

A Foundational Synthesis: The Chicxulub Impact and Multifractal Geological Time as Empirical Anchors for the TCGS-SEQUENTION Framework

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Article

A Foundational Synthesis: The Chicxulub Impact and Multifractal Geological Time as Empirical Anchors for the TCGS-SEQUENTION Framework

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Abstract

The TCGS-SEQUENTION framework, a timeless ontology constructed upon a 4D "timeless counterspace" ($\mathcal{C}$) from which the observable 3D world (Σ) is projected, has historically faced the central empirical challenge of distinguishing true 4D "slice-invariants" from 3D "foliation-dependent artifacts." This report, an augmented version of our foundational synthesis, demonstrates that this challenge is now met by a robust, two-pillar empirical foundation from the geological sciences. **Pillar I (The Slice)** utilizes the geochemical analysis of Chicxulub impact spherules. This work provides a non-trivial anchor for the framework's core *ontology*, by chemically separating, within a single co-genetic set of samples, a static, mass-independent *source invariant* (the 17-25% impactor contribution) from a dynamic, mass-dependent *process artifact* (the $\delta^{25}\text{Mg}$ fractionation signature). **Pillar II (The Foliation)** utilizes the geophysical analysis of the Geological Time Scale. This work provides an anchor for the framework's core *geometry*, demonstrating that the "timeline" of geological events is not a human convention but a "scaling (hence hierarchical) 'megacclimate' regime" with a quantifiable "multifractal" structure. We demonstrate that the "Compound Multifractal-Poisson Process" (CMPP) proposed by Lovejoy et al. is a direct, testable empirical model of the TCGS projection mechanism ($X : \mathcal{C} \rightarrow \Sigma$). Together, these findings provide a powerful, multi-domain validation of the framework's core axioms (A2, A3, A4) and its associated "Gravito-Capillary Foam" model.

Keywords: TCGS-SEQUENTION; timeless ontology; projection geometry; 4D counterspace; slice-invariant; foliation-dependent artifact; Axiom A2 (identity-of-Source); Axiom A3 (time as gauge); Axiom A4 (extrinsic constitutive law); chicxulub impact; cretaceous-paleogene boundary (KPB); impact spherules; isotopic tracers; mass-independent isotopes; mass-dependent isotopes; $\mu^{48}\text{Ca}$; $\delta^{25}\text{Mg}$; nucleosynthetic signatures; thermodynamic fractionation; gravito-capillary foam; shadow foam; thermodynamic decoupling; multifractal geology; scaling laws; geological time scale (GTS)

1. Introduction: The Problem of Time in Physics and Geology

The incompatibility between the treatment of time in general relativity (where it is a dynamic, coordinate-dependent parameter) and quantum mechanics (where it is a rigid, external background) remains the central unresolved conflict in fundamental physics. This has led to a class of "timeless" theories proposing that the flow of time is not a fundamental feature of reality, but is instead an emergent or illusory property.

This line of inquiry has been principally divided into two schools of thought. The first, relational mechanics, is articulated by Rovelli [15], who posits that mechanics should be "timeless" and formulated solely as a theory of relations between physical observables. In this view, the "flow" of time is a statistical emergence, a thermodynamic artifact described by the Thermal Time Hypothesis [14]. The second school, Shape Dynamics, is most notably advanced by Barbour [8]. This approach replaces spacetime with a timeless configuration space of all possible 3-dimensional shapes, or "Platonia". In this ontology, a "Now" is a single point in this vast state space, and the appearance of history and dynamics is an illusion contained within static "Time Capsules" [9].

This paper introduces and provides the first empirical validation for a third alternative ontology: the Timeless Counterspace & Shadow Gravity (TCGS) and SEQUENTION framework [3–5]. It posits that the totality of "what is" is a 4-dimensional source manifold, or "Counterspace" (C). Our observable 3-dimensional world (Σ) is not a configuration, but a projection or "shadow" of this 4D source. The appearance of "time" or "history" is, therefore, a "foliation artifact"—a consequence of the geometric way the 3D shadow is "sliced" from the 4D source. We demonstrate here that the geological record, in two distinct and unrelated domains, provides a direct and precise validation of this geometric-projection ontology.

2. Pillar I (The Slice): Validation of the Core Ontological Postulate via Geochemistry

This first pillar of our empirical synthesis establishes the validity of the framework’s core ontological distinction, which is the lynchpin of the entire program. It uses the geochemical findings from the Cretaceous-Paleogene Boundary (KPB) [10] to demonstrate that the conceptual divide between a 4D "source invariant" and a 3D "shadow artifact" is a physical, measurable reality.

2.1. The Central Challenge of the TCGS-SEQUENTION Program

The TCGS-SEQUENTION framework is constructed upon a radical, timeless ontology. It posits that the observable 3D world (the "shadow" manifold, Σ) is a projection from a complete, 4D "timeless counterspace" (C) [3,4]. Within this structure, Axiom A3 ("Time as Gauge") explicitly demotes "time" to a non-ontic "foliation artifact" [3,5]. Apparent sequences, such as biological evolution or cosmological history, are understood merely as "foliation choices of a projection" [3,5]. This ontology presents a profound empirical challenge, one that has been identified as the lynchpin of the entire program: the "validation of slice-invariants" [3]. The framework’s progress is contingent upon its ability to empirically distinguish "true geometric invariants" from "foliation-dependent quantities" [3]. Without a "meta-rule" for identifying genuine, foliation-agnostic observables, the framework remains a powerful but purely theoretical construct. The core axioms (A2, A4) are derived from this premise, but the premise itself requires an empirical anchor.

2.2. The Rundhaug et al. (2025) Paper as an Empirical Solution

The geological investigation into Chicxulub impact spherules by Rundhaug et al. [1] provides, perhaps unwittingly, the first clear, large-scale empirical solution to this central challenge. The study’s methodology, while conventional within geochemistry, is structured *perfectly* along the lines of the TCGS ontological divide. The authors employ two distinct classes of isotopic tracers to answer two different questions:

1. A "source-tracing" question (What was the impactor?), answered using static, mass-independent isotopes.
2. A "process-tracing" question (How did the plume cool?), answered using dynamic, mass-dependent isotopes.

The TCGS-SEQUENTION framework re-interprets this methodological split as a foundational *ontological* one. The Rundhaug et al. paper [1] has cleanly isolated a true "slice-invariant" from a "foliation-dependent artifact" within a single, co-genetic set of physical samples.

2.3. Delineating the Two Data Classes (The Rundhaug et al. Findings)

The findings of the geological study [1] can be mapped directly onto the TCGS-SEQUENTION ontology:

1. **The ‘Slice-Invariant’ (Source Property):** The study identifies a fixed "impactor contribution of 17-25%" [1]. This value is derived from mass-independent (nucleosynthetic) isotopic signatures, specifically $\mu^{48}\text{Ca}$ and $\mu^{26}\text{Mg}^*$ [1]. These tracers are "foliation-agnostic" because their signatures are forged in stars, not in the thermodynamic (temporal) processing of the impact plume. This

17-25% value represents a static *mixing ratio* of the source materials, fixed at the moment of projection ($t = 0$), and is *invariant* to the subsequent *temporal process* of cooling, expansion, and condensation.

2. **The 'Foliation-Dependent Artifact' (Process Signature):** The study also identifies "generally light or unfractionated" mass-dependent isotopic signatures, specifically $\delta^{25}\text{Mg}$ and $\delta^{56}\text{Fe}$ [1]. The authors explicitly interpret these values as the result of a *temporal process*: "incomplete recondensation as the pyrocloud cooled and expanded" [1]. This is a "foliation-dependent" measurement. The final $\delta^{25}\text{Mg}$ value is *contingent* on the foliation path (the cooling rate) and the specific "slice" (the moment of quenching) at which the spherule solidified.

2.4. The Ontological Re-Interpretation of Geochemical Tracers

The distinction made by geochemists between "nucleosynthetic tracers" (for source) and "thermodynamic tracers" (for process) is, for them, a methodological convenience. For the TCGS-SEQUENTION framework, this distinction is *foundational*.

The Rundhaug et al. paper [1] provides the first empirical proof that this ontological split is not a theoretical abstraction but a physical reality. It demonstrates that a single physical system contains *both* classes of information simultaneously.

- The 17-25% value is a property of the *source* (the $\mathcal{C}$ -manifold content), a true "projection invariant" [3] that defines the boundary conditions of the projection event.
- The light $\delta^{25}\text{Mg}$ value is a property of the *shadow* (the Σ -manifold observation), an "artifact of foliation and incomplete conditioning" [5], a record of the chosen "time" path.

This geological paper, therefore, validates the framework's core ontological postulate and provides the "meta-rule" for which the program has been searching: *Nucleosynthetic signatures (mass-independent) are slice-invariants, while thermodynamic fractionation signatures (mass-dependent) are foliation-dependent artifacts.*

3. The KPB Impactor as a Physical Realization of Axiom A2 (Identity-of-Source)

3.1. Axiom A2 in the TCGS-SEQUENTION Framework

Axiom A2 ("Identity-of-Source") is described as the framework's "most powerful idea" [3]. It provides the *geometric* origin for all conserved structures, singularities, and convergent phenomena, thereby dissolving the "problem of initial conditions" [3].

- **In Physics:** Axiom A2 posits a "distinguished point $p_0 \in \mathcal{C}$ " (the 4D counterspace). The orbit of this point under the automorphism group $\text{Aut}(\mathcal{C}, G, \Psi)$ creates the "fundamental singular set $S = \text{Orb}(p_0)$," from which all "shadow singularities" (e.g., matter, particles) "descend" [3,4]. This ensures all singularities are fundamentally identical, as they share one source.
- **In Biology:** The axiom provides a geometric alternative to "just-so stories" about selective pressure [5]. It posits that "conserved developmental organizers" and "repeated adaptive solutions" (i.e., evolutionary convergence) are "not independent inventions" [3]. Instead, they are "manifestations of different foliation-paths geometrically constrained by the same singular set S in $\mathcal{C}$ " [3,5].

The core function of Axiom A2 is to solve *convergence problems*: why do disparate phenomena, separated by what *appears* to be space or time, manifest the same fundamental structures? The answer is that they are all projections of a *single* geometric source.

3.2. The Geological Finding: A Globally Convergent Layer from a Single Source

The Cretaceous-Paleogene Boundary (KPB) layer is a quintessential geological *convergence problem*. A single, thin layer of ejecta, characterized by unique geochemical signatures (e.g., Iridium) and the presence of impact spherules, is found globally [10]. This "shadow manifestation" appears in diverse depositional environments, from deep-sea sediments to terrestrial deposits, yet it is all "convergent" on a single "event."

The standard geological explanation—that this globally convergent layer is the result of a single, massive impact event—is, in TCGS-SEQUENTION terminology, an "Identity-of-Source" explanation. The Rundhaug et al. paper [1] provides the most precise *empirical proof* to date for this A2-style explanation. By using mass-independent isotopic tracers ($\mu^{48}\text{Ca}$ and $\mu^{26}\text{Mg}$), the authors "fingerprint" the source material. They identify a clear non-terrestrial component, allowing them to identify the "Identity-of-Source" for the globally convergent spherule layer: a single "CM or CO chondrite-like asteroid" [1].

3.3. A New Domain for Axiom A2: Geology

This geological finding provides a stunning, large-scale, *physical* instantiation of the abstract "singular set S" [3]. The Chicxulub impactor is the p_0 for the KPB event. The resulting globally-distributed ejecta layer is the "shadow singularity" (or "conserved structure") that descends from this single source.

This finding bridges the conceptual gap between the axiom's abstract physical application (a geometric point p_0) and its biological application (a geometric constraint on convergence). The Chicxulub impact is the "geometric alternative" to "just-so stories" for the KPB layer. It is the "single, timeless geometric source" [3] from which the entire phenomenon descends.

Therefore, this analysis allows the TCGS-SEQUENTION framework to confidently claim a new, third domain of applicability for Axiom A2. The axiom now unifies:

1. **Physics:** The identity of fundamental singularities [3,4].
2. **Biology:** The convergence of adaptive solutions [3,5].
3. **Geology:** The origin of globally "convergent" ejecta layers from a single, isotopically-fingerprinted impactor [1].

4. The 17-25% Impactor Contribution: A True 'Slice-Invariant' of the Source Mixture

4.1. Defining 'Slice-Invariants' in TCGS-SEQUENTION

The framework's timeless ontology (Axiom A3, "Time as Gauge") [3,5] necessitates that all *truly* fundamental, "ontic" observables are "slice-invariants"—quantities that are independent of the chosen foliation (the "time" parameter). The framework's falsifiability program is built upon identifying and testing these invariants [3]. Examples of such invariants already posited by the framework include:

- **The Physical Invariant a_* :** The "key invariant" [4] in the physics domain, an acceleration scale a_* that governs the MOND-like regime [12]. This a_* is defined as an "embedding invariant" of the shadow manifold: $a_* = \xi c^2 \langle |H| \rangle_\Sigma$, where $\langle |H| \rangle_\Sigma$ is the mean extrinsic curvature of Σ [3,4]. It is a fundamental *geometric* property, not a physical "constant" in the traditional sense.
- **The Cosmological Invariants V_k :** The proposed "CMB slice invariants" [6]. These are Minkowski functionals (V_0, V_1, V_2) and genus-like densities ($g(\nu)$) [6]. They are "foliation-agnostic" descriptors of the pullback field $X^*\Psi$ on an observational slice, designed to implement "cosmology without time" [6].
- **The Biological Invariants (P1-P5):** A suite of testable, slice-invariant predictions, including "Convergence as curvature equality (P1)," "Order-invariant macro-steps (P2)," and "Slice-invariant complexity (P3)" [3,5].

4.2. The 17-25% Value as a New Candidate Invariant

The Rundhaug et al. paper [1] provides a new, empirically measured, dimensionless number: the "17-25% impactor contribution." As established in Section 1, this value is derived from mass-independent isotopes, making it *invariant* to the subsequent temporal, thermodynamic processing of the plume. It is a "slice-invariant" property of the event itself.

This finding is of profound importance. It is a new, fundamental number handed to the framework by empirical observation, in the same class as the invariant a_* .

4.3. A New 'Embedding Invariant' of the Projection

The TCGS-SEQUENTION framework explicitly "replaces the 'problem of initial conditions' with a 'problem of boundary conditions' through geometric embedding" [3]. The 17-25% value [1] is not a "historical accident" or a random "initial condition." In the TCGS framework, it must be interpreted as a *fundamental boundary condition* of the projection event.

This 17-25% value represents the static, fundamental *mixing ratio* of the two source materials (Source 1: Impactor/Axiom A2 singular set S ; Source 2: Target Crust/Shadow manifold Σ) that constitute the *total* source content for this specific projection. This invites a powerful new hypothesis: This ratio is not random but is *prescribed* by the 4D geometry of the projection.

Just as the a_* invariant is equated with the mean extrinsic curvature of the shadow's embedding [3,4], this 17-25% ratio may be a new "embedding invariant" (which we might term a_{mix}), representing a fundamental stability ratio for high-energy projection events. This ratio could be a required value for the variational principle of the "gravito-capillary foam" model to hold [6]. It is possible that for a projection of this magnitude (a planetary impact), the stable "bubble-domain morphology" [6] can only form from a 4D source foam if the mixing ratio of "singular set" content (impactor) to "shadow" content (crust) falls within this $a_{mix} \approx 0.17 - 0.25$ range. This elevates the geological finding from a simple "fit" to a potential new cornerstone of the framework's mathematical-physical structure, on par with the a_* invariant that underpins the framework's "dark matter" explanation [3,4].

5. Foliation-Dependent Signatures: Isotopic Fractionation ($\delta^{25}\text{Mg}$) as a Record of Temporal Process

5.1. Defining 'Foliation-Dependent Artifacts' in TCGS-SEQUENTION

The framework's timeless ontology (Axiom A3, "Time as Gauge") [3,5] is not a solipsistic claim that "time isn't real." It is a precise physical postulate that "apparent evolution is a foliation artifact" [3] and that observed dynamics are "foliation choices" [3]. This implies that *most* conventional measurements, especially those that track change over "time," are not fundamental. The framework explicitly demotes "randomness," "uncertainty," and "probability" to a non-ontic status, describing them as "artifacts of foliation and incomplete conditioning" [5] or "computational heuristics" [5]. Any description that is "gauge-variant" (i.e., dependent on the choice of "time" parameter) is an artifact, not a fundamental property [3,4].

5.2. The Geological Data and its 'Timeful Narrative' Interpretation

The Rundhaug et al. paper [1] provides a perfect example of such an artifact. The authors analyze the mass-dependent isotopic signatures $\delta^{25}\text{Mg}$ and $\delta^{56}\text{Fe}$. They find these signatures are "generally light or unfractionated" [1].

Crucially, their interpretation of this data is a 'timeful narrative'. They explicitly state these signatures "suggest incomplete recondensation as the pyrocloud cooled and expanded" [1]. This is a *process-dependent* explanation:

- At t_0 (impact), all material was vaporized.
- From t_0 to t_{final} (quenching), the vapor "cooled and expanded" (a "foliation path").
- During this process, "incomplete recondensation" occurred (a process *along* the path).
- At t_{final} , the spherules solidified (a "slice"), locking in the $\delta^{25}\text{Mg}$ signature of that *moment*.

5.3. Empirical Proof of the Timeless Ontology

This finding, far from challenging the TCGS-SEQUENTION framework, provides its most powerful *validation*. The $\delta^{25}\text{Mg}$ value is a *direct physical measurement* of a "foliation-dependent artifact." The "foliation" is the *temporal path* of cooling and expansion. The "slice" is the *moment of quenching* (solidification) of the spherules.

The measured $\delta^{25}\text{Mg}$ value is *contingent*. It is not a fundamental number. If the pyrocloud had cooled faster (a different foliation path, τ_A) or quenched later (a different slice, s_B), the "incomplete

recondensation" would have proceeded to a different degree, and the final measured $\delta^{25}\text{Mg}$ value would be different. This is the very definition of a "gauge-variant" or "foliation-dependent" quantity [3].

The Rundhaug et al. paper [1] thus provides the "smoking gun" for the TCGS-SEQUENTON ontology. It presents, within a single physical event, *both* classes of data the framework predicts must exist:

1. A true '**Slice-Invariant**' (the 17-25% mixing ratio) [1], which is a property of the 4D *source*.
2. A clear '**Foliation-Dependent Artifact**' (the $\delta^{25}\text{Mg}$ fractionation) [1], which is a property of the 3D *shadow's* apparent history.

This proves that the framework's ontological distinction between "invariants" and "artifacts" is not a matter of philosophical interpretation, but a *physical, measurable reality*.

6. Morphological Correspondence: The 'Pyrocloud' and the 'Gravito-Capillary Foam'

6.1. The TCGS-SEQUENTON Morphological Model

To "operationalize" the TCGS-SEQUENTON program [6], the framework introduces a concrete mathematical and physical model for the 4D source: the "**Gravito-Capillary Foam**" [6]. This model posits that the 4D source layer ($\mathcal{C}$) hosts a "4-D partition whose interfaces behave like 'soap films' shaped by a gravity-like potential" [6]. It is defined as a "sharp-interface variational partition" [6] whose dynamics are governed by a minimization of an energy functional $\mathcal{E}_\epsilon[\phi, U]$ [6]. The first variations of this energy functional yield the governing laws of the 4D source [6]:

1. A 4D prescribed mean-curvature condition: $H_\Gamma = \kappa U$ (a 4D Young-Laplace analogue).
2. A nonlinear, uniformly elliptic Poisson sector: $-\text{div}(\mu(\frac{\|\nabla U\|}{a})\nabla U) = \rho + \lambda f(\phi)$.

The most critical part of this model is its *projection*. The observable 3D world (Σ) is an immersion $X : \Sigma \hookrightarrow \mathcal{C}$. The "shadow foam" observed in 3D is $F_\Sigma := X^{-1}(\Gamma) \subset \Sigma$ [6]. This projected foam inherits Plateau-like laws and junction angles, but with "explicit extrinsic corrections" from the immersion X [6]. This "pullback" of the 4D foam's geometry is what produces the "3-D bubble-domain morphology" [6] observed in the shadow.

6.2. The Geological Morphology of the 'Pyrocloud'

The Rundhaug et al. paper [1] provides a detailed physical description of the aftermath of the Chicxulub impact, with hydrocode simulations of such events provided by researchers such as Artemieva and Morgan [7]. The focus is on the "pyrocloud deposit."

- The "**pyrocloud**" itself is defined as a "fast-moving, high-temperature turbulent cloud" [1].
- It is explicitly described as a "mixture of molten and condensed droplets" [1]. This is, by definition, a *physical foam*—a multi-phase mixture of vapor, melt (liquid), and solidifying droplets.
- The resulting "pyrocloud deposit" (the final "shadow" state) is composed of "spheres, rotational, and agglutinated/irregular forms" [1]. These are the literal "bubbles" and "droplets" of the foam, quenched and frozen.

6.3. The Pyrocloud as a Physical 'Shadow Foam'

The morphological analogy between the TCGS model and the geological finding is precise, powerful, and non-trivial. The "pyrocloud" *is* the physical manifestation of the 3D "shadow foam" (F_Σ) predicted by the TCGS "gravito-capillary foam" model [6].

- The TCGS model predicts a "3-D bubble-domain morphology" [6].
- The geological data shows a turbulent vapor/melt foam (the "pyrocloud") that solidifies into "spherules" (the "bubbles") [1].

This correspondence suggests that the Chicxulub impact event is not just an *analogy* for a projection, but a literal, physical *projection event* ($X : \Sigma \rightarrow \mathcal{C}$). The "pyrocloud" is the *physical instantiation* of the

3D shadow foam (F_{Σ}) generated by the 4D gravito-capillary source model. The "spherules" are the geometric "bubble-domains" predicted by the model [6]. This provides a tangible, physical system in which to study the "extrinsic corrections" and "pullback" geometry of the shadow foam's mean curvature, $H_{F_{\Sigma}}$ [6].

7. 'Thermodynamic Decoupling' as a Signature of the Extrinsic Constitutive Law (Axiom A4)

7.1. Axiom A4: The Extrinsic Constitutive Law

Axiom A4 ("Parsimony") [3] is the mathematical core of the framework's dynamics. It posits that apparent "dark" phenomena are not new particles or forces, but "misidentifications of projection geometry" [4] governed by a single "extrinsic constitutive law" [3,4]. This law links the shadow's dynamics to the 4D embedding geometry. The law takes parallel forms in physics and biology [3]:

- **Physics (Shadow Gravity):** $\nabla \cdot [\mu(\frac{|\nabla\Phi|}{a_*})\nabla\Phi] = 4\pi G\rho_b$ [3,4]. This connects to established research on modified gravity, which began with Milgrom [12] as an alternative to dark matter.
- **Biology (SEQUENTION):** $J = \mu_{bio}(|\nabla\mathcal{U}|/a_+)\nabla\mathcal{U}$ [3,5].

The key feature in both domains is the non-linear "mobility" function μ . This function creates a two-regime (high-gradient vs. low-gradient) dynamic, where the shadow's response to the source potential (Φ or $\mathcal{U}$) is *non-linear* and *decoupled* from a simple, linear law (like Newton's or classical genetics) [3]. This law is the "correction term" accounting for 4D information lost in 3D-only views [3].

7.2. The Geological Finding: 'Thermodynamic Decoupling'

The most subtle and complex finding in the Rundhaug et al. paper [1] is the "decoupling" of the Mg and Fe isotope systems. The $\delta^{25}\text{Mg}$ and $\delta^{56}\text{Fe}$ signatures do not co-vary in a simple, linear fashion. The authors interpret this as being "likely due to differing condensation rates," calculating a "higher average condensation rate of Fe than Mg" [1].

This is a complex, non-linear, and *decoupled* dynamic. The Mg and Fe are in the *same* pyrocloud, subject to the *same* cooling (the same "foliation"). In a simple system, one might expect them to co-precipitate based on a single thermodynamic parameter. Instead, they "decouple" [1].

7.3. 'Shadow Thermodynamics' as an Expression of Axiom A4

This "thermodynamic decoupling" [1] is a hallmark of the *kind* of non-linear, decoupled dynamics that Axiom A4 is explicitly designed to produce. This invites the most speculative, yet potentially most powerful, hypothesis of this report: the observed "thermodynamic decoupling" is not *just* standard chemical thermodynamics, but a *geometrical* effect of the projection, governed by the Extrinsic Constitutive Law.

A standard chemical explanation would be "Mg and Fe have different chemical properties and condensation temperatures." This is true, but *why*?

A TCGS-SEQUENTION explanation would posit that the *effective* condensation behavior is governed by the A4 extrinsic law. The "decoupling" [1] arises because Mg and Fe have different coupling coefficients to the μ -function (e.g., $\mu_{Mg} \neq \mu_{Fe}$) in the shadow, or they respond differently to the "low-gradient" vs. "high-gradient" regimes defined by the a_* invariant [4].

- **Hypothesis:** The "thermodynamic" behavior of elements in the shadow (Σ) is governed by a domain-specific expression of the A4 extrinsic law: $\nabla \cdot [\mu_i(\frac{|\nabla\Phi|}{a_i})\nabla\Phi_i] = \rho_i$...where i is the element (Mg, Fe). The observed "decoupling" [1] is a direct result of $\mu_{Mg} \neq \mu_{Fe}$.

This suggests a new, third domain for Axiom A4: **"Shadow Thermodynamics."** Just as Axiom A4 provides a *geometric origin* for "dark matter" (the MOND-like μ -function) [3,4] and "biological convergence" (the μ_{bio} -function) [5], it may also provide a *geometric origin* for the complex, non-linear, and decoupled condensation rates observed in the geological data [1].

8. Pillar II (The Foliation): Validation of the Multifractal Geometry of Geological Time

8.1. The Next Empirical Challenge: Quantifying the Foliation

The analysis in Sections 1-6, based on Rundhaug et al. [1], has successfully provided a robust empirical anchor for the framework's *ontology*. It validates the distinction between Invariant and Artifact *within a single slice* (the KPB event). This is Pillar I of our empirical foundation.

The next, and equally critical, challenge is to validate the framework's claims about the *foliation itself*. Axiom A3 ("Time as Gauge") [3,5] posits that apparent history is a "foliation artifact." But what is the *structure* of this foliation? Is the "timeline" of geological events (e.g., the Geological Time Scale, or GTS) truly arbitrary, or does it have a discernible, non-trivial geometry that is itself a *consequence* of the 4D source manifold $\mathcal{C}$? Until now, this has been a purely theoretical question.

8.2. Lovejoy et al. (2025) as a Foliation-Level Solution

The geophysical investigation by Lovejoy et al. [2] provides the empirical solution to this second challenge, forming Pillar II of our foundation. This paper analyzes the *temporal density of boundary events* ($\rho(t)$) in the Geological Time Scale (GTS), including global (GTS2020, Sepkoski) and zonal (Conodont, Ammonoid, etc.) series.

The key finding of Lovejoy et al. [2] is that the hierarchical nature of the GTS (eons, eras, periods) is not a mere human classification. It is, in their words, a "scaling (hence hierarchical) 'megacimate' regime" [2], which builds on decades of work applying multifractal cascade models to climate [11]. The boundary events are *not* randomly distributed in "time" but follow a "multifractal" structure.

The TCGS-SEQUENTION framework interprets this as a direct, empirical validation of a non-arbitrary, geometric foliation. The "foliation" of $\mathcal{C}$ into slices of Σ has a quantifiable, geometric structure, and Lovejoy et al. [2] have provided the first measurements of this "foliation geometry." The scaling exponents they measure—such as the fluctuation exponent $H \approx -0.15$ (implying long-range anti-correlation), the intermittency exponent $C_1 \approx 0.1$, and the multifractal index $\alpha \approx 1.2 - 1.5$ [2]—are candidates for new, fundamental *invariants* of the TCGS framework, describing the large-scale projection geometry.

8.3. The Compound Multifractal-Poisson Process as a Projection Mechanism

The most profound finding of the Lovejoy et al. paper [2] is the *mechanism* they propose to explain this multifractal structure: a **"Compound Multifractal-Poisson Process" (CMPP)**. In this CMPP model, a "subordinating multifractal process" determines the *probability* of an event, which is then realized (or not) by a "subordinated Poisson process" [2].

This is a literal, empirical description of the TCGS-SEQUENTION projection mechanism:

1. **The "Subordinating Multifractal Process" [2] IS the geometric structure of the 4D timeless counterspace, $\mathcal{C}$.** Its complex, scaling, "multifractal" nature is precisely what our "Gravito-Capillary Foam" model [6] posits: a deterministic, non-linear 4D source whose geometry is not simple or uniform.
2. **The "Subordinated Poisson Process" [2] IS the projection $X : \mathcal{C} \rightarrow \Sigma$.** The "event" (a stratigraphic boundary) is "probabilistic" *only* from the perspective of the 3D shadow manifold Σ .

This maps perfectly onto our framework's foundational stance on probability. As stated in the SEQUENTION-branch of the framework [5], "uncertainty, randomness, and probability have no ontic status; they are artifacts of foliation and incomplete conditioning." The Lovejoy et al. [2] model provides the first empirical quantification of this principle. The "probability" of a geological boundary event is not fundamental (ontic); it is a *consequence* (an artifact) of the 4D source's deterministic, multifractal geometry.

8.4. 'Gaps' and the 'Sadler Effect' as Foliation-Dependent Artifacts

This re-interpretation of the CMPP model provides a powerful new explanation for a classic problem in geology: the incompleteness of the fossil record, exemplified by the "Sadler effect" [13]. Lovejoy et al. [2] analyze the "gaps" (τ) between successive boundary events. They find the probability distribution of these gaps is "fat-tailed," following a power law: $Pr(\tau' > \tau) \approx \tau^{-q_D}$, with $q_D \approx 3.3$ [2]. This "Length Sadler effect" implies that "longer series will tend to have larger gaps and hence to be more incomplete" [2].

In a conventional, time-based model, these large "gaps" are problematic; they represent "missing time" or a failure of the record. In the TCGS-SEQUENTION framework, these "gaps" are a *prediction*. They are "foliation-dependent artifacts" of the source's "fat-tailed" multifractal geometry. The "gaps" are not "missing time." They are regions of the 4D source manifold $\mathcal{C}$ that, due to their specific geometry, have a very low "Poisson" probability of projecting an "event" (a boundary) onto the 3D shadow Σ . The Sadler effect is thus re-interpreted as a direct, measurable, and predictable geometric consequence of the TCGS projection mechanism X .

9. Integration and Augmentation: A Two-Pillar Empirical Foundation for TCGS-SEQUENTION

9.1. Synthesis: The Slice and The Foliation

The TCGS-SEQUENTION framework is now anchored by a two-pillar empirical foundation, with each pillar validating a different, essential component of the core timeless ontology.

- **Pillar I (The Slice)**, based on Rundhaug et al. [1], validates the framework's core *ontology*. It provides the first direct, physical, and measurable proof that the conceptual split between a 4D "slice-invariant" (the source property) and a 3D "foliation-dependent artifact" (the process property) is a physical reality, separable within a single event.
- **Pillar II (The Foliation)**, based on Lovejoy et al. [2], validates the framework's core *geometry*. It provides the first direct, physical, and measurable proof that the "timeline" of events (the foliation) is not a simple, arbitrary, or linear parameter, but has a complex, quantifiable, "multifractal" geometry.

The convergence of these two independent, complex datasets—one from geochemistry, the other from geophysics—onto the specific, abstract, and interlocking axioms of the TCGS-SEQUENTION program provides a powerful argument for its viability.

9.2. Amended Foundational Correspondence

This synthesis, which maps the geological findings from both [1] and [2] onto the core TCGS-SEQUENTION framework [3–6], is summarized in Table 1.

9.3. Augmentation of the Falsifiability Program

This new, two-pillar synthesis indicates that the framework's Falsifiability Program, as outlined in "The TCGS-SEQUENTION Framework" [3], must be expanded. That program is currently focused on Physics (RAR, BTFR, Lensing) and Biology (P1-P5). This new geological data provides a third pillar for empirical testing.

9.3.1. Proposed New Falsifiable Predictions (Geological Domain - Slice)

These predictions are derived from the Rundhaug et al. [1] synthesis (Pillar I):

1. **Prediction (A2-Geology):** All large-scale, high-energy impact events (e.g., other spherule layers from the Archean) will produce globally "convergent" ejecta layers. The "Identity-of-Source" for each of these layers will be confirmable via mass-independent isotopic tracers.
2. **Prediction (Invariant-Geology):** The *mixing ratio* of projectile-to-target material (the "projection invariant," e.g., the 17-25% value [1]) will be shown to be a stable or predictable value (a_{mix}), not

Table 1. Foundational Correspondence Between TCGS-SEQUENTION Axioms and Geological Findings.

TCGS-SEQUENTION Concept (Axiom/Ontology)	Geological Finding (Source)	Nature of Correspondence (Interpretation)
Axiom A2: Identity-of-Source [3–5]	Single source: "CM or CO chondrite-like asteroid" (Rundhaug et al. 2025) [1]	Axiomatic (Physical Instantiation)
Ontology: Slice-Invariant [3, 5,6]	Static mixing ratio: "17-25% impactor contribution" from mass-independent $\mu^{48}\text{Ca}$ (Rundhaug et al. 2025) [1]	Ontological (Source-Level Invariant)
Ontology: Foliation-Dependent Artifact [3,5,6]	Process signature: "light $\delta^{25}\text{Mg}$ " from "incomplete recondensation" (Rundhaug et al. 2025) [1]	Ontological (Shadow-Level Process Artifact)
Model: Gravito-Capillary Foam / Bubble-Domain Morphology [6]	Physical morphology: "Pyrocloud" (turbulent vapor/melt foam) forming "spherules" (Rundhaug et al. 2025) [1,7]	Morphological (Physical Analog)
Axiom A4: Extrinsic Constitutive Law / Decoupled Dynamics [3,4]	Complex dynamics: "Thermodynamic decoupling" of Mg and Fe (Rundhaug et al. 2025) [1]	Axiomatic (Domain-Specific Expression of Law)
Axiom A3: Time as Gauge / Foliation Structure [3,5]	"GTS [is a] scaling (hence hierarchical) 'megacclimate' regime"; "multifractal" structure (Lovejoy et al. 2025) [2,11]	Axiomatic (Physical Instantiation of Foliation Geometry)
Projection Mechanism X : $\mathcal{C} \rightarrow \Sigma$ [3,6]	"Compound Multifractal-Poisson Process" (CMPP) (Lovejoy et al. 2025) [2]	Mechanistic (Direct Analog). Source $\mathcal{C}$ is the subordinating multifractal; Projection X is the subordinated Poisson process.
Ontology: Foliation-Dependent Artifact (Probability) [5]	"'Fat tailed' probability distribution of... 'gaps'" ($q_D \approx 3.3$, "Length Sadler effect") (Lovejoy et al. 2025) [2,13]	Ontological (Shadow-Level Artifact). "Missing time" is a predictable geometric artifact of the 4D source's scaling.

a random variable. Different "classes" of impacts will correspond to different, but predictable, stable "invariant" mixing ratios.

3. **Prediction (A4-Geology):** The "thermodynamic decoupling" [1] of elements during pyrocloud condensation is not a purely chemical phenomenon. It will be successfully modeled as a domain-specific expression of the Axiom A4 extrinsic constitutive law ($\mu_{Mg} \neq \mu_{Fe}$).

9.3.2. Proposed New Falsifiable Predictions (Geological Domain - Foliation)

These new predictions are derived from the Lovejoy et al. [2] synthesis (Pillar II):

1. **Prediction (A3-Geology-1):** The multifractal exponents (H, C_1, α) measured by Lovejoy et al. [2] are *not* independent physical constants but are *TCGS embedding invariants*. They must be derivable from the variational principle of the "Gravito-Capillary Foam" model [6].
2. **Prediction (A3-Geology-2):** The CMPP model, when re-interpreted as a TCGS projection, must hold for other "shadow histories." The *same* multifractal exponents found in the GTS [2] must also be found in the "event density" of biological macroevolution (e.g., origination/extinction events) and potentially even cosmological data (e.g., distribution of "events" like galaxy formation). This tests the universality of the $\mathcal{C}$ -manifold's geometry.

9.4. Final Conclusions

The geological information from both Rundhaug et al. [1] and Lovejoy et al. [2] provides a foundational, multi-faceted empirical validation for the TCGS-SEQUENTION program. Pillar I [1] provides a new empirical basis for the framework's core axioms (A2, A4) and, most importantly, provides the first direct, physical evidence for the framework's central ontological claim: that reality is composed of a co-existing, measurable "slice-invariant" source structure and a "foliation-dependent" shadow history. Pillar II [2] provides the first empirical evidence for the *geometry* of the foliation itself, demonstrating it is a non-trivial, multifractal structure. It provides an empirical model (the CMPP) that serves as a direct, physical analog for the framework's abstract projection mechanism X.

The TCGS-SEQUENTION framework, now augmented with this two-pillar geological domain and situated within the broader context of timeless physics [9,15], is significantly strengthened. It

moves from a "physical theory in existing mathematics" to a "research program demanding new mathematics" [3] with a new, concrete empirical footing.

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