
Earth
Distance: 19,703 km
Radius: 6,378.1 km
Apparent diameter: 28° 18' 37.8"
2006 09 09 09:19:08 UTC
Real time
SNOWBALL EARTH
Speed: 0.00000 m/s
Follow Earth
FOV: 25° 29' 37.2" (1.00×)

SNOWBALL EARTH: DEFINITION

The term "**Snowball Earth**" denotes a scientific theory suggesting the complete coverage of the Earth's surface by ice.

Between 800 and 550 million years ago, our planet is believed to have undergone at least two (Sturtian and Marinoan), possibly three, extensive glacial phases.

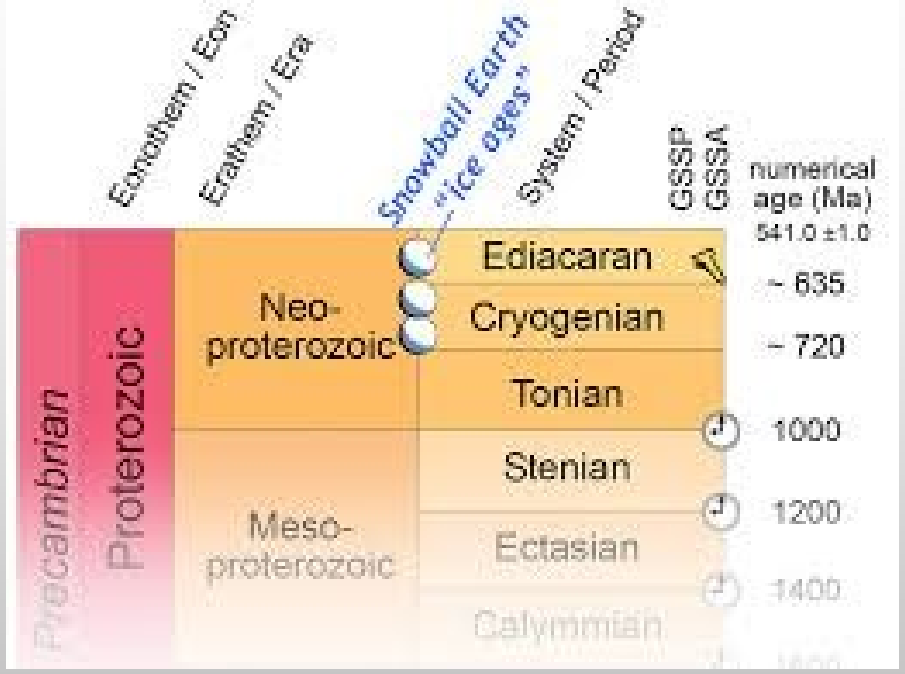
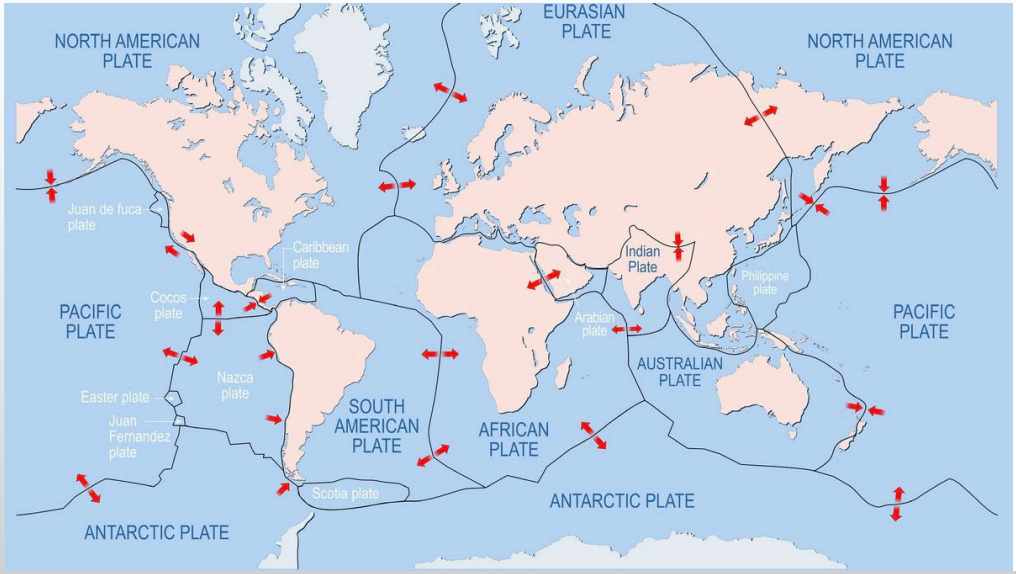


Plate tectonics is the scientific theory that explains the **movement of Earth's lithospheric plates** on the fluid-like asthenosphere beneath them. **This movement causes the formation of continents, ocean basins, mountains, earthquakes, and volcanic activity, shaping the planet's surface over time**

SNOWBALL EARTH: POSSIBLE CAUSE



Map of the present-day tectonic plates

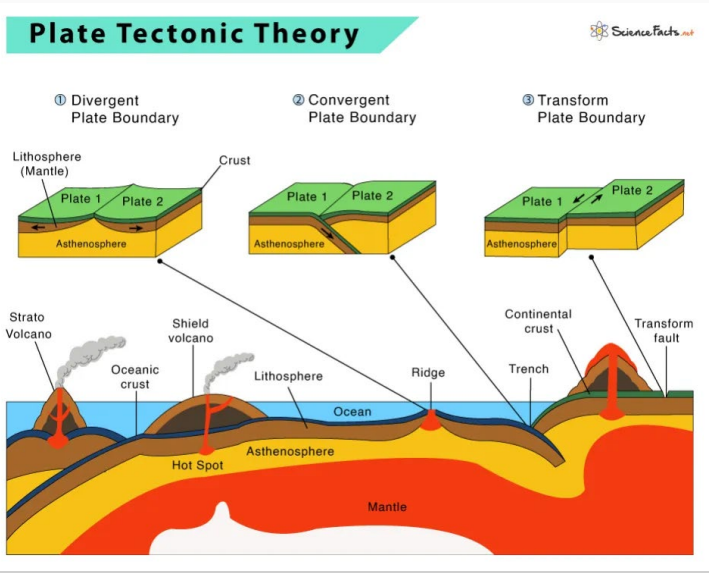


Plate Tectonic Theory

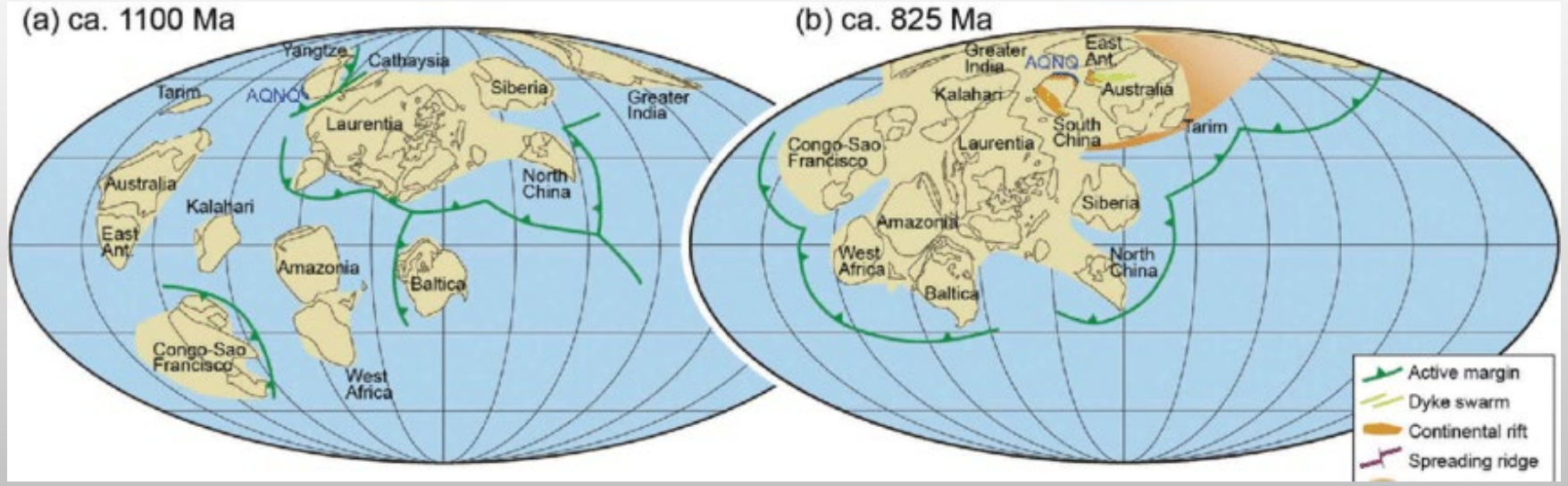
Plate tectonics

Plate tectonic is the scientific theory that explains the movement of Earth's lithospheric plates on the fluid-like asthenosphere beneath them.

This movement causes the formation of continents, ocean basins, mountains, earthquakes, and volcanic activity, shaping the planet’s surface over time.

SNOWBALL EARTH: POSSIBLE CAUSE

The proposed trigger for this significant climatic shift is attributed to the **fragmentation of the supercontinent Rodinia**.



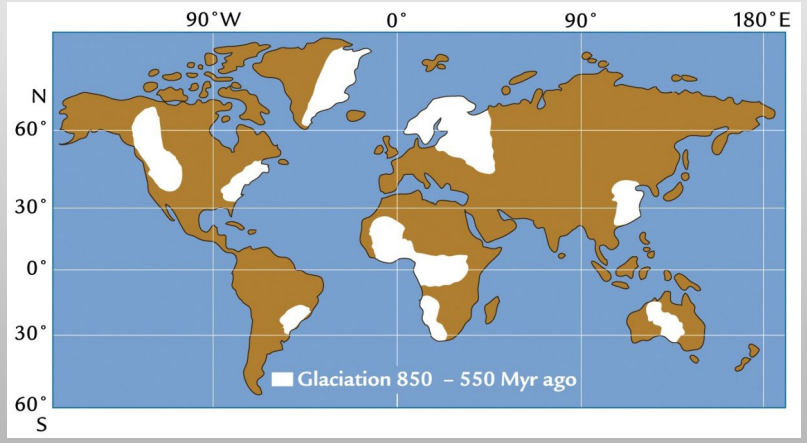
Rodinia, which formed around the start of the Neoproterozoic (approximately 1.0 billion years ago), began to break apart during the Cryogenian period (around 0.8 billion years ago).

This disintegration phase resulted in **vigorous rift activity, accompanied by a notable increase in basalt production**. Basalt, being highly porous, facilitated intense weathering phenomena.

GLACIAL DEPOSITS (SIR DOUGLAS MAWSON)


Sir Douglas Mawson
(1882-1958)

Australian explorer and geologist Douglas Mawson devoted much of his career to studying Neoproterozoic stratigraphy in South Australia. He identified extensive glacial rock (tillite) deposits and proposed the idea of global glaciation.

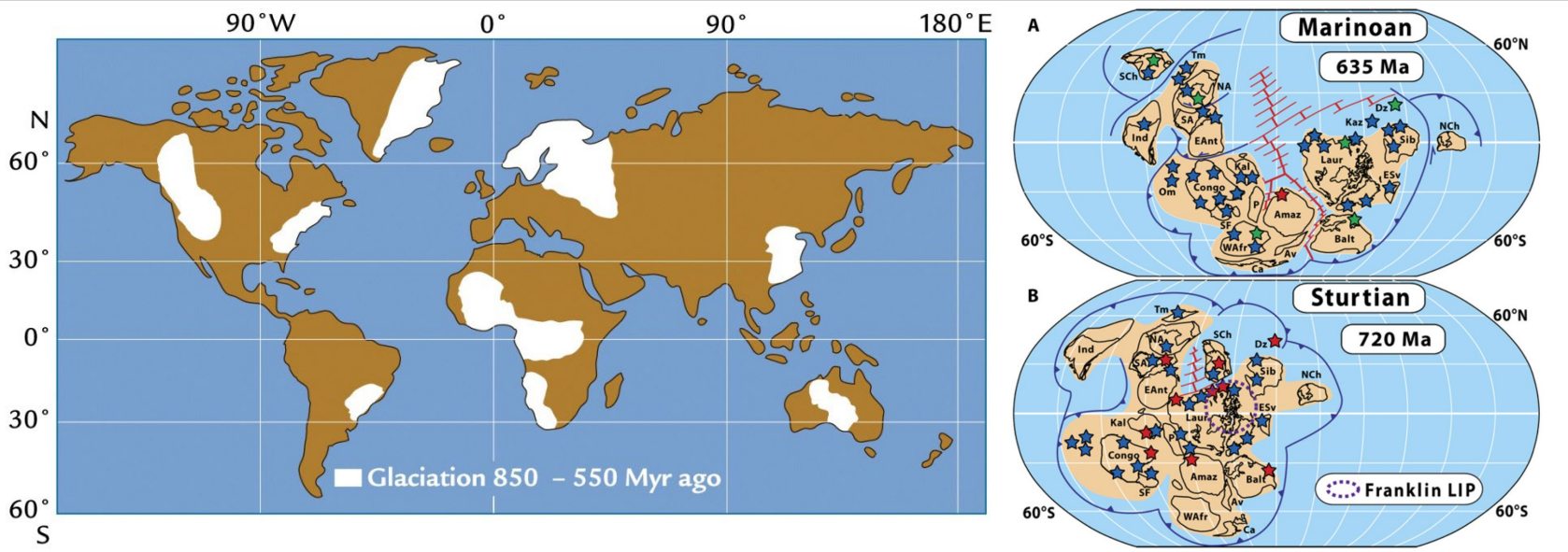


TILLITES: Internationally recognized name indicating **rocks deposited by a glacier in a glacial or periglacial environment or in polar regions**. Tillites are usually hardened, lithified sedimentary rocks; By mapping the distribution of the tillites found on the earth's crust, according to their age, it is possible to reach paleogeographic conclusions on the original reciprocal position of the continental masses and of the same with respect to the two terrestrial poles, all this in support of the Theory of Plate Tectonics.

WERE AUSTRALIAN SEDIMENTS DEPOSITED AT HIGH OR LOW LATITUDES?

Mawson's idea was based on the mistaken belief that Australia was at low latitudes, suggesting global glaciation.

However, Wegener's theory of continental drift (1912) and later plate tectonics showed that Australia was actually at mid latidutes when the glacial deposits formed, explaining their origins.



NAMIBIA'S SEDIMENTS

Ref: Hoffman, P. F.; Kaufman, A. J.; Halverson, G. P.; Schrag, D. P. (1998).

Ghaub Formation (635 Ma) of the Otavi Group, Namibia.

Interest in the "Snowball Earth" hypothesis surged in 1998 when Paul F. Hoffman and colleagues (Harvard) discovered a unique Neoproterozoic succession in Namibia.

They found **glacial deposits** interlayered with **sediments typical of subtropical environments**.

ICE-ALBEDO FEEDBACK MODEL (1969)

Russian climatologist Mikhail Budyko developed a simple energy balance model to study the impact of ice cover on Earth's climate.

His model predicted that if ice extended beyond polar regions, increased albedo would trigger further cooling, potentially leading to global ice cover. However, Budyko concluded that such conditions never occurred on Earth, and the model's inability to offer an exit from this scenario limited its applicability.

ALBEDO The albedo of a surface is the fraction of light or, more generally, of incident radiation that is reflected back.

albedo = 1 all incident light is reflected

albedo = 0 incident light is not reflected.

Examples:

Fresh snow albedo reaches up to 0.9

Albedo of a blackboard has an albedo of about 0.15.

Earth's mean albedo = 0.3

SNOWBALL EARTH

The term "Snowball Earth" was introduced by Joseph Kirschvink in 1992. His work made key contributions, including:

(1) linking Banded Iron Formations (BIF) to a major glacial phase, and

(2) proposing that volcanic CO_2 buildup could trigger a greenhouse effect, offering an exit from global ice coverage.

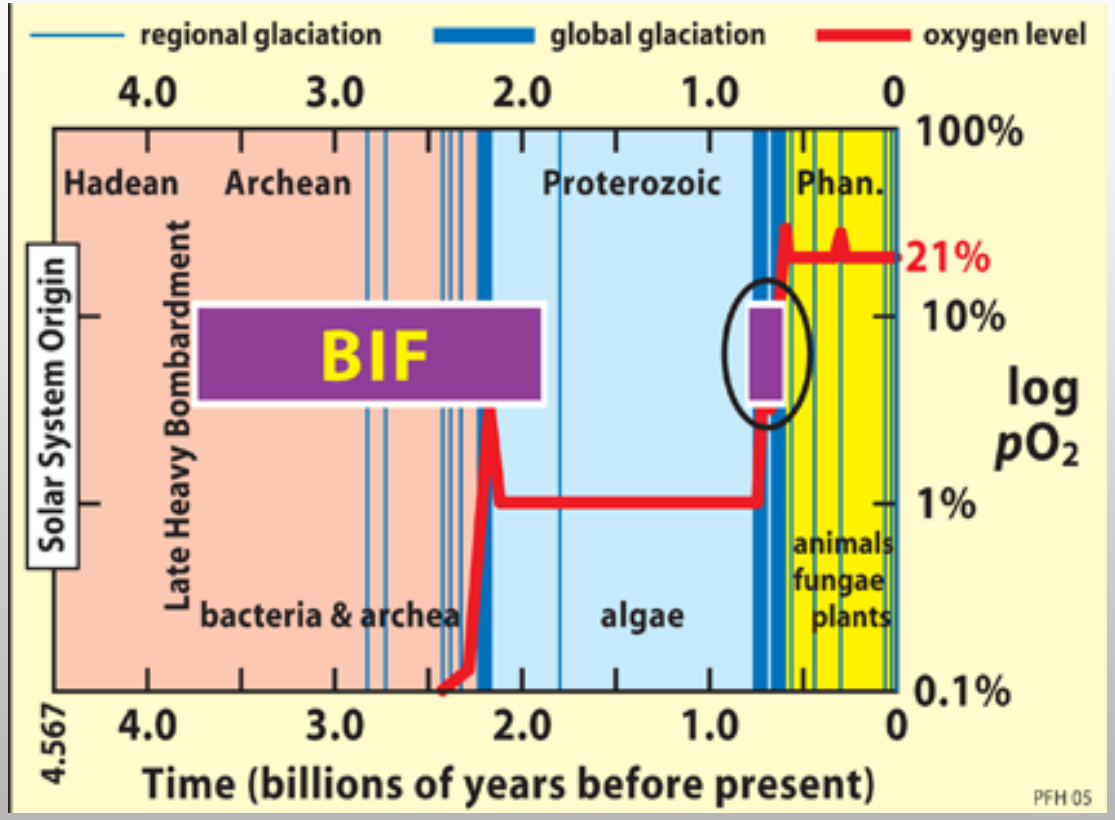
DEFINITION

BIF (Banded Iron Formation) represents a sedimentary rock distinctive of old sedimentary deposits. This lithology comprises alternating layers with high concentrations of oxidized iron (hematite - Fe_2O_3) and beds composed of chert and clay.

BANDED IRON FORMATION: When and why

WHEN

Banded Iron Formations (BIF) are primarily found between 3.8 and 1.8 billion years ago in the Archean and Proterozoic, with a resurgence around 720-635 million years ago during the Cryogenian period.



BANDED IRON FORMATION: When and why

WHY

Banded Iron Formations (BIFs) form from the oceanic precipitation of iron (Fe). The rise of photosynthetic cyanobacteria produced free oxygen, which oxidized dissolved iron from weathered basalt minerals.

$4Fe^{2+}O_2^{-}$ (aq) + O_2 (aq) → $2Fe^{23+}O_3^{2-}$ (s)

This process was intermittent, creating alternating layers of iron oxides and clays, influenced by seasonal or orbital factors. However, no oxidized or clayey layers thicker than 10 cm have been found.

Ice-rafted dropstone in BIF, Sayunei Fm, Rapitan Gp, NT, Canada

BANDED IRON FORMATION: meaning

BIFs, especially during **the Great Oxygenation Event** (around 2.4 billion years ago) and the Snowball Earth era, indicate **alternating intervals of iron-rich, low-oxygen waters** (clays and black chert) and **more oxygenated periods with iron oxide formation** (reddish iron layers).

During **Snowball Earth**, BIFs suggest fluctuations between **oxygen-poor waters, likely due to glacial isolation**, and **oxygen-rich phases where photosynthetic bacteria increased oxygen production**, leading to more iron oxide deposition.

THE RECOVERY OF THE PRE-EVENT CONDITIONS: THE ESCAPE ROUTE

The following are potential escape mechanisms from Snowball Earth conditions:

1.The accumulation of **CO_2 from volcanic degassing** (Kirschvink, 1992).

2.Ice cover reduced the weathering of basalts, decreasing carbon sequestration and leading to increased atmospheric CO_2 and higher temperatures.

3.Ice cover likely caused an extinction or reduction of bacteria in water, aligning with low-oxygen conditions and the formation of BIFs. Surviving species, possibly near the equator, contributed to restoring normal conditions during deglaciation.

THE SLUSHBALL EARTH THEORY - 1

The "Slushball Earth" theory, first proposed by Richard Cowen in 2000, suggests partial ice coverage (around 60%), maintaining cold but stable conditions.

Newer models (Baum and Crowley, 2001) support this idea, indicating that equatorial oceans may have had thin or no ice, allowing photosynthetic organisms to survive.

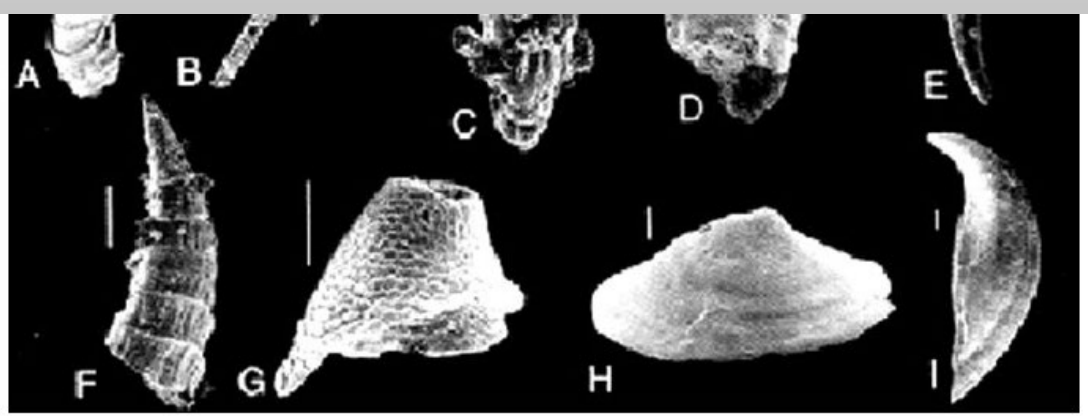
Dropstones provide evidence of ice-free oceans near continents.

THE SLUSHBALL EARTH THEORY AND EVOLUTION

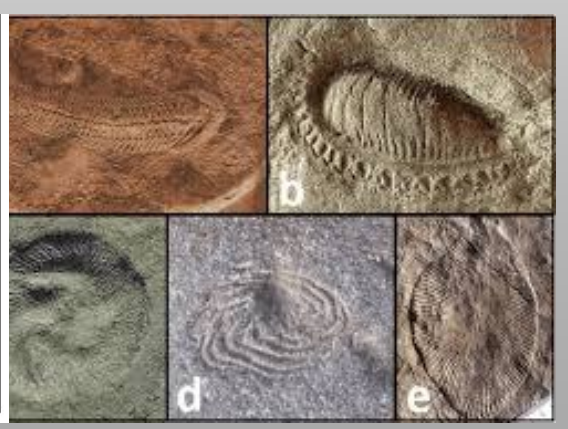
The author speculates that "Slushball Earth" conditions may have favored the radiation of early micro-metazoans, thriving in nutrient-rich tropical waters. By the end of Slushball Earth, these organisms could have migrated, leading to the evolution of larger metazoans.

Macro-metazoans (s.l.) → Ediacaran fauna (vendobionta) – Proterozoic
Macro-metazoans (s.s.) → Cambrian (Tommotian) explosion

METAZOAN is any of a group (Metazoa) that comprises all animals having the body composed of cells differentiated into tissues and organs.



Tommothian small shelly fauna (Clarkson, 1986)



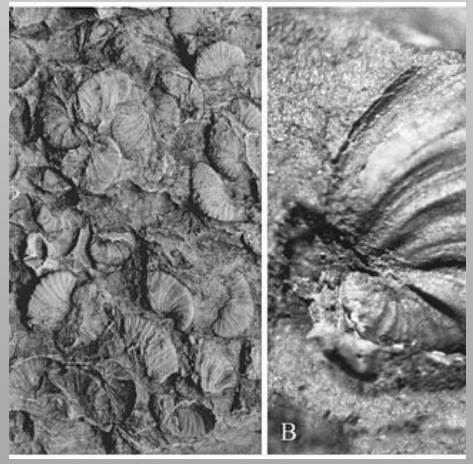
Ediacaran fauna

THE SLUSHBALL EARTH THEORY AND EVOLUTION

Ediacara fauna refers to a group of soft-bodied organisms that lived during the Ediacaran period, approximately 635 to 541 million years ago. These organisms, found in fossil beds worldwide, represent some of the earliest complex life forms, predating the Cambrian explosion. They include a variety of enigmatic, soft-bodied creatures that likely had no direct modern descendants, often referred to as **vendobionta**.

Ediacaran fauna

Tommotian shells belong to an early phase of the Cambrian period, around 541 to 521 million years ago, known as the **Tommotian stage**. This period marks the appearance of the first small, hard-shelled animals, a crucial development in the fossil record, and the beginning of the **Cambrian explosion**, when many major animal groups first appeared. These organisms, characterized by their mineralized shells, played an important role in shaping the early ecosystems of the Cambrian.

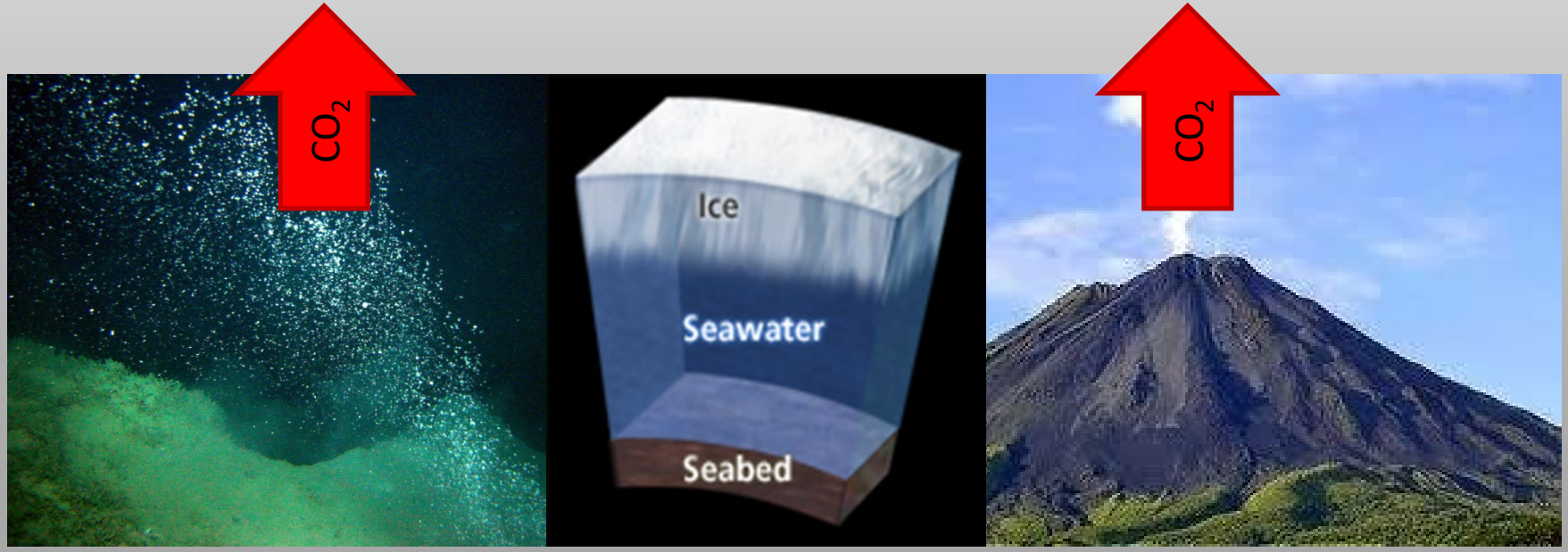


Tommothian small shelly fauna (Clarkson, 1986)

ARGUMENTS AGAINST SNOWBALL EARTH -1

THE ROLE OF METHANE AND CARBON DIOXIDE EMISSIONS IN THE SNOWBALL CYCLE Kirschvink (1992).

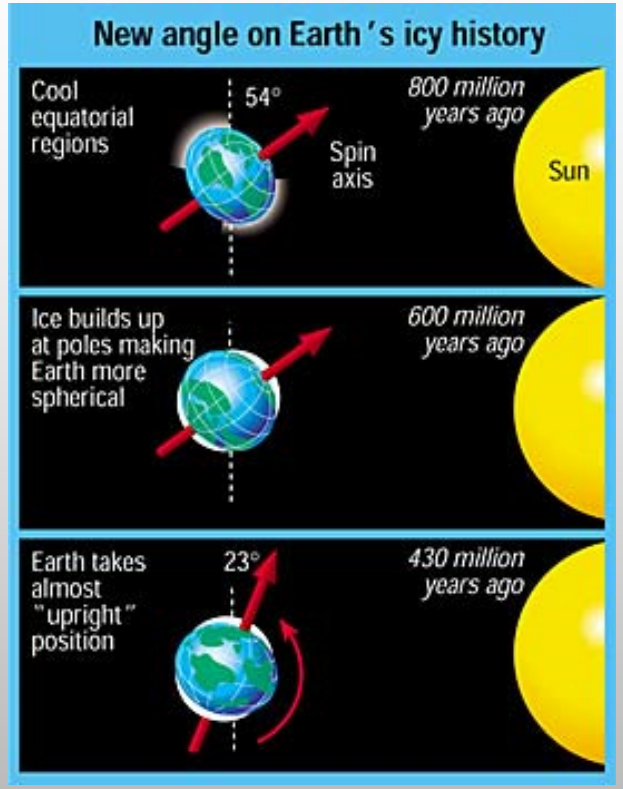
Volcanic activity likely continued releasing CO_2 during glaciation, along with CH4 emissions. These processes may have caused a temperature rise, allowing Earth to escape Snowball conditions.
This potential exit mechanism might also have inhibited the full establishment of a Snowball Earth scenario.



ARGUMENTS AGAINST SNOWBALL EARTH -2

THE TILT OF THE EARTH (Jenkins, 2000)

Jenkins (2000) proposed that the Earth's axial tilt during the Proterozoic (2500-540 Ma) was greater, around 54°, causing low latitudes to receive less energy than high latitudes. This could explain the presence of glaciers at low latitudes without global glaciation. As the Earth's tilt shifted closer to its current angle by the end of the Proterozoic, it may explain why such extensive glaciations did not occur in the Phanerozoic.



Present distribution of Cryogenian glacial-periglacial deposits.

ARGUMENTS AGAINST SNOWBALL EARTH -3

THE ORIGINS OF GLACIAL MODELS AND THE HYDROLOGICAL CYCLE

Geological evidence suggests the presence of "wet and mobile glaciers," which wouldn't have formed under full ice coverage. Some authors, like Walker, propose that warmer phases caused ice melt, enabling these glaciers to grow.

Dry glaciers: In colder climates, basal melting is minimal or absent, and flow is entirely through ductile flow.
Wet glaciers: In warmer climates, basal slip can predominate.

Ductile flow is the slow, plastic movement of ice within a glacier, occurring as the ice deforms under its own weight. In colder climates, where basal melting is minimal or absent, glacier movement happens entirely through this internal deformation.

ARGUMENTS AGAINST SNOWBALL EARTH -4

Sedimentary challenge to Snowball Earth

Allen & Etienne (2008), Nature Geoscience

Abstract

Evidence from the magnetic field fossilized in sedimentary rocks suggests that, more than 600 million years ago, ice occupied tropical latitudes.

A popular explanation for these findings, the ***Snowball Earth concept, envisages a fully frozen Earth for millions of years, caused by a runaway ice–albedo feedback*****.** A rapid, catastrophic meltback at very high levels of atmospheric carbon dioxide is thought to have ended this extreme climatic state.

However, ***sedimentary rocks deposited during these cold intervals indicate that dynamic glaciers and ice streams continued to deliver large amounts of sediment to open oceans throughout the glacial cycle***.

The sedimentary evidence therefore indicates that despite the severity of glaciation, some oceans must have remained ice-free. Significant areas of open ocean have important implications for the survival and diversification of life and for the workings of the global carbon cycle.

Some Like It Hot (1959)

.....Well, nobody's perfect