

Cryogenian Worlds and the Appearance of Animals

CHO-015 · Cosmic History and Its Observers

A Chronological Scientific History from the Early Universe to the Present

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Abstract

Background

The Cryogenian and Ediacaran intervals join profound climatic change to the emergence of macroscopic ecosystems and increasingly persuasive evidence for animals. The record does not support a single moment when animals appeared. Molecular clocks, body fossils, trace fossils, developmental patterns and environmental proxies measure different things at different resolutions.

Evidence

This synthesis uses controlled full-text chronostratigraphic, geochemical, palaeontological and molecular-clock sources. It keeps radiometric constraints distinct from geological events, modelled divergence from observed fossils, biological affinity from morphology, and coordinated behaviour from sentience. Claims supported only by abstracts, metadata or an unconsulted primary source are not promoted in this synthesis.

Synthesis

The Sturtian glaciation lasted more than 55 million years, while Marinoan termination is constrained near 635 million years ago. Geochemical evidence indicates that even a snowball world could contain marine oxygen production, nitrogen cycling and some open water. Molecular-clock studies place crown-animal origins across broad and conflicting intervals, including Tonian and Cryogenian results. A roughly 890-million-year-old sponge interpretation is explicitly conditional. In the Ediacaran, fossils and traces record developmental patterning, possible early animal-grade bodies, sediment disturbance, mobility, directional preference, reproductive strategies and increasingly structured communities. Local low-oxygen conditions show that animal ecosystems cannot be reduced to a simple global oxygen threshold.

Conclusion

Animals emerged through a long, unresolved history rather than a single threshold. By the Cambrian boundary, the record supports diverse body plans, ecological engineering and coordinated movement, but the timing of crown-animal origins, the affinity of older candidates and the relation between oxygenation and diversification remain model-dependent or contested. Fossil behaviour does not by itself establish learning, a particular nervous system, sentience or consciousness.

Keywords: Cryogenian; Ediacaran; Snowball Earth; animal origins; molecular clocks; trace fossils; rangeomorphs; oxygenation; behaviour; preservation

1. Chronological orientation

This article follows the interval from the base of the Cryogenian at 720 million years ago to the base of the Cambrian at 538.8 million years ago [1]. Its animal-priority overlay extends back to 1000 million years ago so that older published animal candidates can be examined rather than excluded by the article boundary. The overlay changes the comparison set, not the chronological spine.

The named stratigraphic chart, version 2026/06, gives the Cambrian base as 538.8 ± 0.6 million years ago [1]. The central value defines the editorial seam; it does not remove the published uncertainty.

The dates used here describe different relationships. A volcanic age may lie below a glacial deposit and supply only a maximum constraint. A dated tuff inside the deposit may constrain deposition directly. A molecular clock estimates a lineage split under specified models and calibrations. A fossil horizon records an occurrence, while the organism's phylogenetic placement remains an interpretation. These relations cannot be exchanged without changing the claim.

2. The inherited state at the Cryogenian boundary

At 720 million years ago, eukaryotic life already included several modes of multicellular organisation and trophic interaction. CHO-015 inherits that biological context without reopening the earlier history of eukaryotic origins. Its central questions are narrower: how Cryogenian environments changed, what the Ediacaran record shows about early animals, and which capacities can be supported without projecting later animal traits backward.

The opening climate was not one uniform condition. The term Snowball Earth names a family of hypotheses about extensive global glaciation, not a direct observation that every ocean surface was continuously sealed or that biological activity ceased. Chronology, climate state and biological refugia therefore require separate evidence.

3. The duration and structure of Cryogenian glaciation

Multi-craton constraints place the Sturtian glaciation at approximately 717 to 660 million years ago and support a duration exceeding 55 million years [2]. In northwestern Canada, a rhyolite beneath the glacial deposits has an eruptive age of 717.43 ± 0.14 million years and provides a maximum constraint, whereas a tuff within the glacial deposits yields 716.47 ± 0.24 million years and is interpreted as depositional or synglacial [3]. The two numbers are close, but their geological relations are different.

The end of the Marinoan glaciation is constrained near 635 million years ago. A post-cap-carbonate rhenium-osmium age of 632.3 ± 5.9 million years is consistent, within uncertainty, with this termination [2]. These ages constrain a transition recorded in particular stratigraphic settings; they do not establish one globally instantaneous deglaciation.

4. Biological activity in a snowball world

Geochemical evidence from Marinoan strata has been interpreted as recording marine oxygen production, an active nitrogen cycle and some open water during glaciation [4]. The result argues against treating a globally glaciated interval as necessarily sterile or chemically uniform. It does not show that all oceans remained open, oxygenated or biologically productive.

The biological importance of refugia depends on scale. Local open water can sustain production without defining the state of the global ocean. A geochemical proxy can support a process without identifying the organisms responsible. Evidence for activity during glaciation therefore narrows the range of viable environmental histories, but it does not by itself date the origin of animals.

5. Early Ediacaran time and oxygen mosaics

An astronomically calibrated framework spans approximately 57.6 million years of the early Ediacaran, linking the aftermath of Marinoan deglaciation to the EN1 and EN2 intervals and the Weng'an and Lantian biotas [14]. This framework improves temporal placement. It does not determine biological affinity.

Later Ediacaran ecosystems also resist a simple oxygenation narrative. Fossil-bearing Siberian carbonates preserve local and broader redox signals interpreted as pervasive local anoxia and widespread euxinia [5]. The authors retain alternatives in which organisms tolerated intermittent anoxia or experienced brief oxygenated episodes not captured by the proxies. A diverse assemblage under low-oxygen conditions therefore shows ecological persistence under local stress, not independence from oxygen in every setting.

These records weaken any single-step account in which a uniform rise in oxygen immediately produces animals. Environmental change mattered, but its spatial scale, duration and biological consequences varied. The sources support associations and constraints rather than one universal trigger.

6. The age of animals as a model problem

Molecular clocks estimate divergence, not first fossil occurrence. One analysis reports a composite posterior interval of 833.5 to 649.8 million years for crown Metazoa and concludes that crown animals originated during the Cryogenian [6]. The interval crosses the Tonian-Cryogenian boundary, while the authors' own period-level conclusion is Cryogenian. Both facts belong to the result.

A separate phylogenomic analysis infers a Tonian origin for crown-group Metazoa [7]. Its estimates vary with clock model, root prior, calibrations and topology. The disagreement is not resolved by choosing the older estimate or averaging the two intervals. It records sensitivity to model structure and to the evidence used to calibrate deep evolutionary time.

The fossil record supplies a different class of evidence. Vermiform microstructure in reefs correlated with strata dated 892 ± 13 million years ago has been interpreted conditionally as possible keratose sponge tissue [8]. The conditional matters. If the structures are fossilised sponge tissue, they would extend the animal record far into the Tonian; if the morphology has a non-sponge origin, the chronological implication disappears. The source is therefore evidence for a candidate, not a secure observed date for animal origins.

7. Ediacaran bodies and developmental organisation

Ediacaran fossils reveal several forms of organisation without arranging them into a single ladder. Growth geometry in *Fractofusus andersoni* documents patterned morphogenesis, and the authors interpret rangeomorphs from assemblages older than about 574 million years as among the earliest total-group eumetazoans [15]. The developmental observations and the phylogenetic conclusion remain distinct.

At roughly 571 million years ago, a Brazilian assemblage contains shelled and carbonaceous microfossils assigned by the authors to several animal groups [10]. The assemblage broadens the range of candidate body forms, but each taxonomic assignment retains its own morphological and preservation limits.

Small *Ikaria wariootia* body fossils from South Australia were linked morphologically and spatially to *Helminthoidichnites* traces and proposed as the trace maker [9]. This association connects a body plan with locomotory behaviour more directly than either record alone, while the body-trace attribution and age relations still carry uncertainty.

Late in the Ediacaran, *Dengyingia pennata* preserves two-sided differentiation and morphology interpreted as compatible with current-oriented suspension feeding in strata about 550 to 543 million years old [13]. The functional interpretation does not settle the broader affinity of Ediacaran fronds. The Tongshan Lagerstätte, approximately 551 to 543.74 ± 0.87 million years old, preserves rangeomorph fronds and Burgess-Shale-type tissues in a deep-water assemblage [16]. Its exceptional preservation expands the visible community while also demonstrating how strongly the known record depends on preservation windows.

8. Ecological engineering and coordinated behaviour

Terminal Ediacaran trace assemblages record increasing sediment disturbance before the Cambrian [11]. The term bulldozer describes an ecological effect, not a formal taxon. Mixing and displacement of sediment changed substrates and resource distributions, but the record does not identify one universal cause of later Cambrian diversification.

Fossil orientation and bending patterns in *Spriggina floundersi* reject a simple current-alignment explanation for the observed asymmetry. The authors infer coordinated motility and behavioural handedness [12]. The preserved pattern supports directional behaviour. It does not independently establish learning, subjective experience or a specific nervous-system architecture.

Community structure also depended on reproduction. Spatial modelling of communities around 574 million years ago indicates that stoloniferous reproduction could alter resource competition and diversity patterns [17]. This is a process-level hypothesis tied to particular spatial evidence, not a universal explanation for Ediacaran diversification.

9. Contingency and contemporaries

The Ediacaran record contains contemporaneous experiments rather than a necessary sequence from simple forms to modern animals. Rangeomorph developmental systems, small bilaterian candidates, shelled and carbonaceous microfossils, frondose suspension feeders, trace-making organisms and sediment-disturbing communities overlapped across different regions and preservation settings [9-17]. Their coexistence does not establish direct ancestry among them.

Climate and ecology were equally contingent. Biological activity persisted during severe glaciation, low-oxygen settings hosted diverse communities, and exceptional deposits preserved organisms that ordinary sedimentary environments may have erased [4,5,16]. The surviving record therefore reflects both evolutionary history and geological opportunity.

10. Competing interpretations and unresolved questions

Four uncertainties remain central.

First, molecular clocks disagree about whether crown-animal origins fall in the Tonian or Cryogenian, and their broad intervals depend on priors, calibrations and model choices [6,7].

Second, the oldest body-fossil candidates remain conditional. The approximately 890-million-year-old vermiform structures may record sponge tissue, but the animal interpretation is not equivalent to an observed diagnostic animal body [8].

Third, several Ediacaran fossils combine persuasive biological structure with unsettled affinity. Developmental geometry, bilateral form and functional morphology can narrow the possibilities without resolving every phylogenetic position [9,13,15].

Fourth, environmental association is not a single causal mechanism. Open-water evidence during glaciation and animal communities under local anoxia show that climate, redox state and ecology interacted at several scales [4,5]. Neither source establishes a universal oxygen threshold for animal life.

11. Claim classes and evidential limits

The following statement distinguishes supported claim classes, speculative content and open questions.

- **Measured or observed:** radiometric ages, stratigraphic relations, fossil geometry, body orientation, trace distributions and geochemical measurements reported by the cited studies.
- **Reconstructed:** glacial correlation, organismal affinity, ecological function and body-trace association.
- **Model-dependent:** molecular-clock intervals and process models for community competition.
- **Contested:** deep animal affinities, the period of crown-animal origin and several Ediacaran phylogenetic placements.
- **Speculative:** none in this synthesis.
- **Open:** the exact timing of animal origins, the identity of some early candidates, the global structure of Cryogenian refugia and the fraction of Ediacaran diversity lost to preservation.

This synthesis does not promote claims whose controlled support remains limited to an abstract, metadata record or unconsulted primary source. Those candidates can be reconsidered if qualifying source access changes.

12. Observer capacities

The record supports environmental detection, regulated response, locomotion, orientation and coordinated behaviour in several forms. These observations are relevant to the later history of animal sensing and action, but they do not by themselves demonstrate flexible learning, memory, pain, pleasure, sentience or phenomenal consciousness.

No body plan, trace, feeding structure, reproductive strategy or directional preference is treated here as a consciousness proxy. The first explicit assessment under the series' sentience evidence framework belongs to CHO-016, where Cambrian sensory systems and behavioural evidence can be tested under a broader comparative record.

13. Boundary and exclusions

CHO-015 owns Cryogenian glaciations, Neoproterozoic oxygenation within its window, Ediacaran ecosystems and the adjudication of early animal candidates. CHO-014 supplies Tonian eukaryotic and environmental context without retaining ownership of animal-priority claims.

The interval ends at the half-open Cambrian boundary of 538.8 million years ago [1]. Sources that span the boundary contribute only their pre-boundary evidence here. Cambrian diversification, predation, sensory worlds and the first explicit assessment of integrated animal sensing or sentience belong to CHO-016.

14. Closing state at the Cambrian boundary

By 538.8 million years ago, the controlled evidence supports a world transformed by long glaciations, deglacial reorganisation, spatially variable redox conditions, macroscopic communities, trace-making organisms, patterned development, ecological engineering and coordinated movement. It does not support a single date for animal origins, a resolved phylogeny for every Ediacaran form, a universal oxygen trigger or an inference of sentience from fossils alone.

CHO-016 inherits animals with established ecological and behavioural diversity, together with the unresolved question of how later nervous and sensory systems changed what animals could detect, integrate and experience.

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Disclosure

This document is a scholarly synthesis; it is not primary research and has not been peer reviewed. Juan Segurola is the sole author. He approved the final text and is responsible for its content.