What would happen to sea level if Greenland's ice sheet melted? (part 2)

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MATH 111A
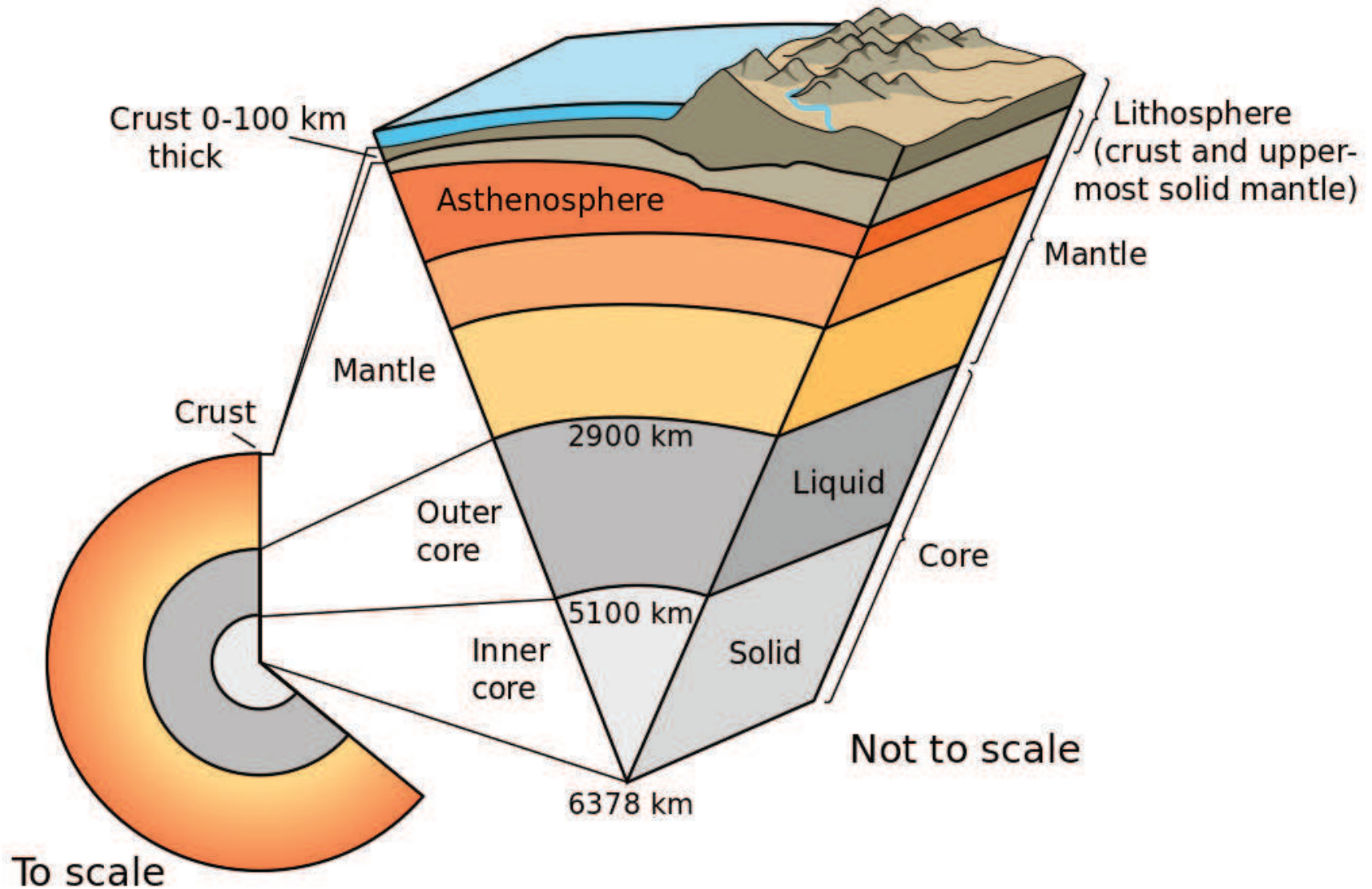Introduction to Mathematical Modeling
La Jolla, CA, 20 November 2017

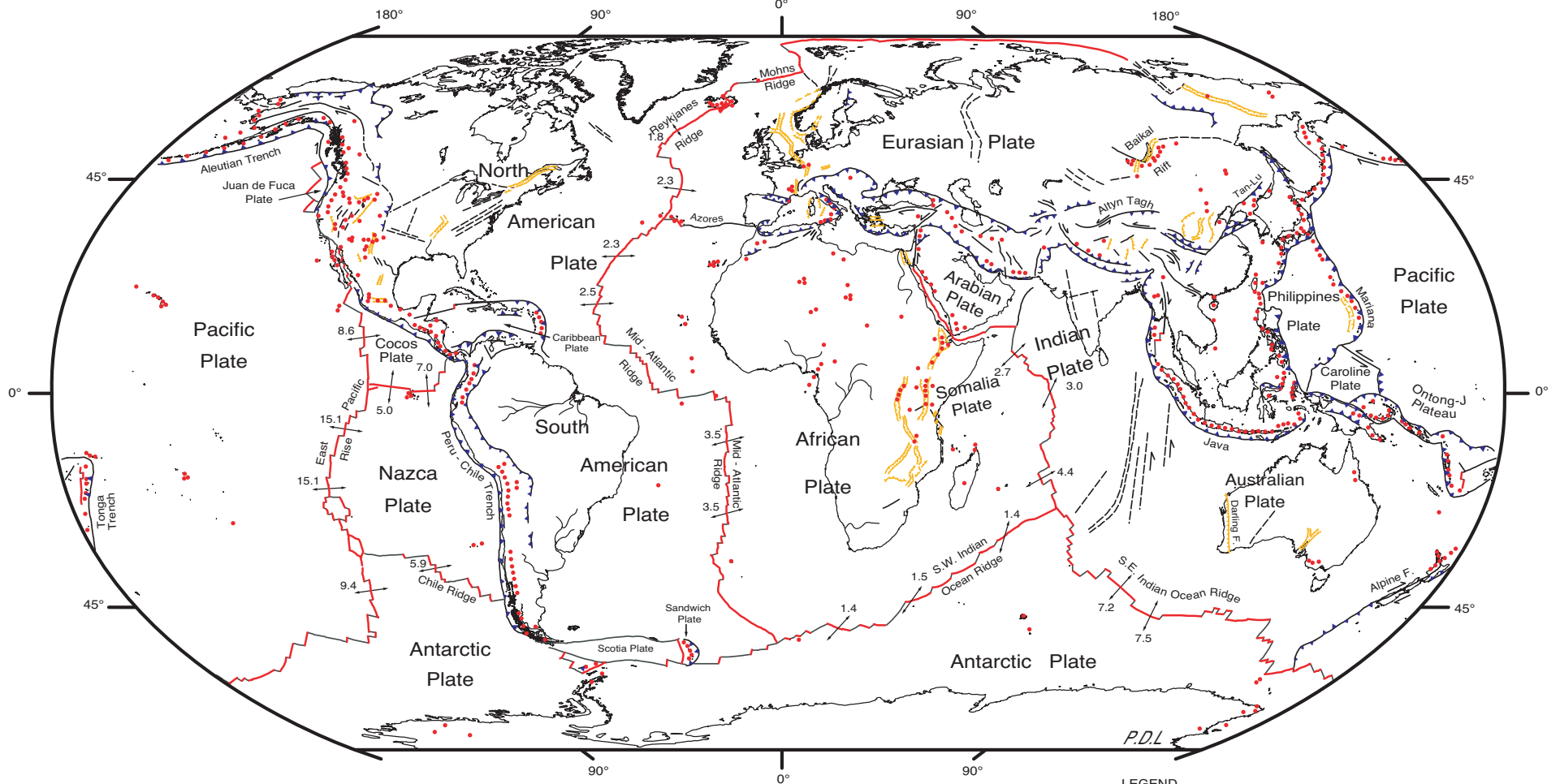**The non-uniformity of sea level rise could be due to many factors**

- Change in ocean temperature will change water volume.

- The Earth's rotation causes a bulge at the equator.

- Melting of Greenland ice sheet will allow Earth's crust to rebound.

- Melting of Greenland ice sheet will change gravitational field.

- ...

Which of these effects are important relative to the $\approx 7m$ rise in global sea level from complete melting of the Greenland ice sheet, specifically for Nuuk?

Global geology of the Earth

Crust 0-100 km thick

Lithosphere (crust and upper-most solid mantle)

Asthenosphere

Mantle

Mantle

Crust

2900 km

Liquid

Outer core

5100 km

Core

Inner core

Solid

6378 km

Not to scale

To scale

Lithosphere

DIGITAL TECTONIC ACTIVITY MAP OF THE EARTH
Tectonism and Volcanism of the Last One Million Years

DTAM - 1

NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771
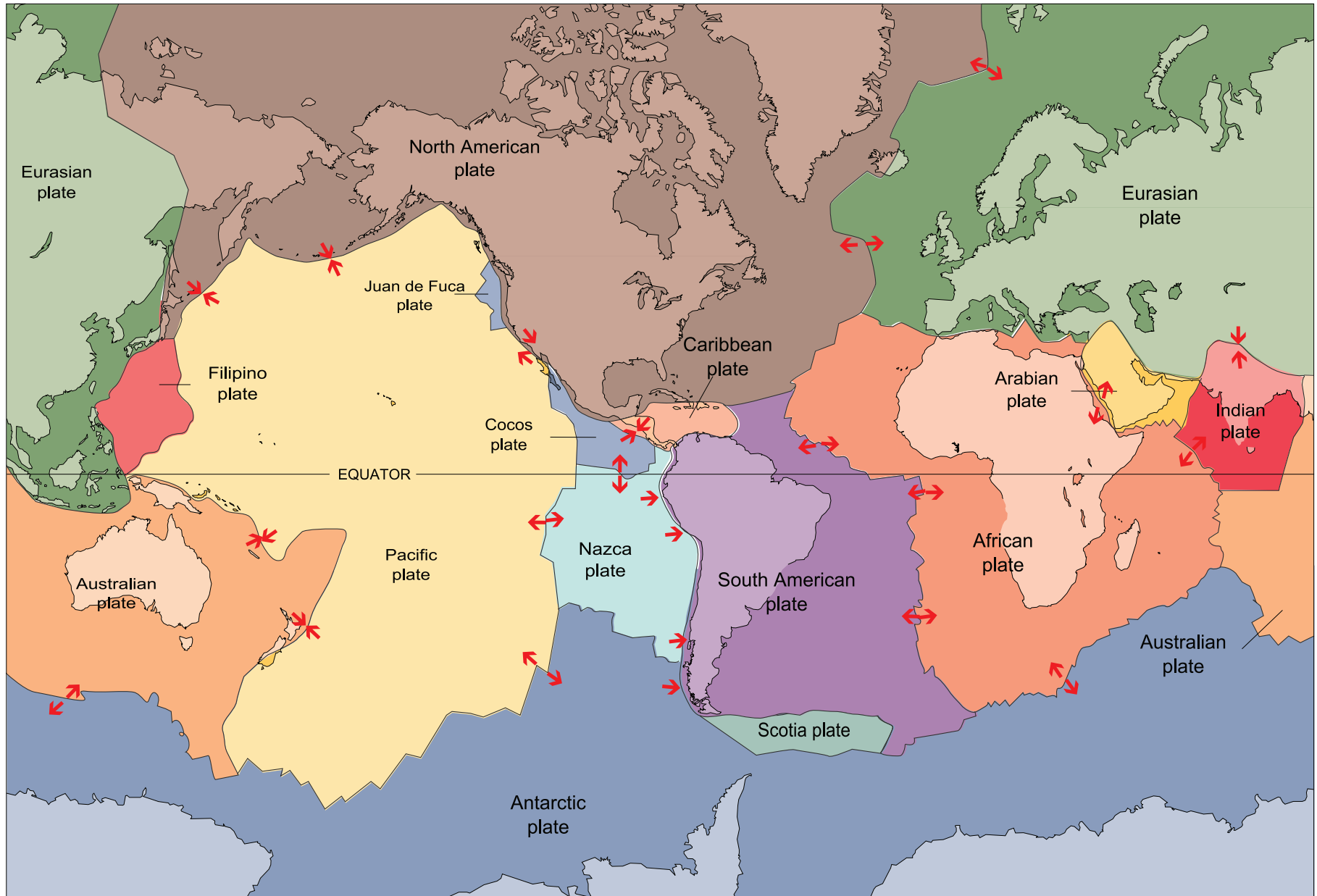
Robinson Projection
October 2002

LEGEND

Actively-spreading ridges and transform faults

Total spreading rate, cm/year

1.4 Major active fault or fault zone; dashed where nature, location, or activity uncertain

Normal fault or rift; hachures on downthrown side

Reverse fault (overthrust, subduction zones); generalized; barbs on upthrown side

Volcanic centers active within the last one million years; generalized. Minor basaltic centers and seamounts omitted.
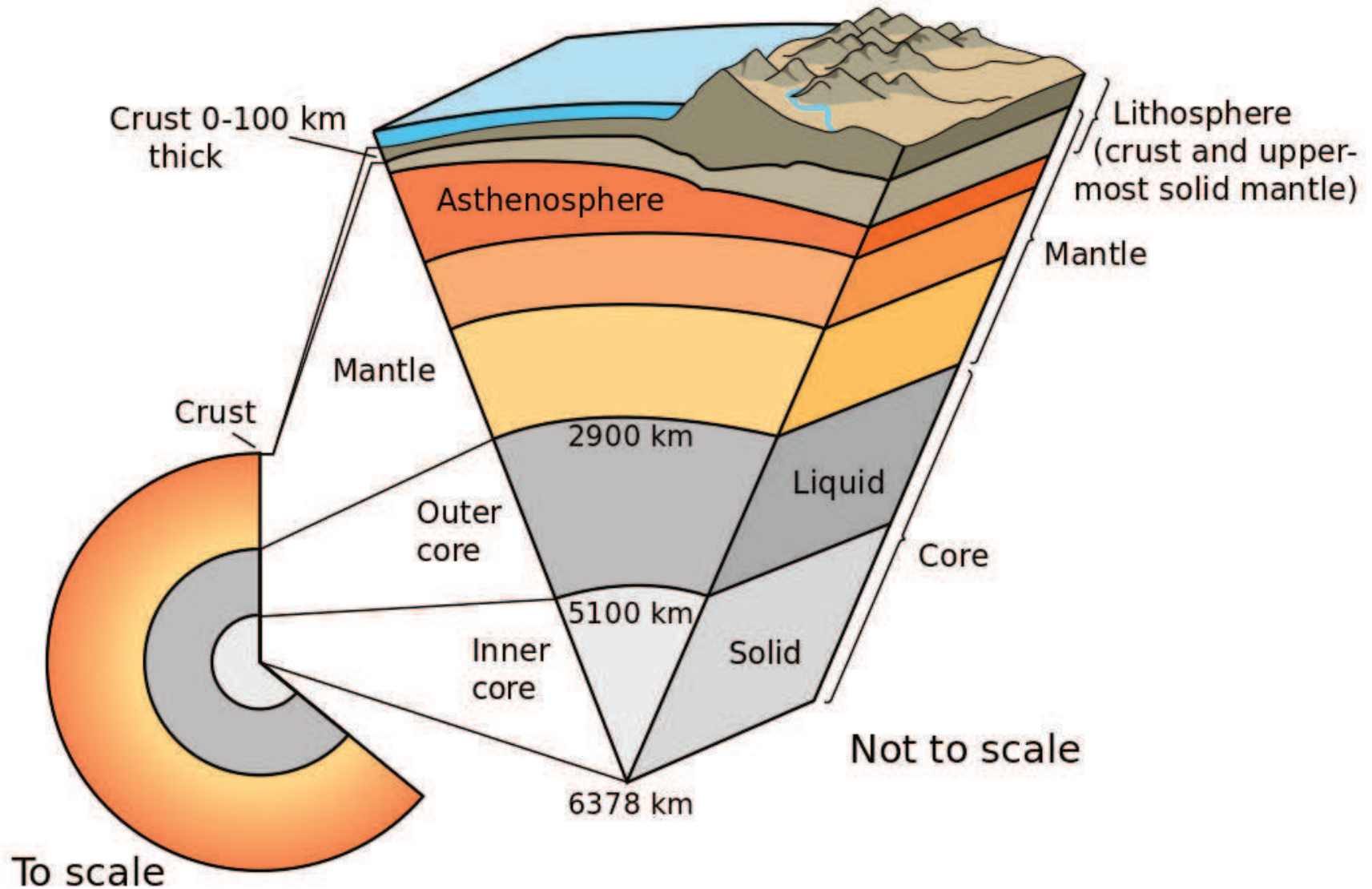
G221.001

NASA, https://visibleearth.nasa.gov/view.php?id=88415

Tectonic plates

The North American Plate

area $\approx 7.6 \times 10^7 \, km^2$

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Asthenosphere

Ocean floor

At a **rift** between separating plates, lava oozes upward and forms new crust

At a subduction zone, one plate pushes the other down into the mantle

Where plates colide, deep oceanic **trenches** and **mountain ranges** are formed

Lithosphere   Continent

Con

Asthenosphere

Upward flow

Downward flow

Deep mantle

... from the Greek, $\dot{\alpha}\sigma\theta\epsilon\nu\acute{\eta}\varsigma$, weak.

The upper mantle, from about $80km$ to $200km$ below the surface. Temperature above $1300°$C, so ductile.

Density $\approx 3g/cm^3$, *i.e.*, about three times the density of water.

Glacial isostatic adjustment

Recall that the $2.9 \times 10^6\,km^3$ of the Greenland ice sheet would melt into approximately $V = 2.61 \times 10^6\,km^3$ of water.

That weight is currently displacing approximately a volume $V/3$ of asthenosphere.

Assuming the North American Plate is rigid, this corresponds to a vertical displacement of

$$d \approx \frac{2.61 \times 10^6\,km^3/3}{7.6 \times 10^7\,km^2} \approx 0.011km = 11m.$$

(If Greenland rose independently of the rest of the North American Plate, its vertical displacement would be

$$d \approx \frac{2.61 \times 10^6\,km^3/3}{2.2 \times 10^6\,km^2} \approx 0.395km = 395m.)$$

Glacial isostatic adjustment

But the asthenosphere flows very slowly, so glacial isostatic adjustment is a long process.
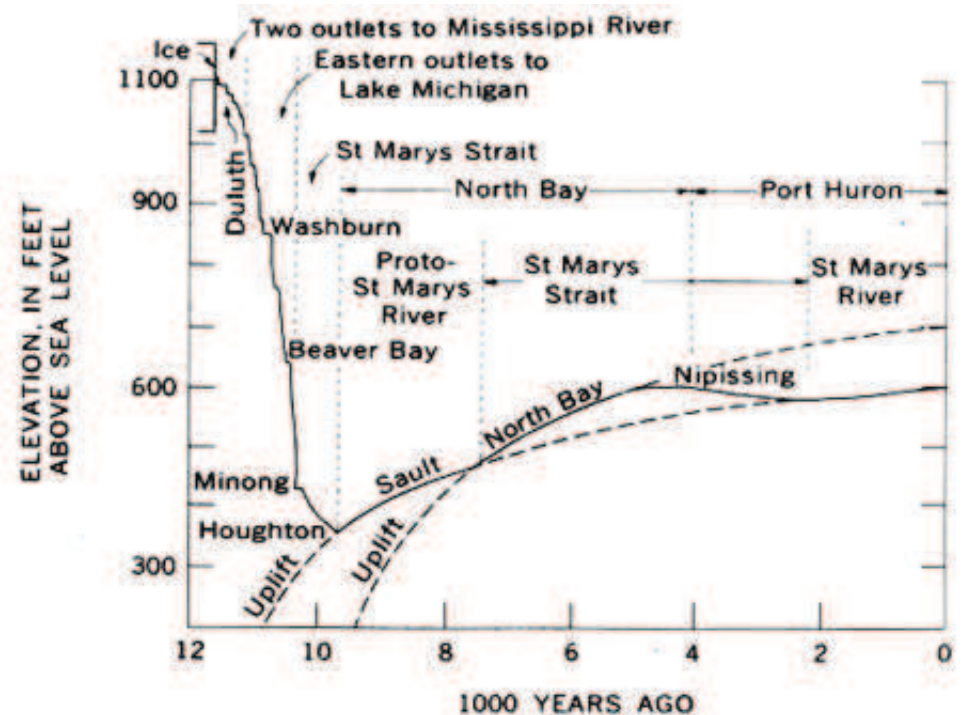
Bathurst Inlet, Nunavit Bay

Glacial isostatic adjustment

But the asthenosphere flows very slowly, so glacial isostatic adjustment is a long process.

The North American Plate is still rebounding from the Last Glacial Maximum, about $20K$ years ago.

Water level in the Lake Superior Basin over the last $12K$ years:

N. K. Huber, *Glacial and Postglacial Geologic History of Isle Royale National Park, Michigan*, Geological Survey Professional Paper 754-A (USGS 1973).

So while glacial isostatic adjustment might eventually lift Nuuk back above sea level, it still seems likely to flood first.