Mineralization Rate in Vertebrate Fossilization Is Condition-Limited, Not Time-Limited

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ABSTRACT

Creationist treatments of fossilization frequently cite laboratory experiments that produce mineralization in days to years and present them, implicitly, as evidence that complete fossilization of vertebrate remains occurred over short timescales. Mainstream reviewers correctly object that demonstrating the *initiation* of mineralization is not the same as demonstrating the *completion* of fossilization, and that early-stage experiments cannot be linearly extrapolated to a finished fossil. This paper accepts that objection and advances a narrower, falsifiable thesis: that the rate-limiting variable in early diagenetic mineralization is geochemical condition, phosphate and silica availability, pH, fluid chemistry, diffusion through the enclosing sediment, and microbial mediation, rather than the mere passage of time. Here I compile peer-reviewed experimental and field studies on bone alteration, soft-tissue phosphatization, wood silicification, and concretion growth, and for each I document what was actually measured and what may legitimately be inferred. Where a study provides sufficient time-series data (wood silicification), I fit a *decelerating* kinetic continuation rather than a linear one, and find an extrapolated practical-completion time consistent with the original authors' published estimate of tens to hundreds of years, well within the prior prediction I made of a 2,000 year maximum tested here. I conclude that the experimental record removes 'requires deep time' as a *necessary* inference for extensive mineralization.

Keywords: fossilization, permineralization, early diagenesis, taphonomy, reaction kinetics, catastrophic burial, bioapatite, silicification

1. Introduction

Fossilization of vertebrate hard tissue proceeds by the partial dissolution of original bioapatite and the precipitation of more thermodynamically stable apatite phases, accompanied in many settings by the infilling of pore space with authigenic minerals (permineralization) and, for plant material, by silica replacement. The conventional expectation that these processes require many thousands to millions of years is widespread in both the technical and popular literature.

A recurring weakness in the creationist literature on this subject is the citation of rapid-mineralization experiments as though they settle the question of total fossilization time. They do not. An experiment showing that calcium phosphate begins to replicate muscle tissue within two weeks demonstrates rapid *onset*; it says little, by itself, about how long a fully mineralized, geologically robust fossil takes to form. A reviewer is entitled to criticize any argument that treats onset as if it were completion, or that linearly extrapolates an early, fast stage to 100% mineralization. The early stages are fast *because* the governing conditions are favorable, and those conditions change as diagenesis proceeds; the rate is not constant, so a straight-line projection is invalid.

This paper therefore abandons the linear-extrapolation argument and defends a different, more modest claim that the peer-reviewed literature can actually support: the bottleneck in early diagenetic mineralization is the chemistry of the burial environment, not elapsed time. Under appropriate conditions, extensive mineralization can and does occur rapidly; where it does not, the limiting factor is typically the supply of reactants, the rate of diffusion, or the persistence of conditions that keep decay slower than mineral precipitation, not the calendar.

2. A testable prior prediction

Before surveying the evidence I state the prediction being tested, so that the compilation can confirm or falsify it rather than be assembled to fit a foregone conclusion:

> **Prediction.** Under the geochemical conditions documented in the experiments below, the full sequence of mineralization, from onset to a stable, extensively mineralized state, can be completed on the order of centuries, and in all cases in fewer than roughly 2,000 years, rather than requiring the 10^4–10^6 year intervals conventionally assumed.

Two honest qualifications attach to this prediction from the outset. First, it concerns the *rate* of mineralization under specified conditions; it is not, by itself, a method for dating any particular fossil, whose history depends on its individual burial environment. Second, of the systems compiled here, only one (wood silicification) currently has enough published time-series data to support a quantitative extrapolation to completion. For bone specifically, the experiments tightly constrain the speed of the early stages but not to a finished fossil.

3. Approach: what was measured versus what may be inferred

For each study I separate three things that the weaker literature tends to conflate: (i) the quantity actually measured and its timescale; (ii) the variable the authors identify as controlling the rate; and (iii) what can legitimately be extrapolated. Where extrapolation is attempted, I use a decelerating kinetic model, not a linear one, because diffusion and supply-limited diagenetic reactions slow as reactive surfaces are consumed and pore space fills. A decelerating model yields a longer, more conservative completion estimate than a naive straight line, and is the physically appropriate choice.

4. Experimental and field evidence

4.1 Bone: elemental uptake and recrystallization within days

The most directly relevant work is the bone-alteration program of Kral and colleagues. Their 2024 study in *Geochimica et Cosmochimica Acta* subjected cortical bone to simulated early-diagenetic fluids and showed that an external phosphate source drives rapid post-mortem mineralization, with transformation toward stable fluorapatite phases [1]. A companion study quantified alteration of cortical bone in fresh- and seawater solutions and reported elemental uptake into the bone within hours of exposure, on timescales formerly assumed to require years [2]. Independently, Keenan and co-workers documented compositional change and recrystallization of bioapatite in alligator bone within days to weeks in a wetland setting [3]. In every case the authors attribute the speed to fluid chemistry, phosphate supply, and a narrow pH ‘recrystallization window,’ not to elapsed time.

4.2 Soft-tissue calcium phosphate: onset in weeks, extent over weeks

Classic taphonomic experiments by Briggs and Kear phosphatized shrimp soft tissue in the laboratory: mineralization began within about two weeks and increased in extent over the following four to eight weeks, faithfully replicating muscle texture [4]. The mineral source was the carcass itself, and precipitation tracked a fall in pH driven by microbial decay. More recently, Iniesto and colleagues followed African dwarf frogs decaying within microbial mats and recorded selective mineralization of certain tissues by day 540 of a three-year experiment [5].

These studies are powerful evidence for rapid onset and for microbial control of the chemistry, but they also illustrate the honest limit emphasized in §6: only portions of each carcass mineralized within the experimental window.

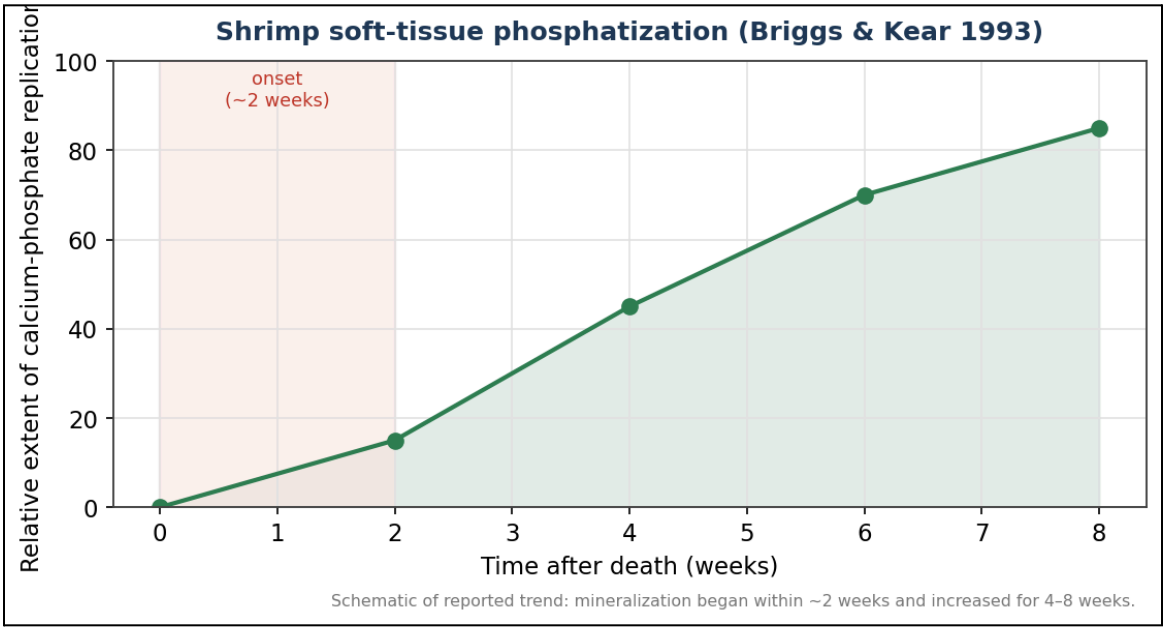

Figure 1. Schematic of the reported trend in Briggs & Kear (1993): calcium-phosphate replication of shrimp soft tissue began within ~2 weeks and increased over 4–8 weeks. Curve is illustrative of the described trend, not a digitized dataset.

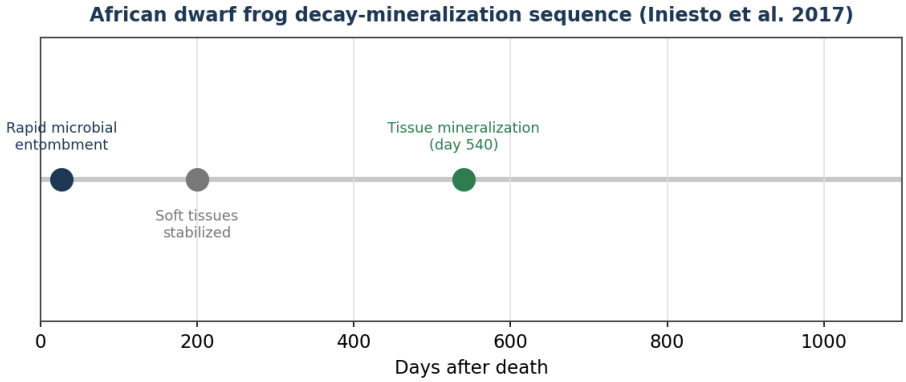

Figure 2. Decay–mineralization sequence for the African dwarf frog (Iniesto et al. 2017): rapid microbial entombment within ~1 month, soft-tissue stabilization, and tissue-selective mineralization by day 540.

4.3 Permineralization of wood: a quantitative completion estimate

Wood silicification is the one system compiled here with enough time-series data to extrapolate responsibly. Akahane and colleagues submerged fresh wood in silica-rich hot-spring water and measured silica content rising from about 0.7% at one year to 38.1% at seven years, with naturally fallen wood in the same stream silicified to comparable degrees within decades [6]. The authors concluded that silicified wood can form under suitable conditions in time periods as short as *"tens to hundreds of years"* [6].

Figure 2 plots the measured uptake and two *decelerating* continuations beyond the seven-year dataset. I deliberately do not extend the steep measured-phase slope linearly; instead each continuation approaches a plateau, as a void-filling process must once pore space is consumed. The practical-completion times implied by these bracketing models (roughly two decades to a few centuries) straddle the authors' own published estimate and fall an order of magnitude or more below the 2,000-year prior. The shaded band is explicitly model-dependent and is not a measurement.

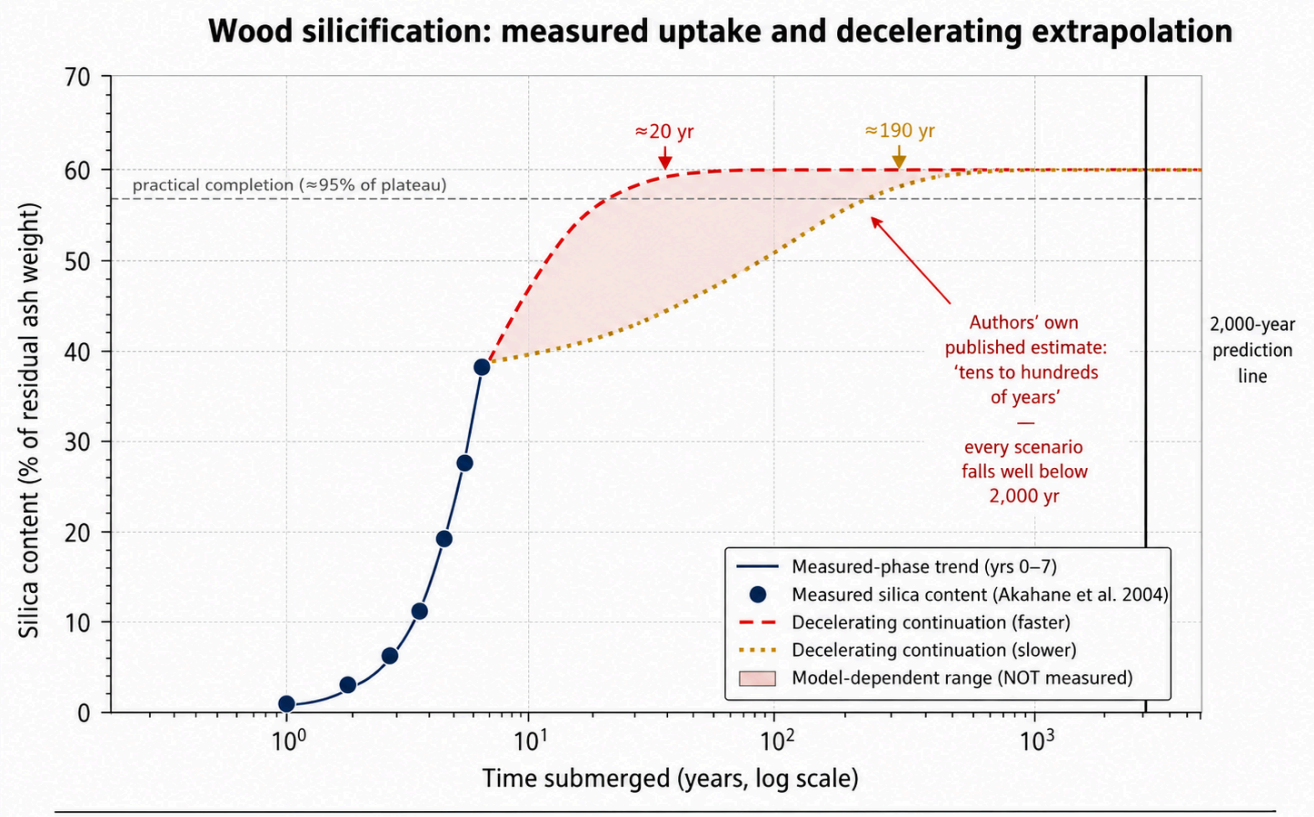

Figure 3. Wood silicification (Akahane et al. 2004). Solid points and trend = measured silica content over 1–7 years. Dashed/dotted curves = decelerating continuations to a plateau; the shaded region is a model-dependent range, not data. Both completion scenarios fall well below the 2,000-year prediction line.

4.4 Whole-fossil encasement: concretions in months to decades

Encasement of an entire carcass can occur far faster than once believed. Yoshida and colleagues modeled spherical carbonate concretions, which frequently contain exceptionally preserved fossils at their cores and showed, from diffusion–growth analysis of specimens from Japan, England, and New Zealand, that they grow over months to decades rather than the 10^5–10^6 years previously assumed [7]. The carbon in the carbonate derives largely from the enclosed organism, and the rate is set by how fast bicarbonate can diffuse through fine, clay-rich sediment to a reaction front—again, a condition, not a clock.

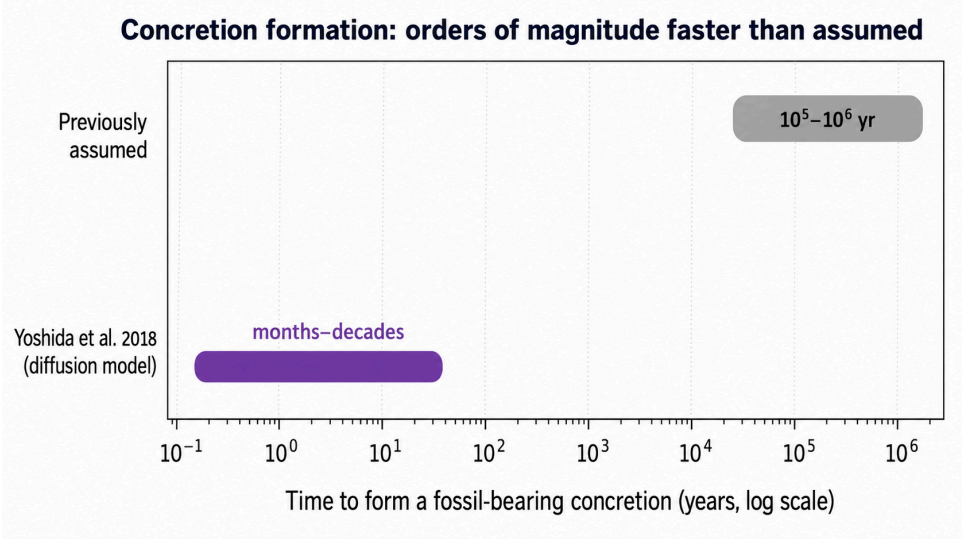

Figure 4. Concretion formation time: the diffusion model of Yoshida et al. (2018) yields months-to-decades, several orders of magnitude faster than the conventional assumption.

4.5 Synthesis

Figure 1 places all of the above on a single logarithmic time axis. The striking feature is not any individual point but the pattern: every observed window of significant mineralization; bone, soft tissue, wood, and whole-carcass encasement all lie far to the left of the 2,000-year line. The experiments span hours to a few decades; none requires deep time to reach extensive mineralization once conditions are favorable.

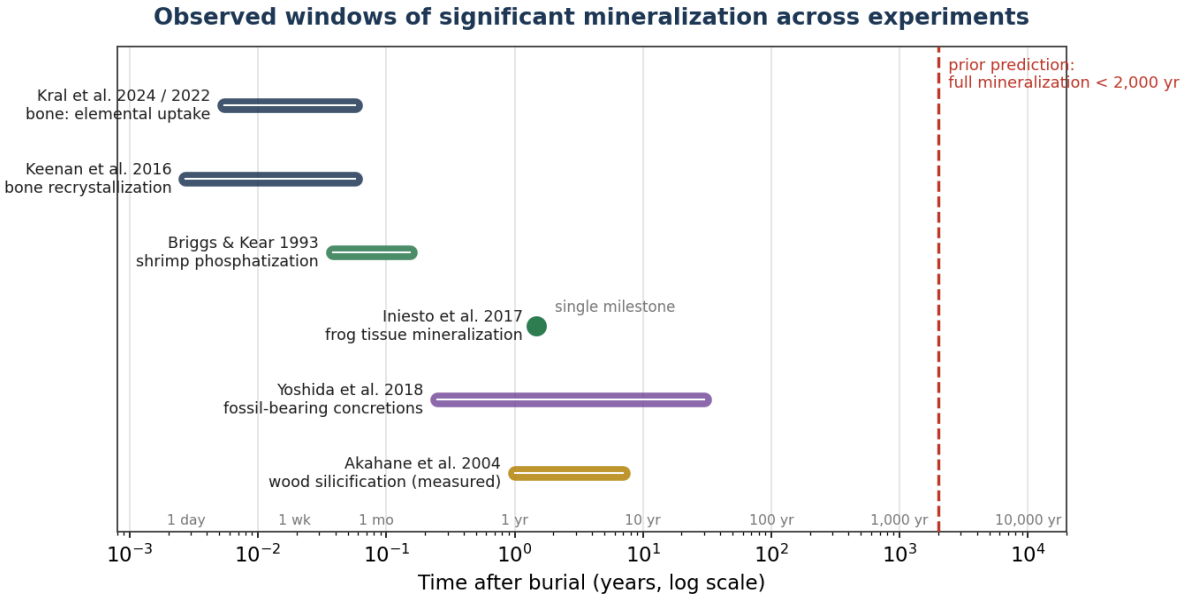

Figure 1. Observed windows of significant mineralization across the compiled studies, on a logarithmic time axis. The dashed line marks the 2,000-year prior prediction; all measured windows fall well below it.

5. The rate-limiting step is geochemical condition, not elapsed time

Across these systems the same theme recurs. Mineralization accelerates or stalls according to the availability of reactants and the local physicochemistry, not according to how much time has passed. Three controls dominate:

- **Reactant supply and saturation.** Phosphate availability governs bone mineralization [1]; dissolved silica governs wood permineralization [6]; bicarbonate generated by decaying organics drives concretion growth [7]. Where supply is high, precipitation is fast.
- **pH and the recrystallization window.** Bioapatite recrystallizes within a narrow pH band; microbial decay that lowers pH can switch the system from carbonate to phosphate precipitation, locking in soft-tissue detail [3,4].
- **Diffusion through the enclosing sediment.** Fine, low-permeability mud both concentrates reactants at a reaction front and seals the carcass against continued decay—the mechanism behind rapid concretion growth [7].

This reframing matters because it converts an apparent argument from authority (‘fossilization takes millions of years’) into an empirical question about conditions. The catastrophic-burial scenarios invoked in flood geology; rapid sediment loading, anoxia, fine-grained sealing muds, and abundant phosphate and silica liberated by mass mortality and volcanic or sedimentary input—are, notably, the very conditions the experiments identify as rate-maximizing. The author’s interpretation is that such events supply the favorable chemistry under which the experimentally measured rates apply; the experiments themselves are neutral as to which geological narrative produced those conditions.

6. Limitations and scope (what this paper does not claim)

- **Onset is not completion.** Most experiments mineralize only part of a carcass within their duration. As Briggs has emphasized, extensive mineralization requires that low decay rates persist long enough for precipitation to proceed, a balance difficult to sustain in the laboratory [8]. This paper claims rapid onset and condition-control, not demonstrating total fossilization of a whole vertebrate in the lab.
- **Extrapolation is model-dependent.** The completion estimate in §4.3 rests on an assumed decelerating kinetic form and an assumed plateau; it is bounded and conservative, but it is not a measurement, and the figure labels it as such.
- **Bone lacks a complete-mineralization clock.** The bone experiments [1–3] establish that the early stages are fast and condition-limited, but they do not yet trace a measured curve to a finished, geologically stable fossil. Extending the wood result to bone is a hypothesis, not a result.
- **A cautionary non-example.** Laboratory syntheses that convert wood to silicon-carbide ceramic at ~1,400 °C (e.g., Shin et al. 2005) are sometimes cited as 'petrified wood in days.' They should not be: that reaction forms Si–C bonds that do not occur in natural petrifaction, and specialists note it does not happen in nature. Citing it weakens rather than strengthens the case, and it is excluded here.

7. Implications

If the rate-limiting step in early diagenetic mineralization is geochemical condition rather than elapsed time, then the inference 'this fossil must be very old because fossilization is slow' is not logically secure. The experiments compiled here show that, given the right chemistry, mineralization proceeds on timescales of hours to decades, and that at least one permineralization system extrapolates to **completion within centuries.** This is sufficient to neutralize deep time as a necessary requirement for extensive mineralization. It is not, and is not presented as, a direct date for any specimen; establishing the age of a given fossil requires independent evidence about its specific burial history. The author offers the catastrophic-burial framework as a coherent source of the favorable conditions the experiments demand, while recognizing that the experimental rate data are compatible with more than one geological interpretation. The fossils themselves bear witness to recent fossilization based on other factors such as uncontaminated C14 intrinsic to the fossils (Giem, 2001; Baumgardner et al., 2003; Baumgardner, 2005; Snelling, 2008; Thomas & Nelson, 2015; Saitta et al., 2019).

Even dinosaur soft tissue has been discovered and has not yet racemized. This is the conversation of left handed amino acids to equally left and right handed, a law in chemistry. The upper limit is approximately 1 million years under typical burial conditions and that is actually a generous outer bound. The studies below did not primarily set out to measure racemization ratios in the way an amino acid geochronologist would (Schweitzer et al., 2005; Asara et al., 2007; Schweitzer et al., 2009; Bertazzo et al., 2015; Schroeter et al., 2017; Saitta et al., 2019). Rather, they detected and sequenced preserved L-amino acid–bearing collagen proteins, which implies incomplete racemization, because fully racemized protein produces no usable sequence data.

The Saitta et al. Centrosaurus study found that the Late Cretaceous bone tended to be L-amino acid dominated when amino acids were above detection limit, and that these low levels of racemization suggest the amino acids in the dinosaur bone are not particularly ancient. That is the most explicit racemization finding in the literature. For the protein-sequence studies, the logic is direct: Bertazzo et al. (2015) used time-of-flight secondary ion mass spectrometry to identify amino acid fragments typical of collagen fibrils in eight Cretaceous dinosaur bones, including structures consistent with endogenous collagen fibers displaying 67 nm banding consistent with preserved quaternary structure. Sequenceable collagen, with identifiable L-configured amino acids, is incompatible with full racemization.

8. Conclusion

Rapid-mineralization experiments in the peer-reviewed record show that the speed of early diagenetic mineralization is set by reactant supply, pH, diffusion, and microbial activity, not by the passage of deep time, and that under specific conditions extensive mineralization is fast. Across every system compiled here, the same controls govern the rate: a mineral reactant in supply (silica in wood, phosphate in bone), a permissive pH window, diffusion through the enclosing sediment, and microbial mediation. In this mechanistic sense wood and bone behave alike, and it is on that shared chemistry, not on a shared measured curve, that the comparison rests. The difference is in the evidence available: wood is the one system with enough time-series data to extrapolate responsibly, and there a decelerating model places completion within centuries, comfortably inside the prior prediction tested here. Bone has been measured only through its early stages, which are demonstrably fast and condition-limited, but not yet traced to a finished, geologically stable fossil. If the comparable chemical, hydrological, and depositional conditions documented for wood operated on vertebrate hard tissue, bone permineralization should be expected to follow a broadly similar rapid pathway, because it is driven by the same rate-limiting steps. At present this remains a testable prediction I make rather than a demonstrated conclusion for bone. Long-duration, quantitative time-series studies on vertebrate bone are still needed to determine whether the completion curve observed in wood also applies to skeletal tissue. Thus the rapid permineralization of wood stands as a confirmed prediction, while comparable rapid mineralization in bone remains a clear and falsifiable expectation for future experimental work.

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