Geophysical Research Letters

Supporting Information for

The enigma of Neoproterozoic giant ooids—Fingerprints of extreme climate?

Elizabeth J. Trower[1]

[1]Department of Geological Sciences, University of Colorado Boulder, Boulder, CO, USA 80309.

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Introduction

This document includes one supplementary text section (S1) with exemplar PHREEQC input and five supplementary figures (S1 - S2) that provide background for how the range of bed shear velocities was determined (S1), sensitivity of results to water depth (S2), comparison of abrasion rates to Atal and Lavé (2009) (S3), sensitivity of results to transport intermittency (S4), and models of aragonite and calcite giant ooids at 0°C (S5).

Text S1.

Example PHREEQC code for aragonite and calcite supersaturation at T = 25°C, 40°C:

```
DATABASE c:\phreeqc\database\PHREEQC.dat
TITLE Aragonite and calcite supersaturation
SOLUTION 1 Modern-like Neoproterozoic seawater
  units       mmol/kgw
  density    1.024
  temp  40
```

```
  pressure   1     atm
  Ca    10
  Mg    50
  Na    459
  K     9.7
  Cl    536
  Si    0.1
  Fe    0.00036
  B     0.426
  Mn    0.00018
  P     0.0032
  S(6)  27.6  as SO4
  C(4)  2.3   as HCO3    CO2(g)     -4.5
  Alkalinity 2
END
```

Example PHREEQC code for ikaite supersaturation at T = 0°C:

```
DATABASE c:\phreeqc\database\frezchem.dat
TITLE Ikaite supersaturation
SOLUTION 1 Cold Neoproterozoic seawater
  units       mmol/kgw
  density    1.05
  temp  0
  Ca    3
  Mg    15
  Na    900
  K     20
  Cl    1000
  S(6)  60    as SO4
  C(4)  2     as HCO3    CO2(g)     -3.5
  Alkalinity 4
END
```

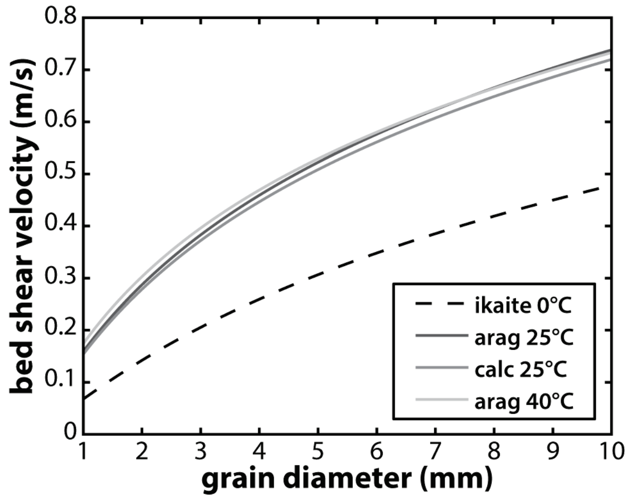

Figure S1. Bed shear velocity (u_*) as a function of grain diameter (D) for P = 2.5.

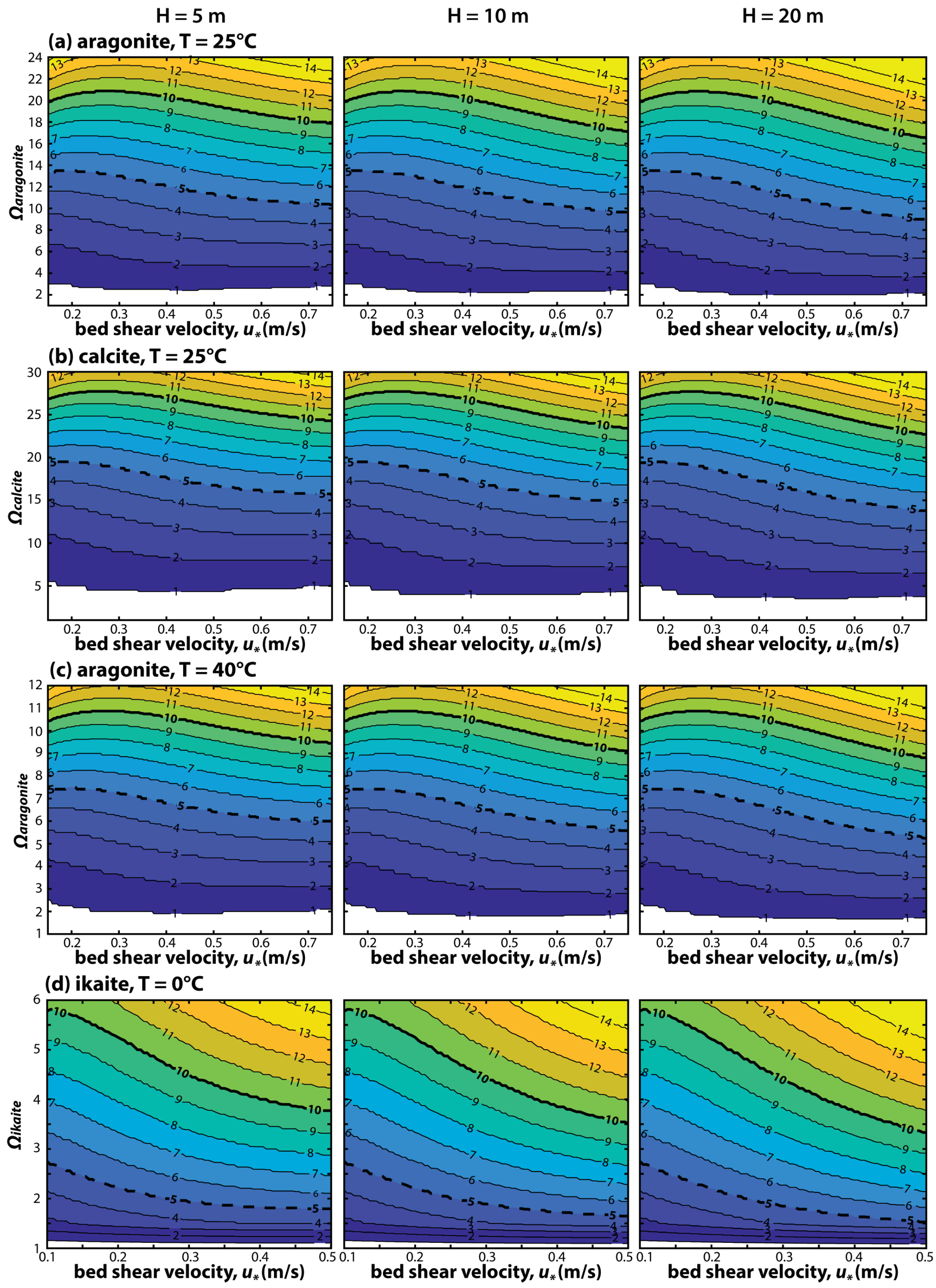

Figure S2. Contour plots of equilibrium ooid diameter (D_{eq}) as a function of carbonate mineral saturation state (Ω) and bed shear velocity (u_*) showing sensitivity to water depth (H) for each of the four scenarios: (a) aragonite, T = 25°C, (b) calcite, T = 25°C, (c) aragonite at T = 40°C, (d) ikaite at T = 0°C. H = 5 m (left column) was used for the models in the main manuscript; deeper water depths (middle column, H = 10 m; right column, H = 20 m) require slightly lower Ω values than H = 5 m. Solid bold lines indicate combinations of Ω and u_* consistent with D_{eq} = 10 mm; bold dashed lines indicate combinations of Ω and u_* consistent with D_{eq} = 5 mm.

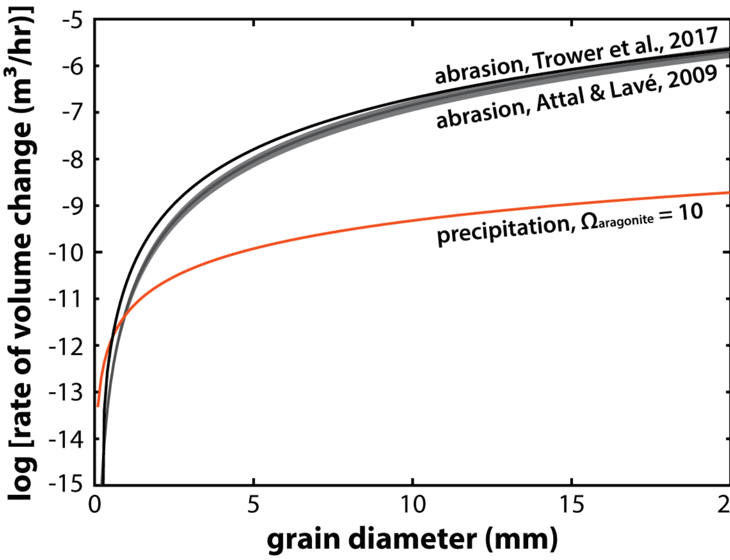

Figure S3. Comparison of abrasion rates estimated using the Trower et al. (2017) model (black line) vs. the Attal and Lavé (2009) model (grey line, with shaded grey area indicating standard deviation). The Trower et al. (2017) model predicts abrasion rates with similar magnitudes as the Attal and Lavé (2009) model. The model predictions diverge somewhat for grain diameters <10 mm, but the Attal and Lavé (2009) model was based on grain diameters >10 mm and the Trower et al. (2017) model was based on sand-size grains. The Trower et al. (2017) model was based on a bedrock erosion model for both sand- and gravel-size sediment, so this process-based approach was deemed more appropriate for grain sizes <10 mm than extrapolating the empirical model of Attal and Lavé (2009). Notably, both models predict abrasion rates 2-3 orders of magnitude greater than the rate of growth due to aragonite precipitation at $\Omega_{aragonite}$ = 10, consistent with the requirement of very high saturation states to balance the rapid abrasion rates for giant ooids.

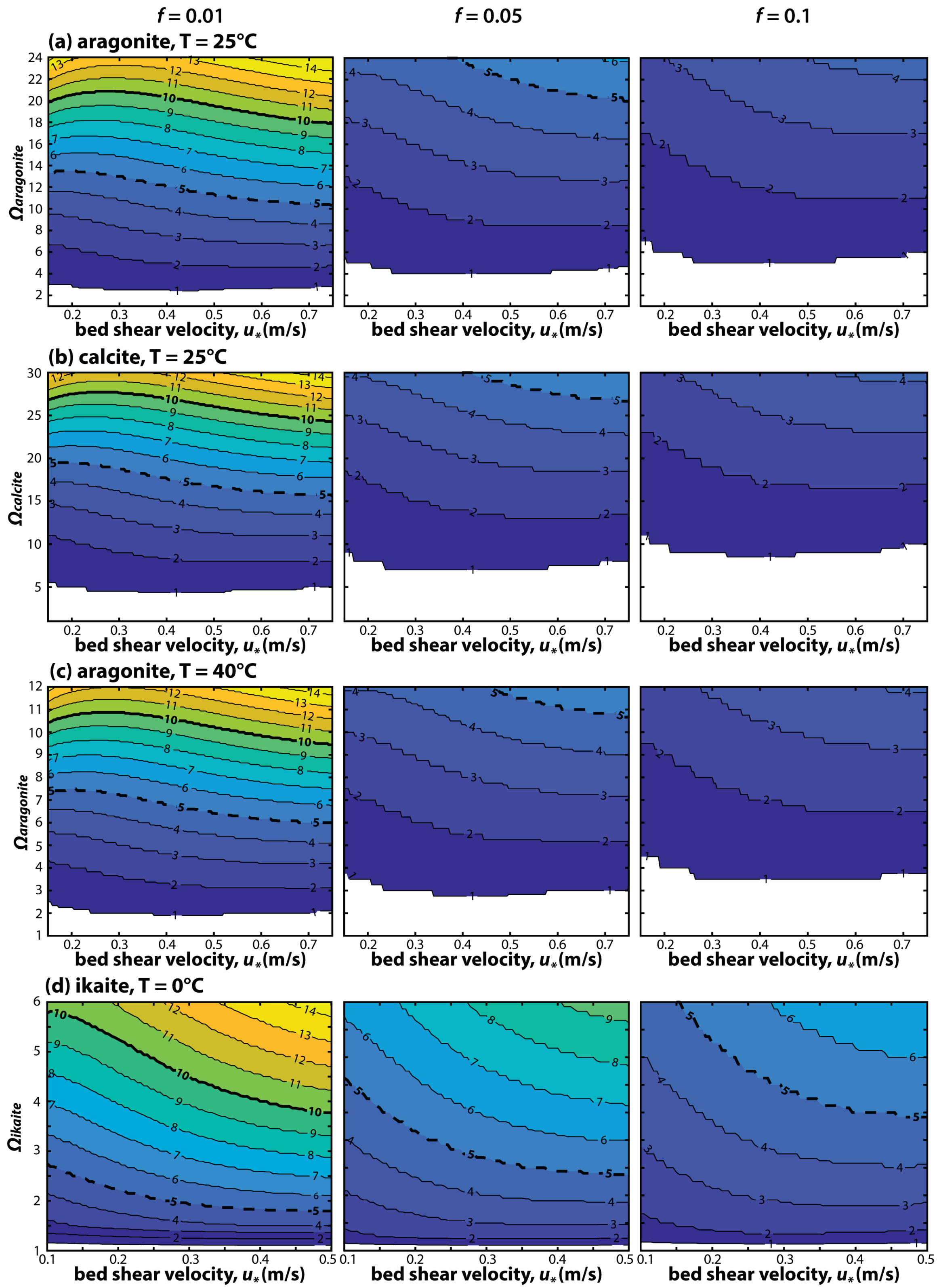

Figure S4. Contour plots of equilibrium ooid diameter (D_{eq}) as a function of carbonate mineral saturation state (Ω) and bed shear velocity (u_*) showing sensitivity to intermittency of movement (f) for each of the four scenarios: (a) aragonite, T = 25°C, (b) calcite, T = 25°C, (c) aragonite at T = 40°C, (d) ikaite at T = 0°C. For larger values of f (more frequent transport), larger Ω values are required for any particular D_{eq}, indicating that the Ω values estimated for f = 0.01 are minimum values.

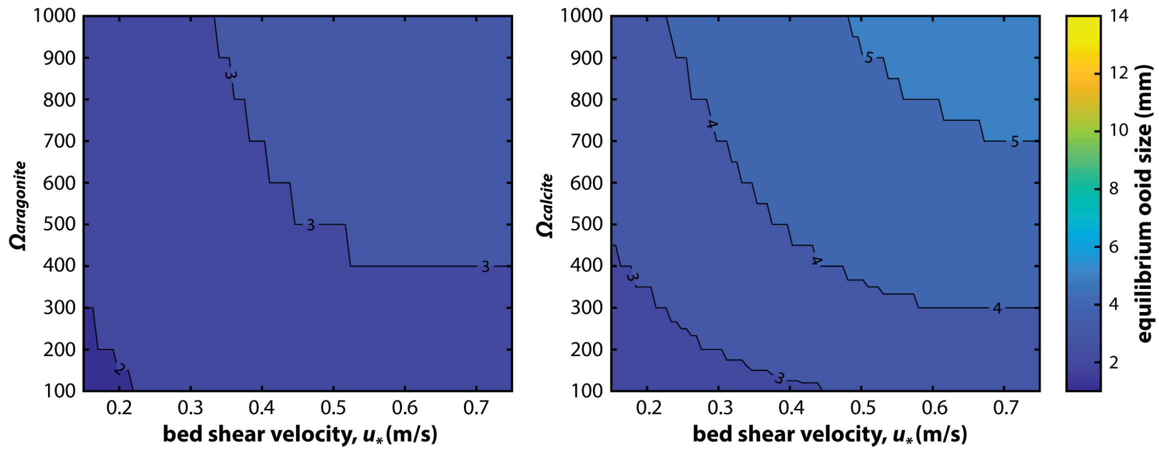

Figure S5. Contour plots of equilibrium ooid size (D_{eq}) as a function of bed shear velocity (u_*) and carbonate mineral saturation state (Ω) for aragonite and calcite at T = 0°C. Even at exceedingly high supersaturations ($\Omega_{aragonite} = \Omega_{calcite} = 1000$), aragonite and calcite precipitation rates are not sufficiently rapid to outpace abrasion, so giant ooids with D_{eq} = 10 mm are not possible under these conditions.