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TITLE: How Volcanism Controls Climate Change

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ABSTRACT BODY: Large explosive volcanoes eject megatons of sulfur dioxide into the lower stratosphere where it spreads around the world within months and is oxidized slowly to form a sulfuric-acid aerosol with particle sizes that grow large enough to reflect and scatter solar radiation, cooling Earth ~0.5^{o}C for up to 3 years. Explosive eruptions also deplete total column ozone ~6% causing up to 3^{o}C winter warming at mid-latitudes over continents. Global cooling predominates.

Extrusive, basaltic volcanoes deplete ozone ~6% but do not eject much sulfur dioxide into the lower stratosphere, causing net global warming. Anthropogenic chlorofluorocarbons (CFCs) deplete ozone ~3% for up to a century while each volcanic eruption, even small ones, depletes ozone twice as much but for less than a decade through eruption of halogens and ensuing photochemical processes. The 2010 eruption of Eyjafjallajökull, the 2011 eruption of Grímsvötn, plus anthropogenic CFCs depleted ozone over Toronto Canada 14% in 2012, causing an unusually warm winter and drought.

Total column ozone determines how much solar ultraviolet energy with wavelengths between 290 and 340 nanometers reaches Earth where it is absorbed most efficiently by the ocean. A 25% depletion of ozone increases the amount of this radiation reaching Earth by 1 W m^{-2} for overhead sun and 0.25 W m^{-2} for a solar zenith angle of 70 degrees. The tropopause is the boundary between the troposphere heated from below by a sun-warmed Earth and the stratosphere heated from above by the Sun through photodissociation primarily of oxygen and ozone. The mean annual height of the tropopause increased ~160 m between 1980 and 2004 at the same time that northern mid-latitude total column ozone was depleted by ~4%, the lower stratosphere cooled ~2^{o}C, the upper troposphere warmed ~0.1^{o}C, and mean surface temperatures in the northern hemisphere rose ~0.5^{o}C. Regional total ozone columns are observed to increase as rapidly as 20% within 5 hours with an associated 5 km decrease in tropopause height.

Changes in the rates and types of volcanism have been the primary cause of climate change throughout geologic time. Large explosive volcanoes erupting as frequently as once per decade increment the world into ice ages. Extensive, effusive basaltic volcanism warms the world out of ice ages. Twelve of the 13 dated basaltic table mountains in Iceland experienced their final eruptive phase during the last deglaciation when deposits of sulfate and volcanic ash fell over Greenland at their highest rates. Massive flood basalts are typically accompanied by extreme warming, ozone depletion, and major mass extinctions. The Paleocene-Eocene Thermal Maximum occurred when subaerial extrusion of basalts related to the opening of the Greenland-Norwegian Sea suddenly increased to rates greater than 3000 cubic km per km of rift per million years. Dansgaard-Oeschger sudden warming events are contemporaneous with increased volcanism especially in Iceland and last longer when that volcanism lasts longer. Sudden influxes of fresh water often observed in the North Atlantic during these events are most likely caused by extensive sub-glacial volcanism. The Medieval Warm Period, Little Ice Age, major droughts, and many sudden changes in human civilization began with substantial increases in volcanism. Extensive submarine volcanism does not affect climate directly but is linked with increases in ocean acidity and anoxic events.

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INDEX TERMS: 8408 VOLCANOLOGY Volcano/climate interactions, 0370 ATMOSPHERIC COMPOSITION AND STRUCTURE Volcanic effects, 1605 GLOBAL CHANGE Abrupt/rapid climate change, 0360 ATMOSPHERIC COMPOSITION AND STRUCTURE Radiation: transmission and scattering.

Additional Details

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