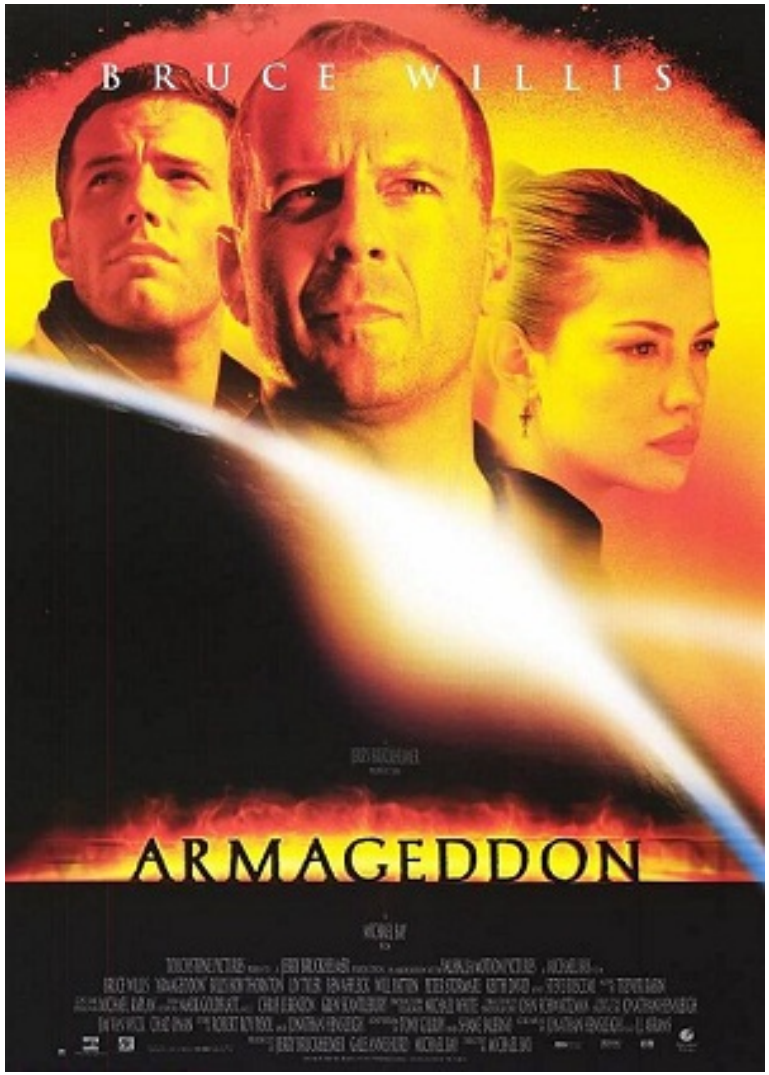


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Image courtesy of ESA

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Image courtesy of Dan Durda/FIAAA/B612 Foundation

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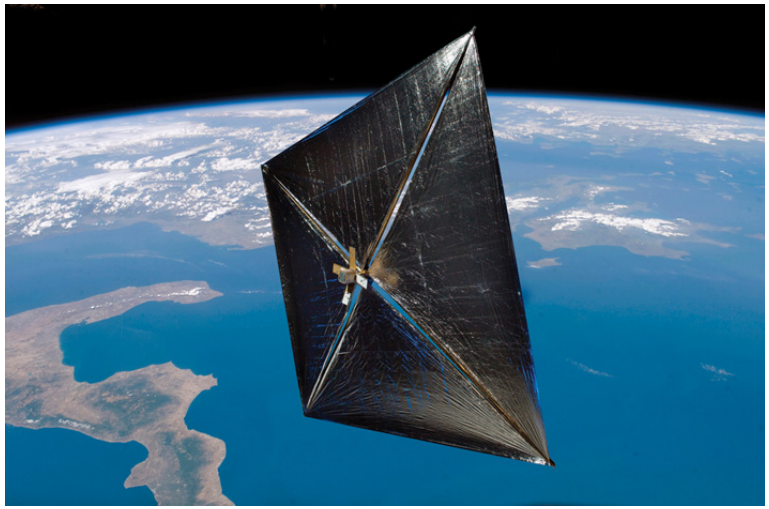


Image courtesy of NASA

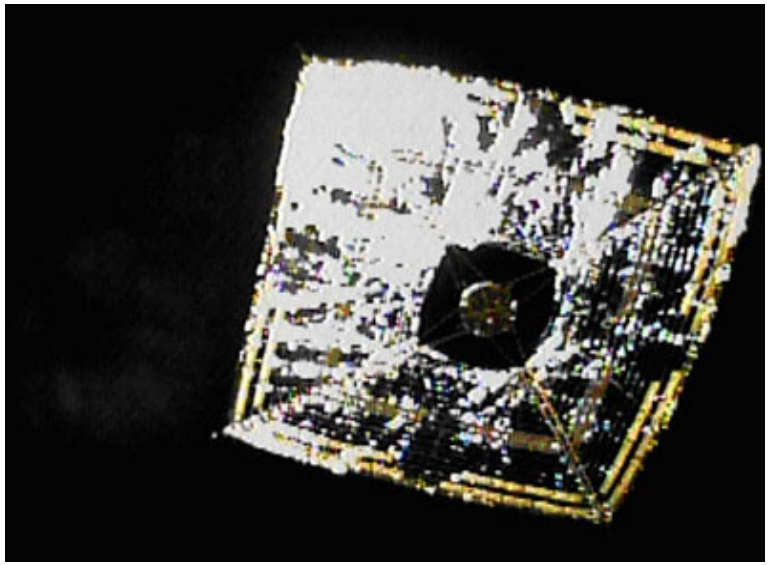
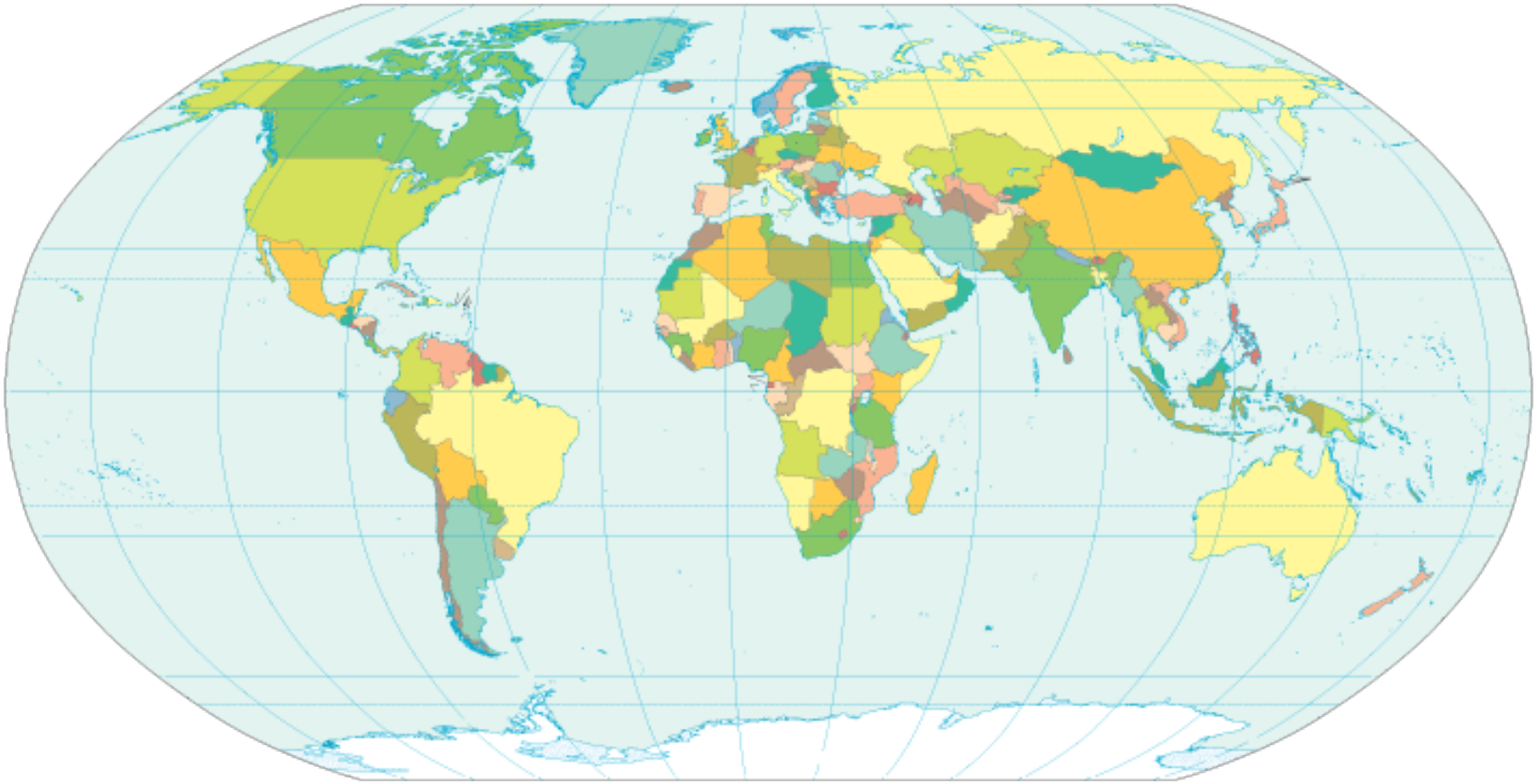


Image courtesy of JAXA

Political implications!



Map courtesy of the CIA World Factbook

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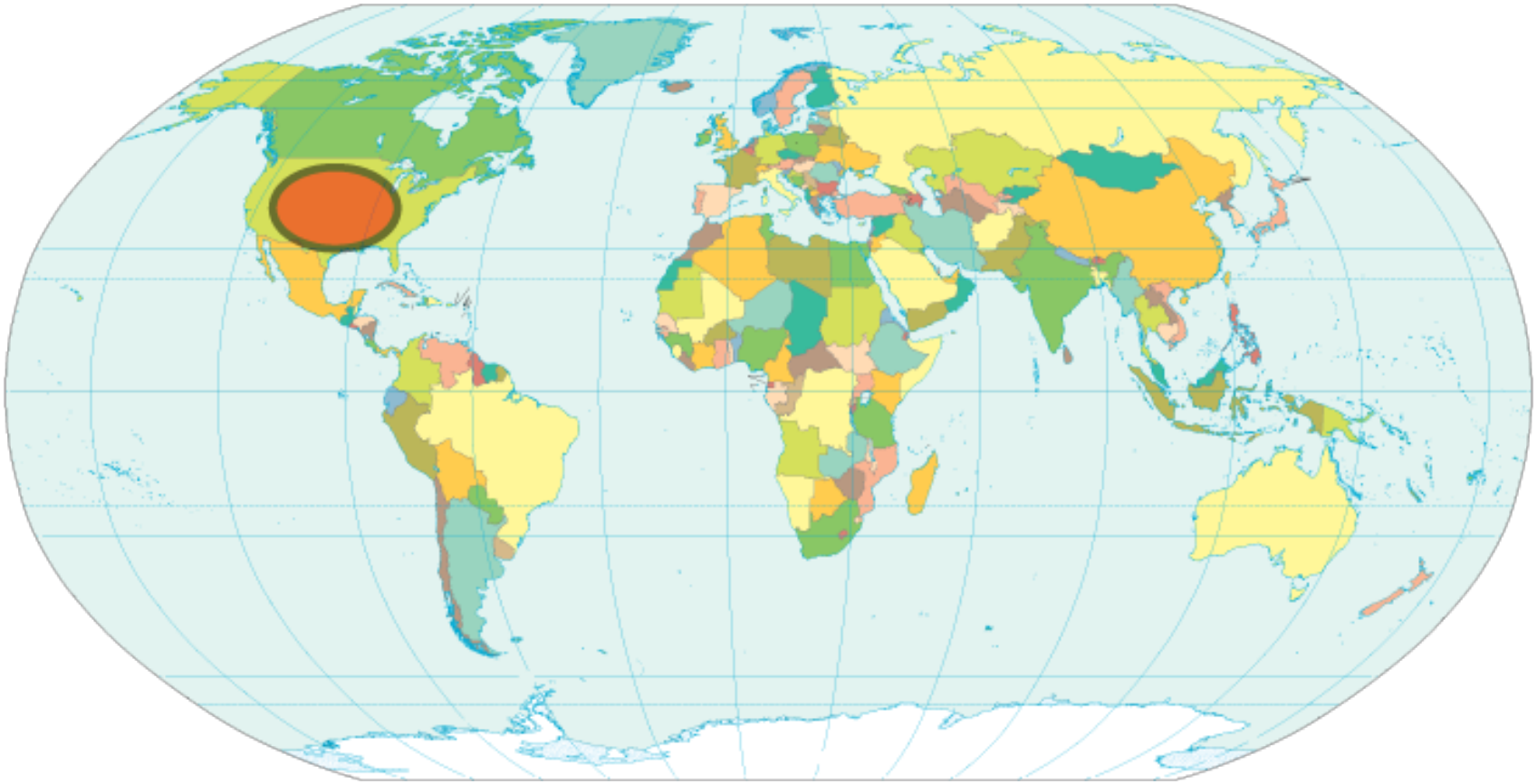

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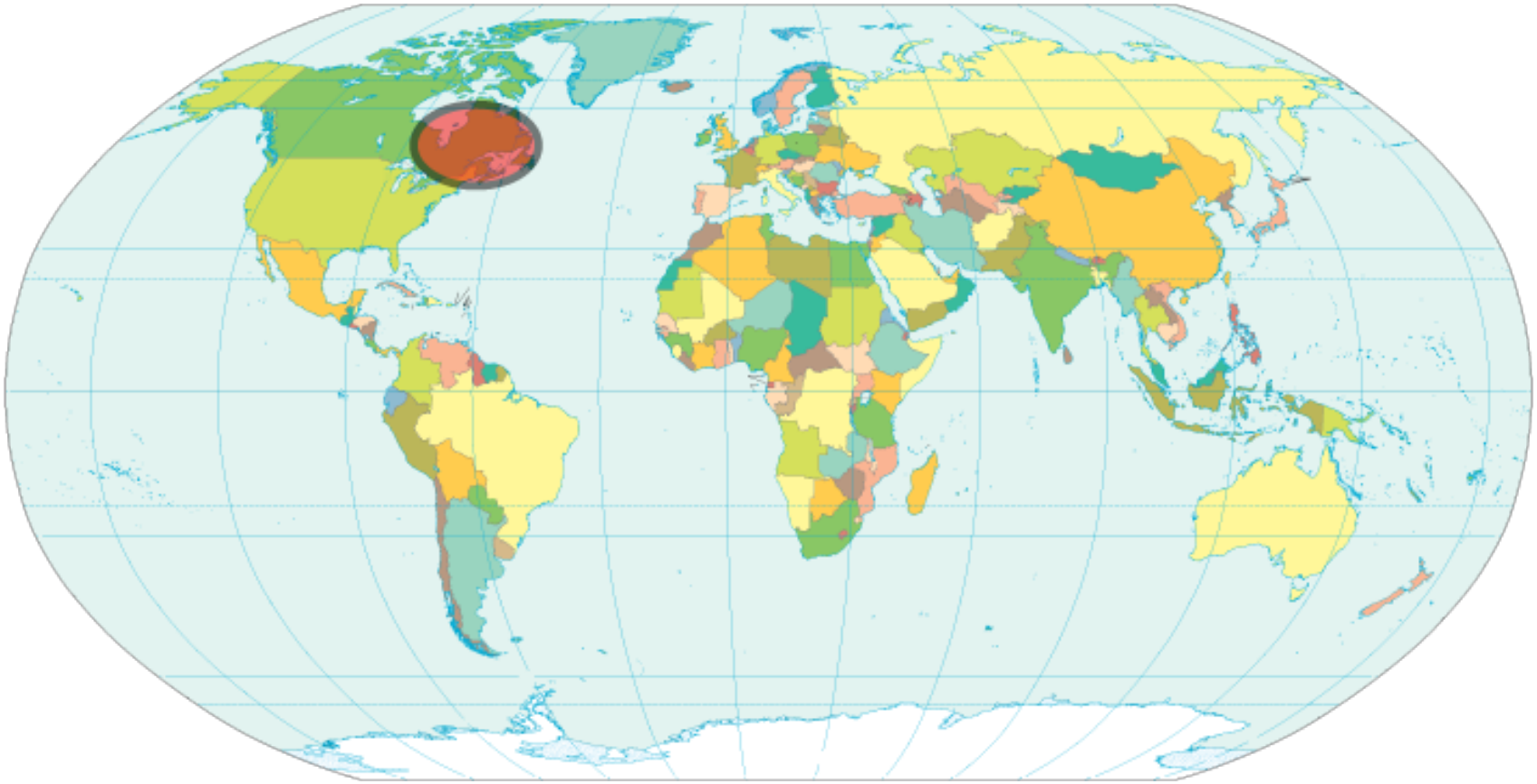

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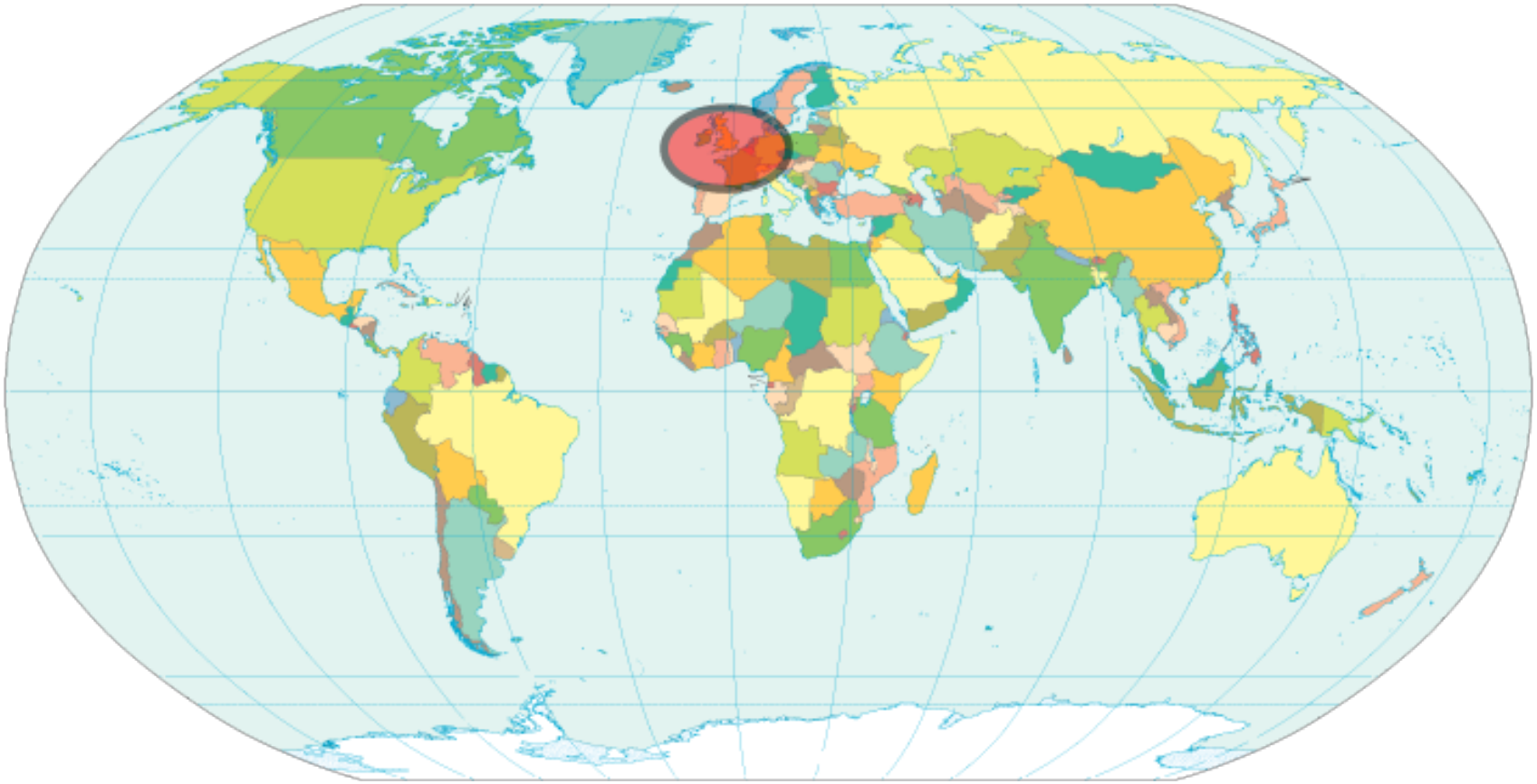

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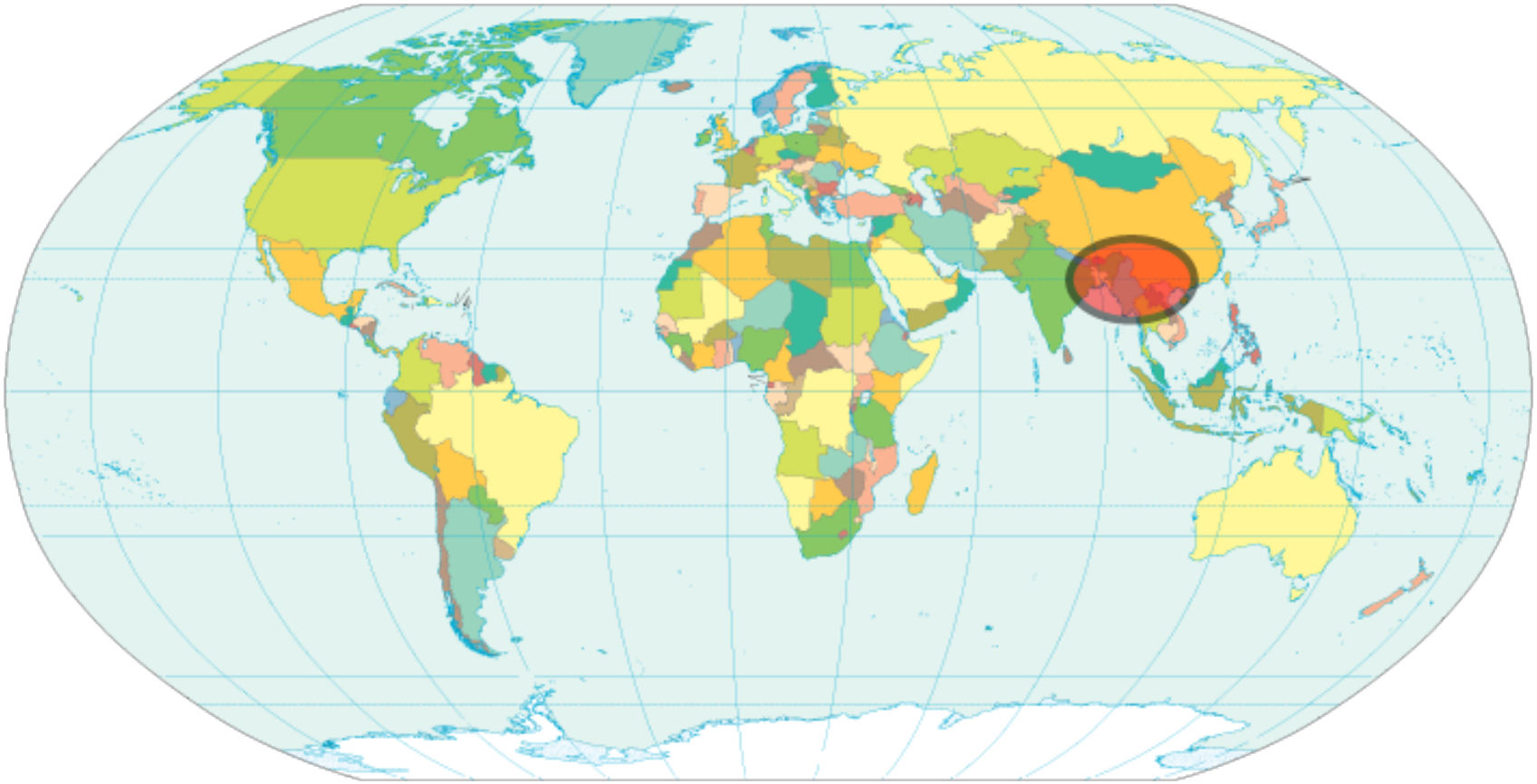

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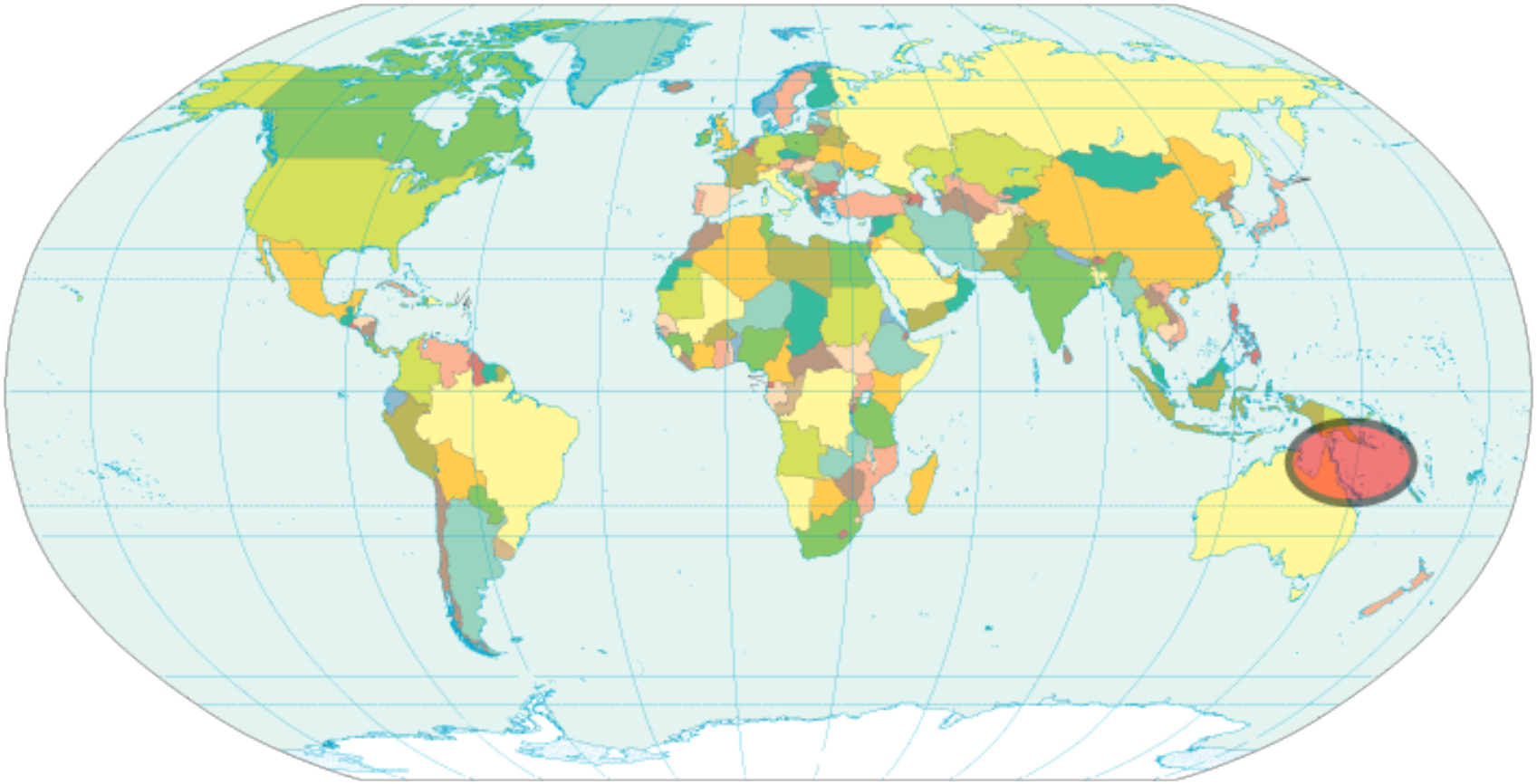

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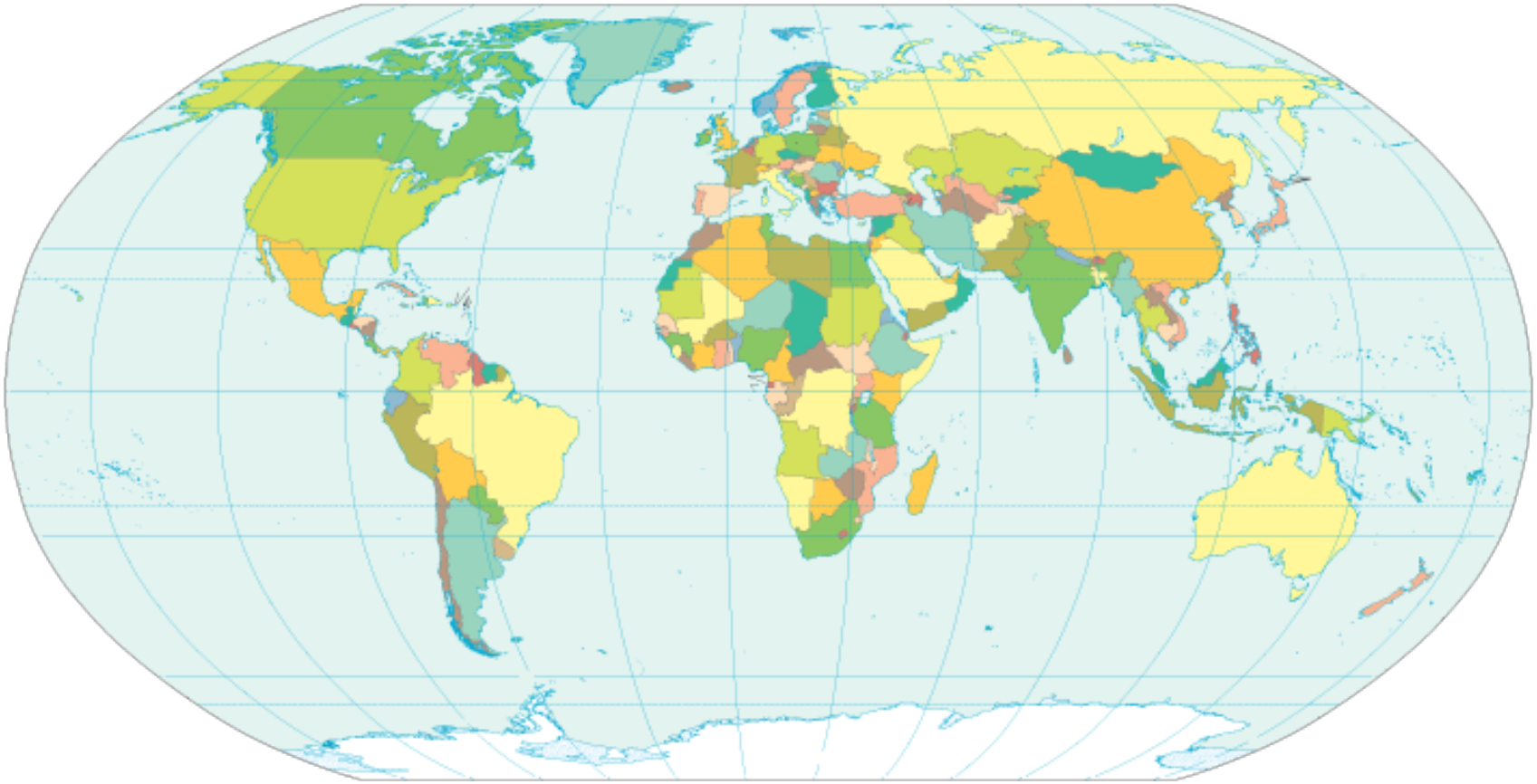

Map courtesy of the CIA World Factbook

Summary

Image courtesy of David A.Hardy/Photo Researchers

- Impacts have played a key role in the history of the Earth, and the Solar System as a whole
- Key events such as the extinction of the dinosaurs and the formation of the Moon can be attributed to impacts
- Several strategies have been devised in the event we discover an NEO on a collision course with Earth

Thank you

Questions?