An Estimate of the Volume of Phanerozoic Ice

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We live in an "Icehouse" world. Both the North and South poles are covered by snow and ice. During the last 540 million years, there have been 4 other time intervals characterized by extensive polar ice caps: (latest Ordovician (445 Ma), latest Devonian (360 Ma), the Permo-Carboniferous (350 - 280 Ma), and the late Cenozoic (35 - 0 Ma)). The combined duration of these frigid intervals is approximately 130 million years, or ~25% of Phanerozoic history.

The modern icehouse world is probably the most severe of all icehouse worlds because it is the only time in Earth history when the North and South poles were concurrently glaciated. Using published stratigraphic descriptions (e.g., Montanez & Poulsen, 2013; Fielder, Montanez, & Isbell, 2008; Hambrey & Harland, 1981) and a compilation of lithologic indicators of glacial conditions (tillites, dropstones, & glendonites; Boucot et al. 2013), I have mapped the areal extent of Phanerozoic ice, sea ice, and snow for the time periods when icehouse conditions prevailed. Figure 1 plots the estimated area of snow and ice during Phanerozoic. The volume of Phanerozoic ice is assumed to be roughly proportional to these areas. Since the water removed from the ocean to form continental ice is preferentially enriched in 16O, it is possible to calculate the resulting δ18O/ δ16O composition of the remaining oceanic reservoir. These calculations may be useful when estimating paleotemperatures using the δ18O/ δ16O record preserved in fossils.

% Ice & Snow Cover during the last 540 million years

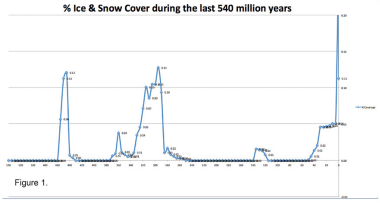
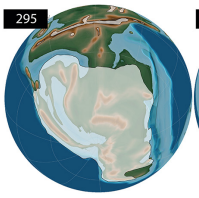
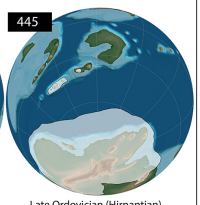


Figure 1.

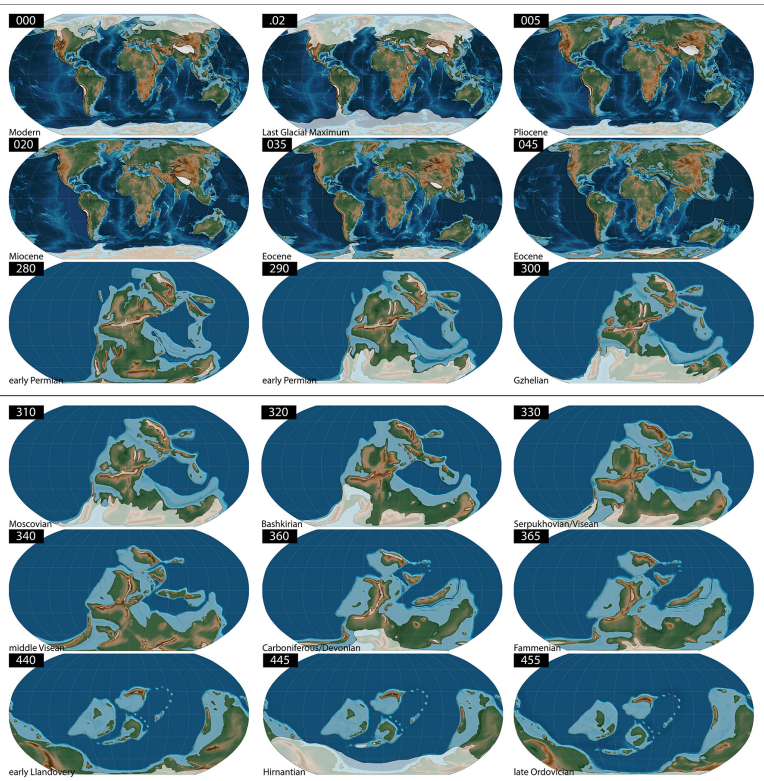
"Map it, and it will all come out right."
- Charles Lapworth (1842 - 1920)



Permo-Carboniferous (Asselian)
Glacial Maximum



Late Ordovician (Hirnantian)
Glacial Maximum



ICE HOUSE EARTH

Humans have evolved during one of the most severe icehouse climates in Earth history. "Icehouse" climate is simply defined as a time when permanent ice covers one or both of the polar regions.

The Phanerozoic temperature curve shown in Figure 2 highlights the other times in Earth history when the polar regions were covered by ice and snow (inverted blue areas). Maximum icehouse conditions occurred 20,000 years ago, during the last glacial maximum (LGM). At that time, ~20% the Earth was covered by snow and ice. Even today, during the winter months 11% of the Earth is covered by snow & ice.

There were other times in the Earth's distant past characterized by icehouse conditions comparable our Modern icehouse: 1) The Late Ordovician Icehouse (LOI), 450 Ma – 440 Ma,
2) the Permo-Carboniferous Icehouse (PCI), 360 Ma – 280 Ma, and the Late Cenozoic Icehouse, 35 Ma – 0 Ma (LCI). Other periods of modest cooling occurred during the Late Devonian (~360 Ma) and the earliest Cretaceous (~130 Ma). Not shown on Figure 2, is the most severe Icehouse of all ti the Neoproterozoic "Snowball Earth". At that time the entire Earth was covered by snow and ice.

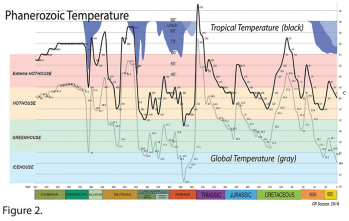


Figure 2.

What Makes an Icehouse World?

As shown in Figure 2, the Earth's climate fluctuates between "Icehouse" and "Hothouse" conditions. What causes the climate to shift between Hothouse to Icehouse worlds? The answer is both simple and complex. The simple answer is that plate tectonic activity and the motion of the continents across the surface of the Earth drives global climate change. This is because plate tectonic activity, including volcanic eruptions triggered by processes deep in the mantle, regulates the amount of C in the atmosphere and the reflectivity (albedo) of the surface of the Earth. The more complex answ is shown by the diagram in Figure 3.

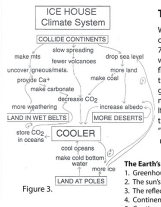


Figure 3.

The Earth's Seven Thermostats

We all use thermostats to regulate the temperature of our homes. Well, think of the Earth as a house with 7 different thermostats. These thermostats can be set to warm the Earth by increasing greenhouse gases or flooding the continents with broad shallow seas. Or, the thermostats can be set to make the Earth cooler by redu greenhouse gases or creating wide desert belts. What's more, some of these thermostats are linked in complex w If you set one thermostat higher, it may cause another thermostat to rise or fall. (If you'd like to learn more abou "Earth's Seven Thermostats", ask Chris to explain Figure 3 more detail.)

The Earth's Seven Thermostats:

1. Greenhouse gases, including CO2.
2. The sun's brightness and orbital modulation of sunlight (Milankovitch C
3. The reflectivity (albedo) of the Earth's surface.
4. Continental Collisions and Mountain-Building (provide a sink for CO2)
5. Continental Rifting, Sea-Floor Spreading & Large Igneous Provinces (control sea level & provide a source of CO2)
6. The latitudinal position of the continents (affects albedo and vegetation
7. Gulf Stream-type circulation and the temperature stratification of the oc