Once \( O_2 \) is created, its survival is controlled by reaction with reduced molecules, especially organic C.

Organic C (or some other reduced substance) must build up in a reservoir with a long residence time if \( O_2 \) is to accumulate.
So why so long for $O_2$ to rise (~2.3 Gyr)?

Supply versus Sinks:
1. Late appearance of abundant cyanobacteria.
2. First occurrence of organic carbon burial.
   Continental Shelves are where most C is buried.
   Rifting of early continent to create mud filled basins
3. Mantle becomes more oxidized?
   Progressive oxidation of planet due to H escape
   Change in depth of mantle mixing?

Organic reservoirs

Biological C Pump

$CO_2 + H_2O \rightarrow \text{CH}_2\text{O} + O_2$

$\text{CH}_2\text{O} + O_2 \rightarrow CO_2 + H_2O$
Organic reservoirs

What feedbacks link organic C burial and weathering to maintain balance?

More efficient burial of organic matter at times of low O₂?

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_4\text{O} + \text{O}_2 \]

More efficient weathering/combustion of organic matter at times of high O₂?

\[ \text{CH}_4\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Less efficient photosynthesis at times of high O₂?

Rubisco O₂ uptake.

Organic Carbon, Oxygen and Nutrient Coupling
Continental Collision Hypothesis

- Mountain building increases erosion
  - Igneous rocks
- Fe, PO₄ input increases
- Productivity increases
- C-org burial increases
- O₂ increases

Campbell & Allen, 2008, Nature

Inorganic C reservoirs

Today, 4x more carbonate burial than organic C burial

The Rock/Silicate Weathering Cycle
**Isotopic consequence of biological carbon pump**

![Graph showing isotopic consequence of biological carbon pump]

**Secular variation in the organic carbon burial flux (\(f_{\text{org}}\)) through the Late Proterozoic.** For comparison, the present-day value for \(f_{\text{org}}\) is estimated as \(3.8 \times 10^{15} \text{ mol C Ma}^{-1}\). The calculated curves suggest that organic carbon burial was low throughout most of the Late Proterozoic until about 600 Ma when \(f_{\text{org}}\) increased sharply to 2-4 times the modern rate and then decreased rapidly into the Cambrian.

![Graph showing secular variations in \(\delta^{13}C\) of average carbon reservoir (\(\delta_{\text{org}}\)) and the main fraction of carbon preserved as organic carbon (\(\delta_{\text{org}}\)) in the sedimentary reservoir through the Late Proterozoic. The \(\delta_{\text{org}}\) curve is calculated by integrating the marine carbonate curve in Fig. 3 (see Eqn. 5). The magnitude of these changes is related to the residence time (\(\tau\)) of carbon in the average carbonate reservoir. We vary this parameter over a likely range between 100 to 500 Ma. Shorter residence times yield greater variation, yet overall trends remain the same.**

![Graph showing secular variations]
Published δ¹³C values for marine carbonates over time (Shields & Veizer, 2002)
Evidence for Proterozoic glaciation in Norway. The Bigganjarga tillite overlies a striated bedrock surface on sandstone of the Veidnesbotn Formation.

Thick layer of calcium carbonate (CaCO₃) above glacial deposits.

Paleomagnetism

Assuming a time-averaged geocentric axial dipole:
\[ \tan \text{inclination} = 2 \tan \text{latitude} \]

Evidence? Geochemical evidence that photosynthesis turned off