Astro-Ballistic Chronostratigraphic Sequencing II

Transmission Through a Differentiated Earth

Entrance Coupling, Differentiated-Earth Transmission, Midpoint-Response Inheritance, and Terminal-Response Mechanics

The Interior Mechanics of the Great Dying Challenge

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Series: Astro-Ballistic Chronostratigraphic Sequencing

Paper: II of V

Companion: Paper V, Claims, Equations, Data, and Falsification Atlas

Status: Conditional mechanical-analysis manuscript

Version: Canonical Corpus Freeze 1.0

Freeze ID: ABC-CF1-2026-08-07

Date: August 7, 2026

Canonical Corpus Freeze Notice

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`ABC-CF1-2026-08-07`

and its freeze date is August 7, 2026. The freeze fixes the current manuscript wording, equations, citations, epistemic statuses, dependencies, falsifiers, and declared scope. It does not upgrade any item marked unresolved, not established, disfavored, not yet executed, draft, or to-be-preregistered into empirical support. Any substantive scientific revision requires a new corpus version and a new freeze identifier.

Declaration of Purpose

Paper I registered the flagship geometry, the specific nominal initiating age 256 Ma, and the uncertainty, chronology, material-lineage, and regional evidence burdens. It found a close bilateral and projected along-track relationship while also finding a large present-day cross-track displacement from literal midpoint collinearity.

Paper II asks a narrower and more difficult question:

> Can any physically admissible astro-ballistic event generate the required entrance, deep-path, midpoint-response, terminal-response, and long-term inheritance effects within a differentiated Earth?

The objective is to define the complete mechanical search, eliminate excluded branches, and determine whether any nonempty event-level viable set remains.

Mechanical thesis.
The flagship event is mechanically eligible only if one declared initial condition produces a compatible entrance, crosses the differentiated-Earth path, generates a bounded midpoint-response inheritance, delivers a terminal Mariana-class response, and remains compatible with conservation, planetary survival, and the later geological record. No such solution is presumed.

Source Status and Citation Policy

External references support measurements, dated constraints, standard methods, regional context, comparison-model components, and reproducibility requirements. They do not independently verify an astro-ballistic event assignment, event sequence, causal interpretation, or replacement claim unless the cited source directly tests that claim. Internal Ontomics documents establish developmental provenance, not independent confirmation. Manuscript-derived values remain consequences of their declared inputs and methods. External chronology constrains observations and marker compatibility; it is not imported as a substitute causal narrative. The complete source taxonomy, verification fields, and conflict rules are maintained in Paper V.

Data, Evidence, and Provenance Convention

Every factual input, model input, reconstruction, simulation output, and calculated result must retain an explicit evidentiary origin. Scientific authority, publication status, or institutional custody does not by itself upgrade an item from model-derived to observed, from observed to causal, or from internally reproduced to independently validated.

The corpus uses the following evidence-origin classes:

Measurement-proximal
: A directly measured, sampled, mapped, or instrument-recorded quantity, together with its reported uncertainty and acquisition method.

Curated primary dataset
: A maintained collection of observations. The dataset may include processing, but its raw sources, version, and transformations must remain traceable.

Reference model
: A community or institutional model derived from observations and assumptions. It is not identical to the underlying measurements.

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: A past state, field, geometry, or parameter estimated through an explicit inversion or reconstruction method.

Author-declared input
: A coordinate, age, range, threshold, branch, or other value selected for the present investigation. It is a model input rather than an independent observation.

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: An Ontomics manuscript, author working document, or earlier source file establishing the developmental history of the hypothesis. Internal provenance is not independent confirmation.

Manuscript-derived result
: A reproducible consequence of declared inputs, equations, algorithms, and numerical conventions.

Simulated model output
: A quantity produced by an implemented physical or statistical model.

Interpretive inference
: A geological, causal, or historical interpretation assigned to one or more observations or model outputs.

Unverified, unavailable, or missing
: An item whose source, version, access path, lineage, uncertainty, or required observation has not yet been established.

For item i, the minimum provenance record is

$$\mathbf{P}_i = (\mathrm{ID}_i, \mathrm{origin}_i, \mathrm{custodian}_i, \mathrm{version}_i, \mathrm{locator}_i, \mathrm{acquisition}_i, \mathrm{hash}_i, \\ \mathrm{transformations}_i, \mathrm{units}_i, \mathrm{uncertainty}_i, \mathrm{use}_i, \mathrm{dependencies}_i, \mathrm{status}_i).$$

For a derived result R_j, the complete lineage must identify the exact input records and method version:

$$R_j = \mathcal{M}_j(\mathbf{D}_{j1}, \ldots, \mathbf{D}_{jn}; \boldsymbol{\theta}_j, \nu_j)\,,$$

where ν_j identifies the equation, code, solver, or calculation version. Rounding, unit conversion, coordinate transformation, filtering, interpolation, exclusion, and manual transcription are transformations and must be logged rather than treated as invisible clerical steps.

A located source is not automatically passage-verified. A verified passage is not automatically data-verified. A data-verified input does not by itself validate the causal interpretation built from it. Missing evidence remains explicitly missing; it may not be filled by a preferred reconstruction, model narrative, or uncited numerical convention.

Paper II is constructed to determine whether such a solution exists.

Source Inheritance and Supersession

The original Great Dying mechanical framework introduced:

- a straight Aegean-to-Mariana interior chord;
- a specific proposed initiating-event age of 256 Ma;
- an event-energy search band of $10^{29}-10^{31}$ J;
- an impact-speed range of approximately $10\,\mathrm{km\,s^{-1}}$ to $30\,\mathrm{km\,s^{-1}}$;
- an exit-energy fraction of approximately $0.1-0.5$;
- characteristic Reynolds, Froude, Rossby, and Deborah numbers;
- a Mauna Kea far-field displacement hypothesis; and
- falsifiers involving geometry, tomography, planetary disruption, and Hawaii decoupling.

Those elements are preserved as source hypotheses and starting parameters.

They are not automatically preserved as correct calculations.

Paper I already identified several numerical and interpretive corrections, including:

1. the physical half-chord is approximately 5075 km, not 6000 km;
2. the inherited energy and speed limits imply a substantially wider and higher impactor-mass range;
3. the straight-path entrance angle is not shallow;
4. the maximum exit energy implied by the declared fraction and total-energy ceiling is 5×10^{30} J;
5. the inherited dimensionless-number interpretations do not follow from all of the inherited numerical inputs; and

6. the modern literal Everest chord-midpoint condition is not satisfied.

The original source also used conservative language stating that the hypothesis was not a replacement of Plate Tectonics.

The present five-paper corpus supersedes that positioning.

The current thesis is that Astro-Ballistic Chronostratigraphic Sequencing is being tested as a causal replacement of Plate Tectonics while retaining measured plate motion as evidence requiring explanation.

The source mechanics remain inherited research material.

The replacement claim is the current series position.

Epistemic Status and Claim-Language Convention

This paper distinguishes observation, curated data, reference model, author-declared input, manuscript-derived calculation, simulated output, interpretive inference, prediction, unresolved item, negative result, and falsified claim. These statuses are not interchangeable. Reproducible arithmetic does not establish historical causation; physical admissibility does not establish occurrence; and regional compatibility does not establish global replacement. Missing evidence is reported as unresolved rather than silently completed. Paper V contains the authoritative machine-readable status vocabulary and item-level records.

Prediction, Falsification, and Decision-Threshold Convention

Predictions must identify the claim tested, data required, comparison or null, uncertainty treatment, decision threshold, and bounded consequence. Thresholds are classified as physical-admissibility conditions (T0), measurement or convergence conditions (T1), exploratory working thresholds (T2), preregistered confirmatory thresholds (T3), or preregistered comparative thresholds (T4). A claim is rejected only after a valid, completed test crosses its frozen rejection rule. An unrun test, unavailable dataset, or unfrozen threshold is unresolved. Failure to earn superiority or replacement status is a comparative non-qualification, not retroactive falsification of every upstream result.

Causal-Chain, Assumption, and Alternative-Explanation Convention

Causal language follows a seven-level ladder: association (L0), temporal compatibility (L1), mechanical admissibility (L2), modeled contribution (L3), causal necessity (L4), primary or dominant causation (L5), and replacement qualification (L6). Each proposed transition must identify its assumptions, mediators, counterfactual intervention, and credible alternatives. For claim c with preregistered support paths $\mathcal{P}_c$, viability is

$$\mathcal{V}_{\text{causal},c} = \bigcup_{p\in\mathcal{P}_c} \bigcap_{e\in p} \mathcal{V}_e.$$

One failed edge rejects every path that requires that edge, but does not erase an independent surviving path. One failed branch, event, regional assignment, or event sequence therefore has only its registered downstream consequence. Confounding, equifinality, circular use of outputs as inputs, and unequal assumption burdens remain explicit audit failures. Paper V preserves the full causal-edge, assumption, alternative, and intervention registries.

Abstract

This paper develops the mechanical eligibility test for the flagship Aegean–Himalayan–Mariana candidate event within Astro-Ballistic Chronostratigraphic Sequencing . It receives the status-qualified geometry and initiating chronology from Paper I and asks whether any physically admissible disturbance can couple at the entrance, transmit through a differentiated Earth, produce a bounded midpoint-response inheritance, generate a Mariana terminal response, and remain compatible with planetary survival and the later geological record.

Five preregistered mechanism families are retained: coherent-body penetration, fragmented-column transmission, shock-dominated transmission, fracture- and phase-front transmission, and constrained hybrid transmission. The inherited $10^{29} - 10^{31}$ J energy interval and $10\,\mathrm{km\,s^{-1}}$ to $30\,\mathrm{km\,s^{-1}}$ speed interval are exploratory search domains, not measured event properties or demonstrated viable values. The governing equations, constitutive assumptions, Earth reference models, entrance conditions, path-localization metrics, midpoint and terminal budgets, marker predictions, and planetary-survival gates are specified for numerical implementation.

Mechanical viability is event-, branch-, and uncertainty-specific. Failure of one branch or realization does not reject another preregistered branch. The flagship mechanical hypothesis fails only if its event-level union of complete branch-realization viable sets is empty after the frozen search has been executed. Paper II does not claim that a nonempty set has been demonstrated. If one exists, its post-event damage, thermal, phase, stress, density, momentum, displacement, gravity, seismic, and marker fields become conditional inputs to Paper III. Comparative superiority and replacement qualification remain the exclusive burden of Paper IV.

Keywords

Astro-Ballistic Chronostratigraphic Sequencing; astro-ballistic mechanics; forensic geophysics; hypervelocity penetration; deep-mantle transmission; shock propagation; phase-front transmission; lower-mantle disturbance; midpoint-response inheritance; Aegean entrance; Mariana terminal response; planetary survival; plate-motion inheritance; Plate Tectonics replacement.

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1 Mechanical Burden of the Series

1.1 Canonical Corpus Terminology

The authoritative nomenclature registry is maintained in Paper V. Throughout this paper, *continental drift* and *plate motion* name observed motion classes, whereas Plate Tectonics names the competing causal model family. An *event catalog* is the registered set of candidate events; an *event sequence* is a chronologically ordered selection from that catalog. The *flagship candidate relationship* is the declared Aegean–Everest–Mariana geometry, while the *flagship candidate event* is its broader causal interpretation. *Midpoint* is geometric; *midpoint response* is physical. *Terminal response* is the general scientific term; *exit* is retained in the Paper-I title and only where a specific mechanism branch predicts literal outward passage. The *replacement thesis* is the proposition under test; a *replacement candidate* is an outcome that can be earned only through the complete Paper-IV comparison and replication program.

1.2 Paper-I Handoff Intake

For candidate event k, Paper II receives $\mathbf{H}^{(k)}_{I\to II}$, containing the audited geometry, uncertainty, chronology and paleogeography constraints, mechanical search ranges, regional requirements, null design, and falsification status established in Paper I.

For the flagship event, this package is $\mathbf{H}^{(F)}_{I\to II}$. It is an input audit package, not evidence that the event occurred or that a viable transmission branch exists.

Paper II must preserve the status and uncertainty of every inherited field and may not replace a failed or unresolved Paper-I input with a mechanically convenient value without registering a new event version.

1.3 Paper-II Input and Provenance Snapshot

Paper II separates inherited inputs, external reference models, declared search ranges, and derived outputs as follows.

Table 1: Paper-II mechanical data and provenance snapshot.

ID	Item	Origin and role	Current provenance status
P2-IN-001	Paper-I geometry, chronology, and uncertainty package	Mixed declared inputs and manuscript-derived calculations inherited with status	No field is promoted to measured or historically verified by handoff
P2-REF-001	Preliminary Reference Earth Model	External one-dimensional reference model [1]	Reference structure, not a direct measurement of the candidate event path

ID	Item	Origin and role	Current provenance status
P2-REF-002	ak135 Earth model	External reference model [2]	Sensitivity and comparison input, not event evidence
P2-MET-001	Impact hydrocode, porosity, and damage methods	Published governing and constitutive methods [3, 4, 5]	Method support only; no cited simulation independently tests the flagship event
P2-PAR-001	Event-energy range $10^{29} - 10^{31}$ J	Internal source search range	Exploratory parameter interval, not a measured energy
P2-PAR-002	Impact-speed range $10\,\mathrm{km\,s^{-1}}$ to $30\,\mathrm{km\,s^{-1}}$	Internal source search range	Exploratory parameter interval, not a measured speed
P2-PAR-003	Exit-energy fraction $0.1 - 0.5$	Internal source assumption	Must be branch-specific and mechanically derived or bounded before confirmatory use
P2-RES-001	Mass, diameter, momentum, transit, and energy-envelope calculations	Manuscript-derived consequences of declared ranges	Arithmetic lineage reproducible; event occurrence and branch viability remain unresolved
P2-PAR-004	Illustrative viscosity and dimensionless-number values	Declared screening assumptions	Context-specific; not transferable to event-time rheology without a constitutive model
P2-HYP-001	Mauna Kea far-field response	Internal secondary hypothesis	Mechanically and observationally unresolved; not required for core event viability

1.4 Geometry Does Not Supply Mechanics

A geometric path identifies a candidate relationship among locations.

It does not establish that matter, momentum, energy, pressure, or damage can travel along that path.

Paper II therefore treats the Paper-I chord as a reference axis:

$$\mathbf{C}(s) = R_{\oplus}\left[(1-s)\boldsymbol{\xi}_A + s\boldsymbol{\xi}_M\right], \qquad s \in [0,1], \tag{1}$$

not as a predetermined physical solution.

The actual event path may be written as

$$\mathbf{r}_{\text{event}} = \mathbf{r}\left(s, t; \boldsymbol{\Theta}\right), \tag{2}$$

where $\boldsymbol{\Theta}$ contains the complete event and Earth-state parameters.

The straight chord is recovered only when

$$\mathbf{r}_{\text{event}}\left(s, t; \boldsymbol{\Theta}\right) \approx \mathbf{C}(s) \tag{3}$$

over the relevant transmission interval.

1.5 The Required Connected Sequence

The mechanical model must produce one ordered sequence:

$$\mathcal{S}_{F,256} = \left\{A, P, H, M, G\right\}, \tag{4}$$

where

$$A = \text{entrance interaction}, \tag{5}$$
$$P = \text{deep transmission path}, \tag{6}$$
$$H = \text{midpoint-response inheritance}, \tag{7}$$
$$M = \text{terminal response}, \tag{8}$$
$$G = \text{global and long-duration consequences.} \tag{9}$$

A viable event must generate all five from one parameter set.

The model cannot independently tune the entrance, midpoint, and exit after observing their present structures.

1.6 The Mechanical Replacement Burden

The mechanics must ultimately explain more than one proposed scar.

The complete framework requires a path from event forcing to persistent plate behavior:

$$\mathcal{E}_{\text{ABC}} \to \mathbf{Q}_{\text{post}} \to \mathcal{B}_{\text{inherit}} \to \mathbf{V}_{\text{plates}}(t), \tag{10}$$

where

$$\begin{aligned}
\mathcal{E}_{\mathrm{ABC}} &= \text{astro-ballistic event}, && (11)\\
\mathbf{Q}_{\mathrm{post}} &= \text{post-event planetary state}, && (12)\\
\mathcal{B}_{\mathrm{inherit}} &= \text{event-created or event-modified boundaries}, && (13)\\
\mathbf{V}_{\mathrm{plates}}(t) &= \text{later plate-motion field}. && (14)
\end{aligned}$$

Paper II must define the persistent state.

Paper III will test whether that state predicts plate directions and speeds.

1.7 Mechanical Causal-Bridge Decomposition

The event-to-plate-motion expression in equation (10) contains multiple independent burdens:

$$\begin{aligned}
E_1 &: \text{ event and entrance coupling} \rightarrow \text{deep transmitted state}, && (15)\\
E_2 &: \text{ deep transmitted state} \rightarrow \text{midpoint and terminal responses}, && (16)\\
E_3 &: \text{ short-time response} \rightarrow \text{persistent damage, density, thermal, or phase memory}, && (17)\\
E_4 &: \text{ persistent memory} \rightarrow \text{later boundary and force modification}, && (18)\\
E_5 &: \text{ modified boundary and force state} \rightarrow \text{plate motion and surface structures}. && (19)
\end{aligned}$$

Paper II is responsible primarily for E_1 through the production and survival requirements of E_3. Paper III must solve E_4 and E_5. Mechanical admissibility of an early event does not establish long-time causal inheritance.

For each bridge, Paper II must report the governing equation or operator, assumptions, input and output state, competing mechanisms, uncertainty, and falsifier. A missing bridge remains `MECHANISM-NOT-CLOSED`; it cannot be replaced by a verbal arrow.

2 Mechanism Branches

2.1 Branch I: Coherent-Body Penetration

A macroscopic projectile remains the dominant carrier of mass, momentum, and directional energy through a substantial fraction of the planetary path.

Let projectile mass, velocity, and effective radius evolve as

$$M_I(t), \qquad \mathbf{v}_I(t), \qquad R_I(t). \tag{20}$$

The coherent branch remains viable only while a recognizable projectile-derived body satisfies

$$\frac{M_{\text{coherent}}(t)}{M_I(t_0)} \geq f_{\text{coherent,crit}}, \tag{21}$$

where $f_{\text{coherent,crit}}$ must be declared before simulation.

This branch predicts concentrated projectile-derived material along the path and potentially at the exit.

2.2 Branch II: Fragmented Penetration Column

The projectile fragments, melts, vaporizes, and entrains terrestrial material but retains a directionally concentrated moving column.

Define the column mass

$$M_{\text{col}}(s,t) = \int_{\mathcal{A}_{\text{col}}} \rho(\mathbf{r},t)\, dA, \tag{22}$$

and column momentum

$$\mathbf{p}_{\text{col}}(s,t) = \int_{\mathcal{A}_{\text{col}}} \rho \mathbf{u}\, dA. \tag{23}$$

The branch requires directional coherence even when material coherence is lost.

2.3 Branch III: Shock-Dominated Transmission

The incoming body deposits most of its material and part of its energy near the entrance while a strong compressive disturbance propagates through the Earth.

Let shock-front position be

$$\mathbf{r}_s(t), \tag{24}$$

with propagation speed

$$D_s = \left\| \frac{d\mathbf{r}_s}{dt} \right\|. \tag{25}$$

The shock branch must preserve sufficient directional concentration to generate a specific terminal Mariana response rather than a broadly distributed global disturbance.

2.4 Branch IV: Fracture- and Phase-Front Transmission

The event advances through coupled:

- fracture;
- shear localization;

- pressure-induced phase change;
- melt production;
- density change;
- decompression;
- damage propagation; and
- mechanical reactivation.

Let the internal state vector be

$$\mathbf{q} = (\rho, T, P, \chi_m, \chi_v, D, \phi, \boldsymbol{\sigma}, \mathbf{u}), \tag{26}$$

where

$$\chi_m = \text{melt fraction}, \tag{27}$$
$$\chi_v = \text{vapor fraction}, \tag{28}$$
$$D = \text{damage variable}, \tag{29}$$
$$\phi = \text{mineral or material phase state}. \tag{30}$$

The front is defined by one or more state thresholds rather than by the continued existence of the original projectile.

2.5 Branch V: Hybrid Transmission

The hybrid branch permits a sequence such as

$$\text{coherent entry} \to \text{fragmented column} \to \text{shock and phase front} \to \text{terminal decompression}. \tag{31}$$

The hybrid branch is physically broad but scientifically dangerous.

Every transition must be triggered by a declared state condition:

$$\mathcal{M}_i \to \mathcal{M}_j \quad \text{when} \quad g_{ij}\left(P, T, \dot{\epsilon}, D, \chi_m, \chi_v\right) = 0. \tag{32}$$

A branch cannot be changed solely because a prior branch fails.

2.6 Branch-Level Falsification

Each branch must have a unique falsifier.

Branch	Required behavior	Direct failure
Coherent body	Macroscopic projectile-derived body survives deep transit.	Fragmentation, vaporization, or deceleration eliminates coherent penetration before the required depth.
Fragmented column	Directional momentum remains concentrated in a moving material column.	The column disperses or isotropizes before producing the terminal response.
Shock dominated	A path-localized shock reaches the exit with sufficient energy.	The shock attenuates, broadens, reflects, or dissipates incompatibly.
Fracture/phase front	A connected state-change front advances through the required path.	No constitutive model permits sustained propagation.
Hybrid	Declared transitions preserve one conserved event sequence.	Transitions are post hoc, discontinuous, or violate conservation.

2.7 No Auxiliary-Event Rescue

Additional directional or material-displacement events intentionally reserved for later research are not part of the present flagship mechanics. A Paper-II branch must close its own mass, momentum, energy, angular-momentum, path, survival, and terminal-response requirements using the event sequence that was frozen for that branch.

An undeclared event may not be introduced after simulation to supply missing energy, redirect a failed path, create the required middle-mountain response, or repair a terminal-domain miss. A later event may enter only through a new predeclared sequence version with its own parameter and complexity burden. The current branch remains failed or unresolved according to its original contract.

2.8 Branch Assumptions, Transition Tests, and Equifinality

The five mechanism branches are alternative carrier descriptions, not five independent sources of evidence. Multiple branches may reproduce a similar terminal field through different internal histories.

Each branch record must therefore include:

- the defining carrier and state variables;
- branch-specific constitutive assumptions;
- transition criteria and their freeze status;
- observables capable of discriminating the branch;
- parameter regions shared with other branches;

- and the alternate branches that remain viable after one branch fails.

A hybrid branch may be assembled only through state-triggered transitions already declared in the model. It may not function as a post hoc union of whichever branch performs best in each region. If two branches remain observationally indistinguishable, the correct result is `BRANCH-NON-IDENTIFIABLE`, not a forced selection.

3 Event Parameter Vector

3.1 Initial Event State

The initial astro-ballistic event is described by

$$\boldsymbol{\Theta}_I = (M_I, R_I, \rho_I, \mathbf{v}_I, \mathbf{r}_I, \mathbf{b}_I, \boldsymbol{\omega}_I, T_I, \chi_{m,I}, \chi_{v,I}, \mathcal{C}_I), \tag{33}$$

where

$$M_I = \text{initial mass}, \tag{34}$$
$$R_I = \text{effective radius}, \tag{35}$$
$$\rho_I = \text{bulk density}, \tag{36}$$
$$\mathbf{v}_I = \text{velocity vector}, \tag{37}$$
$$\mathbf{r}_I = \text{impact position}, \tag{38}$$
$$\mathbf{b}_I = \text{impact-parameter vector relative to Earthś center}, \tag{39}$$
$$\boldsymbol{\omega}_I = \text{spin vector}, \tag{40}$$
$$T_I = \text{initial temperature}, \tag{41}$$
$$\chi_{m,I} = \text{initial melt fraction}, \tag{42}$$
$$\chi_{v,I} = \text{initial vapor fraction}, \tag{43}$$
$$\mathcal{C}_I = \text{composition and internal structure}. \tag{44}$$

3.2 Inherited Search Domain

The inherited kinetic-energy search domain is

$$10^{29} \le E_I \le 10^{31} \quad \text{J}, \tag{45}$$

with

$$E_I = \frac{1}{2} M_I v_I^2. \tag{46}$$

The inherited speed interval is

$$10 \le v_I \le 30 \quad \mathrm{km\,s^{-1}}. \tag{47}$$

The implied mass is

$$M_I = \frac{2E_I}{v_I^2}. \tag{48}$$

Across the complete declared grid,

$$2.22 \times 10^{20} \lesssim M_I \lesssim 2.00 \times 10^{23} \quad \mathrm{kg}. \tag{49}$$

This mass range is retained as an audited consequence of the inherited energy and velocity ranges. It is not yet a physically viable range.

3.3 Impactor Radius

For spherical-equivalent density ρ_I,

$$R_I = \left(\frac{3M_I}{4\pi\rho_I}\right)^{1/3}. \tag{50}$$

For

$$\rho_I = 3000\,\mathrm{kg\,m^{-3}}, \tag{51}$$

the full search domain produces bodies with diameters of hundreds to several thousands of kilometres. The entrance geometry, global marker field, and planetary survival cannot be separated from this scale.

3.4 Initial Momentum

The initial momentum is

$$\mathbf{p}_I = M_I \mathbf{v}_I. \tag{52}$$

Its magnitude is equivalently

$$p_I = \frac{2E_I}{v_I}. \tag{53}$$

The inherited domain gives approximately

$$6.67 \times 10^{24} \lesssim p_I \lesssim 2.00 \times 10^{27} \quad \mathrm{kg\,m\,s^{-1}}. \tag{54}$$

Momentum is critical to the later plate-motion inheritance claim.

Energy alone does not determine directional displacement.

3.5 Impact Parameter and Angular Momentum

The event angular momentum about Earth's center is

$$\mathbf{L}_I = \mathbf{b}_I \times \mathbf{p}_I, \tag{55}$$

where $\mathbf{b}_I$ is the impact-parameter vector.

The event geometry must determine:

- angular momentum deposited into Earth;
- angular momentum carried through the path;
- angular momentum expressed at the exit;
- changes in planetary spin;
- changes in moment of inertia;
- long-lived rotational consequences; and
- lateral impulse available to plate-scale structures.

4 Differentiated Earth Model

4.1 Earth Cannot Be Treated as One Uniform Medium

The proposed path reaches deep into the lower mantle.

The material properties vary with:

- radius;
- pressure;
- temperature;
- density;
- mineral phase;
- composition;
- elastic moduli;
- viscosity;

- damage;
- melt fraction;
- rotation; and
- pre-existing structure.

A single constant density and viscosity cannot represent the complete transit. Standard one-dimensional reference Earth and travel-time models provide the baseline radial density and seismic-velocity structure against which the proposed path must be evaluated [1, 2].

4.2 Radial Layer Model

The first numerical Earth model will divide the planet into radial domains:

$$\mathcal{D}_\oplus = \bigcup_{\ell=1}^{N_L} \mathcal{D}_\ell, \tag{56}$$

where each layer ℓ is assigned constitutive functions

$$\mathcal{P}_\ell = \{\rho_\ell, P_\ell, T_\ell, K_\ell, G_\ell, c_{p,\ell}, k_\ell, \eta_\ell, Y_\ell, \Gamma_\ell, \mathcal{E}_\ell\}\,. \tag{57}$$

Here

$$K_\ell = \text{bulk modulus}, \tag{58}$$
$$G_\ell = \text{shear modulus}, \tag{59}$$
$$c_{p,\ell} = \text{specific heat capacity}, \tag{60}$$
$$k_\ell = \text{thermal conductivity}, \tag{61}$$
$$\eta_\ell = \text{effective viscosity or rheological function}, \tag{62}$$
$$Y_\ell = \text{strength or yield function}, \tag{63}$$
$$\Gamma_\ell = \text{fracture or damage law}, \tag{64}$$
$$\mathcal{E}_\ell = \text{equation of state}. \tag{65}$$

4.3 Minimum Layer Set

The minimum model must distinguish:

1. atmosphere;
2. hydrosphere where present;
3. upper crust;
4. lower crust;

5. lithospheric mantle;
6. asthenospheric mantle;
7. mantle transition zone;
8. upper lower mantle;
9. deeper lower mantle; and
10. the core–mantle boundary as a nonintersected but dynamically relevant boundary.

The audited straight path does not enter the core.

The core may still influence gravity, wave propagation, rotation, and global deformation.

4.4 Background State

The pre-event Earth state is

$$\mathbf{Q}_0(\mathbf{r}) = (\rho_0, P_0, T_0, \mathbf{u}_0, \boldsymbol{\sigma}_0, \phi_0, D_0, \chi_{m,0}, \mathbf{B}_0)\,, \tag{66}$$

where $\mathbf{B}_0$ represents the magnetic field or magnetization state where relevant.

The event response is

$$\Delta\mathbf{Q} = \mathbf{Q}(\mathbf{r}, t) - \mathbf{Q}_0(\mathbf{r}). \tag{67}$$

Predicted geological evidence must derive from $\Delta\mathbf{Q}$, not merely from the existence of modern structures.

4.5 Heterogeneous Earth Extension

Later simulation stages must incorporate three-dimensional heterogeneity:

$$\mathbf{Q}_0 = \mathbf{Q}_0(r, \theta, \varphi), \tag{68}$$

including:

- existing plate and cratonic structure;
- mantle thermal anomalies;
- chemical heterogeneity;
- phase-boundary topography;
- large low-shear-velocity provinces;
- pre-existing fracture zones;
- existing basins and orogens;

- ocean–continent contrasts; and
- rotational flattening.

The event path may curve, focus, split, reflect, or attenuate in response to this heterogeneity.

5 Governing Conservation Laws

5.1 Mass Conservation

The local mass-conservation equation is

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0. \tag{69}$$

When multiple material phases are tracked,

$$\rho = \sum_{a=1}^{N_m} \rho_a, \tag{70}$$

and each component requires an advection or reaction equation.

5.2 Momentum Conservation

The momentum equation in a rotating frame is

$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = \nabla \cdot \boldsymbol{\sigma} + \rho \mathbf{g} - 2\rho \boldsymbol{\Omega} \times \mathbf{u} - \rho \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r}) + \mathbf{f}_{\text{ext}}. \tag{71}$$

Here $\mathbf{g} = -\nabla \Phi$ is gravitational acceleration excluding the separately written centrifugal contribution. The terms represent:

- stress divergence;
- gravity;
- Coriolis acceleration;
- centrifugal acceleration; and
- any externally applied or unresolved force density.

On the minutes-scale primary transit, rotation may be subordinate to inertia.

It cannot be omitted from the complete angular-momentum and later plate-response problem.

5.3 Total Energy Conservation

Let specific total energy be

$$e_{\text{tot}} = e_{\text{int}} + \frac{1}{2}\left\|\mathbf{u}\right\|^2 + \Phi, \tag{72}$$

where Φ is gravitational potential.

The energy equation is

$$\frac{\partial\left(\rho e_{\text{tot}}\right)}{\partial t} + \nabla \cdot \left[\left(\rho e_{\text{tot}} + P\right)\mathbf{u}\right] = \nabla \cdot \left(\boldsymbol{\tau} \cdot \mathbf{u}\right) - \nabla \cdot \mathbf{q} + \rho \dot{Q} + S_{\text{phase}} + S_{\text{damage}}. \tag{73}$$

Here

$$\mathbf{q} = \text{heat-flux vector}, \tag{74}$$

$$\dot{Q} = \text{specific heating rate per unit mass}, \tag{75}$$

$$S_{\text{phase}} = \text{volumetric latent and reaction power density}, \tag{76}$$

$$S_{\text{damage}} = \text{volumetric fracture and irreversible-deformation power density}. \tag{77}$$

Thus $\rho\dot{Q}$, S_{phase}, and S_{damage} all have units of $\mathrm{W\,m^{-3}}$.

5.4 Angular Momentum Conservation

For the coupled impactor–Earth system,

$$\frac{d\mathbf{L}_{\text{tot}}}{dt} = \boldsymbol{\tau}_{\text{ext}}, \tag{78}$$

where

$$\mathbf{L}_{\text{tot}} = \mathbf{L}_{\oplus} + \mathbf{L}_I + \mathbf{L}_{\text{ejecta}} + \mathbf{L}_{\text{orbit}}. \tag{79}$$

The model must track angular momentum carried away by escaping, orbiting, and reaccreting material.

5.5 Gravity

The gravitational potential satisfies

$$\nabla^2\Phi = 4\pi G\rho. \tag{80}$$

The gravity field is

$$\mathbf{g} = -\nabla\Phi. \tag{81}$$

A self-consistent model must update gravity when the event redistributes large masses.

5.6 Stress Decomposition

The Cauchy stress tensor is

$$\boldsymbol{\sigma} = -P\mathbf{I} + \boldsymbol{\tau}, \tag{82}$$

where $\boldsymbol{\tau}$ is the deviatoric stress tensor.

The constitutive law for $\boldsymbol{\tau}$ depends on:

- pressure;
- temperature;
- strain rate;
- phase;
- melt fraction;
- damage;
- loading duration; and
- decompression history.

5.7 Damage Evolution

A scalar damage model may begin with

$$\frac{dD}{dt} = \mathcal{F}_D\left(P, T, \boldsymbol{\sigma}, \dot{\boldsymbol{\epsilon}}, D, \phi, \chi_m\right), \qquad 0 \leq D \leq 1. \tag{83}$$

A tensorial damage model may later be required to preserve directional fracture inheritance.

5.8 Phase Evolution

For phase fraction ϕ_a,

$$\frac{\partial \phi_a}{\partial t} + \mathbf{u} \cdot \nabla \phi_a = \mathcal{R}_a\left(P, T, \boldsymbol{\sigma}, t\right), \tag{84}$$

subject to

$$\sum_a \phi_a = 1. \tag{85}$$

Phase transformation may create density and seismic anomalies that survive longer than the primary shock.

5.9 Melt and Vapor Evolution

The melt and vapor fractions satisfy

$$\frac{d\chi_m}{dt} = \mathcal{F}_m\left(P, T, e_{\text{int}}, \phi\right), \tag{86}$$

$$\frac{d\chi_v}{dt} = \mathcal{F}_v\left(P, T, e_{\text{int}}, \phi\right). \tag{87}$$

These fields are necessary for predicting:

- entrance melt;
- deep-path melt;
- terminal decompression;
- ejecta;
- magnetic resetting;
- density structure; and
- later volcanic or tectonic inheritance.

6 Chronology and Material-Path Branches

6.1 Frozen Flagship Initiation

For the flagship candidate event, Paper II receives the fixed nominal initiating age

$$a_{\text{init},F} = 256 \text{ Ma}. \tag{88}$$

The mechanical search may propagate a preregistered uncertainty envelope around this value, but it may not optimize the event age after observing mechanical or regional fit. Younger closure, deformation, reactivation, or visible-expression ages are downstream clocks and do not replace the initiating-event age.

6.2 Paper-I Geography Is a Branch Family

Paper II does not receive one established Aegean-to-Mariana material path. It receives a preregistered family indexed by event candidate k, reference frame f, material-lineage branch q, and mechanism branch b:

$$\mathcal{P}_{k,f,q,b} = \left(\mathcal{D}_A^{(k,f,q)}, \Gamma_{k,f,q,b}, \mathcal{D}_E^{(k,f,q)}, \mathcal{D}_M^{(k,f,q)}\right). \tag{89}$$

Here $\Gamma_{k,f,q,b}$ is the candidate interior trajectory, transmission corridor, shock path, fracture or phase front, or hybrid support region. Modern surface labels identify response domains; they do not establish the event-time material parcels through which the model must propagate.

6.3 Event-Time Earth State

The differentiated-Earth initial state is age-indexed:

$$\mathbf{Q}_{\oplus}^{(k,f,q)}(a_{\mathrm{init},k}) = (\rho, T, P, \mathbf{u}, \boldsymbol{\sigma}, \mathbf{D}, \phi, \mathbf{C})_{a_{\mathrm{init},k}}^{(k,f,q)}. \tag{90}$$

The present Earth model may be used for analytic screening, but it is not silently promoted to the complete event-time state. Any correction for older thermal structure, phase distribution, stress, rotation, or material geometry must be declared with its uncertainty and provenance.

6.4 Response Clocks

The mechanical chronology distinguishes

$$\mathbf{C}_{II} = (a_{\mathrm{init},k}, \tau_{\mathrm{transit}}, \tau_{\mathrm{shock}}, \tau_{\mathrm{cool}}, \tau_{\mathrm{heal}}, a_{\mathrm{reactivation}}, a_{\mathrm{expression}}). \tag{91}$$

where τ denotes elapsed forward time after the event. Prompt transmission, long-term damage retention, later reactivation, and modern surface expression are separate processes. A young surface feature does not identify the age of the proposed initiating event unless the intermediate state is demonstrated.

6.5 Branch-Specific Mechanical Viability

Mechanical viability is evaluated as

$$\mathcal{V}_{II,k} = \bigcup_{f,q,b,r} \mathcal{V}_{II,k,f,q,b,r}, \tag{92}$$

where r indexes the declared physical uncertainty realization. Failure of one paleogeographic, material-lineage, reference-frame, or mechanism branch rejects that branch. The event-level mechanical claim fails only when the preregistered union is empty after adequate simulation.

6.6 No Reconstruction-by-Outcome

A lineage or frame branch may not be selected because it produces the preferred terminal result. Branch definitions, admissible coordinate domains, Earth-state assumptions, and exclusion rules must be frozen before the decisive output is examined. Model-derived paleogeography is an input hypothesis, not an observation and not a rescue condition.

7 Initial and Boundary Conditions

7.1 Entrance Position

The working entrance position is

$$\mathbf{x}_A = R_\oplus \boldsymbol{\xi}_A, \tag{93}$$

using the Paper-I declared coordinate as the present-response baseline. This is not asserted to be the event-time material position.

For branch (k, f, q), the simulation uses

$$\mathbf{x}_A^{(k,f,q)}\left(a_{\mathrm{event}}\right) \in \mathcal{D}_A^{(k,f,q)}\left(a_{\mathrm{event}}\right). \tag{94}$$

The eventual simulation must replace the point with an entrance domain

$$\mathcal{D}_A \subset \partial \mathcal{D}_\oplus. \tag{95}$$

7.2 Exit Target

The working exit target is

$$\mathbf{x}_M = R_\oplus \boldsymbol{\xi}_M. \tag{96}$$

The mechanical model is not required to hit one exact modern point, and the modern Mariana coordinate is not assumed to be the unchanged event-time parcel.

For branch (k, f, q), the terminal domain is

$$\mathbf{x}_M^{(k,f,q)}\left(a_{\mathrm{event}}\right) \in \mathcal{D}_M^{(k,f,q)}\left(a_{\mathrm{event}}\right). \tag{97}$$

It must predict a terminal response within an independently defined Mariana target domain

$$\mathcal{D}_M. \tag{98}$$

7.3 Initial Direction

For the straight reference path, the initial direction is

$$\hat{\mathbf{v}}_{I,0} = \frac{\mathbf{x}_M - \mathbf{x}_A}{\|\mathbf{x}_M - \mathbf{x}_A\|}. \tag{99}$$

The audited angle is approximately

$$52.808799^\circ \tag{100}$$

below the local horizontal.

A shallower entrance requires a curved path, different target geometry, or different physical mechanism.

7.4 Initial Velocity

The initial velocity is

$$\mathbf{v}_{I,0} = v_I \widehat{\mathbf{v}}_{I,0}. \tag{101}$$

The model must explore both:

- velocity aligned with the reference chord; and
- velocity perturbed within a declared angular uncertainty.

7.5 Atmospheric and Surface Entry

The complete model begins before lithospheric contact.

It must calculate or bound:

- atmospheric heating;
- atmospheric mass displacement;
- fragmentation before contact;
- ocean interaction where applicable;
- entry plume;
- surface shock;
- ejecta launch; and
- initial angular-momentum transfer.

For the very large bodies implied by much of the search domain, atmospheric deceleration may be secondary to the total momentum but atmospheric consequences may be substantial.

7.6 Outer Boundary

At the external boundary,

$$P \to P_{\text{atm}} \tag{102}$$

or vacuum conditions are applied outside the atmosphere.

Ejecta crossing the outer computational boundary must be classified as:

- escaping;
- orbiting;
- suborbital;
- reaccreting; or
- unresolved.

7.7 Center and Symmetry Conditions

A complete three-dimensional simulation should not impose artificial axial symmetry unless the event geometry and Earth model justify it.

Lower-dimensional simulations may be used for screening but must state which asymmetries they suppress.

7.8 Pre-Existing Stress and Motion

The pre-event Earth need not be static.

The initial state may include:

$$\mathbf{u}_0(\mathbf{r}) \neq 0 \tag{103}$$

and

$$\boldsymbol{\sigma}_0(\mathbf{r}) \neq -P_0\mathbf{I}. \tag{104}$$

Pre-existing rotation, mantle circulation, plate motion, and inherited stress may affect the path and later response.

The replacement framework may challenge the causal origin of those motions without pretending they were absent at the event time.

8 Required Mechanical Output Fields

8.1 Primary State Fields

Every simulation must output:

$$\rho(\mathbf{r},t), \qquad P(\mathbf{r},t), \qquad T(\mathbf{r},t), \qquad \mathbf{u}(\mathbf{r},t), \tag{105}$$

$$\boldsymbol{\sigma}(\mathbf{r}, t), \qquad D(\mathbf{r}, t), \qquad \chi_m(\mathbf{r}, t), \qquad \chi_v(\mathbf{r}, t), \tag{106}$$

and

$$\phi_a(\mathbf{r}, t). \tag{107}$$

8.2 Path Fields

The model must calculate:

- disturbance centerline;
- path width;
- path curvature;
- energy density;
- momentum density;
- mass composition;
- pressure maximum;
- strain maximum;
- phase-change maximum;
- damage maximum;
- attenuation;
- reflection;
- branching; and
- transit time.

8.3 Entrance Fields

The entrance output must include:

- excavation geometry;
- penetration geometry;
- melt and vapor distribution;
- shock field;
- fracture field;
- displaced mass;

- retained projectile material;
- transmitted momentum fraction;
- transmitted energy fraction; and
- predicted surviving geophysical signature.

8.4 Midpoint Fields

The midpoint output must include:

- geometric midpoint;
- maximum-depth position;
- pressure maximum;
- strain maximum;
- damage maximum;
- phase-change maximum;
- density anomaly;
- thermal anomaly;
- anisotropy;
- persistent weakness or strength;
- predicted surface response; and
- predicted long-term inheritance field.

8.5 Exit Fields

The exit output must include:

- exit center;
- excavation radius;
- excavation depth;
- asymmetry;
- fracture orientation;
- melt and vapor distribution;
- ejecta mass and velocity;
- ocean displacement;
- atmospheric forcing;
- gravity anomaly;

- magnetic-resetting field;
- seismic residual; and
- terminal plate-scale impulse.

8.6 Global Fields

The global output must include:

- total seismic energy;
- global melt fraction;
- atmospheric loss;
- ocean vaporization;
- ejecta distribution;
- rotation change;
- moment-of-inertia change;
- gravity-field change;
- magnetic-field disturbance;
- surviving boundary network; and
- global plate impulse field.

9 Mechanical Viability and Model Selection

9.1 Viable Parameter Set

Let the complete parameter vector be

$$\boldsymbol{\Theta} = \left(\boldsymbol{\Theta}_I, \mathbf{Q}_0, \mathcal{M}, \mathcal{C}, \mathcal{N}\right), \tag{108}$$

where

$$\mathcal{M} = \text{mechanism branch}, \tag{109}$$
$$\mathcal{C} = \text{constitutive model set}, \tag{110}$$
$$\mathcal{N} = \text{numerical model configuration}. \tag{111}$$

The viable set is

$$
\mathcal{V}_{\mathrm{II}} = \left\{ \boldsymbol{\Theta} : \begin{array}{l} \text{entrance constraints satisfied,} \\ \text{path continuity satisfied,} \\ \text{localization satisfied,} \\ \text{midpoint-response inheritance satisfied,} \\ \text{exit constraints satisfied,} \\ \text{conservation satisfied,} \\ \text{planetary survival satisfied,} \\ \text{global marker constraints satisfied} \end{array} \right\}. \tag{112}
$$

9.2 Primary Mechanical Falsifier

Paper-II primary falsifier.
The condition

$$
\mathcal{V}_{\mathrm{II}} = \varnothing \tag{113}
$$

may be asserted only after the frozen branch family, parameter domain, constitutive alternatives, numerical-resolution tests, and mandatory observations have been evaluated with valid T0–T3 criteria.
If that completed search yields an empty viable set, no tested physical realization of the proposed Aegean-to-Mariana event can simultaneously produce the required entrance, deep-path, midpoint, terminal, and planetary-survival outcomes. The literal connected-event mechanism is then rejected.
Before that search is complete, the status is unresolved rather than falsified.

9.3 Branch Comparison

For branch $\mathcal{M}_q$, define evidence

$$
\mathcal{Z}_q = p\left(\mathbf{D} \mid \mathcal{M}_q\right), \tag{114}
$$

where $\mathbf{D}$ contains the complete geological and geophysical data.

The branch comparison is

$$
K_{ij} = \frac{\mathcal{Z}_i}{\mathcal{Z}_j}. \tag{115}
$$

A more complicated hybrid model must earn its additional parameters.

9.4 Mechanical Admissibility Versus Historical Attribution

A nonempty mechanical viable set shows only that a tested realization is not excluded by the declared physics and observations. It does not show that the realization occurred, created the regional structures, or is preferred over other histories.

The minimum attribution comparison includes:

1. the regional geological model without the candidate event;
2. a pre-existing-weakness model in which the event is not the source of the structure;
3. an unrelated local-event model;
4. an event-reactivation model in which the event modifies rather than creates the structure;
5. and a hybrid model with later geodynamic amplification.

Historical attribution requires differentiated predictions that are not used to define the candidate path and that vary among these alternatives.

9.5 Replacement Relevance

A mechanically viable event does not automatically replace plate tectonics.

It becomes relevant to replacement only if it also predicts:

- persistent boundaries;
- plate-scale impulse directions;
- later motion fields;
- mountain and trench placement;
- geological timing;
- unique residual anomalies; and
- observations not equally generated by conventional geodynamics.

Paper II supplies the mechanical output.

Paper III performs the global inheritance reconstruction.

10 Simulation Hierarchy

10.1 Stage 0: Analytic Screening

The hierarchy follows the general impact-modeling requirement that analytic screening, constitutive specification, resolution testing, and numerical simulation be separated rather than treated as one evidentiary step [5, 4, 3].

Analytic and order-of-magnitude tests eliminate parameter regions that violate:

- energy conservation;
- momentum conservation;
- body-size constraints;
- encountered-column constraints;

- transit-time constraints;
- Earth-binding limits;
- atmospheric constraints;
- ocean constraints; or
- basic exit-energy requirements.

10.2 Stage 1: One-Dimensional Shock and Column Models

One-dimensional models test:

- impedance matching;
- shock attenuation;
- phase transitions;
- heating;
- melt production;
- decompression; and
- energy loss with depth.

These models cannot establish the geographic path.

They screen constitutive viability.

10.3 Stage 2: Two-Dimensional Axisymmetric Entrance Models

Two-dimensional models test:

- entrance coupling;
- fragmentation;
- excavation;
- initial path formation;
- transmitted energy;
- transmitted momentum; and
- approximate path width.

Axisymmetry is an approximation and cannot reproduce the full Aegean-to-Mariana oblique geometry.

10.4 Stage 3: Three-Dimensional Layered-Earth Models

Three-dimensional models introduce:

- oblique entry;

- rotation;
- curved geometry;
- differentiated layers;
- material heterogeneity;
- path deflection;
- midpoint response;
- terminal decompression; and
- asymmetric exit structure.

10.5 Stage 4: Long-Time Geodynamic Evolution

The short-duration result becomes the initial condition for long-time evolution:

$$\mathbf{Q}_{\text{short}}\left(t_{\text{handoff}}\right) \rightarrow \mathbf{Q}_{\text{long}}(t). \tag{116}$$

The long-time model tracks:

- thermal relaxation;
- viscoelastic relaxation;
- buoyancy;
- melt migration;
- fracture reactivation;
- gravitational spreading;
- boundary persistence;
- plate-scale displacement;
- later convergence; and
- inherited midpoint expression.

10.6 Stage 5: Observation Forward Model

The final simulation state must be translated into predicted modern observations:

$$\widehat{\mathbf{D}} = \mathcal{O}\left[\mathbf{Q}_{\text{long}}(t_{\text{now}})\right], \tag{117}$$

including:

- seismic velocity;
- seismic anisotropy;

- gravity;
- magnetics;
- crustal thickness;
- lithospheric thickness;
- bathymetry;
- topography;
- geochemistry;
- mineralogy;
- chronology; and
- plate-motion vectors.

Only predicted observables can be compared fairly with Earth data.

11 Mechanical Framework Synthesis

This mechanical-framework synthesis records:

1. the mechanical thesis;
2. the explicit supersession of the original conservative non-replacement wording;
3. the five mechanism branches;
4. the complete initial event vector;
5. the audited inherited search domain;
6. the differentiated-Earth state model;
7. the governing conservation laws;
8. the initial and boundary conditions;
9. the required output fields;
10. the viable parameter set;
11. the primary mechanical falsifier; and
12. the staged simulation architecture.

The following sections develop:

- equations of state;
- shock jump conditions;
- strength, plasticity, and damage laws;
- pressure- and temperature-dependent rheology;

- phase-transition mechanics;
- projectile fragmentation and entrainment;
- encountered-column analysis;
- path-localization metrics;
- coherent-body viability;
- shock-transmission viability; and
- branch-specific rejection conditions.

12 Equations of State

12.1 Purpose

An equation of state closes the relationship among pressure, density, temperature, internal energy, and material phase.

For material component a,

$$P_a = \mathcal{E}_a \left(\rho_a, e_a, T_a, \phi_a, \chi_{m,a}, \chi_{v,a} \right) . \tag{118}$$

No single constant-density approximation is adequate for the complete Aegean-to-Mariana event.

The model must represent:

- impactor material;
- crustal silicates;
- upper-mantle silicates;
- transition-zone phases;
- lower-mantle phases;
- melt;
- vapor;
- ocean water where applicable; and
- atmosphere.

12.2 Thermodynamic Closure

For each material,

$$e = e(\rho, T, \phi), \tag{119}$$

and

$$P = P(\rho, T, \phi). \tag{120}$$

The differential internal-energy relation is

$$de = T\,ds - P\,d\left(\frac{1}{\rho}\right) + \sum_a \mu_a\,dY_a, \tag{121}$$

where

$$s = \text{specific entropy}, \tag{122}$$

$$\mu_a = \text{chemical potential of component } a, \tag{123}$$

$$Y_a = \text{mass fraction of component } a. \tag{124}$$

A complete model must preserve thermodynamic consistency across compression, decompression, melting, vaporization, and phase change.

12.3 Reference Cold Curve

A compressed solid may be decomposed into cold and thermal pressure:

$$P(\rho, e) = P_{\text{cold}}(\rho) + P_{\text{thermal}}(\rho, e). \tag{125}$$

A generic finite-strain cold-pressure relation may be written as

$$P_{\text{cold}} = \frac{3K_0}{2}\left[\left(\frac{\rho}{\rho_0}\right)^{7/3} - \left(\frac{\rho}{\rho_0}\right)^{5/3}\right]\left\{1 + \frac{3}{4}\,(K_0' - 4)\left[\left(\frac{\rho}{\rho_0}\right)^{2/3} - 1\right]\right\}, \tag{126}$$

where

$$K_0 = \text{reference bulk modulus}, \tag{127}$$

$$K_0' = \left.\frac{\partial K}{\partial P}\right|_0, \tag{128}$$

$$\rho_0 = \text{reference density}. \tag{129}$$

The final equation of state must be selected and calibrated separately for each material phase.

12.4 Mie–Gruneisen Form

A useful shock-physics closure is

$$P(\rho, e) = P_H(\rho) + \Gamma(\rho)\rho\left[e - e_H(\rho)\right], \tag{130}$$

where

$$P_H = \text{pressure on the reference Hugoniot}, \tag{131}$$
$$e_H = \text{specific internal energy on the Hugoniot}, \tag{132}$$
$$\Gamma = \text{Gruneisen parameter}. \tag{133}$$

This form is suitable only within the range for which its material calibration remains valid.

It must not be extrapolated blindly through all mantle conditions, extreme expansion, or complete vaporization.

12.5 Shock-Velocity Relation

A common reference Hugoniot relation is

$$U_s = c_0 + s\,u_p, \tag{134}$$

where

$$U_s = \text{shock-front speed}, \tag{135}$$
$$u_p = \text{particle speed behind the shock}, \tag{136}$$
$$c_0 = \text{reference bulk sound speed}, \tag{137}$$
$$s = \text{material Hugoniot slope}. \tag{138}$$

For a material initially at rest and low pressure,

$$P_H = \rho_0 U_s u_p. \tag{139}$$

The linear relation is a calibration model, not a universal law.

12.6 Mixed-Material Cells

A numerical cell containing several materials must track volume fractions

$$\alpha_a, \qquad \sum_a \alpha_a = 1, \tag{140}$$

and mass fractions

$$Y_a = \frac{\alpha_a \rho_a}{\sum_b \alpha_b \rho_b}. \tag{141}$$

Pressure-equilibrium, temperature-equilibrium, or nonequilibrium mixture assumptions must be stated explicitly.

Artificial averaging can erase the concentrated impactor-derived column that the theory requires.

12.7 Equation-of-State Selection Matrix

Table 3: Minimum equation-of-state requirements by material class.

Material class	**Required behavior**	**Failure caused by inadequate closure**
Impactor	Compression, fragmentation, melting, vaporization, expansion	Incorrect penetration depth and transmitted momentum
Crust	Porosity collapse, brittle failure, melting, vaporization	Incorrect entrance excavation and shock coupling
Upper mantle	High-pressure compression, phase change, melt generation	Incorrect attenuation and path width
Transition zone	Pressure-dependent mineral transitions and density change	Incorrect reflection, transmission, and focusing
Lower mantle	Extreme-pressure thermodynamics and strength loss	Incorrect deep-path propagation and midpoint response
Water	Compression, phase change, vaporization, supercritical behavior	Incorrect exit decompression and ocean consequences
Atmosphere	Compressible flow, ionization, heating, expansion	Incorrect entry and global atmospheric consequences

12.8 Equation-of-State Falsifier

A mechanism branch fails if its required penetration, shock, localization, or terminal energy disappears under every physically defensible equation-of-state model.

A favorable result obtained only through an unphysical or uncalibrated equation of state is not a viable solution.

13 Shock Jump Conditions

13.1 Rankine–Hugoniot Conditions

Across a planar shock moving with speed U_s, conservation of mass requires

$$\rho_0 U_s = \rho_1 (U_s - u_p). \tag{142}$$

Momentum conservation requires

$$P_1 - P_0 = \rho_0 U_s u_p. \tag{143}$$

Energy conservation requires

$$e_1 - e_0 = \frac{1}{2}(P_1 + P_0)\left(\frac{1}{\rho_0} - \frac{1}{\rho_1}\right). \tag{144}$$

These equations determine the admissible post-shock states for a declared equation of state. Impact hydrocodes additionally require calibrated porosity, damage, strength, and deformation prescriptions [5, 4, 3].

13.2 Compression Ratio

The compression ratio is

$$\mathcal{R}_\rho = \frac{\rho_1}{\rho_0}. \tag{145}$$

The event model must calculate how compression changes across:

- impactor–crust contact;
- crust–mantle boundaries;
- lithosphere–asthenosphere transition;
- mantle transition-zone boundaries;
- lower-mantle gradients; and
- exit decompression.

13.3 Acoustic Impedance

Material impedance is

$$Z = \rho c, \tag{146}$$

where c is the appropriate wave speed.

For a normally incident small-amplitude wave, the pressure reflection coefficient is

$$\mathcal{R}_P = \frac{Z_2 - Z_1}{Z_2 + Z_1}, \tag{147}$$

and the pressure transmission coefficient is

$$\mathcal{T}_P = \frac{2Z_2}{Z_2 + Z_1}. \tag{148}$$

The extreme nonlinear event requires full shock treatment, but the impedance contrast remains a useful indicator of possible reflection, transmission, and focusing.

13.4 Oblique Shock Geometry

For shock-normal unit vector $\widehat{\mathbf{n}}$, decompose velocity into

$$\mathbf{u} = u_n \widehat{\mathbf{n}} + \mathbf{u}_t, \tag{149}$$

where

$$u_n = \mathbf{u} \cdot \widehat{\mathbf{n}}, \tag{150}$$

$$\mathbf{u}_t = \mathbf{u} - u_n \widehat{\mathbf{n}}. \tag{151}$$

The normal component governs the principal compressive jump.

The tangential component influences shear, path deflection, fragmentation, and asymmetric entrance or exit structure.

13.5 Shock Mach Number

The local shock Mach number is

$$\mathcal{M}_s = \frac{U_s}{c_0}. \tag{152}$$

The ordinary acoustic Mach number of material flow is

$$\mathcal{M} = \frac{\|\mathbf{u}\|}{c}. \tag{153}$$

Both quantities vary strongly with depth and material state.

13.6 Shock Energy Flux

A directional shock-energy flux scale is

$$F_s \sim \left(P + \frac{1}{2}\rho u^2 + \rho e \right) u_n. \tag{154}$$

The integrated energy crossing path-normal surface $\mathcal{A}(s)$ is

$$\dot{E}_{\text{path}}(s,t) = \int_{\mathcal{A}(s)} F_s \, dA. \tag{155}$$

The ratio

$$f_E(s,t) = \frac{\int_0^t \dot{E}_{\text{path}}(s,t')\, dt'}{E_I} \tag{156}$$

measures the fraction of initial energy transmitted beyond path location s.

13.7 Shock Momentum Flux

The directional momentum flux is

$$\mathbf{\Pi} = \rho \mathbf{u} \otimes \mathbf{u} + P\mathbf{I} - \boldsymbol{\tau}. \tag{157}$$

The path-directed momentum rate is

$$\dot{\mathbf{p}}_{\text{path}} = \int_{\mathcal{A}(s)} \mathbf{\Pi} \cdot \widehat{\mathbf{n}}_s \, dA. \tag{158}$$

The exit claim requires not merely high pressure but sufficient directional momentum remaining near the Mariana target.

13.8 Shock Attenuation

A reduced empirical attenuation model may be written as

$$P_{\max}(s) = P_A \left(\frac{r_A}{r(s)}\right)^n \exp\left[-\int_0^s \alpha_P(s')\, ds'\right], \tag{159}$$

where

$$n = \text{geometric spreading exponent}, \tag{160}$$

$$\alpha_P = \text{material attenuation coefficient}. \tag{161}$$

This expression is a screening model only.

The full simulation must derive attenuation from conservation, constitutive behavior, geometry, and phase change.

13.9 Shock-Branch Requirement

The shock-dominated branch remains viable only if

$$E_{\text{shock}}\,(s=1) \geq E_{\text{exit,min}}, \tag{162}$$

while simultaneously satisfying:

$$\Lambda_{\text{path}} \geq \Lambda_{\text{crit}}, \tag{163}$$

and all planetary-survival limits.

14 Strength, Plasticity, and Damage

14.1 Pressure and Deviatoric Stress

The stress tensor is decomposed as

$$\boldsymbol{\sigma} = -P\mathbf{I} + \mathbf{s}, \tag{164}$$

where

$$\operatorname{tr}\mathbf{s} = 0. \tag{165}$$

The second invariant of deviatoric stress is

$$J_2 = \frac{1}{2}\mathbf{s} : \mathbf{s}. \tag{166}$$

14.2 Equivalent Stress

The von Mises equivalent stress is

$$\sigma_{\text{eq}} = \sqrt{3J_2}. \tag{167}$$

A pressure-independent yield criterion would be

$$f_{\text{VM}} = \sigma_{\text{eq}} - Y \leq 0. \tag{168}$$

Rock and mantle materials are pressure dependent, so this expression is insufficient as the complete constitutive law.

14.3 Pressure-Dependent Yield

A generic pressure-dependent yield surface may be written as

$$f = \sqrt{J_2} + \alpha I_1 - k \leq 0, \tag{169}$$

where

$$I_1 = \operatorname{tr} \boldsymbol{\sigma}, \tag{170}$$
$$\alpha = \text{pressure-sensitivity parameter}, \tag{171}$$
$$k = \text{cohesive-strength parameter}. \tag{172}$$

The parameters must vary with:

$$\alpha = \alpha(P, T, \dot{\epsilon}, D, \phi), \tag{173}$$

and

$$k = k(P, T, \dot{\epsilon}, D, \phi). \tag{174}$$

14.4 Plastic Strain

Decompose total strain as

$$\boldsymbol{\epsilon} = \boldsymbol{\epsilon}^e + \boldsymbol{\epsilon}^p + \boldsymbol{\epsilon}^{th} + \boldsymbol{\epsilon}^{tr}, \tag{175}$$

where

$$\boldsymbol{\epsilon}^e = \text{elastic strain}, \tag{176}$$
$$\boldsymbol{\epsilon}^p = \text{plastic strain}, \tag{177}$$
$$\boldsymbol{\epsilon}^{th} = \text{thermal strain}, \tag{178}$$
$$\boldsymbol{\epsilon}^{tr} = \text{phase-transformation strain}. \tag{179}$$

The plastic strain rate may be written as

$$\dot{\boldsymbol{\epsilon}}^p = \dot{\lambda} \frac{\partial g}{\partial \boldsymbol{\sigma}}, \tag{180}$$

where g is the plastic potential.

14.5 Strength Degradation

A damage-dependent strength law may be written as

$$Y_{\text{eff}} = (1 - D) Y_{\text{intact}} + D Y_{\text{damaged}}, \tag{181}$$

where

$$0 \leq D \leq 1. \tag{182}$$

The intact and damaged strengths must each depend on pressure, temperature, strain rate, and phase.

14.6 Damage Initiation

Damage may initiate when a criterion such as

$$\mathcal{F}_{\text{init}}\left(\sigma_1, \sigma_2, \sigma_3, P, T, \dot{\epsilon}, \phi\right) \geq 1 \tag{183}$$

is satisfied.

The model must distinguish:

- tensile fracture;
- shear fracture;
- pore collapse;
- comminution;
- thermal cracking;
- decompression failure; and
- melt-assisted weakening.

14.7 Damage Evolution

One generic rate form is

$$\dot{D} = \frac{1 - D}{\tau_D} \left\langle \mathcal{F}_{\text{init}} - 1 \right\rangle^{m_D}, \tag{184}$$

where

$$\langle x \rangle = \max(x, 0). \tag{185}$$

The characteristic damage time τ_D and exponent m_D must be calibrated.

14.8 Directional Damage Tensor

A scalar damage variable cannot preserve all directional information.

For plate-boundary inheritance, a second-order damage tensor may be required:

$$\mathbf{D} = \sum_{a=1}^{3} D_a \mathbf{n}_a \otimes \mathbf{n}_a. \tag{186}$$

This field can encode:

- preferred fracture orientation;
- anisotropic weakness;
- later reactivation direction;
- seismic anisotropy; and
- potential future plate-boundary orientation.

14.9 Fracture-Energy Budget

The energy consumed by fracture is

$$E_{\text{fract}} = \int_{\mathcal{A}_{\text{fract}}} G_c(\mathbf{r})\, dA, \tag{187}$$

where G_c is the critical fracture energy per unit area.

The model must conserve this energy explicitly or through an equivalent damage-dissipation term.

14.10 Damage-Inheritance Requirement

For damage to contribute to later plate organization, the post-event field must satisfy

$$D(\mathbf{r}, t_{\text{handoff}}) \geq D_{\text{inherit}} \tag{188}$$

over a connected, mechanically meaningful structure.

A transient shattered volume that heals without influencing later motion does not satisfy the replacement thesis.

15 Pressure-, Temperature-, and Rate-Dependent Rheology

15.1 No Single Mantle Viscosity

The value

$$\eta \sim 1 \times 10^{21}\,\text{Pa s} \tag{189}$$

is associated with long-timescale mantle flow.

It cannot be inserted directly into a minutes-scale hypervelocity transit and treated as a complete material law.

The event requires

$$\eta_{\text{eff}} = \eta_{\text{eff}} \left(P, T, \dot{\epsilon}, \phi, \chi_m, D, t \right). \tag{190}$$

15.2 Maxwell Viscoelasticity

A Maxwell material satisfies

$$\dot{\boldsymbol{\epsilon}} = \frac{1}{2G}\dot{\mathbf{s}} + \frac{1}{2\eta}\mathbf{s}. \tag{191}$$

The Maxwell relaxation time is

$$\tau_M = \frac{\eta}{G}. \tag{192}$$

For loading time t_L, define

$$\text{De}_M = \frac{\tau_M}{t_L}. \tag{193}$$

When

$$\text{De}_M \gg 1, \tag{194}$$

the response is predominantly elastic over the loading interval.

When

$$\text{De}_M \ll 1, \tag{195}$$

viscous relaxation dominates.

The relevant event-loading time may be seconds to minutes locally, while later geodynamic relaxation spans much longer intervals.

15.3 Power-Law Creep

A generic creep law is

$$\dot{\epsilon}_{\text{cr}} = A\sigma^n d^{-m} \exp\left[-\frac{Q + PV^*}{RT} \right], \tag{196}$$

where

$$A = \text{material prefactor,} \tag{197}$$

$$n = \text{stress exponent,} \tag{198}$$

$$d = \text{grain size,} \tag{199}$$

$$m = \text{grain-size exponent,} \tag{200}$$

$$Q = \text{activation energy,} \tag{201}$$

$$V^* = \text{activation volume.} \tag{202}$$

Ordinary creep laws may be relevant to long-time inheritance but may not govern the primary shock state.

15.4 Effective Viscosity From Creep

For scalar stress and strain-rate measures,

$$\eta_{\text{creep}} = \frac{\sigma}{2\dot{\epsilon}_{\text{cr}}}. \tag{203}$$

The model must cap or replace this viscosity when:

- the material yields;
- damage localizes;
- melting becomes substantial;
- vaporization occurs;
- inertial flow dominates; or
- the constitutive calibration is exceeded.

15.5 Strain-Rate Regimes

The event spans multiple strain-rate regimes:

$$\dot{\epsilon} \sim \frac{U}{L_c}, \tag{204}$$

where L_c is a local deformation scale.

For

$$U = 20\,\text{km}\,\text{s}^{-1} \tag{205}$$

and characteristic scales from

$$L_c = 1\,\text{km to } 1000\,\text{km}, \tag{206}$$

the implied reference strain rates span approximately

$$2 \times 10^{-2} \lesssim \dot{\epsilon} \lesssim 20 \quad \text{s}^{-1}. \tag{207}$$

These rates differ enormously from ordinary mantle-convection strain rates.

15.6 Thermal Softening

A generic thermal-softening factor is

$$S_T = \max\left[0, 1 - \left(\frac{T - T_0}{T_m - T_0}\right)^q\right], \tag{208}$$

where T_m is the pressure-dependent melting temperature.

The effective strength may be written as

$$Y_{\text{eff}} = Y_0 S_T S_D S_{\dot{\epsilon}} S_P, \tag{209}$$

where the additional factors represent damage, strain-rate, and pressure dependence.

15.7 Melt Weakening

For melt fraction χ_m, one possible interpolation is

$$\eta_{\text{mix}} = \eta_s \exp\left(-\beta_m \chi_m\right), \tag{210}$$

up to the point where a suspension or fluid formulation becomes more appropriate.

The coefficient β_m must be calibrated rather than selected to force path propagation.

15.8 Two-Timescale Mechanical Model

The primary event and later inheritance require different mechanical regimes.

Short-timescale model
Compressible, inertial, shock-dominated, strength- and phase-sensitive response.

Long-timescale model
Viscoelastic, plastic, buoyant, thermochemical, gravitational, and damage-reactivation response.

The handoff time t_h must be chosen when the short-duration shock calculation has decayed enough for a long-time geodynamic model to become appropriate.

15.9 Rheological Falsifier

If all defensible high-pressure, high-temperature, high-strain-rate rheologies disperse or arrest the disturbance before it produces the required midpoint and exit fields, the relevant transmission branches are rejected.

16 Phase Transitions, Melting, and Vaporization

16.1 Phase-State Vector

For each material, define phase fractions

$$\boldsymbol{\phi} = \left(\phi_1, \phi_2, \ldots, \phi_{N_\phi}\right), \qquad \sum_a \phi_a = 1. \tag{211}$$

The phase set must include the relevant high-pressure mineral states, melt, vapor, and mixed phases.

16.2 Phase Equilibrium

For phases a and b, equilibrium occurs when their Gibbs free energies are equal:

$$G_a(P, T) = G_b(P, T). \tag{212}$$

The equilibrium boundary satisfies the Clapeyron relation

$$\frac{dP}{dT} = \frac{\Delta S}{\Delta V} = \frac{L_{ab}}{T\Delta V}, \tag{213}$$

where L_{ab} is latent heat.

16.3 Kinetic Delay

Extreme loading may drive material out of equilibrium.

A phase fraction may evolve as

$$\dot{\phi}_a = \frac{\phi_a^{\mathrm{eq}}(P, T) - \phi_a}{\tau_{\phi,a}}, \tag{214}$$

where $\tau_{\phi,a}$ is the transformation timescale.

If

$$\tau_{\phi,a} \gg t_{\mathrm{load}}, \tag{215}$$

the phase may remain metastable during the primary passage.

16.4 Enthalpy Formulation

Specific enthalpy is

$$h = e + \frac{P}{\rho}. \tag{216}$$

A phase-change enthalpy representation may be written as

$$h(T, P) = h_{\text{sens}}(T, P) + \chi_m L_m(P) + \chi_v L_v(P), \tag{217}$$

where

$$L_m = \text{latent heat of melting}, \tag{218}$$

$$L_v = \text{latent heat of vaporization}. \tag{219}$$

16.5 Melt Fraction

Within a pressure-dependent solidus–liquidus interval, an initial melt fraction model is

$$\chi_m = \begin{cases} 0, & T \leq T_{\text{sol}}(P), \\ \dfrac{T - T_{\text{sol}}(P)}{T_{\text{liq}}(P) - T_{\text{sol}}(P)}, & T_{\text{sol}}(P) < T < T_{\text{liq}}(P), \\ 1, & T \geq T_{\text{liq}}(P). \end{cases} \tag{220}$$

A final model may require nonequilibrium melt kinetics and composition-dependent boundaries.

16.6 Vapor Fraction

A similar first screening relation is

$$\chi_v = \mathcal{F}_v \left(P, T, e, \mathcal{C}\right). \tag{221}$$

Exit decompression may generate vapor even when the deep path remains predominantly condensed.

16.7 Phase-Boundary Reflection and Focusing

At phase boundary b, define incident, reflected, and transmitted energies:

$$E_{\text{inc},b} = E_{\text{refl},b} + E_{\text{trans},b} + E_{\text{diss},b} + E_{\text{phase},b}. \tag{222}$$

A midpoint pressure maximum may arise from:

- impedance contrast;
- converging geometry;
- phase-transition energy;
- path curvature;
- reflected-wave interference;
- material entrainment; or
- decompression after maximum depth.

The location must emerge from the model.

16.8 Persistent Phase Memory

A phase anomaly contributes to later forensic evidence only if it survives.

Define survival fraction

$$S_\phi(t) = \frac{\int_{\mathcal{V}} |\phi(\mathbf{r},t) - \phi_0(\mathbf{r})| \, dV}{\int_{\mathcal{V}} |\phi(\mathbf{r},t_h) - \phi_0(\mathbf{r})| \, dV}. \tag{223}$$

The midpoint-inheritance hypothesis requires

$$S_\phi(t_{\text{relevant}}) > S_{\phi,\text{crit}} \tag{224}$$

for at least one observable phase, density, or seismic consequence.

16.9 Thermal-Anomaly Survival

The thermal anomaly evolves according to

$$\rho c_p \frac{DT}{Dt} = \nabla \cdot (k \nabla T) + \Phi_{\text{visc}} + \Phi_{\text{plastic}} + Q_{\text{phase}} + Q_{\text{radio}} + Q_{\text{adv}}, \tag{225}$$

where the Φ terms represent mechanical dissipation.

A local conductive timescale is

$$\tau_\kappa = \frac{L_T^2}{\kappa}, \tag{226}$$

with thermal diffusivity

$$\kappa = \frac{k}{\rho c_p}. \tag{227}$$

Large thermal structures may persist long enough to affect later buoyancy and deformation.

16.10 Phase and Melt Falsifier

If the mechanism requires a phase, melt, or vapor volume whose predicted modern or stratigraphic consequences are absent, the corresponding parameter region is eliminated.

17 Fragmentation, Entrainment, and Column Loading

17.1 Fragmentation Criterion

A projectile-derived body fragments when internal tensile, shear, thermal, or pressure-gradient stresses exceed its effective strength.

A generic fragmentation condition is

$$\mathcal{F}_{\text{frag}} = \frac{\sigma_{\text{drive}}}{Y_I(P, T, \dot{\epsilon}, D)} \geq 1. \tag{228}$$

The driving stress may include:

- dynamic pressure;
- shock-pressure gradients;
- tidal stress;
- thermal stress;
- rotation;
- differential deceleration; and
- phase-transition stress.

17.2 Fragment-Size Distribution

After fragmentation, let the fragment-size distribution be

$$\frac{dN}{dR_f} = C_f R_f^{-q_f}, \tag{229}$$

over

$$R_{f,\text{min}} \leq R_f \leq R_{f,\text{max}}. \tag{230}$$

The model must conserve the total projectile-derived mass:

$$M_I = \int \frac{4}{3}\pi\rho_f R_f^3 \frac{dN}{dR_f}\, dR_f + M_{\text{melt}} + M_{\text{vapor}}. \tag{231}$$

17.3 Fragment Deceleration

For fragment j,

$$M_j \frac{d\mathbf{v}_j}{dt} = -\frac{1}{2} C_{D,j} \rho_t A_j \left| \mathbf{v}_j - \mathbf{u} \right| (\mathbf{v}_j - \mathbf{u}) + \mathbf{F}_{P,j} + \mathbf{F}_{g,j} + \mathbf{F}_{\mathrm{int},j}. \tag{232}$$

Smaller fragments possess greater area-to-mass ratios and generally decelerate more rapidly.

17.4 Entrainment

Let $M_t(s)$ be target material incorporated into the moving disturbance.

An entrainment law may be written as

$$\frac{dM_t}{ds} = C_e \rho_t(s) A_{\mathrm{mix}}(s), \tag{233}$$

where

$$C_e = \text{entrainment coefficient}, \tag{234}$$

$$A_{\mathrm{mix}} = \text{effective mixing area}. \tag{235}$$

The moving column mass becomes

$$M_{\mathrm{col}}(s) = M_{I,\mathrm{remaining}}(s) + M_t(s). \tag{236}$$

Entrainment increases mass while generally reducing specific momentum and altering composition.

17.5 Momentum Dilution

Ignoring external force for a screening estimate,

$$M_{\mathrm{col}}(s) U(s) \approx p_{\mathrm{col}}(s). \tag{237}$$

If momentum were approximately conserved while mass increased,

$$U(s) \propto \frac{1}{M_{\mathrm{col}}(s)}. \tag{238}$$

The actual event additionally loses momentum laterally and transfers momentum into surrounding Earth.

17.6 Projectile Column Density

For a spherical projectile,

$$\Sigma_I = \frac{M_I}{\pi R_I^2} = \frac{4}{3}\rho_I R_I. \tag{239}$$

The Earth-path column density is

$$\Sigma_\oplus = \int_{\text{path}} \rho_\oplus(s)\, ds. \tag{240}$$

Define

$$\Pi_\Sigma = \frac{\Sigma_I}{\Sigma_\oplus}. \tag{241}$$

17.7 Illustrative Column-Density Screening

For an illustrative mean path density

$$\bar{\rho}_\oplus = 4500\,\mathrm{kg\,m^{-3}} \tag{242}$$

and audited path length

$$L_{\text{chord}} = 1.015\,056\,7 \times 10^7\ \mathrm{m}, \tag{243}$$

the reference Earth-column density is

$$\Sigma_\oplus \approx 4.568 \times 10^{10} \quad \mathrm{kg\,m^{-2}}. \tag{244}$$

For impactor density

$$\rho_I = 3000\,\mathrm{kg\,m^{-3}}, \tag{245}$$

representative corners of the inherited parameter domain give:

Table 4: Illustrative projectile-to-Earth column-density ratios. These values are screening estimates, not penetration solutions.

Energy	**Speed**	**Impactor radius**	$\mathbf{\Pi_\Sigma}$
10^{29} J	$30\,\mathrm{km\,s^{-1}}$	260 km	0.0228
10^{29} J	$10\,\mathrm{km\,s^{-1}}$	542 km	0.0475
10^{31} J	$30\,\mathrm{km\,s^{-1}}$	1209 km	0.1059
10^{31} J	$10\,\mathrm{km\,s^{-1}}$	2515 km	0.2203

All four illustrative ratios are below unity.

This means the target mass per unit frontal area along the reference path exceeds the projectile mass per unit frontal area.

Mechanical screening result M4.
Across representative corners of the inherited parameter domain, the projectile column density is smaller than the reference Earth-path column density.
This does not mathematically prohibit a connected high-energy disturbance, but it strongly disfavors treating the event as ordinary rigid-body penetration through a passive medium.

17.8 Swept-Mass Ratio

For effective cross-sectional area A_{eff},

$$M_{\mathrm{swept}} = \int_0^{L_{\mathrm{path}}} \rho_t(s) A_{\mathrm{eff}}(s)\, ds. \tag{246}$$

Define

$$\Pi_M = \frac{M_{\mathrm{swept}}}{M_I}. \tag{247}$$

A coherent-body model becomes increasingly implausible as

$$\Pi_M \gg 1 \tag{248}$$

unless the effective interaction area becomes substantially smaller than the initial projectile cross section or the surrounding material is redirected through an explicitly modeled mechanism.

17.9 Composition Tracer

Let $c_I(\mathbf{r}, t)$ denote the local mass fraction of projectile-derived material.

It obeys

$$\frac{\partial (\rho c_I)}{\partial t} + \nabla \cdot (\rho c_I \mathbf{u}) = \nabla \cdot (\rho \mathcal{D}_I \nabla c_I) + S_I, \tag{249}$$

where

$$\mathcal{D}_I = \text{effective mixing diffusivity}, \tag{250}$$

$$S_I = \text{source or phase-transfer term}. \tag{251}$$

The model must predict whether impactor-derived material should remain detectable at the entrance, path, midpoint, or exit.

17.10 Fragmented-Column Viability

The fragmented-column branch requires:

$$\frac{\|\mathbf{p}_{\text{col}}(s)\|}{p_I} \geq \mu_{\text{crit}}(s), \tag{252}$$

and

$$\frac{R_{\text{col}}(s)}{L_{\text{path}}} \leq \epsilon_{\text{spread}}, \tag{253}$$

through the region needed to produce the terminal response.

18 Path Localization, Attenuation, and Deflection

18.1 Reference Axis

Let $\mathbf{C}(s)$ be the Paper-I reference chord.

For physical location $\mathbf{r}$, define the minimum distance to that axis:

$$d_\perp (\mathbf{r}, \mathbf{C}) = \min_{s \in [0,1]} \|\mathbf{r} - \mathbf{C}(s)\| . \tag{254}$$

18.2 Path Tube

Define a path tube of radius $R_p(s,t)$:

$$\mathcal{V}_p = \{\mathbf{r} : d_\perp (\mathbf{r}, \mathbf{r}_{\text{event}}) \leq R_p\} . \tag{255}$$

The path radius may be defined through an energy-containment condition:

$$\int_{d_\perp \le R_p} e_{\text{dist}}\, dV = f_p \int_{\mathcal{V}_\oplus} e_{\text{dist}}\, dV, \tag{256}$$

where f_p may be set to a declared value such as 0.50, 0.75, or 0.90.

18.3 Energy Localization Fraction

The energy localization fraction is

$$\Lambda_E(t) = \frac{\displaystyle\int_{\mathcal{V}_p} e_{\text{dist}}(\mathbf{r}, t)\, dV}{\displaystyle\int_{\mathcal{V}_\oplus} e_{\text{dist}}(\mathbf{r}, t)\, dV}. \tag{257}$$

The disturbed energy density should exclude the undisturbed planetary background.

18.4 Momentum Localization Fraction

Define path-axis unit tangent

$$\widehat{\mathbf{t}}(s, t) = \frac{\partial \mathbf{r}_{\text{event}}/\partial s}{\|\partial \mathbf{r}_{\text{event}}/\partial s\|}. \tag{258}$$

The directional momentum within the tube is

$$p_{\|,p}(t) = \int_{\mathcal{V}_p} \rho \left(\mathbf{u} \cdot \widehat{\mathbf{t}}\right) dV. \tag{259}$$

The momentum localization fraction is

$$\Lambda_p(t) = \frac{\left|p_{\|,p}(t)\right|}{\displaystyle\int_{\mathcal{V}_\oplus} \rho \, \|\mathbf{u}\| \, dV}. \tag{260}$$

18.5 Angular Dispersion

Let local momentum element be $d\mathbf{p}$.

Its angle relative to the desired path direction is

$$\psi = \arccos\left(\frac{d\mathbf{p} \cdot \widehat{\mathbf{t}}}{\|d\mathbf{p}\|}\right). \tag{261}$$

The momentum-weighted angular variance is

$$\sigma_\psi^2 = \frac{\int \psi^2 \|d\mathbf{p}\|}{\int \|d\mathbf{p}\|}. \tag{262}$$

The exit model requires sufficiently small angular dispersion or a later focusing mechanism.

18.6 Path Deflection

The displacement of the physical path from the reference chord is

$$\boldsymbol{\delta}_r(s,t) = \mathbf{r}_{\text{event}}(s,t) - \mathbf{C}(s). \tag{263}$$

The deflection magnitude is

$$\delta_r(s,t) = \|\boldsymbol{\delta}_r(s,t)\|. \tag{264}$$

The total curvature is

$$\kappa(s,t) = \frac{\|\mathbf{r}' \times \mathbf{r}''\|}{\|\mathbf{r}'\|^3}. \tag{265}$$

A curved path proposed to resolve the Everest cross-track displacement must emerge from material forces rather than be drawn through the desired target.

18.7 Attenuation Coefficients

Define cumulative energy attenuation

$$\mathcal{A}_E(s) = -\ln\left[\frac{E_{\text{dir}}(s)}{E_{\text{dir}}(0)}\right], \tag{266}$$

and momentum attenuation

$$\mathcal{A}_p(s) = -\ln\left[\frac{p_{\text{dir}}(s)}{p_{\text{dir}}(0)}\right]. \tag{267}$$

Local attenuation rates are

$$\alpha_E(s) = \frac{d\mathcal{A}_E}{ds}, \tag{268}$$

$$\alpha_p(s) = \frac{d\mathcal{A}_p}{ds}. \tag{269}$$

18.8 Branching Ratio

If the disturbance splits into branches b,

$$f_b = \frac{E_b}{\sum_j E_j}, \qquad \sum_b f_b = 1. \tag{270}$$

A Mariana terminal branch must retain sufficient energy and momentum after all reflected, lateral, and global branches are included.

18.9 Midpoint-Target Offset

Let $\mathbf{x}_H$ denote the selected Himalayan material target.

The minimum mechanical-path distance to that target is

$$d_H^{\text{mech}} = \min_{s,t} \left\| \mathbf{r}_{\text{event}}(s,t) - \mathbf{x}_H(t) \right\|. \tag{271}$$

This is the relevant mechanical quantity.

It need not equal the geometric chord-midpoint misfit.

18.10 Exit-Target Misfit

For exit target domain $\mathcal{D}_M$, define

$$d_M^{\text{exit}} = \min_{\mathbf{x}\in\mathcal{D}_M} \left\| \mathbf{r}_{\text{event}}(1, t_{\text{exit}}) - \mathbf{x} \right\|. \tag{272}$$

The allowed exit misfit must be declared from the physical size of the predicted terminal structure.

18.11 Localization Viability Conditions

A mechanism branch is path viable only if:

$$\Lambda_E(t_{\text{exit}}) \geq \Lambda_{E,\text{crit}}, \tag{273}$$
$$\Lambda_p(t_{\text{exit}}) \geq \Lambda_{p,\text{crit}}, \tag{274}$$
$$\sigma_\psi(t_{\text{exit}}) \leq \sigma_{\psi,\text{crit}}, \tag{275}$$
$$E_{\text{exit}} \geq E_{\text{exit,min}}, \tag{276}$$
$$p_{\text{exit}} \geq p_{\text{exit,min}}, \tag{277}$$
$$d_M^{\text{exit}} \leq d_{M,\text{crit}}. \tag{278}$$

The thresholds must be specified before the terminal result is examined.

19 Branch-Specific Viability Tests

19.1 Coherent-Body Branch

The coherent-body branch requires all of the following:

CB1. a non-negligible coherent mass survives entrance;

CB2. fragmentation remains below the declared critical threshold;

CB3. ablation and vaporization do not destroy the body;

CB4. encountered-mass loading does not stop the body;

CB5. the body remains path localized;

CB6. the body reaches the required depth;

CB7. the body or its direct material continuation reaches the exit; and

CB8. predicted projectile-derived material is compatible with observations.

Define coherent survival fraction

$$f_{\mathrm{coh}}(s) = \frac{M_{\mathrm{coherent}}(s)}{M_I}. \tag{279}$$

The branch survives only if

$$f_{\mathrm{coh}}(1) \geq f_{\mathrm{coh,crit}}. \tag{280}$$

Coherent-body falsifier.
If every defensible material model fragments, melts, vaporizes, entrains, or decelerates the projectile below the declared coherent survival threshold before it reaches the required deep-path and exit regions, coherent-body penetration is rejected.

19.2 Fragmented-Column Branch

The fragmented-column branch requires:

FC1. loss of solid coherence without loss of directional organization;

FC2. sufficient column momentum;

FC3. bounded radial spreading;

FC4. controlled entrainment;

FC5. sufficient terminal energy;

FC6. a predicted mixed-material composition; and

FC7. a path width compatible with geological observations.

Define column-coherence index

$$\mathcal{K}_{\text{col}} = \Lambda_p \exp\left[-\left(\frac{R_{\text{col}}}{R_{\text{crit}}}\right)^2\right]. \tag{281}$$

The branch requires

$$\mathcal{K}_{\text{col}} \geq \mathcal{K}_{\text{crit}}. \tag{282}$$

Fragmented-column falsifier.
If fragmentation produces lateral dispersion, momentum dilution, or entrainment sufficient to prevent a concentrated terminal Mariana response, the fragmented-column branch is rejected.

19.3 Shock-Dominated Branch

The shock branch requires:

SH1. formation of a sufficiently strong entrance shock;

SH2. directional rather than nearly spherical propagation;

SH3. survival through material and phase boundaries;

SH4. acceptable attenuation;

SH5. a mechanically predicted midpoint field;

SH6. sufficient terminal pressure and energy;

SH7. an exit morphology consistent with shock emergence; and

SH8. compatible global seismic and thermal consequences.

Define terminal shock ratio

$$\Pi_{\text{shock}} = \frac{E_{\text{shock,exit}}}{E_{\text{exit,min}}}. \tag{283}$$

The branch requires

$$\Pi_{\text{shock}} \geq 1. \tag{284}$$

Shock-branch falsifier.
If the shock becomes too diffuse, attenuated, reflected, or globalized to produce the required localized terminal response, the shock-dominated branch is rejected.

19.4 Fracture- and Phase-Front Branch

This branch requires:

PF1. a connected damage or phase front;

PF2. physically calibrated propagation laws;

PF3. sufficient propagation speed;

PF4. directional continuity;

PF5. a mechanism for passing through high-confinement regions;

PF6. a persistent inherited structure;

PF7. terminal decompression or failure; and

PF8. predicted modern geophysical evidence.

Let front position be defined by threshold state variable q_c:

$$\mathcal{F}_q(t) = \{\mathbf{r} : q(\mathbf{r}, t) = q_c\} . \tag{285}$$

The front must connect the entrance and terminal-response domains:

$$\mathcal{F}_q : \mathcal{D}_A \longrightarrow \mathcal{D}_M . \tag{286}$$

Phase-front falsifier.
If no calibrated damage, fracture, melt, or phase-transition law produces a connected, directional front through the required depth and distance, the fracture- and phase-front branch is rejected.

19.5 Hybrid Branch

The hybrid branch requires:

HY1. explicit branch-transition criteria;

HY2. conservation through each transition;

HY3. no retroactive mechanism switching;

HY4. a continuous path of causal influence;

HY5. a single event parameter vector;

HY6. one shared entrance, midpoint, and exit prediction set; and

HY7. complexity penalties for added transitions and parameters.

For branch sequence

$$\mathcal{M}_1 \to \mathcal{M}_2 \to \cdots \to \mathcal{M}_N , \tag{287}$$

the transition residuals are

$$\epsilon_M^{(j)} = M_j^+ - M_j^-, \tag{288}$$
$$\boldsymbol{\epsilon}_p^{(j)} = \mathbf{p}_j^+ - \mathbf{p}_j^-, \tag{289}$$
$$\epsilon_E^{(j)} = E_j^+ - E_j^-. \tag{290}$$

A conservative numerical solution requires these residuals to remain within declared tolerances.

Hybrid-branch falsifier.
If the hybrid model survives only by changing mechanism after each failed prediction, introducing unconstrained transitions, or violating mass, momentum, energy, or chronology, the hybrid branch is rejected as non-falsifiable.

19.6 Branch Comparison Matrix

Table 5: Branch-specific evidence and principal mechanical risk.

Branch	**Primary carrier**	**Distinctive predicted evidence**	**Principal risk**
Coherent body	Projectile-derived macroscopic body	Concentrated foreign material and narrow terminal mass delivery	Column loading, melting, and fragmentation
Fragmented column	Mixed fragments, melt, vapor, and entrained mantle	Elongated mixed-composition path and broad but directional exit	Momentum dilution and radial dispersion
Shock dominated	Compressive energy and momentum flux	Pressure-, phase-, and damage-defined path without abundant projectile material	Attenuation and global isotropization
Fracture/phase front	Propagating damage and material-state transition	Long-lived anisotropic weakness and phase anomalies	No viable propagation law through deep confinement
Hybrid	Sequential combination	Layer-dependent transitions and multiple forensic marker classes	Excess flexibility and post hoc rescue

19.7 Global Branch Decision Rule

Let

$$\mathcal{V}_q \tag{291}$$

be the viable parameter set for mechanism branch q.

The complete mechanical viable set is

$$\mathcal{V}_{\mathrm{II}} = \bigcup_q \mathcal{V}_q. \tag{292}$$

The literal connected event remains mechanically open only if

$$\mathcal{V}_{\mathrm{II}} \neq \varnothing. \tag{293}$$

If every branch is empty,

$$\forall q, \qquad \mathcal{V}_q = \varnothing, \tag{294}$$

then

$$\mathcal{V}_{\mathrm{II}} = \varnothing, \tag{295}$$

and the connected Aegean-to-Mariana transmission mechanism is rejected.

20 Constitutive and Transmission Synthesis

This constitutive-and-transmission synthesis records:

1. the equation-of-state hierarchy;
2. the Rankine–Hugoniot shock constraints;
3. pressure-dependent strength and plasticity;
4. damage initiation and directional damage inheritance;
5. short- and long-timescale rheological separation;
6. phase-transition, melt, vapor, and thermal-memory equations;
7. fragmentation and entrainment mechanics;
8. projectile and Earth-path column-density comparison;
9. energy and momentum localization metrics;
10. physical-path curvature and target-misfit definitions;
11. branch-specific viability requirements; and
12. branch-specific falsification conditions.

The strongest screening result is that representative impactors within the inherited parameter domain possess less mass per frontal area than the reference Earth column along the complete path.

This result does not eliminate every shock, phase-front, or hybrid transmission model.

It substantially raises the burden on any ordinary coherent-projectile interpretation.

The following sections develop:

- entrance coupling and excavation;
- oblique-entry geometry;
- atmosphere, ocean, and crust interaction;
- penetration-depth screening;
- entrance energy and momentum partition;
- predicted Aegean morphology;
- entrance-derived seismic, gravity, and magnetic fields;
- entrance chronology and preservation;
- entrance parameter inversion; and
- complete entrance falsification tests.

21 Entrance Geometry and Oblique Coupling

21.1 Local Entrance Frame

Let the declared entrance coordinate be represented by the unit radial vector

$$\widehat{\mathbf{n}}_A = \boldsymbol{\xi}_A. \tag{296}$$

This vector points outward from Earth's center.

The inward radial direction is

$$-\widehat{\mathbf{n}}_A. \tag{297}$$

Define the local east unit vector

$$\widehat{\mathbf{e}}_A = \begin{pmatrix} -\sin\lambda_A \\ \cos\lambda_A \\ 0 \end{pmatrix}, \tag{298}$$

and the local north unit vector

$$\widehat{\mathbf{q}}_A = \widehat{\mathbf{n}}_A \times \widehat{\mathbf{e}}_A. \tag{299}$$

The local orthonormal basis is therefore

$$\mathcal{B}_A = \{\widehat{\mathbf{e}}_A, \widehat{\mathbf{q}}_A, \widehat{\mathbf{n}}_A\}. \tag{300}$$

21.2 Incident Velocity Components

Let the incident velocity immediately before lithospheric contact be

$$\mathbf{v}_{I,A}. \tag{301}$$

Its inward normal component is

$$v_n = -\mathbf{v}_{I,A} \cdot \widehat{\mathbf{n}}_A, \qquad v_n > 0, \tag{302}$$

and the tangential component is

$$\mathbf{v}_t = \mathbf{v}_{I,A} + v_n \widehat{\mathbf{n}}_A. \tag{303}$$

Its magnitude is

$$v_t = \|\mathbf{v}_t\|. \tag{304}$$

The total speed satisfies

$$v_I^2 = v_n^2 + v_t^2. \tag{305}$$

21.3 Incidence Angle

The incidence angle below the local horizontal is

$$\alpha_A = \arcsin\left(\frac{v_n}{v_I}\right). \tag{306}$$

For the straight Paper-I reference chord,

$$\alpha_A = 52.808799^\circ. \tag{307}$$

The corresponding angle from the inward radial direction is

$$\beta_A = 90^\circ - \alpha_A = 37.191201^\circ. \tag{308}$$

The reference event is therefore oblique but not grazing.

21.4 Normal and Tangential Energy Fractions

The incident kinetic energy can be separated into normal and tangential components:

$$E_n = \frac{1}{2} M_I v_n^2, \tag{309}$$

and

$$E_t = \frac{1}{2} M_I v_t^2. \tag{310}$$

The corresponding fractions are

$$f_n = \frac{E_n}{E_I} = \sin^2 \alpha_A, \tag{311}$$

and

$$f_t = \frac{E_t}{E_I} = \cos^2 \alpha_A. \tag{312}$$

For the audited straight-path angle,

$$f_n = 0.634608, \tag{313}$$

$$f_t = 0.365392. \tag{314}$$

Approximately 63.5% of the reference kinetic energy is associated with the normal velocity component and approximately 36.5% with the tangential component.

These are geometric decompositions.

They are not equivalent to the actual fractions coupled into excavation, heating, horizontal momentum, or deep transmission.

21.5 Downrange Direction

The local downrange direction is

$$\hat{\mathbf{d}}_A = \frac{\mathbf{v}_t}{v_t}. \tag{315}$$

Its azimuth in the local east–north frame is

$$\gamma_A = \operatorname{atan2}\left(\widehat{\mathbf{d}}_A \cdot \widehat{\mathbf{e}}_A, \widehat{\mathbf{d}}_A \cdot \widehat{\mathbf{q}}_A\right). \tag{316}$$

The predicted Aegean entrance asymmetry, fault orientations, ejecta distribution, and deep transmission corridor must be referenced to γ_A.

21.6 Projected Contact Geometry

For a spherical projectile of radius R_I, the purely geometric projection of its circular cross section onto a horizontal tangent plane has a screening aspect ratio

$$\mathcal{R}_{\text{proj}} = \frac{1}{\sin \alpha_A}. \tag{317}$$

For the audited incidence,

$$\mathcal{R}_{\text{proj}} \approx 1.2553. \tag{318}$$

This quantity is not a predicted crater or basin aspect ratio.

It describes only the geometric projection of the incoming body.

Actual morphology depends on:

- projectile size;
- projectile deformation;
- crustal and oceanic thickness;
- impact speed;
- target strength;
- gravity;
- melting;
- excavation flow;
- post-event collapse; and
- later tectonic overprint.

21.7 Entrance Coordinate Versus Coupling Center

The selected geographic coordinate need not equal the mechanical center of energy deposition.

Define:

$$\mathbf{x}_{A,\mathrm{coord}} = \text{declared entrance coordinate,} \tag{319}$$

$$\mathbf{x}_{A,E} = \text{energy-deposition centroid,} \tag{320}$$

$$\mathbf{x}_{A,p} = \text{momentum-coupling centroid,} \tag{321}$$

$$\mathbf{x}_{A,\mathrm{exc}} = \text{excavation centroid,} \tag{322}$$

$$\mathbf{x}_{A,\mathrm{deep}} = \text{deep-path initiation point.} \tag{323}$$

The offsets are

$$\boldsymbol{\delta}_{A,E} = \mathbf{x}_{A,E} - \mathbf{x}_{A,\mathrm{coord}}, \tag{324}$$

$$\boldsymbol{\delta}_{A,p} = \mathbf{x}_{A,p} - \mathbf{x}_{A,\mathrm{coord}}, \tag{325}$$

and similarly for excavation and deep-path initiation.

Oblique entry generally permits these centroids to differ.

21.8 Entrance-Domain Requirement

The physical entrance must be represented by a domain

$$\mathcal{D}_A = \{\mathbf{x} : \mathcal{F}_A(\mathbf{x}) \geq \mathcal{F}_{A,\mathrm{crit}}\}, \tag{326}$$

where $\mathcal{F}_A$ may combine predicted:

- pressure;
- damage;
- melt fraction;
- excavation;
- projectile-material concentration;
- gravity anomaly;
- magnetic resetting; and
- persistent structural inheritance.

The entrance coordinate is valid only if it lies within or near the forward-modeled entrance domain.

22 Atmospheric and Oceanic Entry

22.1 Atmospheric Column Density

Let atmospheric density along the incoming path be

$$\rho_{\text{atm}}(s). \tag{327}$$

The encountered atmospheric column density is

$$\Sigma_{\text{atm}} = \int_{\text{entry}} \rho_{\text{atm}}(s)\, ds. \tag{328}$$

The projectile ballistic coefficient is

$$\mathcal{B}_I = \frac{M_I}{C_D A_I}, \tag{329}$$

where

$$A_I = \pi R_I^2. \tag{330}$$

A reduced atmospheric deceleration estimate is

$$\frac{v_{\text{surf}}}{v_\infty} \approx \exp\left(-\frac{\Sigma_{\text{atm}}}{2\mathcal{B}_I}\right). \tag{331}$$

This approximation neglects fragmentation, lift, changing area, ablation, compressibility, radiation, and atmospheric blowoff.

It is used only to screen whether ordinary aerodynamic deceleration can remove a significant fraction of the momentum of an extremely large body.

22.2 Atmospheric Energy Deposition

The drag-energy deposition rate is

$$\frac{dE_{\text{atm}}}{ds} = \frac{1}{2} C_D \rho_{\text{atm}} A_I v^2. \tag{332}$$

The total atmospheric energy deposition is

$$E_{\text{atm}} = \int_{\text{entry}} \frac{dE_{\text{atm}}}{ds}\, ds. \tag{333}$$

The atmospheric fraction is

$$f_{\text{atm}} = \frac{E_{\text{atm}}}{E_I}. \tag{334}$$

Even when f_{atm} is small, the absolute atmospheric energy may be globally significant.

22.3 Atmospheric Shock and Blowoff

The model must calculate:

- bow-shock pressure;
- atmospheric heating;
- ionization;
- lateral atmospheric displacement;
- atmospheric escape;
- global pressure-wave propagation;
- dust and vapor injection;
- radiant heating; and
- chemical consequences.

A sufficiently large event may interact with the atmosphere as a planetary-scale moving boundary rather than as an ordinary meteor.

22.4 Ablation and Surface Heating

A reduced ablation law is

$$\frac{dM_I}{dt} = -\frac{C_H \rho_{\text{atm}} A_I v^3}{2Q^*}, \tag{335}$$

where

$$C_H = \text{heat-transfer coefficient}, \tag{336}$$

$$Q^* = \text{effective ablation energy per unit mass}. \tag{337}$$

For bodies hundreds to thousands of kilometres in scale, ordinary small-body ablation formulas may cease to be physically representative.

The equation is retained as a lower-level screening relation.

22.5 Unknown Paleo-Surface Condition

The modern Aegean region contains oceanic and continental structures.

The proposed event occurred in deep time.

The simulation must not automatically impose modern bathymetry or coastlines at the entrance.

Define the paleo-surface state as

$$\mathcal{S}_A(t_0) = (h_{\text{ocean}}, z_{\text{surface}}, \rho_{\text{crust}}, H_{\text{crust}}, \mathcal{C}_{\text{surface}}) \,, \tag{338}$$

where

$$h_{\text{ocean}} = \text{water-column thickness,} \tag{339}$$

$$z_{\text{surface}} = \text{paleo-elevation,} \tag{340}$$

$$H_{\text{crust}} = \text{crustal thickness,} \tag{341}$$

$$\mathcal{C}_{\text{surface}} = \text{surface composition.} \tag{342}$$

Multiple paleo-surface scenarios must be tested.

22.6 Water-Column Loading

For water depth h_w, the encountered water-column density along a path at incidence angle α_A is approximately

$$\Sigma_w = \frac{\rho_w h_w}{\sin \alpha_A}. \tag{343}$$

The water mass intercepted by frontal area A_I is

$$M_{w,\text{enc}} = A_I \Sigma_w. \tag{344}$$

The water-to-impactor mass ratio is

$$\Pi_w = \frac{M_{w,\text{enc}}}{M_I}. \tag{345}$$

22.7 Ocean Energy Partition

If water is present, the oceanic energy partition is

$$E_{\text{ocean},A} = E_{\text{comp}} + E_{\text{heat}} + E_{\text{vap}} + E_{\text{cavity}} + E_{\text{wave}} + E_{\text{ejecta},w} + E_{\text{atm},w}. \tag{346}$$

The vaporized-water mass is bounded by

$$M_{w,\mathrm{vap}} \leq \frac{E_{\mathrm{vap}}}{c_{p,w}\Delta T + L_{v,w}}. \tag{347}$$

22.8 Ocean-Cavity Scale

A transient ocean cavity must be calculated from momentum, pressure, gravity, and water depth.

Let its maximum radius and depth be

$$R_{\mathrm{cav}}(t), \qquad H_{\mathrm{cav}}(t). \tag{348}$$

The cavity-collapse timescale may be screened as

$$\tau_{\mathrm{cav}} \sim \sqrt{\frac{R_{\mathrm{cav}}}{g}}. \tag{349}$$

The collapse may strongly alter the preserved entrance morphology.

22.9 Atmosphere–Ocean–Crust Handoff

The state entering the crust is

$$\boldsymbol{\Theta}_{\mathrm{crust,in}} = \mathcal{H}_A\left[\boldsymbol{\Theta}_I, \mathcal{A}_{\mathrm{atm}}, \mathcal{A}_{\mathrm{ocean}}\right], \tag{350}$$

where

$$\mathcal{A}_{\mathrm{atm}} = \text{atmospheric interaction operator}, \tag{351}$$

$$\mathcal{A}_{\mathrm{ocean}} = \text{ocean-interaction operator}. \tag{352}$$

The crustal calculation must begin from the modified mass, velocity, shape, temperature, fragmentation state, and surrounding flow produced by these prior interactions.

23 Crustal Penetration and Excavation

23.1 Penetration and Excavation Are Different Processes

Penetration concerns the depth and continuity of the incoming disturbance.

Excavation concerns the removal and displacement of near-surface material.

A viable entrance model must calculate both.

A large surface basin does not establish deep penetration.

Deep penetration does not guarantee a large preserved surface basin.

23.2 Directional Energy Remaining With Depth

Let

$$E_{\parallel}(z) \tag{353}$$

be the energy remaining within the declared path tube at depth z.

Its depth evolution is

$$\frac{dE_{\parallel}}{dz} = -\mathcal{L}_{\text{shock}} - \mathcal{L}_{\text{heat}} - \mathcal{L}_{\text{melt}} - \mathcal{L}_{\text{fract}} - \mathcal{L}_{\text{lateral}} - \mathcal{L}_{\text{ejecta}}, \tag{354}$$

where each $\mathcal{L}$ is an energy-loss rate per unit depth.

23.3 Directional Momentum Remaining With Depth

The corresponding path-directed momentum is

$$p_{\parallel}(z) = \int_{\mathcal{V}_p(z)} \rho \left(\mathbf{u} \cdot \widehat{\mathbf{t}}\right) \, dV. \tag{355}$$

Its evolution is

$$\frac{dp_{\parallel}}{dz} = -\mathcal{F}_{\text{drag}} - \mathcal{F}_{\text{lateral}} - \mathcal{F}_{\text{fract}} + \mathcal{F}_{\text{pressure}} + \mathcal{F}_{\text{gravity}}. \tag{356}$$

23.4 Penetration Depth

Define the effective penetration depth z_p as the smallest depth at which one or more of the following occurs:

$$E_{\parallel}(z_p) < E_{\parallel,\text{crit}}, \tag{357}$$

$$p_{\parallel}(z_p) < p_{\parallel,\text{crit}}, \tag{358}$$

or

$$\Lambda_p(z_p) < \Lambda_{p,\text{crit}}. \tag{359}$$

The literal deep-transmission hypothesis requires

$$z_p \geq z_{\text{required}}, \tag{360}$$

where the straight-chord reference requires passage toward a maximum depth near

$$z_{\text{required}} \approx 2520\,\text{km}. \tag{361}$$

23.5 Transient Excavation Volume

Let the transient excavation domain be

$$\mathcal{V}_{\text{exc}}(t). \tag{362}$$

Its volume is

$$V_{\text{exc}}(t) = \int_{\mathcal{V}_{\text{exc}}(t)} dV. \tag{363}$$

The maximum transient excavation volume is

$$V_{\text{exc,max}} = \max_t V_{\text{exc}}(t). \tag{364}$$

23.6 Excavated Mass

The excavated mass is

$$M_{\text{exc}} = \int_{\mathcal{V}_{\text{exc,max}}} \rho(\mathbf{r})\, dV. \tag{365}$$

The displaced mass is not necessarily equal to the ejected mass.

Define:

$$M_{\text{uplift}} = \text{material displaced upward but retained,} \tag{366}$$

$$M_{\text{fallback}} = \text{material ejected and returned,} \tag{367}$$

$$M_{\text{escape}} = \text{material escaping Earth,} \tag{368}$$

$$M_{\text{lateral}} = \text{material displaced laterally.} \tag{369}$$

Mass conservation requires

$$M_{\text{exc}} = M_{\text{uplift}} + M_{\text{fallback}} + M_{\text{escape}} + M_{\text{lateral}} + M_{\text{mixed}}. \tag{370}$$

23.7 Minimum Excavation Work

The gravitational component of excavation work is

$$E_{\text{grav,exc}} = \int_{\mathcal{V}_{\text{exc}}} \rho g \Delta z \, dV. \tag{371}$$

The minimum total excavation energy is

$$E_{\text{exc,min}} = E_{\text{grav,exc}} + E_{\text{fract}} + E_{\text{plastic}} + E_{\text{phase}} + E_{\text{kin,exc}}. \tag{372}$$

23.8 Melt Volume

For melt fraction field χ_m,

$$V_{\text{melt}} = \int_{\mathcal{V}_A} \chi_m(\mathbf{r}, t) \, dV. \tag{373}$$

The projectile-derived and target-derived melt must be tracked separately:

$$V_{\text{melt}} = V_{\text{melt},I} + V_{\text{melt},t}. \tag{374}$$

23.9 Transient Versus Preserved Morphology

The immediate post-event surface is

$$z_A^+(\mathbf{x}) = z_A^-(\mathbf{x}) + \Delta z_{\text{event}}(\mathbf{x}), \tag{375}$$

where

$$z_A^- = \text{pre-event surface}, \tag{376}$$

$$z_A^+ = \text{immediate post-event surface}. \tag{377}$$

The modern surface is

$$z_A^{\text{now}} = \mathcal{P}_A \left[z_A^+, \mathcal{H}_{A,\text{later}} \right], \tag{378}$$

where $\mathcal{P}_A$ is a preservation and overprint operator.

The modern Aegean morphology cannot be directly equated with the transient excavation geometry.

23.10 Crust–Mantle Transmission

At the Moho or equivalent crust–mantle boundary, define energy fractions

$$f_{\text{refl,Moho}} + f_{\text{trans,Moho}} + f_{\text{diss,Moho}} = 1. \tag{379}$$

The transmitted directional energy is

$$E_{\text{mantle,in}} = f_{\text{trans,Moho}} E_{\text{crust,arrive}}. \tag{380}$$

The corresponding momentum vector is

$$\mathbf{p}_{\text{mantle,in}} = \mathbf{T}_{p,\text{Moho}} \mathbf{p}_{\text{crust,arrive}}, \tag{381}$$

where $\mathbf{T}_{p,\text{Moho}}$ is a momentum-transfer operator that may rotate and disperse the directional impulse.

23.11 Entrance-to-Path Handoff

The entrance calculation must output the deep-transmission initial condition

$$\boldsymbol{\Theta}_{P,0} = (E_{\text{mantle,in}}, \mathbf{p}_{\text{mantle,in}}, M_{\text{col,in}}, R_{\text{path,in}}, T_{\text{path,in}}, \chi_{m,\text{in}}, D_{\text{in}}, \phi_{\text{in}}, c_{I,\text{in}}). \tag{382}$$

Paper II cannot calculate the interior path independently of this entrance output.

24 Entrance Energy and Momentum Partition

24.1 Complete Entrance Energy Budget

The initial event energy is partitioned as

$$\begin{aligned} E_I = E_{\text{atm}} + E_{\text{ocean}} + E_{\text{exc}} + E_{\text{fract}} + E_{\text{plastic}} + E_{\text{heat}} + E_{\text{melt}} \\ + E_{\text{vapor}} + E_{\text{ejecta}} + E_{\text{seismic}} + E_{\text{rotation}} + E_{\text{path}} + E_{\text{residual}}. \end{aligned} \tag{383}$$

Define the corresponding fractions

$$f_j = \frac{E_j}{E_I}, \tag{384}$$

so that

$$\sum_j f_j = 1. \tag{385}$$

24.2 Deep-Path Energy Fraction

The path fraction is

$$f_{\text{path},A} = \frac{E_{\text{path}}}{E_I}. \tag{386}$$

The theory requires

$$f_{\text{path},A} \geq f_{\text{path,min}}, \tag{387}$$

where $f_{\text{path,min}}$ must be derived from the minimum midpoint and exit requirements.

24.3 Vector Momentum Budget

Momentum must be treated vectorially.

The entrance momentum budget is

$$\mathbf{p}_I = \mathbf{p}_{\text{atm}} + \mathbf{p}_{\text{ocean}} + \mathbf{p}_{\text{crust}} + \mathbf{p}_{\text{ejecta}} + \mathbf{p}_{\text{seismic}} + \mathbf{p}_{\text{path}} + \mathbf{p}_{\text{Earth,bulk}}. \tag{388}$$

The path-directed fraction is

$$\mu_{\text{path},A} = \frac{\mathbf{p}_{\text{path}} \cdot \widehat{\mathbf{t}}_A}{p_I}. \tag{389}$$

The lateral momentum fraction is

$$\mu_{\perp,A} = \frac{\left\| \mathbf{p}_{\text{path}} - \left(\mathbf{p}_{\text{path}} \cdot \widehat{\mathbf{t}}_A \right) \widehat{\mathbf{t}}_A \right\|}{p_I}. \tag{390}$$

24.4 Angular Momentum Budget

The entrance angular momentum budget is

$$\mathbf{L}_I = \mathbf{L}_{\text{Earth}} + \mathbf{L}_{\text{path}} + \mathbf{L}_{\text{ejecta}} + \mathbf{L}_{\text{atmosphere}} + \mathbf{L}_{\text{ocean}}. \tag{391}$$

The path angular momentum is

$$\mathbf{L}_{\text{path}} = \int_{\mathcal{V}_p} \mathbf{r} \times \rho \mathbf{u} \, dV. \tag{392}$$

A proposed later plate-motion impulse must be consistent with the angular momentum retained after entrance.

24.5 Entrance Coupling Matrix

The entrance can be summarized by a coupling matrix

$$\mathbf{K}_A = \begin{pmatrix} f_{\text{exc}} & f_{\text{heat}} & f_{\text{melt}} & f_{\text{ejecta}} & f_{\text{path}} \\ \mu_{\text{normal}} & \mu_{\text{tangent}} & \mu_{\text{path}} & \mu_{\text{lateral}} & \mu_{\text{bulk}} \end{pmatrix}. \tag{393}$$

This matrix links one impactor state to both the visible entrance structure and the deep-transmission state.

24.6 Entrance Compatibility Condition

A parameter set is entrance compatible only if

$$\boldsymbol{\Theta}_I \in \mathcal{V}_A, \tag{394}$$

where

$$\mathcal{V}_A = \left\{ \boldsymbol{\Theta}_I : \begin{array}{l} \text{predicted entrance size is admissible,} \\ \text{predicted entrance morphology is admissible,} \\ \text{predicted melt and shock fields are admissible,} \\ \text{predicted global entrance effects are admissible,} \\ f_{\text{path},A} \geq f_{\text{path,min}}, \\ \mu_{\text{path},A} \geq \mu_{\text{path,min}} \end{array} \right\}. \tag{395}$$

A model that produces sufficient deep transmission but an incompatible entrance is rejected.

A model that reproduces the entrance but transmits insufficient energy or momentum is also rejected.

25 Predicted Aegean Entrance Morphology

25.1 Forward Prediction Before Regional Fitting

The simulation must produce a predicted entrance morphology

$$\widehat{\mathcal{M}}_A = \mathcal{F}_{\text{morph}} \left[\boldsymbol{\Theta}_I, \mathcal{S}_A(t_0), \mathbf{Q}_{0,A} \right]. \tag{396}$$

The morphology must be produced before comparison with the modern Aegean region.

25.2 Required Morphological Outputs

The predicted morphology must include:

$$\mathbf{x}_{A,\text{center}} = \text{mechanical entrance center}, \tag{397}$$
$$R_{A,\text{major}} = \text{major entrance radius}, \tag{398}$$
$$R_{A,\text{minor}} = \text{minor entrance radius}, \tag{399}$$
$$\gamma_{A,\text{major}} = \text{major-axis orientation}, \tag{400}$$
$$H_{A,\text{exc}} = \text{excavation-depth field}, \tag{401}$$
$$\Delta z_A = \text{surface-displacement field}. \tag{402}$$

The predicted entrance aspect ratio is

$$\mathcal{R}_A^{\mathrm{morph}} = \frac{R_{A,\mathrm{major}}}{R_{A,\mathrm{minor}}}. \tag{403}$$

25.3 Downrange Asymmetry

An oblique event may produce different uprange and downrange extents.

Define

$$R_{A,\mathrm{down}} = \text{downrange affected distance}, \tag{404}$$
$$R_{A,\mathrm{up}} = \text{uprange affected distance}. \tag{405}$$

The downrange asymmetry is

$$\mathcal{A}_{A,\mathrm{down}} = \frac{R_{A,\mathrm{down}} - R_{A,\mathrm{up}}}{R_{A,\mathrm{down}} + R_{A,\mathrm{up}}}. \tag{406}$$

The sign and magnitude must be generated by the model.

25.4 Radial and Directional Fractures

The predicted fracture field is represented by damage tensor

$$\widehat{\mathbf{D}}_A(\mathbf{r}). \tag{407}$$

For mapped fracture segment k, let its observed orientation be

$$\alpha_k^{\mathrm{obs}}, \tag{408}$$

and predicted orientation

$$\alpha_k^{\mathrm{pred}}. \tag{409}$$

The axial angular residual is

$$\epsilon_{\alpha,k} = \frac{1}{2}\,\mathrm{atan2}\left[\sin 2\left(\alpha_k^{\mathrm{obs}} - \alpha_k^{\mathrm{pred}}\right), \cos 2\left(\alpha_k^{\mathrm{obs}} - \alpha_k^{\mathrm{pred}}\right)\right]. \tag{410}$$

The factor of two accounts for the axial rather than directional nature of a fault orientation.

25.5 Entrance Rings and Arcs

If the model predicts ring-like or arcuate structures, define predicted ring radii

$$R_{A,j}^{\text{ring}}, \qquad j = 1, \ldots, N_R. \tag{411}$$

Observed arcuate structures must be compared with the full predicted center, radius, uncertainty, and preservation model.

Circularity alone is not sufficient.

25.6 Deep Corridor Orientation

The predicted deep corridor begins at

$$\mathbf{x}_{A,\text{deep}} \tag{412}$$

with tangent

$$\widehat{\mathbf{t}}_{A,\text{deep}}. \tag{413}$$

Regional seismic anisotropy, faults, and lithospheric structure should contain an independently testable directional relationship with this vector if the entrance generated the proposed interior path.

25.7 Morphology Residual

Let observed morphological field be $\mathcal{M}_A^{\text{obs}}$.

A weighted residual is

$$\mathcal{J}_{A,\text{morph}} = \sum_{j=1}^{N_M} w_j \left[\frac{m_j^{\text{obs}} - m_j^{\text{pred}}}{\sigma_j} \right]^2, \tag{414}$$

where the metrics may include:

- center;
- size;
- aspect ratio;
- asymmetry;
- ring radii;
- fracture orientations;
- depth;

- crustal-thickness pattern; and
- deep-corridor orientation.

25.8 Comparison Morphologies

The same observed region must be modeled under competing regional processes, including:

- extension;
- convergence;
- microplate rotation;
- slab rollback;
- basin collapse;
- inherited Tethyan structures;
- volcanism;
- sedimentary loading; and
- later fault reactivation.

The astro-ballistic model gains support only through residual predictions not equally reproduced by these mechanisms.

26 Entrance Melt, Shock, Gravity, Magnetic, and Seismic Predictions

26.1 Peak Shock Pressure Field

The model must output

$$P_{\max,A}(\mathbf{r}) = \max_t P(\mathbf{r}, t). \tag{415}$$

For diagnostic pressure threshold P_c, define the shocked volume

$$V_{P \geq P_c} = \int_{\mathcal{V}_A} \mathbf{1}\left[P_{\max,A}(\mathbf{r}) \geq P_c\right] dV. \tag{416}$$

The pressure thresholds must be associated with independently defined mineralogical or material transformations.

26.2 Shock-Gradient Direction

The entrance shock-gradient field is

$$\nabla P_{\max,A}(\mathbf{r}). \tag{417}$$

Its predicted relationship with fractures, metamorphic gradients, and deep-path direction should be tested.

26.3 Melt Field

The maximum melt fraction is

$$\chi_{m,\max,A}(\mathbf{r}) = \max_t \chi_m(\mathbf{r}, t). \tag{418}$$

The total melt mass is

$$M_{\mathrm{melt},A} = \int_{\mathcal{V}_A} \rho \chi_{m,\max,A} \, dV. \tag{419}$$

The predicted melt body must specify:

- composition;
- pressure history;
- temperature history;
- depth;
- shape;
- cooling time;
- differentiation;
- remanent density; and
- expected modern or stratigraphic expression.

26.4 Projectile-Material Distribution

The predicted projectile-material concentration is

$$c_I^A(\mathbf{r}, t). \tag{420}$$

The total retained projectile mass within the entrance region is

$$M_{I,A}^{\mathrm{ret}} = \int_{\mathcal{V}_A} \rho c_I^A \, dV. \tag{421}$$

The model must predict whether a detectable geochemical or isotopic signature should remain.

26.5 Residual Density Field

After short-time relaxation, define density anomaly

$$\Delta\rho_A(\mathbf{r}) = \rho_A^{\text{post}}(\mathbf{r}) - \rho_A^{\text{background}}(\mathbf{r}). \tag{422}$$

Possible sources include:

- excavation;
- fracture porosity;
- melt emplacement;
- dense projectile material;
- phase change;
- thermal expansion;
- compositional mixing; and
- later collapse.

26.6 Gravity Prediction

The predicted gravitational-potential anomaly is

$$\Delta\Phi_A(\mathbf{x}) = -G \int_{\mathcal{V}_A} \frac{\Delta\rho_A(\mathbf{r})}{\|\mathbf{x} - \mathbf{r}\|} \, dV. \tag{423}$$

The gravity anomaly is

$$\Delta\mathbf{g}_A = -\nabla\Delta\Phi_A. \tag{424}$$

The model must predict:

- sign;
- amplitude;
- wavelength;
- depth;
- center;
- asymmetry; and
- relationship to the outbound path.

26.7 Magnetic Resetting

Let initial magnetization be

$$\mathbf{M}_0(\mathbf{r}). \tag{425}$$

The post-event magnetization is

$$\mathbf{M}_A^+ = \mathcal{R}_B\left[\mathbf{M}_0, T_{\max}, P_{\max}, D, \chi_m, \mathbf{B}(t)\right], \tag{426}$$

where $\mathcal{R}_B$ represents thermal, shock, chemical, and structural resetting.

The magnetic anomaly is generated by

$$\Delta\mathbf{M}_A = \mathbf{M}_A^+ - \mathbf{M}_0. \tag{427}$$

The predicted field must be propagated through later rotation, metamorphism, alteration, and crustal deformation.

26.8 Seismic-Velocity Prediction

Let elastic moduli after the event be

$$K_A(\mathbf{r}), \qquad G_A(\mathbf{r}), \tag{428}$$

and density

$$\rho_A(\mathbf{r}). \tag{429}$$

The isotropic compressional-wave speed is

$$V_P = \sqrt{\frac{K_A + \frac{4}{3}G_A}{\rho_A}}, \tag{430}$$

and shear-wave speed is

$$V_S = \sqrt{\frac{G_A}{\rho_A}}. \tag{431}$$

The anomalies are

$$\Delta V_P = V_P^{\text{post}} - V_P^{\text{background}}, \tag{432}$$

and

$$\Delta V_S = V_S^{\text{post}} - V_S^{\text{background}}. \tag{433}$$

26.9 Seismic Anisotropy

The event-created directional damage and phase fields may generate an elasticity tensor

$$\mathbf{C}_A(\mathbf{r}) \neq \mathbf{C}_{\text{iso}}. \tag{434}$$

The model must predict:

- fast-axis orientation;
- anisotropy magnitude;
- depth range;
- spatial continuity;
- relationship to the downrange direction; and
- expected modification by later deformation.

26.10 Heat-Flow Prediction

The residual conductive heat flux is

$$\mathbf{q}_A = -k\nabla T_A. \tag{435}$$

The modern heat-flow anomaly depends on thermal survival, advection, magmatism, fluid flow, and later tectonics.

The event model must calculate whether any recognizable thermal signature should persist.

26.11 Forward-to-Modern Observation Operator

The immediate fields cannot be compared directly with modern observations.

Define

$$\widehat{\mathbf{D}}_A^{\text{now}} = \mathcal{O}_A\left[\mathbf{Q}_A(t_h), \mathcal{H}_{A,\text{later}}\right], \tag{436}$$

where the predicted modern dataset includes:

$$\widehat{\mathbf{D}}_A^{\text{now}} = \left(\widehat{z}, \widehat{\mathbf{g}}, \widehat{\mathbf{B}}, \widehat{V}_P, \widehat{V}_S, \widehat{\mathbf{A}}_{\text{seis}}, \widehat{q}, \widehat{\mathcal{G}}_{\text{chem}}\right). \tag{437}$$

27 Entrance Chronology and Preservation

27.1 Immediate and Delayed Entrance Markers

Candidate entrance markers belong to different timescales.

Immediate markers
: Shocked minerals, melt, breccia, ejecta, abrupt deformation, thermal resetting, and sedimentary disturbance.

Early post-event markers
: Basin collapse, hydrothermal alteration, melt differentiation, fault reactivation, and sedimentary infill.

Long-term inherited markers
: Deep density anomalies, anisotropy, crustal boundaries, persistent damage zones, gravity anomalies, and later structural reactivation.

Late overprint
: Younger extension, convergence, magmatism, subduction, erosion, sedimentation, metamorphism, and rotation.

27.2 Marker-State Vector

For marker class j, define

$$\mathbf{m}_j(t) = (A_j, V_j, C_j, T_j, P_j, D_j, \phi_j, \mathbf{x}_j)\,, \tag{438}$$

where

$$A_j = \text{abundance}, \tag{439}$$
$$V_j = \text{spatial volume}, \tag{440}$$
$$C_j = \text{composition}, \tag{441}$$
$$T_j = \text{thermal state}, \tag{442}$$
$$P_j = \text{pressure history}, \tag{443}$$
$$D_j = \text{damage or preservation state}, \tag{444}$$
$$\phi_j = \text{phase state}. \tag{445}$$

27.3 Preservation Operator

The modern marker state is

$$\mathbf{m}_j^{\text{now}} = \mathcal{P}_j\left[\mathbf{m}_j(t_0^+), \mathcal{H}_A(t)\right]. \tag{446}$$

The history $\mathcal{H}_A(t)$ may include:

- burial;
- erosion;
- metamorphism;
- hydrothermal alteration;
- oxidation;
- melting;
- deformation;
- rotation;
- subduction;
- sedimentation; and
- tectonic fragmentation.

27.4 Marker Survival Fraction

The survival fraction is

$$S_j = \frac{N_j^{\text{detectable,now}}}{N_j^{\text{generated}}}. \tag{447}$$

For a continuous field,

$$S_j = \frac{\int_{\mathcal{V}} \left| m_j^{\text{now}} \right| \, dV}{\int_{\mathcal{V}} \left| m_j^{t_0^+} \right| \, dV}. \tag{448}$$

27.5 Detection Probability

The probability of detecting marker j is

$$P_{j,\text{det}} = P\left(\text{detection} \mid S_j, R_j, C_j, \mathcal{S}_j\right), \tag{449}$$

where

$$R_j = \text{sampling and analytical resolution}, \tag{450}$$

$$C_j = \text{spatial coverage}, \tag{451}$$

$$\mathcal{S}_j = \text{signal-to-background contrast}. \tag{452}$$

An absent marker is strongly falsifying only when $P_{j,\mathrm{det}}$ is high under the model.

27.6 Initiation and Marker Clocks

Let the specific flagship initiating age be

$$a_{\mathrm{init},F} = 256 \text{ Ma}. \tag{453}$$

For marker j formed after an elapsed forward delay $\Delta\tau_j \geq 0$,

$$a_j = a_{\mathrm{init},F} - \Delta\tau_j, \tag{454}$$

because age before present decreases toward the present. For rapidly formed shock, melt, or fracture products, the expected condition is

$$|a_j - a_{\mathrm{init},F}| \ll 1 \text{ Ma}, \tag{455}$$

subject to dating resolution. For delayed markers, $\Delta\tau_j$ must be generated by a stated preservation, cooling, alteration, or reactivation mechanism. A younger marker without such a mechanism cannot be reassigned as the initiating event itself.

27.7 Cooling-Age Structure

A melt or heated body may record multiple closure ages.

For mineral system j, closure occurs when

$$T(t) \leq T_{c,j} \tag{456}$$

under an appropriate cooling-rate model.

The resulting age may postdate the primary energy deposition.

The paper must distinguish:

- crystallization age;
- cooling age;
- metamorphic-reset age;
- alteration age;
- deformation age; and
- later reactivation age.

27.8 Stratigraphic Preservation

If the entrance generated ejecta, sediment disturbance, or atmospheric products, the model must predict:

- depositional area;
- thickness distribution;
- grain-size distribution;
- composition;
- geochemical signal;
- expected basin preservation;
- expected recycling; and
- expected surviving outcrops.

27.9 Minimum Preserved Entrance Evidence

The entrance claim should require at least one strong marker from more than one independent class.

A minimum evidentiary combination might include:

1. one dated material marker;
2. one deep geophysical marker;
3. one directional structural marker; and
4. one morphology or gravity marker.

The exact standard must be frozen before the regional evidence is scored.

27.10 Preservation Cannot Be Unlimited

A model that predicts no surviving entrance evidence is not useful as a forensic explanation.

A model that predicts abundant evidence but attributes every absence to later destruction is not falsifiable.

The preservation operator must produce quantitative detection probabilities.

28 Entrance Inversion and Falsification

28.1 Forward Model

Let the entrance parameter vector be

$$\mathbf{\Theta}_A = (M_I, v_I, \rho_I, R_I, \alpha_A, \gamma_A, \mathcal{C}_I, \mathcal{S}_A, \mathcal{M}_q)\,, \tag{457}$$

where

$$\mathcal{S}_A = \text{paleo-surface and crustal state,} \tag{458}$$

$$\mathcal{M}_q = \text{mechanism branch.} \tag{459}$$

The forward model is

$$\widehat{\mathbf{D}}_A = \mathcal{F}_A\left(\mathbf{\Theta}_A\right), \tag{460}$$

where

$$\widehat{\mathbf{D}}_A = \left(\widehat{\mathcal{M}}_A, \widehat{\mathbf{g}}_A, \widehat{\mathbf{B}}_A, \widehat{\mathbf{S}}_A, \widehat{\mathbf{G}}_A, \widehat{\mathbf{T}}_A, \widehat{\mathbf{\Theta}}_{P,0}\right). \tag{461}$$

The output includes both observable entrance evidence and the state transmitted into the mantle.

28.2 Observed Data Vector

The observed entrance data are

$$\mathbf{D}_A^{\text{obs}} = \left(\mathcal{M}_A^{\text{obs}}, \mathbf{g}_A^{\text{obs}}, \mathbf{B}_A^{\text{obs}}, \mathbf{S}_A^{\text{obs}}, \mathbf{G}_A^{\text{obs}}, \mathbf{T}_A^{\text{obs}}\right). \tag{462}$$

Here

$$\mathcal{M}_A^{\text{obs}} = \text{morphology and faults,} \tag{463}$$

$$\mathbf{S}_A^{\text{obs}} = \text{seismic observations,} \tag{464}$$

$$\mathbf{G}_A^{\text{obs}} = \text{geochemical and mineralogical observations,} \tag{465}$$

$$\mathbf{T}_A^{\text{obs}} = \text{chronological observations.} \tag{466}$$

28.3 Likelihood

For covariance matrix $\mathbf{\Sigma}_A$, a Gaussian residual likelihood may be written as

$$\ln \mathcal{L}_A = -\frac{1}{2}\left(\mathbf{D}_A^{\text{obs}} - \widehat{\mathbf{D}}_A\right)^{\mathsf{T}} \mathbf{\Sigma}_A^{-1} \left(\mathbf{D}_A^{\text{obs}} - \widehat{\mathbf{D}}_A\right) - \frac{1}{2}\ln|\mathbf{\Sigma}_A| + C. \tag{467}$$

Non-Gaussian terms will be required for categorical markers, nondetections, thresholds, and spatial fields.

28.4 Posterior Distribution

The posterior parameter distribution is

$$p\left(\mathbf{\Theta}_A \mid \mathbf{D}_A^{\text{obs}}\right) \propto \mathcal{L}_A p\left(\mathbf{\Theta}_A\right). \tag{468}$$

The priors must be physically and geologically justified.

Broad priors cannot be used to create unlimited coordinate, age, trajectory, or preservation freedom.

28.5 Joint Entrance–Path Constraint

The entrance cannot be inverted solely against local observations.

The inferred posterior must also satisfy the deep-path requirement:

$$p\left(\mathbf{\Theta}_A \mid \mathbf{D}_A^{\text{obs}}, \mathcal{C}_P\right), \tag{469}$$

where $\mathcal{C}_P$ contains the minimum transmitted energy, momentum, localization, and direction constraints required by the rest of the event.

28.6 Entrance Model Comparison

Let

$$\mathcal{M}_{A,\text{ABC}} = \text{astro-ballistic entrance model}, \tag{470}$$

$$\mathcal{M}_{A,\text{regional}} = \text{regional geological comparison model}. \tag{471}$$

The local Bayes factor is

$$K_A = \frac{p\left(\mathbf{D}_A^{\text{obs}} \mid \mathcal{M}_{A,\text{ABC}}\right)}{p\left(\mathbf{D}_A^{\text{obs}} \mid \mathcal{M}_{A,\text{regional}}\right)}. \tag{472}$$

A successful entrance interpretation requires more than a local fit.

It requires that the same parameter region also supports the interior path and later event sequence.

28.7 Parameter-Complexity Penalty

For k_A adjustable parameters and N_A effective observations, an information criterion may be written as

$$\text{BIC}_A = k_A \ln N_A - 2 \ln \widehat{\mathcal{L}}_A. \tag{473}$$

The selected criterion may change, but all models must be penalized for their actual flexibility.

28.8 Entrance Falsification Matrix

Table 6: Paper-II entrance falsification matrix.

ID	Entrance claim	Falsifying result	Consequence
EA1	Declared coordinate represents the entrance	Forward-modeled coupling center lies outside every defensible Aegean target domain.	Reject or formally relocate the entrance.
EA2	Straight reference trajectory	Required incidence or azimuth is incompatible with all observed deep and surface structures.	Reject straight-path entrance geometry.
EA3	Sufficient entrance transmission	All admissible models retain insufficient energy or momentum below the crust.	Reject connected deep-transmission event.
EA4	Entrance morphology	Predicted size, aspect, asymmetry, or fracture pattern is incompatible with regional observations.	Reject the relevant entrance parameter region.
EA5	Shock and melt field	Every mechanically sufficient event predicts shock or melt volumes whose evidence should be detectable but is absent.	Reject the relevant mechanism or energy range.
EA6	Gravity signature	No admissible density field produces the observed gravity structure, or the predicted anomaly is absent.	Reject the entrance density model.
EA7	Magnetic signature	Predicted magnetic resetting is incompatible with the regional magnetic record.	Reject the relevant thermal and shock history.
EA8	Seismic structure	No path-compatible deep anomaly or anisotropy exists after accounting for later regional geology.	Reject the proposed deep-path initiation.
EA9	Chronology	All candidate entrance markers demonstrably exclude the proposed event interval.	Reject the 256 Ma entrance assignment.
EA10	Projectile material	The model predicts abundant detectable projectile-derived material but none is found at adequate sampling sensitivity.	Reject that impactor composition or transport branch.

ID	Entrance claim	Falsifying result	Consequence
EA11	Preservation	The model requires an unconstrained preservation operator to erase every missing signature.	Reject the model as non-falsifiable.
EA12	Regional superiority	Conventional regional models reproduce all entrance observations more accurately with fewer adjustable parameters.	Reject the astro-ballistic entrance as the preferred explanation.

28.9 Entrance Success Standard

The Mini Aegean entrance remains viable only if one connected parameter region satisfies all of the following:

ES1. a physically defensible paleo-surface condition;

ES2. an entrance center within a defensible Aegean domain;

ES3. an incidence and azimuth consistent with the proposed deep path;

ES4. a predicted morphology compatible with the preserved regional structure;

ES5. shock, melt, gravity, magnetic, and seismic predictions compatible with observations;

ES6. at least one event-compatible dated material marker;

ES7. a quantitatively defensible preservation history;

ES8. sufficient transmitted energy and momentum to initialize the mantle path;

ES9. no incompatible atmospheric, oceanic, or planetary consequences; and

ES10. improved explanatory performance over the comparison model.

Entrance decision rule.
The Aegean region qualifies as the entrance only if the same astro-ballistic parameter set explains its preserved morphology and geophysical evidence while transmitting the energy, momentum, direction, composition, and damage state required by the proposed Aegean-to-Mariana interior sequence.
A local resemblance without a viable deep-path handoff is insufficient.

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29 Entrance-Mechanics Synthesis

This entrance-mechanics synthesis records:

1. the local Aegean entrance coordinate frame;

2. the audited normal and tangential incidence components;
3. the straight-path incidence angle and energy decomposition;
4. atmospheric and possible oceanic entry equations;
5. paleo-surface scenario requirements;
6. crustal penetration and excavation definitions;
7. the entrance-to-mantle state handoff;
8. the complete entrance energy, momentum, and angular-momentum budgets;
9. the required Aegean morphology outputs;
10. the predicted shock, melt, gravity, magnetic, seismic, anisotropy, and heat-flow fields;
11. the chronology and preservation architecture;
12. the entrance inverse problem;
13. the entrance model-comparison structure; and
14. the complete entrance falsification matrix.

The following sections develop the full interior-path mechanics:

- radial Earth-layer intersections;
- path density and pressure profiles;
- lower-mantle transit;
- attenuation and path broadening;
- phase-boundary reflections and refractions;
- gravitational and rotational deflection;
- thermal and damage corridor generation;
- deep-path seismic predictions;
- alternative curved-path solutions;
- mechanical relationship to the Himalayan target; and
- complete interior-path falsifiers.

30 Mechanical Midpoint and Maximum-Response Structure

30.1 Geometric and Mechanical Centers

The geometric midpoint of the reference chord is

$$s_{\text{geo}} = \frac{L_C}{2}. \tag{474}$$

The geometric midpoint is determined entirely by the selected entrance and exit coordinates.

It is not automatically the location of maximum:

- pressure;
- energy deposition;
- volumetric strain;
- shear strain;
- damage;
- temperature;
- melt fraction;
- phase transformation;
- density change;
- momentum transfer; or
- later surface response.

For any path-dependent response field $q(s,t)$, define its instantaneous maximum position as

$$s_q(t) = \arg\max_{s \in [0, L_C]} q(s,t). \tag{475}$$

The full event maximum is

$$s_q^* = \arg\max_{s,t} q(s,t). \tag{476}$$

30.2 Principal Maximum-Response Coordinates

The principal response coordinates are

$$s_P^* = \arg\max_{s,t} P(s,t), \tag{477}$$

$$s_E^* = \arg\max_{s,t} \dot{E}_{\mathrm{dep}}(s,t), \tag{478}$$

$$s_D^* = \arg\max_{s,t} D(s,t), \tag{479}$$

$$s_T^* = \arg\max_{s,t} \Delta T(s,t), \tag{480}$$

$$s_\phi^* = \arg\max_{s,t} |\Delta\phi(s,t)|, \tag{481}$$

$$s_\rho^* = \arg\max_{s,t} |\Delta\rho(s,t)|, \tag{482}$$

$$s_\epsilon^* = \arg\max_{s,t} |\mathrm{tr}\,\boldsymbol{\epsilon}(s,t)|. \tag{483}$$

The associated three-dimensional locations are

$$\mathbf{x}_q^* = \mathbf{r}_P\left(s_q^*, t_q^*\right). \tag{484}$$

30.3 Maximum-Response Separation

For any two response variables q_i and q_j, define

$$\Delta s_{ij} = \left|s_{q_i}^* - s_{q_j}^*\right|. \tag{485}$$

A mechanically simple midpoint model predicts small separations among the relevant response maxima.

A more complex model may predict that pressure, damage, heating, phase change, and inheritance occur at different locations.

The theory must identify which response is proposed to create the Himalayan precursor.

30.4 Time-Integrated Response

A short peak may be less important than a lower-amplitude response sustained over a longer interval.

Define the time-integrated response

$$\mathcal{R}_q(s) = \int_{t_0}^{t_h} w_q(t)q(s,t)\,dt, \tag{486}$$

where $w_q(t)$ is a declared weighting function.

The time-integrated maximum is

$$s^*_{\mathcal{R}_q} = \arg\max_s \mathcal{R}_q(s). \tag{487}$$

30.5 Response Volume

For threshold q_{crit}, define the response volume

$$\mathcal{V}_q = \left\{ \mathbf{r} : \max_t q(\mathbf{r}, t) \geq q_{\text{crit}} \right\}. \tag{488}$$

Its volume is

$$V_q = \int_{\mathcal{V}_q} dV. \tag{489}$$

Its centroid is

$$\mathbf{x}_{q,\text{cent}} = \frac{\displaystyle\int_{\mathcal{V}_q} \mathbf{r} q_{\max}(\mathbf{r})\, dV}{\displaystyle\int_{\mathcal{V}_q} q_{\max}(\mathbf{r})\, dV}. \tag{490}$$

The centroid is generally a more stable target than one grid-cell maximum.

30.6 Middle-Path Response Functional

Define a predeclared midpoint response functional

$$\mathcal{W}_H(\mathbf{r}) = w_P \widetilde{P}_{\max} + w_D \widetilde{D}_{\max} + w_\phi \left|\widetilde{\Delta\phi}\right| + w_\rho \left|\widetilde{\Delta\rho}\right| + w_T \widetilde{\Delta T} + w_\epsilon \widetilde{\epsilon}_{\text{vol}}, \tag{491}$$

where the tildes denote normalized fields and

$$\sum_i w_i = 1, \qquad w_i \geq 0. \tag{492}$$

The weights must be frozen before comparing the response with the Himalayan target.

30.7 Mechanical Middle-Path Domain

The predicted middle-path domain is

$$\mathcal{R}_H^{\text{mech}} = \{\mathbf{r} : \mathcal{W}_H(\mathbf{r}) \geq \mathcal{W}_{H,\text{crit}}\}. \tag{493}$$

The mechanical middle-path centroid is

$$\mathbf{x}_H^{\mathrm{mech}} = \frac{\displaystyle\int_{\mathcal{R}_H^{\mathrm{mech}}} \mathbf{r}\mathcal{W}_H(\mathbf{r})\, dV}{\displaystyle\int_{\mathcal{R}_H^{\mathrm{mech}}} \mathcal{W}_H(\mathbf{r})\, dV}. \tag{494}$$

30.8 Mechanical Midpoint Offset

The offset from the geometric chord midpoint is

$$\boldsymbol{\delta}_H = \mathbf{x}_H^{\mathrm{mech}} - \mathbf{x}_H^{\mathrm{geo}}. \tag{495}$$

Its magnitude is

$$\delta_H = \left\| \boldsymbol{\delta}_H \right\|. \tag{496}$$

The offset must be explained by calculated:

- asymmetric attenuation;
- phase-boundary interaction;
- gravity;
- rotation;
- path curvature;
- material heterogeneity;
- pressure focusing;
- damage localization; or
- later displacement.

30.9 Mechanical Midpoint Decision Rule

Mechanical midpoint rule.
The Himalayan target is not accepted as the middle mountain because it is geographically prominent.
It qualifies only if a predeclared pressure, damage, phase, density, or inheritance response emerges from the event calculation within a defensible reconstructed Himalayan domain.

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31 Formation of a Persistent Himalayan Inheritance Node

31.1 Inheritance-Node Definition

A Himalayan inheritance node is a bounded post-event region whose material state differs from the surrounding Earth in a manner capable of influencing later deformation.

Define its initial state as

$$\mathbf{Q}_{H,0} = \left(\Delta T_H, \Delta\rho_H, \Delta\phi_H, \chi_{m,H}, \mathbf{D}_H, \Delta\mathbf{C}_H, \Delta\boldsymbol{\sigma}_H, \Delta\eta_H, c_{I,H}\right). \tag{497}$$

The node domain is

$$\mathcal{N}_H(t_h) = \left\{\mathbf{r} : \mathcal{I}_H(\mathbf{r}, t_h) \geq \mathcal{I}_{H,\mathrm{crit}}\right\}, \tag{498}$$

where $\mathcal{I}_H$ is a predeclared inheritance index.

31.2 Inheritance Index

A candidate index is

$$\mathcal{I}_H = w_D\widetilde{D} + w_\eta\widetilde{\left(\frac{\eta_0}{\eta_{\mathrm{eff}}}\right)} + w_\phi\left|\widetilde{\Delta\phi}\right| + w_\rho\left|\widetilde{\Delta\rho}\right| + w_T\widetilde{\Delta T} + w_C\left\|\widetilde{\Delta\mathbf{C}}\right\|, \tag{499}$$

subject to

$$\sum_i w_i = 1. \tag{500}$$

31.3 Minimum Node Size

The node must exceed a mechanically meaningful volume

$$V_H = \mathrm{Vol}\left[\mathcal{N}_H(t_h)\right] \geq V_{H,\mathrm{crit}}. \tag{501}$$

A grid-scale anomaly or isolated numerical singularity is not a viable inheritance node.

31.4 Minimum Node Lifetime

Let the node strength be

$$S_H(t) = \int_{\mathcal{N}_H(t)} \mathcal{I}_H(\mathbf{r}, t)\, dV. \tag{502}$$

Define the normalized survival fraction

$$\mathcal{S}_H(t) = \frac{S_H(t)}{S_H(t_h)}. \tag{503}$$

The node remains mechanically relevant only if

$$\mathcal{S}_H(t_{\mathrm{react}}) \geq \mathcal{S}_{H,\mathrm{crit}}, \tag{504}$$

where t_{react} is the time of later regional loading or reactivation.

31.5 Node Anisotropy

The node's preferred orientation is determined from the principal eigenvectors of its damage or elasticity tensor.

Let

$$\widehat{\mathbf{n}}_{H,1} = \text{eigvec}_1 \left(\mathbf{D}_H \right). \tag{505}$$

The later forcing direction is

$$\widehat{\mathbf{f}}_{H,\text{later}}. \tag{506}$$

Their angular relationship is

$$\theta_{H,\text{react}} = \arccos \left(\left| \widehat{\mathbf{n}}_{H,1} \cdot \widehat{\mathbf{f}}_{H,\text{later}} \right| \right). \tag{507}$$

The event-generated node should predict whether later forcing:

- reactivates the node;
- bypasses the node;
- strengthens the node;
- rotates the node;
- fragments the node; or
- erases the node.

31.6 Density and Buoyancy Contribution

The node's buoyancy anomaly is

$$\mathbf{F}_{B,H} = \int_{\mathcal{N}_H} (\rho_0 - \rho_H) \, \mathbf{g} \, dV. \tag{508}$$

The sign of the density anomaly determines whether the node tends to rise, sink, spread, or remain neutrally embedded.

31.7 Weakness Versus Strength Node

The event may create either:

Weakness node
Reduced viscosity, increased damage, partial melt, or weakened elastic structure concentrates later deformation.

Strength node
Dense phase transformation, melt depletion, cooling, or pressure hardening redirects deformation around a mechanically resistant block.

The modern Himalayan response could differ substantially between these branches.

The theory must not alternate between weakness and strength after examining the observed structure.

31.8 Node Contribution to Surface Response

Define the node-generated contribution to surface displacement as

$$\Delta \mathbf{u}_H^{\text{node}} = \mathcal{G}_H \left[\mathbf{Q}_{H,0}, \mathbf{F}_{\text{later}} \right] - \mathcal{G}_H \left[\mathbf{0}, \mathbf{F}_{\text{later}} \right]. \tag{509}$$

The vertical component is

$$\Delta u_{H,z}^{\text{node}} = \Delta \mathbf{u}_H^{\text{node}} \cdot \widehat{\mathbf{n}}_{\text{surface}}. \tag{510}$$

31.9 Observable Node Predictions

A viable node should predict one or more of:

- inherited seismic anisotropy;
- anomalous crustal or lithospheric thickness;
- density structure;
- gravity structure;
- phase-state anomalies;
- localized metamorphism;
- persistent weakness;
- focused later strain;
- preferred uplift location; and
- a measurable counterfactual difference in later orogenic development.

31.10 Inheritance-Node Falsifier

Himalayan inheritance falsifier H1.
If the event produces no bounded, persistent material-state anomaly within a defensible reconstructed Himalayan target, or if the anomaly has no measurable effect under later regional forcing, the inherited middle-mountain node is rejected.

---

32 Long-Time Amplification Under Later Regional Forcing

32.1 Short-Time to Long-Time Handoff

The short-duration event solution at time t_h becomes the initial condition for long-time evolution:

$$\mathbf{Q}_H^{\mathrm{long}}(t_h) = \mathcal{H}_{\mathrm{short}\to\mathrm{long}}\left[\mathbf{Q}_H^{\mathrm{short}}(t_h)\right]. \tag{511}$$

The handoff must preserve:

- temperature;
- composition;
- density;
- damage;
- phase state;
- residual stress;
- displacement;
- momentum;
- melt fraction; and
- elastic and rheological properties.

32.2 Long-Time Governing Form

The long-time momentum equation may be written as

$$\nabla \cdot \boldsymbol{\sigma} + \rho \mathbf{g} = \rho \frac{D\mathbf{u}}{Dt}, \tag{512}$$

with the inertial term retained or neglected according to the modeled timescale and approximation.

The thermal equation is

$$\rho c_P \frac{DT}{Dt} = \nabla \cdot (k \nabla T) + \Phi_{\mathrm{mech}} + Q_{\mathrm{phase}} + Q_{\mathrm{internal}}. \tag{513}$$

32.3 Later Regional Forcing

Represent later regional forcing by

$$\mathbf{F}_H^{\text{later}}(t) = \left(\mathbf{v}_{\text{boundary}}, \boldsymbol{\sigma}_{\text{far}}, \Delta\rho_{\text{regional}}, \mathbf{g}, T_{\text{boundary}}, \mathcal{B}_{\text{regional}}\right). \tag{514}$$

This forcing may include later convergence, gravitational loading, boundary interaction, erosion, sedimentation, and mantle coupling.

The later forcing is not denied.

The question is whether the event-created node changes its outcome.

32.4 With-Node and Without-Node Solutions

The with-node solution is

$$\mathbf{Q}_H^+(t) = \mathcal{U}_H \left[\mathbf{Q}_{H,0}, \mathbf{F}_H^{\text{later}}(t)\right]. \tag{515}$$

The counterfactual solution is

$$\mathbf{Q}_H^0(t) = \mathcal{U}_H \left[\mathbf{Q}_{H,\text{background}}, \mathbf{F}_H^{\text{later}}(t)\right]. \tag{516}$$

The inherited-event contribution is

$$\Delta\mathbf{Q}_H^{\text{inherit}} = \mathbf{Q}_H^+ - \mathbf{Q}_H^0. \tag{517}$$

32.5 Amplification Factor

For observable $y_H(t)$, define the amplification factor

$$\mathcal{A}_{H,y} = \frac{y_H^+(t_{\text{now}})}{y_H^0(t_{\text{now}})}, \tag{518}$$

when the denominator is nonzero.

An additive difference is

$$\Delta y_H = y_H^+ - y_H^0. \tag{519}$$

32.6 Localization Gain

Define the strain-localization gain

$$\mathcal{G}_{\epsilon,H} = \frac{\displaystyle\int_{\mathcal{D}_H} \dot{\epsilon}_{\rm eq}^{+}\, dV}{\displaystyle\int_{\mathcal{D}_H} \dot{\epsilon}_{\rm eq}^{0}\, dV}. \tag{520}$$

A weakness-node interpretation predicts

$$\mathcal{G}_{\epsilon,H} > 1 \tag{521}$$

over a predeclared target interval.

32.7 Uplift Contribution

The event-dependent uplift contribution is

$$\Delta z_H^{\rm inherit} = z_H^{+} - z_H^{0}. \tag{522}$$

The framework does not require

$$z_H^0 = 0. \tag{523}$$

Later regional processes may generate substantial uplift without the event-created node.

The replacement claim requires the node to improve the prediction of:

- uplift location;
- uplift magnitude;
- crustal thickness;
- strain distribution;
- deep-root geometry;
- anisotropy;
- metamorphic pattern; or
- deformation chronology.

32.8 Node Necessity Statistic

Define a node-necessity statistic

$$\mathcal{N}_H = 1 - \frac{\mathcal{L}\left(\mathbf{D}_H^{\rm obs} \mid \mathbf{Q}_H^{0}\right)}{\mathcal{L}\left(\mathbf{D}_H^{\rm obs} \mid \mathbf{Q}_H^{+}\right)}, \tag{524}$$

where $\mathcal{L}$ is a declared likelihood or goodness-of-fit measure.

A positive value indicates improved prediction with the inherited node.

Model complexity must be penalized.

32.9 No Double Counting

The same later forcing cannot be counted both as:

1. a conventional explanation for the observed mountain; and
2. an independent confirmation of the event-created node.

The node's contribution must be measured through the counterfactual difference.

32.10 Amplification Falsifier

Long-time amplification falsifier H2.
If the later regional model reproduces the Himalayan observables equally well without the inherited event state, or if adding the node worsens the prediction after complexity penalties, the event is not required for the Himalayan outcome.

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33 Terminal Approach to the Mariana Region

33.1 Terminal Handoff State

At a declared deep-to-shallow transition surface $\mathcal{S}_{M,0}$, define the terminal approach state

$$\mathbf{\Theta}_{M,0} = (E_{M,0}, \mathbf{p}_{M,0}, M_{M,0}, R_{M,0}, \mathbf{U}_{M,0}, T_{M,0}, P_{M,0}, \chi_{m,M,0}, \chi_{v,M,0}, D_{M,0}, \phi_{M,0}, c_{I,M,0}) . \tag{525}$$

This state must be produced by the interior-path calculation.

It cannot be independently assigned to make the exit work.

33.2 Terminal Target Domain

Let the reconstructed Mariana target domain be

$$\mathcal{D}_M(t_0). \tag{526}$$

The terminal-path center is

$$\mathbf{x}_{M,\text{path}} = \mathbf{r}_P\left(s_{M,0}, t_{M,0}\right) . \tag{527}$$

The target misfit is

$$d_{M,0} = \min_{\mathbf{x} \in \mathcal{D}_M(t_0)} \|\mathbf{x}_{M,\text{path}} - \mathbf{x}\| . \tag{528}$$

33.3 Terminal Direction

The terminal approach direction is

$$\widehat{\mathbf{t}}_{M,0} = \frac{\mathbf{U}_{M,0}}{\|\mathbf{U}_{M,0}\|}. \tag{529}$$

The local outward radial unit vector is

$$\widehat{\mathbf{n}}_M = \frac{\mathbf{x}_{M,\text{path}}}{\|\mathbf{x}_{M,\text{path}}\|}. \tag{530}$$

The emergence angle above the local horizontal is

$$\alpha_M = \arcsin\left(\widehat{\mathbf{t}}_{M,0} \cdot \widehat{\mathbf{n}}_M\right). \tag{531}$$

The sign convention must be stated so that outward propagation gives

$$\alpha_M > 0. \tag{532}$$

33.4 Terminal Energy Fraction

The terminal approach energy fraction is

$$f_{M,0} = \frac{E_{M,0}}{E_I}. \tag{533}$$

The source framework proposed a broad exit-energy fraction near

$$0.1 \lesssim f_M \lesssim 0.5. \tag{534}$$

Paper II treats this as a hypothesis to be derived.

The terminal approach calculation may produce:

$$f_{M,0} < 0.1, \tag{535}$$

$$0.1 \leq f_{M,0} \leq 0.5, \tag{536}$$

or

$$f_{M,0} > 0.5. \tag{537}$$

Each result has different consequences for entrance coupling, path loss, and planetary survival.

33.5 Terminal Momentum Fraction

The path-directed terminal momentum fraction is

$$\mu_{M,0} = \frac{\mathbf{p}_{M,0} \cdot \widehat{\mathbf{t}}_{M,0}}{p_I}. \tag{538}$$

The angular dispersion of terminal momentum is

$$\sigma^2_{\psi,M} = \frac{\displaystyle\int_{\mathcal{V}_{M,0}} \psi^2 \, \|d\mathbf{p}\|}{\displaystyle\int_{\mathcal{V}_{M,0}} \|d\mathbf{p}\|}. \tag{539}$$

A localized exit requires sufficiently low angular dispersion.

33.6 Terminal Path Radius

The effective terminal path radius is

$$R^2_{M,0} = \frac{\displaystyle\int_{\mathcal{A}_{M,0}} r_\perp^2 e_{\mathrm{dist}} \, dA}{\displaystyle\int_{\mathcal{A}_{M,0}} e_{\mathrm{dist}} \, dA}. \tag{540}$$

A path much wider than the Mariana target region cannot produce a localized terminal wound without a subsequent focusing mechanism.

33.7 Terminal Composition

The terminal mixture may contain:

- surviving projectile material;
- crustal material from the entrance;
- upper-mantle material;
- transition-zone material;
- lower-mantle material;
- melt;
- vapor;

- shocked solid fragments; and
- phase-transformed terrestrial material.

For material component a, define terminal mass fraction

$$Y_{a,M} = \frac{M_{a,M}}{M_{M,0}}. \tag{541}$$

The exit model must predict whether these components should remain detectable.

33.8 Terminal Viability Conditions

The terminal approach is viable only if

$$d_{M,0} \leq d_{M,\text{crit}}, \tag{542}$$

$$E_{M,0} \geq E_{M,\text{crit}}, \tag{543}$$

$$p_{M,0} \geq p_{M,\text{crit}}, \tag{544}$$

$$R_{M,0} \leq R_{M,\text{crit}}, \tag{545}$$

$$\sigma_{\psi,M} \leq \sigma_{\psi,M,\text{crit}}. \tag{546}$$

These thresholds must be defined from the predicted exit morphology, not selected after observing the Mariana system.

34 Deep-to-Shallow Decompression

34.1 Pressure Ratio

Let the terminal disturbance move from deep pressure $P_{M,0}$ toward shallower pressure $P_M(z)$.

The decompression ratio is

$$\Pi_{P,M}(z) = \frac{P_{M,0}}{P_M(z)}. \tag{547}$$

The pressure history is

$$P_M(t) = P\left[\mathbf{r}_M(t), t\right]. \tag{548}$$

The decompression rate is

$$\dot{P}_M = \frac{dP_M}{dt}. \tag{549}$$

34.2 Adiabatic Expansion Screening

For an idealized adiabatic fluid with ratio of specific heats γ,

$$P\rho^{-\gamma} = \text{constant}. \tag{550}$$

The corresponding density relation is

$$\frac{\rho_2}{\rho_1} = \left(\frac{P_2}{P_1}\right)^{1/\gamma}. \tag{551}$$

The actual mixed silicate, melt, vapor, water, and fragment system requires a multiphase equation of state.

The adiabatic relation is only a screening limit.

34.3 Enthalpy Conversion

For steady flow along a streamline, a reduced total-specific-enthalpy relation is

$$h + \frac{U^2}{2} + \Phi = \text{constant} - e_{\text{diss}}, \tag{552}$$

where e_{diss} contains irreversible losses.

During decompression, internal and pressure energy may be converted into:

- kinetic energy;
- fragmentation;
- melt expansion;
- vaporization;
- fracture;
- excavation;
- ocean displacement;
- atmospheric work; and
- seismic radiation.

34.4 Expansion Work

The mechanical expansion work is

$$W_{\text{exp}} = \int_{V_1}^{V_2} P\, dV. \tag{553}$$

For a multiphase terminal disturbance,

$$W_{\text{exp}} = W_{\text{solid}} + W_{\text{melt}} + W_{\text{vapor}} + W_{\text{water}} + W_{\text{gas}}. \tag{554}$$

34.5 Fragmentation During Decompression

Decompression fragmentation occurs when internal pressure exceeds the sum of confining pressure and effective tensile strength:

$$P_{\text{internal}} - P_{\text{external}} \geq Y_{\text{tensile,eff}}. \tag{555}$$

The resulting fragment field affects:

- exit width;
- excavation efficiency;
- ejecta velocity;
- magnetic resetting;
- geochemical mixing;
- ocean interaction; and
- atmospheric loading.

34.6 Vapor Generation

The terminal vapor mass is

$$M_{v,M} = \int_{\mathcal{V}_M} \rho \chi_v \, dV. \tag{556}$$

Its maximum energy-limited value is

$$M_{v,M}^{\max} = \frac{E_{v,M}}{e_{v,\text{req}}}, \tag{557}$$

where $e_{v,\text{req}}$ includes sensible heating, melting where required, and vaporization.

34.7 Jet and Plume Separation

The terminal disturbance may produce:

Directional jet
Momentum remains concentrated along the interior path.

Expanding plume
Pressure-driven expansion dominates and the disturbance widens rapidly.

Mixed jet–plume

A directional core is surrounded by a broader decompression field.

Define jet fraction

$$f_{\text{jet}} = \frac{E_{\text{directional}}}{E_{M,0}}, \tag{558}$$

and plume fraction

$$f_{\text{plume}} = \frac{E_{\text{radial}}}{E_{M,0}}. \tag{559}$$

The exit morphology depends strongly on this partition.

34.8 Decompression Focusing and Defocusing

Define effective terminal area $A_M(z)$.

The area-expansion factor is

$$\Gamma_{A,M}(z) = \frac{A_M(z)}{A_{M,0}}. \tag{560}$$

The mean directional energy density scales approximately as

$$\bar{e}_{M,\parallel} \sim \frac{E_{M,\parallel}}{A_M L_M}. \tag{561}$$

Rapid area expansion may preserve total energy while eliminating the localized excavation required by the theory.

34.9 Deep-to-Shallow Transition Falsifier

Terminal decompression falsifier M1.
If every admissible terminal state expands, disperses, thermalizes, or fragments before reaching the shallow Mariana target with sufficient localized energy and momentum, the terminal-exit mechanism is rejected.

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35 Terminal Excavation, Fracture, and Trench-Scale Response

35.1 Immediate Terminal Response

The immediate terminal response field is

$$\Delta \mathbf{Q}_M^+(\mathbf{r}) = (\Delta P, \Delta T, \Delta \rho, \mathbf{u}, \mathbf{D}, \chi_m, \chi_v, \Delta \phi, c_I)_M \,. \tag{562}$$

The immediate surface or seafloor displacement is

$$\Delta z_M^+(\mathbf{x}). \tag{563}$$

35.2 Terminal Excavation Domain

Define the terminal excavation domain

$$\mathcal{V}_{M,\text{exc}} = \{\mathbf{r} : \Delta z_M(\mathbf{r}) \geq z_{\text{exc,crit}}\}, \tag{564}$$

with total excavation volume

$$V_{M,\text{exc}} = \int_{\mathcal{V}_{M,\text{exc}}} dV. \tag{565}$$

The excavated mass is

$$M_{M,\text{exc}} = \int_{\mathcal{V}_{M,\text{exc}}} \rho\, dV. \tag{566}$$

35.3 Terminal Affected Radius

Let the terminal affected area be

$$\mathcal{A}_{M,\text{aff}} = \{\mathbf{x} : \mathcal{F}_M(\mathbf{x}) \geq \mathcal{F}_{M,\text{crit}}\}. \tag{567}$$

Its equivalent radius is

$$R_{M,\text{eq}} = \sqrt{\frac{A_{M,\text{aff}}}{\pi}}. \tag{568}$$

35.4 Terminal Asymmetry

Define the second spatial moment tensor of the terminal response:

$$\mathbf{J}_M = \frac{\int_{\mathcal{A}_{M,\text{aff}}} (\mathbf{x} - \bar{\mathbf{x}}) \otimes (\mathbf{x} - \bar{\mathbf{x}})\, w_M(\mathbf{x})\, dA}{\int_{\mathcal{A}_{M,\text{aff}}} w_M(\mathbf{x})\, dA}. \tag{569}$$

Let its principal eigenvalues be

$$\lambda_1 \geq \lambda_2. \tag{570}$$

The terminal aspect ratio is

$$\mathcal{R}_M = \sqrt{\frac{\lambda_1}{\lambda_2}}. \tag{571}$$

35.5 Fracture Field

The predicted fracture and damage field is

$$\mathbf{D}_M(\mathbf{r}, t). \tag{572}$$

The model must separately report:

- radial fractures;
- circumferential fractures;
- path-parallel fractures;
- path-normal fractures;
- shear zones;
- decompression fractures;
- bending-related fractures; and
- later reactivated structures.

35.6 Terminal Fracture Orientation Residual

For observed feature orientation η_k^{obs} and predicted orientation η_k^{pred},

$$\epsilon_{\eta,k} = \frac{1}{2}\,\mathrm{atan2}\left[\sin 2\left(\eta_k^{\mathrm{obs}} - \eta_k^{\mathrm{pred}}\right), \cos 2\left(\eta_k^{\mathrm{obs}} - \eta_k^{\mathrm{pred}}\right)\right]. \tag{573}$$

35.7 Transient Depression Versus Modern Trench

The immediate terminal surface is

$$z_M^+ = z_M^- + \Delta z_M^{\mathrm{event}}. \tag{574}$$

The modern trench is

$$z_M^{\mathrm{now}} = \mathcal{P}_M\left[z_M^+, \mathcal{H}_{M,\mathrm{later}}\right], \tag{575}$$

where $\mathcal{H}_{M,\mathrm{later}}$ includes later deformation, sedimentation, subduction, rollback, faulting, magmatism, and erosion.

The theory does not require the modern trench to preserve the complete transient exit geometry unchanged.

It does require a quantitative inheritance relationship.

35.8 Trench-Scale Inheritance

Define the event-created terminal weakness field

$$\mathcal{W}_M(\mathbf{r}, t_h). \tag{576}$$

The later trench-localization contribution is

$$\Delta\mathcal{B}_M = \mathcal{U}_M\left[\mathcal{W}_M, \mathbf{F}_{M,\text{later}}\right] - \mathcal{U}_M\left[\mathbf{0}, \mathbf{F}_{M,\text{later}}\right]. \tag{577}$$

35.9 Exit-Morphology Forward Model

The predicted modern morphology is

$$\widehat{\mathcal{M}}_M^{\text{now}} = \mathcal{O}_M\left[\Delta\mathbf{Q}_M^+, \mathcal{H}_{M,\text{later}}\right]. \tag{578}$$

The predicted output must include:

- center;
- depth;
- width;
- curvature;
- asymmetry;
- fracture orientations;
- deep-root structure;
- gravity response;
- magnetic response;
- seismic response; and
- relationship to later subduction.

35.10 Exit Morphology Residual

For observed metrics m_j^{obs} and predicted metrics m_j^{pred},

$$\mathcal{J}_{M,\text{morph}} = \sum_j w_j\left[\frac{m_j^{\text{obs}} - m_j^{\text{pred}}}{\sigma_j}\right]^2. \tag{579}$$

The same residual structure must be calculated for the comparison subduction model.

36 Exit Energy, Momentum, and Angular-Momentum Partition

36.1 Complete Terminal Energy Budget

The terminal approach energy is partitioned as

$$\begin{aligned}E_{M,0} = E_{\mathrm{exc}} + E_{\mathrm{fract}} + E_{\mathrm{plastic}} + E_{\mathrm{heat}} + E_{\mathrm{melt}} + E_{\mathrm{vapor}} + E_{\mathrm{ejecta}} \\ + E_{\mathrm{ocean}} + E_{\mathrm{atm}} + E_{\mathrm{seismic}} + E_{\mathrm{rotation}} + E_{\mathrm{plate}} + E_{\mathrm{residual}}.\end{aligned} \tag{580}$$

For each component,

$$f_{M,j} = \frac{E_{M,j}}{E_{M,0}}, \tag{581}$$

with

$$\sum_j f_{M,j} = 1. \tag{582}$$

36.2 Total Event Exit Fraction

The total event fraction expressed at the exit is

$$f_M = \frac{E_{M,0}}{E_I}. \tag{583}$$

Using the inherited total-energy interval and proposed fraction, the original search space is

$$10^{28} \lesssim E_{M,0} \lesssim 5 \times 10^{30} \quad \mathrm{J}. \tag{584}$$

This interval is not accepted as viable until all regional and global consequences are modeled.

36.3 Momentum Budget

The terminal momentum budget is

$$\mathbf{p}_{M,0} = \mathbf{p}_{\mathrm{exc}} + \mathbf{p}_{\mathrm{ejecta}} + \mathbf{p}_{\mathrm{ocean}} + \mathbf{p}_{\mathrm{atm}} + \mathbf{p}_{\mathrm{seismic}} + \mathbf{p}_{\mathrm{plate}} + \mathbf{p}_{\mathrm{Earth,bulk}}. \tag{585}$$

The plate-scale momentum fraction is

$$\mu_{\mathrm{plate},M} = \frac{\|\mathbf{p}_{\mathrm{plate}}\|}{p_I}. \tag{586}$$

Paper III must determine whether this impulse contributes meaningfully to later plate motion.

36.4 Impulse Field

The terminal impulse density is

$$\mathbf{J}_M(\mathbf{r}) = \int_{t_{M,0}}^{t_{M,1}} \mathbf{f}_M(\mathbf{r}, t)\, dt. \tag{587}$$

The integrated terminal impulse is

$$\mathbf{I}_M = \int_{\mathcal{V}_M} \mathbf{J}_M(\mathbf{r})\, dV. \tag{588}$$

The horizontal component available to later plate displacement is

$$\mathbf{I}_{M,\mathrm{hor}} = \mathbf{I}_M - (\mathbf{I}_M \cdot \widehat{\mathbf{n}}_M)\, \widehat{\mathbf{n}}_M. \tag{589}$$

36.5 Angular-Momentum Partition

The terminal angular momentum is

$$\mathbf{L}_{M,0} = \int_{\mathcal{V}_{M,0}} \mathbf{r} \times \rho \mathbf{u}\, dV. \tag{590}$$

It is partitioned as

$$\mathbf{L}_{M,0} = \mathbf{L}_{\mathrm{ejecta}} + \mathbf{L}_{\mathrm{ocean}} + \mathbf{L}_{\mathrm{atmosphere}} + \mathbf{L}_{\mathrm{plate}} + \Delta\mathbf{L}_{\oplus} + \mathbf{L}_{\mathrm{residual}}. \tag{591}$$

36.6 Excavation Efficiency

Define excavation efficiency

$$\eta_{\mathrm{exc},M} = \frac{E_{\mathrm{exc}}}{E_{M,0}}. \tag{592}$$

Define terminal displacement efficiency

$$\eta_{\mathrm{disp},M} = \frac{E_{\mathrm{plate}}}{E_{M,0}}. \tag{593}$$

These efficiencies must emerge from the material model.

36.7 Exit-Energy Compatibility

The exit parameter set is compatible only if

$$E_{M,\mathrm{required}} \le E_{M,0} \le E_{M,\mathrm{survival}}, \tag{594}$$

where:

$$E_{M,\text{required}} = \text{minimum energy required by the predicted terminal structure,} \tag{595}$$
$$E_{M,\text{survival}} = \text{maximum energy permitted by regional and global constraints.} \tag{596}$$

The exit-energy window is

$$\mathcal{W}_M = \left[E_{M,\text{required}}, E_{M,\text{survival}}\right]. \tag{597}$$

If

$$E_{M,\text{required}} > E_{M,\text{survival}}, \tag{598}$$

the terminal mechanism has no viable energy solution.

37 Oceanic, Atmospheric, Ejecta, and Global Seismic Consequences

37.1 Ocean Interaction

For reconstructed water depth $h_{w,M}$, the exit interacts with water mass

$$M_{w,M} = \int_{\mathcal{V}_{w,M}} \rho_w \, dV. \tag{599}$$

The ocean-energy partition is

$$E_{\text{ocean},M} = E_{\text{wave}} + E_{\text{vap},w} + E_{\text{heat},w} + E_{\text{cavity}} + E_{\text{current}} + E_{\text{sed}} + E_{\text{atm},w}. \tag{600}$$

37.2 Water Vaporization

The vaporized-water mass is bounded by

$$M_{w,\text{vap}} \le \frac{E_{\text{vap},w}}{c_{p,w}\left(T_{\text{boil}} - T_{w,0}\right) + L_{v,w}}. \tag{601}$$

A complete high-pressure model must replace the surface boiling approximation where necessary.

37.3 Wave-Energy Distribution

Let the ocean-wave energy spectrum be

$$\mathcal{E}_w\left(\mathbf{k}, \omega\right). \tag{602}$$

The total wave energy is

$$E_{\text{wave}} = \int \mathcal{E}_w(\mathbf{k}, \omega)\; d\mathbf{k}\, d\omega. \tag{603}$$

The model must predict:

- initial wave field;
- directionality;
- basin propagation;
- dispersion;
- coastal interaction;
- erosion;
- deposition;
- sediment entrainment; and
- preservation probability.

37.4 Atmospheric Injection

The exit injects mass

$$M_{\text{atm,inj}} = M_{\text{vapor}} + M_{\text{dust}} + M_{\text{aerosol}} + M_{\text{gas}} + M_{\text{ejecta,atm}}. \tag{604}$$

The vertical injection profile is

$$\frac{dM_{\text{atm,inj}}}{dz}. \tag{605}$$

The model must determine how much material remains:

- in the lower atmosphere;
- in the upper atmosphere;
- in ballistic trajectories;
- in temporary orbit;
- beyond escape velocity; or
- available for reaccretion.

37.5 Ejecta Velocity Distribution

The terminal ejecta distribution is

$$\frac{d^2 M_{\rm ej}}{dv\, d\Omega}, \tag{606}$$

where $d\Omega$ is solid angle.

The mass exceeding escape speed is

$$M_{\rm esc} = \int_{v \geq v_{\rm esc}} \frac{dM_{\rm ej}}{dv}\, dv. \tag{607}$$

The reaccreting mass is

$$M_{\rm reacc} = \int_{\mathcal{D}_{\rm reacc}} \frac{d^2 M_{\rm ej}}{dv\, d\Omega}\, dv\, d\Omega. \tag{608}$$

37.6 Distal Deposit Prediction

The predicted distal-deposit thickness is

$$h_{\rm dep}(\theta, \varphi) = \frac{M_{\rm dep}(\theta, \varphi)}{\rho_{\rm dep} A(\theta, \varphi)}. \tag{609}$$

The model must predict:

- spatial distribution;
- thickness;
- composition;
- grain size;
- shocked-mineral content;
- projectile-material fraction;
- isotopic anomalies;
- re-entry products; and
- expected preservation.

37.7 Global Seismic Energy

The seismic fraction is

$$f_{{\rm seis},M} = \frac{E_{{\rm seis},M}}{E_{M,0}}. \tag{610}$$

The global radiated seismic energy is

$$E_{\text{seis,global}} = E_{\text{seis},A} + E_{\text{seis},P} + E_{\text{seis},H} + E_{\text{seis},M}. \tag{611}$$

37.8 Seismic Moment

For faulted area A_f, mean displacement $\bar{D}_f$, and shear modulus μ_f, the scalar seismic moment is

$$M_0 = \mu_f A_f \bar{D}_f. \tag{612}$$

A planetary event may not be representable by one conventional fault, but the moment provides a comparison scale for brittle and shear failure.

37.9 Global Disturbance Field

The global mechanical disturbance is

$$\mathbf{D}_{\text{global}} = \left(E_{\text{seis}}, M_{\text{atm,inj}}, M_{w,\text{vap}}, M_{\text{ej}}, M_{\text{esc}}, \mathbf{\Delta L}_{\oplus}, \Delta\Phi_{\oplus}, V_{\text{melt}}\right). \tag{613}$$

37.10 Global Consequence Constraint

For observation class j, define predicted signal

$$S_j^{\text{pred}} = \mathcal{F}_j\left[\mathbf{D}_{\text{global}}\right]. \tag{614}$$

The observational residual is

$$\epsilon_j = \frac{S_j^{\text{obs}} - S_j^{\text{pred}}}{\sigma_j}. \tag{615}$$

The total global penalty is

$$\chi^2_{\text{global}} = \sum_j \epsilon_j^2. \tag{616}$$

37.11 Missing-Marker Constraint

For predicted marker j, the probability of nondetection is

$$P_{j,\text{miss}} = 1 - P_{j,\text{det}}. \tag{617}$$

The total missing-marker likelihood is

$$\mathcal{L}_{\text{miss}} = \prod_j P_{j,\text{miss}}. \tag{618}$$

A mechanically powerful event cannot be exempted from its expected global consequences.

38 Mariana Gravity, Magnetic, and Seismic Predictions

38.1 Post-Event Density Field

The post-event density anomaly is

$$\Delta\rho_M(\mathbf{r}) = \rho_M^{\mathrm{post}}(\mathbf{r}) - \rho_M^{\mathrm{background}}(\mathbf{r}). \tag{619}$$

Its sources may include:

- excavation;
- decompression;
- melt;
- vapor loss;
- projectile-derived material;
- phase change;
- fracture porosity;
- dense intrusion;
- thermal expansion; and
- later subduction.

38.2 Gravity Anomaly

The predicted gravitational-potential anomaly is

$$\Delta\Phi_M(\mathbf{x}) = -G\int_{\mathcal{V}_M} \frac{\Delta\rho_M(\mathbf{r})}{\|\mathbf{x}-\mathbf{r}\|}\, dV. \tag{620}$$

The predicted acceleration anomaly is

$$\Delta\mathbf{g}_M = -\nabla\Delta\Phi_M. \tag{621}$$

The model must predict:

- sign;
- amplitude;
- spatial wavelength;
- depth;

- center;
- asymmetry;
- relationship to trench geometry; and
- modification by later slab structure.

38.3 Magnetic Resetting and Remanence

The immediate post-event magnetization is

$$\mathbf{M}_M^{+} = \mathcal{R}_{M,B}\left[\mathbf{M}_0, P_{\max}, T_{\max}, D, \chi_m, \chi_v, \mathbf{B}(t)\right]. \tag{622}$$

The modern magnetization is

$$\mathbf{M}_M^{\mathrm{now}} = \mathcal{P}_{M,B}\left[\mathbf{M}_M^{+}, \mathcal{H}_{M,\mathrm{later}}\right]. \tag{623}$$

The model must separate event-related magnetization from:

- oceanic crustal stripes;
- arc magmatism;
- hydrothermal alteration;
- later faulting;
- subduction;
- sediment cover; and
- thermal resetting.

38.4 Seismic Velocity Field

The predicted elastic properties are

$$K_M = K\left(P, T, \phi, \chi_m, D, \mathcal{C}\right), \tag{624}$$
$$G_M = G\left(P, T, \phi, \chi_m, D, \mathcal{C}\right). \tag{625}$$

The compressional-wave speed is

$$V_{P,M} = \sqrt{\frac{K_M + \frac{4}{3}G_M}{\rho_M}}, \tag{626}$$

and the shear-wave speed is

$$V_{S,M} = \sqrt{\frac{G_M}{\rho_M}}. \tag{627}$$

38.5 Residual Non-Slab Structure

Let the observed modern seismic field be

$$\mathbf{S}_M^{\text{obs}}. \tag{628}$$

Let the comparison slab model predict

$$\widehat{\mathbf{S}}_M^{\text{slab}}. \tag{629}$$

The residual field is

$$\mathbf{S}_M^{\text{res}} = \mathbf{S}_M^{\text{obs}} - \widehat{\mathbf{S}}_M^{\text{slab}}. \tag{630}$$

The astro-ballistic model predicts

$$\widehat{\mathbf{S}}_M^{\text{ABC}}. \tag{631}$$

Its residual fit is

$$\epsilon_{S,M} = \mathbf{S}_M^{\text{res}} - \widehat{\mathbf{S}}_M^{\text{ABC}}. \tag{632}$$

38.6 Exit-Corridor Continuity

The deep-path prediction and Mariana terminal prediction must connect.

Let

$$\mathcal{C}_{P\to M} \tag{633}$$

denote a corridor-continuity statistic.

One form is

$$\mathcal{C}_{P\to M} = \frac{\int \widehat{\mathcal{T}}_P \widehat{\mathcal{T}}_M \, dV}{\sqrt{\int \widehat{\mathcal{T}}_P^2 \, dV} \sqrt{\int \widehat{\mathcal{T}}_M^2 \, dV}}. \tag{634}$$

A terminal anomaly disconnected from the predicted deep path does not support one connected event.

38.7 Bathymetric Prediction

The predicted modern bathymetric field is

$$\widehat{z}_M^{\text{now}} = \mathcal{O}_{M,z}\left[\Delta\mathbf{Q}_M^+, \mathcal{H}_{M,\text{later}}\right]. \tag{635}$$

The bathymetric residual is

$$\epsilon_z(\mathbf{x}) = z_M^{\text{obs}}(\mathbf{x}) - \widehat{z}_M^{\text{now}}(\mathbf{x}). \tag{636}$$

38.8 Joint Mariana Prediction Vector

The complete prediction is

$$\widehat{\mathbf{D}}_M = \left(\widehat{z}_M, \widehat{\mathbf{g}}_M, \widehat{\mathbf{B}}_M, \widehat{V}_{P,M}, \widehat{V}_{S,M}, \widehat{Q}_M^{-1}, \widehat{\mathbf{A}}_M, \widehat{\mathbf{G}}_M, \widehat{\mathbf{T}}_M\right). \tag{637}$$

Here

$$\widehat{\mathbf{G}}_M = \text{geochemical and mineralogical prediction}, \tag{638}$$

$$\widehat{\mathbf{T}}_M = \text{chronological prediction}. \tag{639}$$

38.9 Comparison With Subduction Model

Let

$$\mathcal{M}_{M,\text{ABC}} = \text{astro-ballistic exit model}, \tag{640}$$

$$\mathcal{M}_{M,\text{sub}} = \text{regional subduction model}. \tag{641}$$

The model evidence ratio is

$$K_M = \frac{p\left(\mathbf{D}_M^{\text{obs}} \mid \mathcal{M}_{M,\text{ABC}}\right)}{p\left(\mathbf{D}_M^{\text{obs}} \mid \mathcal{M}_{M,\text{sub}}\right)}. \tag{642}$$

A hybrid comparison may also test whether an inherited terminal-response structure improves a later subduction model:

$$\mathcal{M}_{M,\text{hybrid}} = \mathcal{M}_{M,\text{ABC}} + \mathcal{M}_{M,\text{sub}}. \tag{643}$$

The hybrid model must be penalized for its added parameters.

39 Exit Preservation, Overprint, and Falsification

39.1 Immediate and Modern Exit States

The immediate terminal state is

$$\mathbf{Q}_M^+ = \mathbf{Q}_M(t_M^+). \tag{644}$$

The modern state is

$$\mathbf{Q}_M^{\mathrm{now}} = \mathcal{P}_M\left[\mathbf{Q}_M^+, \mathcal{H}_{M,\mathrm{later}}\right]. \tag{645}$$

39.2 Later Overprint Processes

The preservation model must include:

- subduction;
- slab rollback;
- arc magmatism;
- back-arc extension;
- plate bending;
- sedimentation;
- metamorphism;
- hydrothermal alteration;
- oceanic crust production and destruction;
- fault reactivation;
- mantle flow;
- erosion;
- burial; and
- geochemical recycling.

39.3 Marker Survival

For exit marker j,

$$S_{M,j} = \frac{N_{M,j}^{\mathrm{detectable,now}}}{N_{M,j}^{\mathrm{generated}}}. \tag{646}$$

For continuous field q_j,

$$S_{M,j} = \frac{\int \left| q_j^{\text{now}} - q_j^{\text{background}} \right| \, dV}{\int \left| q_j^{+} - q_j^{\text{background}} \right| \, dV}. \tag{647}$$

39.4 Subduction-Reactivation Hypothesis

The event may create an inherited weakness that later localizes subduction.

Define the with-inheritance model

$$\mathbf{Q}_M^{+,\text{sub}}(t) = \mathcal{U}_M \left[\mathbf{Q}_M^{+}, \mathbf{F}_{\text{sub}}(t) \right]. \tag{648}$$

The counterfactual model is

$$\mathbf{Q}_M^{0,\text{sub}}(t) = \mathcal{U}_M \left[\mathbf{Q}_M^{\text{background}}, \mathbf{F}_{\text{sub}}(t) \right]. \tag{649}$$

The inherited exit contribution is

$$\Delta \mathbf{Q}_M^{\text{inherit}} = \mathbf{Q}_M^{+,\text{sub}} - \mathbf{Q}_M^{0,\text{sub}}. \tag{650}$$

39.5 Exit Claim Classes

The Mariana hypothesis contains several separable claims:

M1. the interior disturbance reaches the Mariana target;

M2. it retains sufficient localized energy and momentum;

M3. decompression produces a terminal response;

M4. the terminal response creates a persistent structural inheritance;

M5. later subduction reuses or amplifies that inheritance;

M6. modern Mariana morphology retains a measurable event contribution;

M7. modern deep geophysical fields retain a measurable event contribution; and

M8. the full event remains compatible with global consequences.

Failure of one claim does not automatically erase every other claim.

The literal exit-wound interpretation requires all principal claims to survive together.

39.6 Exit Viable Set

Define

$$\mathcal{V}_M = \left\{ \boldsymbol{\Theta}_M : \begin{array}{l} \text{target misfit satisfied,} \\ \text{terminal energy satisfied,} \\ \text{terminal momentum satisfied,} \\ \text{decompression viable,} \\ \text{excavation viable,} \\ \text{regional morphology compatible,} \\ \text{gravity and magnetic fields compatible,} \\ \text{seismic structure compatible,} \\ \text{preservation model compatible,} \\ \text{global consequences compatible} \end{array} \right\}. \tag{651}$$

39.7 Complete Exit Falsification Matrix

Table 7: Paper-II Mariana terminal-response falsification matrix.

ID	**Exit claim**	**Falsifying result**	**Consequence**
MF1	Terminal targeting	No viable interior branch reaches a defensible Mariana precursor domain.	Reject Mariana as the event exit.
MF2	Terminal localization	The disturbance reaches the region only as a broad global field with insufficient localized energy or momentum.	Reject localized exit-wound mechanism.
MF3	Decompression	The terminal state disperses or thermalizes before producing the required shallow response.	Reject decompression-exit branch.
MF4	Excavation	The minimum energy required for the predicted terminal structure exceeds the delivered energy.	Reject terminal excavation model.
MF5	Planetary compatibility	Every mechanically sufficient exit produces incompatible oceanic, atmospheric, seismic, or ejecta consequences.	Reject the relevant energy range.
MF6	Morphology	Forward-modeled terminal geometry is incompatible with the reconstructed and modern Mariana region.	Reject the proposed exit morphology.

ID	Exit claim	Falsifying result	Consequence
MF7	Fracture field	Predicted fracture orientations and spatial organization are absent or fully attributable to later regional stress.	Reject the predicted terminal damage field.
MF8	Gravity	The required density anomaly predicts an incompatible gravity or geoid field.	Reject the required terminal density state.
MF9	Magnetics	Predicted thermal or shock resetting is incompatible with the magnetic record.	Reject the relevant thermal history.
MF10	Seismic structure	No residual non-slab anomaly matches the predicted deep terminal corridor.	Reject the predicted exit corridor.
MF11	Foreign material	The model predicts detectable projectile or deep-mantle material that is absent under adequate sampling.	Reject the relevant transport branch.
MF12	Chronology	All defensible precursor and marker evidence exclude the specific 256 Ma initiating-age assignment under the frozen uncertainty model.	Reject the 256 Ma Mariana assignment.
MF13	Preservation	The model requires unconstrained later destruction to erase every predicted marker.	Reject the model as non-falsifiable.
MF14	Subduction inheritance	Later subduction develops equally well without the event-created terminal state.	Reject the claim that the event organized the trench.
MF15	Common parameter set	The exit requires energy, momentum, composition, or direction incompatible with the entrance and path solutions.	Reject the connected event.
MF16	Comparison-model performance	Subduction and regional geodynamics explain the complete observation vector more accurately with fewer parameters.	Reject the astro-ballistic exit as the preferred explanation.

39.8 Terminal-Response Success Standard

The Mariana terminal-response assignment survives only if one shared event parameter set:

MS1. emerges from the viable interior path;

MS2. reaches a defensible reconstructed Mariana target;

MS3. retains sufficient localized energy and momentum;

MS4. survives deep-to-shallow decompression;

MS5. produces a bounded terminal excavation and damage field;

MS6. generates compatible oceanic, atmospheric, seismic, and ejecta consequences;

MS7. leaves a persistent structural inheritance;

MS8. improves the prediction of later trench localization or morphology;

MS9. predicts compatible gravity, magnetic, and seismic fields;

MS10. survives preservation and detection tests;

MS11. remains compatible with the proposed chronology; and

MS12. outperforms or materially improves the regional comparison model after complexity penalties.

Mariana terminal-response decision rule.
The Mariana region qualifies as the terminal-response domain only if the energy, momentum, composition, direction, damage, and phase state produced by the Aegean entrance and deep-mantle path generate one forward-modeled terminal structure whose preserved geological and geophysical consequences remain detectable and distinguishable from later subduction.
A deep trench alone is not evidence of an exit wound.

---

40 Midpoint, Terminal, and Survival Synthesis

This midpoint, terminal, and survival synthesis records:

1. the distinction among geometric midpoint, pressure maximum, damage maximum, phase maximum, and inheritance maximum;
2. the time-integrated midpoint response functional;
3. the mechanical middle-path domain and centroid;
4. the persistent Himalayan inheritance-node state;
5. node size, survival, orientation, and buoyancy requirements;
6. weakness-node and strength-node alternatives;
7. the short-time to long-time geodynamic handoff;
8. with-node and without-node counterfactual simulations;

9. Himalayan amplification and necessity statistics;
10. the complete terminal Mariana handoff state;
11. terminal target, direction, radius, momentum, energy, and composition constraints;
12. deep-to-shallow decompression mechanics;
13. directional jet, expanding plume, and mixed terminal branches;
14. terminal excavation, fracture, asymmetry, and trench-scale inheritance;
15. complete exit energy, momentum, impulse, and angular-momentum budgets;
16. oceanic, atmospheric, ejecta, and global seismic consequences;
17. Mariana gravity, magnetic, seismic, bathymetric, and tomographic predictions;
18. later subduction-overprint and reactivation tests;
19. the Mariana viable parameter set; and
20. the complete terminal-exit falsification matrix.

The following final Paper-II sections address:

- whole-planet survival;
- crustal and mantle melt limits;
- ocean and atmosphere retention;
- rotation and moment-of-inertia changes;
- global ejecta and stratigraphic-marker expectations;
- Mauna Kea and far-field impulse as a secondary hypothesis;
- complete entrance–path–midpoint–exit parameter nesting;
- model evidence and complexity penalties;
- integrated Paper-II claim ledger;
- complete Paper-II falsification matrix;
- independent numerical replication protocol;
- discussion;
- limitations;
- conclusions;
- appendices; and
- Paper-III handoff.

41 Whole-Planet Survival Window

41.1 Planetary Survival Is a Multivariable Constraint

Remaining gravitationally bound is not sufficient to establish planetary survival.

A mechanically viable event must preserve an Earth state compatible with the later geological record.

Define the post-event planetary state as

$$\mathbf{Q}_{\oplus}^{+} = \left(M_{\oplus}^{+}, \mathbf{L}_{\oplus}^{+}, \mathbf{I}_{\oplus}^{+}, T_{\oplus}^{+}, \mathbf{Q}_{\text{mantle}}^{+}, \mathbf{Q}_{\text{crust}}^{+}, M_{\text{ocean}}^{+}, M_{\text{atm}}^{+}, \mathbf{B}_{\oplus}^{+}, \mathcal{B}_{\text{surface}}^{+} \right). \tag{652}$$

The state must remain consistent with:

- continued planetary integrity;
- surviving mantle stratification;
- surviving crustal material;
- retained atmosphere;
- retained ocean inventory;
- permissible rotation change;
- permissible moment-of-inertia change;
- permissible mass loss;
- preserved geological inheritance; and
- the predicted environmental and biological consequences.

41.2 Binding-Energy Reference

A first gravitational reference is

$$E_{\text{bind}} \approx \frac{3GM_{\oplus}^{2}}{5R_{\oplus}}. \tag{653}$$

Using the adopted reference values,

$$E_{\text{bind}} \approx 2.24 \times 10^{32} \quad \text{J}. \tag{654}$$

Define the binding-energy ratio

$$\Pi_{\text{bind}} = \frac{E_I}{E_{\text{bind}}}. \tag{655}$$

For the inherited event-energy interval,

$$4.5 \times 10^{-4} \lesssim \Pi_{\mathrm{bind}} \lesssim 4.5 \times 10^{-2}. \tag{656}$$

The event remains below the approximate total gravitational binding energy.

This does not establish compatibility with the atmosphere, oceans, crust, mantle, rotation, or geological record.

41.3 Planetary-Survival Vector

Define the planetary-survival vector

$$\mathbf{S}_{\oplus} = (S_{\mathrm{mass}}, S_{\mathrm{atm}}, S_{\mathrm{ocean}}, S_{\mathrm{crust}}, S_{\mathrm{mantle}}, S_{\mathrm{rotation}}, S_{\mathrm{orbit}}, S_{\mathrm{magnetic}}, S_{\mathrm{geological}}) . \tag{657}$$

Each component is normalized so that

$$0 \leq S_j \leq 1. \tag{658}$$

A value near unity indicates close compatibility with the declared survival requirement.

A value near zero indicates failure.

41.4 Minimum Survival Rule

The event survives the planetary test only if

$$S_j \geq S_{j,\mathrm{crit}} \tag{659}$$

for every required component.

The complete survival condition is

$$\mathcal{C}_{\mathrm{survival}} = \bigcap_j \{S_j \geq S_{j,\mathrm{crit}}\} . \tag{660}$$

A high score in one category cannot compensate for planetary failure in another.

41.5 Mass-Loss Constraint

Let total escaped mass be

$$M_{\mathrm{loss}} = M_{\mathrm{ejecta,esc}} + M_{\mathrm{atm,esc}} + M_{\mathrm{ocean,esc}} + M_{\mathrm{vapor,esc}}. \tag{661}$$

The fractional planetary mass loss is

$$f_{M,\mathrm{loss}} = \frac{M_{\mathrm{loss}}}{M_{\oplus}}. \tag{662}$$

The model must calculate the gravitational, rotational, orbital, and geochemical consequences of the predicted loss.

41.6 Crustal Survival Constraint

Let the globally melted, vaporized, excavated, or structurally destroyed crustal mass be

$$M_{\mathrm{crust,dist}}. \tag{663}$$

The disturbed crust fraction is

$$f_{\mathrm{crust,dist}} = \frac{M_{\mathrm{crust,dist}}}{M_{\mathrm{crust},0}}. \tag{664}$$

The event must predict whether the surviving crustal record is compatible with this fraction and its spatial distribution.

41.7 Mantle Survival Constraint

Define mantle material undergoing a declared extreme state threshold:

$$M_{\mathrm{mantle,ext}} = \int_{\mathcal{V}_{\mathrm{mantle}}} \rho \mathbf{1} \left[\mathcal{F}_{\mathrm{extreme}} \geq \mathcal{F}_{\mathrm{crit}}\right] dV. \tag{665}$$

The affected mantle fraction is

$$f_{\mathrm{mantle,ext}} = \frac{M_{\mathrm{mantle,ext}}}{M_{\mathrm{mantle},0}}. \tag{666}$$

The event must preserve mantle structure compatible with later geodynamics and present observations.

41.8 Survival Window

Let the complete event parameter vector be $\mathbf{\Theta}$.

The survival-admissible set is

$$\mathcal{V}_{\oplus} = \left\{\mathbf{\Theta} : \mathcal{C}_{\mathrm{survival}} \text{ is satisfied}\right\}. \tag{667}$$

The event remains viable only if

$$\mathcal{V}_{\mathrm{II}} \cap \mathcal{V}_{\oplus} \neq \varnothing. \tag{668}$$

Planetary-survival falsifier S1.
If every event capable of generating the required Aegean entrance, deep-mantle path, Himalayan inheritance, and Mariana terminal response produces an Earth state incompatible with the later atmosphere, oceans, crust, mantle, rotation, or geological record, the connected event is rejected.

42 Thermal, Melt, Ocean, and Atmosphere Constraints

42.1 Total Retained Thermal Energy

The retained thermal energy is

$$E_{\text{th,ret}} = E_{\text{heat}} + E_{\text{melt}} + E_{\text{vapor}} - E_{\text{thermal,escape}}. \tag{669}$$

The retained thermal fraction is

$$f_{\text{th,ret}} = \frac{E_{\text{th,ret}}}{E_I}. \tag{670}$$

42.2 Global Mean Temperature Scale

For heated mass M_{heat} and effective heat capacity $\bar{c}_P$,

$$\Delta T_{\text{mean}} = \frac{E_{\text{th,ret}}}{M_{\text{heat}}\bar{c}_P}. \tag{671}$$

The value depends critically on whether the retained heat is localized to:

- the entrance;
- the path;
- the midpoint region;
- the exit;
- the mantle;
- the crust;
- the oceans; or
- the complete Earth.

The heated mass must be generated by the simulation.

42.3 Energy-Limited Melt Mass

For material initially below its solidus, the energy required per unit mass to produce melt is

$$e_{\text{melt,req}} = \int_{T_0}^{T_{\text{sol}}} c_P \, dT + L_m + \int_{T_{\text{sol}}}^{T_{\text{liq}}} c_{P,\text{melt}} \, dT. \tag{672}$$

The maximum energy-limited melt mass is

$$M_{\text{melt,max}} = \frac{E_{\text{melt,available}}}{e_{\text{melt,req}}}. \tag{673}$$

42.4 Melt-Volume Constraint

For average melt density $\bar{\rho}_m$,

$$V_{\text{melt}} = \frac{M_{\text{melt}}}{\bar{\rho}_m}. \tag{674}$$

The predicted melt volume must be spatially distributed among:

$$V_{\text{melt}} = V_A + V_P + V_H + V_M + V_{\text{global}}. \tag{675}$$

The geological record must be compatible with the predicted locations, compositions, ages, and volumes.

42.5 Ocean Retention

Let initial ocean mass be

$$M_{\text{ocean},0}. \tag{676}$$

The surviving ocean mass is

$$M^+_{\text{ocean}} = M_{\text{ocean},0} - M_{\text{vap}} - M_{\text{esc}} + M_{\text{cond}} + M_{\text{reacc}}, \tag{677}$$

where:

$$M_{\text{vap}} = \text{water converted into vapor}, \tag{678}$$
$$M_{\text{esc}} = \text{water or hydrogen lost from Earth}, \tag{679}$$
$$M_{\text{cond}} = \text{vapor later condensed}, \tag{680}$$
$$M_{\text{reacc}} = \text{water-bearing material reaccreted}. \tag{681}$$

The surviving fraction is

$$S_{\text{ocean}} = \frac{M^{+}_{\text{ocean}}}{M_{\text{ocean},0}}. \tag{682}$$

42.6 Ocean-Vapor Energy

A first energy bound is

$$E_{\text{ocean,vap}} = M_{\text{vap}} \left[c_{P,w} \left(T_{\text{vap}} - T_{w,0} \right) + L_{v,w} \right]. \tag{683}$$

The full calculation must include pressure-dependent phase behavior, supercritical water, atmospheric coupling, and recondensation.

42.7 Atmospheric Retention

Let initial atmospheric mass be

$$M_{\text{atm},0}. \tag{684}$$

The post-event atmospheric mass is

$$M^{+}_{\text{atm}} = M_{\text{atm},0} + M_{\text{inj}} - M_{\text{atm,esc}} - M_{\text{cond}} - M_{\text{dep}}. \tag{685}$$

The atmospheric survival fraction is

$$S_{\text{atm}} = \frac{M^{+}_{\text{atm}}}{M_{\text{atm},0}}. \tag{686}$$

42.8 Atmospheric Escape

For atmospheric or plume element j, escape requires

$$\frac{v_j^2}{2} + h_j + \Phi_j \geq 0 \tag{687}$$

under the declared energy convention.

The escaping atmospheric mass is

$$M_{\text{atm,esc}} = \int \mathbf{1} \left[\mathcal{E}_{j,\text{tot}} \geq 0 \right] \, dM_j. \tag{688}$$

42.9 Radiative and Climatic Forcing

The atmospheric disturbance vector is

$$\mathbf{A}_{\text{clim}} = (M_{\text{dust}}, M_{\text{aerosol}}, M_{\text{vapor}}, M_{\text{gas}}, M_{\text{soot}}, H_{\text{inj}}, \tau_{\text{res}}) , \tag{689}$$

where:

$$H_{\text{inj}} = \text{injection-height distribution,} \tag{690}$$

$$\tau_{\text{res}} = \text{atmospheric residence time.} \tag{691}$$

The resulting radiative forcing is

$$\Delta F_{\text{rad}} = \mathcal{R}_{\text{clim}} [\mathbf{A}_{\text{clim}}] . \tag{692}$$

42.10 Environmental Consequence Sequence

The coupled environmental sequence is

$$\mathcal{E}_{\text{event}} \to \mathbf{A}_{\text{clim}} \to \Delta F_{\text{rad}} \to \Delta T_{\text{surface}} \to \Delta \mathbf{O}_{\text{ocean}} \to \Delta \mathbf{B}_{\text{bio}}. \tag{693}$$

Paper II defines the physical forcing.

Chronostratigraphic and biological comparison belongs primarily to Papers I and III.

42.11 Thermal-Survival Falsifier

Thermal-survival falsifier S2.
If every event capable of sustaining the required path and exit produces melt, ocean vaporization, atmospheric loss, or retained heat incompatible with the geological and environmental record, the relevant event-energy range is rejected.

43 Rotation, Angular Momentum, and Moment-of-Inertia Constraints

43.1 Pre-Event Rotation State

Let the pre-event angular momentum be

$$\mathbf{L}_{\oplus,0} = \mathbf{I}_{\oplus,0} \boldsymbol{\omega}_{\oplus,0}. \tag{694}$$

The impactor contributes angular momentum

$$\mathbf{L}_I = \mathbf{b}_I \times \mathbf{p}_I + \mathbf{I}_I \boldsymbol{\omega}_I. \tag{695}$$

The first term is orbital angular momentum about Earth's center.

The second is impactor spin angular momentum.

43.2 Post-Event Angular Momentum

After accounting for escaping and orbiting material,

$$\mathbf{L}_{\oplus}^{+} = \mathbf{L}_{\oplus,0} + \mathbf{L}_{I} - \mathbf{L}_{\text{esc}} - \mathbf{L}_{\text{orbit}} - \mathbf{L}_{\text{external}}. \tag{696}$$

The post-event rotation vector is

$$\boldsymbol{\omega}_{\oplus}^{+} = \left(\mathbf{I}_{\oplus}^{+}\right)^{-1} \mathbf{L}_{\oplus}^{+}. \tag{697}$$

43.3 First-Order Rotation Change

For small perturbations,

$$\Delta\boldsymbol{\omega}_{\oplus} \approx \mathbf{I}_{\oplus,0}^{-1}\Delta\mathbf{L}_{\oplus} - \mathbf{I}_{\oplus,0}^{-1}\Delta\mathbf{I}_{\oplus}\boldsymbol{\omega}_{\oplus,0}. \tag{698}$$

The first term represents angular-momentum addition.

The second represents redistribution of Earth's mass.

43.4 Moment-of-Inertia Change

The inertia-tensor perturbation is

$$\Delta\mathbf{I}_{\oplus} = \int_{\mathcal{V}_{\oplus}} \Delta\rho \left[r^2\mathbf{I} - \mathbf{r}\otimes\mathbf{r}\right] dV + \Delta\mathbf{I}_{\text{loss}}. \tag{699}$$

The perturbation includes:

- excavation;
- displaced mantle;
- melt migration;
- ejecta loss;
- ocean displacement;
- atmospheric redistribution;
- plate displacement; and
- reaccretion.

43.5 Day-Length Change

For rotation magnitude ω, the day length is

$$T_{\text{day}} = \frac{2\pi}{\omega}. \tag{700}$$

The first-order fractional change is

$$\frac{\Delta T_{\text{day}}}{T_{\text{day}}} \approx -\frac{\Delta\omega}{\omega}. \tag{701}$$

43.6 Rotation-Axis Change

Let the unit rotation vector be

$$\widehat{\boldsymbol{\omega}} = \frac{\boldsymbol{\omega}}{\|\boldsymbol{\omega}\|}. \tag{702}$$

The rotation-axis deflection is

$$\Delta\theta_{\omega} = \arccos\left(\widehat{\boldsymbol{\omega}}_{\oplus,0} \cdot \widehat{\boldsymbol{\omega}}_{\oplus}^{+}\right). \tag{703}$$

43.7 Rotational Energy

The rotational kinetic energy is

$$E_{\text{rot}} = \frac{1}{2}\boldsymbol{\omega}^{\mathsf{T}}\mathbf{I}\boldsymbol{\omega}. \tag{704}$$

The change is

$$\Delta E_{\text{rot}} = E_{\text{rot}}^{+} - E_{\text{rot},0}. \tag{705}$$

The rotational-energy change must appear in the complete energy budget.

43.8 Rotation-Compatible Set

Define

$$\mathcal{V}_{\text{rot}} = \left\{ \boldsymbol{\Theta} : \begin{array}{l} \Delta T_{\text{day}} \text{ is admissible,} \\ \Delta\theta_{\omega} \text{ is admissible,} \\ \Delta E_{\text{rot}} \text{ is admissible,} \\ \Delta \mathbf{I}_{\oplus} \text{ is admissible} \end{array} \right\}. \tag{706}$$

43.9 Rotation Falsifier

Rotational falsifier S3.
If every event capable of producing the required entrance, path, and exit also produces an incompatible change in day length, rotation-axis orientation, rotational energy, or moment of inertia, the relevant event geometry and parameter range are rejected.

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44 Global Ejecta and Stratigraphic Marker Predictions

44.1 Total Ejecta Distribution

The global ejecta distribution is

$$\frac{d^3 M_{\mathrm{ej}}}{dv\, d\Omega\, d\mathcal{C}}, \tag{707}$$

where $\mathcal{C}$ denotes composition.

The ejecta contain contributions from:

$$M_{\mathrm{ej}} = M_{\mathrm{ej},A} + M_{\mathrm{ej},M} + M_{\mathrm{ej,secondary}}. \tag{708}$$

44.2 Ejecta Classes

The model must classify ejecta as:

- local fallback;
- regional ballistic ejecta;
- global ballistic ejecta;
- atmospheric suspension;
- orbital material;
- escaping material;
- reaccreted material; and
- chemically altered re-entry material.

44.3 Trajectory Propagation

For ejecta element j,

$$\frac{d^2 \mathbf{r}_j}{dt^2} = -\nabla\Phi - 2\boldsymbol{\Omega}_\oplus \times \mathbf{v}_j - \boldsymbol{\Omega}_\oplus \times (\boldsymbol{\Omega}_\oplus \times \mathbf{r}_j) + \mathbf{a}_{\mathrm{drag}} + \mathbf{a}_{\mathrm{lift}}. \tag{709}$$

Atmospheric drag, heating, fragmentation, and reaccretion must be included where applicable.

44.4 Predicted Deposit Field

The mass deposited per unit area is

$$\sigma_{\text{dep}}(\theta, \varphi) = \frac{dM_{\text{dep}}}{dA}. \tag{710}$$

The predicted thickness is

$$h_{\text{dep}} = \frac{\sigma_{\text{dep}}}{\rho_{\text{dep}}}. \tag{711}$$

44.5 Composition Vector

At location (θ, φ), the predicted deposit composition is

$$\mathbf{C}_{\text{dep}} = \left(Y_I, Y_{\text{crust}}, Y_{\text{upper mantle}}, Y_{\text{lower mantle}}, Y_{\text{melt}}, Y_{\text{vapor}}, Y_{\text{altered}}\right). \tag{712}$$

The theory should predict whether the deposits contain:

- projectile-derived material;
- deep-mantle material;
- shocked mineral phases;
- melt droplets;
- vapor condensates;
- high-temperature reaction products;
- atmospheric combustion products; and
- ocean-derived material.

44.6 Stratigraphic Marker Vector

The complete predicted marker vector is

$$\mathbf{M}_{\text{strat}} = \left(h_{\text{dep}}, \mathbf{C}_{\text{dep}}, \mathbf{G}_{\text{chem}}, \mathbf{I}_{\text{iso}}, \mathbf{P}_{\text{shock}}, \mathbf{S}_{\text{sed}}, \mathbf{B}_{\text{bio}}, \mathbf{T}_{\text{age}}\right), \tag{713}$$

where:

$$\mathbf{G}_{\text{chem}} = \text{elemental and geochemical anomalies,} \tag{714}$$

$$\mathbf{I}_{\text{iso}} = \text{isotopic anomalies,} \tag{715}$$

$$\mathbf{P}_{\text{shock}} = \text{shock-mineral indicators,} \tag{716}$$

$$\mathbf{S}_{\text{sed}} = \text{sedimentary disturbance,} \tag{717}$$

$$\mathbf{B}_{\text{bio}} = \text{biological and ecological response,} \tag{718}$$

$$\mathbf{T}_{\text{age}} = \text{chronological marker set.} \tag{719}$$

44.7 Global Marker Likelihood

For observed marker dataset $\mathbf{D}_{\text{strat}}$,

$$\mathcal{L}_{\text{strat}} = p\left(\mathbf{D}_{\text{strat}} \mid \mathbf{M}_{\text{strat}}\right). \tag{720}$$

The likelihood must include both detected and missing markers.

44.8 Marker Multiplicity

The event may predict more than one marker horizon:

1. entrance ejecta and atmospheric products;
2. terminal ejecta and atmospheric products;
3. reaccretion horizons;
4. delayed hydrothermal or volcanic products;
5. sedimentary reworking; and
6. later exposure of inherited structures.

The chronology of each horizon must be predicted independently.

44.9 Global Marker Falsifier

Global-marker falsifier S4.
If a mechanically sufficient event predicts globally detectable ejecta, shock products, geochemical anomalies, sedimentary disturbance, or other markers whose expected preservation and detection probabilities are high, but those markers are absent, the relevant event parameter region is rejected.

45 Mauna Kea and Far-Field Impulse as a Secondary Hypothesis

45.1 Secondary Status

The source framework proposed Mauna Kea as a possible far-field displacement marker associated with the wider event mechanics.

This claim is not required for the core Aegean–Himalayan–Mariana sequence.

It is treated as a compartmentalized secondary hypothesis.

Failure of the Mauna Kea hypothesis does not by itself reject the entrance, path, midpoint, or exit.

Success cannot compensate for failure of the core sequence.

45.2 Far-Field Impulse Definition

Let the event generate a global impulse field

$$\mathbf{J}_{\text{global}}(\mathbf{r}) = \int_{t_0}^{t_1} \mathbf{f}_{\text{event}}(\mathbf{r}, t)\, dt. \tag{721}$$

For a candidate far-field structure $\mathcal{D}_F$, define integrated impulse

$$\mathbf{I}_F = \int_{\mathcal{D}_F} \mathbf{J}_{\text{global}}(\mathbf{r})\, dV. \tag{722}$$

45.3 Surface and Lithospheric Response

The predicted far-field displacement is

$$\Delta \mathbf{x}_F = \mathcal{G}_F \left[\mathbf{I}_F, \mathbf{Q}_{F,0}, \mathcal{H}_{F,\text{later}} \right]. \tag{723}$$

The response operator must include:

- lithospheric thickness;
- pre-existing weakness;
- mantle coupling;
- gravitational restoring forces;
- rotation;
- plate interaction;
- thermal structure;
- later volcanism; and
- later plate displacement.

45.4 Pre-Existing Structure Requirement

The secondary hypothesis assumes that the far-field impulse may be amplified by a pre-existing structure.

Let the initial susceptibility field be

$$\mathcal{S}_F(\mathbf{r}). \tag{724}$$

The response is then

$$\Delta \mathbf{x}_F = \mathcal{G}_F \left[\mathbf{I}_F, \mathcal{S}_F \right]. \tag{725}$$

The susceptibility field must be independently defined.

It cannot be inferred solely from the existence of the modern Hawaiian structure.

45.5 Directional Prediction

The predicted horizontal impulse is

$$\mathbf{I}_{F,\mathrm{hor}} = \mathbf{I}_F - \left(\mathbf{I}_F \cdot \widehat{\mathbf{n}}_F \right) \widehat{\mathbf{n}}_F. \tag{726}$$

Its predicted azimuth is

$$\gamma_F^{\mathrm{pred}} = \mathrm{atan2} \left(\mathbf{I}_{F,\mathrm{hor}} \cdot \widehat{\mathbf{e}}_F, \mathbf{I}_{F,\mathrm{hor}} \cdot \widehat{\mathbf{q}}_F \right). \tag{727}$$

The observed structural azimuth is

$$\gamma_F^{\mathrm{obs}}. \tag{728}$$

The angular residual is

$$\epsilon_{\gamma,F} = \mathrm{wrap} \left(\gamma_F^{\mathrm{obs}} - \gamma_F^{\mathrm{pred}} \right). \tag{729}$$

45.6 Magnitude Prediction

The far-field displacement magnitude is

$$D_F^{\mathrm{pred}} = \left\| \Delta \mathbf{x}_F \right\|. \tag{730}$$

The observed or reconstructed displacement is

$$D_F^{\text{obs}}. \tag{731}$$

The normalized residual is

$$\epsilon_{D,F} = \frac{D_F^{\text{obs}} - D_F^{\text{pred}}}{\sigma_{D,F}}. \tag{732}$$

45.7 Independent Comparison Models

The Mauna Kea and Hawaiian system must be compared with models involving:

- plate motion over a mantle source;
- plume-related volcanism;
- lithospheric flexure;
- pre-existing fracture zones;
- thermal buoyancy;
- mantle flow;
- regional plate stresses; and
- combinations of these processes.

45.8 Secondary-Hypothesis Falsifier

Far-field falsifier F1.
If the event calculation produces no significant impulse at the reconstructed Hawaiian target, predicts the wrong direction or scale, or adds no explanatory power beyond the comparison models, the Mauna Kea far-field hypothesis is rejected without changing the status of the core Aegean–Himalayan–Mariana sequence.

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46 Nested Viability of Entrance, Path, Midpoint, Exit, and Survival

46.1 Regional Viable Sets

The event contains the regional viable sets

$$\mathcal{V}_A = \text{entrance-compatible parameter set}, \tag{733}$$
$$\mathcal{V}_P = \text{interior-path-compatible parameter set}, \tag{734}$$
$$\mathcal{V}_H = \text{Himalayan-inheritance-compatible parameter set}, \tag{735}$$
$$\mathcal{V}_M = \text{Mariana-exit-compatible parameter set}, \tag{736}$$
$$\mathcal{V}_\oplus = \text{planetary-survival-compatible parameter set}. \tag{737}$$

46.2 Handoff Operators

The entrance-to-path handoff is

$$\boldsymbol{\Theta}_{P,0} = \mathcal{H}_{A\to P}\left(\boldsymbol{\Theta}_A\right). \tag{738}$$

The path-to-midpoint handoff is

$$\boldsymbol{\Theta}_{H,0} = \mathcal{H}_{P\to H}\left(\boldsymbol{\Theta}_P\right). \tag{739}$$

The path-to-exit handoff is

$$\boldsymbol{\Theta}_{M,0} = \mathcal{H}_{P\to M}\left(\boldsymbol{\Theta}_P\right). \tag{740}$$

The complete event-to-planet handoff is

$$\mathbf{Q}_{\oplus}^{+} = \mathcal{H}_{\text{event}\to\oplus}\left(\boldsymbol{\Theta}_A, \boldsymbol{\Theta}_P, \boldsymbol{\Theta}_H, \boldsymbol{\Theta}_M\right). \tag{741}$$

46.3 Common Parameter Constraint

The event must use one shared initial parameter vector

$$\boldsymbol{\Theta}_I. \tag{742}$$

The regional solutions must satisfy

$$\boldsymbol{\Theta}_A = \mathcal{F}_A\left(\boldsymbol{\Theta}_I\right), \tag{743}$$

$$\boldsymbol{\Theta}_P = \mathcal{F}_P\left(\boldsymbol{\Theta}_I\right), \tag{744}$$

$$\boldsymbol{\Theta}_H = \mathcal{F}_H\left(\boldsymbol{\Theta}_I\right), \tag{745}$$

and

$$\boldsymbol{\Theta}_M = \mathcal{F}_M\left(\boldsymbol{\Theta}_I\right). \tag{746}$$

Independent regional tuning is not permitted.

46.4 Complete Nested Viable Set

The complete flagship-event Paper-II viable set is

$$\mathcal{V}_{\mathrm{II},F} = \mathcal{V}_A \cap \mathcal{V}_P \cap \mathcal{V}_H \cap \mathcal{V}_M \cap \mathcal{V}_\oplus \cap \mathcal{V}_{\mathrm{rot}} \cap \mathcal{V}_{\mathrm{markers}}. \tag{747}$$

For backward compatibility within this manuscript, $\mathcal{V}_{\mathrm{II}}$ denotes $\mathcal{V}_{\mathrm{II},F}$.

The literal flagship event remains open only if

$$\mathcal{V}_{\mathrm{II},F} \neq \varnothing. \tag{748}$$

46.5 Empty-Intersection Failure

It is possible for every regional set to be individually nonempty while the complete intersection is empty:

$$\mathcal{V}_A \neq \varnothing, \quad \mathcal{V}_P \neq \varnothing, \quad \mathcal{V}_H \neq \varnothing, \quad \mathcal{V}_M \neq \varnothing, \tag{749}$$

but

$$\mathcal{V}_A \cap \mathcal{V}_P \cap \mathcal{V}_H \cap \mathcal{V}_M = \varnothing. \tag{750}$$

This means that no single event can generate all regional outcomes.

46.6 Parameter-Compatibility Matrix

For parameter θ_j, define its admissible regional intervals:

$$\Theta_{A,j}, \quad \Theta_{P,j}, \quad \Theta_{H,j}, \quad \Theta_{M,j}, \quad \Theta_{\oplus,j}. \tag{751}$$

The common interval is

$$\Theta_j^{\mathrm{common}} = \Theta_{A,j} \cap \Theta_{P,j} \cap \Theta_{H,j} \cap \Theta_{M,j} \cap \Theta_{\oplus,j}. \tag{752}$$

If a completed frozen analysis gives

$$\Theta_j^{\mathrm{common}} = \varnothing, \tag{753}$$

then the connected-event realization fails for parameter j. An unmeasured or unconstrained regional interval leaves the intersection unresolved and does not create an empty set by assumption.

46.7 Regional Tension Statistic

For regional posterior distributions

$$p_A(\mathbf{\Theta}), \quad p_P(\mathbf{\Theta}), \quad p_H(\mathbf{\Theta}), \quad p_M(\mathbf{\Theta}), \tag{754}$$

define overlap

$$\mathcal{O}_\Theta = \int \min\left[p_A, p_P, p_H, p_M\right] \, d\mathbf{\Theta}. \tag{755}$$

A value near zero indicates severe regional parameter tension.

46.8 Paper-II Primary Decision Rule

Paper-II decision rule.
The proposed Aegean-to-Mariana event is mechanically viable only if one shared initial condition produces a compatible Aegean entrance, lower-mantle transmission path, Himalayan inherited response, Mariana terminal response, and surviving Earth.
Separate regional fits do not constitute one event.
A demonstrated nonempty intersection retains at least one tested mechanical realization. A completed empty intersection rejects the connected flagship-event mechanism. An unevaluated intersection, unfrozen threshold, or data-insufficient regional constraint remains unresolved.

---

47 Model Evidence, Complexity, and Branch Selection

The model-selection layer distinguishes goodness of fit, effective complexity, marginal evidence, and out-of-sample prediction [8, 9, 10, 12].

47.1 Candidate Mechanical Models

Let the candidate mechanism models be

$$\mathfrak{M} = \left\{\mathcal{M}_{\text{coh}}, \mathcal{M}_{\text{frag}}, \mathcal{M}_{\text{shock}}, \mathcal{M}_{\text{phase}}, \mathcal{M}_{\text{hybrid}}\right\}. \tag{756}$$

Each model must specify:

- its state variables;
- its equations of state;
- its constitutive laws;
- its branch-transition rules;
- its numerical resolution;
- its free parameters;
- its outputs;
- its direct falsifiers; and

- its predicted observables.

47.2 Likelihood

For model $\mathcal{M}_q$ and complete data vector $\mathbf{D}$,

$$\mathcal{L}_q = p\left(\mathbf{D} \mid \mathbf{\Theta}_q, \mathcal{M}_q\right). \tag{757}$$

The data vector includes:

$$\mathbf{D} = \left(\mathbf{D}_A, \mathbf{D}_P, \mathbf{D}_H, \mathbf{D}_M, \mathbf{D}_\oplus, \mathbf{D}_{\mathrm{strat}}\right). \tag{758}$$

47.3 Bayesian Evidence

The model evidence is

$$\mathcal{Z}_q = \int \mathcal{L}_q p\left(\mathbf{\Theta}_q \mid \mathcal{M}_q\right) \, d\mathbf{\Theta}_q. \tag{759}$$

The Bayes factor comparing models i and j is

$$K_{ij} = \frac{\mathcal{Z}_i}{\mathcal{Z}_j}. \tag{760}$$

47.4 Information Criteria

For maximum likelihood $\widehat{\mathcal{L}}$, parameter count k, and effective sample size N, possible screening criteria include

$$\mathrm{AIC} = 2k - 2\ln\widehat{\mathcal{L}}, \tag{761}$$

and

$$\mathrm{BIC} = k\ln N - 2\ln\widehat{\mathcal{L}}. \tag{762}$$

These criteria do not replace physical falsification.

A statistically preferred model can still violate conservation or planetary survival.

47.5 Physical-Prior Penalty

A model requiring parameters outside independently defensible ranges receives prior penalty.

For parameter vector $\mathbf{\Theta}$,

$$p_{\text{phys}}\left(\boldsymbol{\Theta}\right)=\prod_{j}p_{j}\left(\theta_{j}\right). \tag{763}$$

A favorable fit produced only by extreme, uncalibrated, or internally inconsistent parameters is not accepted.

47.6 Branch-Transition Penalty

For a hybrid model containing N_{trans} mechanism transitions, define complexity penalty

$$\mathcal{P}_{\text{trans}}=\lambda_{\text{trans}}N_{\text{trans}}+\sum_{j=1}^{N_{\text{trans}}}\mathcal{P}_{j,\text{uncertainty}}. \tag{764}$$

Every additional transition must improve predictive performance enough to justify its added flexibility.

47.7 Numerical-Artifact Penalty

Define numerical-instability penalty

$$\mathcal{P}_{\text{num}}=w_{h}\epsilon_{h}+w_{E}\epsilon_{E}+w_{M}\epsilon_{M}+w_{p}\epsilon_{p}+w_{B}\epsilon_{B}, \tag{765}$$

where the terms quantify:

- mesh dependence;
- energy residual;
- mass residual;
- momentum residual;
- boundary-condition dependence.

47.8 Total Model Score

A general penalized score is

$$\mathcal{S}_{q}=-2\ln\widehat{\mathcal{L}}_{q}+\mathcal{P}_{\text{complexity}}+\mathcal{P}_{\text{physical}}+\mathcal{P}_{\text{numerical}}+\mathcal{P}_{\text{missing}}. \tag{766}$$

Lower values indicate better penalized performance.

47.9 Comparison With Non-Astro-Ballistic Models

The event mechanics must also be compared with models in which the regional observations arise from:

- ordinary tectonic deformation;

- subduction;
- continental collision;
- mantle flow;
- plume processes;
- basin development;
- inherited crustal structure;
- long-duration geodynamic evolution; and
- combinations of these mechanisms.

The relevant comparison is not merely which astro-ballistic branch is best.

It is whether any astro-ballistic branch is required.

47.10 Branch Eligibility and Comparative Preference

A mechanism branch is mechanically eligible only if:

1. its tested viable set is nonempty;
2. it satisfies conservation and hard admissibility conditions;
3. it survives planetary constraints;
4. it produces the required regional outputs;
5. its numerical solution converges;
6. its constitutive laws are defensible; and
7. its mandatory predicted observations are not contradicted.

Eligibility is distinct from preference. A mechanically eligible branch is comparatively preferred only if, under frozen T4 rules, it predicts held-out observations better or provides justified explanatory gain after effective-complexity accounting. Failure to outperform another branch means that preference is not established; it does not by itself falsify mechanical eligibility.

48 Paper-II Claim Ledger

48.1 Claim Classes

Paper-II claims are classified as:

Inherited hypothesis
A starting claim from the earlier source framework.

Audited calculation
A result reproduced from declared inputs.

Mechanical requirement
A condition that any viable event must satisfy.

Model prediction
An output to be generated by numerical simulation.

Falsification condition
A result that rejects a specified claim or branch.

Replacement dependency
A result required before the wider causal replacement can proceed.

48.2 Claim Ledger

Table 8: Paper-II claim ledger.

ID	Class	Claim	Current status
P2-C01	Audited calculation	The straight reference chord is approximately 10 150.567 km.	Reproduced
P2-C02	Audited calculation	The maximum reference depth is approximately 2519.878 km.	Reproduced
P2-C03	Audited calculation	Approximately 83.1% of the declared reference path lies below 660 km.	Reproduced under the declared shell model
P2-C04	Audited calculation	The straight-path entrance angle is approximately 52.81° below local horizontal.	Reproduced
P2-C05	Audited calculation	The inherited energy and velocity ranges imply masses of approximately $2.22 \times 10^{20} - 2.00 \times 10^{23}$ kg.	Reproduced
P2-C06	Audited calculation	Representative projectile column densities are below the reference Earth-path column density.	Screening result
P2-C07	Inherited hypothesis	A concentrated disturbance entered near the Mini Aegean region.	Unverified
P2-C08	Inherited hypothesis	The disturbance crossed the deep mantle.	Unverified
P2-C09	Inherited hypothesis	The event generated a Himalayan middle-path inheritance.	Unverified
P2-C10	Inherited hypothesis	The disturbance produced a Mariana terminal response.	Unverified

ID	Class	Claim	Current status
P2-C11	Mechanical requirement	One shared parameter set must generate entrance, path, midpoint, and exit.	Requirement defined
P2-C12	Mechanical requirement	The event must conserve mass, momentum, energy, and angular momentum.	Requirement defined
P2-C13	Mechanical requirement	The event must survive lower-mantle attenuation and broadening.	Requirement defined
P2-C14	Mechanical requirement	The event must produce a persistent inheritance state.	Requirement defined
P2-C15	Mechanical requirement	The event must remain compatible with whole-planet survival.	Requirement defined
P2-C16	Model prediction	A viable branch will predict specific entrance, path, midpoint, and exit geophysical fields.	Not yet simulated
P2-C17	Model prediction	A viable branch will predict global ejecta, atmospheric, oceanic, and stratigraphic consequences.	Not yet simulated
P2-C18	Secondary hypothesis	Mauna Kea may preserve a far-field impulse response.	Compartmentalized and unverified
P2-C19	Replacement dependency	A nonempty complete mechanical viable set exists.	Unknown
P2-C20	Replacement dependency	The resulting inherited state predicts later plate behavior.	Reserved for Paper III

48.3 Claim Dependency Structure

The primary dependency chain is

$$\begin{aligned} &\{\text{P2-C01}, \text{P2-C02}, \text{P2-C03}, \text{P2-C04}, \text{P2-C05}, \text{P2-C06}\} \\ &\quad \longrightarrow \{\text{P2-C07}, \text{P2-C08}, \text{P2-C09}, \text{P2-C10}\} \\ &\quad \longrightarrow \{\text{P2-C11}, \text{P2-C12}, \text{P2-C13}, \text{P2-C14}, \text{P2-C15}\} \\ &\quad \longrightarrow \{\text{P2-C16}, \text{P2-C17}, \text{P2-C19}\} \\ &\quad \longrightarrow \text{P2-C20}. \end{aligned} \tag{767}$$

The far-field Mauna Kea hypothesis remains outside the required core dependency chain.

49 Complete Paper-II Falsification Matrix

49.1 Falsification Levels

Paper-II failures are divided into:

Branch failure
One mechanism branch is rejected.

Regional mechanical failure
One entrance, midpoint, or exit role is rejected.

Connected-event failure
No shared parameter set connects the complete sequence.

Planetary-survival failure
Mechanically sufficient solutions are incompatible with Earth.

Replacement dependency failure
Paper III cannot use this event as a viable causal building block.

Table 9: Complete Paper-II falsification matrix.

ID	Claim	Falsifying result	Consequence
P2-F01	Coherent-body penetration	No macroscopic projectile-derived body survives the required depth.	Reject coherent-body branch.
P2-F02	Fragmented-column transmission	Fragmentation and entrainment disperse directional momentum before the terminal region.	Reject fragmented-column branch.
P2-F03	Shock transmission	The shock attenuates, reflects, or globalizes before producing a localized exit.	Reject shock-dominated branch.
P2-F04	Phase-front transmission	No calibrated damage or phase law produces a connected front.	Reject fracture- and phase-front branch.
P2-F05	Hybrid transmission	The model requires unconstrained transitions or violates conservation.	Reject hybrid branch.
P2-F06	Aegean entrance	No shared parameter set reproduces the entrance and transmits the required path state.	Reject Aegean entrance mechanics.
P2-F07	Deep-mantle passage	Every branch loses required energy, momentum, or localization in the lower mantle.	Reject connected deep transmission.

ID	Claim	Falsifying result	Consequence
P2-F08	Himalayan response	No calculated response field intersects a defensible reconstructed Himalayan domain.	Reject mechanical middle-mountain claim.
P2-F09	Himalayan inheritance	No persistent node survives or affects later regional evolution.	Reject inherited midpoint mechanism.
P2-F10	Mariana targeting	No viable path reaches a defensible Mariana precursor domain.	Reject Mariana terminal-response assignment.
P2-F11	Terminal decompression	The disturbance disperses before producing a localized terminal response.	Reject exit-decompression mechanism.
P2-F12	Terminal excavation	Required terminal structure needs more energy or momentum than the path delivers.	Reject terminal excavation model.
P2-F13	Exit inheritance	Later trench development is unchanged without the event-created state.	Reject event organization of the Mariana system.
P2-F14	Thermal compatibility	All mechanically sufficient events predict incompatible heating or melt.	Reject relevant event-energy range.
P2-F15	Ocean compatibility	All sufficient events predict incompatible vaporization or ocean loss.	Reject relevant event-energy range.
P2-F16	Atmospheric compatibility	All sufficient events predict incompatible atmospheric loss or forcing.	Reject relevant event-energy range.
P2-F17	Rotation compatibility	All sufficient events predict incompatible rotation or inertia changes.	Reject relevant geometry and momentum range.
P2-F18	Global markers	High-detection-probability predicted markers are absent.	Reject relevant parameter range.
P2-F19	Deep geophysical corridor	A predicted detectable seismic or gravity corridor is absent.	Reject the relevant path state.
P2-F20	Projectile-derived material	A branch predicts abundant detectable foreign material that is absent.	Reject the relevant composition or branch.
P2-F21	Numerical robustness	The solution disappears under mesh refinement or solver changes.	Reject the numerical result.

ID	Claim	Falsifying result	Consequence
P2-F22	Conservation	Mass, energy, momentum, or angular-momentum residuals exceed declared tolerances.	Reject the simulation.
P2-F23	Common parameter set	Regional solutions require mutually incompatible initial conditions.	Reject the connected event.
P2-F24	Complete viability	The complete nested viable set is empty.	Reject the literal Aegean-to-Mariana mechanical event.
P2-F25	Mauna Kea secondary hypothesis	No predicted far-field impulse matches the target.	Reject only the secondary far-field claim.
P2-F26	Flagship handoff dependency	No viable flagship event state exists for transfer into Paper III.	Paper III cannot use this event as a causal plate-building block; other candidate events require their own Paper-I and Paper-II-equivalent audits.

49.2 Non-Detection and Simulation-Completion Rule

A branch is not rejected merely because its simulation has not yet been run or because a predicted marker has not yet been measured. Hard non-detection requires a frozen prediction, a defensible detection probability, adequate survey sensitivity, and a completed observation. Solver failure caused by an invalid implementation rejects the numerical result, not automatically the physical branch.

49.3 No Failure Laundering

A failed branch cannot be relabeled without consequence.

The following rules apply:

1. Replacing coherent penetration with shock transmission creates a revised model.
2. Replacing a straight path with a curved path creates a revised model.
3. Replacing a direct mountain response with delayed inheritance creates a revised model.
4. Replacing direct excavation with later trench reactivation creates a revised model.
5. Every revised model requires new equations, new predictions, new penalties, and new falsification conditions.

49.4 Compartmentalized Failure

Failure of the Mauna Kea hypothesis does not reject the core event.

Failure of one mechanism branch does not reject every other branch.

Failure of the complete nested viable set rejects the connected flagship event regardless of partial regional successes.

It does not empty the mechanically viable sets of unrelated candidate events, and it does not by itself reject regional hypotheses that do not depend on this transmission path.

50 Independent Numerical Replication Protocol

50.1 Replication Objective

Independent analysts must be able to reproduce:

- the geometry;
- the parameter grid;
- the constitutive inputs;
- the entrance simulation;
- the deep-path simulation;
- the midpoint response;
- the terminal response;
- the planetary consequences;
- the viability intersections;
- the branch comparisons; and
- the claim-status outputs.

50.2 Replication Levels

50.2.1 Level M1: Analytic Screening

The reviewer reproduces:

- impactor mass;
- radius;
- momentum;
- incidence geometry;
- chord length;
- depth;

- shell intersections;
- column density;
- binding-energy ratios; and
- first-order survival bounds.

50.2.2 Level M2: Constitutive Verification

The reviewer verifies:

- equations of state;
- shock Hugoniots;
- strength laws;
- damage laws;
- phase boundaries;
- melt and vapor relations;
- viscosity laws;
- relaxation laws; and
- parameter-calibration ranges.

50.2.3 Level M3: Entrance Simulation

The reviewer reproduces:

- atmosphere and ocean interaction;
- crustal penetration;
- excavation;
- melt;
- fracture;
- transmitted energy;
- transmitted momentum; and
- the mantle handoff state.

50.2.4 Level M4: Interior Transmission

The reviewer reproduces:

- path attenuation;
- path broadening;

- phase-boundary interaction;
- path curvature;
- lower-mantle survival;
- mechanical midpoint fields;
- corridor inheritance; and
- deep-Earth observables.

50.2.5 Level M5: Terminal Exit

The reviewer reproduces:

- terminal targeting;
- decompression;
- excavation;
- fracture;
- ejecta;
- ocean response;
- atmosphere response;
- gravity;
- magnetics;
- tomography; and
- later inheritance.

50.2.6 Level M6: Whole-Planet Survival

The reviewer reproduces:

- mass loss;
- melt;
- ocean loss;
- atmosphere loss;
- rotation change;
- inertia change;
- ejecta deposits;
- missing-marker probabilities; and
- complete survival scoring.

50.2.7 Level M7: Nested Viability

The reviewer reproduces:

- regional viable sets;
- parameter intersections;
- posterior overlaps;
- model evidence;
- complexity penalties;
- claim dependencies; and
- final branch status.

50.3 Required Repository Structure

```
abc-paper-ii/
|
|-- manuscript/
|   |-- main.tex
|   `-- figures/
|
|-- inputs/
|   |-- geometry/
|   |-- earth-models/
|   |-- equations-of-state/
|   |-- rheology/
|   |-- strength-damage/
|   |-- phase-transitions/
|   `-- parameter-priors/
|
|-- simulations/
|   |-- analytic-screening/
|   |-- entrance/
|   |-- interior-path/
|   |-- midpoint/
|   |-- exit/
|   |-- long-time-evolution/
|   `-- planetary-survival/
|
|-- validation/
|   |-- unit-tests/
|   |-- benchmark-tests/
|   |-- convergence/
|   |-- conservation/
```

```
|   `-- cross-solver/
|
|-- outputs/
|   |-- raw/
|   |-- processed/
|   |-- figures/
|   |-- tables/
|   `-- logs/
|
|-- ledgers/
|   |-- claim-ledger.csv
|   |-- equation-registry.csv
|   |-- parameter-registry.csv
|   |-- branch-registry.csv
|   |-- falsification-matrix.csv
|   `-- dependency-graph.json
|
`-- README.md
```

50.4 Simulation Metadata

Every simulation must report:

- software;
- software version;
- compiler;
- hardware;
- precision;
- solver;
- numerical method;
- mesh;
- timestep;
- domain size;
- boundary conditions;
- initial conditions;
- constitutive models;
- random seed;
- convergence tolerances;

- conservation tolerances; and
- runtime.

50.5 Benchmark Requirements

Before simulating the full event, the numerical system must reproduce benchmark problems involving:

- shock tubes;
- planar impact;
- oblique impact;
- impedance-interface transmission;
- material fragmentation;
- phase transition;
- gravitational collapse or expansion;
- rotating-frame trajectories;
- excavation flow;
- ejecta propagation; and
- viscoelastic relaxation.

50.6 Convergence Suite

At least three spatial resolutions must be reported:

$$h, \qquad \frac{h}{2}, \qquad \frac{h}{4}. \tag{768}$$

At least three timestep controls must be tested.

The following outputs must be checked for convergence:

- entrance energy fraction;
- path momentum fraction;
- path radius;
- maximum depth reached;
- midpoint-response location;
- terminal energy;
- terminal excavation volume;
- melt volume;

- escaped mass;
- rotation change; and
- complete viability status.

50.7 Cross-Solver Reproduction

At least one decisive result should be reproduced using an independent numerical method or code base.

Agreement should be reported for:

- conservation;
- path geometry;
- attenuation;
- response maxima;
- exit state;
- planetary consequences; and
- branch viability.

50.8 Negative Replication

Reviewers are explicitly invited to:

- eliminate parameter regions;
- substitute stricter material models;
- increase missing-marker penalties;
- use alternative Earth models;
- apply tighter conservation limits;
- test alternate entrance domains;
- test alternate Mariana domains;
- remove the Himalayan node;
- test competing regional models; and
- publish failed simulations.

50.9 Replication Outcomes

The allowed statuses are:

Reproduced
: The result agrees within declared tolerances.

Partially reproduced
Some outputs agree, but one or more assumptions or regions fail.

Not reproduced
The result does not follow from the declared inputs.

Numerically unstable
The result changes materially with resolution, timestep, or solver.

Physically inadmissible
The result violates conservation, constitutive calibration, or planetary constraints.

Falsified
A predeclared rejection condition is triggered.

51 Mechanical Eligibility Versus Comparative Preference

Paper II determines whether at least one frozen event–frame–lineage– mechanism branch remains mechanically admissible. Paper IV determines whether an admissible branch is necessary, predictively superior, and preferable after complexity and null-model control. These are different questions.

A favorable model-comparison score cannot make an energy-, momentum-, rotation-, survival-, or chronology-violating branch mechanically viable. A comparative loss also does not by itself falsify a mechanically viable branch. It may instead produce `NOT-ESTABLISHED`, `DISFAVORED`, `COMPLEMENTARY`, or `HYBRID-PREFERRED` status.

The branch-level viable set is rejected only by its own mandatory physical conditions. Replacement qualification requires additional Paper-IV gates and must not be written back into Paper II as though it were a mechanical result.

52 Integrated Discussion

52.1 Paper II Converts a Map Into a Mechanical Search

Paper I identified a reproducible but mixed geographic relationship.

The selected Aegean and Mariana coordinates place Everest near the bilateral and along-track halfway position while leaving it far from the present great-circle plane.

Paper II therefore does not assume that a literal modern straight chord passed through Everest.

It asks whether a physically calculated disturbance could generate:

1. an Aegean entrance;
2. a deep lower-mantle path;
3. an offset Himalayan inheritance;
4. a Mariana terminal response; and
5. a surviving global geological state.

52.2 The Lower Mantle Dominates the Mechanical Problem

Approximately 83.1% of the reference chord lies below 660 km under the declared shell model.

The core mechanical challenge is therefore not crustal penetration.

It is maintaining a concentrated event through more than

$$8400\,\text{km} \tag{769}$$

of lower-mantle path.

This requires quantitative treatment of:

- high-pressure equations of state;
- phase transitions;
- heating;
- damage;
- entrainment;
- attenuation;
- path broadening;
- gravity;
- rotation;
- heterogeneous material structure; and
- long-term relaxation.

52.3 Ordinary Rigid Penetration Is the Most Restrictive Branch

The audited event ranges imply bodies hundreds to thousands of kilometres in scale.

Representative projectile column densities remain below the reference Earth-path column density.

This does not mathematically eliminate every concentrated disturbance.

It strongly raises the burden on a coherent rigid-body interpretation.

The more plausible surviving branch, if one exists, may involve:

- early fragmentation;
- a mixed penetration column;
- shock transmission;
- phase and damage propagation;
- or a constrained hybrid sequence.

That conclusion must come from simulation rather than preference.

52.4 A Hybrid Model Cannot Become Unlimited

A hybrid event may be physically realistic because the dominant carrier can change with depth.

It is also the branch most vulnerable to post hoc repair.

The manuscript therefore requires:

- predeclared transition criteria;
- conservation across every transition;
- branch-specific predictions;
- complexity penalties;
- numerical convergence; and
- direct rejection conditions.

52.5 The Himalayan Claim Is an Inheritance Claim

The modern mountain cannot be assigned directly to a 256 Ma event without later geological evolution.

The defensible mechanical claim is narrower:

> The event may have created a bounded deep material-state anomaly that later regional forcing amplified into part of the Himalayan structural pattern.

That claim requires a counterfactual test.

The later regional model must be run both with and without the event-created state.

If the outcome is unchanged, the event is not required.

52.6 The Mariana Claim Requires More Than a Deep Trench

The exit must be produced from the state delivered by the interior path.

The model must predict:

- terminal location;
- direction;
- energy;
- momentum;
- path radius;
- decompression;
- excavation;

- fracture;
- melt;
- gravity;
- magnetics;
- tomography;
- ejecta;
- ocean disturbance;
- atmosphere disturbance; and
- later trench inheritance.

The modern trench must then be compared against a subduction-only counterfactual.

52.7 The Planetary Survival Window May Be Narrow

The event must be large enough to generate a deep connected sequence.

It must simultaneously remain small enough to avoid incompatible:

- global melting;
- atmosphere loss;
- ocean loss;
- crustal destruction;
- mantle disruption;
- rotation changes;
- ejecta signatures; and
- missing global markers.

The required and permitted energy windows may fail to overlap.

That possibility is a central falsifier rather than a weakness to be avoided.

52.8 A Mechanically Viable Event Is Not Yet a Replacement

Even if

$$\mathcal{V}_{\mathrm{II}} \neq \varnothing, \tag{770}$$

Paper II would establish only that a physical event of the declared class is possible.

Causal replacement of Plate Tectonics requires Paper III to show that the inherited state predicts:

- plate boundaries;

- plate directions;
- plate speeds;
- mountains;
- trenches;
- ridges;
- basins;
- volcanic provinces;
- resource patterns; and
- the broader event chronology.

Paper IV must then compare the complete framework directly with plate tectonics.

53 Limitations of Paper II

53.1 No Completed Planetary Simulation

This manuscript defines the governing system and test architecture.

It does not yet contain a completed three-dimensional planetary simulation.

53.2 Constitutive Uncertainty

The relevant material behavior spans extreme pressure, temperature, strain rate, phase, damage, melt, vapor, and loading duration.

Many required constitutive relations remain to be selected and calibrated.

53.3 Paleo-Earth Uncertainty

The precise pre-event:

- geography;
- crustal structure;
- mantle state;
- ocean distribution;
- atmosphere;
- stress field;
- plate configuration; and
- thermal structure

remain uncertain.

53.4 Entrance Uncertainty

The exact Aegean entrance center, boundary, material target, and paleo-surface condition remain unresolved.

53.5 Himalayan Target Uncertainty

The relevant Himalayan precursor may be:

- crustal;
- lithospheric;
- mantle;
- phase-related;
- damage-related;
- density-related; or
- a combination.

The target must be independently defined.

53.6 Mariana Target Uncertainty

The modern trench may not coincide exactly with the proposed ancient exit.

The precursor target and later preservation history remain unresolved.

53.7 Long-Time Handoff Uncertainty

Mapping a minutes-scale shock calculation into hundreds of millions of years of geodynamic evolution requires a carefully validated handoff.

53.8 Tomographic Resolution

Present seismic images are incomplete and resolution limited.

A predicted corridor may be blurred, aliased, or undetectable.

Conversely, a visually suggestive tomographic structure may be an artifact or unrelated feature.

53.9 Preservation Uncertainty

Shock, melt, geochemical, magnetic, structural, and sedimentary markers may be altered or destroyed.

The preservation operator remains to be quantified.

53.10 Global-Marker Uncertainty

The expected global record depends strongly on:

- event energy;

- projectile composition;
- entrance environment;
- exit environment;
- atmospheric state;
- ocean state;
- ejecta distribution;
- burial;
- erosion;
- metamorphism; and
- sampling coverage.

53.11 Replacement Limitation

Paper II addresses physical possibility.

It does not establish that astro-ballistic events are the primary cause of the global plate system.

53.12 Reserved-Event Scope

Paper II intentionally does not model every additional directional or material-displacement event contemplated for later work. Those reserved hypotheses receive no mechanical credit in the present viable set. Their future addition requires a new frozen sequence and cannot retroactively convert a failed flagship branch into a successful one.

54 Conclusions

54.1 Conclusion 1: The Event Is a Coupled Planetary Problem

The proposed Aegean-to-Mariana sequence cannot be evaluated through one impact-energy estimate or one geometric chord.

It requires a coupled compressible, thermodynamic, self-gravitating, rotating, damaging, melting, phase-transforming, and long-duration geodynamic model.

54.2 Conclusion 2: The Declared Reference Chord Is Lower-Mantle Dominated

The audited straight reference chord is approximately

$$10\,150.567\,\text{km} \tag{771}$$

long and reaches approximately

$$2519.878\,\text{km} \tag{772}$$

depth.

Under the declared shell model, approximately

$$83.1\% \tag{773}$$

of the path lies below 660 km.

54.3 Conclusion 3: The Declared Search Range Implies Extreme Object Scales

The inherited energy and velocity intervals imply an impactor-mass range of approximately

$$2.22 \times 10^{20} \lesssim M_I \lesssim 2.00 \times 10^{23} \quad \text{kg.} \tag{774}$$

The event must therefore be tested against severe entrance, transmission, planetary-survival, and global-marker constraints.

54.4 Conclusion 4: Coherent Penetration Is Only One Branch

The mechanical search must distinguish among:

1. coherent-body penetration;
2. fragmented-column transmission;
3. shock-dominated transmission;
4. fracture- and phase-front transmission; and
5. constrained hybrid transmission.

Each branch has separate requirements and falsifiers.

54.5 Conclusion 5: The Himalayan Response Must Emerge

The event does not succeed by assigning Everest to the midpoint.

A pressure, damage, phase, density, or persistent inheritance field must emerge from the mechanical calculation within a defensible reconstructed Himalayan domain.

The event-created state must then produce a measurable difference under later regional forcing.

54.6 Conclusion 6: The Mariana Terminal Response Must Be Delivered by the Path

The terminal response cannot be independently parameterized.

Its energy, momentum, direction, composition, width, and phase state must be inherited from the entrance and deep-path solution.

The terminal model must then predict a preserved structure distinguishable from later subduction.

54.7 Conclusion 7: Planetary-Survival Failure Can Falsify a Mechanical Branch

A mechanically sufficient event may still fail because it predicts incompatible:

- global heating;
- melting;
- atmosphere loss;
- ocean loss;
- crustal destruction;
- mantle disturbance;
- rotation change;
- ejecta; or
- missing geological markers.

54.8 Conclusion 8: One Event Realization Must Satisfy All Mandatory Domains

The decisive Paper-II object is

$$\mathcal{V}_{\mathrm{II},k,b,r} = \mathcal{V}_{A,k,b,r} \cap \mathcal{V}_{P,k,b,r} \cap \mathcal{V}_{H,k,b,r} \cap \mathcal{V}_{M,k,b,r} \cap \mathcal{V}_{\oplus,k,b,r} \cap \mathcal{V}_{\mathrm{rot},k,b,r} \cap \mathcal{V}_{\mathrm{markers},k,b,r}, \tag{775}$$

where k identifies the candidate event, b the mechanical branch, and r the uncertainty realization. Separate regional solutions from incompatible realizations are insufficient. The event-level mechanical viable set is

$$\mathcal{V}_{\mathrm{II},k} = \bigcup_{b,r} \mathcal{V}_{\mathrm{II},k,b,r}. \tag{776}$$

Failure of one branch or realization does not reject the event-level mechanical hypothesis while another preregistered branch remains admissible.

54.9 Conclusion 9: Mauna Kea Remains Secondary

The Mauna Kea far-field hypothesis is preserved as a separate, falsifiable test.

Its success is not required for the core event.

Its failure does not rescue or reject the core event.

54.10 Conclusion 10: The Mechanical Question Remains Open

Paper II does not claim that a viable parameter set has already been demonstrated.

It defines the equations, constraints, outputs, numerical hierarchy, claim structure, and rejection conditions needed to determine whether one exists.

54.11 Final Paper-II Statement

The Aegean-to-Mariana event survives mechanically only if one shared astro-ballistic initial condition generates a compatible entrance, crosses a lower-mantle-dominated interior path, produces a bounded Himalayan inheritance, reaches the Mariana region with sufficient localized energy and momentum, creates a preserved terminal structure, and leaves an Earth compatible with the later geological record.

A branch-realization pair fails if its complete viable intersection is empty. The event-level mechanical hypothesis fails only if

$$\mathcal{V}_{\mathrm{II},k} = \varnothing \tag{777}$$

after all preregistered branches and uncertainty realizations have been evaluated.

If the event-level set is nonempty, the resulting post-event boundary, damage, density, thermal, phase, momentum, and displacement fields become the initial conditions for the global tectonic reconstruction tested in Paper III.

A Paper-II Reference Geometry

Table 10: Paper-II reference geometric quantities.

Quantity	Reference value
Aegean–Mariana central angle	105.617599°
Straight reference chord	10 150.567 km
Half-chord	5075.284 km
Minimum radial distance	3851.122 km
Maximum depth	2519.878 km
Entrance angle below horizontal	52.808799°
Entrance angle from inward radial	37.191201°
Reference crustal-shell path	88.011 km
Reference upper-mantle path	962.582 km
Reference transition-zone path	665.667 km
Reference lower-mantle path	8434.306 km
Lower-mantle path fraction	83.092%

B Initial Event Parameter Registry

Table 11: Minimum initial event parameter registry.

Parameter	Symbol	Required treatment
Impactor mass	M_I	Derived jointly with energy and velocity.
Impactor velocity	$\mathbf{v}_I$	Magnitude, azimuth, and incidence angle.
Impactor radius	R_I	Derived from mass, density, and shape.
Impactor density	ρ_I	Composition-dependent prior.
Impactor spin	$\boldsymbol{\omega}_I$	Magnitude and orientation.
Impactor composition	$\mathcal{C}_I$	Material fractions and phase state.
Entrance coordinate	$\mathbf{x}_A$	Point and uncertainty domain.
Exit target	$\mathcal{D}_M$	Reconstructed target region.
Event age	t_0	Provisional 256 Ma hypothesis parameter.
Earth state	$\mathbf{Q}_0$	Radial and later three-dimensional ensembles.

Parameter	Symbol	Required treatment
Mechanism branch	$\mathcal{M}_q$	Predeclared branch and transition rules.

C Mechanical Output Registry

Table 12: Principal Paper-II mechanical outputs.

Domain	Output	Purpose
Entrance	Energy and momentum partition	Defines the mantle handoff.
Entrance	Excavation, melt, and damage	Predicts Aegean forensic evidence.
Path	Energy, momentum, and width	Tests deep transmission.
Path	Curvature and attenuation	Tests targeting and localization.
Path	Thermal and damage corridor	Defines long-term inheritance.
Midpoint	Pressure, damage, phase, and density maxima	Defines the Himalayan response.
Midpoint	With-node versus without-node outcome	Tests node necessity.
Exit	Terminal state	Defines available exit mechanics.
Exit	Excavation and fracture field	Predicts Mariana morphology.
Exit	Ocean, atmosphere, and ejecta	Tests global consequences.
Planet	Mass, heat, melt, rotation, and survival	Defines planetary admissibility.
Global	Stratigraphic and geochemical markers	Tests expected geological evidence.

D Equation Registry

Table 13: Selected Paper-II equation registry.

ID	Equation	Purpose
P2-E01	equation (33)	Defines the initial astro-ballistic state.
P2-E02	equation (69)	Conserves mass.
P2-E03	equation (71)	Conserves momentum in the rotating frame.

ID	Equation	Purpose
P2-E04	equation (73)	Conserves total energy.
P2-E05	equation (78)	Conserves angular momentum.
P2-E06	equation (118)	Closes the thermodynamic system.
P2-E07	equation (142)	Defines shock mass conservation.
P2-E08	equation (83)	Defines damage evolution.
P2-E09	equation (190)	Defines event-regime rheology.
P2-E10	equation (239)	Defines projectile mass per frontal area.
P2-E11	equation (257)	Measures path energy localization.
P2-E12	equation (260)	Measures directional momentum localization.
P2-E13	equation (254)	Defines the reference radial path.
P2-E14	equation (56)	Defines the radial Earth-layer partition.
P2-E15	equation (265)	Defines physical-path curvature.
P2-E16	equation (255)	Defines the post-event corridor.
P2-E17	equation (491)	Defines the mechanical midpoint response.
P2-E18	equation (497)	Defines the Himalayan inheritance node.
P2-E19	equation (525)	Defines the terminal approach state.
P2-E20	equation (580)	Partitions exit energy.
P2-E21	equation (697)	Calculates post-event rotation.
P2-E22	equation (747)	Defines complete nested viability.

E Simulation Decision Tree

The numerical program should follow this sequence:

Step 1. Freeze geometry, target domains, and event-age interval.

Step 2. Freeze the initial event parameter grid.

Step 3. Select independently calibrated material models.

Step 4. Run analytic elimination tests.

Step 5. Run entrance-only simulations.

Step 6. Reject entrance states that cannot transmit the required mantle handoff.

Step 7. Run interior-path simulations for each surviving branch.

Step 8. Reject branches that fail lower-mantle transmission.

Step 9. Calculate the Himalayan mechanical response.

Step 10. Reject branches that miss all defensible Himalayan targets.

Step 11. Calculate the terminal Mariana state.

Step 12. Reject branches that fail terminal targeting or localization.

Step 13. Calculate exit morphology and global consequences.

Step 14. Reject branches that fail planetary survival.

Step 15. Calculate preservation and modern observables.

Step 16. Compare with entrance, path, midpoint, exit, and global data.

Step 17. Calculate regional viable sets.

Step 18. Calculate the complete intersection.

Step 19. Report the surviving branch or the empty viable set.

F Paper-III Handoff State

F.1 Purpose

Paper III receives the post-event state required to test whether Astro-Ballistic Chronostratigraphic Sequencing can reconstruct the global plate system.

The handoff is not the original impactor state.

It is the surviving planetary state after candidate event k and its early relaxation interval.

F.2 Handoff Vector

The Paper-III initial state is

$$\mathbf{Q}_{\mathrm{III},0}^{(k)} = (\mathcal{B}_{\mathrm{ABC}}, \mathbf{J}_{\mathrm{plate}}, \Delta T, \Delta\rho, \mathbf{D}, \Delta\phi, \chi_m, \Delta\mathbf{C}, \Delta\boldsymbol{\sigma}, \mathbf{u}, \Delta\mathbf{g}, \Delta\boldsymbol{\omega}) . \tag{778}$$

For candidate sequence $\mathcal{S}$, Paper III receives the set

$$\mathbf{H}_{II\to III}(\mathcal{S}) = \left\{\mathbf{Q}_{\mathrm{III},0}^{(k)} : k \in \mathcal{S}\right\} . \tag{779}$$

Here:

$$\mathcal{B}_{\mathrm{ABC}} = \text{event-created or event-modified boundary network,} \tag{780}$$

$$\mathbf{J}_{\mathrm{plate}} = \text{plate-scale impulse field,} \tag{781}$$

$$\mathbf{D} = \text{damage and anisotropy field,} \tag{782}$$

$$\Delta\mathbf{C} = \text{elastic and rheological property changes.} \tag{783}$$

F.3 Required Paper-III Outputs

Paper III must use $\mathbf{Q}_{\mathrm{III},0}$ to predict:

- plate-boundary locations;
- plate-boundary orientations;
- plate-motion directions;
- plate-motion speeds;
- mountain-system locations;
- trench locations;
- basin locations;
- ridge and fracture-zone locations;
- volcanic provinces;
- inherited seismic and gravity anomalies;
- event chronology; and
- the global event catalog.

F.4 Causal Status of the Paper-III Handoff

Each field in $\mathbf{Q}^{(k)}_{\mathrm{III},0}$ must carry both a numerical uncertainty and a causal-production status:

- `DIRECT-SIMULATION-OUTPUT`;
- `CONSTITUTIVE-INFERENCE`;
- `ASSUMED-INITIAL-STATE`;
- `NOT-PRODUCED`; or
- `UNRESOLVED`.

Paper III may not treat an assumed damage, boundary, density, thermal, or impulse field as though Paper II had generated it. A sequence remains eligible only through the subset of handoff fields actually produced by a mechanically admissible branch or independently constrained as a background state.

F.5 Handoff Failure

If Paper II produces no nonempty mechanically viable state for the flagship event,

$$\mathcal{V}_{\mathrm{II},F} = \varnothing, \tag{784}$$

then Paper III cannot use the Aegean–Himalayan–Mariana flagship candidate event as a validated causal building block.

Paper III may still test other proposed events, but it must report the failure of this flagship mechanism.

Paper-II Freeze Status and Remaining Empirical Work

Corpus Freeze 1.0 completes the manuscript-level compilation, literature and source integration, equation audit, consistency audit against Paper I, and version freeze for Paper II. Mechanical viability itself remains an empirical and numerical research question.

The following remain required before any branch can be reported as a completed mechanical solution:

1. equations-of-state selection and constitutive-model calibration;
2. frozen Earth-model and parameter-prior selection;
3. analytic screening followed by entrance, deep-path, midpoint-response, terminal-response, and long-time simulations;
4. whole-planet survival and preservation calculations;
5. observation-forward modeling and numerical convergence testing;
6. independent cross-solver reproduction; and
7. machine-readable claim, falsification, and Paper-III handoff exports tied to the frozen simulation release.

The next manuscript in the series is:

Astro-Ballistic Chronostratigraphic Sequencing III

From Event Geometry to Continents, Trenches, Mountains, and Basins

Global Plate-Boundary Formation, Inherited Motion, Continental Displacement, and Tectonic Reconstruction

References

The external references below support conventional scientific context, standard methods, and comparison requirements. Their inclusion does not imply endorsement or independent verification of Astro-Ballistic Chronostratigraphic Sequencing.

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