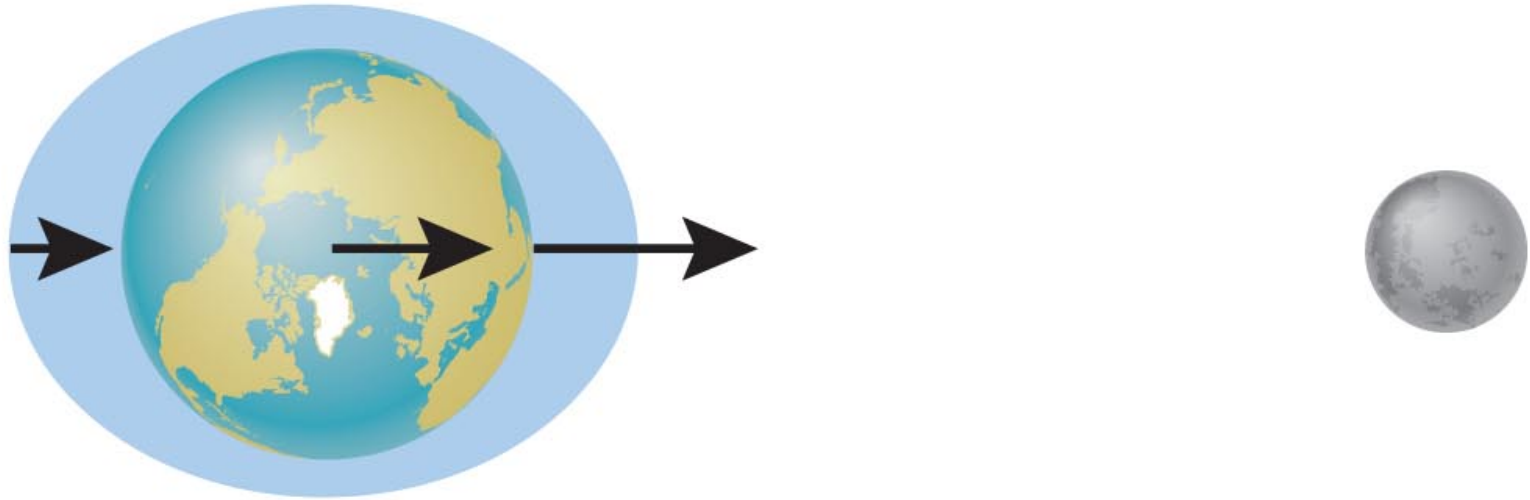


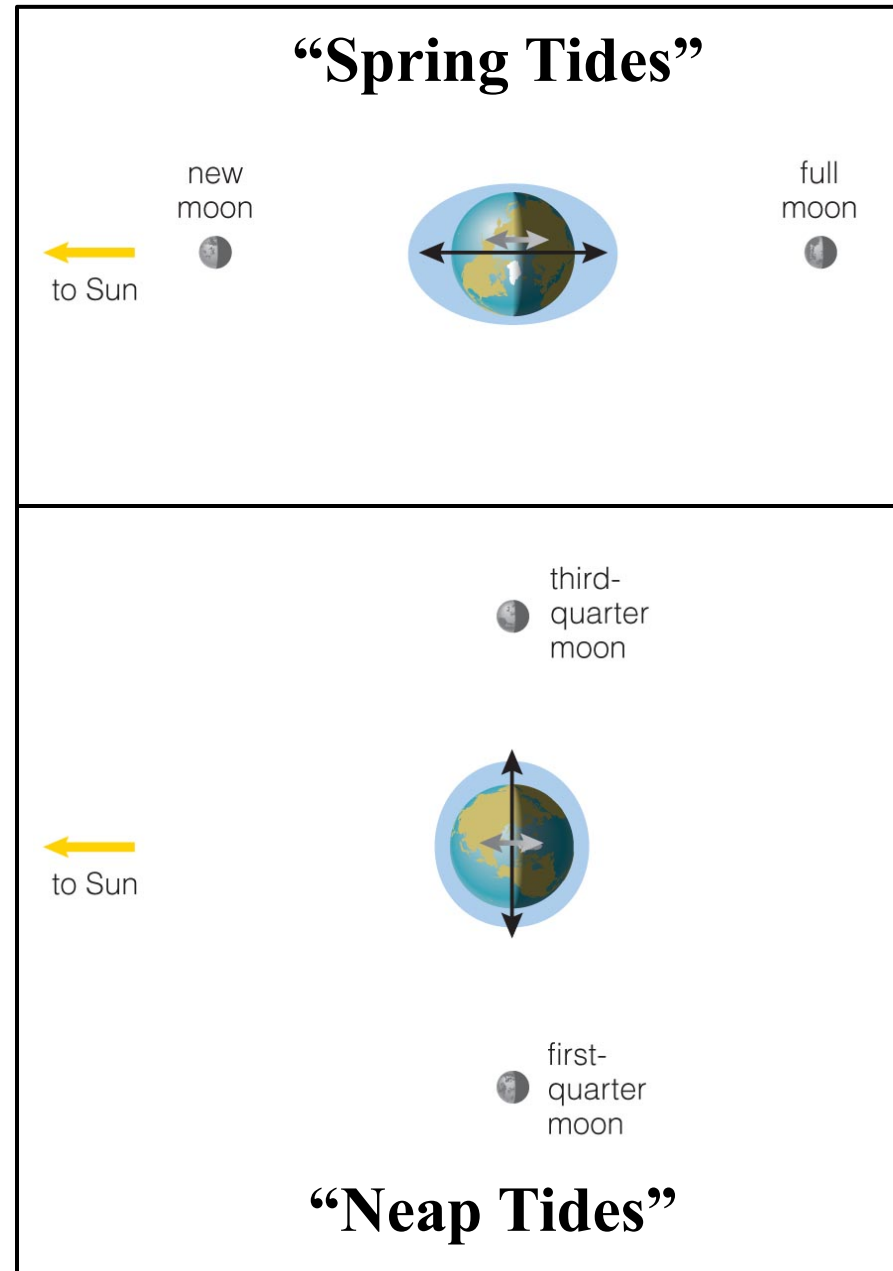
How does gravity cause tides?



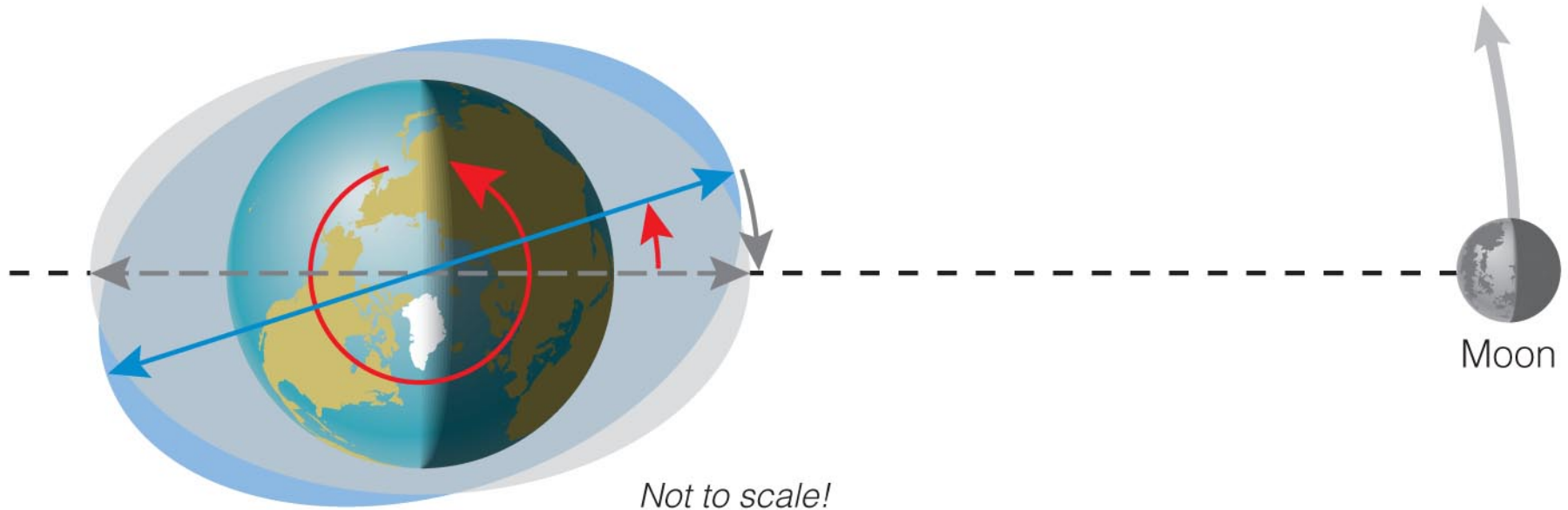
- Moon's gravity pulls harder on near side of Earth than on far side.
- Difference in Moon's gravitational pull from one side to the other “stretches” the Earth.
- Water easier to deform → ocean tides

Tides and Lunar Phase

- Since the tidal stretching is two-sided, as the Earth rotates, there are *two* high tides and *two* low tides a day.
- Strength of tides depends on Earth/Moon/Sun alignment → phase of Moon.

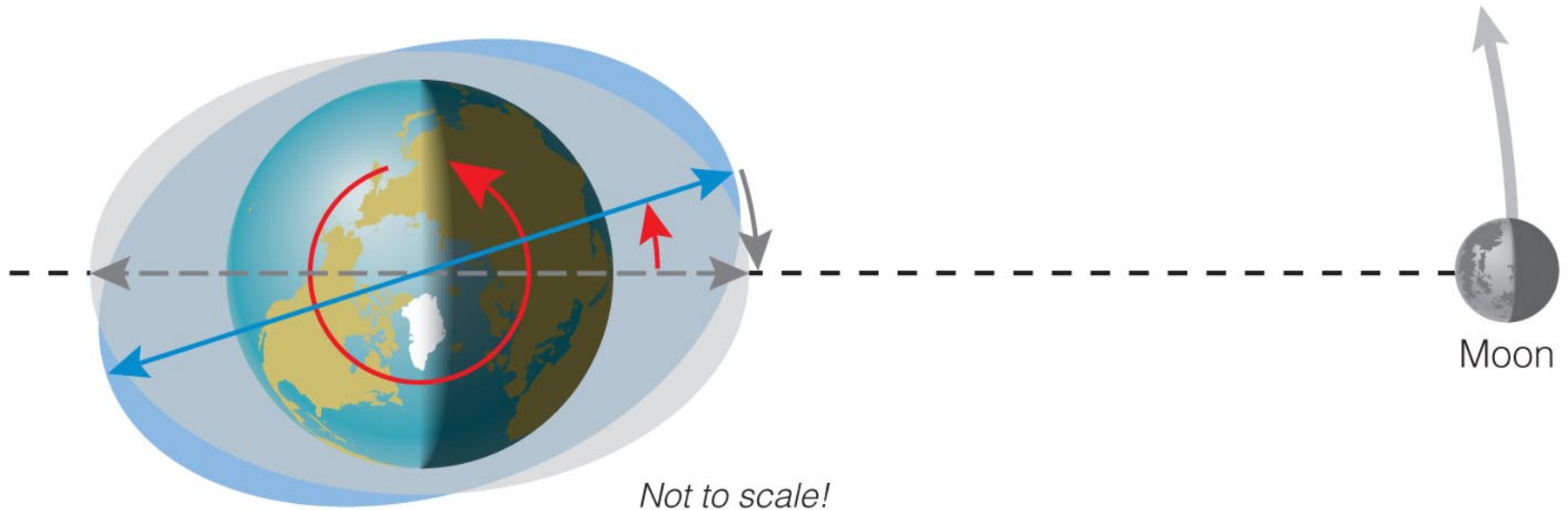


Tidal Friction



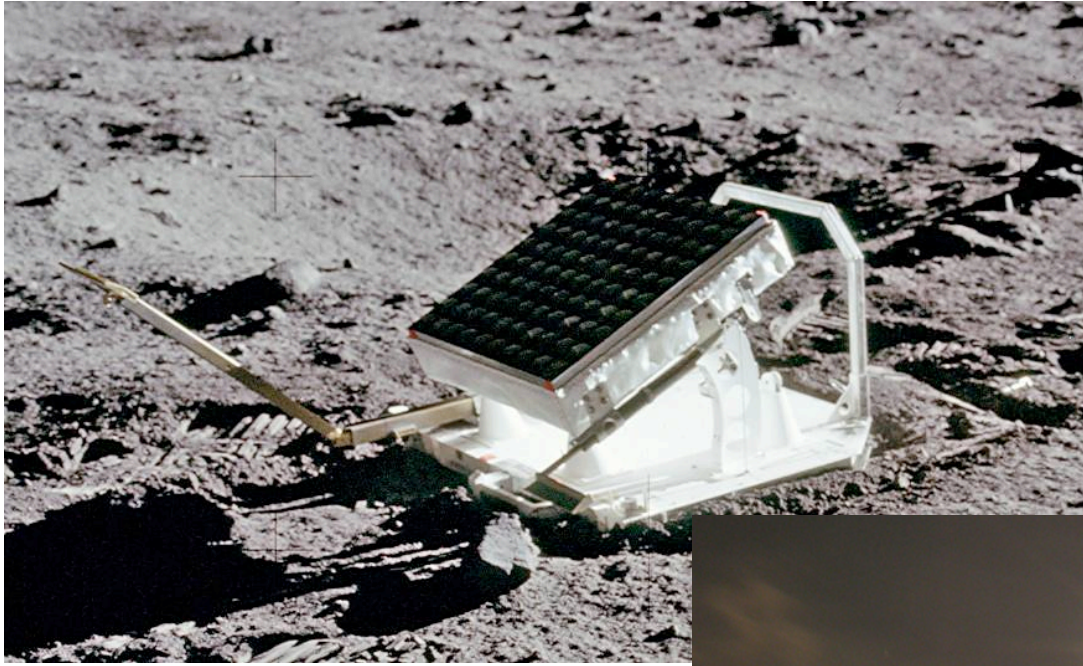
- The Earth's rotation drags the tidal bulge forward from the Earth-Moon line.
- Since the bulge leads the Moon, the Moon is pulled a little bit forward in its orbit. It gains orbital energy.

Tidal Friction

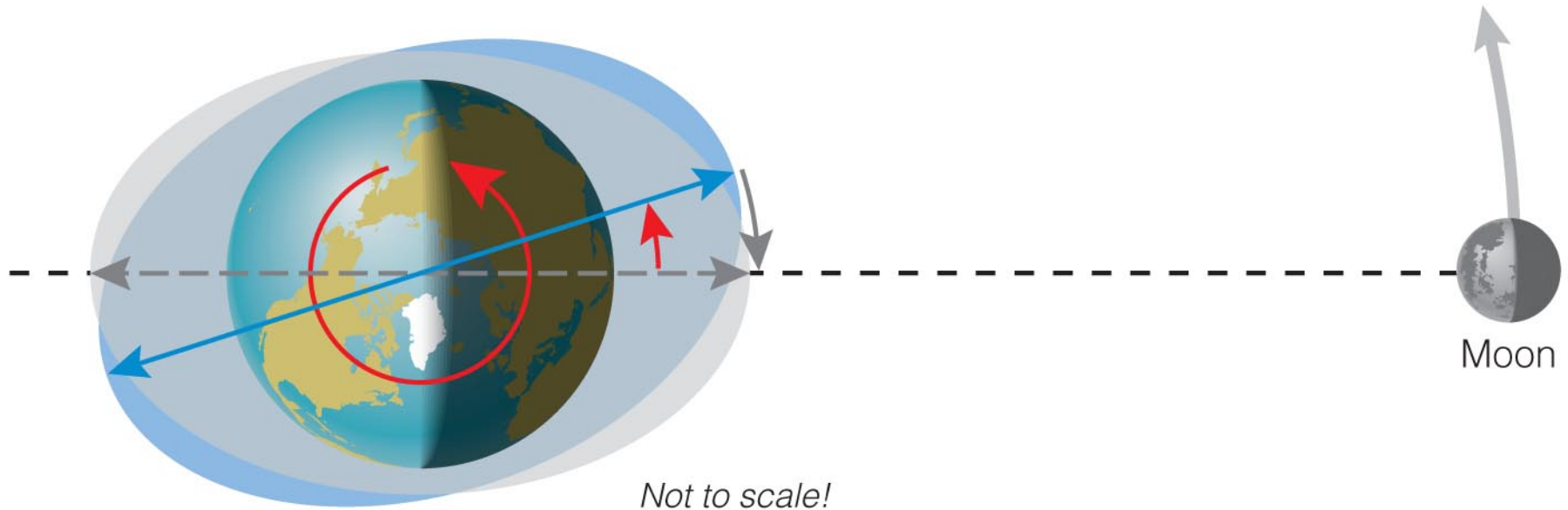


- If the Moon is gaining energy, it **must** be moving away from the Earth!
- How fast? About 38 millimeters per year!

Tidal Friction

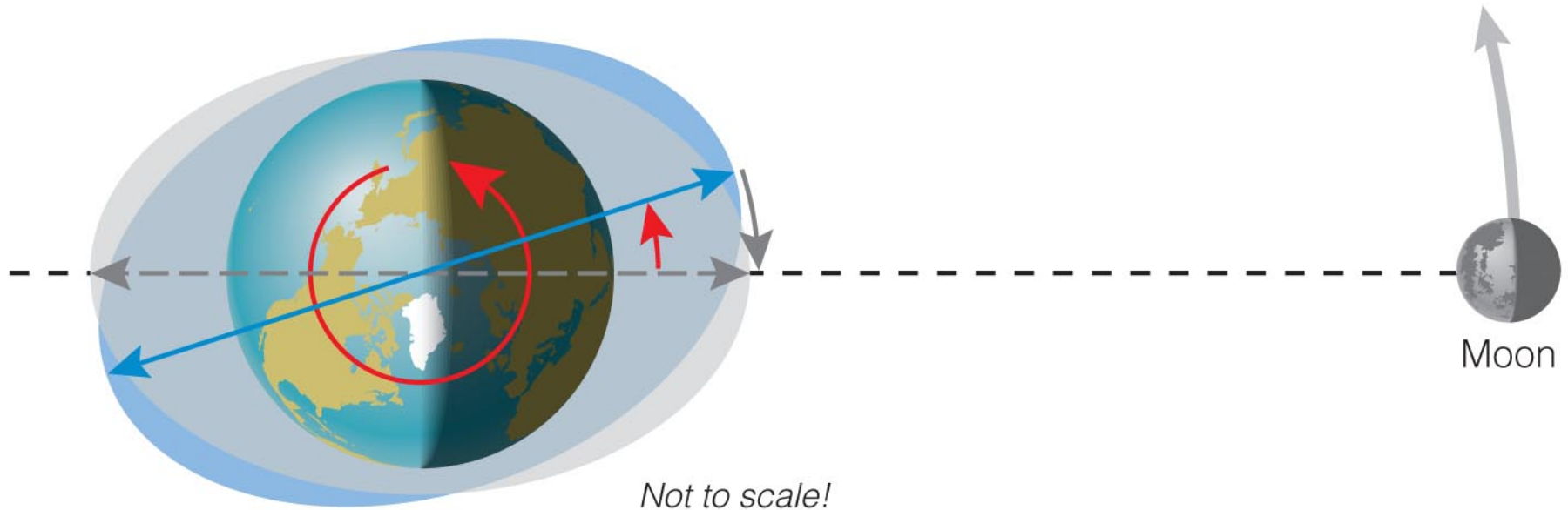


Tidal Friction



- If the moon is moving away, it must be gaining angular momentum:
$$\text{Angular momentum} = \text{mass} \times \text{distance} \times \text{speed}$$
- Angular momentum is conserved, so something must also be losing angular momentum. What?

Tidal Friction



- The Earth must be slowing its rotation – days are getting longer!
- How fast? About one second longer every 50,000 years!

Tidal Friction

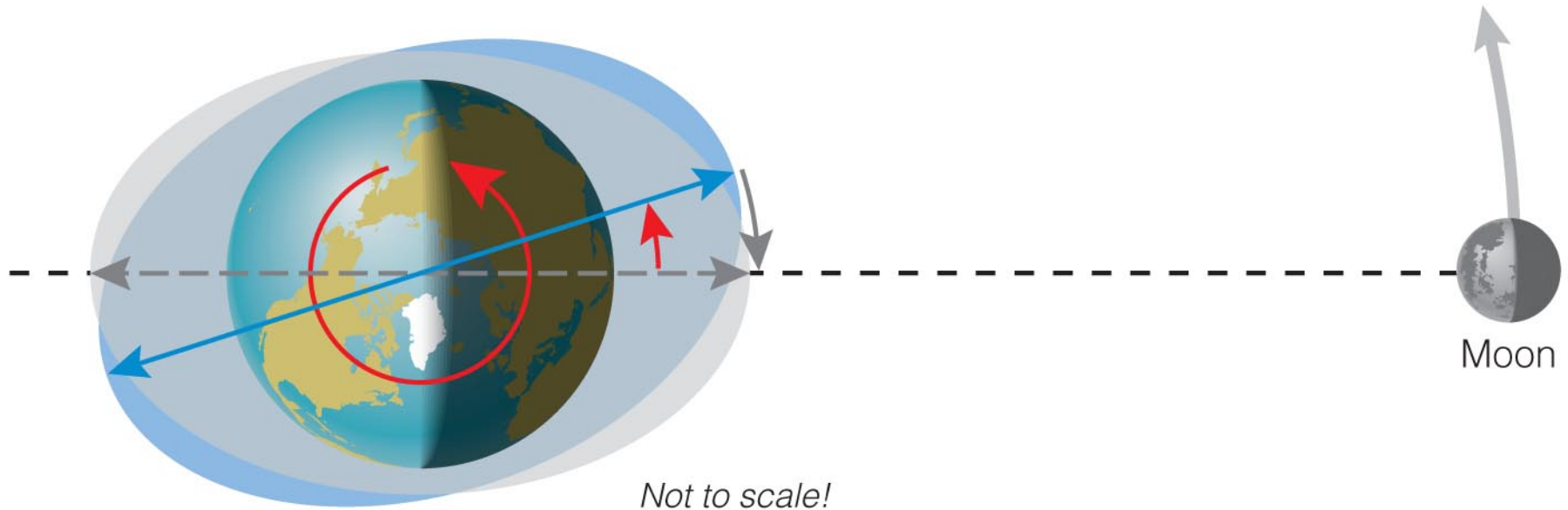
Tidal rhythmite

Layers of sediment laid down on regular basis due to tides.

Shows that ~ 600 million years ago, the day was only about 21.9 hours long!



Tidal Friction



- When will it all stop? When the Earth's rotation slows enough so that it no longer drags the bulges forward.

In about 50 billion years, we would achieve synchronous rotation: 1 day = 1 month = 47 current days!

Tidal Friction

Synchronous Rotation

Earth rotation period = Moon orbital period

- What would the Moon look like from Earth?
- What would the Earth look like from the Moon?

What other object have we talked about that shows synchronous rotation?

What have we learned?

- **How do gravity and energy together allow us to understand orbits?**
 - Change in total energy is needed to change orbit
 - Add enough energy (escape velocity) and object leaves.
- **How does gravity cause tides?**
 - The Moon's gravity stretches Earth and its oceans.
 - Tidal friction causing Moon to move further away from Earth.
 - Earth's day is getting longer.