The footprints of climate change throughout the geologic record

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The footprints of climate change throughout the history of Earth show clearly that major global warming usually occurs suddenly, often within years, while major global cooling occurs incrementally over centuries to millennia. Periods of global warming are initiated very erratically, not cyclically.

The Dansgaard–Oeschger events, observed in Greenland ice cores, document 25 times of sudden warming followed by slow cooling in the past 120,000 years. On average a cycle lasts 5000 years, but the sequence is very erratic. Warming is often from temperatures typical during the depths of the last ice age to at least 50% of the temperature increase typical at the beginning of the Holocene. Most of these events are contemporaneous with major basaltic volcanism in Iceland.

Fine layers of sediment in the Eocene Green River Formation (53 to 48 Ma) in southwestern Wyoming document sudden warming from a temperate climate similar to Florida today where oil shales may form to a very hot climate similar to Lake Magadi in Kenya where trona is currently precipitating. Surdam (2013) estimates that hundreds of these sequences occurred on average every 5000 years or so.

Detailed studies of Brachiopod Habitat Temperatures throughout the Paleozoic document continual and rapid climate change although sequences as short as 5000 years cannot be resolved with available data (Giles, 2012).

Global cooling of approximately 0.5^{o}C for 3 years has been observed throughout written history to follow most large explosive volcanic eruptions. These eruptions eject water vapor and sulfur dioxide into the lower stratosphere forming sulfuric acid aerosols that spread worldwide within months, that persist for a few years, and whose droplets grow large enough to reflect and scatter sunlight, causing net global cooling. This cooling of the whole ocean surface for a few years is shown by computer modeling to decrease ocean temperatures at depths of 2000 feet for as long as a century after each event (Gleckler et al., 2006). Sequences of many such large explosive eruptions (Gregory et al., 2006) per century are modeled and observed to cool the ocean and the world incrementally into ice-age conditions over tens of thousands of years (Lisiecki and Raymo, 2005).

Sudden global warming, on the other hand, is observed during and immediately following major effusive volcanic eruptions that extrude basaltic lava over large areas without forming significant stratospheric aerosols. In 6 months, starting in August 2014, the volcano Bárðarbunga in Iceland extruded basaltic lava over an area of 84 km^2, the highest rate of lava extrusion since 1783, apparently causing 2015 and 2016 to be the hottest years since thermometers were invented. In 935 AD, the volcano Eldgjá erupted basaltic lava over an area of 800 km^2, leading to the onset of the medieval warm period. Around 230 BC, extrusion of basalts over an area of more than 700 km^2 in the Snake River Plain occurred at the onset of the Roman Warm Period.

Around 252 Ma, basalts covered 7 million km^2 of Siberia, an area equivalent to 87% of the contiguous United States, leading to massive warming and extinction of 96% of marine species and 70% of terrestrial invertebrate species at the end of the Triassic period. Around 201 Ma, basalts of the Central Atlantic Magmatic Province covered an area of 11 million km^2 during a period of major warming at the end of the Triassic period. Around 65.5 Ma, basalts covered an area of 500,000 km^2 in India during major warming at the end of the Cretaceous period. Ernst (2014) documents hundreds of these Large Igneous Provinces that punctuate the geologic time scale with periods of rapid onset and extended warming as well as periods of major mass extinctions.

The balance between explosive and effusive volcanic eruptions driven by plate tectonics appears to have the primary effect on very rapid changes of climate throughout the geologic record. It is not clear what role CO_2 plays.