AN ESTIMATE OF THE VOLUME OF PHANEROZOIC ICE

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November 22, 2022

Abstract

We live in an "Ice House" world that has extensive ice cover at both poles. However, it has not always been this way. During the last 540 million years there have been only 4 other time intervals characterized by extensive polar ice caps (latest Ordovician, latest Devonian, Permo-Carboniferous, and late Cenozoic). The combined duration of these frigid intervals was approximately 160 million years, or ~30% of Phanerozoic history. During the remaining 380 million years the Earth lacked permanent polar ice caps, though some winter snow and ice may have accumulated at high latitudes during cool, greenhouse intervals (Silurian-early Devonian, late Jurassic – early Cretaceous). The modern ice house world is probably the most severe of all ice house worlds because it is the only time in Earth history when the North and South polar regions were concurrently glaciated. Using the compilation of lithologic indicators of glacial conditions (tillites, dropstone, & glendonites) compiled by Boucot et al. (2013), I have mapped the areal extent of polar ice caps (millions of km2) for the time periods when ice house conditions prevailed. Using a simple algorithm that estimates the thickness of the ice based on the total area of the ice cap, I have calculated the corresponding volume of continental ice (millions of km3) for each of these time intervals. Converting solid ice to liquid water, the equivalent volume of evaporated ocean water was calculated. Expressed as a percentage of the present-day volume of ocean water (1.35 billion km3), I estimated the amount of water removed from the oceans during each of these ice house intervals. Preliminary results, indicate that the five largest ice volume events were the Hirnantian (444.5 Ma) – 2%, Modern World – 2%, Pliocene (3 Ma) – 2%, early Permian (280 Ma) – 1.5%, and late Miocene (10-15 Ma) – 1.4%. Since the water removed from the oceans by evaporation is preferential enriched in 16O, it is possible to calculate the resulting δ18O of the remaining oceanic reservoir. These calculations may be useful when estimating paleotemperatures from the δ18O record of fossil organisms.

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 ∂18O/ ∂16O composition of the remaining oceanic reservoir. These calculations may be useful when estimating paleotemperatures using the ∂18O/ ∂16O record preserved in fossils.

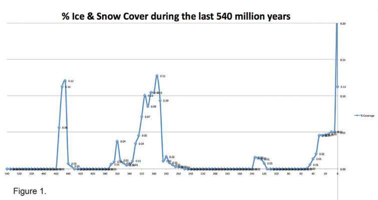
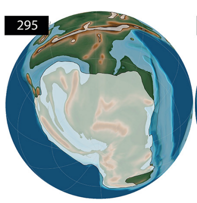
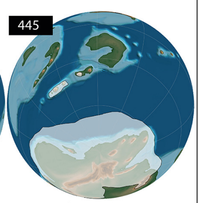


Figure 1.

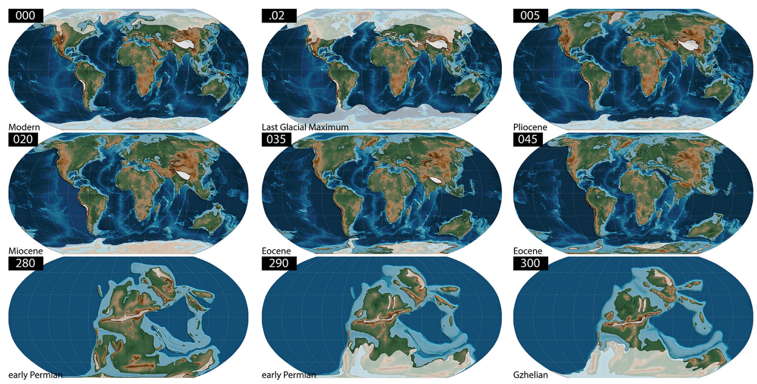
"Map it, and it will all come out right."
- Charles Lapworth (1842 - 1920)

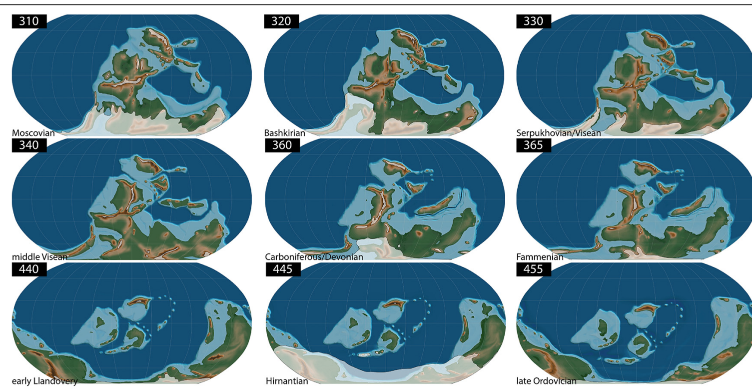


Permo-Carboniferous (Asselian)
Glacial Maximum



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 Phanerozooic 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 tir the Neoproterozoic "Snowball Earth". At that time the entire Earth was covered by snow and ice.

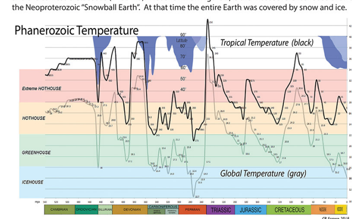


Figure 2.

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 ansv is shown by the diagram in Figure 3.

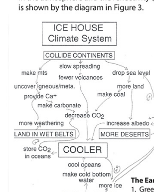


Figure 3.

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 Colisions 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