2008

Paleontological Parks and Global Change

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Dunn, Regan; Fremd, Theodore; and Smith, Matthew, "Paleontological Parks and Global Change" (2008). *U.S. National Park Service Publications and Papers*. 21.
https://digitalcommons.unl.edu/natlpark/21

Published in Weber, Samantha, and David Harmon, eds. 2008. Rethinking Protected Areas in a Changing World: Proceedings of the 2007 GWS Biennial Conference on Parks, Protected Areas, and Cultural Sites. Hancock, Michigan: The George Wright Society.

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Introduction

Paleontology, the study of organisms and processes preserved in a geologic context, can be practiced in over 180 units of the national park system. Much more than just the collecting of different kinds of fossils to be stored in a museum, the study of the fossil record is the only means by which we can understand past climatic changes and the effects of such changes on biotas (changes such as extinction, speciation, immigration, and evolutionary events). In combination with the fossil record, comprehensive studies of geological, sedimentological, and geochemical records can inform us about other aspects of major climatic perturbations in earth history, such as the causation of climatic shifts, including tectonic events (i.e., mountain-building, plate collisions, and continental movements), greenhouse gas events, and a myriad of other natural processes occurring on geologic timescales.

There is now incontrovertible evidence that CO_2 concentrations are at the highest level in the last 650 thousand years (ky) (Petit et al. 1999; IPCC 2007). Environmental impacts associated with rising levels of elevated CO_2 are being recorded nearly everywhere on earth. Sea and land temperatures are rising rapidly, sea level is increasing, plant and animal ranges are shifting to higher latitudes and higher elevations, acidification of the oceans is occurring, global ice-volume is decreasing, and rates of extinction are unprecedented (IPCC 2007).

Unfortunately, there are individuals, media spokespersons, government officials, and at least one scientific society (American Association of Petroleum Geologists; AAPG 2007) who dispute that current global warming is the result of human activities. Many skeptics of anthropogenically induced global warming rationalize their arguments with the idea that "[t]here have been too many global heating and cooling cycles long before man came along and industrialized the planet" (Rush Limbaugh, August 15, 2005) for this warming to be caused by humans alone. One of the key contributions paleontology can make is an examination of the fossil record to determine whether the processes occurring today are within the natural range of variability recorded in earth history prior to the evolution of *Homo sapiens*. Specifically, how do the rates of current and predicted factors of climate change (i.e., greenhouse gas concentrations, rising sea and air temperatures, rising sea level, decreasing global sea-ice volume, etc.) compare with events preserved in the fossil record?

Homo sapiens has only existed on this planet for about 150,000 years. Our species evolved in an "icehouse" world, where carbon dioxide concentrations are relatively low

(180–380 ppm), where vast glaciers cover the poles, and where a large temperature gradient between the poles and the equator exists. Global climate over the last 2 million years (the Pleistocene epoch), has largely been influenced by orbital forcing mechanisms (Milankovitch cycles) in concert with global ice-volume, sea level, and ocean circulation patterns that have kept the earth in a period of glacial/interglacial cycles. Such "icehouse" conditions developed approximately 34 Ma (million years ago) during the earliest Oligocene, when global CO_2 levels dropped to near present levels, oceans and air temperatures cooled, and large-scale ice-sheets formed on Antarctica (Zachos et al. 1996; DeConto and Pollard 2003). Prior to 34 Ma, earth experienced "greenhouse" or ice-free conditions that had existed since the last major deglaciation 260 Ma. "Greenhouse" climates have atmospheric CO_2 concentrations that are 500 ppm and higher.

Search for an analogue in the fossil record

Paleoclimatologists use changes in ratios of certain stable isotopes derived from various sources such as fossilized shells, teeth, bones, carbonate nodules, and leaf waxes as proxies for climatic parameters. Concentrations of $\delta^{13}C$ are used as a proxy to measure ancient CO_2 concentrations, while $\delta^{18}O$ concentrations indicate ancient temperatures. A nearly continuous record of stable isotope data provides global climate CO_2 and temperature curves for the last 65 million years (see Zachos et al. 2001). Within that time span is a pronounced greenhouse gas event known as the Paleocene-Eocene Thermal Maximum (PETM) that occurred 55.8 Ma. This event is marked by a dramatic negative excursion in $\delta^{13}C$, indicative of a large release of methane (CH_4) and/or CO_2 into the atmosphere within a 10,000-year span. Although the exact source of the greenhouse gas spike is unknown, sources that have been implicated included the dissociation of methane hydrates (Dickens et al. 1995), massive volcanism beneath organic-rich strata in the Norwegian Sea (Svensen et al. 2004), evaporation of epicontinental seaways (Higgins and Schrag 2006), and extensive burning of peatlands (Kurtz et al. 2003). A pronounced increase in global temperature was coincident with the greenhouse gas release. Middle and tropical latitudes experienced a temperature increase between 5–10°C (Wing et al. 2005), while high latitudes experienced an 8–10°C increase in sea surface temperature (Zachos et al. 2003).

Past versus present comparisons

The PETM event is considered by many to be analogous to our present increases in greenhouse gases. Comparisons of the rates of greenhouse gas emissions, coincident temperature increases, and biotic responses from the PETM event to current conditions provide the information necessary to evaluate whether the current conditions are within the natural range of variability known from the last 65 million years.

CO_2 past and present. Records of $\delta^{13}C$ from marine fossils and sediments indicate that during PETM times, CO_2 levels increased from approximately 600 to 2800 ppm in 10 ky (Pagani et al. 2005). Despite some inconsistencies between the amount of $\delta^{13}C$ needed to raise temperatures to PETM levels, the extreme temperature increase, and actual measured values of CO_2 from the marine record (see Pagani et al. 2006), a striking fact emerges. The estimated volume of CO_2 and methane released during this major geologic event pales in comparison to modern levels of CO_2 released from anthropogenic sources.

For instance, during the PETM it is estimated that 0.2 gigatons (Gt) of CO_2 per year were released into the atmosphere (Gibbs et al. 2006). Current levels of anthropogenic CO_2 release, including consumption of fossil fuels and land use change is 8.8 Gt per year (IPCC 2007).

At the current rate of atmospheric CO_2 emissions, 1.9 ppm per year, we could reach PETM levels of atmospheric CO_2 (approximately 2500 ppm) within 1115 years. This estimate is potentially conservative given the current and anticipated acceleration of CO_2 emissions. The IPCC 2000 *Special Report on Emissions Scenarios* (SRES) suggests within their worst-case scenario that we could reach atmospheric CO_2 levels as high as 1000 ppm by the end of this century.

Temperature past and present. Proxy data for ancient temperature based on $\delta^{18}O$ records from marine fossils and temperature estimates made from fossil plant assemblages from the Bighorn Basin of northern Wyoming indicate that during the PETM surface air temperature increased from 5–10°C in approximately 10 ky concurrent with the rise of CO_2 (Wing et al. 2005). It is predicted that surface air temperature will rise anywhere from 1.1–6.4°C by 2100 (IPCC 2007). Predicted temperature increases in the next 100 years exceed those rates attained during the PETM by a hundredfold.

Effects on biotas. The most catastrophic biotic impacts of the PETM event occurred in the oceans. Sedimentological evidence indicates that acidification of oceans occurred, causing major extinctions among benthic foraminiferan species. Surprisingly, terrestrial vertebrates didn't experience high levels of extinction, but major immigration events from Asia to North America occurred over high-latitude land bridges during the PETM event. These groups include many lineages of rodents, perissodactyls, artiodactyls, and creodonts. Terrestrial vegetation also showed changes in geographic distribution that occurred in less than 10 ky. Plant taxa previously known from the Gulf Coast region and Colorado appeared in northern Wyoming during the PETM event, probably as a result of the rapid temperature rise (Wing et al. 2005).

The effects of the current warming trend on extant populations have been modeled taking several factors into account (see Thomas et al. 2004). These factors include the variable rates of extinction expected among several groups of plants and animals depending on their specific habitat needs, the presence or absence of restrictions to range shifts such as human-made barriers or altered habitats, and the effects of temperature rise on different ecosystems. Thomas et al. (2004) provide estimates of extinction rates for the year 2050 that range from 15–37% of all species. Similarly, the IPCC (2007) projects that we will see the extinction of 20–30% of earth's species by 2100. With an estimated total diversity of 10–30 million species on earth (Erwin 1991) that is a loss of 2–11 million species by the end of the century.

The PETM is considered to have been one of the most rapidly occurring greenhouse events in earth history. However, is the PETM really a good analogue for our modern climatic crisis? With respect to CO_2 emissions and transient temperature increases, anthropogenic forces appear to be altering the earth's carbon cycle and global climate at rates one hundredfold faster than the PETM event. One major difference between the PETM and the current crisis is the rate of extinction. The PETM event shows very little perturbation to terrestrial ecosystems besides changes in dispersal patterns and shifts in species' ranges. The high rates of extinction expected in the next 100 years have the potential to far surpass those recorded from the PETM. Why? The PETM greenhouse event occurred in a greenhouse world free of human constraints on plant and animal movements. In an ice-free world, the effect of a warming event should have less impact on biotas that are adapted to warm climates, and are able to move about freely to find suitable habitat. The pressing question we need to address now is: What happens when an icehouse world transitions to a greenhouse world very rapidly? How will rapid temperature increases affect cold-adapted ecosystems whose species' ranges are additionally restricted by human-altered land surfaces? The last time earth experienced a major greenhouse event in an icehouse world was during the late Permian, approximately 250 Ma. This event was the most catastrophic extinction event in earth history, during which about 95% of both marine and terrestrial species on earth perished (Montañez et al. 2007). It is significant to note that there were no human-induced barriers to dispersal 250 million years ago.

The National Park Service and global climate change

The national park system, especially the more than 180 units containing significant fossil resources, is in a unique position to both conduct research and educate the public on what the geological record informs us about our current climatic situation. Several of the paleontology parks in the western U.S. contain rocks that span significant climatic perturbations. For instance, taken together, Fossil Butte National Monument (Wyoming, 50 Ma), John Day Fossil Beds National Monument (Oregon, 45–5 Ma), Badlands National Park (South Dakota, 37–28 Ma), Florissant Fossil Beds National Monument (Colorado, 34 Ma), Agate Fossil Beds National Monument (Nebraska, 20 Ma), and Hagerman Fossil Beds National Monument (Idaho, 3–4 Ma), contain fossil resources that span almost the entire Cenozoic (the last 65 Ma). Study of these fossil resources helps us understand how terrestrial environments have changed through time. For instance, a nearly continuous section of geologic time spanning 45–5 Ma is represented by fossiliferous strata in the John Day Basin. Over that 40-million-year span, one can observe shifts in climates from subtropical forests, where alligators and palm trees thrived, to the modern-day near-desert environment inhabited by coyotes and sagebrush. Through that 40-million-year interval, climate has fluctuated and species have evolved at various rates (mammals, for example, average 1.5 my for one species to evolve into another morphologically distinct species). When plants and animals can evolutionarily keep pace with the rate of climatic change, they can adapt; when the rates of climate change exceed organisms' abilities to adapt, mass extinctions occur.

National parks are also well positioned to facilitate and interpret the science of climate change and its potential impacts. Important geological repositories of climatic and paleoenvironmental data are afforded permanent protection. Parks serve as *in situ* laboratories and learning centers that are accessible to everyone. The paleontological parks, especially, are ideally situated to interpret not only the particular paleoclimatic story of their fossil resource, but are also a framework that informs the public about past changes in climate and how they relate to anthropogenic changes in the modern world. This message is one that can be interpreted at all units of the national park system, not just the paleontological parks. Through scientific research, curation, public education, and leading by example, the National Park Service should become a leader in public education on climate change issues.

Virtually all national parks are experiencing environmental changes attributable to increasing global temperatures. Whether these changes are infestations of exotic species, extinction or extirpation events, shrinking glaciers, bleached coral reefs, or severe drought, seeing is believing. It is crucial for the public, our stakeholders, to understand that these potentially irreversible changes are occurring even in protected areas. Humans are certainly the first species in earth's long history to cause, and be cognizant of, the alteration of the planet's physical and chemical properties. These significant alterations risk the existence of most species on the globe, including our own. We also are the first species that can change our behaviors conscientiously to limit our impact on the planet and the organisms that have fostered our existence for so long.

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