LATE PROTEROZOIC ERA

k13 The snowball-Earth hypothesis < Neoproterozoic, 541-1000 Ma >

A BLOCK OF ICE
I stamp my foot and a black wave races across the field,
I close my eyes and white stones spring up that I must avoid,
My hand in the freezing water gropes for and fails to find a block of ice
On which to sign my name and the date and hour of my death.
—Michael Fried *To the Centre of the Earth*, 1994.[1]

Early Ordovician marine fossiliferous sediments and basal sandstone deposited during the transgression of the Sauk epeiric sea widely buried an old age erosion surface in Laurentia's interior.

At the passive margins of Laurentia, these time transgressive Sauk platform sediments are Cambrian in age and *conformable* beneath them are Precambrian *marine* sediments. The youngest of these, which accumulated during the Eocambrian (dawn of the Cambrian) age, are without fossils of animals with hard shells but in them (confined to bedding surfaces) are ichnofossils.

Within the margin of Laurentia, and stratigraphically under the Sauk platform sediments, are mostly *continental* sediments in aulacogens (rift valleys that cut back into the protocontinent's craton margin). The *Late Proterozoic* (or *Neoproterozoic*) is the name given to the time during which these accumulated.[2] The lacuna (gap in recorded time) between Sauk sediments that bury the unconformity and the youngest Neoproterozoic sediments that it truncates (***Figure k13.1***), is called the *Lipalian* interval. The Lipalian interval beneath Early Ordovician marine strata in Laurentia's interior (the Great Lakes area today) and outward from there, decreases in its duration from possibly 100 million years to zero at what was Laurentia's northern and southern margins (as preserved respectively in the western Cordillera and the Appalachians today). Laurentia's easternmost southern margin (***Figure k13.2***) is recorded by platform sediments (now in Northern Ireland and Scotland) shed from the part of the Laurentian shield which is now Greenland.

Neoproterozoic sediments that record subsidence of passive margins of protocontinents elsewhere are called: in Russia, the *Riphean* (Paleosiberia's margin), in Scandinavia, the *Sparagmitian* (Paleobaltica's margin), in Asia, the *Sinian* (Paleochina's margin), and in Australia & Antarctica, the *Neoproterozoic* (Gondwana's margin). Ophiolites of Eocambrian age have also been found in mountain belts. These demark suture lines of protocontinents that joined during the Neoproterozoic.

Time-stratigraphic subdivisions of the Neoproterozoic have been variously proposed. Where Cambrian sediments are conformable, upper Neoproterozoic (Precambrian) sediments can be lithologically the same but in places have megafossils of soft bodied organisms that are distinctive. For these strata and fossils, Preston Cloud and Martin F. Glaessner in 1982 suggested the name Ediacarian after an Australian location where the distinctive "Ediacarian" fossils were first described. They also proposed that the Paleozoic be extended to include the Ediacrian period 541 to ~635 Ma.[3] This has, and has not, been formally adopted, *see* Topic *k15*. So what is now the upper Neoprotozoic?

Conformable beneath Ediacarian (also called *Vendian*) strata are warm-sea limestone formations that contain few signs of past life surviving or migrated into their region from prior frozen times recorded by ice-rafted dropstones and marine diamictites that date about 635 to 720 My (***Figure k13.3***). These glacials are called Varanger for a location in northern Norway where they were first described in 1891. They have occurrences in every continent. Paleomagnetic evidence is that some were deposited near the equator (enough for stabilist Douglas Mawson (1882-1958) to find for a global glaciation).[4] In a Cloud and Glaessner scheme, the Neoproterozoic glacials of a "snowball Earth" (intimated by driftist Walter Brian Harland (1917-2003) in 1964 Euan Nisbet recalls,[5] noted in passing by Joe Kirschvink,[6] and now championed by Paul Felix Hoffman)[7] could be the time-stratigraphic unit that, in the absence useful fossils, defines the Neoproterozoic (or Cryogenian) Era.

Evidence is that the "snowball" freezing was not complete. Philip A. Allen in 2002 describes the Fiq Member (a formation that is 1.5 km thick and exposed across 50 km of sparsely vegetated mountainous terrain) in Oman as "not just a boring old block of sediment deposited during one profound glaciation" but one with evidence that glaciers moved back and forth at least seven times. "We do not have a single longtime freezeup in which the water cycle is shut down completely."[8]

A low stand of the sea recorded at the passive margins of several paleocontinents is evidence of a eustatic low when they formed at the beginning of the Eocambrian from the breakup of a supercontinent called *Pannotia*. The Neoproterozoic Pan-African orogeny resulted from the suturing of Pannotia from two palaeocontinents that had occupied opposite polar latitudes. These had separated out of (so ending the existence of) a supercontinent called *Rodinia*, 760 Ma.

The name Neoproterozoic is routinely used in print for the time back from "the base of the Cambrian" at 541 Ma but this should be "the base of the Paleozoic" at ~635 Ma which is the very vague end-time of the Neoproterozoic glacials that onset 720-1000 Ma. Before then, glacials were during Paleoproterozoic that date ~2.2 -2.4 Ga and during the Mesoarchean centered ~2.9 Ga. ❑

Figure k13.1 [9] Restored cross section of the northern margin of the Laurentia. Cambrian strata are conformable in a passively subsided margin. The platform sediments on the craton record the transgression of the Sauk epeiric sea that began its advance in the Middle Cambrian. The unconformity that these platform sediments bury is an old age erosion surface cut across Precambrian basement rocks and aulacogen-fill sediments of Late and Middle Proterozoic age.[10]

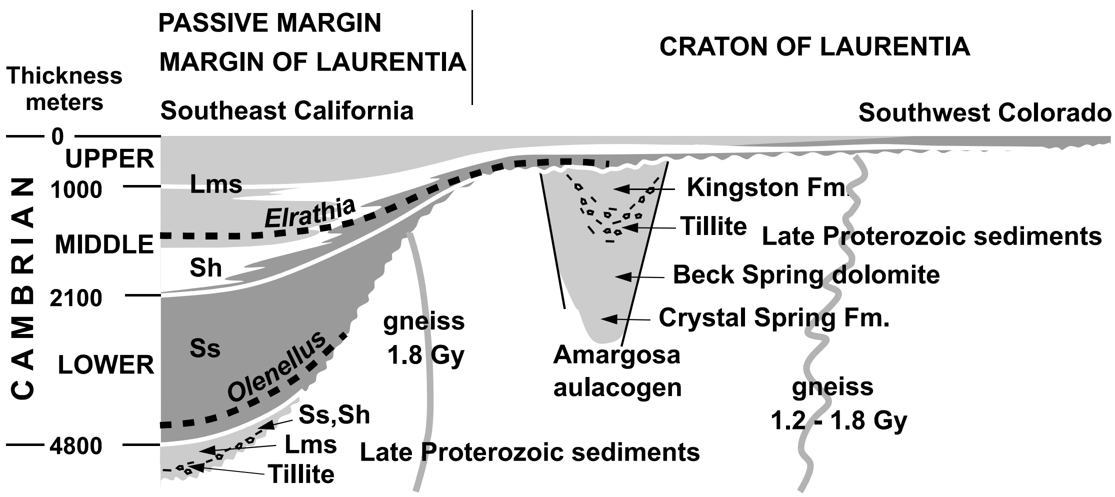


Figure k13.2 [11] Restored cross section of the easternmost southern margin of Laurentia. Neoproterozoic Torridonian platform sediments in Scotland were derived 650-800 Ma from the Laurentian shield which is that of Greenland today. The unconformity which these and Lower Dalradian sediments bury is an old age erosion surface cut across Stoer 900 My sediments, Grenville-orogeny folded Moinian 1.2 Gy sediments, and the Lewisian 1.7-2.3 Gy basement complex.

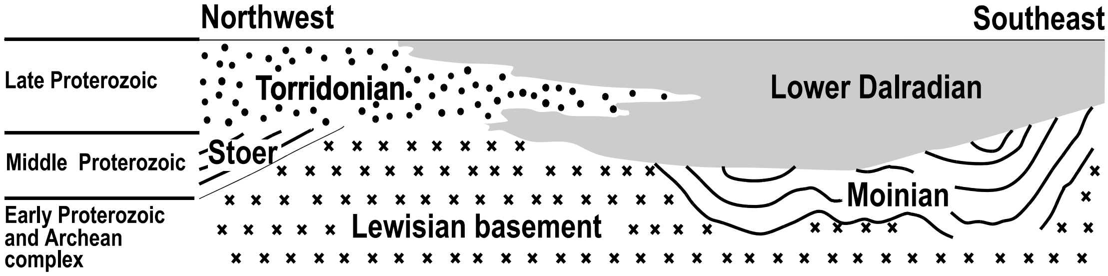


Figure k13.3 Earth presently enjoys a warm time (the Holocene Epoch) that is probably an interglacial as others between glacials during the Quaternary Period “ice age” that started 2.588 million years ago (Ma) when an icesheet began to form on Greenland.

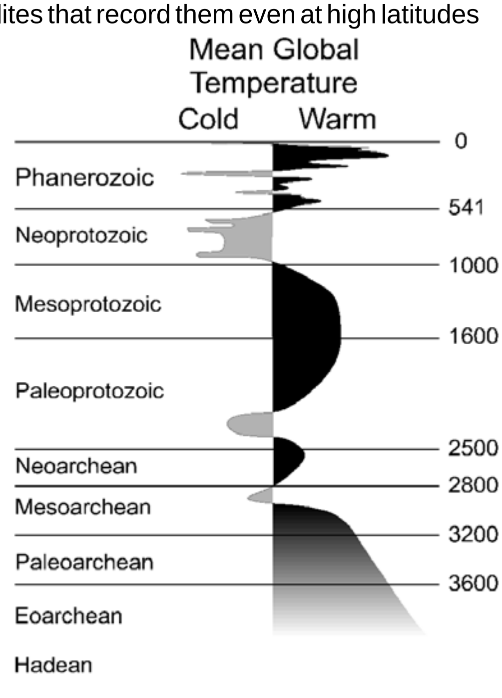
Glacials are the coldest phases of an “icehouse” (which is when ice sheets are somewhere in the world even during interglacials). A “hothouse” is when there are no ice sheets in the world.

The existing icehouse world onset 43 Ma (during the Cenozoic Period). Earlier major icehouses occurred: ~260-340 Ma (during the Permian and Carboniferous periods);[12] ~430-445 Ma (during the Silurian and Ordovician periods); ~582 Ma Gaskiers glaciation, 637-659 Ma Marinoan glaciation, ~723 Sturtian glaciation that may have onset 1000 Ma (all during the Neoproterozoic Era);[13] ~2,250 Ma (during the Paleoproterozoic Era); and, ~2,900 Ma (during the Mesoarchean Era).[14]

The climatic changes of Earth’s latest ice age have a forcing pacemaker which is variation in the astronomical parameters of the planet’s orbit and axis. The stable state for Earth, Victor R. Baker opines, “seems to be the warm greenhouse condition, with cold phases corresponding to metastable periods of glaciation.”

Evidence of the most extensive glaciation in Earth’s history, the Cryogenian Period (between ~635 and ~850 Ma) of the Neoproterozoic Era, is recorded by carbonate-capped glacials. Paleomagnetic evidence is that the glaciation, called the *Varanger (its younger part called the Marinoan glaciation and its older part called the Sturtian glaciation)*, was to low latitudes. The glacials with occurrences in most continental areas, include tillites (which in the absence of any nearby mountains at the time, are judged to be continental), and finely varved argillites with drop stones. Compared to the fluctuating temperature curve of the Phanerozoic, the temperature curve for the Varanger suggests a duration cold that not only appears to be incredible but may very well be given a negative feedback between temperature lowering that causes a flux of atmospheric O_2 into seawater by absorption, and the rate at which organic carbon there is remineralized by it to inorganic carbon that vents as greenhouse CO_2 into the atmosphere.[15] Even if a slushball Earth (with open water persisting at the equator) rather than a hard-snowball Earth (when tropical lands and seas are frozen across and the water cycle is stopped), this “should have been the greatest environmental calamity of all time and yet we can’t find the bodies,” notes Guy M. Narbonne.[16]

The Varanger glacials are unusual for although their distribution could be indicative of prolonged very cold conditions worldwide, interbedded between the tillites that record them even at high latitudes are marine carbonates indicative of very warm interglacial conditions worldwide. The hard-snowball Earth hypothesis includes the idea that the oceans were frozen to depth of a kilometer for durations of even ten millions of years. The hypothesis, which would include killing below ice darkness does not account for the fact that red, green and brown algae survived apparently unscathed. Hot springs as havens have been suggested. Likely, as proven for the Phanerozoic, the temperature of the Neoproterozoic fluctuated rapidly and maybe even more widely.[17] However, corroborating temperature indicators of Neoproterozoic Varangian interglacials have not yet been reported.



Naïve is to assume the climate determining factor to be atmospheric carbon dioxide: Partial pressures of this gas (pCO_2), to quote Jan Veizer in 2000, were “indeed relatively low for the Permo/Carboniferous and Cenozoic icehouse episodes, times of predominantly cold climates lasting tens of millions of years, but for the other two Phanerozoic icehouses—the late Ordovician/earliest Silurian and the late Jurassic/early Cretaceous—all global biogeo-chemical models intimate high pCO_2 levels.”[18]