Natural Climate Change: A Geological Perspective

A presentation to the Seminar on Sustainable Development
NBA 573, BEE 673
Sage Hall B-11

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by
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Truth is so large a target that nobody can wholly miss hitting it, but at the same time, nobody can hit all of it…

Aristotle
Perspective

- Geologic history (4.56 billion years) is to all of recorded human history (6 thousand years) as 1 day is to the last 0.1 seconds of that day: We must use geological evidence to gain perspective.

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.56 Ga</td>
<td>Solar System</td>
<td>24 hrs</td>
</tr>
<tr>
<td>3.8</td>
<td>Amitsog Gneiss</td>
<td>20 hrs</td>
</tr>
<tr>
<td>0.57</td>
<td>Skeletal Creatures</td>
<td>3 hrs</td>
</tr>
<tr>
<td>0.066</td>
<td>Dinosaurs Extinct</td>
<td>21 min</td>
</tr>
<tr>
<td>0.003</td>
<td>Humanoids</td>
<td>1 minute</td>
</tr>
<tr>
<td>0.000006</td>
<td>Recorded History</td>
<td>0.1 sec</td>
</tr>
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</table>
Outline

• Climate Changes:
  – 4.56 GA to 35 Ma (broadest overview)
  – 35 to 0 Ma (descent into and present cold period)
  – 120,000 to 10,800 years (last glacial cycle)
  – 10,800 to 0 years (present interglacial)

• Political Questions
The earth is made clement by 35°C greenhouse warming:

Black Body Temperature of Earth:

\[ R = \sigma T^4 \]

Plank’s constant

energy absorbed by earth from sun \( = \) energy radiated back to space from earth

\[ \left(1 - A\right) R_{\text{sun}} \pi r_{\text{earth}}^2 = R_{\text{earth}} 4\pi r_{\text{earth}}^2 \]

<table>
<thead>
<tr>
<th>Black Body Temperature of Earth</th>
<th>Green House Warming for Earth Temperature = 15°C or Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{\text{earth}} ) = 0.3 (today’s albedo)</td>
<td>(-19.3°C) ( \rightarrow 35°C )</td>
</tr>
<tr>
<td>( T_{\text{sun}} = 0.8 R_{\text{sun}} ) today, ( A = 0.3 )</td>
<td>(4.3°C) ( \rightarrow ) cloud cover important</td>
</tr>
<tr>
<td></td>
<td>(-33°C) ( \rightarrow ) solar radiation important</td>
</tr>
</tbody>
</table>
Glacial conditions seem to have occurred when ocean circulation was blocked by a N-S band of continents.
“Rock Layer that represents the abrupt end Of a 700-million-year old snowball [earth] event. Pure carbonate layers stacked above the glacial deposits precipitated in the warm shallow seas of the hothouse aftermath [of a completely frozen earth].” 4-5 cycles of −50°C to +50°C amy have bred super-adaptable biota and triggered the explosive evolution that followed.
• Global temperature declined from Eocene (50 million years ago) to Pleistocene time (2.5 Ma).

• Ice has covered North America and Europe 15 to 20 times over the last 2 Ma.

• Much of what we know comes from the oxygen isotopic ratio in ice cores and sediments.
Deep-sea Oxygen isotope record for the Last 1.2 Million years

Figure 2-1. A deep-sea oxygen isotope record for the last 1.2 million years shows the cyclic pattern of glaciations and interglacials. From Raymo et al., 1997.

Oceans are isotopically heavy ($^{18}\text{O}$- enriched) when Cold
• Except for 3 ice ages at 800-600, 320-250, and 35-0 Ma, earth has been hotter than present and thermally more stable

• 15 to 20 fairly regular glacial cycles have occurred in last 1.8 million years

• Present temperature highest ~1% of temperatures over last 2 million years

• Glacial cycles becoming more robust and larger amplitude
<table>
<thead>
<tr>
<th>Ka BP</th>
<th>150</th>
<th>140</th>
<th>130</th>
<th>120</th>
<th>110</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
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<tr>
<td>Isotope stages</td>
<td>6</td>
<td>5c</td>
<td>5d</td>
<td>5c</td>
<td>5b</td>
<td>5a</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
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<tr>
<td>PLEISTOCENE</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Saalian</td>
<td>Eem</td>
<td>Lower Weichsel</td>
<td>Middle Weichsel</td>
<td>Upper Weichsel</td>
<td>Holocene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Substantial</td>
<td>Preboreal</td>
<td>Boreal</td>
<td>Preboreal</td>
<td>Downer Dryas</td>
<td>Younger Dryas</td>
<td>Holocene</td>
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</table>

**Figure 1-1.** Late Pleistocene and the Holocene stratigraphy, after Valen et al., 1996. The upper panel indicates approximate age in ka BP. The second panel indicates the marine stratigraphy, i.e. the isotope stages. Uneven numbers denote relatively warm periods, even number relatively cold periods. The last warm period is called Holocene and the last glaciation is called Weichsel in northern Europe, Würm in southern Europe and Wisconsin in North America. A first recognised warm phase during the deglaciation was named Bölling and a second Allerød. Two cold phases are named Older Dryas and Younger Dryas. The beginning of Bölling is dated to 14,3 ka BP, Older Dryas is a short cold event at 14 ka BP, Allerød a warm period ending 12,4 ka BP and Younger Dryas ended and the Holocene begun 10,8 ka BP (Stuiver et al., 1995).
Ice water is light (80 depleted) when cold.
Vostok, Antarctica

Graph showing δD, δ18O, ΔT, and CO₂ over depth and age.
FIGURE 18-5. Diagram of total tree and shrub pollen versus herb pollen from Grande Pile, France, depth scale (m). Radiocarbon dates at various levels are shown, with suggested correlations with the deep-sea oxygen-isotope record (simplified from Woillard and Mook, 1981, Figure 1).

Changes quite sudden

127,000 years BP
Dust Correlates with $\delta^{18}O$

Oxygen isotope and dust record for the period about 8,000 to about 40,000 years ago.
The ECM record has the highest time resolution (15 samples per year) of available measurements, and together with its sensitivity to dust, this makes ECM suitable for investigating the rate of rapid atmospheric circulation changes.

The ECM record discussed here covers the time period 10 to 42 thousand years before present (kyr BP), and allows climate variability to be investigated on timescales of seasons to decades.
• Lots of correlations with climate change:
  – Sea level
  – Temperature indicators (pollen)
  – $\delta D$, $\delta^{18}O$, $\delta^{13}C$, CH$_4$, CO$_2$, dust

• Natural climate change can be very rapid (e.g., years, flickering switch)
Historical Climate Change

- Holocene Maximum (7000-4000 BP)
- Medieval Warm Period (1000-1400 AD)
- Little Ice Age (1400-1860 AD)
- Current Warm Period (1860-present)
See pictures on next slide

Little ice age

No sunspots during parts of little ice age
LIA = little ice age
MWP = Medieval warm period

Before the global warming, in the 1890s the world was, on average, about 0.5 degree cooler than the 1990s. The Sun was in a fury mood, as shown by the low sunspot counts (Opowers).
Royal Meteorological Society, Brucknell
Cosmogenic isotopes more abundant when no sunspots (lower solar wind and weaker magnetosphere shield)
Cosmic Ray Intensity correlates with Sunspot activity

Clouds correlate with cosmic ray intensity (climate connection?)
Solar wind interacts with earth’s magnetic field producing magnetosphere

Nasa image from space shuttle showing solar wind entering pole along magnetic lines of force, producing aurora borealis
• Holocene (current interglacial) changes in climate were:
  – historically significant
  – geologically recorded in areas of high sedimentation (Sargasso Sea)
  – associated with changes in solar activity
A test of the solar cause of Holocene Climate Change:

Sources of ice-rafted material in Canada and Iceland:

Ocean sediment cores record changes in southern limit of icebergs

Bond, Science, 294, 2001
Comparison marine and cosmogenic $^{10}\text{Be}$ timeseries from ice cores indicates solar control

Bond, Science, 294, 2001
Comparison marine and $^{14}$C timeseries from tree rings indicates solar control of iceberg limit

Bond, Science, 294, 2001
Political Questions:
1. Is climate change real?
• Of course!
  – Snowball earth
  – Permial Glaciation
  – Eocene “Indonesian” England → “current” England
  – 15 to 20 ice ages (northern hemisphere glaciations)
  – Holocene optimum
  – Medieval Warm Period
  – Little Ice Age
  – Present Warm Period
3. Should we buy insurance (Kyoto)?

- Insurance against what?
  - Ice age?
  - Global Warming?
  - Warming that will trigger cooling and instability?
  - Solar changes?
  - Avoiding a scheduled ice age?

- CO$_2$ control Expensive!

- Legal collateral damage?
  - Objectivity of science
  - Flexibility to take other approaches (committed careers)

- Opportunity cost
  - Lots of other problems

- Intergovernmental Panel on Climate Change http://www.ipcc
2. Is human activity a factor?

- Perhaps, but we don’t understand how
- Broecker says prodding an angry beast is unwise
- But there are other creatures prodding the beast

Broecker, 2001
Implications for Sustainability?

- Last ~100 yrs unusually climatically stable
- Should not assume this is typical
- Switch is likely to flicker again
My Recommendation

- Make commitments carefully
  - economic rules will be difficult to change, have unanticipated consequences, and affect many careers
  - character of human impact unclear
    - avoiding ice age would be very good, but
    - warming could push us into cooling
    - if sun controls, human actions irrelevant
  - natural changes likely to occur regardless or human actions

- Wait for scientific clarification
  - it will come quickly

- Avoid politization of science
  - majority of scientists always wrong (required for progress)
  - humans tend to over-emphasize own importance
  - objective science best hope
References Cited