CLIMATE CHANGE IN DEEP GEOLOGICAL TIME

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Deep time:

- Geoscientists look into the rock record & their contents (fossils, minerals) to reconstruct the Earth's history
- Earth is 4.6 billion years old
    - Beginning: magma ocean
    - No evolution of complex life until 550 million years ago – single cell organisms until then
    - No plants until 400 million years ago
- If Earth age was turned into a 1 year calendar, humans arrive 11:59:40pm, December 31
    - Humans have been around 2 million years
    - Archaeological and DNA data reveal civilization started in Africa, travelled out to South East Asia, Australia North and South America
    - First Australians arrived 60-100,000 years ago
    - Fundamentally re-engineered the environment and operating conditions

Milankovitch Cycles:

- In the solar system, orbit of the Earth around the sun is not fixed and changes from elliptical shape to less due to eccentricity and precession
    - These are known as Milankovitch cycles
    - Influences amount of energy we receive from the sun
- In geological time frames, they can melt ice sheets and result in rapid sea level changes
    - E.g. South East Asia sea levels present day 110m higher than 20,000 years ago
    - This period was the Last Glacial Maximum (orbital forcing) – the ocean water was sucked up by glaciations and piled up onto the continent, explaining the lower sea levels
    - Created major ice bridges – was one land mass previously

Through History:

- World population growth
    - 1700's industrialisation led to explosion of population growth
    - Immense pressures on natural resources
- Atmospheric CO2
    - Concentration of 350 million exceeded in 1980s – a figure never exceeded previously, however within that time we have already exceeded 400 million
    - Upward trajectory – most atmospheric change is anthropogenic in origin

But why do we care about the effects of climate change?

- Many existing problems will get worse
    - Many natural hazards (bushfires, floods, droughts, etc.) will intensity with climate change
    - Food and water security will become more degraded in many parts of the world, either leading to or accentuating conflicts
        - E.g. Bolivia is a developing, land-locked country whereby water sources are glaciers; however, all melted, thus reliance on imported water from neighboring countries
    - Rising inequality between nations is likely to become worse due to the economic impacts of climate change
    - Land clearing for farming/human housing will amplify the disconnected biogeographic migration pathways for plants and animals → i.e. inability for plants and animals to migrate away from equator
    - Parts of oceanic food chain may collapse due to acidic water, breaking down skeletal structure of planktons

Perspective of Scientists:

- Very much a broad consensus on the link between anthropogenic emissions of CO2 and accelerating climate change
- Cost of inaction likely greater than the cost of action
- Precautionary Principle
    - Human civilization has evolved in a relatively stable climatic period of time, and we may be pushing the environment to 'tipping points'

Phanerozoic Climate Change

- 'Phanerozoic' refers to the last 500 million years. Scientists do not dispute that the Earth has been warmer and cooler than the present, in the past:
    - Greenhouse climates dominate the geological record – it was more common than icehouse conditions, whereby there were permanent ice sheets on land through time
    - 700-800 million years ago there was an episode called 'snowball' whereby entire surface of Earth was covered by ice sheets and the ocean had a 'slushie' texture
    - 50-100 million years ago had very warm conditions
    - 200 million years ago, atmospheric levels were close to 2000 – very warm, and the predicted future scenario exceeds this concentration if we continue to burn all existing fossil fuel

Cenozoic Climate

- 'Cenozoic' refers to the last 50 million years.
- 55 million years ago – early climatic optimum led to long term cooling ever since.
- Superimposed on these long term trends are small perturbations or rapid 'climatic excursions' in the global climate
- Most important of these perturbations = Paleocene-Eocene Thermal Maximum (PETM)
    - Closets thing we had in the geological record to what is experienced today
    - 5-8C warming within 20,000 years
    - 35-50% extinction of benthic foraminifera or microorganisms
- Present vs PETM
    - PETM Carbon emission of 0.3-1.7 Gt per year would have been required for this to occur
    - Today in 2014 - Anthropogenic Carbon emissions of 9.795 Gt per year
    - Therefore, the RATE of change is the bigger concern as has been unprecedented in the past geological record – PETM (2 billion metric tons of carbon annually) vs current (30 billion)

Mass extinctions:

- Whenever there were major perturbations in the atmospheric CO2, associated with mass extinctions
- Five main mass extinctions: end-Ordovician, late Devonian, end-Guadeloupian & end-Permian, end-Triassic, end-Cretaceous
    - Current argument is we are in the 6th
    - End-Permian 250 million years ago: 90% of marine life, 75% of terrestrial life extinct
    - Life returned in different forms as species adapted – thus, some argue that the planet may recover in the future, but without us

Permo-Triassic Extinction:

- Caused by massive volcanism and deep earth process known as 'mantle plumes'
    - Erupted in Siberian Traps
    - Spewed out lava which brought lots of CO2 from the mantle with it – runaway greenhouse gas and release of methane clathrates

    - The magma and lava interacted with buried lime stones and coal in crust → the heat liberated a huge amount of CO_2 in a very short time geologically, causing rapid climate change and animal extinction

End-Cretaceous Extinction:

- 65 Million years ago
- Another mantle plume eruption – ongoing volcanism from Deccan Traps (India), bolide impact in Gulf of Mexico
- Resultant release of CO_2 in atmosphere and rapid climate change, destabilized ecosystem and caused nuclear winter
- Dinosaurs become extinct

Anthropogenic Carbon:

- 35,000 Mt per year
- ~65 X CO_2 input from natural volcanism
    - Latest number from 2014 – 540 mega tons per year
    - However, volcanic CO_2 flux needs more work as the value keeps increasing with additional sampling of volcanically-active regions

Natural/background signals

- Antarctic Ice Core Data
    - Reveals the CO_2 levels in atmosphere in deep time
    - Ice pores in Greenland and Antarctic contain bubbles that capture atmospheric condition at the time that can be measured
- Atmospheric CO_2 from biogenic sediment
    - Composition of shells of fossilized creatures – CO_2 content never exceeded 350 million in the last 2 million years
    - Thus the greatest contributor to climate change is the anthropogenic activities that lead to greenhouse gas emission
- IPCC Projections VS Data
    - IPCC makes projections (predictions) about CO_2 emissions, sea levels and arctic ice extent
    - Very conservative, careful predictions
    - However, their most extreme upper level of predictions is what has actually been happening over past few years

Ice sheet loss:

- Arctic and Greenland ice sheet loss will affect thermohaline circulation (more fresh water)
    - Ice sheet loss is resultant of warm water from equator that is brought under the ice sheet – undercurrents rip the continental icebergs off
    - The more oceanic ice sheets ripped off means weakened support of 'buttressing effect' for continental ice sheets
- Antarctic ice sheet loss will have greatest impact on sea level
    - Note: melting oceanic ice sheets doesn't change sea level – melting continental ice sheets does
    - Larsen ice berg (5000 square metres) will be ~10% of ice sheet area
    - GPS measurements and satellite images used

Ice-free world?

- To predict Earth's deep time climate if dominated by ice-free/low-ice (greenhouse) conditions, more research is needed into the icehouse to greenhouse transitions
- Sea level would be about 65m higher globally
    - 7.5m from Greenland

    - 0.5m from glaciers and ice caps
    - 58m from Antarctica (latest 2013 numbers)

Summary

- Sediments (and ice) passively record atmospheric and oceanic conditions
- The geological record will incorporate evidence of human activity
- Human activity is changing the climate
- The issue is about the RATE of change of the climate with respect to examples in the geological record