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Peer Review File

The log-logistic evolution of meteorite friability and implications for asteroid regolith

Corresponding Author: Professor Christian Hoover

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Professor Hoover,

Your manuscript titled "The log-logistic evolution of meteorite friability and implications for asteroid regolith" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

In particular, please ensure that in the revised manuscript you demonstrate that your results are reliable and reproducible and that the possibility of asteroid heterogeneity and sampling biases are fully accounted for.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Brittany Cymes PhD
Editorial Board Member

Communications Earth & Environment
orcid.org/0000-0002-2020-3476

Joe Aslin
Deputy Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The paper is innovative in that it examines the friability of meteorite samples -- a property not often measured. I am confident the paper will be often cited in the future. It is worthy of publication, but only after a couple of questions are addressed. (1) The authors note that two H5 chondrites show very different behaviors during the tumbling experiments. My question is one

of reproducibility. How can I be sure that different samples of these same individual H5 chondrites, taken from chunks many centimeters apart, would show identical behavior to the measured samples? I think that before these results can be taken seriously, reproducibility must be demonstrated. Otherwise, this paper is just a feasibility study whose broader implications may not be reliable. (2) There are many selection effects operating between the time a sample is residing on an asteroid to the moment it finds its way to the lab. These effects would tend to favor more-consolidated material that might not be representative of the parent asteroid. This is not a fatal flaw in the paper, but it needs to be addressed in the discussion.

Reviewer #2 (Remarks to the Author):

An understanding of the physical properties of meteorites is critical to the understanding
of asteroid evolution by impacts causing cratering and disruption, the production and
evolution of regolith, and the deflection of asteroids on a collision course with the Earth.
However, physical properties measurements on actual samples of asteroids (the meteorites) are scarce. This paper reports the first direct measurements on the friability of asteroidal material. The measurement procedure, which is well-established in geological literature, is properly applied. The samples are well chosen to span the range of porosity of the most common type of meteorite (ordinary chondrites) and to include both hydrous and anhydrous carbonaceous chondrites. This paper is clearly written, appropriately references prior work on meteorite physical properties, and the results are new and important. It is certainly suitable for publication.
I have a couple of concerns, which should be easily addressed by the authors. The paper asserts that cumulative, low velocity impacts are most relevant to asteroid surface evolution (lines 53-54). However, there is general agreement in the literature that the two major mechanisms for the production of asteroid regolith are hypervelocity impact cratering (e.g. Nolan et al., Icarus, 153, 1-15, 2001), rather than low velocity impacts, and fragmentation due to freeze thaw cycling (e.g., Delbo et al., Nature, 508 doi; 10.1038/nature13153) of asteroid surface material. The mean collision sped in the asteroid belt is modeled to be ~5 km/s (e.g., Farinella and Davis, Icarus
97, 111-123, 1992), in the hypervelocity range. For small asteroids much of the smallest debris from these hypervelocity collisions is above the escape speed, but even on small asteroids this is a major cause of boulder fragmentation with the retention of fragments larger than dust.
Although freeze thaw fragmentation only operates over a shallow depth, it is also modeled to be an important contributor to regolith production, and this material is produced with low speed relative to the asteroid, so it is fully retained on the surface. The extent to which the experiments described in this paper are directly relevant to these two mechanisms is not clearly established in this paper, and both mechanisms should be discussed. There is no mention at all of thermal fragmentation in the paper. The authors should note this important mechanism and present any available evidence that the friability results are applicable to this thermal fragmentation.
The paper indicates on line 34 that friability is different from impact strength and is inversely correlated. If I am reading this correctly, the authors suggest that the friability they measure in inversely correlated with the disruption energy (the energy per unit target mass required for the largest fragment of a disruptive collision to be one-half the iinitial target mass). If so, there is experimental data on meteorites supporting this assertion. Flynn et al. (MetSoc 2025, http://www.hou.usra.edu/meetings/metsoc2025/pdf/5236.pdf) reported the energy per unit target mass required for the onset of catastrophic disruption for two of the meteorites they measured (Allende and Aguas Zarcas). They report that Allende is more friable than Aguas Zarcas, and Flynn et al. report the energy to disrupt Allende is greater than that for Aquas Zarcas. This suggests their new results on friability may be directly applicable to hypervelocity collisions.

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Version 1:

Decision Letter:

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Dear Professor Hoover,

Your manuscript titled "The log-logistic evolution of meteorite friability and implications for asteroid regolith" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Best regards,

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Communications Earth & Environment

Joe Aslin
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Communications Sustainability

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REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

As I commented in my initial review, this paper is innovative and worthy of publication. I have looked at the revisions the authors have made and I am satisfied with them. Of course, a future study should analyze more meteorites and several samples of the same meteorite taken centimeters (or more) apart. Nonetheless, this paper serves as the foundation of such future studies. I hope that the authors pursue them.

Reviewer #2 (Remarks to the Author):

A detailed understanding of the physical properties of asteroids, and particularly the range of values of these properties, is essential to the uinderstanding of the evolution of the asteroid belt over time, the production and retention of asteroid regolith, and the conditions required for successful deflection of destruction of an asteroid on a colliosion course with the Earth. Since meteorites provide samples of their asteroid parent bodies, laboratory measurements of the physical properties of meteorites priovide an indication of the properties of their parent bodies. This paper reports the dirrect measurement of thefriability of seven different meteorites sampling a range of meteorite mineralogies and porosities. The technique employed is well-established for the charactyerization of terrestrial samples, but (to y knowledge) this is the first time this technique has been applied to meteorite samples. As such it is an important contribution to the understanding of asteroid properties. This revised version of the manuscript addresses all the concerns I had about the earlier version of the manuscript. It clearly indicates how friability differs from other physical properties (e.g., compressive strength). The revised manuscript is clearly suitable for publication.

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Response to Reviewer #1

The authors thank Reviewer #1 for the positive assessment and for supporting publication of the revised manuscript.

Reviewer #2 (Remarks to the Author):

A detailed understanding of the physical properties of asteroids, and particularly the range of values of these properties, is essential to the understanding of the evolution of the asteroid belt over time, the production and retention of asteroid regolith, and the conditions required for successful deflection or destruction of an asteroid on a collision course with the Earth. Since meteorites provide samples of their asteroid parent bodies, laboratory measurements of the physical properties of meteorites provide an indication of the properties of their parent bodies. This paper reports the direct measurement of the friability of seven different meteorites, sampling a range of meteorite mineralogies and porosities. The technique employed is well-established for the characterization of terrestrial samples, but (to my knowledge) this is the first time this technique has been applied to meteorite samples. As such, it is an important contribution to the understanding of asteroid properties. This revised version of the manuscript addresses all the concerns I had about the earlier version of the manuscript. It clearly indicates how friability differs from other physical properties (e.g., compressive strength). The revised manuscript is clearly suitable for publication.

Response to Reviewer #2

The authors thank Reviewer #2 for the careful evaluation and for confirming that the revised manuscript addresses the earlier concerns and is suitable for publication.