Using the Sedimentary Record to Understand Climates of the Past

Earth Gauge
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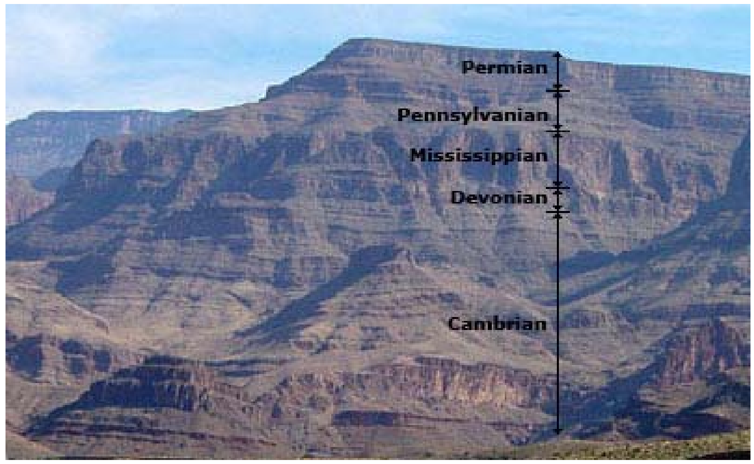
GEOLOGY: AN INTRODUCTION

An understanding of how the planet's climate has changed over centuries, millennia, and millions of years, and how these changes in global atmospheric circulation changed the climate in a specific location, provides a crucial analog for modeling how the planet will respond to predicted climate forcings. One method used to gain such an understanding is an analysis of sedimentary deposits, or the layers of rock (also known as *strata*) that accumulate over time as a result of erosion of other rocks and the activities of living organisms.

The validity of this method is based on two key assumptions: the **law of uniformitarianism**, or the principle that all other things being equal, rates of erosion and sediment deposition were no faster or slower than they are today, and the **law of superposition**, or that the farther down you dig, the farther in the past it was that the layers you are uncovering were deposited. Paleoclimatologists (climatologists who study climate prior to the age of weather records) analyze the make-up and relative sizes of sediment layers, and the fossils and relative isotope concentrations (the concentrations of atoms of the same element, but with different atomic masses) they contain, to make inferences about the predominant conditions when the sediments were deposited. Below are several examples of how this process works.



Strata near Lake Mead illustrate the law of superposition, with the more recently deposited formations on the top. (USGS)

Coral Core Samples: Coral reefs have existed in shallow and warm ocean waters for about 500 million years. Annual coral growth patterns are sensitive to the climatic conditions of that year. For example, in the Gulf of Mexico, winter water temperatures are cooler during positive phases of the Pacific-North American Pattern, or the periodic change in the strength of the high and low pressure centers over North America and the Pacific. The difference in water temperature between positive and negative phases is about five degrees Fahrenheit, and a drop in water temperature of this magnitude means an average decline in annual coral growth of two millimeters. Coral accumulates layers over centuries and millennia, with living corals essentially growing on top of their ancestors' remains. Once the climatic factors that determine how much a particular coral colony will grow in a given year are understood, core samples can be taken and the relative length of the annual layers provides a gauge for the climate variability over the centuries, and in extreme cases millennia (an 11.5 foot coral sample from the south Pacific corresponded to 271 years of accumulation). Corals also accurately record isotopic ratios present in seawater, which fluctuate along with the climate. Two key isotope ratios are:

- **Strontium to Calcium:** In the eastern South Pacific, sea surface temperatures (SSTs) determine the ratio of strontium to calcium in the water. The ratio of these two elements deposited in different coral layers serves as an SST proxy, with higher calcium levels corresponding to warmer waters.

- **Heavy to Light Oxygen:** ^{18}O (oxygen with an atomic mass of 18) becomes relatively less common in sea water as it warms, and relatively more common as it cools, with the opposite being the case for ^{16}O (the more common type of oxygen, with an atomic mass of 16). Analysis of the relative proportions of these isotopes in core samples from the western tropical Pacific have been used to reconstruct the behavior of the El Niño Southern Oscillation (ENSO).

Limestone/Marble Deposits: Over time, coral deposits form into limestone, and if tectonic plate movements cause that limestone to be heated, it is transformed into marble. The presence of limestone or marble deposits in the strata can provide a relative date for when that location was submerged under a warm ocean.

Fossils: Wyoming's Green River Formation, which has been dated to about 53 million years ago, contains fossils of cycad, palm, hibiscus, and ginger leaves. All of these plants require temperatures above freezing year-round. Deposits dating from the same time (known as the Eocene epoch) in Arctic Canada contain stumps, needles, and seeds of a close relative of the redwood, and deposits in the high arctic contain the remains of ginkgos and cypresses. None of these species would be able to survive at such high latitudes in today's climate, and it has been concluded that the Eocene Earth was significantly warmer than the present. Pollen contained in ancient strata is also useful for studying climates of the past, as pollen is abundant (there are plenty of pollen samples in almost all terrestrial deposits), sporopollenin (the substance that makes up the body of pollen strands) is highly resistant to decomposition, and individual types of pollen strands are recognizable and unique. By analyzing deposits under a microscope, paleopalynologists (scientists that study ancient strands of pollen) can determine not only which plants lived in the area when the deposits were laid down, but also the relative abundance of each species based on the relative abundance of each type of pollen strand.

A palm fossil from Wyoming's Green River Formation. (USGS)

Paleopalynology has been used extensively in the Amazon Basin to study the climate shifts that are reflected in the relative proportions of the basin covered by tropical forest, savannah, and grassland (biomes that prefer different climatic conditions).

Oceanic Deposits: Some examples of using deposits on ocean floors for paleoclimate research include:

- **Drop stones:** In high latitude ocean sediments, small pebbles called drop stones appear in sediments dated to about two or three million years ago. These drop stones were picked up by glaciers moving southward across land towards the Atlantic and Pacific Oceans. The glaciers then broke off into icebergs that melted, dropping the pebbles to the ocean bottom. The locations of these drop stones have been used to determine the southern extent of the ice age glaciers that formed over the oceans.

- **Foraminiferal Concentrations:** The relative concentrations of foraminifera (single celled marine organisms with bodies composed of durable calcium carbonate) fossils indicate climate shifts. For example, between January and March in the Cariaco Basin off the coast of Venezuela, easterly trade winds strengthen and cause an upwelling of nutrient rich deep water, which results in a bloom of the foraminiferan species *G. bulloides.* The relative abundances of *G. bulloides* skeletons in sediment core layers serve as a proxy for the strength of the upwelling that occurs, and the upwelling strength serves as a proxy for the strength of the trade winds and the general state of the circulation occurring in the North Atlantic.

Speleotherms: Limestone caverns, which are excavated out over time by slightly-acidic rainwater, contain mineral deposits known as speleotherms. As water drips into the caverns from the ceiling, it deposits minerals it picked up along its journey from the ground into the cavern. These mineral deposits are called speleotherms, and can be shaped like icicles and suspend from the ceiling (stalactites) or can form on the floor (stalagmites). The wetter the climate is, the more water travels into the cavern and the more the speleotherms will grow. Interruptions in water flow (resulting from a severe drought) allow dust to accumulate on the deposits, which causes the exterior of the speleotherms to look "dirty." Analyses of speleotherms from Carlsbad Caverns in New Mexico and 100 or so nearby caves have been used to piece together past climate changes in the American Southwest, with the "dirty" layers corresponding to severe drought events. While analyzing the speleotherm layers can provide a relative date of climatic changes, speleotherms are particularly useful because the water flowing into the caves picks up uranium along the way. Uranium decays into thorium at a uniform pace. Thus, the ratio of uranium to thorium in the different speleotherm layers can be used to give an absolute date for various climate changes.

Sources

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