

# Gradual Destruction of Refractory Stardust in Alkali Brines on Asteroid Bennu

Corresponding Author: Dr Pierre Haenecour

**This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.**

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

The manuscript presents NanoSIMS analyses of presolar grains and organic matter in mottled particles returned from asteroid Bennu by OSIRIS-REx mission. The study identifies a significantly lower abundance of presolar SiC grains relative to angular and hummocky lithologies previously reported and proposes that prolonged interaction with low temperature oxidizing alkaline brines was responsible for the depletion. The observations are interesting and potentially important because presolar SiC is generally regarded as highly resistant to secondary processing.

However, I have concerns regarding two major aspects of the discussion.

(1) The central conclusion of the paper is that low abundance of presolar SiC grains in the mottled particles reflect prolonged interaction with oxidizing alkaline brine. While this interpretation is plausible and supported by other experimental studies demonstrating that SiC can be degraded under certain condition, the evidence present here remains largely circumstantial. The manuscript does not provide direct evidence for SiC dissolution or corrosion product, for e.g. one might expect to observe partially altered SiC grains, corrosion textures, reaction rims. In absence of such observations, the proposed mechanism should be presented more cautiously as a working hypothesis rather than as the preferred explanation. A more balanced statement would be:

"One possible explanation for the depletion of SiC is prolonged interaction with oxidizing alkaline brines. Although direct evidence for SiC dissolution products has not yet been identified, experimental studies demonstrate that alkaline oxidizing fluids can progressively degrade SiC under low-temperature conditions."

In addition, alternative explanations should be discussed, including primary heterogeneity of precursor material and possible limitations imposed by sample statics.

(2) The manuscript proposes an alteration sequence from hummocky to angular to mottled particles largely based on the abundances of presolar grains. However fluids with different chemistries can alter presolar grain abundances differently without requiring a simple alteration sequence. The data may equally support scenario involving multiple aqueous environments with distinct fluid compositions and alteration pathways. Consequently, some statements regarding the degrees of alteration appear stronger than warranted by the available evidences, Just a simple thought – if I wish to reduce 40ppm SiC in other Bennu lithologies to ~8 ppm in mottled particles---with a thought mottled formed with iterative alteration of the angular particles...rate of destruction of SiC into time should explain the observed depletion. If the fluid event is short- negligible effect on SiC. A long -lived fluid system for maybe Myrs is required to alter nanometer sized grains. Point is to show if this condition prevails in Bennu parent body! WHICH ONE-- fluid composition or duration of alteration is dominant factor controlling the depletion?

Apart from this organic matter discussion is comprehensive but reads largely as a review of previous studies. The most significant observation from the present work appears to be the contrasting behaviour of organic matter and presolar grains. While presolar grains appear to have been progressively destroyed, isotopically anomalous OM remained preserved. This observation deserves greater emphasis because it suggests that organic reservoirs may survive fluid activity longer than presolar grains.

Minor point

The manuscript states 22 grains are classified as mainstream SiC and three as Y/Z, which totals 25 grains likely derived from AGB stars. Subsequently 1 type X and 1 AB grains are describes, that totals to 27 grains. However, the text later refers to "these 14 grains originated from AGB"

Over all, the data are of high quality and the observations are important. However, I believe the discussion would be strengthened by more cautious treatment of SiC destruction mechanisms, considering alternative explanations and greater emphasis on contrasting responses of presolar grains and OM to aqueous processing

Earlier written 22 MS, 3 Y/Z= 25 grains. Later 1 X , 1 AB , total 27 but you explain 14 grains originated in AGB????

Maybe stating "Bennu records multiple aqueous regimes, and late-stage alkaline brines may have been capable of modifying even refractory presolar SiC while preserving isotopic anomalous organic matter" would be more apt.

Reviewer #2

(Remarks to the Author)

The manuscript by Haenecour et al. titled "Gradual Destruction of Refractory Stardust in Alkali Brines on Asteroid Bennu" discusses the abundance and distribution of presolar grains and organic matter in mottled particles in samples returned by OSIRIS-REx from asteroid Bennu. The lack of presolar oxide and silicate grains as well as the very low abundance of presolar SiC grains indicate that these phases have been destroyed. The authors make a very compelling case that this alteration took place by interacting with low-temperature, oxidizing alkaline brines.

The results of this study are clearly noteworthy and are new and original. The methodology applied to determining the described abundances is sound and the data analysis agree with what is expected/otherwise done in this field. The manuscript is very well written and the conclusions by the authors are clearly supported by the cited work. I only have a couple of very small comments on the text, but otherwise recommend publication.

Minor comments:

Paragraph lines 95 - 100: Do I interpret this correctly that OREX-803216-0 was excluded since your analysis shows that the initial idea of this being a mottled particle is not supported by the data?

Line 118: You mention that abundances are uncorrected for detection efficiency? It would be good to elaborate if this would have a significant effect or not; my suspicion is that this will not matter at all.

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***Gradual Destruction of Refractory Stardust in Alkali Brines on Asteroid Bennu***  
**Responses to Reviewers**

We provide individual responses in blue to each reviewer's comment below, and modifications to the manuscript are highlighted in yellow. We also formatted the manuscript to comply with Nature Communications' guidelines.

Reviewer #1 (Remarks to the Author):

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However, I have concerns regarding two major aspects of the discussion.

(1) The central conclusion of the paper is that low abundance of presolar SiC grains in the mottled particles reflect prolonged interaction with oxidizing alkaline brine. While this interpretation is plausible and supported by other experimental studies demonstrating that SiC can be degraded under certain condition, the evidence present here remains largely circumstantial. The manuscript does not provide direct evidence for SiC dissolution or corrosion product, for example, one might expect to observe partially altered SiC grains, corrosion textures, reaction rims. In the absence of such observations, the proposed mechanism should be presented more cautiously as a working hypothesis rather than as the preferred explanation. A more balanced statement would be:

"One possible explanation for the depletion of SiC is prolonged interaction with oxidizing alkaline brines. Although direct evidence for SiC dissolution products has not yet been identified, experimental studies demonstrate that alkaline oxidizing fluids can progressively degrade SiC under low-temperature conditions."

We made the change in the manuscript, as suggested.

In addition, alternative explanations should be discussed, including primary heterogeneity of precursor material and possible limitations imposed by sample statistics.

We added alternative explanations to the discussion, as suggested.

(2) The manuscript proposes an alteration sequence from hummocky to angular to mottled particles largely based on the abundances of presolar grains. However, fluids with different chemistries can alter presolar grain abundances differently without requiring a simple alteration sequence. The data may equally support scenario involving multiple aqueous environments with distinct fluid

compositions and alteration pathways. Consequently, some statements regarding the degrees of alteration appear stronger than warranted by the available evidence.

We agree with the reviewer; we did not intend to imply a simple linear sequence of alterations. We made the change in the manuscript to clarify and better reflect the multiple aqueous environments rather than a linear increase, as suggested.

Just a simple thought – if I wish to reduce 40ppm SiC in other Bennu lithologies to ~8 ppm in mottled particles---with a thought mottled formed with iterative alteration of the angular particles...rate of destruction of SiC into time should explain the observed depletion. If the fluid event is short- negligible effect on SiC. A long -lived fluid system for maybe Myrs is required to alter nanometer sized grains. Point is to show if this condition prevails in Bennu parent body! WHICH ONE-- fluid composition or duration of alteration is dominant factor controlling the depletion?

We thank the reviewer for raising this important distinction. We argue that the two factors are coupled rather than competing: fluid composition is the necessary, gating control, while duration determines the magnitude of the effect once the threshold chemistry is met. In typical fluid-rock interactions associated with aqueous alteration, the protective SiO<sub>2</sub> layer on SiC remains stable and essentially halts further reaction regardless of exposure time. However, under alkaline, oxidizing conditions, that layer can dissolve, exposing fresh SiC to ongoing oxidation. In this sense, fluid composition is the dominant factor — it determines whether meaningful SiC destruction can occur at all — while duration governs how much destruction accumulates once those conditions are established. We have clarified this distinction in the revised Discussion, where we also note that the preservation of SiC at initial baseline abundances in the hummocky and angular lithologies — which experienced earlier, chemically distinct fluids — is consistent with this interpretation.

Apart from this, the organic matter discussion is comprehensive but reads largely as a review of previous studies. The most significant observation from the present work appears to be the contrasting behavior of organic matter and presolar grains. While presolar grains appear to have been progressively destroyed, isotopically anomalous OM remained preserved. This observation deserves greater emphasis because it suggests that organic reservoirs may survive fluid activity longer than presolar grains.

We thank the reviewer for this valuable observation. We have restructured the discussion of organic matter to foreground the contrast between OM preservation and the destruction of presolar grains. The paragraph addressing this decoupling now opens the section (and is referenced earlier still, in the closing lines of the presolar grain discussion), and we have condensed the review of competing OM-formation hypotheses so that it supports, rather than precedes, this observation.

Minor point

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Thank you for catching it; it was a typo. We corrected it in the manuscript.

Overall, the data are of high quality, and the observations are important. However, I believe the discussion would be strengthened by more cautious treatment of SiC destruction mechanisms, considering alternative explanations and greater emphasis on contrasting responses of presolar grains and OM to aqueous processing

We addressed those points in the comments above.

Earlier written 22 MS, 3 Y/Z= 25 grains. Later 1 X , 1 AB , total 27 but you explain 14 grains originated in AGB????

See response above; we corrected the typo.

Maybe stating “Bennu records multiple aqueous regimes, and late-stage alkaline brines may have been capable of modifying even refractory presolar SiC while preserving isotopic anomalous organic matter” would be more apt.

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Yes, we clarified it in the text.

Line 118: You mention that abundances are uncorrected for detection efficiency? It would be good to elaborate on whether this would have a significant effect; my suspicion is that it will not matter at all.

We clarified in the text that we did not correct the abundances for detection efficiency to allow direct comparisons with other studies of Bennu, Ryugu, and carbonaceous chondrites. The correction would not have mattered because all abundances were based on similar NanoSIMS analysis routines; the detection efficiency correction would have affected all abundances in the same way, without changing the main observation in our study (no presolar silicate and oxide grains and a significantly lower SiC abundance in the mottled compared to the other samples).