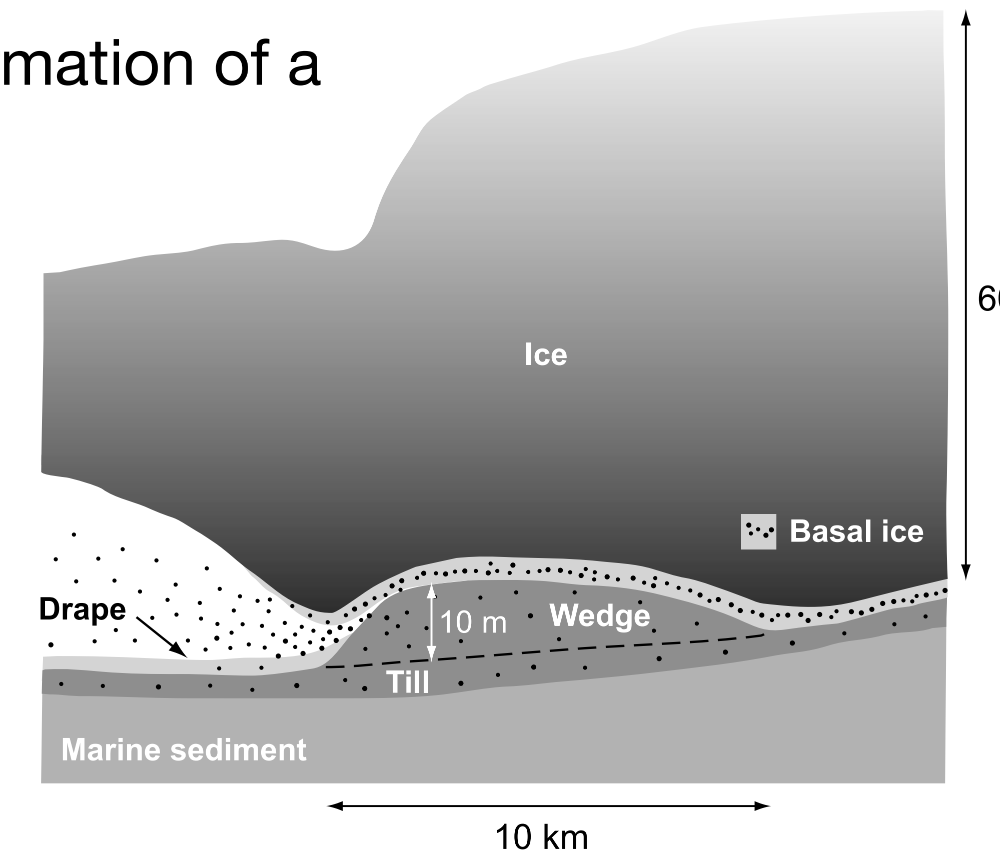
Evolution of marine ice sheets with bed sedimentation

Ian Hewitt & Emilie Herpain
University of Oxford

Introduction & Motivation

Sedimentation occurs near grounding lines, causing formation of a grounding-zone wedge (GZW)



Christoffersen et al 2010

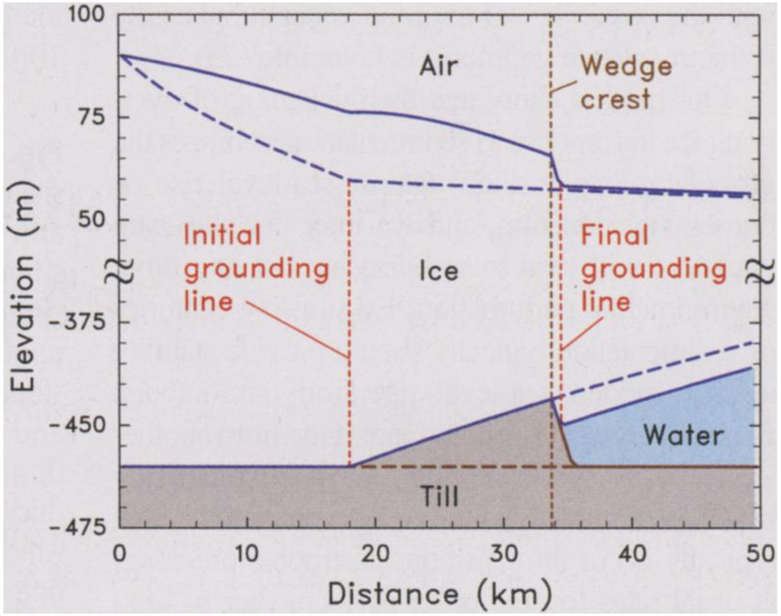
The presence/growth of a wedge can help to stabilise the grounding line (by locally reducing the water depth)

At the same time, the generation of an upward-sloping bed may influence subsequent retreat.

→ We seek to understand the *coupled* dynamics of ice flow and sediment deformation in a marine-ice-sheet setting.

Introduction & Motivation

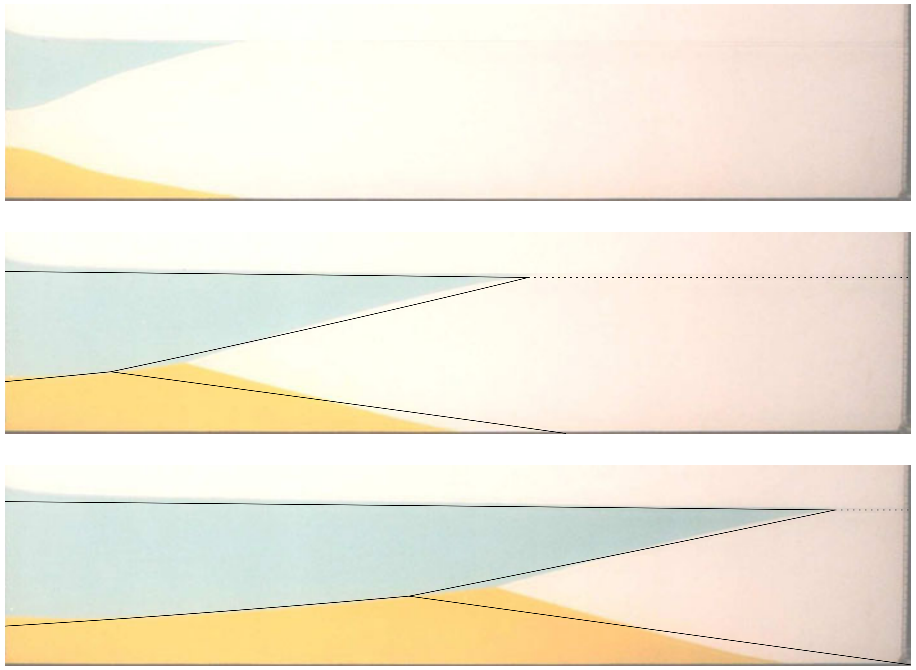
Alley et al 2007 use a numerical model to investigate how presence of a till wedge impacts grounding-line position. Wedge shape is imposed, and static.

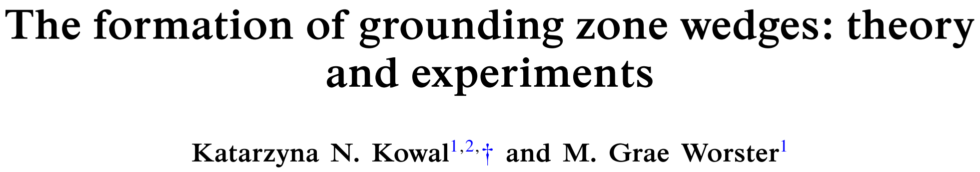


Effect of Sedimentation on Ice-Sheet Grounding-Line Stability

Richard B. Alley,[1*] Sridhar Anandakrishnan,[1] Todd K. Dupont,[1,2]
Byron R. Parizek,[1,3] David Pollard[1]

Kowal & Worster (2020) develop theory and laboratory experiments to examine dynamics of two viscous fluid layers (one buoyant, one dense) near a grounding line.

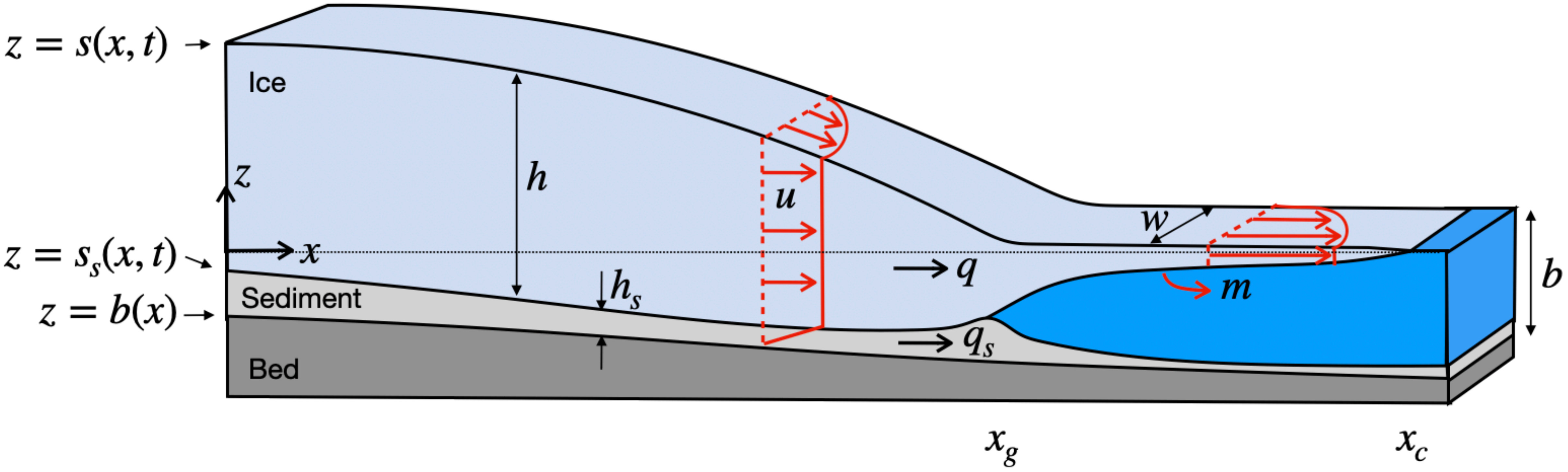




The formation of grounding zone wedges: theory and experiments

Katarzyna N. Kowal[1,2,†] and M. Grae Worster[1]

Two-layer (ice+sediment) gravity-current model



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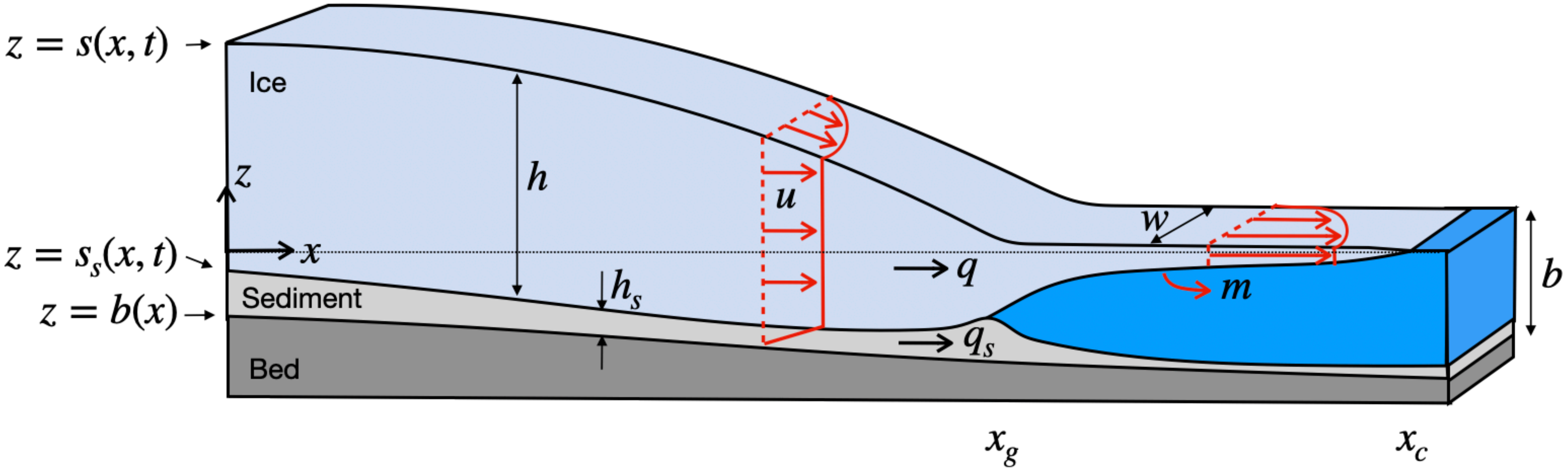

Grounded ice flows according to linear sliding law.

Floating ice flow is resisted by viscous lateral stress (buttressing).

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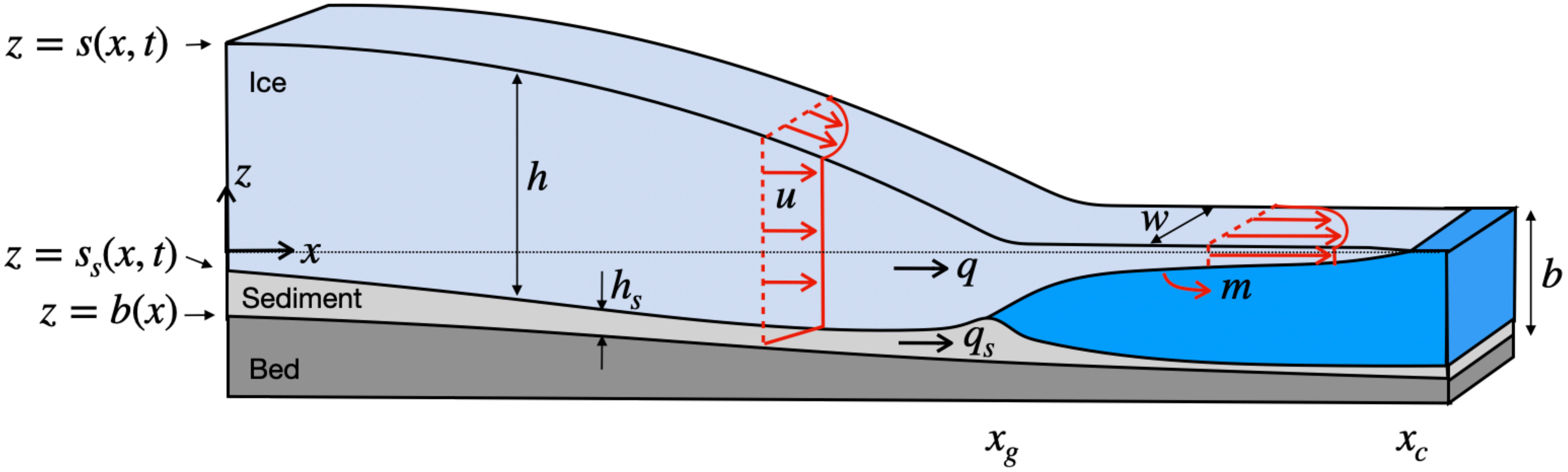

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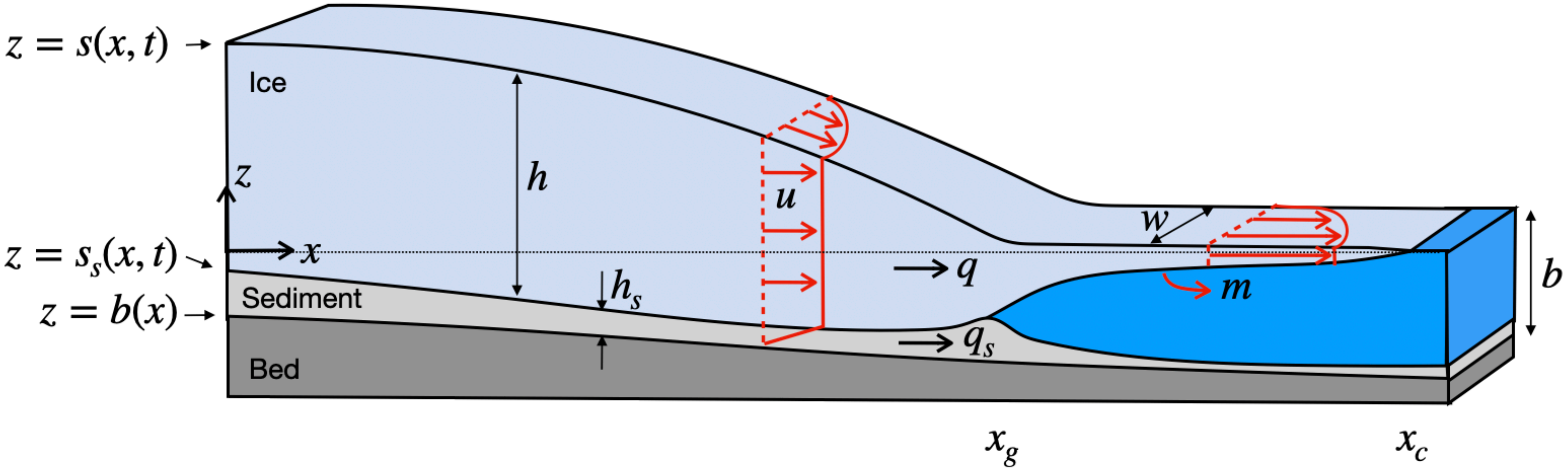

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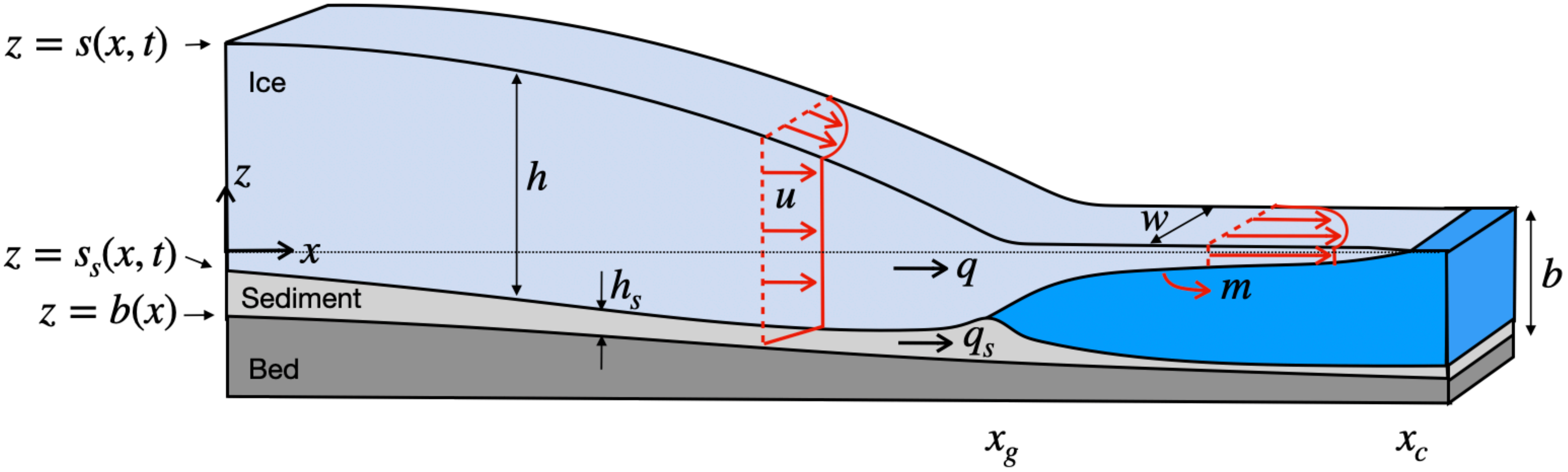

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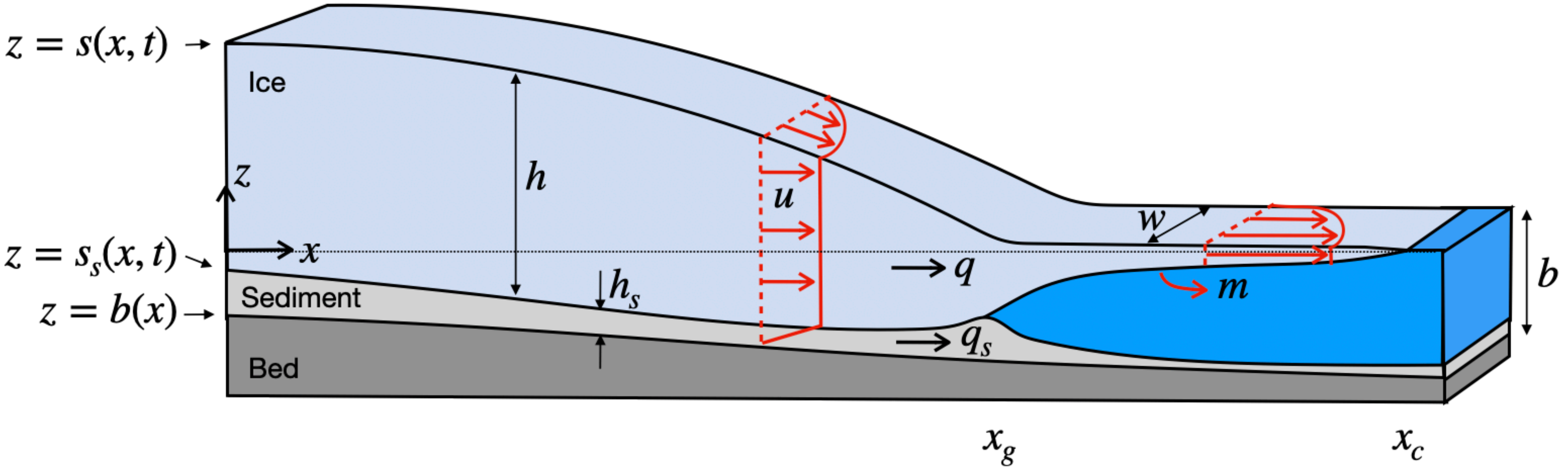
Prescribed fluxes of ice and sediment at left hand boundary.

Two-layer (ice+sediment) gravity-current model



Conservation of ice

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = -m$$

$$q = \begin{cases} -\dfrac{\rho_i g h^2}{C}\dfrac{\partial s}{\partial x} & x < x_g \\ -\dfrac{(\rho_w - \rho_i) g h w}{12\eta_i}\dfrac{\partial h}{\partial x} & x > x_g \end{cases}$$

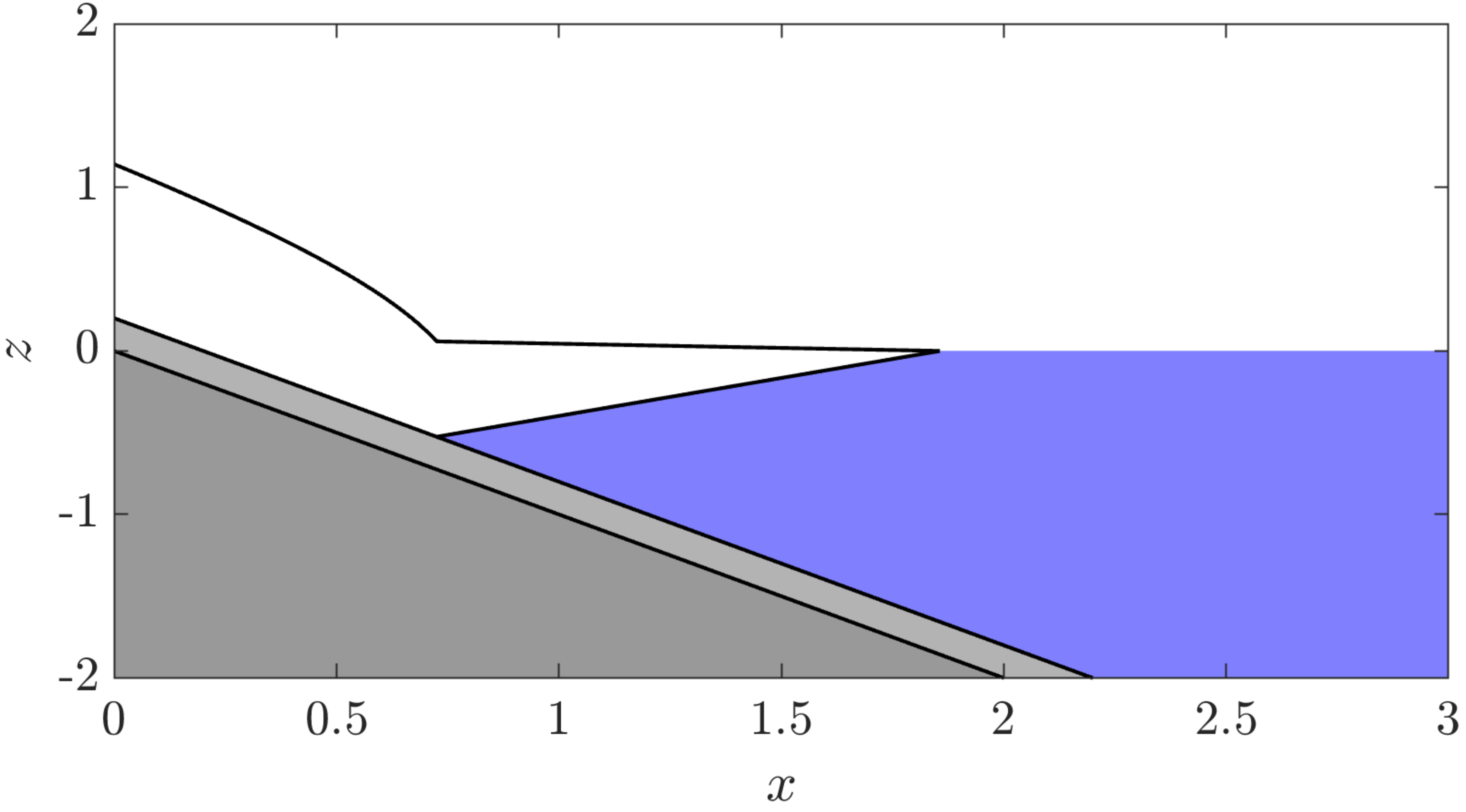
Conservation of sediment

$$\frac{\partial h_s}{\partial t} + \frac{\partial q_s}{\partial x} = 0$$

$$q_s = \begin{cases} -\dfrac{\rho_i g h_s h}{2C}\dfrac{\partial s}{\partial x} - \dfrac{\rho_i g h_s^3}{3\eta_s}\left(\left(\dfrac{\rho_s - \rho_i}{\rho_i}\right)\dfrac{\partial s_s}{\partial x} + \dfrac{\partial s}{\partial x}\right) & x < x_g \\ -\dfrac{(\rho_s - \rho_w) g h_s^3}{3\eta_s}\dfrac{\partial s_s}{\partial x} & x > x_g \end{cases}$$

$$s = \begin{cases} b + h_s + h & x < x_g \\ \left(\frac{\rho_w - \rho_i}{\rho_i}\right) h & x > x_g \end{cases} \qquad s_s = b + h_s \qquad h = -\frac{\rho_w}{\rho_i}(b + h_s) \quad \text{at} \quad x = x_g \qquad q = q_0,\ q_s = q_{s0} \quad \text{at} \quad x = 0$$

Steady states with no sediment motion



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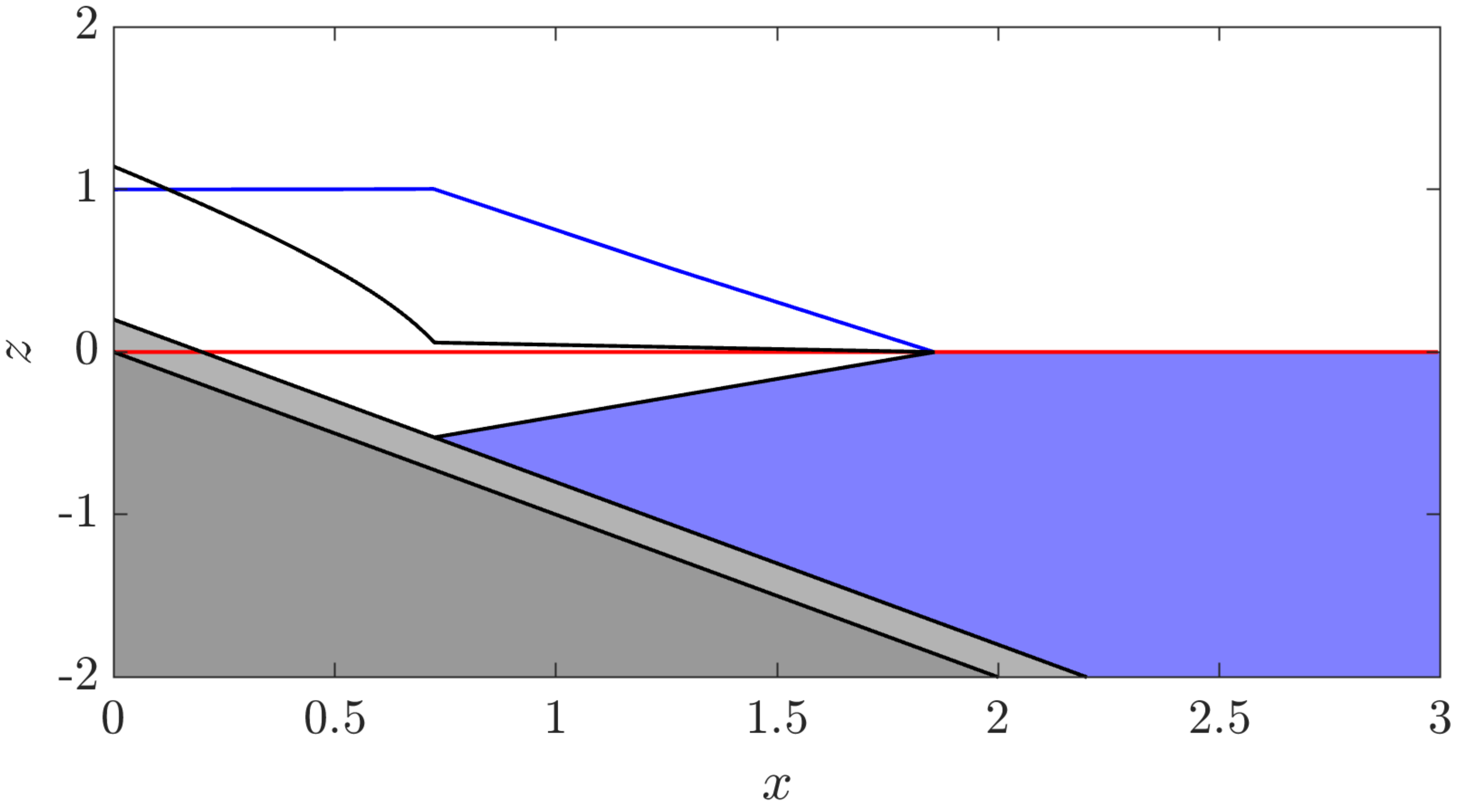

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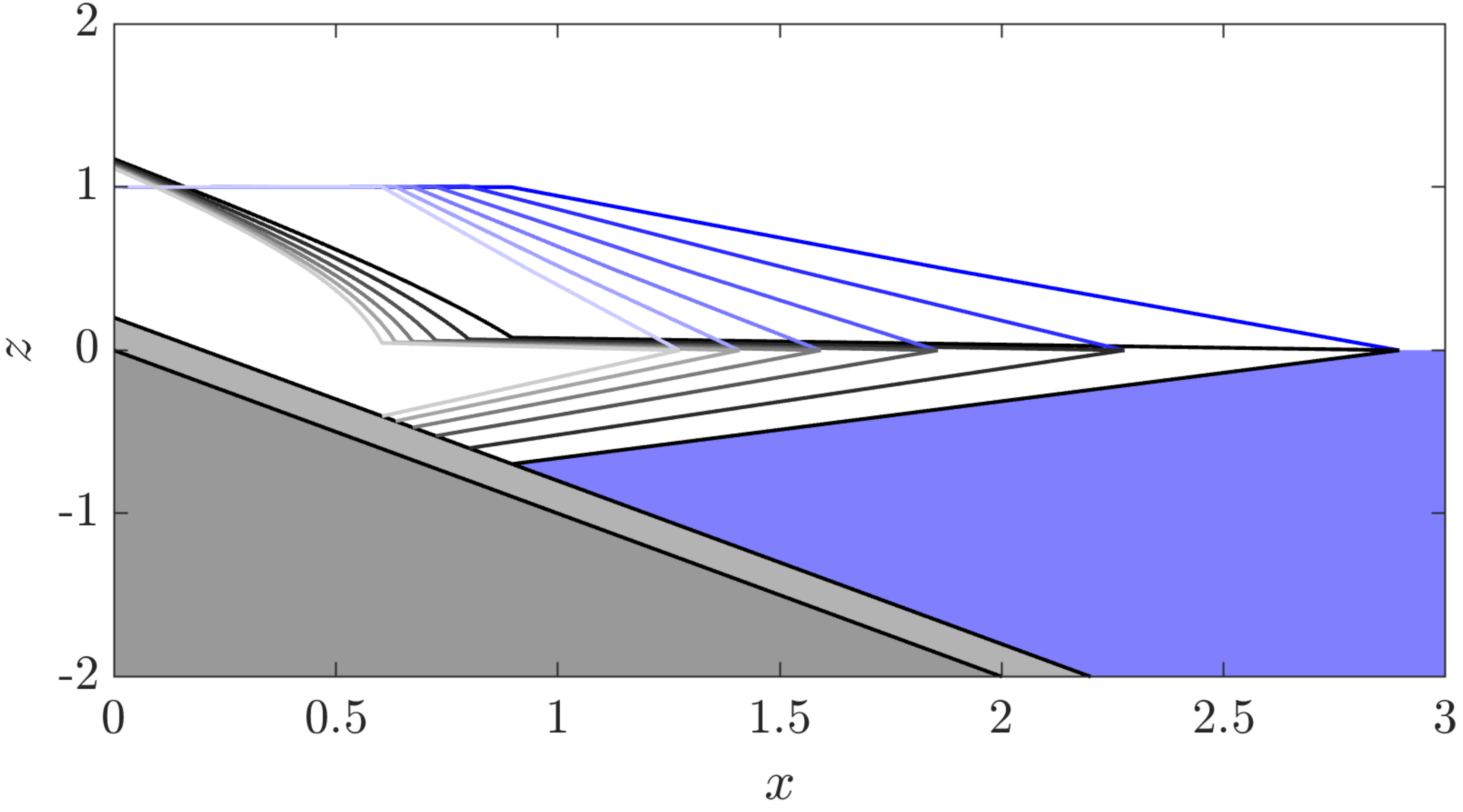
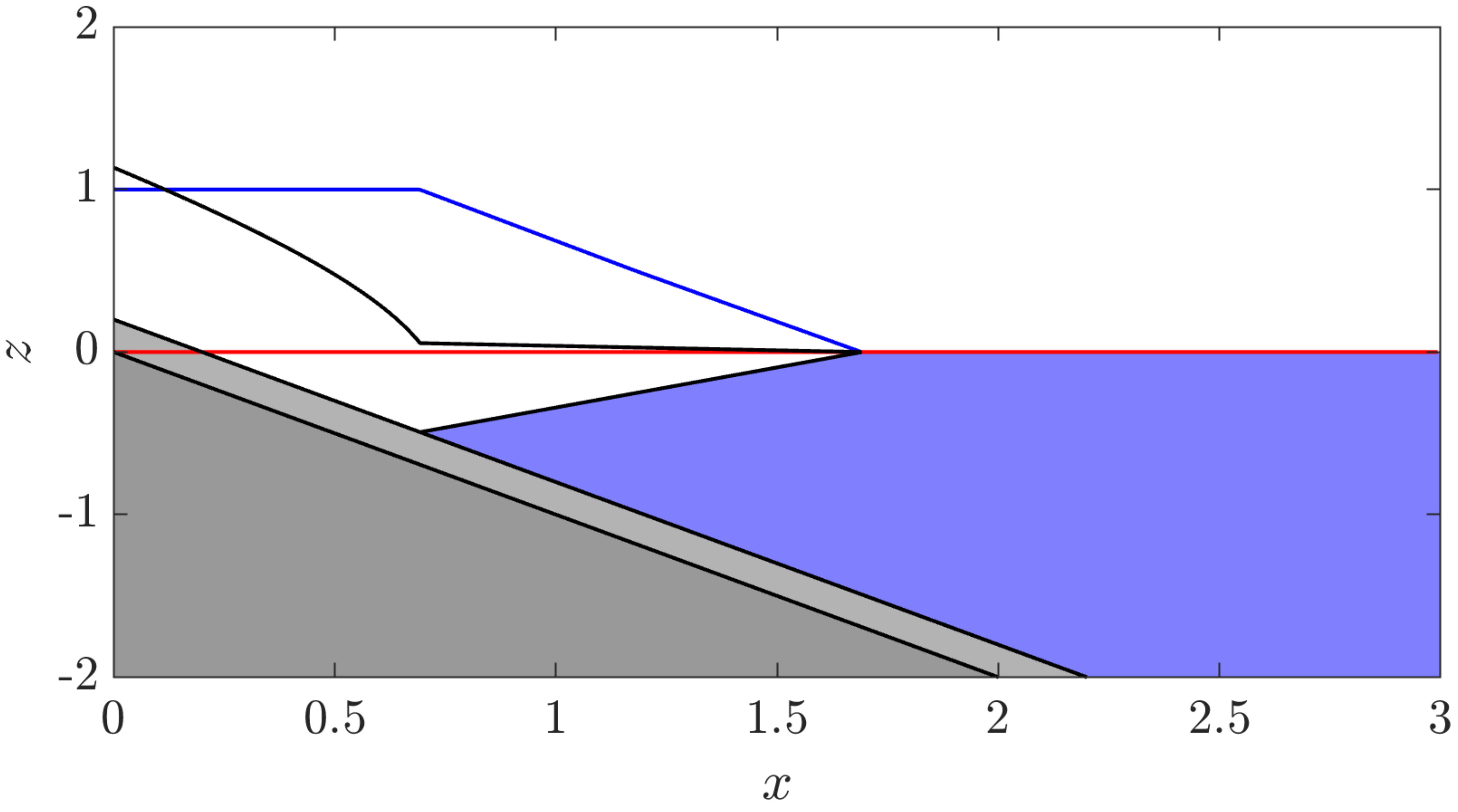


→ Grounding line position depends on ice-shelf melt rate

Evolution with sediment motion



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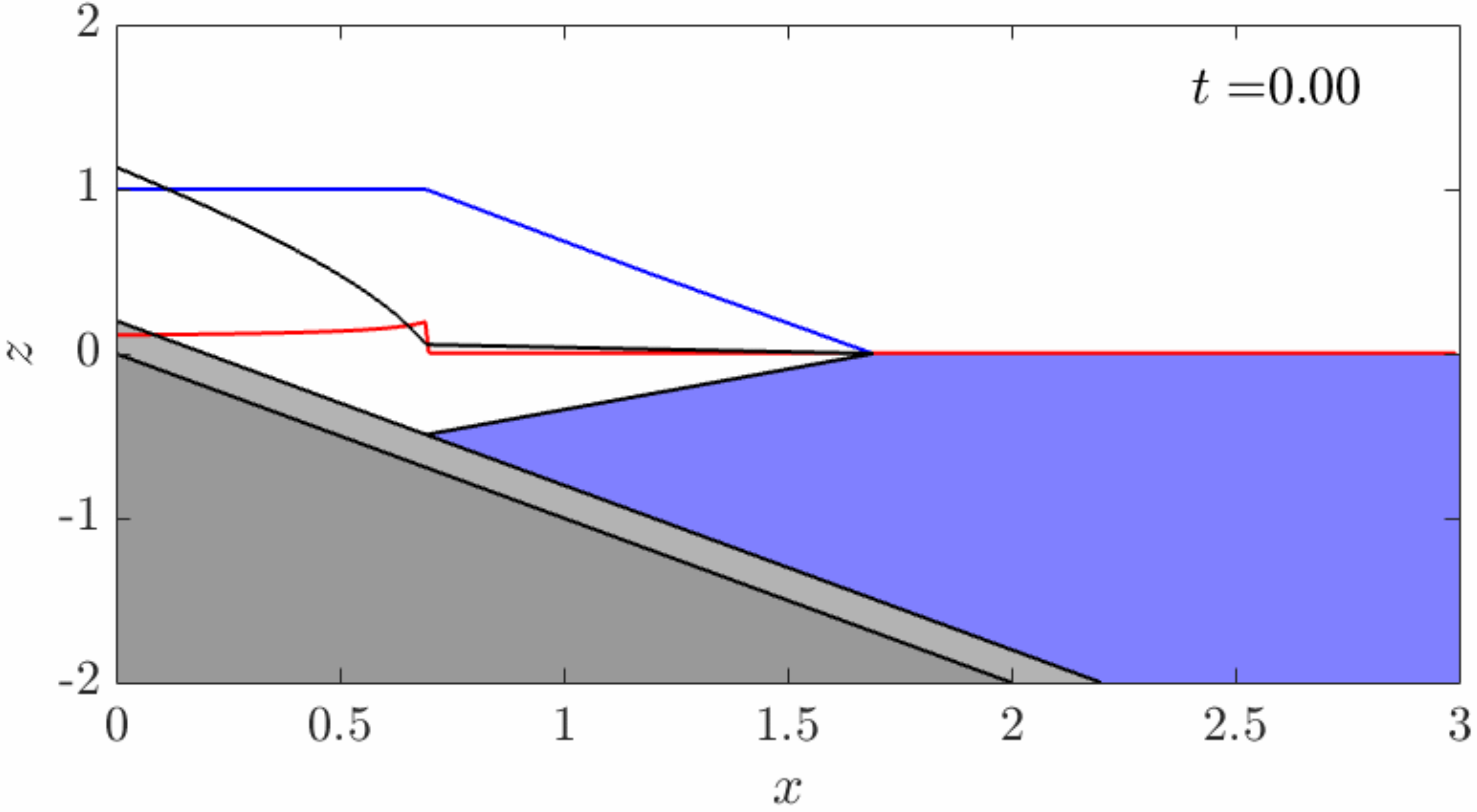

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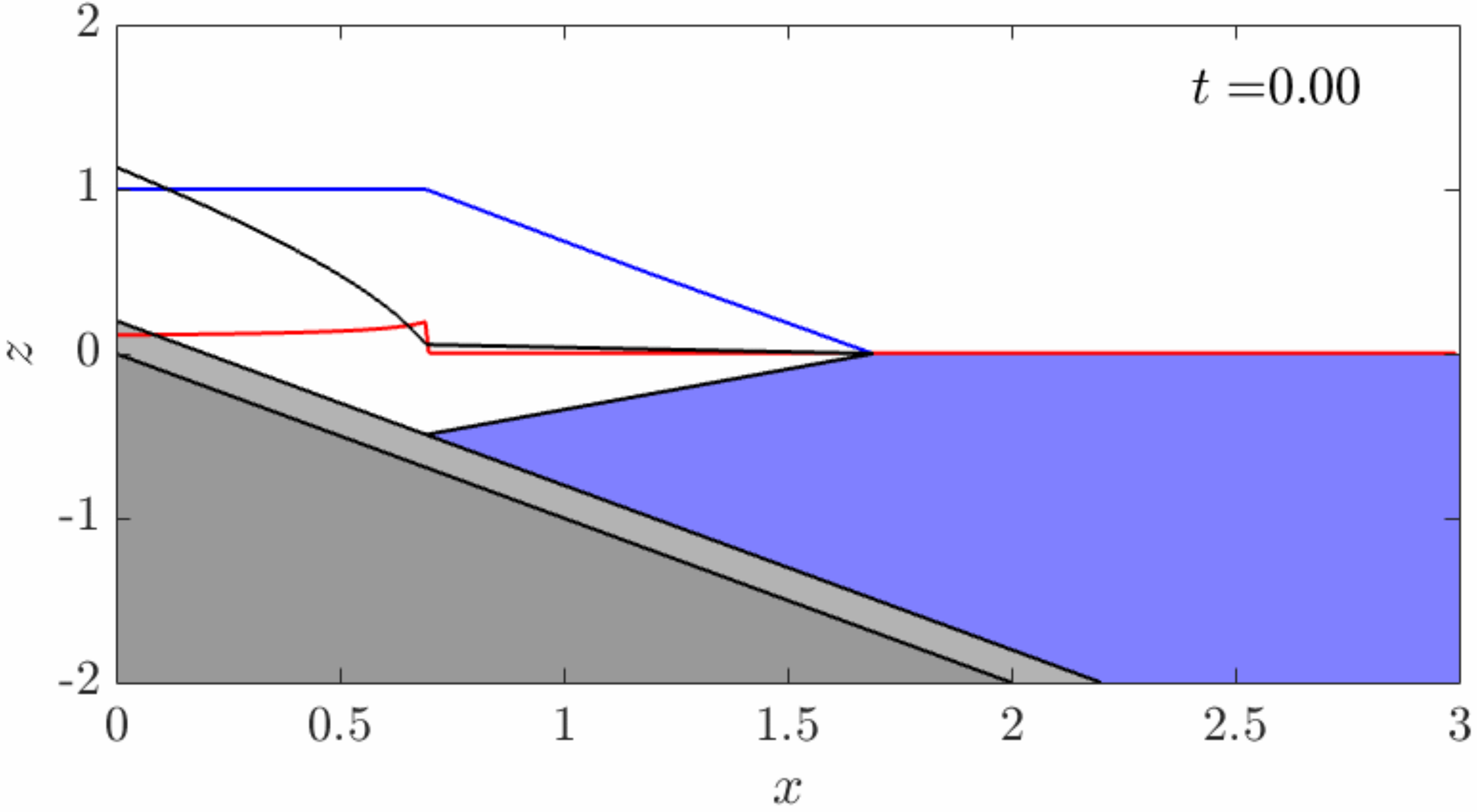

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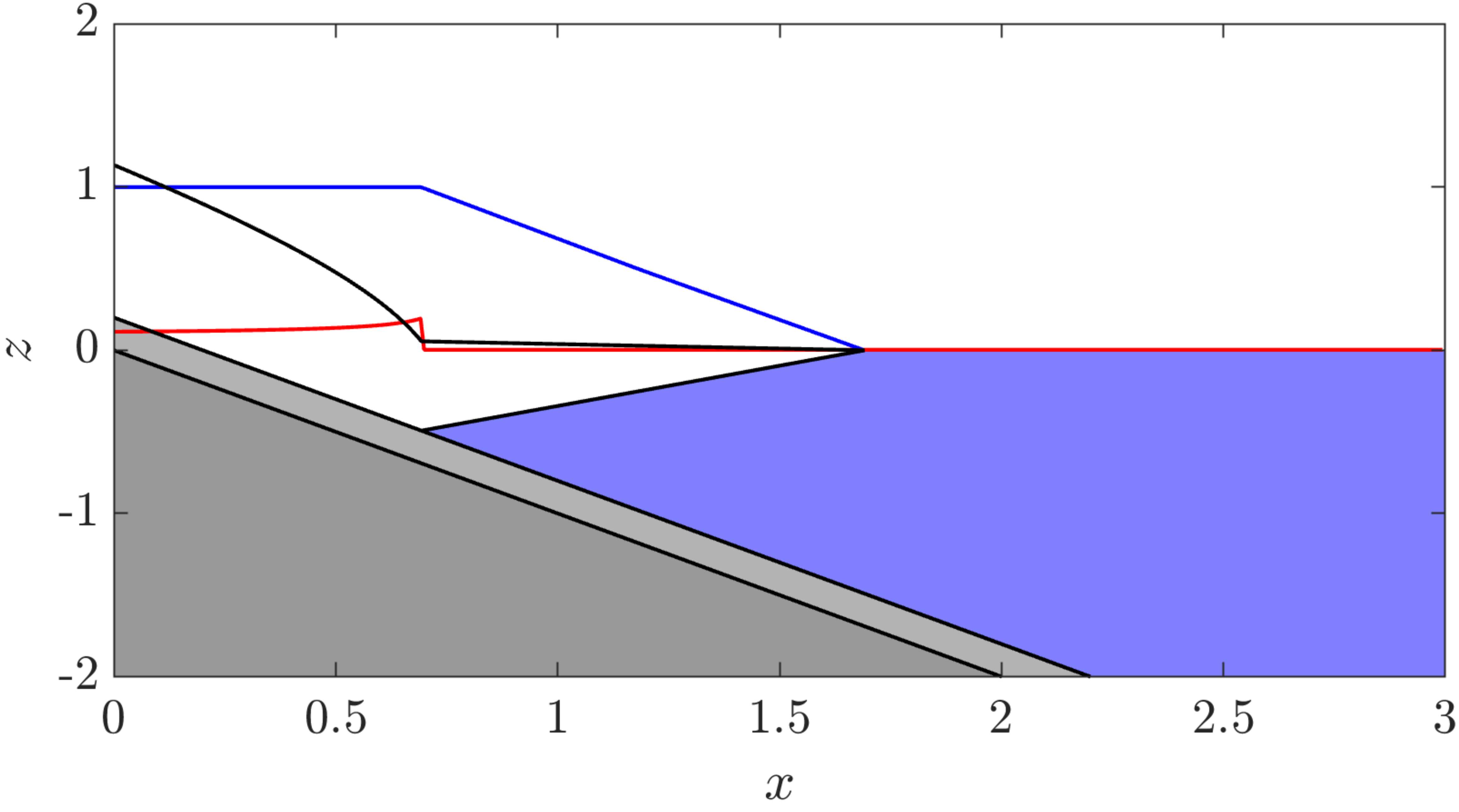

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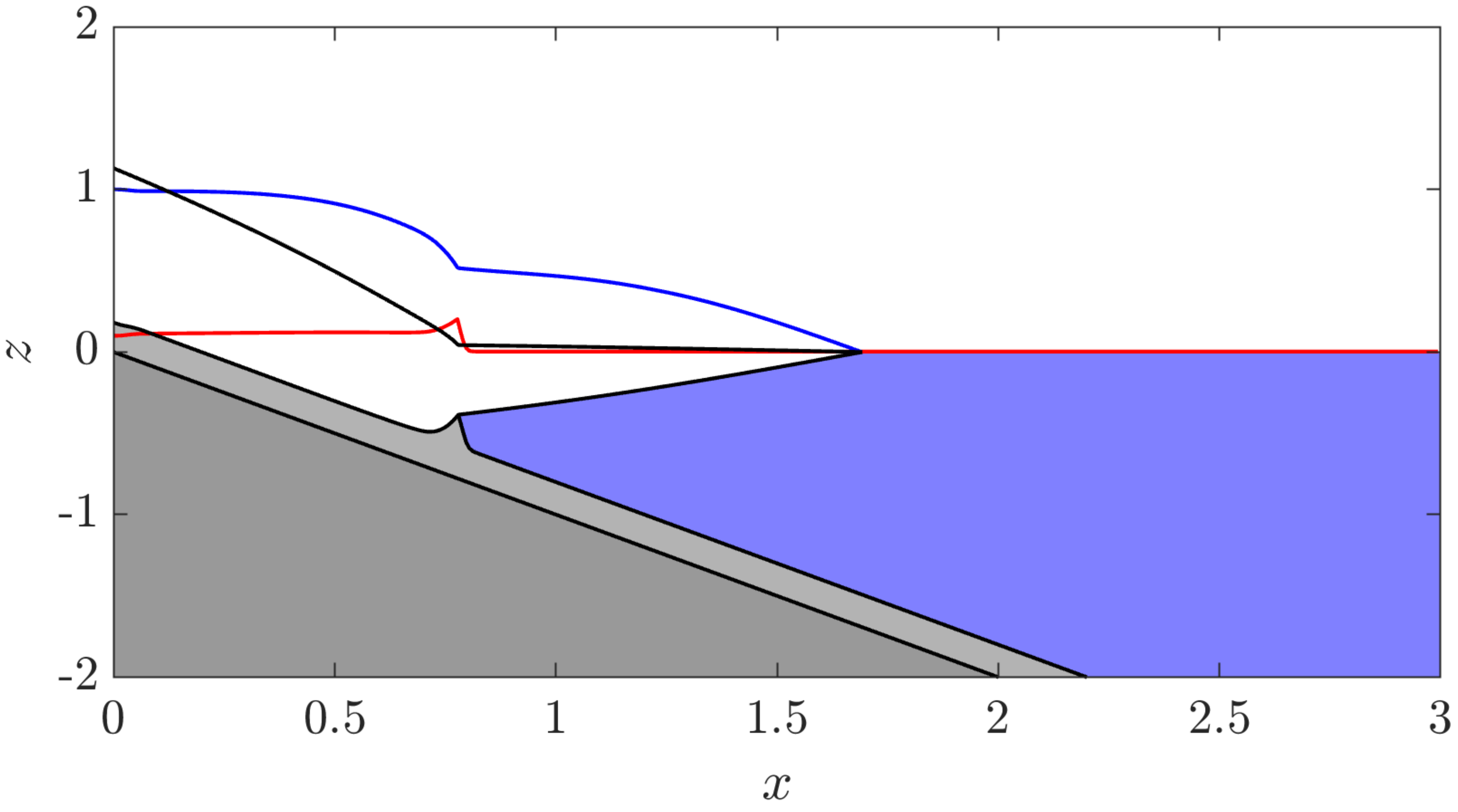

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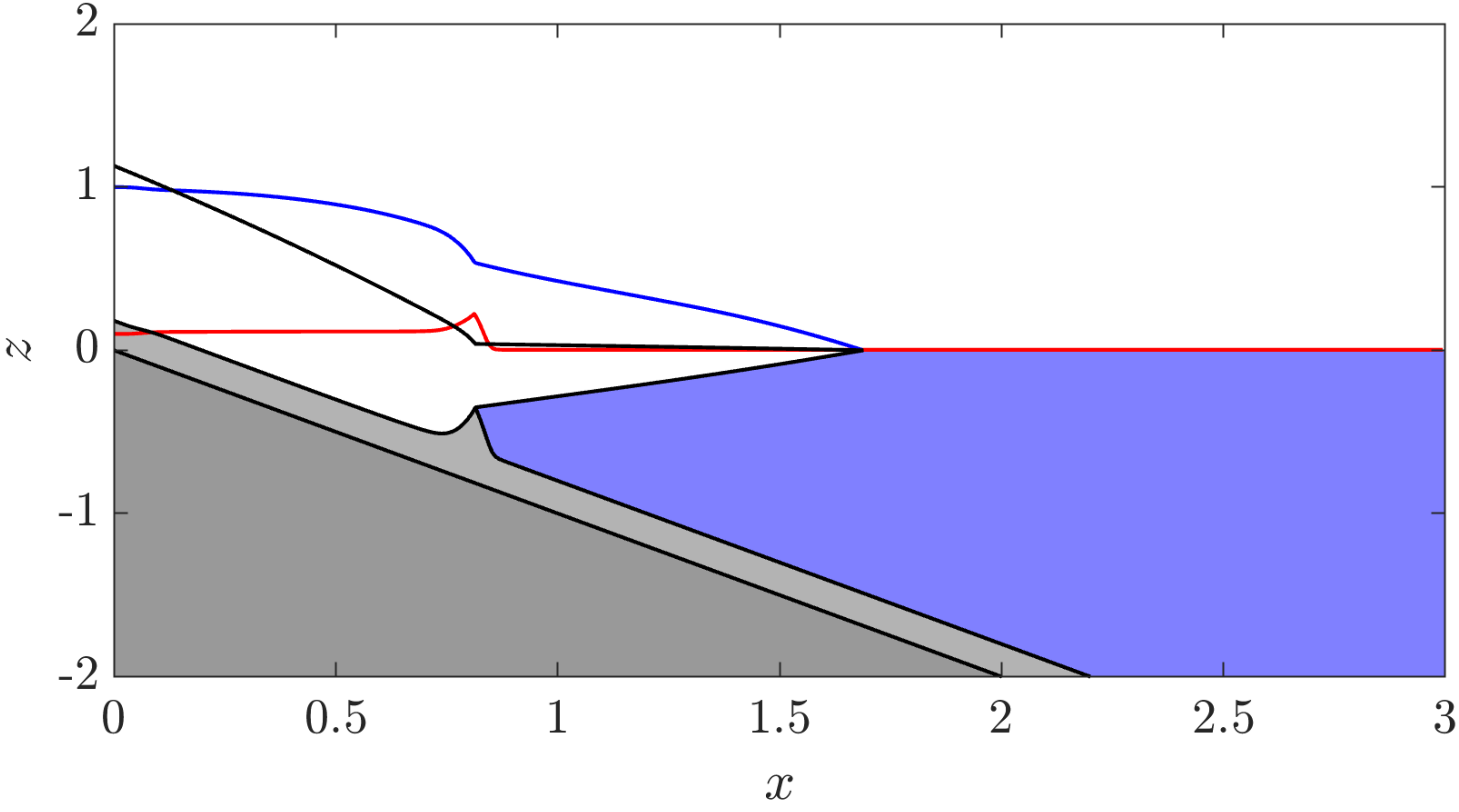

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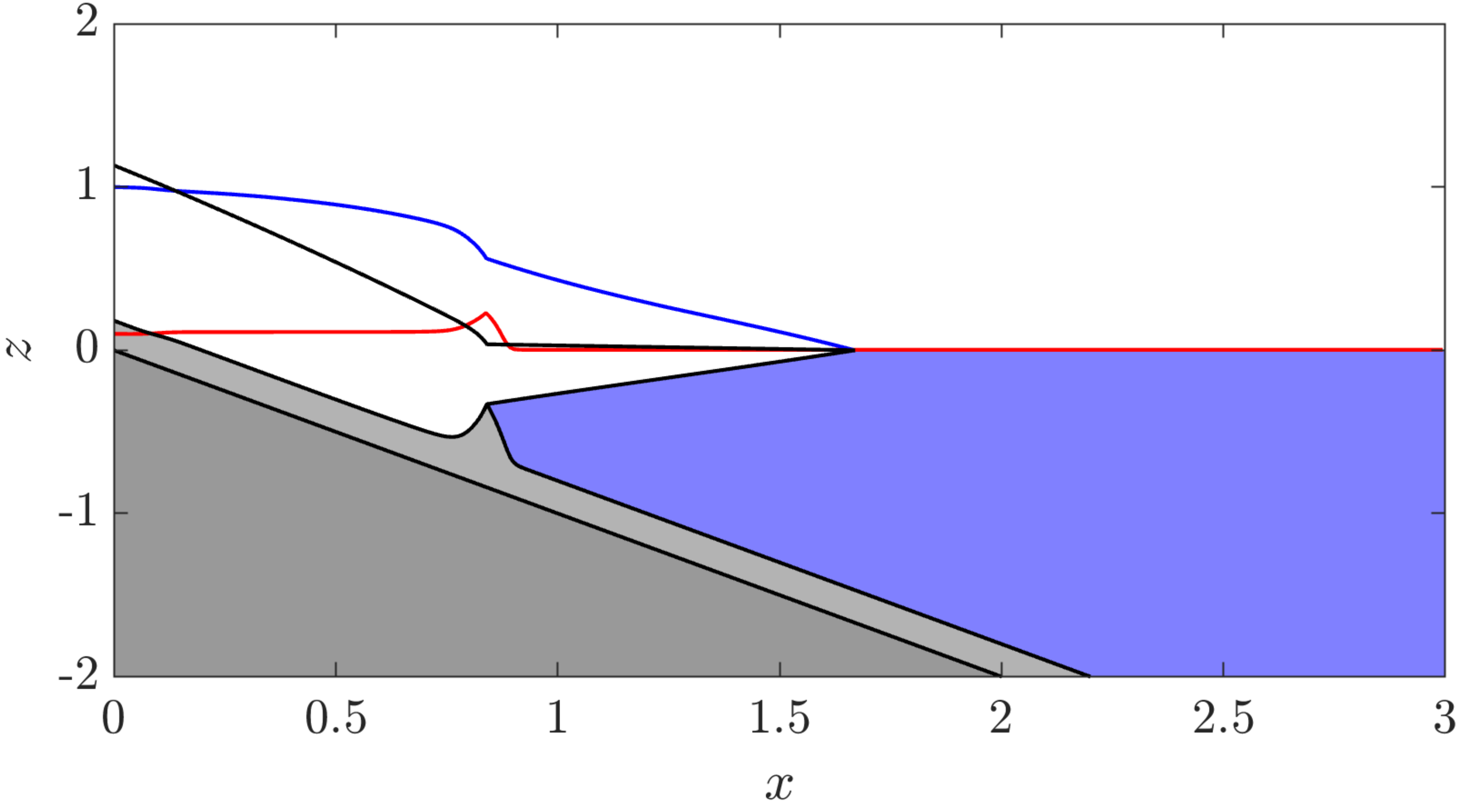

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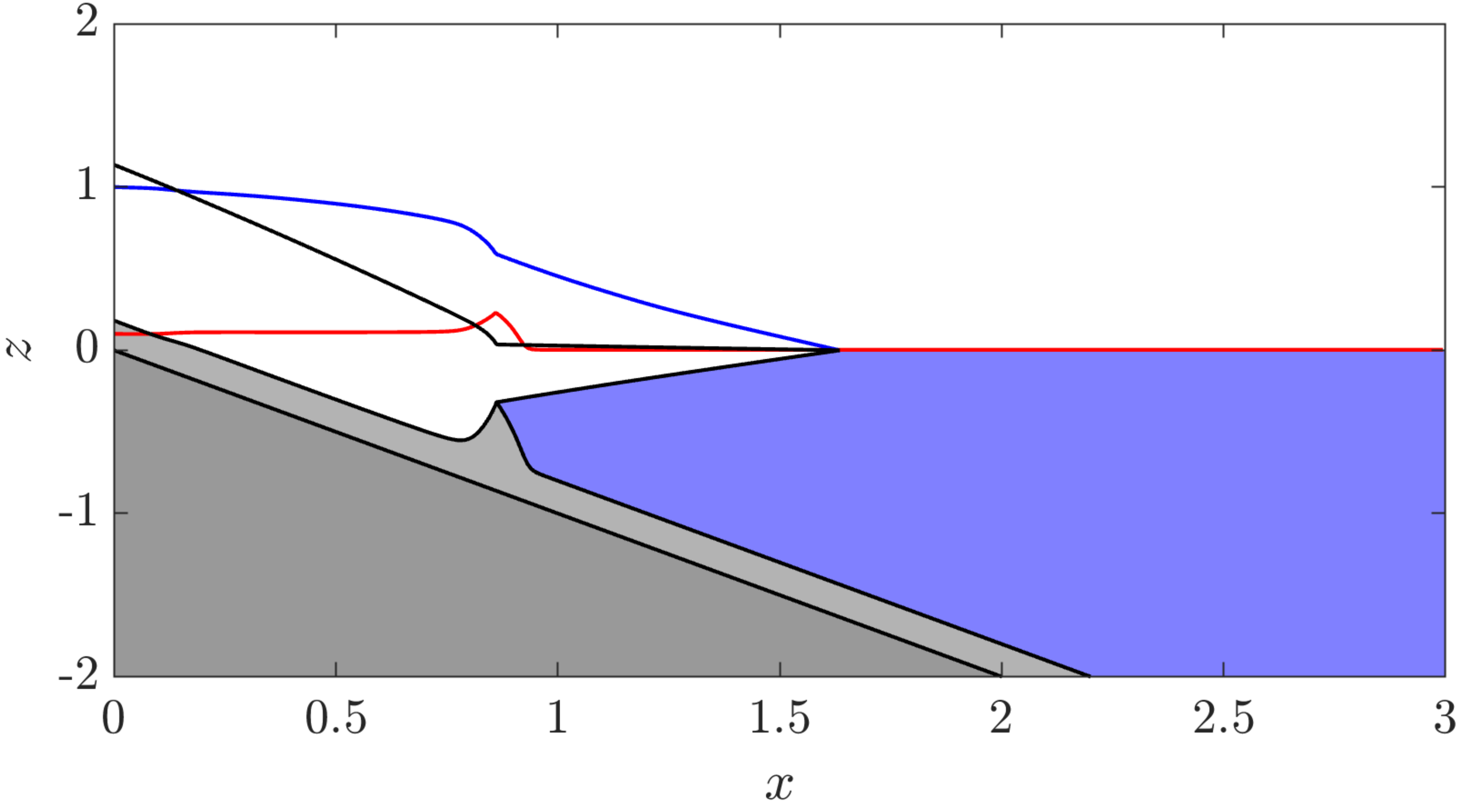

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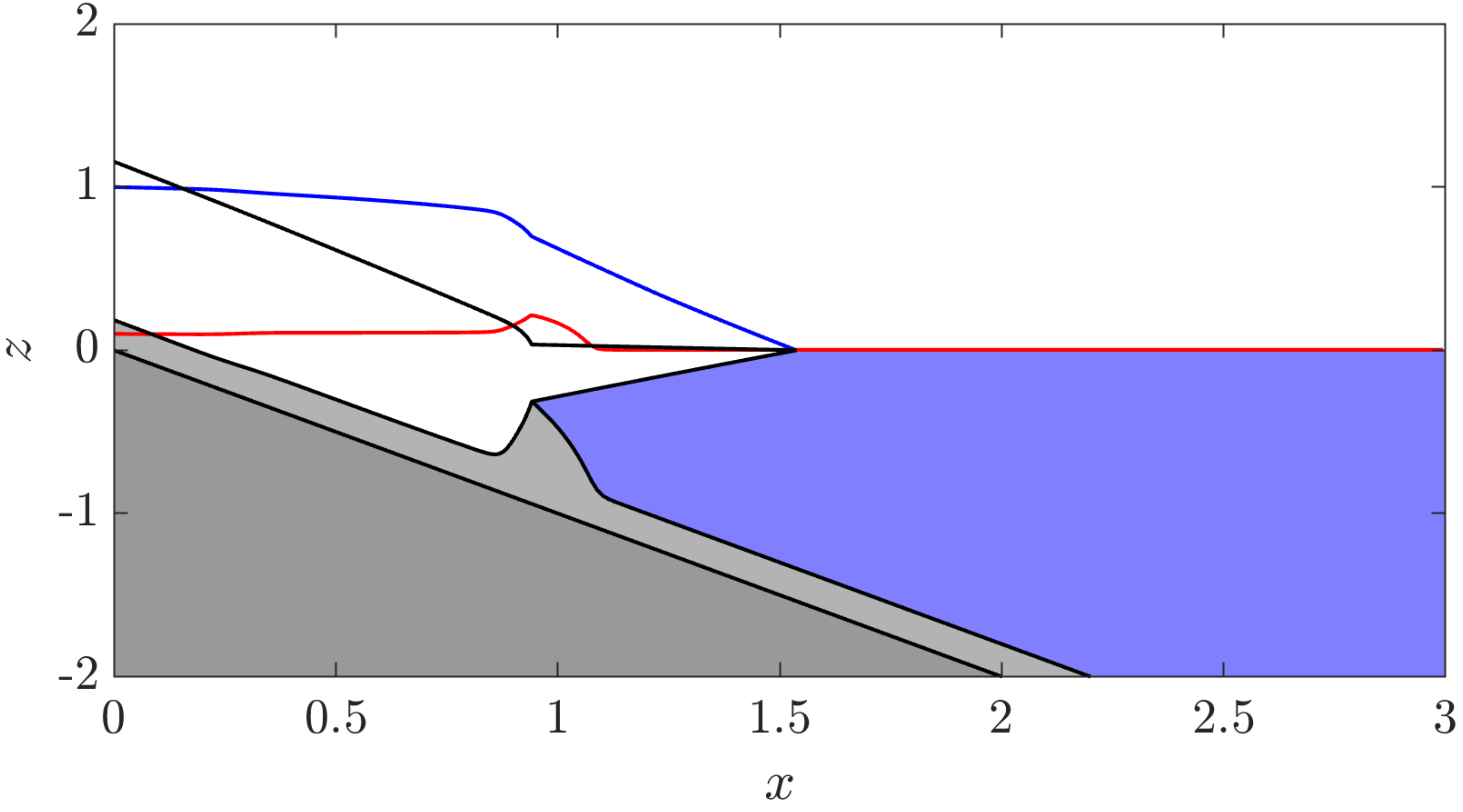

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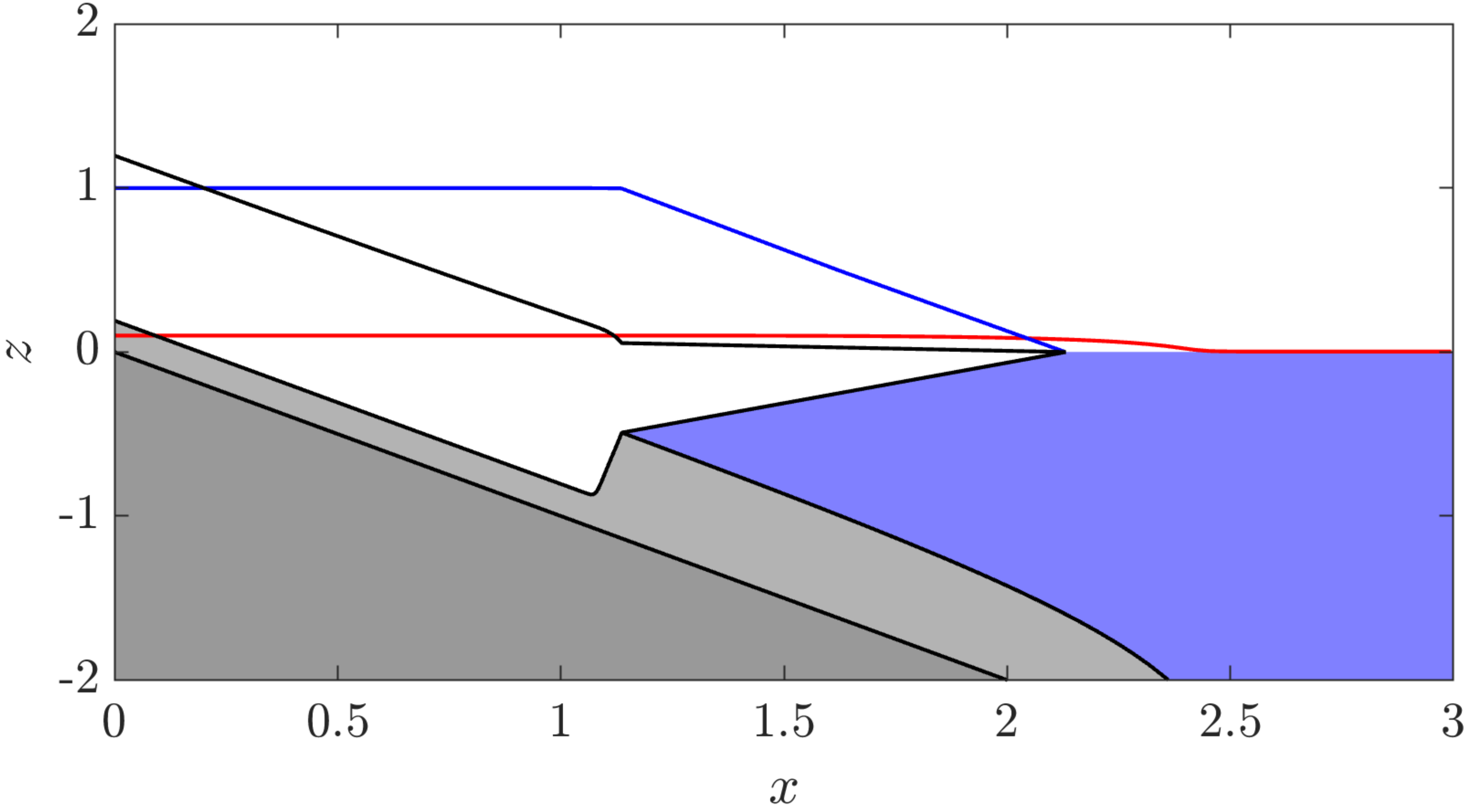
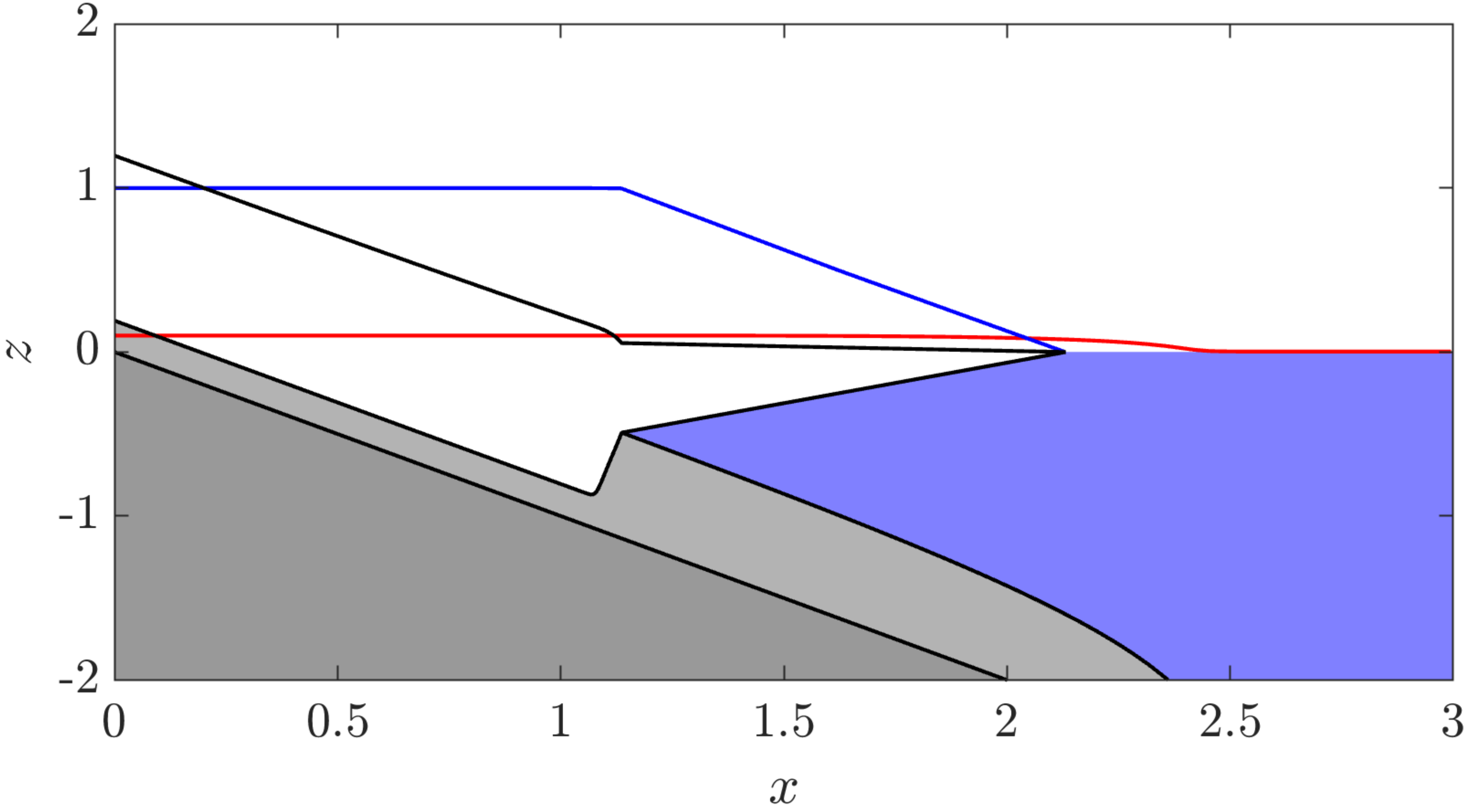


➔ Sediment deposition causes advance of grounding line (to eventual new steady state)

Response to increased melting



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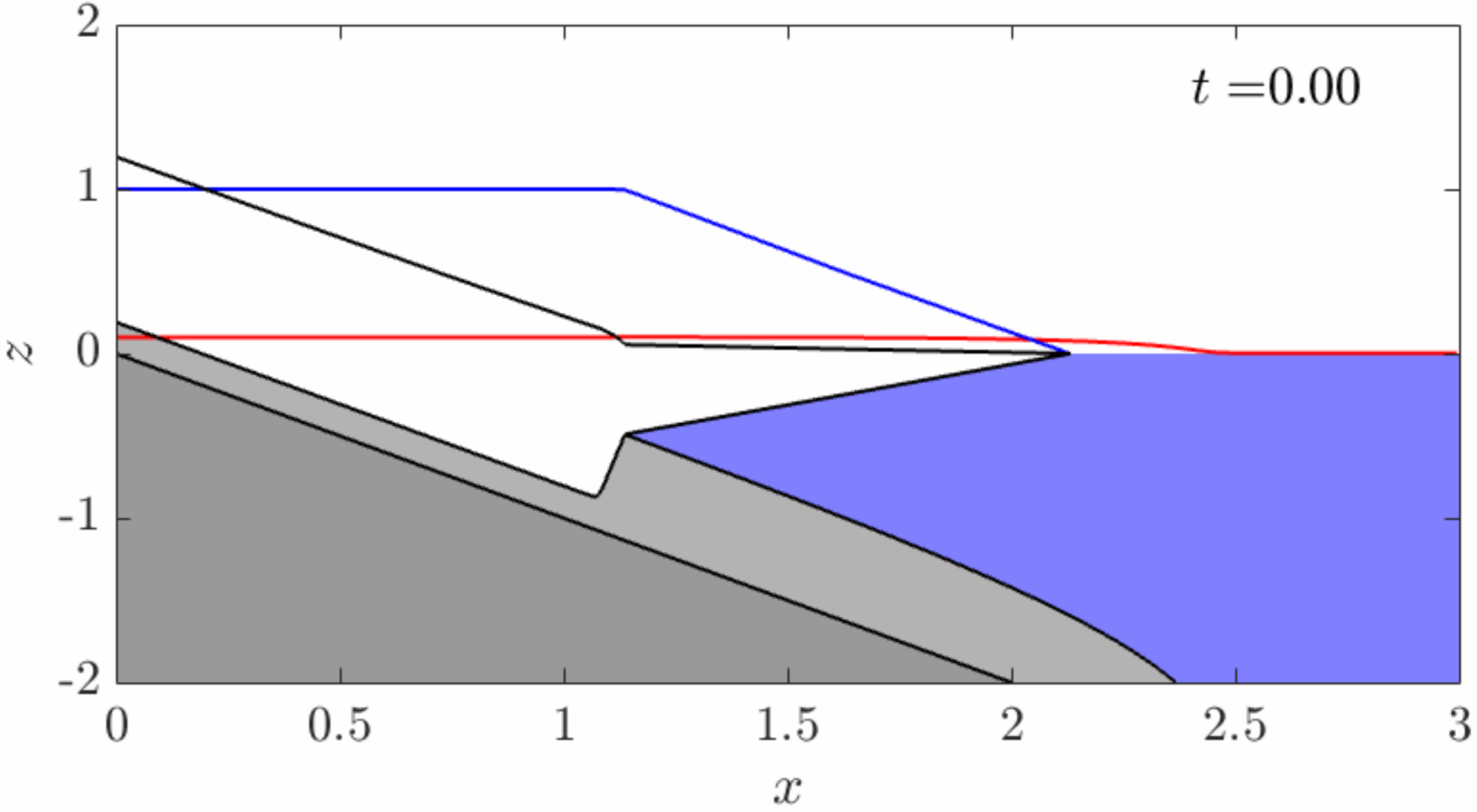

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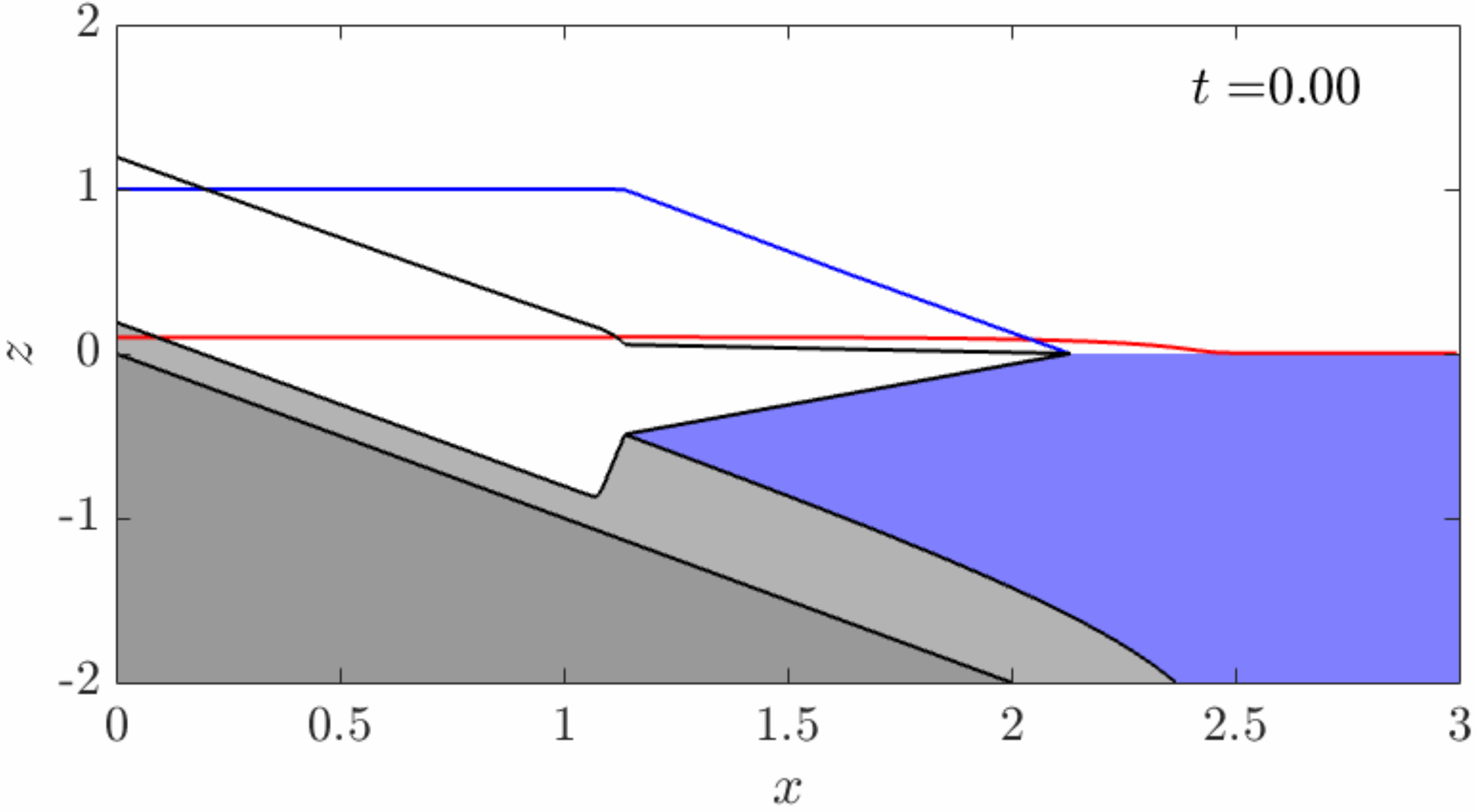

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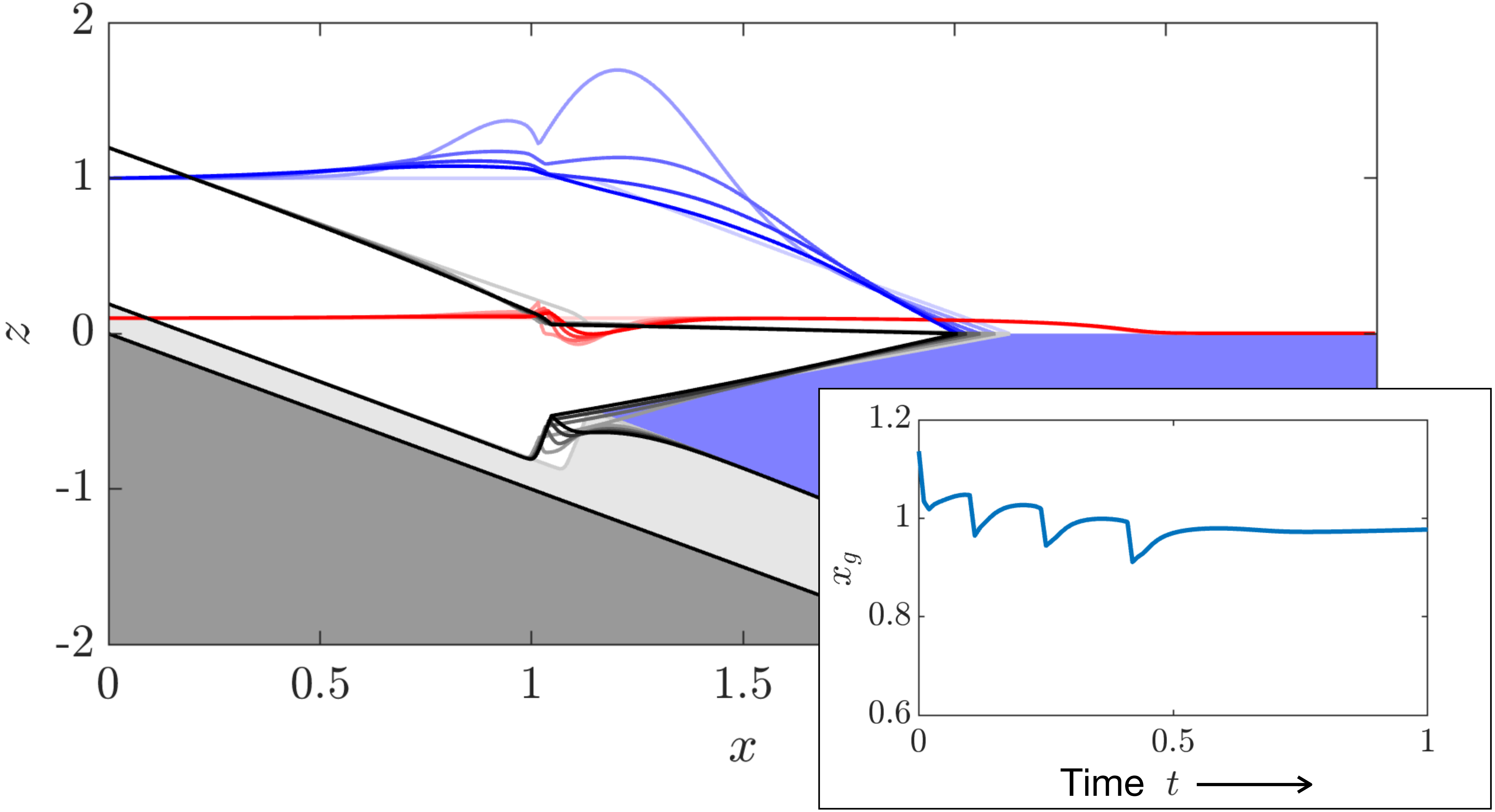
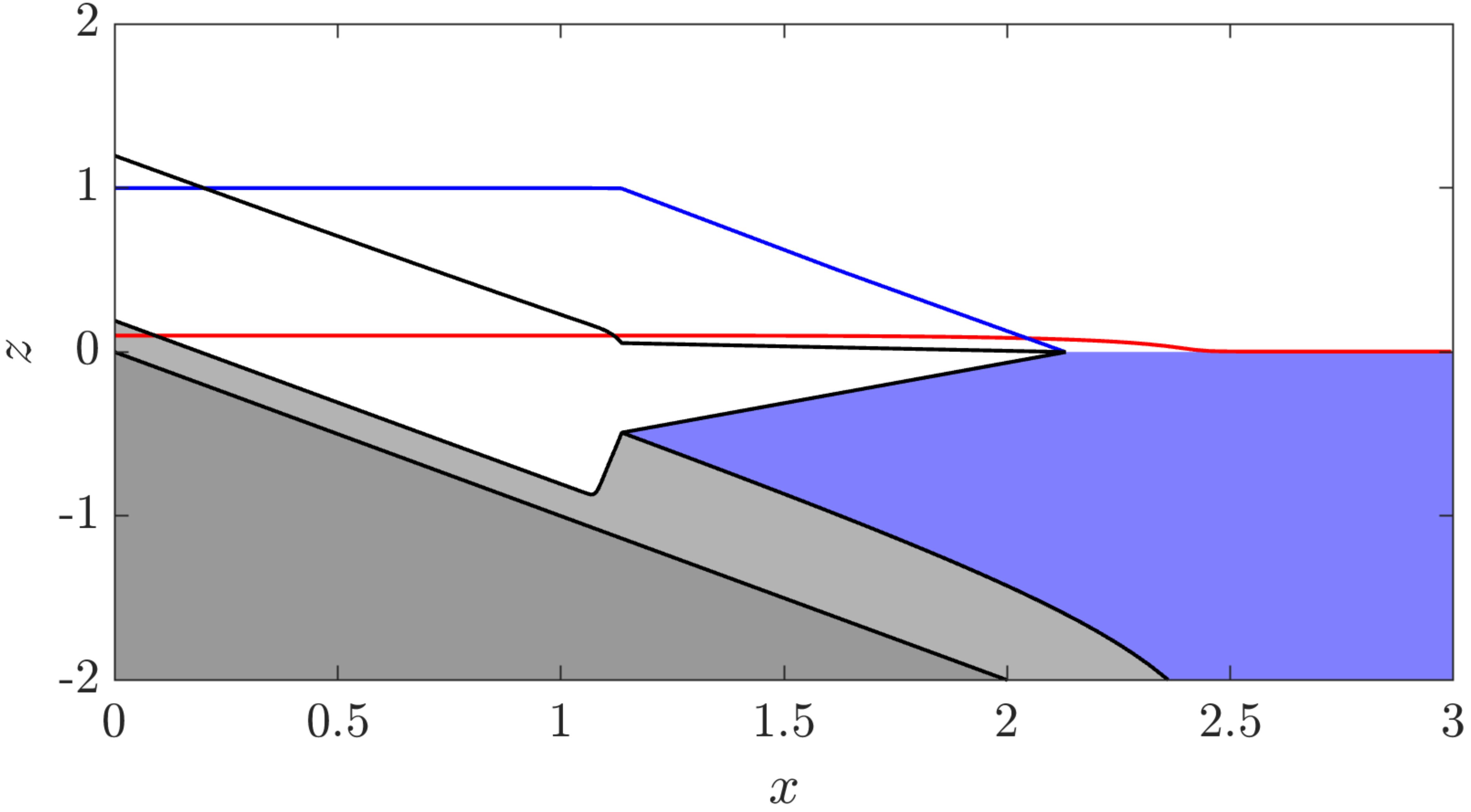


➡ Repeated rapid retreat followed by re-growth of sediment wedge

Response to increased melting (no sediment motion)



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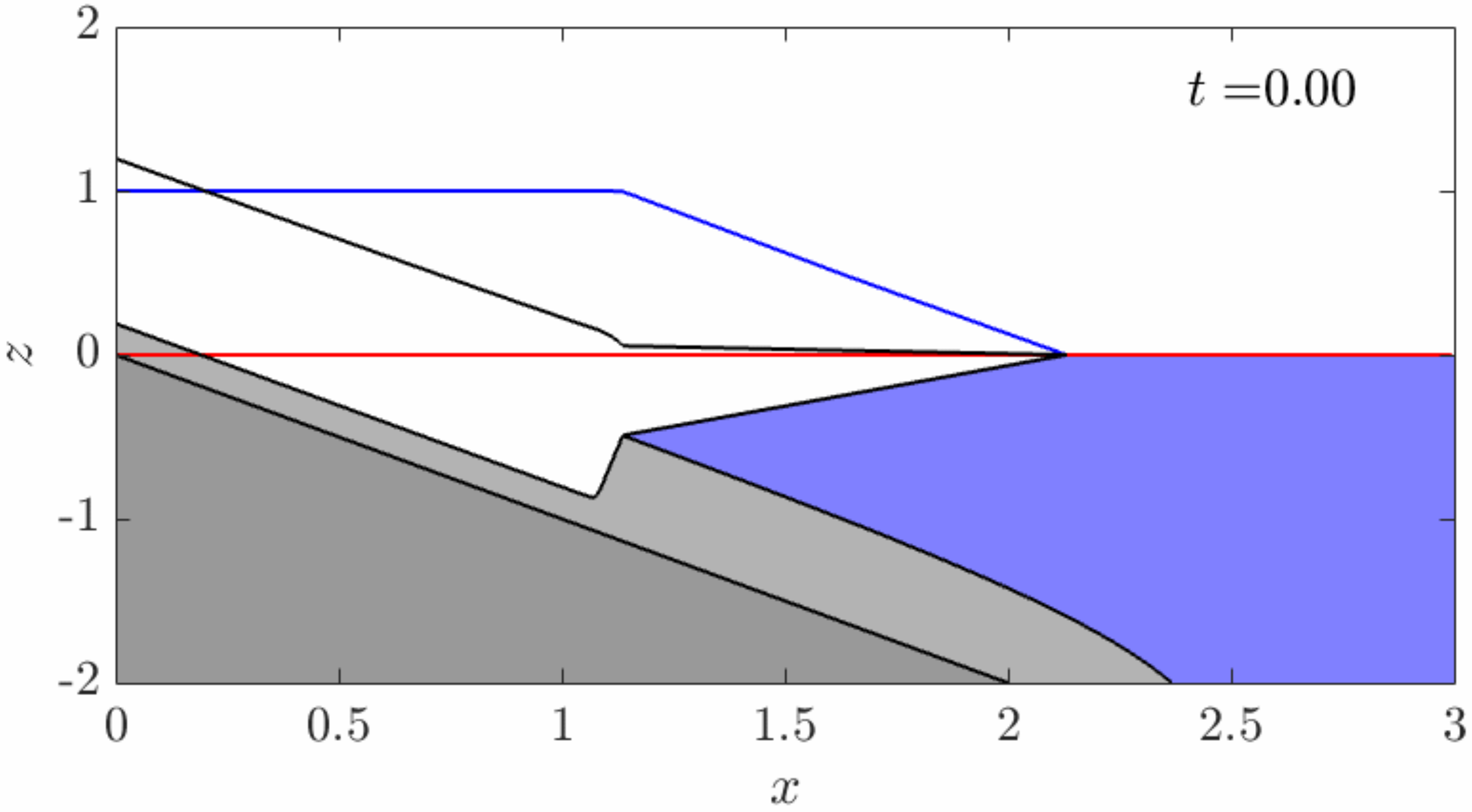

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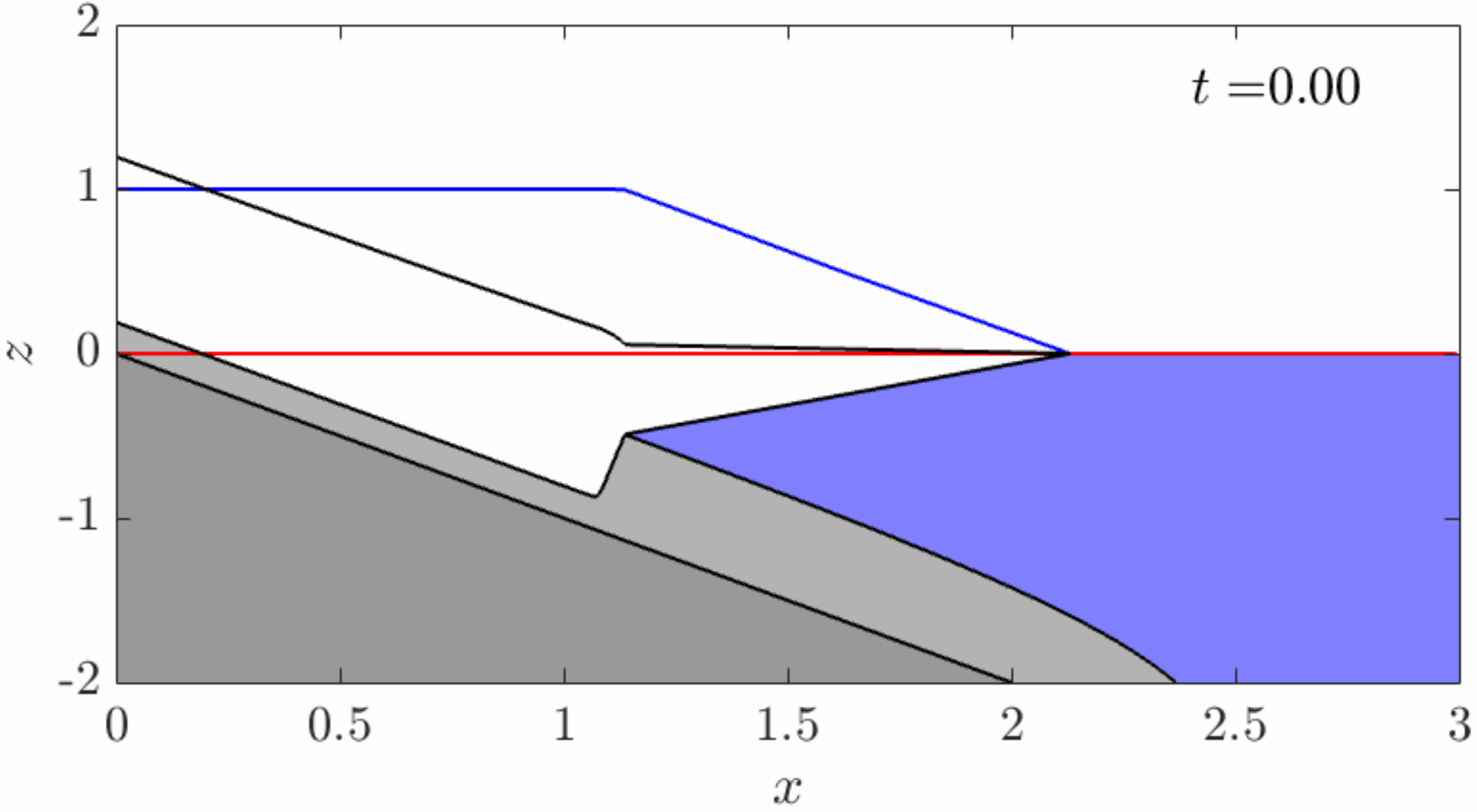

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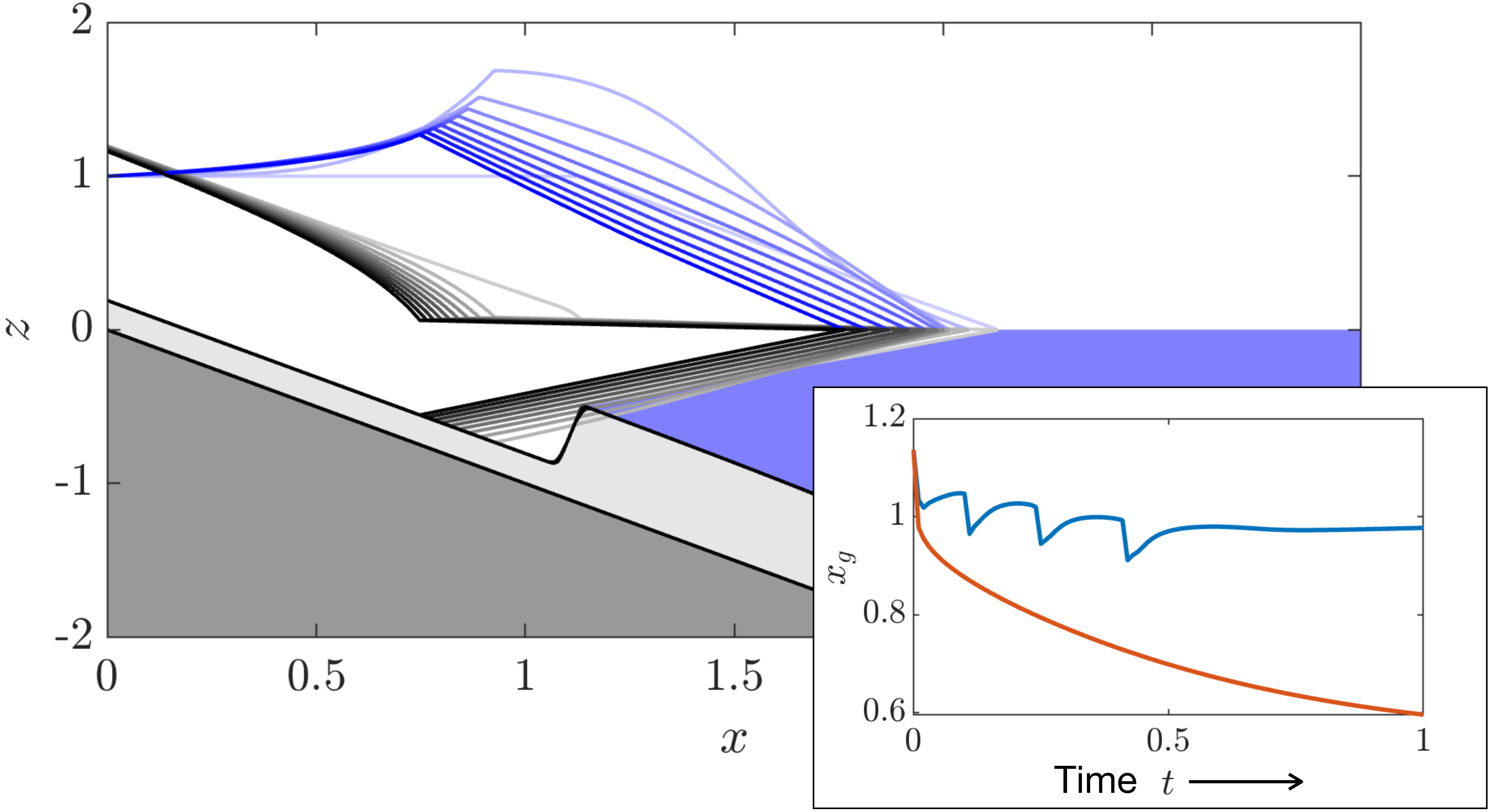

Conclusions

1. Sediment deformation produces a grounding zone wedge, which facilitates advance of the grounding line.

2. The steady state with a grounding zone wedge appears to be stable.

3. Sufficiently sudden increases in ice-shelf melting induce punctuated pattern of grounding-line retreat.

Ian Hewitt, hewitt@maths.ox.ac.uk