Gravity-driven differences in fluvial sediment transport on Mars and Earth

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end of April

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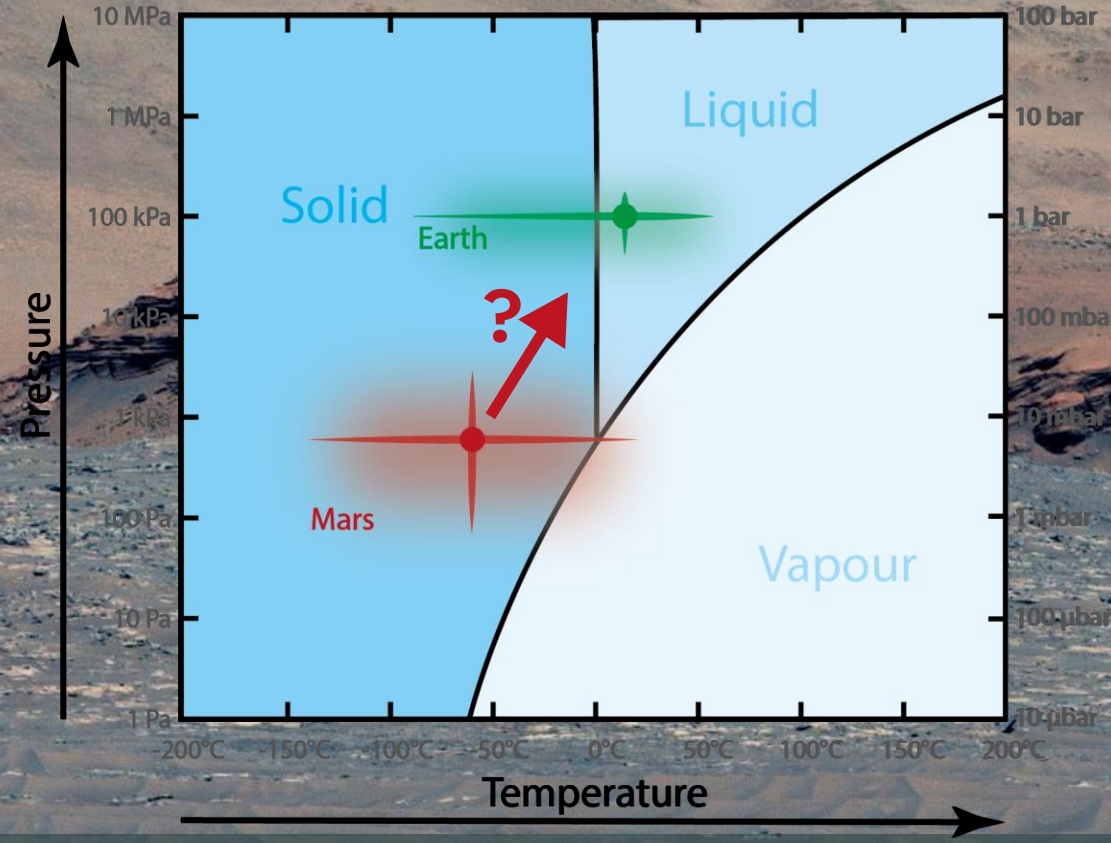
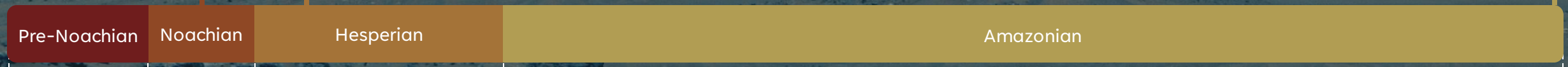
Early Mars

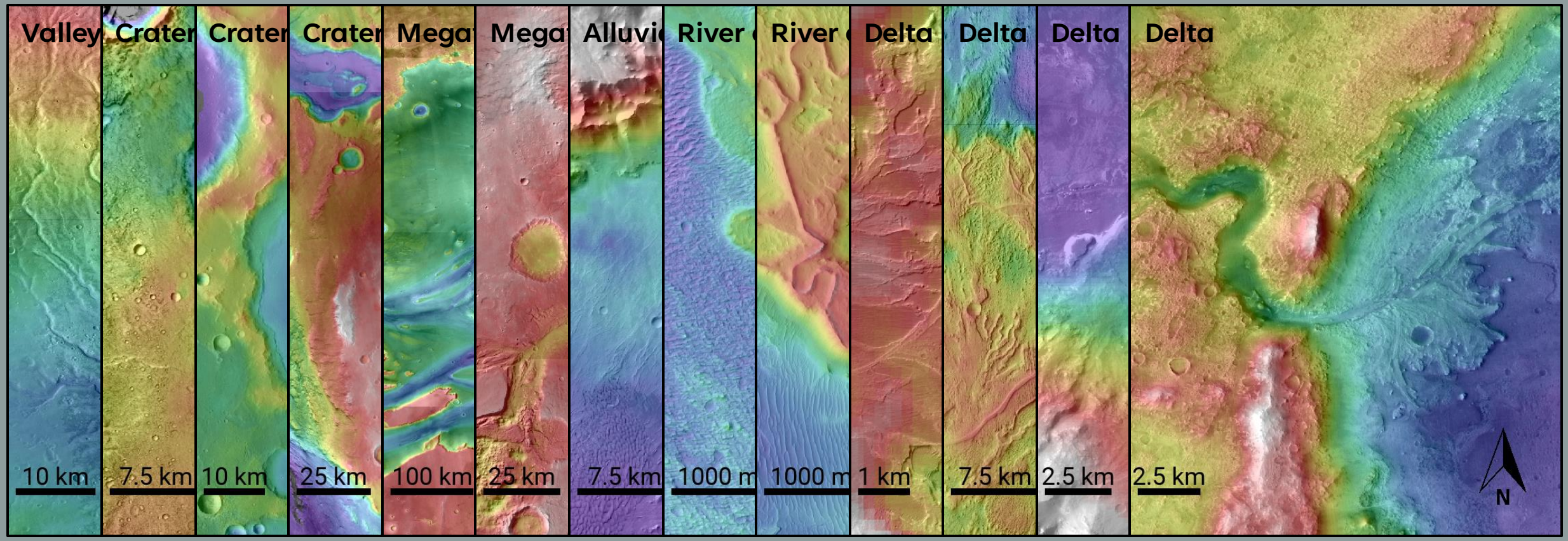


Perseverance rover
Mastcam-Z panorama
NASA/JPL-Caltech/ASU/MSSS

Geological timeline Mars



4.5 — 4.1 — 3.7 — 3.0 billion years ago — Present



VIS + Elevation
Sources: HiRISE, CTX, HRSC, MOLA

Fluvial landforms

Landforms created
or altered by
flowing water

Ancient **fluvial geomorphology** can be used to determine past **conditions** on **Mars**

Hydrological
Environmental
Climate

case,
action,
begin situation,
initial and
boundary conditions

Induction

Deduction

Abduction

effects,
outcome,
end situation,
consequences

rules,
processes,
laws of nature,
generalisations

after Kleinhans et al., 2010

Earth

Mars

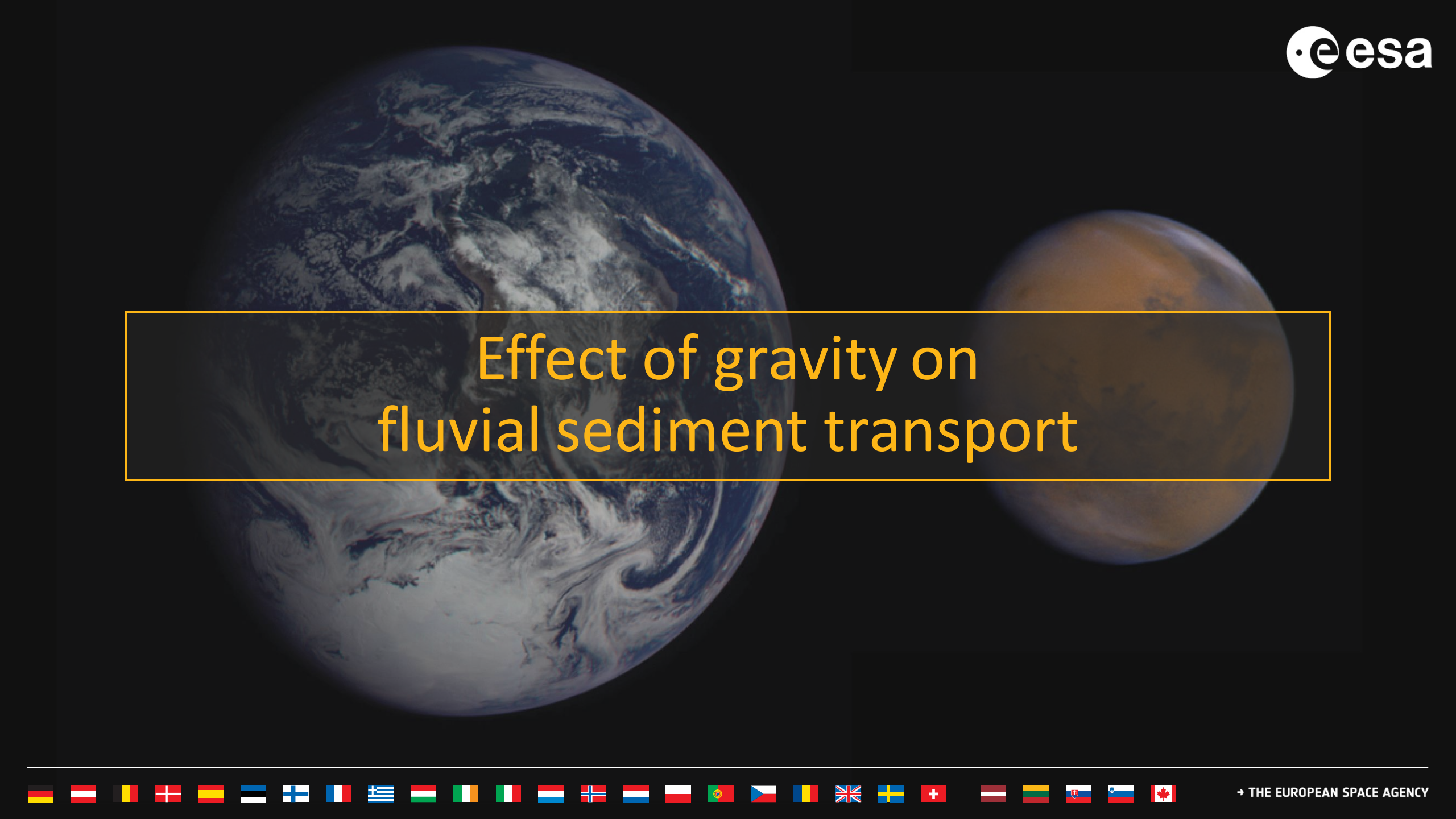
Is it a fair comparison?

Differences Earth and Mars

Examples

- Ice and permafrost
- Sediment density differences
- No organisms
- Minimal tides
- **Gravity**

→ Modelling only option

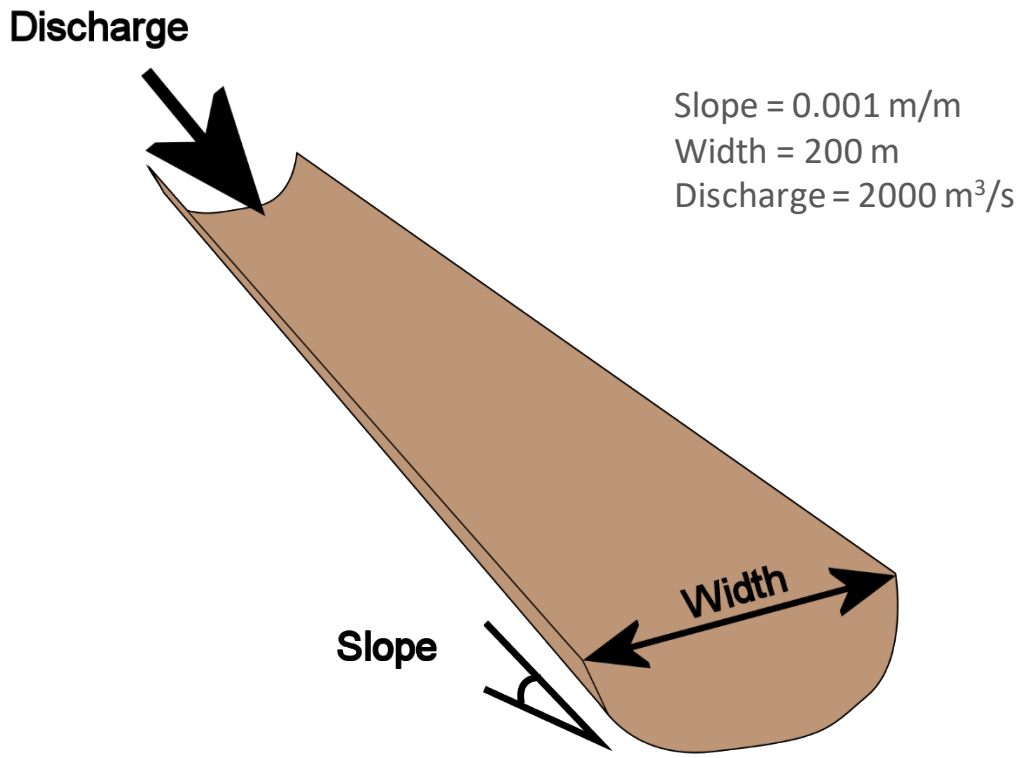


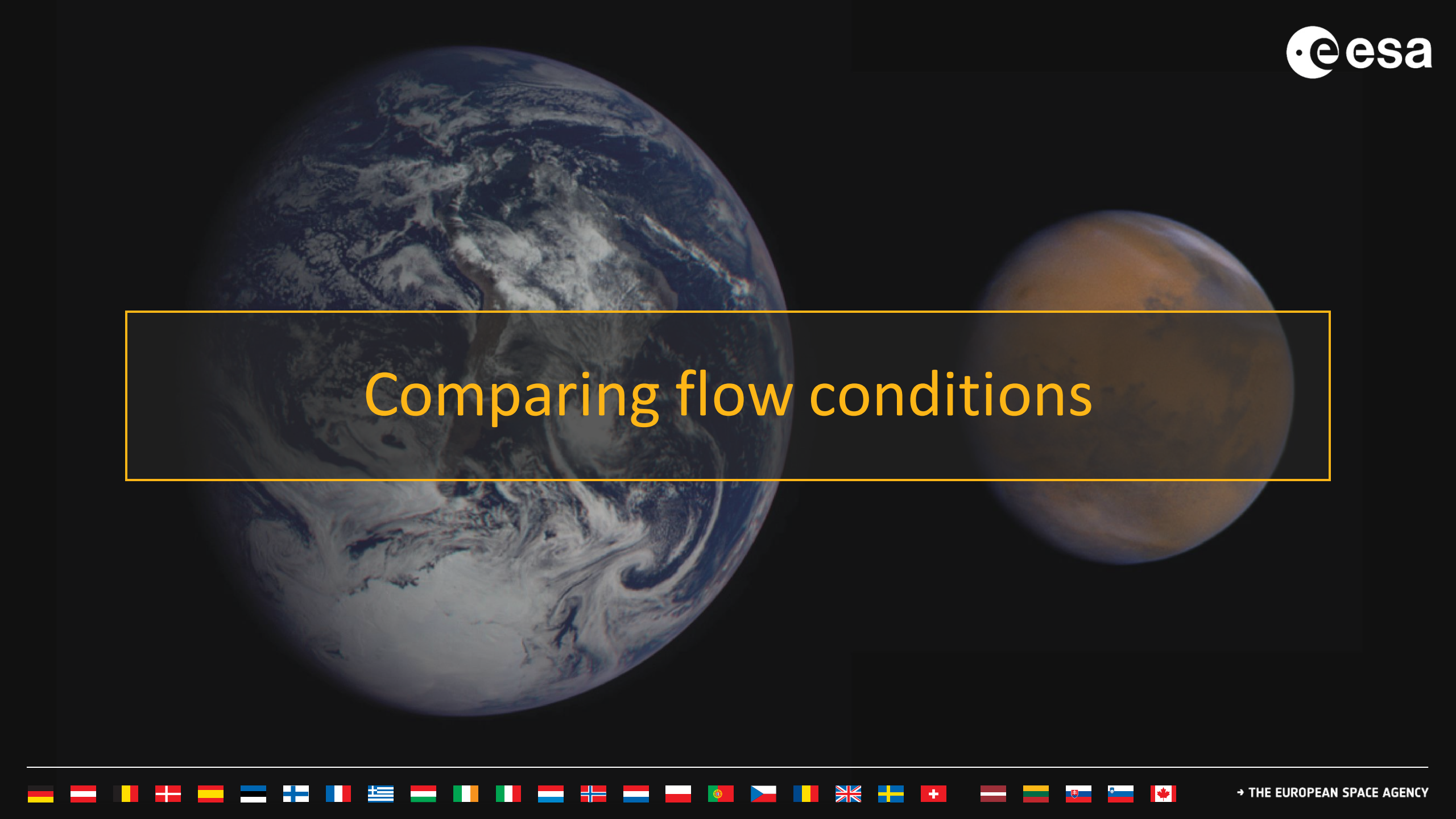
Effect of gravity on fluvial sediment transport

Methodology

Methodology

- Analytical equations (static 1D model)
- Run same scenario for Earth and Mars gravity
- Equal channel shape
  - width
  - slope
- Comparing equal water discharge

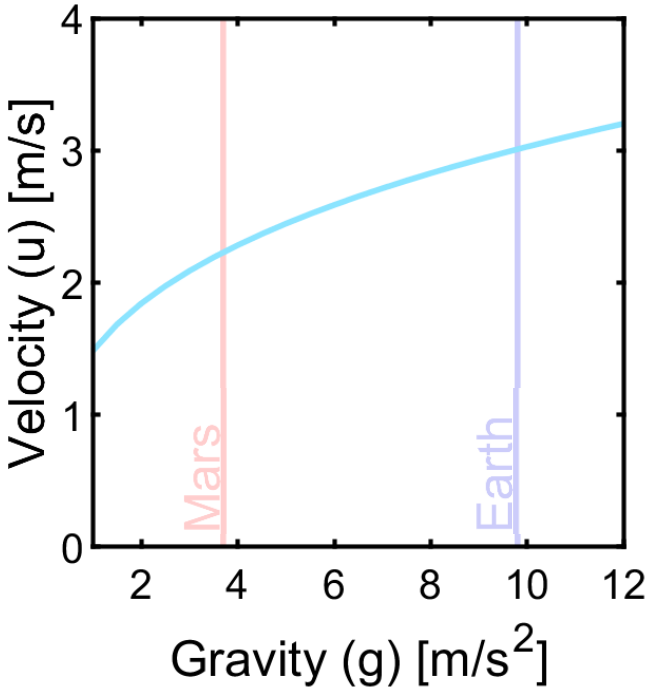




Comparing flow conditions

Comparing flow conditions

For the same discharge (Q) and geometry



Input:
Q = 2000 m3/s
Slope = 0.001 m/m
Width = 200 m

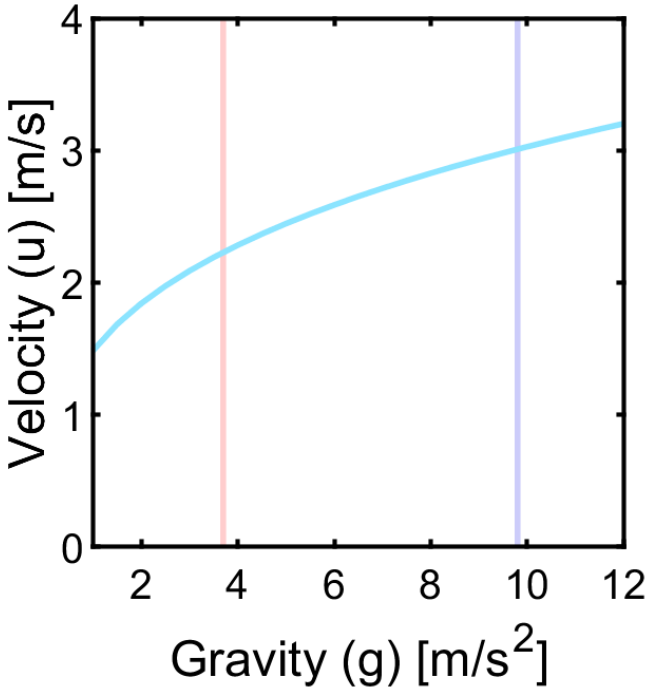
$$u = C\sqrt{R_w S} \quad \text{(Chézy)}$$

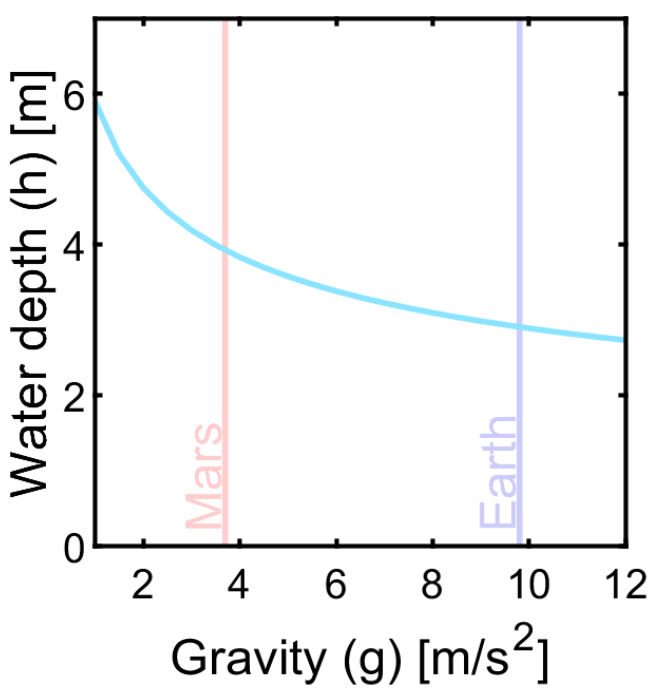
velocity = roughness · $\sqrt{\text{hydraulic radius} \cdot \text{slope}}$

Constants:
g_{Earth} = 9.8 m/s^2
g_{Mars} = 3.7 m/s^2
Roughness = 0.01 m
density = 1000 kg/m^3

Comparing flow conditions

For the same discharge (Q) and geometry





Input:
Q = 2000 m3/s
Slope = 0.001 m/m
Width = 200 m

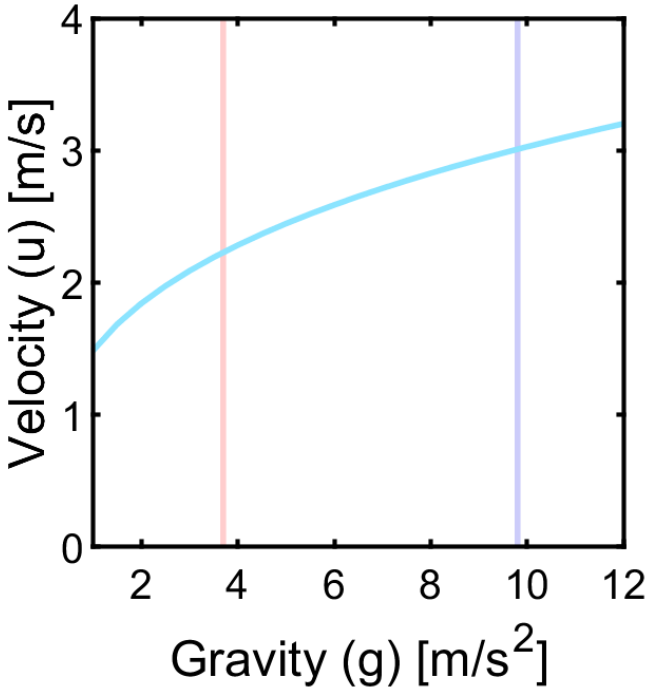
$$h = \frac{Q}{W \cdot u}$$

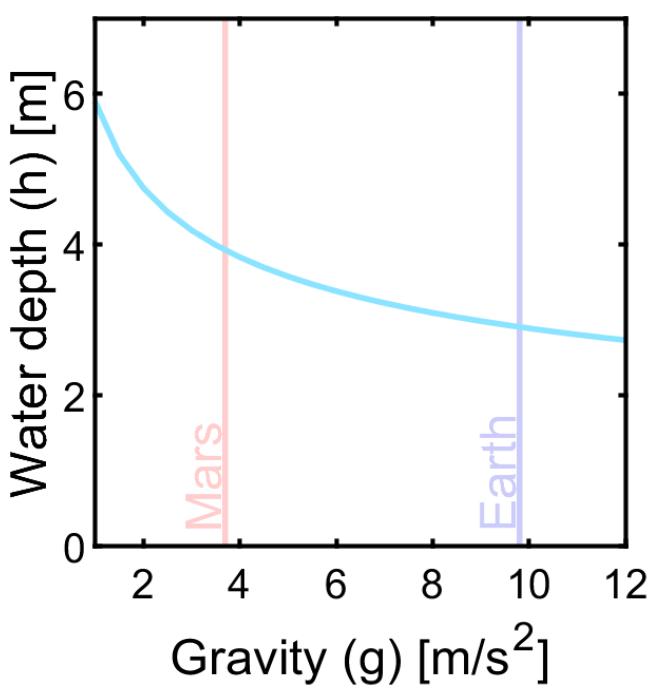
depth = discharge / (width · velocity)

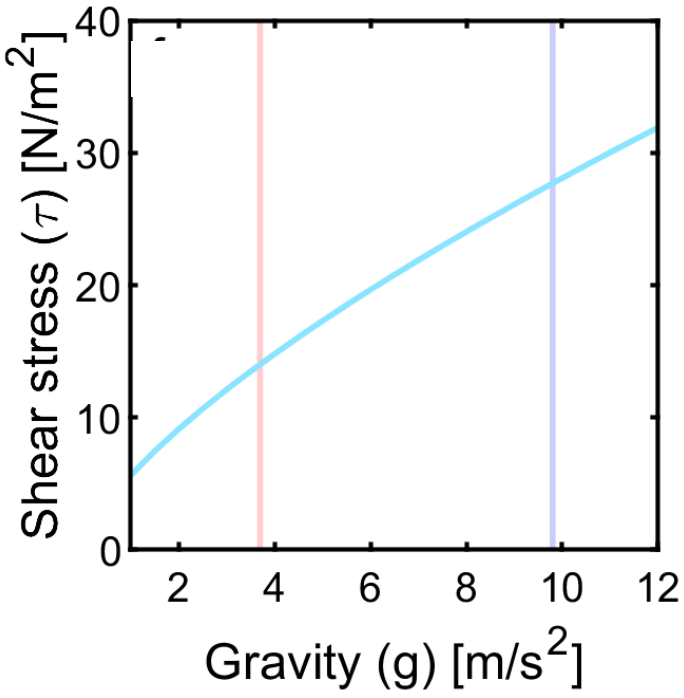
Constants:
g_{Earth} = 9.8 m/s^2
g_{Mars} = 3.7 m/s^2
Roughness = 0.01 m
density = 1000 kg/m^3

Comparing flow conditions

For the same discharge (Q) and geometry







Input:
Q = 2000 m3/s
Slope = 0.001 m/m
Width = 200 m

$$\tau = \rho \cdot g \cdot R_w \cdot S$$

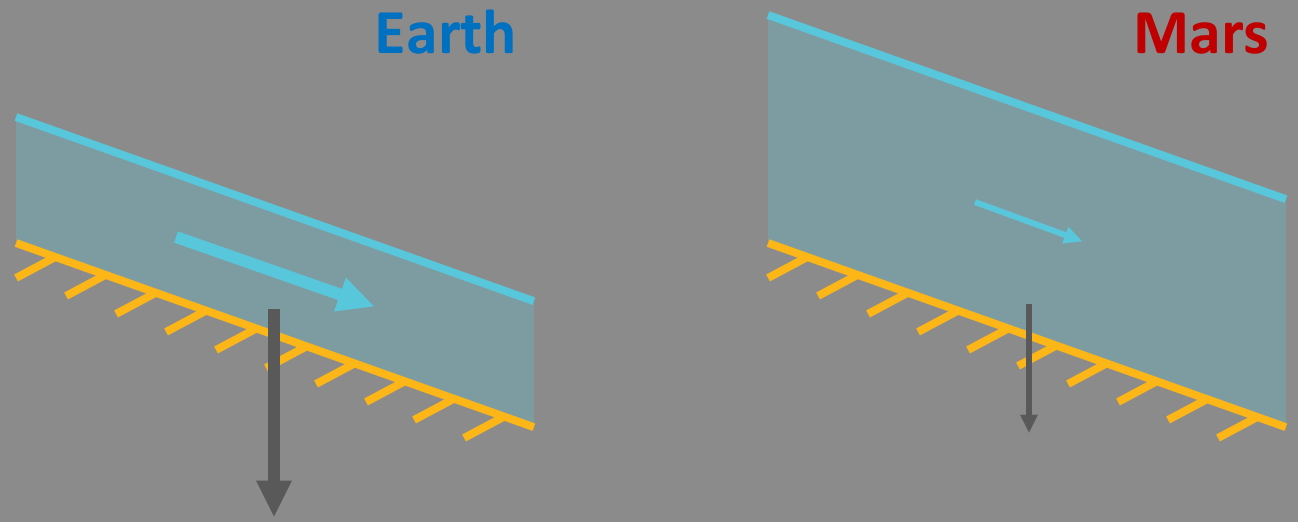
Shear stress = density · gravity acceleration · hydraulic roughness · slope

Constants:
g_{Earth} = 9.8 m/s^2
g_{Mars} = 3.7 m/s^2
Roughness = 0.01 m
density = 1000 kg/m^3

Conclusions for Mars

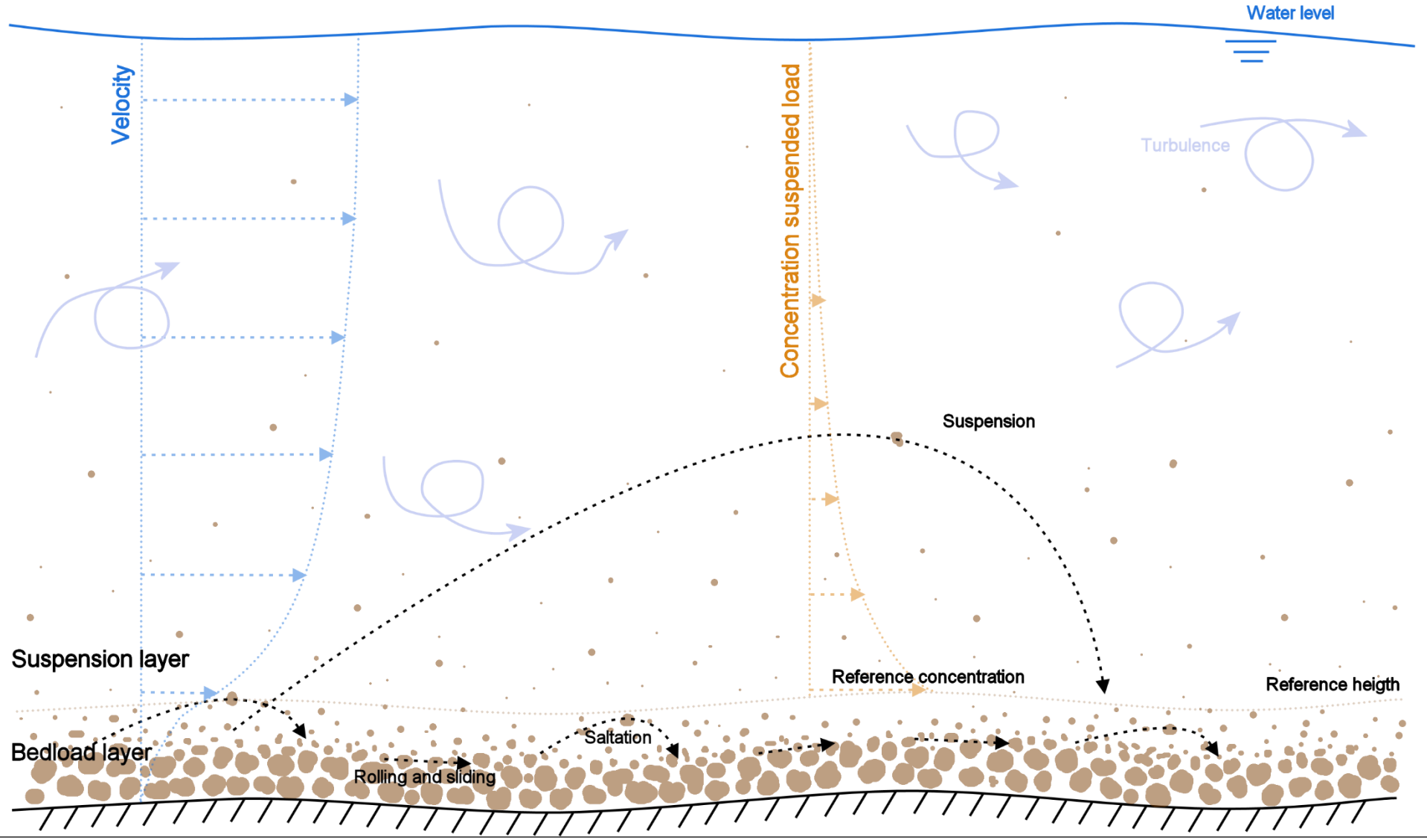
Differences in flow (for equal discharge and morphology)

- Less force pulling water downslope
- Lower velocity
- Higher water depth
- Lower stresses

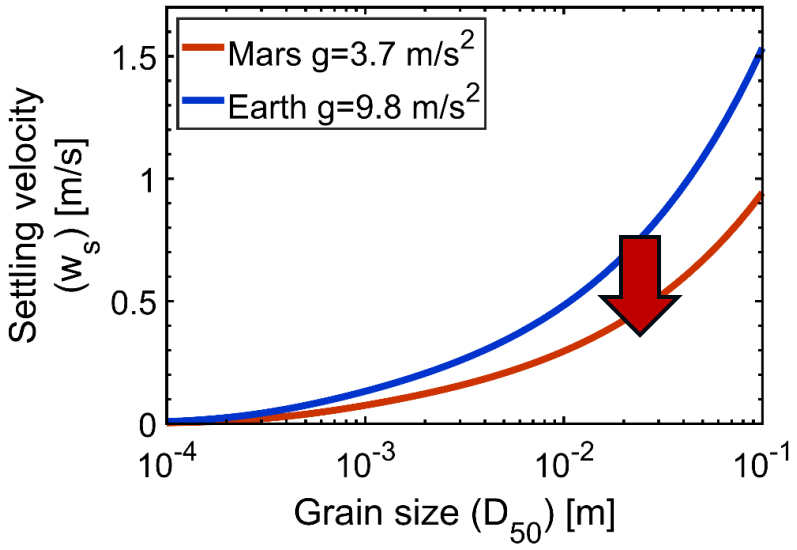


Comparing sediment transport

Transport modes



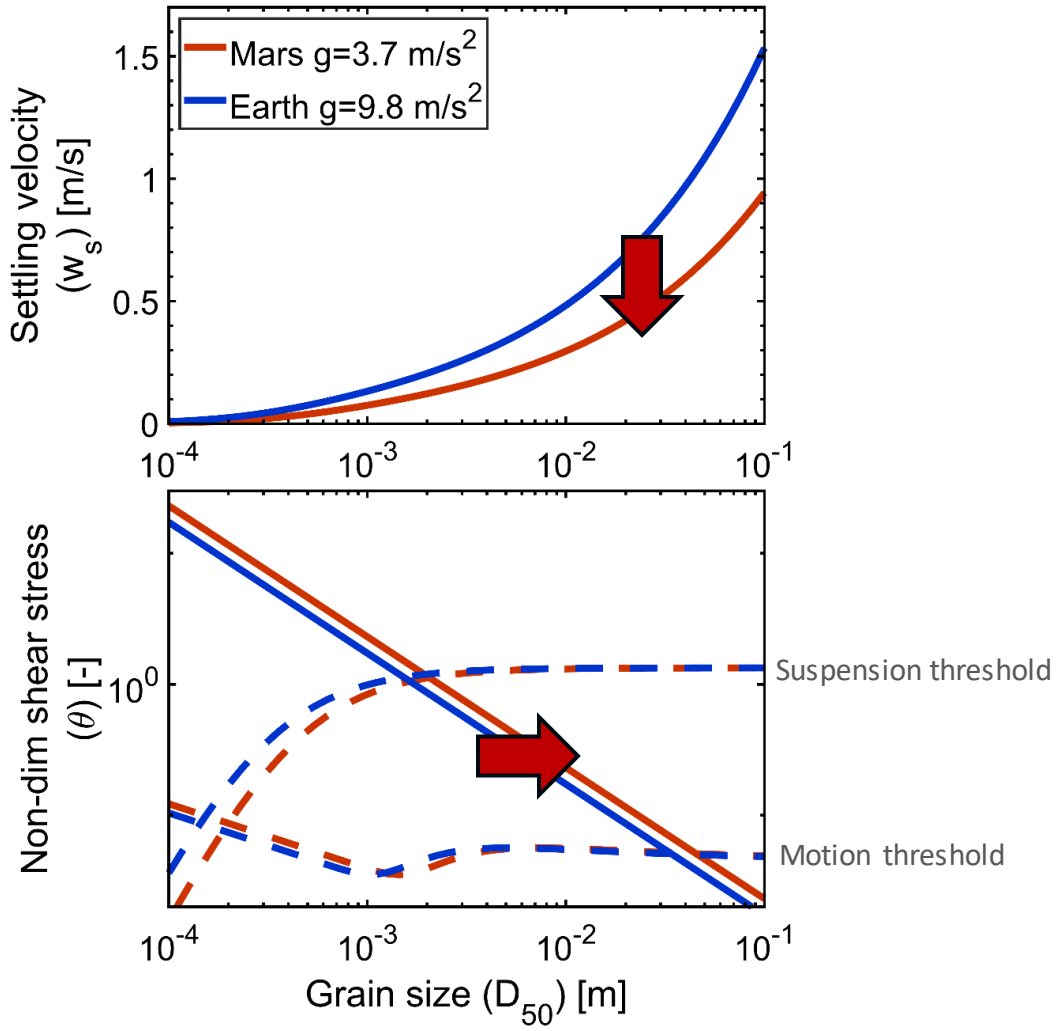
Comparing sediment transport



$$w_s = \frac{RgD^2}{C_1\nu + \sqrt{0.75C_2RgD^3}}$$

Komar, 1980
Burr et al., 2006
Grotzinger et al., 2013
Amy and Dorrell, 2021

Comparing sediment transport

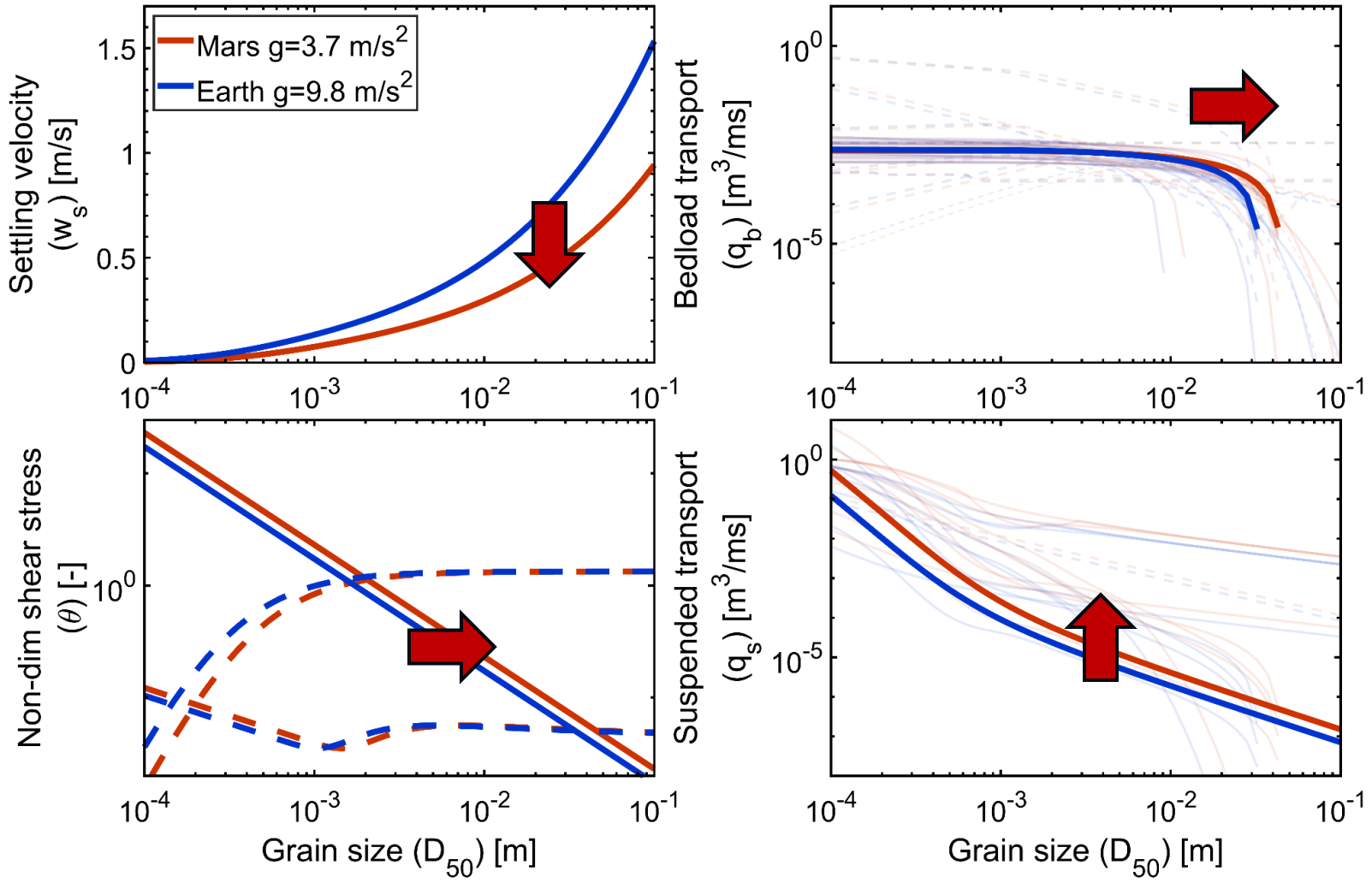


$$w_s = \frac{RgD^2}{C_1\nu + \sqrt{0.75C_2RgD^3}}$$

$$\theta = \frac{\tau}{(\rho_s - \rho)gD_{50}}$$

Komar, 1980
Burr et al., 2006
Grotzinger et al., 2013
Amy and Dorrell, 2021

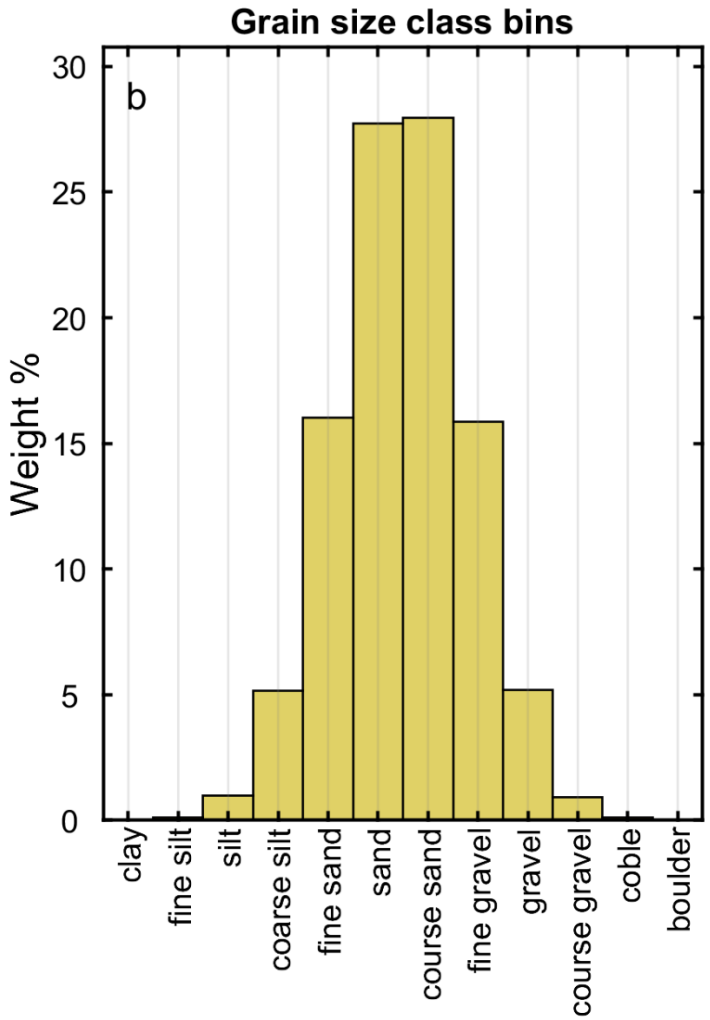
Comparing sediment transport

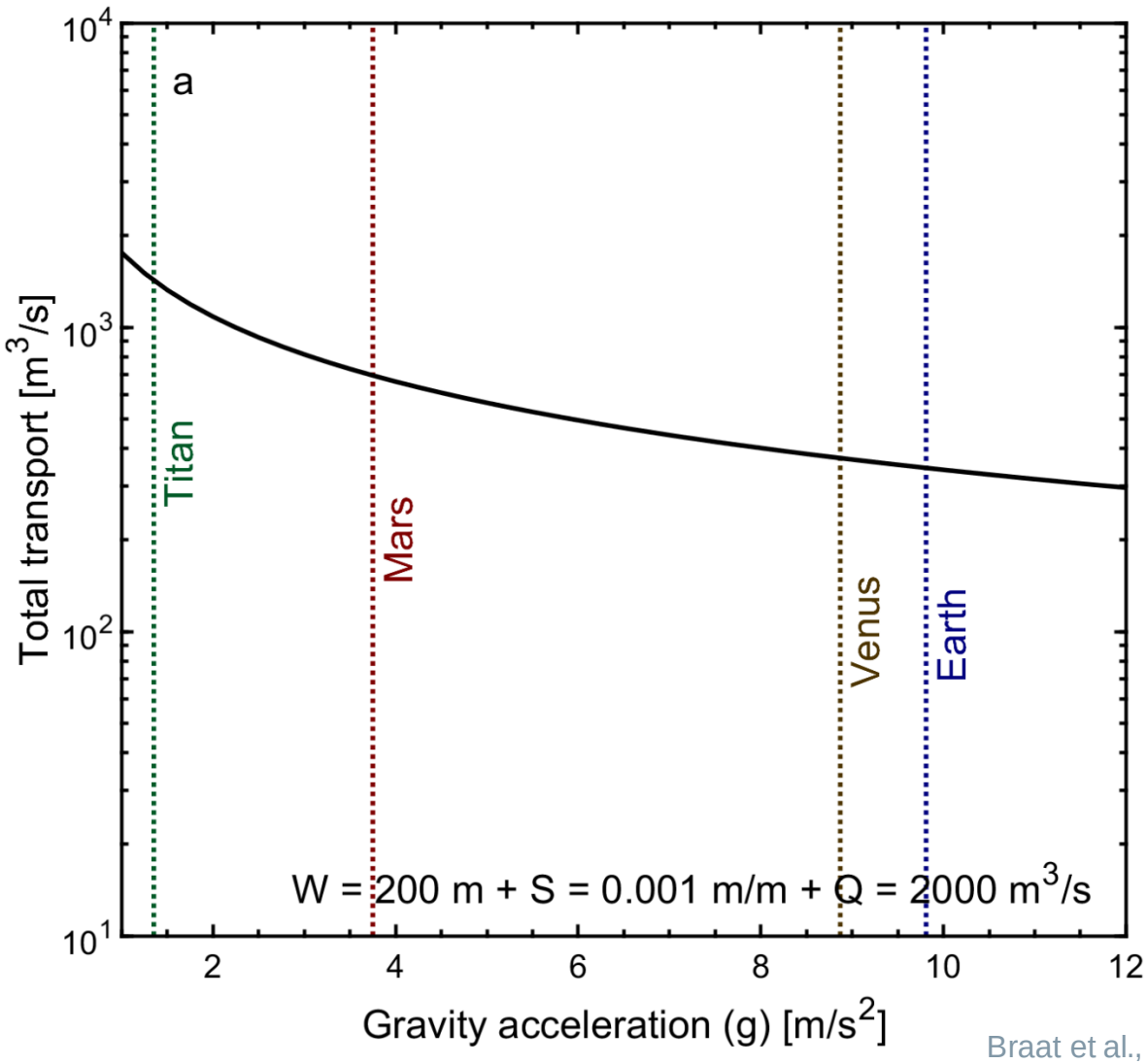


Komar, 1980
Burr et al., 2006
Grotzinger et al., 2013
Amy and Dorrell, 2021

Braat et al., *accepted*

Total sediment transport





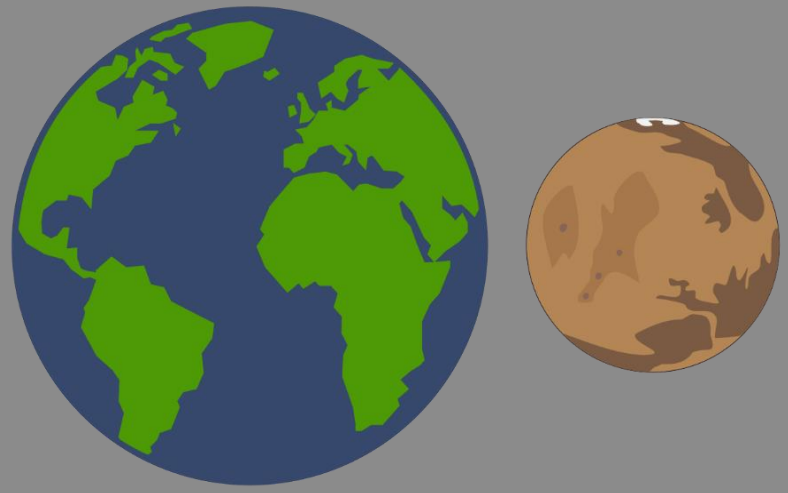
Braat et al., *accepted*

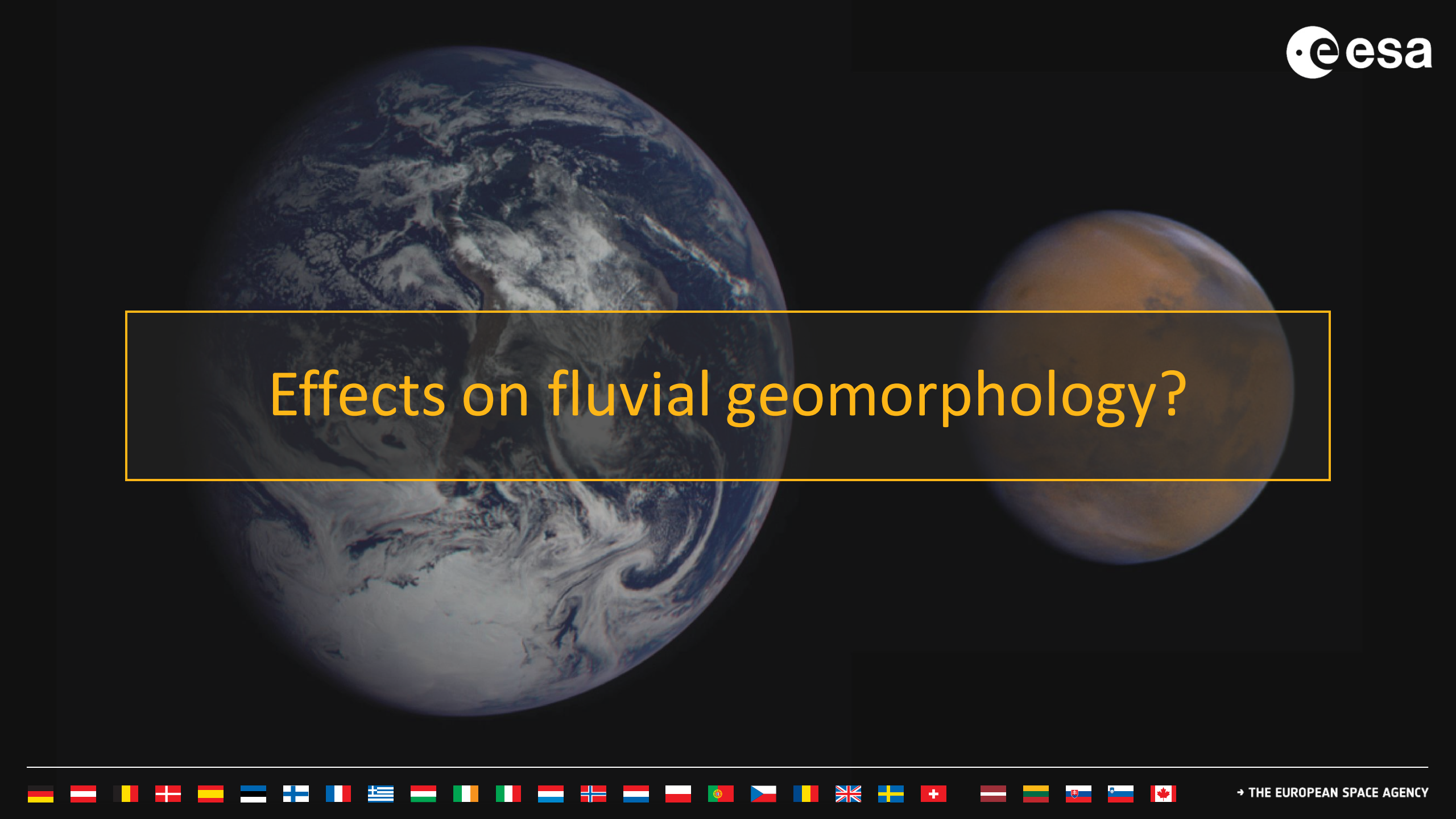
Conclusions for Mars

Differences in sediment transport (for equal discharge)

- Sediment easier mobilised
- Higher sediment transport rates
- More suspended transport (relative and absolute)
- Effect of gravity varies with grain size

➢Effect on morphology expected



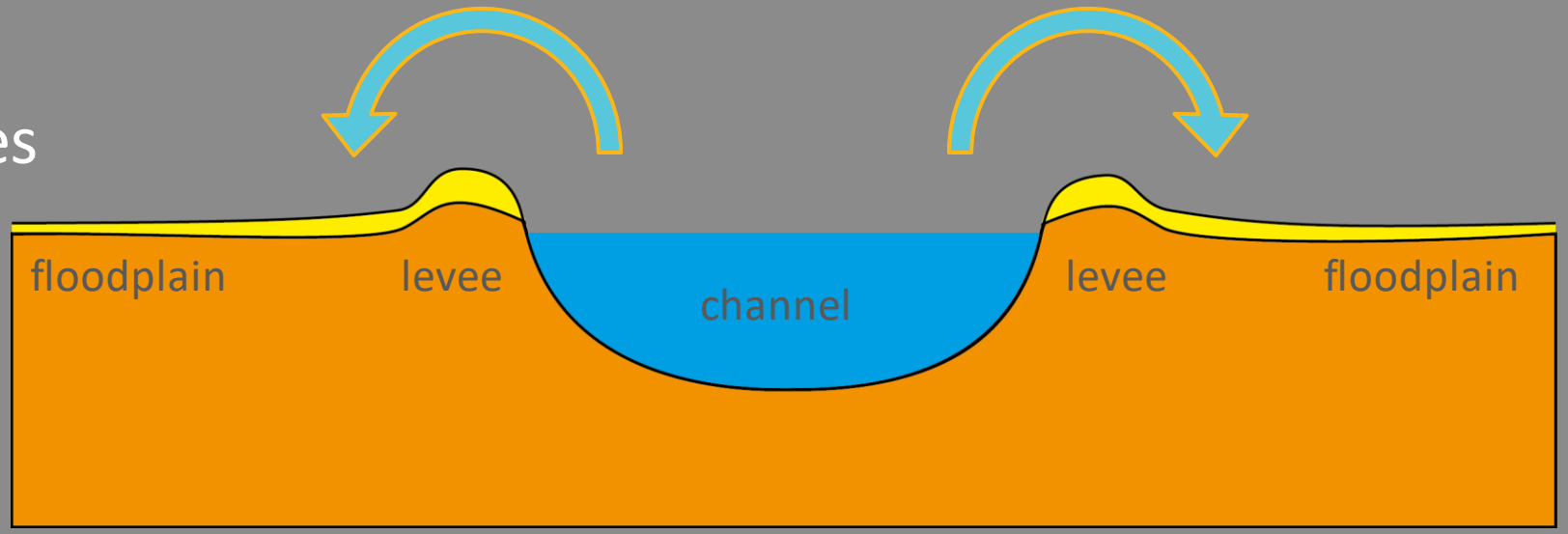


Effects on fluvial geomorphology?

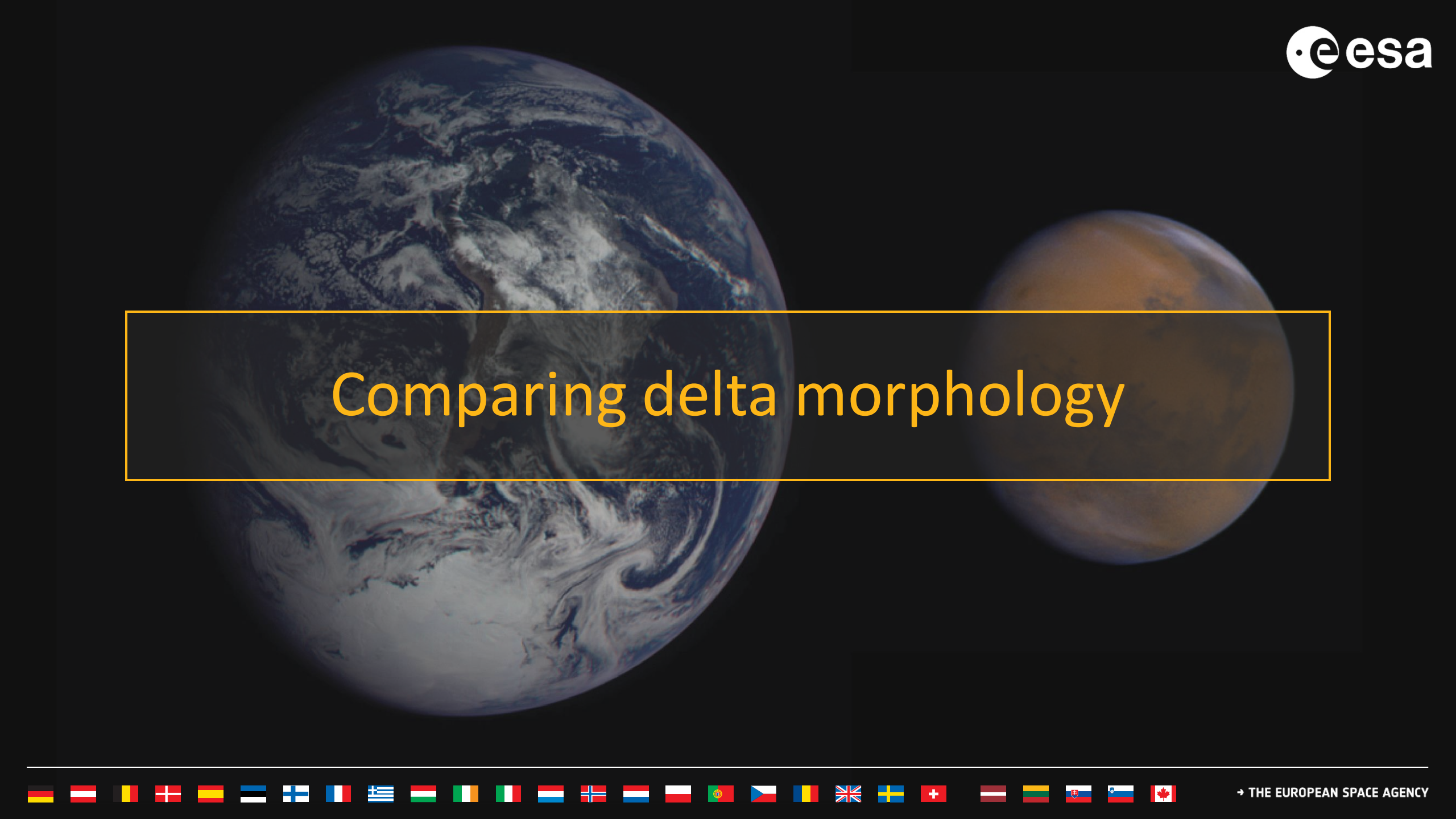
Hypotheses for Mars

Effects of sediment transport differences on morphology

- Faster development of landforms
- More overbank sedimentation
  - Levee building
  - Reduced migration
  - More avulsions
- Lower depositional slopes



Thank you



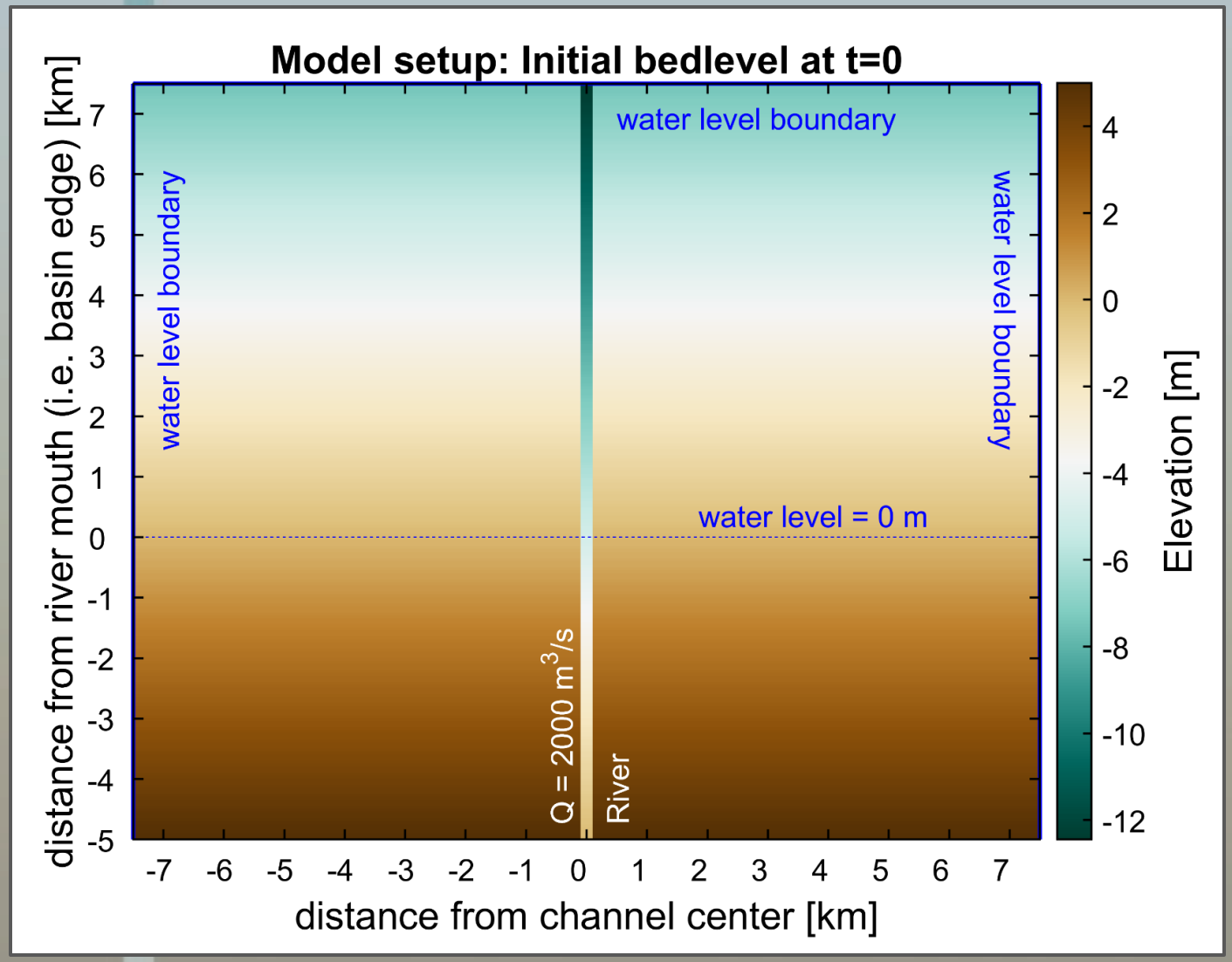
Comparing delta morphology

Hydro-morphodynamic delta model

- River flowing into a basin

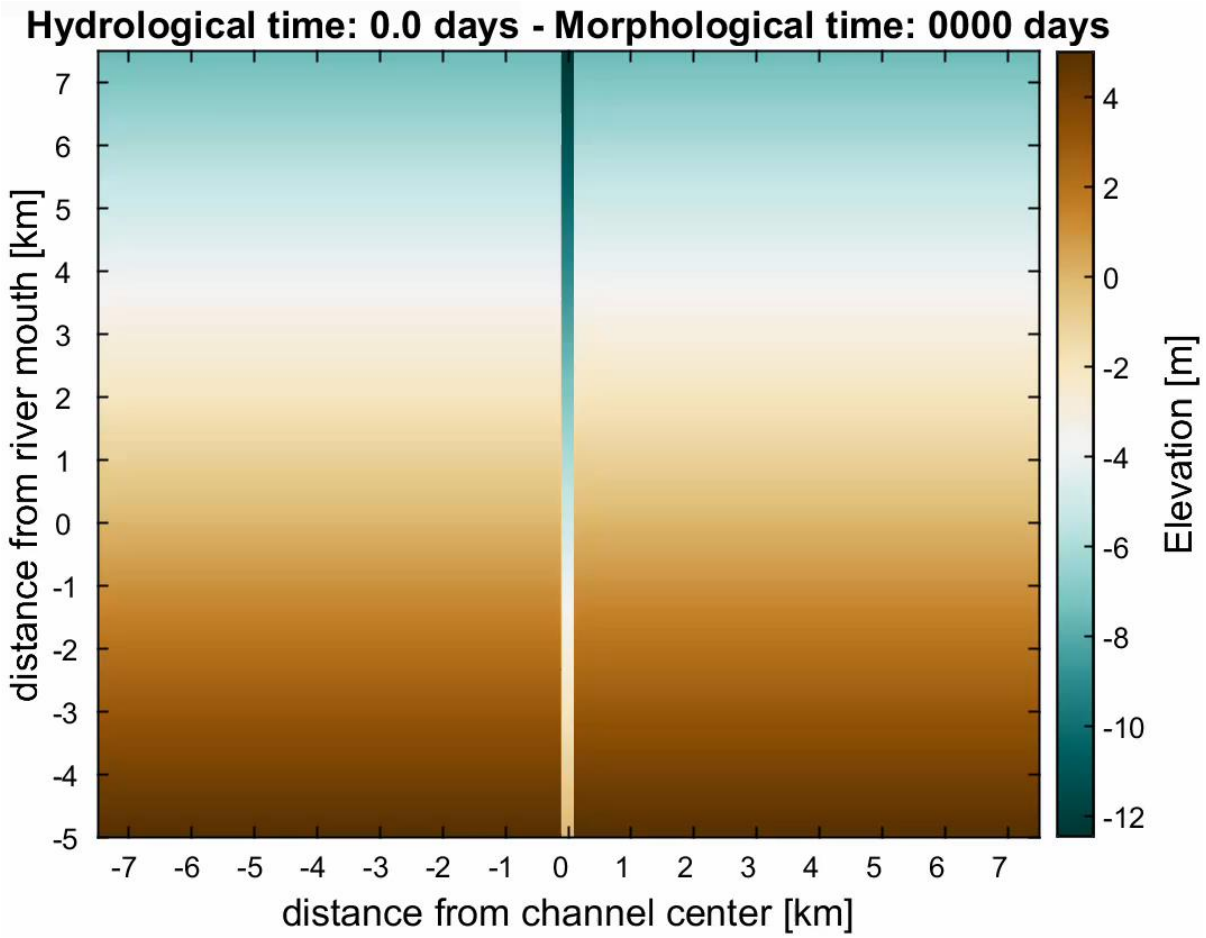
- Sloping plane = 0.001 m/m
- Channel = 200 m wide, 5 m deep

- Grain size = 2 mm
- Transport predictor = van Rijn 2004
- Delft3D Flexible Mesh

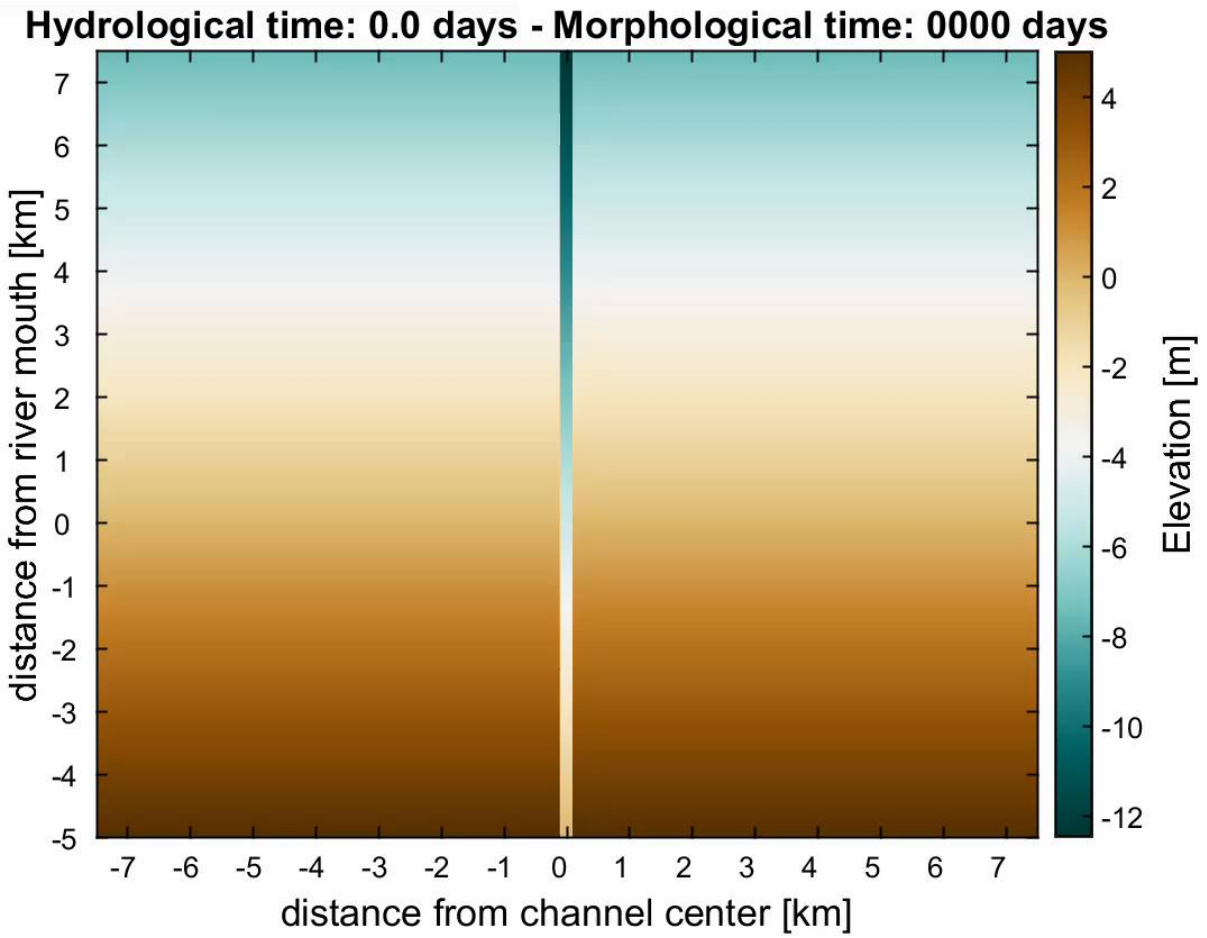


Comparing delta evolution

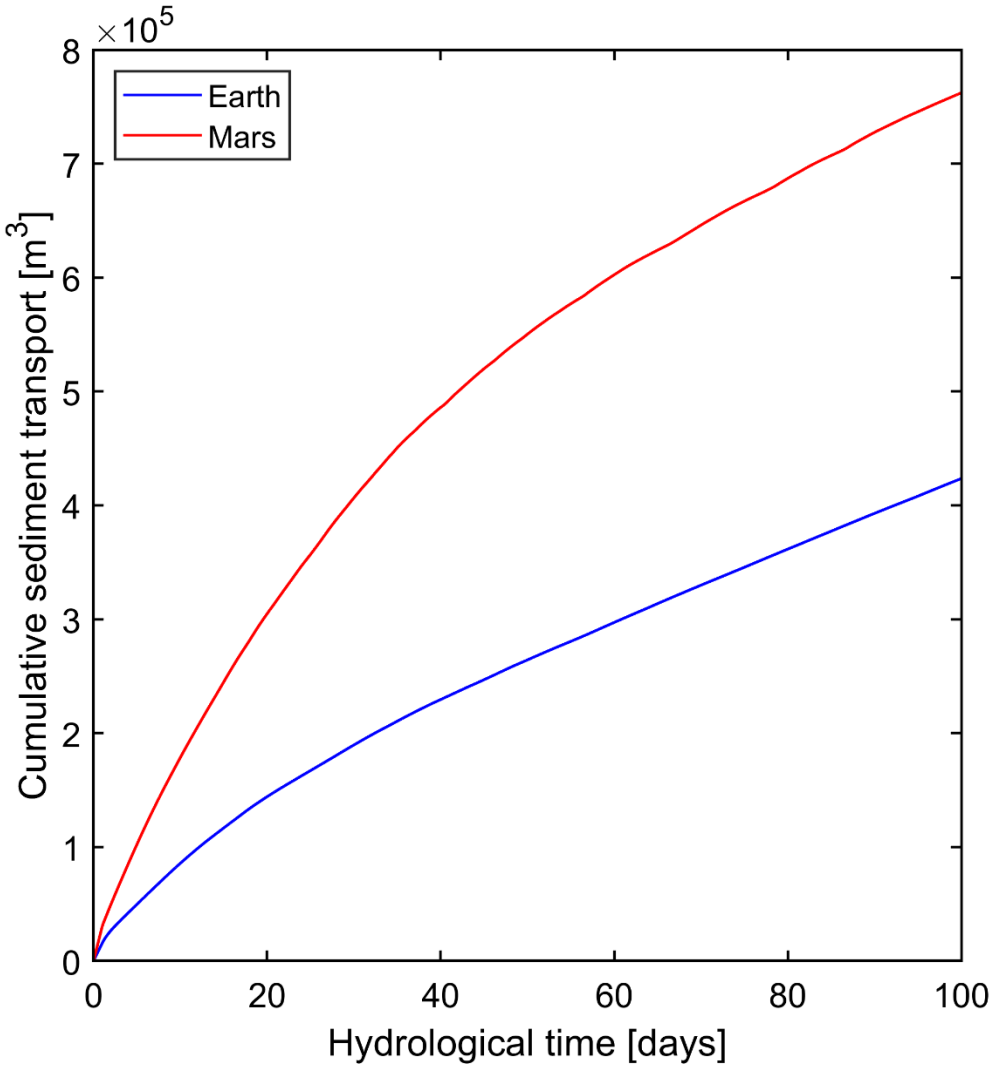
Earth

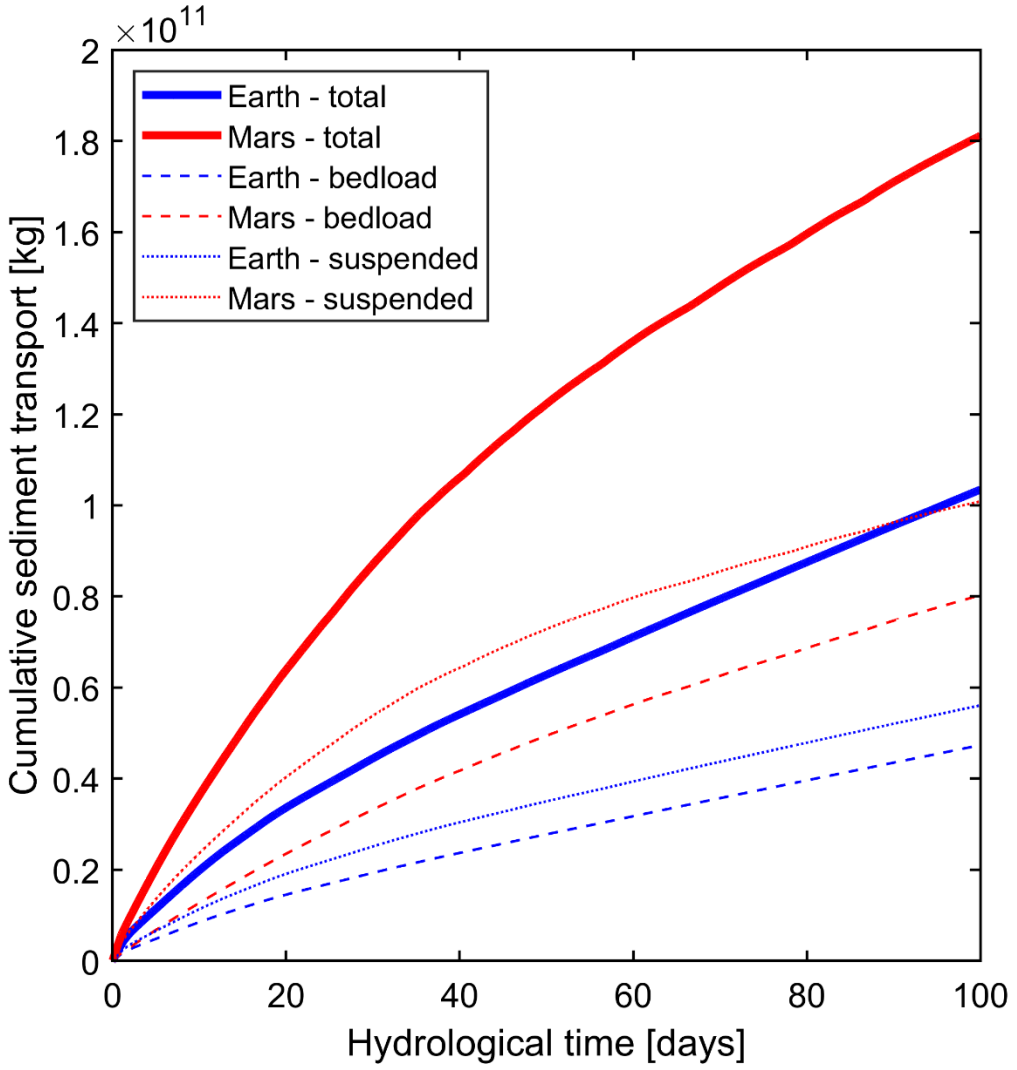


Mars



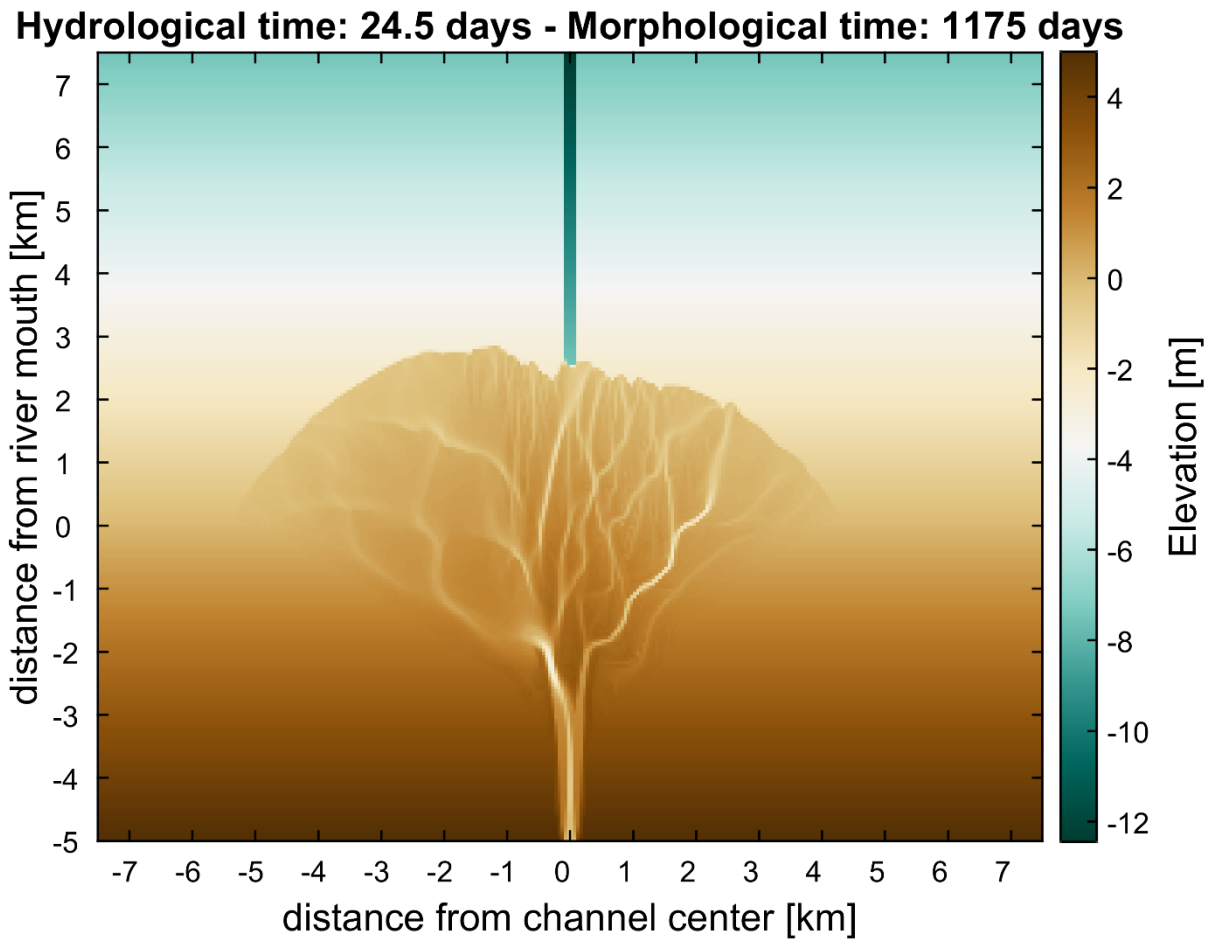
Delta volume



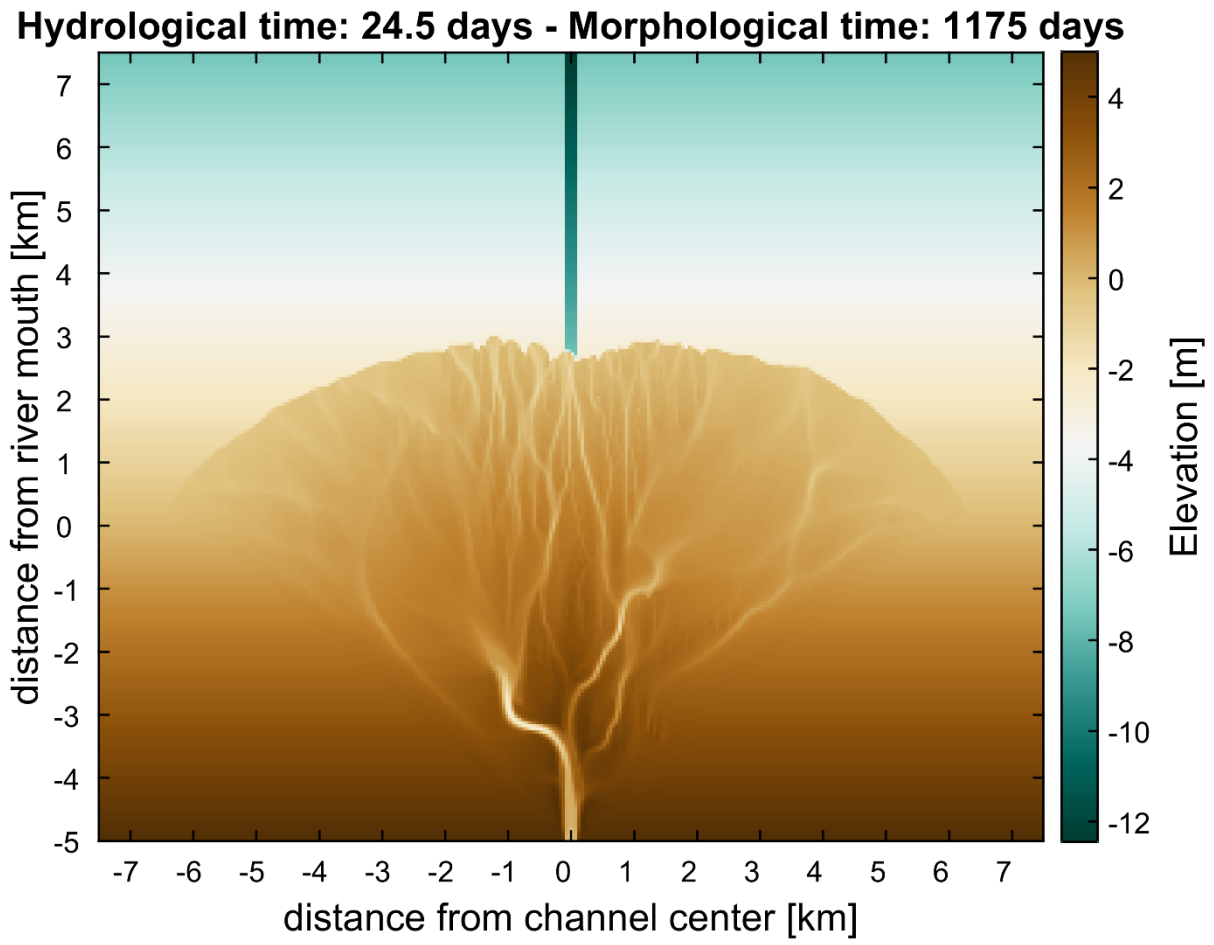


Multiple sediment fractions

Earth



Mars

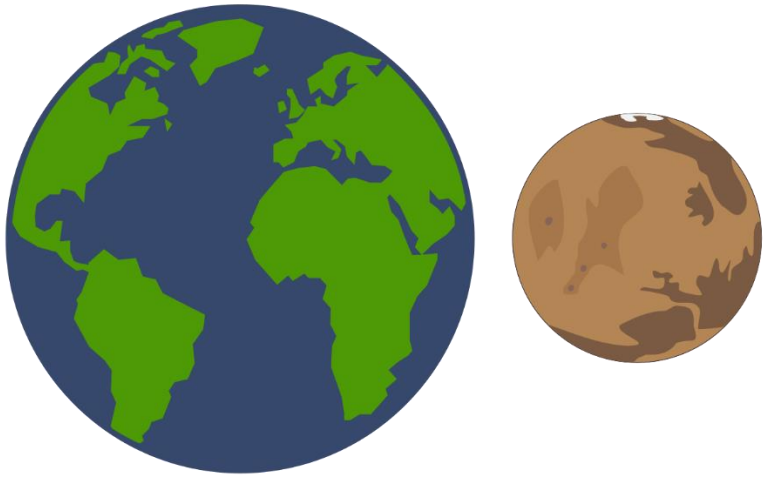


Conclusions for Mars

Effects of lower gravity in Deltas

- Deltas (and other fluvial landforms) develop more rapidly on Mars (for the same river discharge)
- Higher suspended transport rates
- Martian deltas have fewer active channels
- Less dynamic

- No conclusions yet on levees and slopes



Thank you for your attention! Questions?