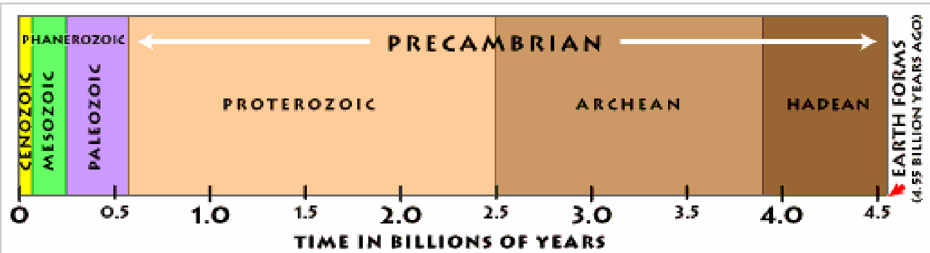
Earth Gauge
A National Environmental Education Foundation Program

Paleoclimate: Precambrian Time

The world as we know it, with continents, an oxygen-rich atmosphere and multicellular organisms did not always exist. Learn more about the first four billion years of Earth's history.

BASIC EARTH HISTORY

By 4.5 billion years ago (Ga, hereafter) Earth was a discrete mass orbiting the Sun. By 4.4 Ga, the planet had an atmosphere, a brittle outermost layer of rock (the lithosphere), and at least some of the surface was covered with water (the hydrosphere). A younger and more chaotic solar system corresponded to frequent impacts with asteroids and comets, some which were large enough to vaporize all of Earth's water. One of these impacts probably broke a chunk off of the Earth (which became the moon) and may have resulted in the Earth having a high obliquity, or a large difference between the planet's rotational axis and its orbit around the Sun (as high as 54 degrees, about double that of modern Earth). This extreme obliquity and a weaker Sun would lead to planet-wide glaciations later, but for the first two billion years, Earth's oxygen-poor, greenhouse gas-rich atmosphere was warmer than the atmosphere of today.



Left: Precambrian time, between the Earth's formation and the appearance of multicellular life, constitutes the vast majority of Earth's history. Image USGS.

LIFE AND CLIMATE

At some point between 4.2 Ga and 3.5 Ga, life established on Earth. As life developed, it shaped the chemistry of the atmosphere and oceans, thus shaping Earth's climate. When something happens to alter the concentrations of nutrients present on Earth's surface (i.e. an asteroid hits or a period of frequent volcanic eruptions occurs), a time of intense natural selection amongst single-celled prokaryotes (mostly bacteria, which do almost all of the planet's nutrient cycling) lasting centuries to millennia is necessary for a new self-sustaining equilibrium state to be reached.

One consequence of oxidation was the convesion of iron disolved in the ocean water into iron oxide, or rust, which formed beds on the ocean bottom between 2.4 and 1.8 Ga. Above: one of these beds in modern day Australia. Image NSF.

FROM OXYGEN-POOR TO OXYGEN-RICH, ca 2.4 Ga

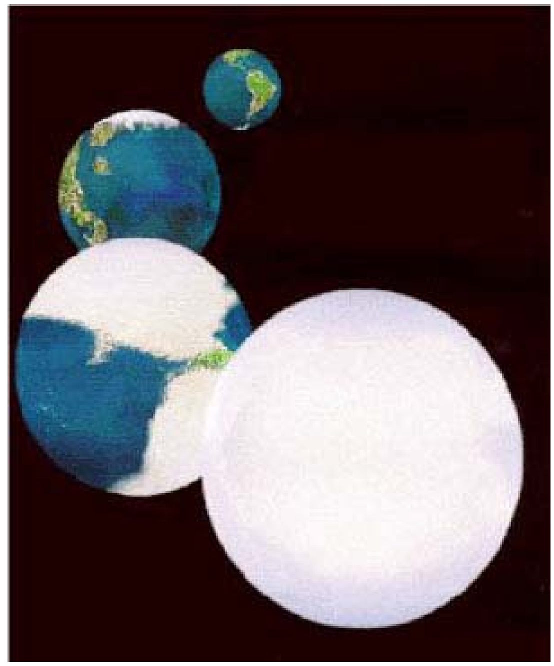
Three interrelated events occurred as atmospheric concentrations of oxygen increased rapidly:

- organisms began to convert atmospheric nitrogen (N_2) into forms useful to life;
- an ozone layer shield developed, which prevents DNA-disrupting UV radiation from reaching the surface; and
- oxygen-carbon photosynthesis, or the system that uses the Sun's energy to convert water and carbon dioxide into sugar and oxygen, became common.

Other circumstances surrounding this transition include changes in the make-up of volcanic gasses, more volcanoes erupting on land than under the ocean, the escape of hydrogen into space, the development of continental masses that sequester carbon, and fewer volcanic eruptions in general. On a global scale, photosynthesis and respiration (respiration is the opposite of photosynthesis, and uses sugars to power cells while releasing carbon dioxide) came into balance over time, promoting a self-sustaining atmospheric composition and a stable climate.

HOT HOUSE vs. SLUSHBALL: FINDING A BALANCE

As long as mantle convection (the flow of molten rock in the earth's interior from the central core to the lithosphere and back again) occurs at a slower rate than oxygen production, the transition from a greenhouse gas-dominated to an oxygen-dominated atmopshere is a one-way process. Since this transition (known as the "Great Oxidation Event") happened at around 2.4 Ga, Earth's atmosphere has always been oxygen-dominated. During the Proterozoic Eon (the age of microscopic life, which spans the time from the Great Oxidation Event to about 540 million years ago), "snowball" or "slushball" Earth events, which were characterized by periods when ice extended into the equatorial latitudes, occurred. There is evidence that "slushball" conditions occurred as early as 3.0 Ga, possibly as a consequence of greenhouse gas concentrations being so high that a "haze" developed in the upper atmosphere and shielded the Earth from much of the Sun's energy. This glaciation was relatively short-lived. The Great Oxidation Event at 2.4 Ga coincided with a slushball event that lasted for several hundred million years. During this period, cycles of glaciation/deglaciation occurred on a period of between four and 30 million years. While the oxidation of Earth's atmosphere made colder temperatures possible, part of this slushball state may have been due to extreme seasonality/obliquity (54 degrees), which promotes glaciation.

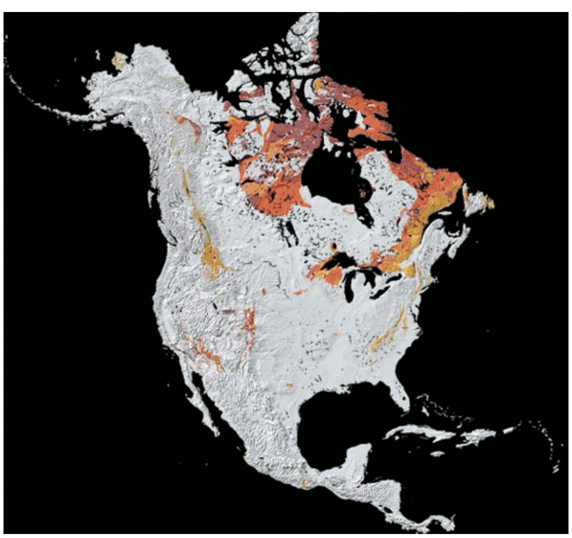


Above: An artist's depiction of the possible levels of Proterozoic glaciation. Note that the complete freeze-over of Earth has been shown to be unlikely. Image NASA

Of course, this glacial state did not last forever. One theory suggests that the amount of oxygen that can be dissolved in seawater is dependent upon the planet's temerature. When the temperature becomes too low, the oceans hold less oxygen, which then bonds to organic carbon (carbon bonded to hydrogen) stored in the seawater and is released as carbon dioxide into the atmosphere. This increase in carbon works to warm the planet and take the Earth out of the slushball state. High concentrations of carbon dioxide are countered by the tendency of plate tectonics to sequester carbon in continental masses, as well as for natural selection to establish a balance between oxygen and carbon concentrations. The transition to and from slushball Earth states were likely the most severe climate fluctuations recorded in the geologic record. Sediments dating to periods when the Earth transitioned from the slushball to warmer climates are characterized by large ripples indicative of high winds and relatively short ocean wave periods; in short, the world was much stormier during these transition events than it is today.

THE RISE OF MULTICELLULAR ORGANISMS

Earth's climate was relatively stable and free of large-scale glaciation events from about 2.0 Ga until about 800 million years ago. It is likely that a concentration of continental land masses at high latitudes promoted large scale glaciations. These events stopped at about 540 million years ago, a time that corresponds to the oxidation of the deep oceans and much of the organic carbon stored there. This time has been recognized as the start of the Phanerozoic Eon (the age of visible life), or the age when single celled organisms merged into multicellular organisms, which resulted in an explosion of diversity and ultimately the development of life as we know it today.



Left: North American continental rock formations that developed between 2.5 Ga and 540 million years ago. Image courtesy of nationalatlas.gov. Right: What is today western North America at the end of the Proterozoic . Image USGS

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