Reviewer Comments and Author Responses

September 6, 2024

1 RC1

"This has been an extremely difficult paper to review. I found the large amount of information contained in the densely written 42 pages with 19 figures overwhelming. Five additional figures are in the appendix and 7 figures in the Supplementary Material. This is too much information for a single manuscript. The research summarized in the paper is thoroughly done and it has the potential to be a truly excellent contribution, but it needs to be presented in a more reader friendly way.

In the conclusion section the authors summarize main findings as follows:

- model formulation with the to incorporate a grain size fining model in a landscape evolution model;
- model testing and validation (not in the conclusion section, but must be written)
- model application to reproduce autogenic processes;
- analysis to show that grain size fining is controlled by a balance between external and internal forcing;
- applications to natural examples

identification of the stratigraphic signature
the case of a flexural foreland basin

- discussion on model applicability and limitation

This is clearly material for two solid, stand alone papers. The model, modeling challenges, limitations and verification can be presented in the first paper with some application to reproduce autogenic processes, if and how these processes depend on model parameters. The second paper can then clearly present main results and applications (control on fining, stratigraphic signatures. . . .).

I hope this helps. "

- Thank you for stating the potential of contribution that warrants further expansion. Upon reflection on the reviewers' recommendations to split the manuscript, we have divided the original manuscript into three standalone papers, each addressing a unique aspect of our research on stratigraphic, fluvial grain size fining. The first paper introduces the new model, GravelScape, detailing its coupling method and validation against previous models, specifically focusing on the impact of altering two parameters (F and G) that reflect subsidence and topography within the basin. This methods paper also identifies limitations in prior approaches, emphasizing the need to compute topography and deposition rates separately from subsidence. The second paper delves into the different factors the impact topography, internal variation, and subsequent grain size fining by varying further inputs (G, K, F, and β that reflect fan extent, basin erodilbility, and more), and correlating between grain size fining and improved autogenic parameters. Paper 2 also proposes a novel framework for distinguishing whether basin dynamics are driven primarily by subsidence (mean deposition) or autogenic (variation) processes with natural examples to facilitate framework application. Out of all the papers, paper 2 underwent the most changes relative to the original manuscript although the core findings of the work remains the same (but improved in presentation and clarity). The third paper extends the model by incorporating flexure, exploring the evolution of foreland basins and stratigraphic profiles over time, with a case study comparison to the Alberta foreland basin. This paper builds on the previous two by considering the system as a dynamic, evolving entity rather than a series of static snapshots. While splitting the work into three standalone papers has led to some overlap in key model equations necessary for understanding the results, we believe the ample, quality content, novel findings, and new methods implemented throughout the works justify the division. A three paper approach allows us to provide further clarity and enhances the accessibility of the material.

2 RC2

" Synopsis

In this manuscript, the authors have undertaken an ambitious modeling exercise to answer an important geoscience problem. They base their modeling framework and plans on a few key tenets. First, they hold that sediment grain size is a primary observable parameter in the stratigraphic record. Thus, earth system models that produce stratigraphic volumes should be formulated to spit out grain size information as a primary output. Second, they assert that mass exchange in two dimensions is the main method by which autogenic noise arises in sedimentary environments. Third, coupling between sediment loading and flexure in the lithosphere should lead to a predictable life cycle of sedimentary basins that produce consistent grain size trends.

These main tenants come together in a set of equations that allow a two-dimensional morphodynamic model to efficiently and parsimoniously balance external (allogenic) and internal (autogenic) dynamics to produce self-consistent grain size trends in a stratigraphic volume. The authors use this modeling framework to examine when the grain size trends in sedimentary systems are dominated by internal dynamics versus external dynamics. They do so via a set of modeling experiments, and a comparison to the Alberta foreland basin.

- This is a good summary of the different components of the work presented. However, the results of the coupling of flexure and sediment load had slightly different intended connotations. We recognize that the life cycle of basins is not always so straight forward or predictable. We wanted to highlight that evolution of a filling basin and final state of grain size fining under bypass may differ between basin set-ups depending on if autogenic fining occurs. Thus, the same life cycle with different orogen-basin spatial configurations and topography can produce differing grain size trends through basin evolution. This deviates from previous assumptions that under the same flux and subsidence state of basin evolution, the same long-term fining trend should be observed across basin set-ups.

Overall comments

I agree strongly with the first reviewer. This manuscript was very challenging to review and to understand. I hope that my synopsis above summarizes the paper's goals and main ideas correctly. I also agree that I think that this piece of work could be quite impactful, and I think that the intellectual effort the authors have undertaken is very important. As far as I can tell, their modeling framework could represent a substantial step forward in our ability to model and understand the handoff between autogenic and allogenic forcing in sedimentary basins. "

- We greatly appreciate the recognition of the potential (with structure improved) impactful, ambitious, and important quality of the work that warrants clarification and expansion (into multiple works as suggested by RC1) opposed to simply cutting out content.

"As written and presented, I am not sure that this paper will have the impact that the authors intend, as I suspect it would not be widely read. My own attempt to connect with the meat of the paper is illustrative: I had a lot of questions about the specific ways that this model treats the internal dynamics of sedimentary systems. For instance, the authors assert in a few parts of the manuscript that fluctuations in the boundary conditions in their model are not shredded by the internal dynamics of the river system, and that information is recoverable (e.g. line 888). This is quite an interesting and exciting statement, but I found myself puzzling over it, because it seems to imply that in some parts of the parameter space, this model behaves like a linear transformer (that is, it adds random noise, but the signal remains recoverable). I struggled to understand why this might be the case, because from everything I know about sedimentary systems, if this model is going to capture those internal dynamics and feedbacks, it should produce specific kinds or colors of noise (mass or grain size fluctuations)."

- We more explicitly explain the autogenic dynamics within the model as physical phenomena and not numerical through including the spatial and temporal validation in paper 1 and through more robust correlations using a few key parameters (deposition, topography variation, and channel dynamics) explained in greater detail in paper 2. More specifically, we removed some of the autogenic parameters (e.g. depositional waves, channel mobility, and local minima) and instead focus primarily on deposotional divergence and rugosity that had the strongest correlations to the autogenic grain size dynamics. We then relate the greater physical autogenic dynamics to the grain size fining through these more clearly correlated and defined parameters. We added a discussion paragraph on the physical nature of autogenic dynamics within the paper 2 " Links between ΔD and $\dot{d}_v$, η, and S" section.

"However, I was unable to really glean some of these big-picture aspects of the model, because the presentation quality is lacking. It is not just a matter of the material being overwhelming like the first reviewer mentioned. "

- To improve clarity and reduce density, we spent significant time improving the figures and writing. We decided to focus on only two parameters (one indicating subsidence changes and the other topography) within the first paper. This resulted in remaking the previous validation figure 12 (with β, F, and G) to only show changing F and G (paper 1 figure 5). In paper 2, we present the grain size results (paper 2 figures 2 3, and 4) of each parameters. Where previously, we only showed a subset of changing G, F, and β (previous preprint figure 16). We also removed less well correlated autogenic parameters and presented only the strongest correlation (paper 2 figure 7) plots. Finally, we improved the general framework (paper 2 Figure 8), that was attempted in original figure 16, by explicitly defining an on average autogenically vs subsidence dominated regime on the figure.

"I'll highlight a couple of specific things about the communication that are unsuccessful, and offer a suggestion or two for each. First I have a suggestion for changes to the overall structure, then I have some ideas about how you could compose your sentences and paragraphs more clearly, and then I have a suggestion for how to make your terminology and other context information more approachable.

In broad structural terms, I agree with the first reviewer that the paper would benefit from being split in two parts."

- Upon reflection of the reviewers comments, we agree that splitting the work is necessary to improve accessibility and comprehension of the content. Please see the above blue comment to RC1 detailing how we split the work.

"Both the model description/experiment and the Alberta case study are dense and unreadable, and both would actually benefit from some expansion. The model description relies heavily on abbreviations and jargon that I suspect is common shorthand in the research team working on this project. I think the authors could make use of a standalone paper to explain each component of their model in plain language first, with lots of subsections and concrete examples. This basic idea also applies to the Alberta case study. "

- In the first paper, we spend more time to introduce the model and the key equations. This gives the space to introduce more parameters that impact topography (β) in paper 2 that also build on the findings from paper 1. In paper 2, we added more examples to the (Part 2-figure 8) framework. In paper 3 (alberta basin), we expanded the introduction and methods regarding foreland basin evolution and improved the paragraph structure and writing flow. We also believe that splitting the work, and any necessary repetition, substantially improved the accessibility of the content.

"Within each section or subsection, I found it very hard to relate individual paragraphs back to the larger purpose of the manuscript. Part of this is because sometimes the paragraphs lacked clear topic sentences or they encompassed several different ideas. The outcome is that longer passages started to read something like a stream of consciousness, and I would have to go back and reread the passage many times to get the meaning. The subject matter that you're trying to communicate in this manuscript is quite complicated, and multi-dimensional. Everything depends on everything else. You—the authors—have spent a long time thinking about and working with these equations and these model outputs. The reader though, is coming to this for the first time, and I had a really hard time holding all of the connections in my head simultaneously. "

- To address this lack of clarity, we both removed unnecessary content, shortened nearly all paragraphs, and only add content when it improved the flow or added clarity. For example, we decided to remove the autogenic recovery time parameter for a future work in order to only focused on the correlations that most impacted the grain size dynamics.

"I think you can make this easier for the reader by breaking up some of your model description and results into smaller self-contained chunks were you describe a single parameter and the influence it has on its own. I think that you could accomplish this through the use of extensive subsections within the sections you're using now. "

- Breaking up the parameter results over different papers and implementing more sections allowed us to have the space to more explicitly break down the impact of the different parameters. Then we only need to refresh the reader of the past results and build upon them. In paper 2, we often re-summarize (eg: start of the discussion) all model parameters and their impacts in plain language as well as produced figures that more clearly show the impacts of each model parameter.

"Concrete examples also help a great deal."

- We added images to the general framework (paper 2 Figure 8), that refer directly to concrete natural environmental examples where we suggest that their is a higher likelihood for autogenic vs subsidence dominated grain size fining within the system.

"The final thing that I will point out as a major way that you can improve communication is to simplify and streamline your terminology and to embrace restating key ideas in plain language throughout the manuscript. Once again you—the authors—have been working with these equations and parameters for months (if not years). We, the reader, have our own relationships with F, G, K, β, and μ. I am perfectly willing to give up my relationship with β temporarily and reassign it to something else while I am sitting down to read your manuscript, but it's hard to do that for 30 different constants and terms. You have helpfully provided a table for this, but even so, it's quite a lot to ask. The cost of relying on so many new terms is that the reading experience stops being frictionless. By the time that I got to page 25, I had forgotten the difference between F and G, and I was not so sure what β referred to. In order me to understand what it is that you were saying, I had to flip back and forth to table 1. "

- Splitting the work inherently entailed that we needed to restate a few key parameters and equations. We also made sure to restate key parameters at the start of each new, major section heading (eg: between discussion and results) and kept this in mind when considering the flow of our work.

"Even then, I'm not sure if I really do understand what "Depositional dimensionless parameter" means."

- We spent more time defining this parameter within paper 2 and explaining its significance with more clarity.

"I think you can easily remedy this by adopting a short, crisp half-sentence that describes each parameter, and sprinkling that phrase throughout the manuscript. For every time that you've gone, say, two pages without restating the meaning of a parameter, just insert the phrase so that the reader is reoriented. There's actually a really good example of this near line 445. You describe the "grain size at a instantaneous time step (Dx)" and then just a page later say "deposited grain size, Dx". By restating in words what it is these parameters refer to, you can sign post for the reader so that they don't get lost."

- We have added more clarification of parameters throughout the manuscripts.

"Similarly, in your introduction you tend to refer to and engage with a large body of literature mainly through reference, and then later use previous author's names as a shorthand for the modeling framework that they developed. While this is customary, I think that there is a better way. I think you can make it a lot easier for your reader by giving these existing modeling frameworks short descriptive names. Thus, instead of saying "Fedele and Paola (2007)'s equations", you could say "1D self-similar grainsize sorting model" or something like that. While of course you should make clear the attribution, for somebody who has not been following the twists and turns of this body of literature, descriptive names will be a more helpful shorthand."

- We went into greater detail on the past approaches and their deviation from our work within paper 1. We then more explicitly define an equation for autogenic grain size fining or grain size deviation in paper 2 where we move away from referring to parameters solely based on past literature.

"Anyway, I think after substantial revision, or maybe reconsideration as two separate manuscripts, this could be a really valuable contribution. I look forward to learning more about it, and thinking about how this model and theoretical framework might apply to my own work."

- The key findings presented in the original manuscript remain constant after the revisions, but the structure, figures, and expansion of key concepts has been greatly improved. The changes described aim to greatly improve the clarity through substantial restructuring and improving the presentation of the correlations of grain size with the autogenic dynamics physically observed within the model. We hope that you agree and would like to thank the reviewers for their constructive comments.