Dear Reviewers,

We sincerely thank you for the time and care you have devoted to reviewing our manuscript. Your comments have been thoughtful, constructive, and highly valuable. They have helped us clarify key conceptual distinctions, strengthen the justification of our approach, improve the explanation of figures and examples, and better articulate the practical implications of POKIMON for geological modelling workflows.

In the following, we respond to each comment in detail and indicate how the manuscript has been revised accordingly.

**First review:**

1-The introduction provides a clear introduction to the challenges of reproducibility and subjectivity in geomodelling, and an overview of related prior-work developing geoscience ontologies. But, it does not really explain why ontologies are necessary in the first place ("The use of formal languages and ontologies is growing in the geosciences", line 50, is not a justification). I suggest that it would be very useful to add one or two short paragraphs outlining the common uses of geoscience ontologies and why (in broad terms) they are necessary for geoscience modelling / data management, and how they are / might be implemented in geological modelling / interpretation workflows.

We agree that the introduction should more clearly justify the necessity of ontologies, rather than simply noting their increasing adoption. In the revised manuscript, we will add a short section explaining why ontologies are methodologically important for geoscience, 3D modelling and data management.

Specifically, we will clarify that ontologies contribute in several keyways:

- Explicit representation and formal logic: By formally encoding geological concepts, relations, and constraints, ontologies make geological assumptions and rules explicit. This enables logical consistency checking, computable validation, and more transparent interpretation of geological representations.
- Semantic Interoperability and Data Integration: Geological workflows often struggle with "semantic silos" where heterogeneous data (field observations, geophysics, and lab results) use inconsistent terminologies. Ontologies act as a shared conceptual framework enabling seamless data integration and reuse across different software environments and multidisciplinary teams.
- Traceability and Reproducibility: By formalizing not just the data, but the modeling workflows themselves (e.g., interpolation choices, constraint definitions, and provenance), ontologies ensure that every step of a model's construction is documented. This is essential for addressing the "black box" nature of many 3D models.

We will also clarify how ontologies can be implemented in practice—for example, as semantic layers associated with geomodel objects, modelling software, or as knowledge graphs supporting reasoning and validation. These additions will better position the ontological contribution as a methodological necessity for addressing subjectivity, reproducibility, and semantic consistency in geological modelling.

2-Figures 8 to 14 are crucial results for the paper, as they illustrate the application of the POKIMON ontology to different modelling scenarios. However, I also found them to be very cryptic (at least to the uninitiated). Please explain these figures in more depth and, if possible, include geological cartoons or cross-sections highlighting the use-case and various geomodels that are being represented. Also consider colouring the edges in the graph by predicate, to help highlight different types of relation. Finally, I found the text in these figures too small to read; please make it larger (there seems to be space).

indeed, the figures correspond to the core application. They are **designed to formally represent the semantic structure of the use cases described in section 3**. In the revised manuscript, we will:

Expand the accompanying explanations in the text.
Improve graphical readability
Enhance visual differentiation of relations.
Provide better links to the use-cases to connect elements of the diagram to elements of the use-cases.

3- I found the order of subsections in Section 5 to be a little confusing; consider re-arranging to something like:

5.1. Models
5.2. Data, norms and constraints
5.3. Simplification [ this is a very important topic and could be expanded on a little ]

we do agree on its importance, but as the manuscript is already long, dense with complex ontological notions, we preferred to avoid increasing the simplification aspect.

5.4. Algorithms and processes [how models are built]
5.5. Model characteristics, content and origins [ i.e. how POKEMON describes the resulting models and their creation ]

We agree on the confusing aspects of the ordering of this section; in fact we tried different scenarios and we settled on this one to convey mainly:

- Models ((1.1) what are these, their type, and (1.2) their inputs (situations))
- Processes (2) how models are built
- Characteristics, which includes : 3.1 origin of the information in a final geomodel, 3.2 what this model honors besides the inputs (norms and constraints), and 3.3 simplification and how multiple built geomodels can be related to each other.

We can arrange the sections to be: 1 models and their types, 2 inputs and initial conditions (data, origins, norms and constraints, and simplification), 3 how models are built (processes) and therefore the text.

4- It would be helpful to provide a few more "worked examples" of how POKEMON can describe specific geological logic. E.g., the simplification of a fault zone to a single fault surface, or common assumptions like dip-slip displacement, reasoning based on geological norms etc. These examples will greatly help the reader see how POKEMON can be applied and explain how Figs. 8 - 14 were obtained and can be interpreted.

We acknowledge the value of additional worked examples, but we believe that the current use cases (Figs. 8–14) already illustrate the **key** mechanisms by which POKIMON captures geological knowledge, including entity types, assumptions, and modelling processes. To maintain clarity and readability, we focus on these essential elements rather than adding further complex scenarios.

We will, however, enhance the explanations of the concepts and the previous examples to make it clearer how common geological simplifications (e.g., representing a fault zone as a single surface) and typical reasoning based on geological norms are expressed within the ontology and reflected in Figs. 8–14. And linked to the use-cases.

5- The "use-case" examples used in this work are all quite small-scale and geologically similar: What are the implications of this? Might larger-scale models (e.g., of the Permian Basin, or Jura mountains) have different ontological requirements? And how about very different geological settings (e.g., volcanic systems, metamorphic terranes, ...)?

The selected use cases are intended as illustrative examples, but the approach is generalizable and not restricted to specific scales or geological settings. POKIMON provides a semantic backbone for organizing any type of geological entities according to the user's preferred geology ontology. Whether modelling large basins, volcanic systems, or metamorphic terranes, the same ontological principles apply to structure the model, capture assumptions, and formalize the modelling workflow.

Please justify why all three examples are so similar (quarry scale, lightly deformed sedimentary rocks).

We selected a single, consistent geological setting to make the examples more understandable and focused. Using different contexts would require introducing new entities, terminology, and brief geological histories for each case, which could distract from the main goal of illustrating the ontological principles and modelling workflow and increase page length.

**Specific comments**

Title: Why all-caps?

No specific reason, to be corrected

Line 11: "geoscience models" - to me this would include geodynamic simulations, weather models, etc. Is this intended? The rest of the paper seems exclusively relevant to 3D structural geological models.

POKIMON provides a **generic framework** capable of representing both the outputs of geomodelling processes and, in principle, both simulated processes as a form of interpretation and their outputs. For clarity and conciseness, the manuscript focuses on 3D structural geological models. We will briefly clarify in the text how POKIMON could also accommodate geodynamic or other simulation-based models.

Line 13: I would disagree with this statement -- most geological maps / models are accompanied by reports that explain in depth the assumptions, reasoning steps and uncertainties in a model.

many geological maps and models are accompanied by reports, but in practice critical information is often incomplete for example, the rationale for certain assumptions, which subset of inputs have been used, intermediate reasoning steps, or how uncertainties were quantified in a given part of the model. These elements are not fully documented. We will reword “typically” to “often” to better reflect this nuance.

Line 17: typo - "geomdelling"

We will address this point in the revised manuscript

Line 21: Why use "geological models" now and not "geoscience models" like in the abstract - please be consistent. I would suggest the very specific term "3D structural geological model (SGM)", to also avoid potential confusion with e.g., numerical simulations.

We will address this point in the n revised manuscript, but prefer to avoid “structural” to avoid the impression that POK is limited to models containing geological structures such as faults or folds.

Line 50: The number of ontologies is certainly growing - but are they actually being used? How / why / in what contexts?

Ontologies are actively used in geosciences, for example to **build knowledge graphs**, support data integration, and formalize domain knowledge for specific applications such as petroleum reservoir characterization and subsurface modelling, and in the specification of standards, e.g. all GeoSciML vocabularies are encoded as ontologies (see https://geosciml.org/resource/def/voc/)

Line 73: If we can define widely used and functional standards without a formal ontology, why do we need ontologies at all? ...I do think that ontologies are important - but this needs to be explained to the reader in this section.

Ontologies are the most prevalent advanced knowledge representation mechanism and provide a robust and expressive framework for knowledge representation that goes beyond the capabilities of existing standards. Standards can define formats or controlled vocabularies, but they are often limited in expressing complex conceptual relationships, reasoning over data, or integrating heterogeneous sources. We will clarify this distinction and explain the advantages of ontologies in the revised text. Indeed, modern standards are being migrated to ontologies, e.g. the GeoSciML and GroundWaterML2 standards each have a conceptual model that is in effect an ontology that is in the process of being converted to a modern ontology language from its UML diagram origins. Ontologies represent a more advanced knowledge representation mechanism than used to express most geoscience standards, which are still communicated in semi-formal mechanisms such as ER or UML diagrams or schema such for databases or XML formats. These have significant restrictions on expressive range and reasoning capability.

Line 115: Consider adding a few paragraphs here on the simplification process - why is it necessary and how is it typically achieved. A formalized description of this simplification process seems (to me) to be one of the most valuable applications of POKEMON ("Gotta catch 'em all? Or just enough to get the job done").

We agree that the simplification process is an important aspect. For clarity and manuscript length, we avoid an extensive formal description, but we will enrich the discussion.

It is crucial to mention that the goal of POKIMON is to provide the semantic structure to make modeling choices explicit and not restricting modelers to a single choice: a geomodeller can either capture all details ("Gotta catch 'em all") or produce a simplified version ("just enough to get the job done"), and both representations can be linked semantically, showing which entities are included in each model.

Figure 1: This needs to be larger. And the text in 1D is unreadable.

The text in 1D is just schematic to show that a model can exist in a textual format (no valuable information is really included within)

Figure 2: This figure could be larger.

Will do.

Line 130: It would be useful to include a short definition (table?) for each of the aspects defined here - they are not self-explanitory.

These are elements that we derive from the use-cases. We will repeat definition briefly and refer back to examples.

Line 231: Is "font" really that important? .... I guess you mean structure (in the information sense)?

we will provide more details about the different depiction attributes of the DCE.

Line 254: Conceptually / demonstratably "incorrect" models are also common? (and, can even still be useful). Please rephrase.

We agree with the idea and we will improve its presentation and integration in the paper.

Section 5.1.1: Why are space and time lumped together? Isn't it common to represent only time (e.g., a chronostratigraphic chart/model) or only space (e.g., a 3D interpolation without explicit / known timing? [even if timing can often be partially inferred from the geometry ] ).

It is in fact an attempt to be consistent for the naming (it was a long debate). So when a geomodel represents only one of the space/time components is considered to be conceptual. A **Space-Time Geomodel** requires both spatial and temporal coordinates to be explicitly defined. Even a classic 3D interpolation implicitly assumes that the represented entities exist in that static state over the time interval depicted, but without such an assumption, it remains conceptual.

Figure 7: Consider including a somewhat more complex geological entity here - e.g., (1) how would an axial-foliation defined by micas in Unit A and a spaced fracture cleavage in Unit B be represented? (2) Or a weathering-related alteration that partially affects A & B in more-foliated regions near the fold hinge? Is the latter "conceptual" or "space-time"?

We consider more complex examples confusing rather than explanatory. The detailed geological entities included in our work do not depend on POKIMON, but on the underlying geological ontology. To clarify, POKIMON **is not an ontology of geoscience entities** like GSO, but rather an ontology for the interpretation of geoscience entities. For example: (1) the GSO has classes such as Axial-Foliation (subClassOf Quality) and Cleavage (subClassOf Quality), which can describe the example and are related through relations like inheresIn UnitA and UnitB, respectively; (2) whether an alteration is spatially constrained as an object determines the model type—if it is, it can be considered a space-time geomodel, whereas a purely conceptual description belongs to a conceptual geomodel.

Figure 8: Please make the text larger.

We will address this point in the revised manuscript.

Figure 9: Please add a (or several) geological sketch(s) to this figure, to help an unfamiliar reader interpret the graph and what it is representing. Please also make the text bigger (ditto all the other figures).

addressed above, and the layout will be addressed in the revised manuscript. We will try to put the use-cases figures near each result diagram.

Line 296: Why is there a bullet point here (outside of a list)?

we explained the derived explains relation. To stay consistent with our general style of explanation, which uses a bullet.

Line 299: Surely geomodels can also be (demonstratably) invalid interpretations?

We will address this point in the revised manuscript.

Line 349: How/why is a machine-learning action different to e.g, kriging? Both are mathematical / statistical approximations of a function?

ML can simulate some mathematical aspects but operates differently and can go beyond. ML can learn complex, non-linear relationships from data without requiring explicit parametric assumptions. Thus, different methods.

Figure 11: Include sub-figures showing the representation process and final DCE?

The details of the representation process are not explicitly modeled in POKIMON. However, we will provide additional examples of DCE contents, such as meshes, surfaces, and their attributes, to clarify how these aspects can be captured.

Line 410: Would common modelling assumptions fit here? E.g., the assumption that a fault is dip-slip rather than oblique, or that folds are cylindrical? Please clarify how such an assumptions would be represented and potentially include an example.
Yes, but not entirely. Modeling assumptions can be represented here. The distinction between observed, interpreted, and assumed entities is based on the degree of ontological commitment to their existence in reality (see our response to Reviewer 2, pages 10–11). However, POKIMON does not decide, for example, that a cylindrical fold must be treated as an assumed entity—otherwise, all geological structures and objects in models would be considered assumed, since they are rarely described with their full spatial and geological properties.

Instead, POKIMON provides the modeler with an explicit classification hierarchy (observed, interpreted, and assumed) to classify the fold according to their degree of certainty—e.g., observed in the field, interpreted from seismic data, or entirely invented for educational purposes. The question of whether a fold is fully cylindrical (taking the example of one observed entirely in the field) is a matter of simplification: for instance, one could model a detailed fold with all its spatial properties (e.g., scanned with LiDAR) and not full cylindrical geometry or a simplified cylindrical version derived from interpolation. In both cases, the fold is not considered assumed, since it is being observed and modeled with some or all of its properties.

Line 415: Are "data" (e.g., bedding measurements) considered to be constraints in this framework? Please clarify, and if yes then clearly state this (as bedding data and contact points are by far the most common constraints used to build 3D structural geological models).

Ontologically, bedding data represents an observation or property of the geological entity, rather than a modeling constraint by itself. Constraints are derived from these observations; for example, bedding information can inform that a surface should not exceed a certain depth, or must intersect a specific location. In other words, the data provides descriptive knowledge, while the modeling constraints are inferred rules or conditions applied during geomodel construction. We will clarify this distinction and provide more detailed examples of constraints in the revised manuscript.
Line 425: Please expand this section to explain how POKIMON can be used to capture the reasoning/choices behind common geological constraints or inferences - this seems critical. E.g., how would the following be represented: "Observations at location A lead me to interpret lithology X. Observations at nearby location B lead me to interpret lithology Y, which should not contact X given the current stratigraphic understanding. Hence, I have inferred that a fault exists between locations A and B."

In POKIMON, the reasoning process itself can be represented explicitly through linked interpretation processes. While the specific logical ‘constraints’ may be implemented via rule-based systems, the ontology provides the structure to formalize inputs, outputs, and supporting principles.

The proposed example can be represented as follows:

- Interpretation Process 1
  - Input: Observations at location A
  - Output: Lithology X
- Interpretation Process 2
  - Input: Observations at location B
  - Output: Lithology Y
- Interpretation Process 3 (Inference step)
  - Input: Lithology X, Lithology Y, and a stratigraphic principle (e.g., that these lithologies should not be in vertical contact under normal stratigraphic conditions)
  - Output: Inferred Fault

Full formalization of geological 'constraint reasoning' (e.g., via logical rules or automated inference mechanisms) is indeed more complex and beyond the present scope, but POKIMON provides the semantic backbone necessary to encode such reasoning steps explicitly and traceably.

Line 438: "Inheres"  ?
"Inheres" is used in the ontological sense (following BFO terminology) to denote a relation between certain dependent properties such as a qualities (e.g. size, thickness, color)  and the entity it depends on. A quality inheres in a bearer if it cannot exist independently of it (e.g., a porosity value inheres in a rock body). We will briefly clarify this term in the text.

Line 445: Commonly referred to as "lumping"?

Yes, we can refer to the term in the manuscript.

Line 530: How does scale / "order of observation" fit here? Do the conceptual and space-time entities for a Fold exist at a specific scale (regional scale fold vs parasitic fold vs micro-fold)? And the real-world entity across all scales? Or are parasitic folds separate entities in the real-world, conceptually, and in space-time (in which case, where do we stop splitting and say "this is a single fold")? How does this multi-scale nature of geological concepts/objects link to simplification / Section 5.3.2.

POKIMON does not prescribe the observational scale at which geological entities must be defined. The decision to represent a regional fold, a parasitic fold, or a micro-fold—and where to stop subdividing—is a modelling choice left to the geomodeller. In this framework, scale is therefore not ontologically fixed but model-dependent. A conceptual or space-time geomodel explicitly defines the level of detail it adopts. Multiple geomodels may coexist: one highly detailed (including small-scale folds) and another simplified (retaining only major folds). Within POKIMON, such models can be semantically related, allowing one to be described as a simplification or abstraction of another, and each can be variously about the same things in reality

Line 543: Pease expand if possible (a few paragraphs would be great) - how do you envisage POKIMON being integrated into routine 3D geological modelling workflows (to capture the model-building processes)? How might the resulting information be used? How might POKIMON help us better assess uncertainty? Outlining a "vision" here will really help the reader to understand why POKIMON is useful and relevant (rather than just complex and abstract).

We agree that articulating a clearer vision of integration into routine workflows is important. In practice, POKIMON can be integrated as a semantic layer associated with 3D modelling environments, without modifying existing geomodelling software. During model construction, key steps—data selection, interpretation, interpolation method choice, constraint definition, simplification decisions—can be recorded as structured semantic entities and processes. Rather than only storing the final surfaces or volumes, the workflow itself becomes explicitly documented: which observations supported which interpretations, which assumptions were introduced, and which computational methods were applied. The resulting information can be used to:

- Trace modelling decisions, enabling reproducibility and comparison between alternative models.
- Compare scenarios, by formally identifying differences in assumptions or constraints.
- Support collaborative modelling, by making implicit reasoning explicit and shareable.

Regarding uncertainty, POKIMON does not compute uncertainty directly but helps localize its origin: uncertainty may arise from sparse observations, interpretative choices, simplifications, or computational parameters. By formally distinguishing these components, the framework enables a more structured assessment of epistemic uncertainty. We will expand this section in the revised manuscript.

**Second review:**

1-From BFO, the authors selected the Continuant and Occurrent classes. However, it is not entirely clear how occurrents, or specifically an earthquake (as suggested by the authors at line 158), can be represented within the model. While it may be possible to constrain geological events as an assumption in model interpretation, the manuscript does not explicitly clarify this integration.

The discussion of Continuant and Occurrent was introduced to explain the primary categories of Basic Formal Ontology (BFO), from which the major classes used in our application are derived. The example of an earthquake was provided solely to illustrate the notion of an Occurrent (i.e., a process unfolding in time), not to indicate that such processes are explicitly modeled in the presented use cases. The current work focuses on static geological models. Consequently, no geological processes (e.g., earthquakes) are instantiated in the case studies, and no simulation processes are described. Occurrents are nevertheless discussed because we use the notion of process to represent modeling activities (interpretation, computation, data selection, etc.), which are essential to the semantic structuring of geomodel production. Indeed geological processes such as earthquakes (for a simulation-oriented geomodel) can be integrated and will be represented as instances of geological processes. As the other geological entities, they will be semantic components associated a semantic content entity. Their epistemic status (observed, interpreted, assumed) would depend on the origin and purpose of their inclusion—an aspect that will be clarified further in the revised manuscript. We will revise the relevant section to explicitly distinguish between (i) the ontological foundation provided by BFO categories and (ii) the scope of the implemented static modeling use cases.

2.1- The distinction between real world and models sometimes appears ambiguous: when geologists collect data, they are following their mental conceptual geomodel (a valid interpretation of a situation) to represent the space-time geomodel, making these two to converge on each other. It is clear which is the aim of the part, but maybe it would be helpful to better explain it.

In this work, we define a conceptual geomodel as a representation of a real-world geological configuration that does not explicitly specify some or all of its spatial and/or temporal coordinates. When such coordinates are explicitly defined, the model qualifies as a space-time geomodel.

We agree that, in practice, geologists often collect data guided by a prior interpretative framework, which may function as a causal model—i.e., a model that explains geological structures or distributions through cause–effect relationships (e.g., tectonic evolution, depositional processes). In such cases, the conceptual geomodel may indeed guide data acquisition. However, we intentionally did not restrict the notion of conceptual geomodel to a causal or even validated interpretation. A conceptual geomodel, as defined here, is not necessarily a "valid" or confirmed interpretation of a geological situation. For example: A geologist may collect data without a fully formed causal hypothesis and construct a conceptual geomodel afterward. A conceptual geomodel may be computationally generated (e.g., algorithmically or via large language models) and therefore not correspond to a specific geologist's mental model. A preliminary or speculative representation may exist without being empirically supported. Therefore, the distinction between real-world configuration and conceptual geomodel is ontological rather than epistemic. The conceptual geomodel is a representation of what could correspond to a geological configuration, but it does not, by definition, guarantee completeness, causal explanation, or validation. We will revise the manuscript to clarify this distinction and explicitly state that a conceptual geomodel is not necessarily a validated or causal interpretation, but a structured representation that may precede, guide, or result from data acquisition.

2.2- This is also related to the "user-based action specification" (line 336), because the user is effecting the input data and the results through a conceptual (but also space-time) model, defining norms and constraints.

See previous

2.3- The introduction of "assumed origin" entities (line 403) raises some conceptual questions. As these elements are grounded in background geological knowledge to support the construction of a synthetic conceptual model, it is unclear whether they should be regarded as observed and/or interpreted origins abstracted from their specific space–time constraints. Clarifying this aspect would help to better position these entities with respect to observed data and interpretative geological reasoning within the modelling workflow. The distinction between observed, interpreted, and assumed origin entities is based on the degree of ontological commitment to their existence in reality, rather than on the nature of the background knowledge mobilized to construct them (since interpretation is involved in all cases).

In this work:

- Observed-origin entities correspond to geological features whose presence is directly recognized in the field and for which there is no dispute regarding their existence (e.g., an outcropping layer or a visible fault plane). The agreement concerns their presence, even if interpretations may later differ.
- Interpreted-origin entities correspond to geological features whose existence is argued for based on indirect evidence, reasoning, or background geological knowledge. Their presence (or absence) can be debated among geologists, and they result from interpretative inference.
- Assumed-origin entities, in contrast, are introduced based on the ontological commitment of their absence. Both modelers know certainly that such entities do not exist in the world. They are hypothetical constructs introduced for explanatory, pedagogical, or simplification purposes. For example, one may introduce a synthetic volcanic body in a model to illustrate structural relationships, while knowing that no such volcanic body exists in the real case.

Technical corrections:

- Line 224: DCE is referred to Description Content Entity, but at line 230 it is referred to Depiction Content Entity.

We will address this point in the revised manuscript

- Line 284: "[…] an Independent Continuant that is __ collection of SCEs […]"; the article is missing.

We don't understand this comment.

- Line 314: the word "sepcification" is spelled incorrectly.

We will address this point in the revised manuscript

- Line 448: "[…] and thus has insignificant impact. ." two dots are presents.

We will address this point in the revised manuscript