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Auxiliary material for

Dynamic morphology of gas hydrate on a methane bubble in water:

 Observations and new insights for hydrate film models

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Geophysical Research Letters

Introduction

The auxiliary material consists of four types of supporting information (SI), which are:

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**Geophysical Research Letters**

Auxiliary material for:

**What controls channel form in steep mountain streams?**

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**Introduction:**

The auxiliary material consists of three types of supporting information (SI), which are:

1. A supporting figure with caption – referred to as S1 in the main text – which is a box and whisker plot showing the composite slope distributions for the channel reaches compiled for this study.

2. Text that gives additional detail on the range of Froude numbers where dunes and anti-dune formation is stable, which may control step-pool formation.

3. A table of the data used in this work; the table includes the reference, the bankfull water discharge (*Q*), bankfull width (*B*) and depth (*H*), channel bed slope (*S*), grain size (*D50* and/or *D84*) and the stream reach classification (i.e., alternate bar, plane bed, step-pool or cascade).

**Contents of this file**

Figure S1

Text

**Additional Supporting Information (Files uploaded separately)**

Table S1 (Excel File)

***Supporting Figure***

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**Figure S1**. Boxplots showing the range of slopes encompassed by each stream reach morphology, where the red line indicates the median slope, the top of the box is the 75th quartile, the bottom of the box is the 25th quartile, the whiskers denote the range of data outside the central box that are not outliers, and the red pluses denote any outliers.

***Supporting Text***

 [1] The anti-dune model was proposed by *Whittaker and Jaeggi* [1982] following their observations of the development of steps subsequent to anti-dune formation during flume experiments. *Kennedy* [1963] used potential flow theory to derive the theoretical domain over which dunes and anti-dunes can form, where dunes emerge under subcritical flows and anti-dunes under supercritical flows. The threshold for transitioning from a subcritical regime (downstream migrating dunes possible) to a super-critical regime (upstream migrating anti-dunes possible) is given by Equation S1,

$Fr^{2}= \frac{\tanh(k)}{k}$ (S1)

which is both a function of the Froude number, defined as

 $Fr= \frac{U}{\sqrt{gH}}$ (S2)

where *U* is the average bankfull velocity, *H* is the bankfull depth, and *g* is the acceleration due to gravity, and the wavenumber, *k*, defined as

$k=2π\frac{H}{L}$ (S3)

where *L* is the bedform wavelength, defined for step-pools as the distance or spacing between consecutive steps. Potential flow theory also predicts that when the Froude number exactly meets the condition prescribed in Equation S1, a plane-bed will result. Field and flume studies of step-pool reaches have shown that the step wavelength typically ranges from 3 to 12 times the bankfull flow depth [*Recking et al.*, 2009], meaning that *k* ranges from 2.1 (*L* = 3*H*) to 0.5 (*L* = 12*H*). This implies that the lower threshold for anti-dune formation, and possibly the onset of step-pools, can occur at a Froude number as low as 0.7 up to 0.96 (from Equation S1).

**References**

Kennedy, J. F. (1963), The mechanics of dunes and antidunes in erodible-bed channels, *J. Fluid Mech.*, *16*(4), 521–544, doi:10.1017/S0022112063000975.

Recking, A., V. Bacchi, M. Naaim, and P. Frey (2009), Antidunes on steep slopes, *J. Geophys. Res. Earth Surf.*, *114*(F4), F04025, doi:10.1029/2008JF001216.

Whittaker, J. G., and M. N. R. Jaeggi (1982), Origin of Step-Pool Systems in Mountain Streams, *J. Hydraul. Div.*, *108*(6), 758–773.