PRIFYSGOL BANGOR UNIVERSITY

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The influence of gravel mixed with sand on the formation and development of ripples

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Outline: the key points

Predicting bedload transport offshore

Is that working well for mixed sediments? No, so **what** is the problem?

Why is this a problem? E.g. predicting erosion/deposition, sedimentary ripple dynamics

Questions addressed in recent research from PhD, MSc and MSci projects at Bangor University:

1. Hiding-Exposure effect (HE): quantification for truly bimodal mixtures?
2. Effect of bimodal sediment mixtures on bed mobility?
3. Which % gravel in sand - gravel mixture is seemingly showing "effective HE"?
4. How does changes in effective transport of fractions manifest itself in ripple migration speed, ripple geometry and internal sedimentary structure?

Sediment Transport – The Basics

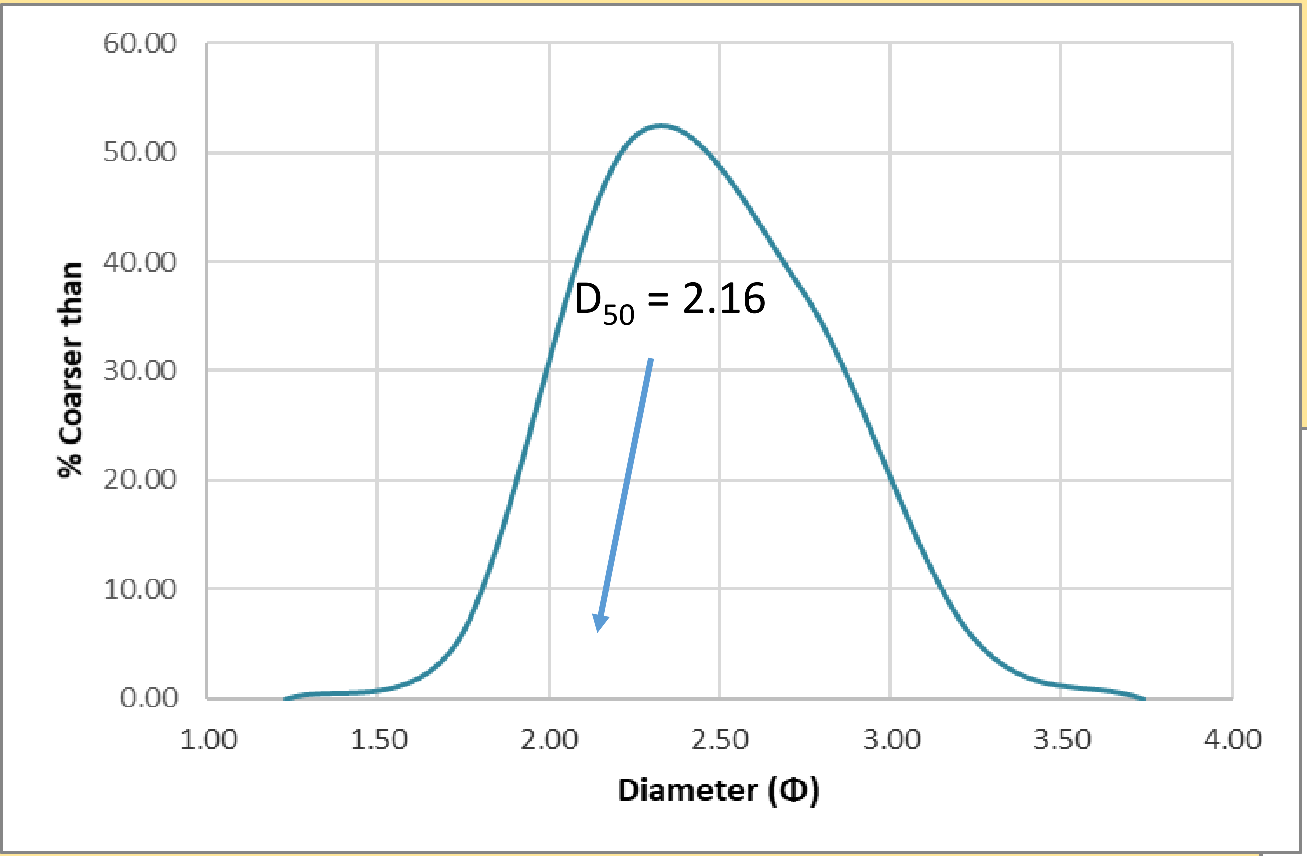
- Bedload transport (q_b):
  the result of excess bed shear-stress (τ) above critical shear-stress (τ_{cr}) at the point of incipient motion.

$$q_b = f(\tau, \tau_{cr})$$

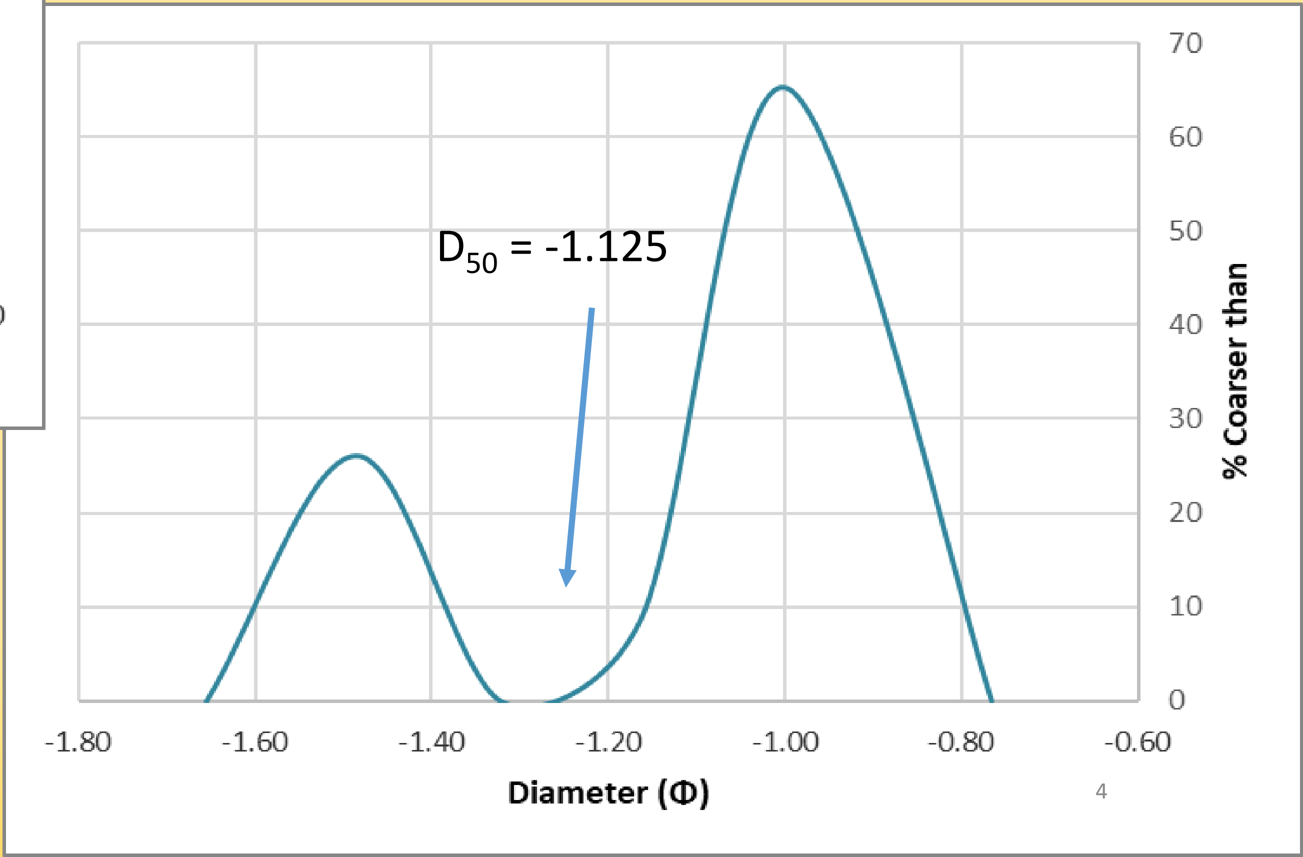
- q_b = function of many other governing variables (like viscosity, submerged specific weight, density, particle size,…) related to the influence by fluid forces, inertia, bedforms etc.
  => unworkable… => simplifications to well-sorted sand in water, and the main variable left are **bed stress** and **median particle size**.

- Most important governing independent dimensionless variable is the Shields parameter.
  Boundary Reynolds number and relative roughness express turbulent structure of flow

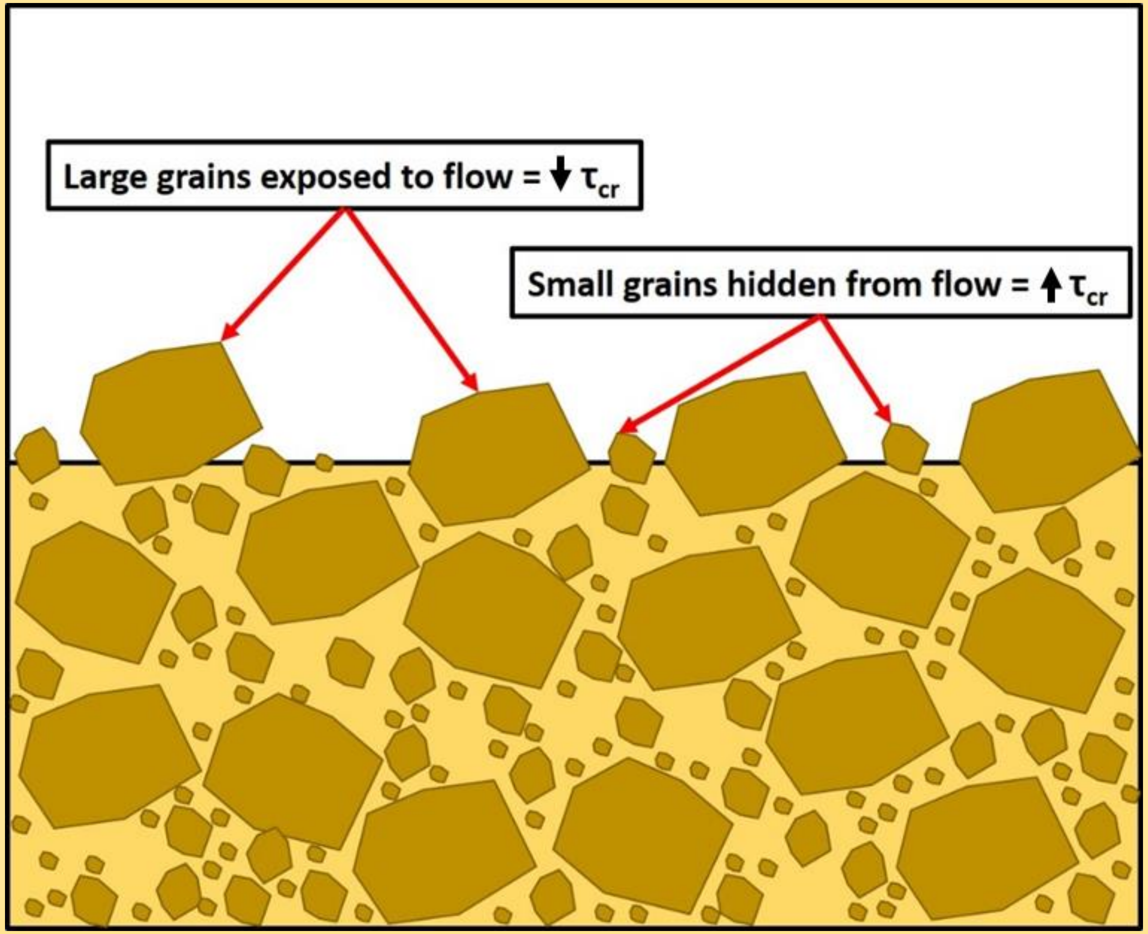
The problem with predicting transport of mixed sediments.



D_{50} = median grain size: what if sediments are bimodal?



The problem with predicting transport of mixed sediments.



Sediment mixtures with BIMODAL distribution:

- *D50 is no longer valid*
- The Hiding-Exposure (HE) effect kicks in…:

Presence of one grain size fraction affects transport of another

(Einstein, 1950)

Large Grains -> τ_{cr} ↓
Small Grains -> τ_{cr} ↑

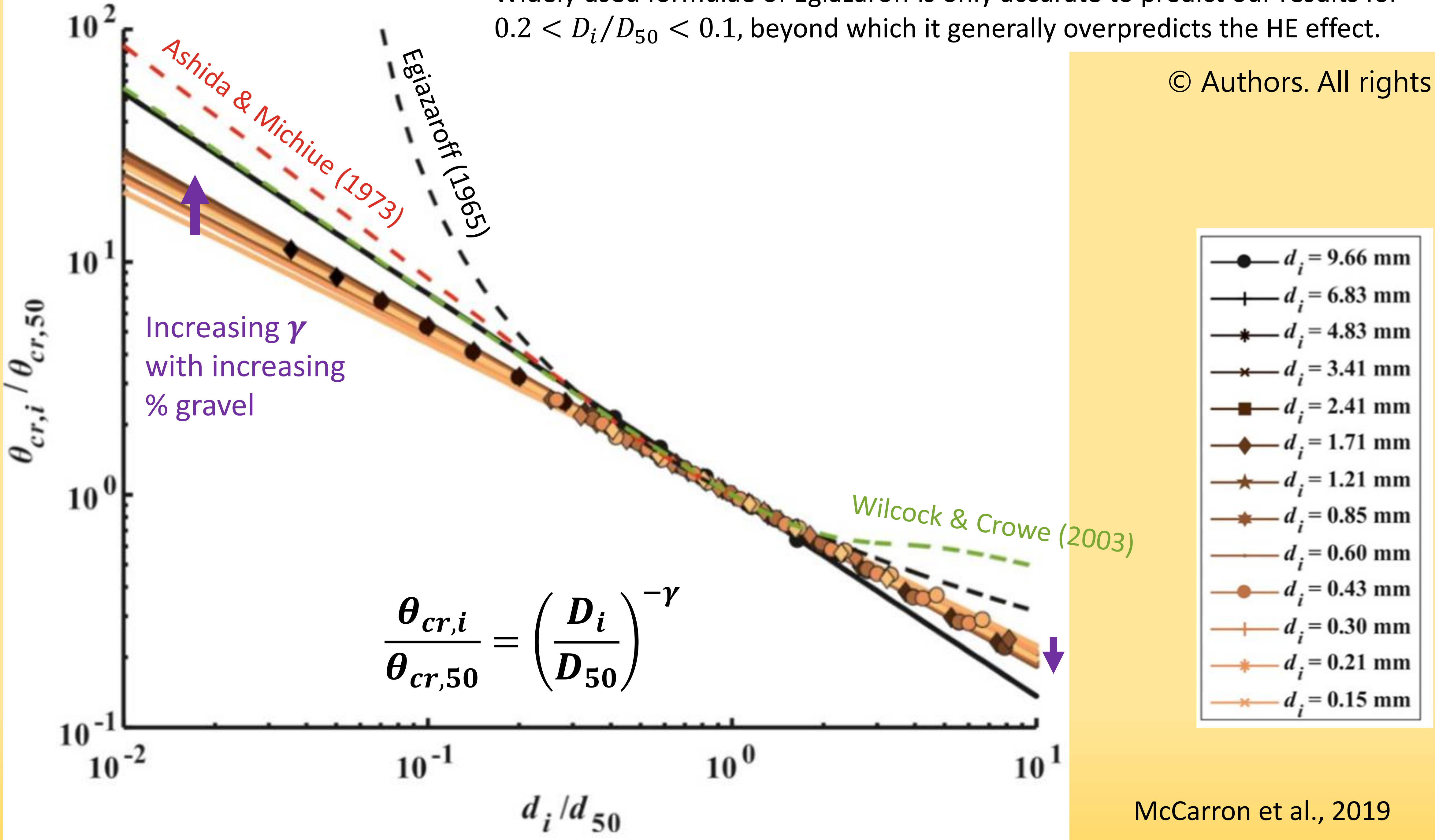
Quantifying the Hiding-Exposure effect – some conclusions

McCarron et al., 2019:

- Threshold of motion increases by up to 75% for sand fractions and decreases by up to 64% for gravel fractions in sand and gravel mixtures.

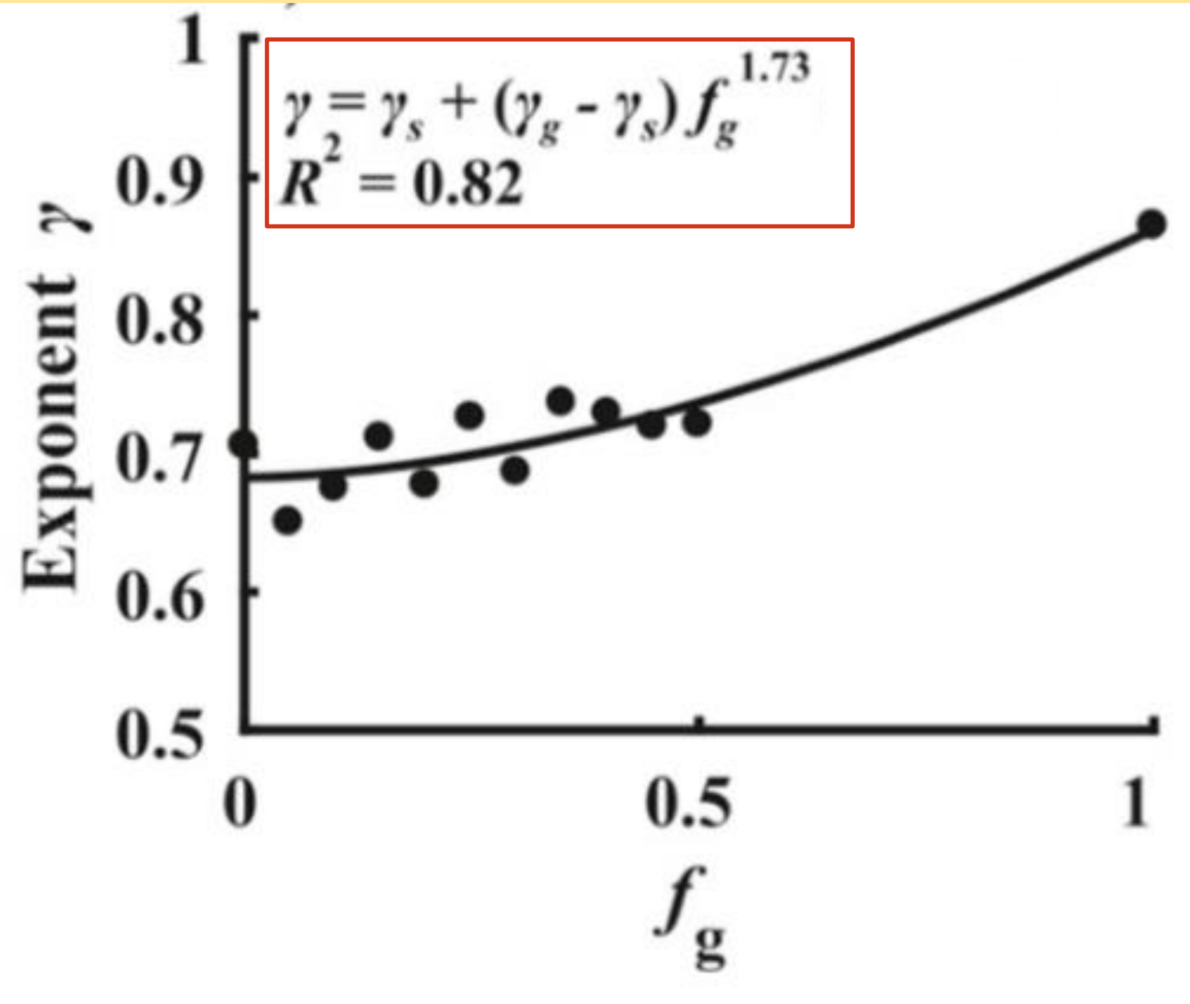
- Strength of HE effect is dependent on mixture composition and best predicted with percentage gravel in a mixture.

Widely used formulae of Egiazaroff is only accurate to predict our results for $0.2 < D_i/D_{50} < 0.1$, beyond which it generally overpredicts the HE effect.



McCarron et al., 2019

Increasing γ with increasing % gravel



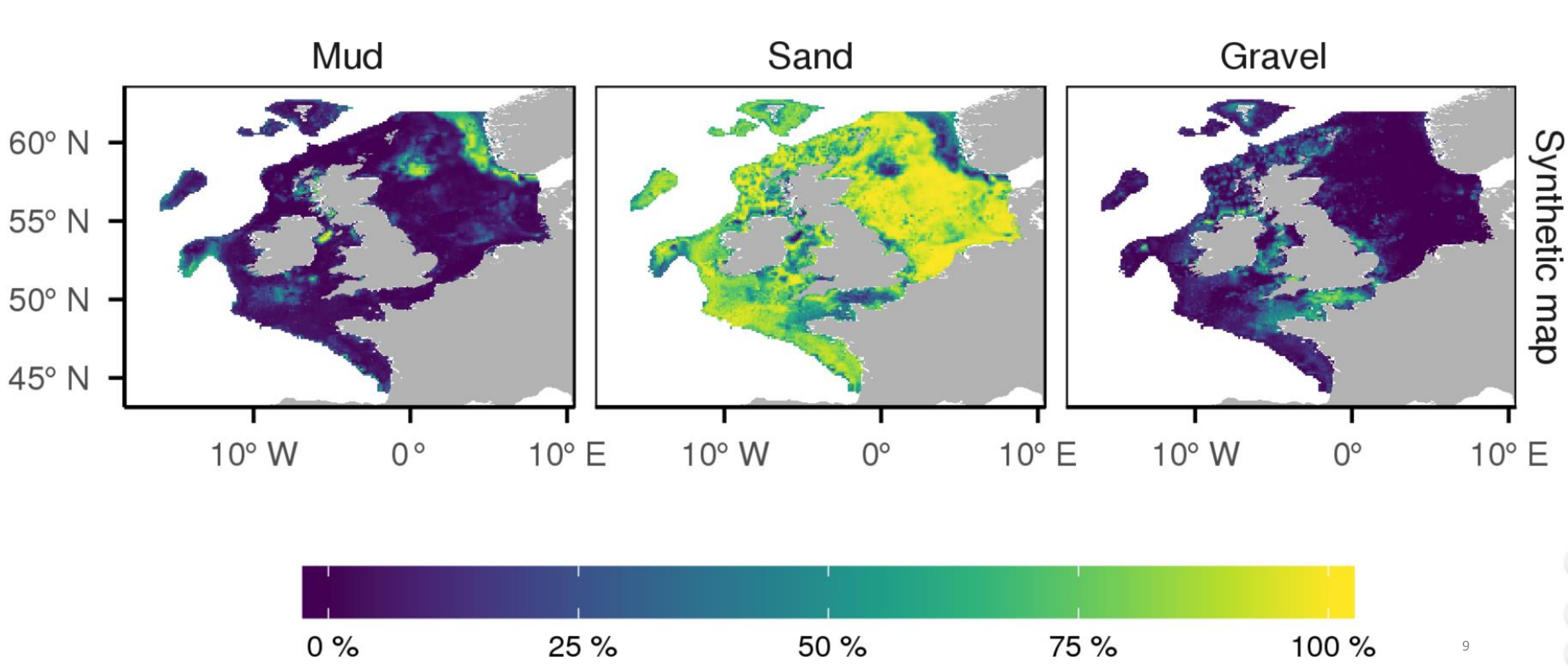
Via revised sediment transport formulae in both current-and wave-driven models (McCarron et al., in prep): effect of this newly quantified HE correction is greatest for gravel percentages between 10 and 20%.

McCarron et al., 2019

But really, is this actually a problem, or is it just the Irish Sea?? NW European data:

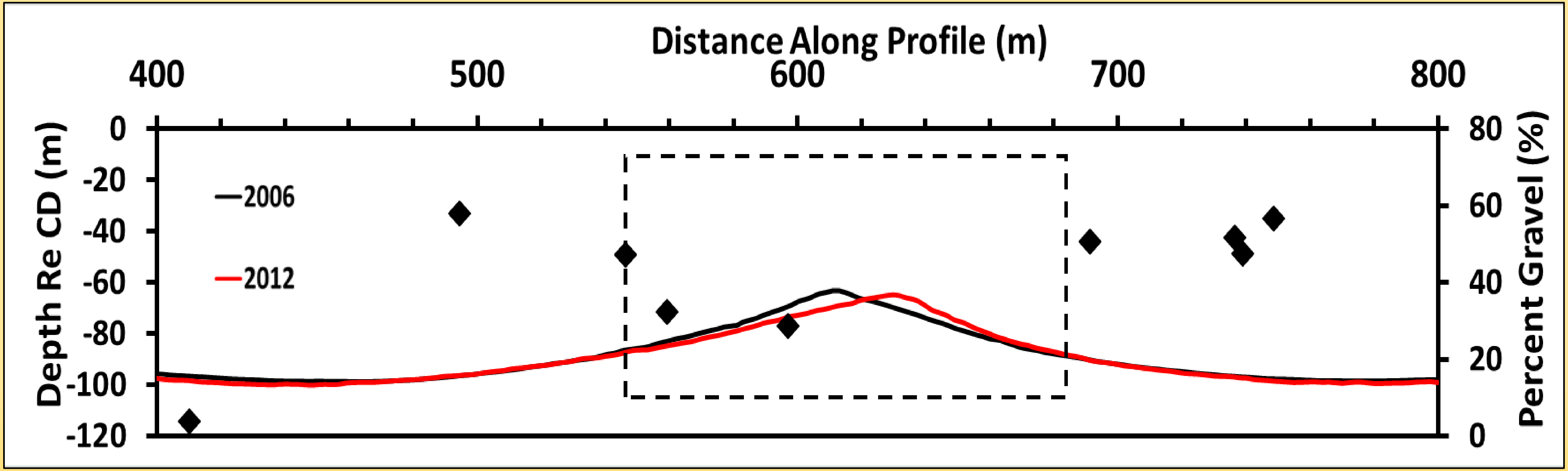
“Further research is therefore necessary to reduce the level of uncertainty in our knowledge of the disturbance of mixed coarse sediments”

Wilson et al., 2018

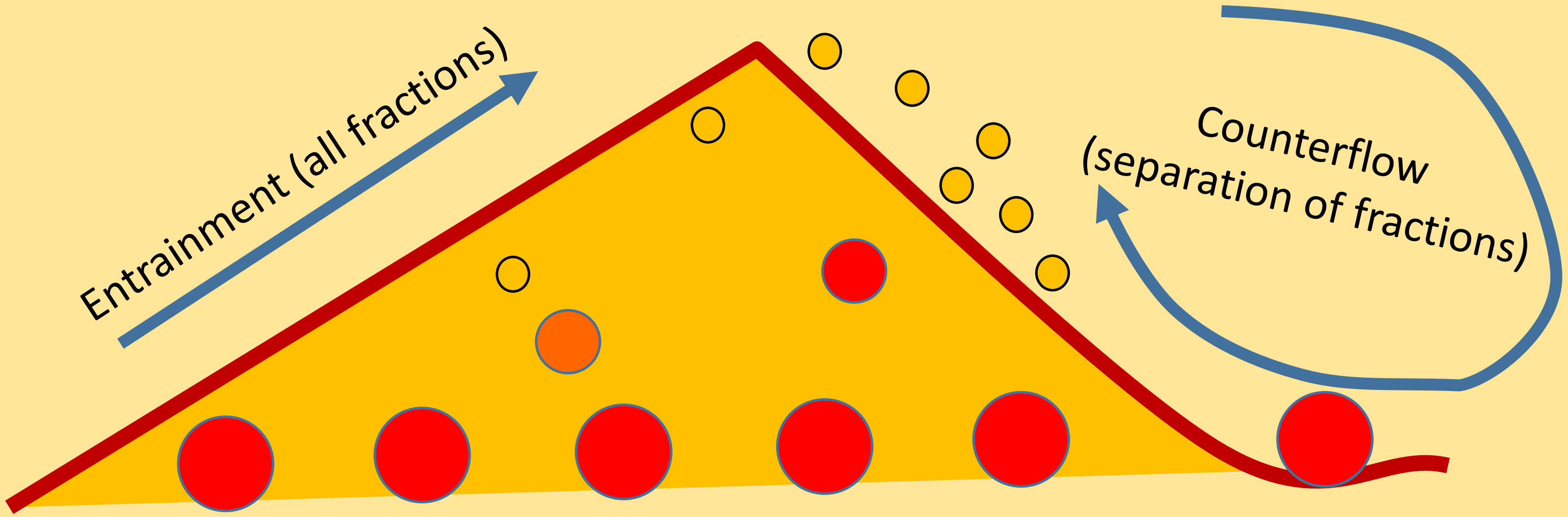


Understanding / predicting sedimentary bedform dynamics in mixed beds

Meanwhile, we see large sediment waves like these (nearly 40m high), with sand and gravel (up to 60% gravel) in their surface sediments:



Understanding / predicting sedimentary bedform dynamics in mixed beds



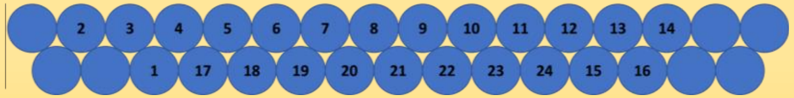
If gravel is more mobile than expected, will it still only mainly deposited at the lower part of lee slopes?

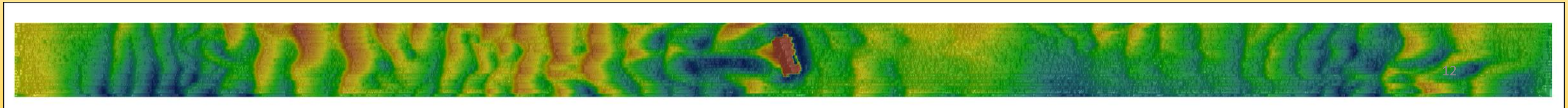
-> affect on internal structure of bedform?

Laboratory analyses

- Object placed at 60° relative to the flow (Orientation of offshore object we study)
- Gravel 2-3mm, Sand 0.1-0.3mm
- 7 Sediment types (Sand with 0%, 5%, 7.5%, 10%, 12.5%, 15%, 20% Gravel)
- 2 flow speeds
  - 26cm/s (Only mobilises sand)
  - 40cm/s (Mobilises both sand and gravel)

- 2 offset rows of transducers for better resolution of final rasters

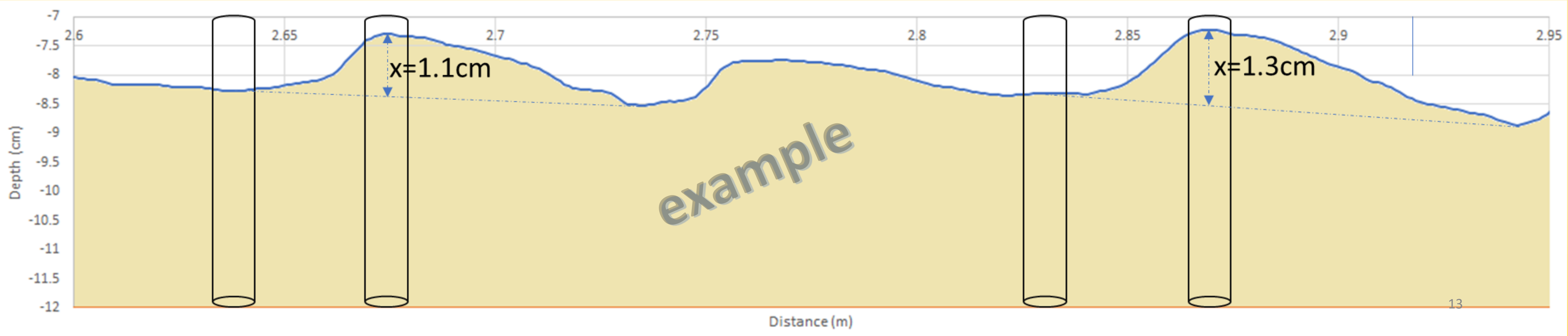




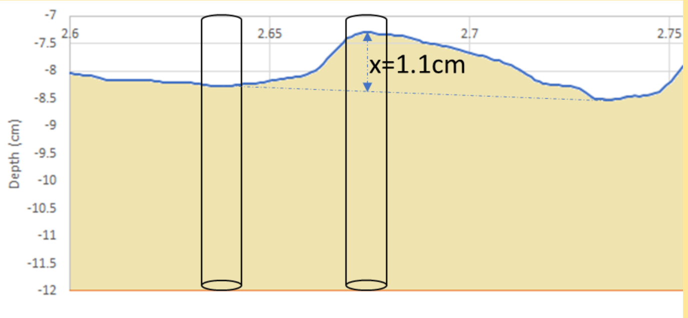
Laboratory analyses: down-core samples

Per "site", minimum 8 'cores' along:

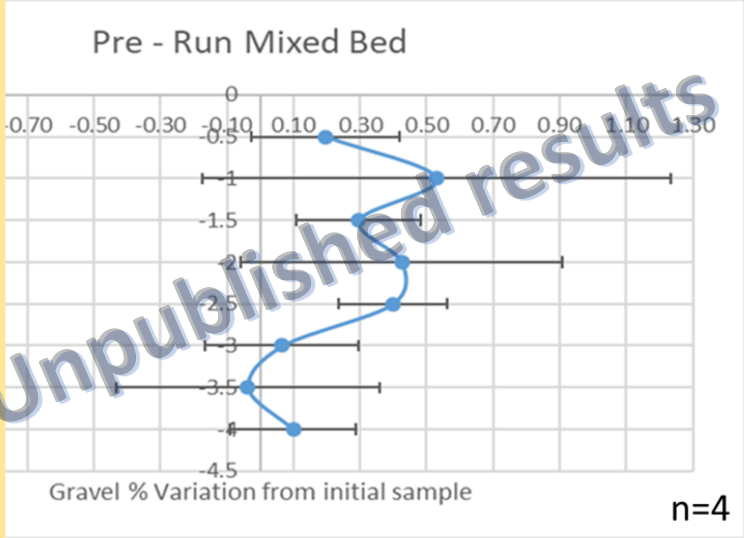
- 2 crests and 2 troughs before + after object
- Scour mark
- Depositional feature

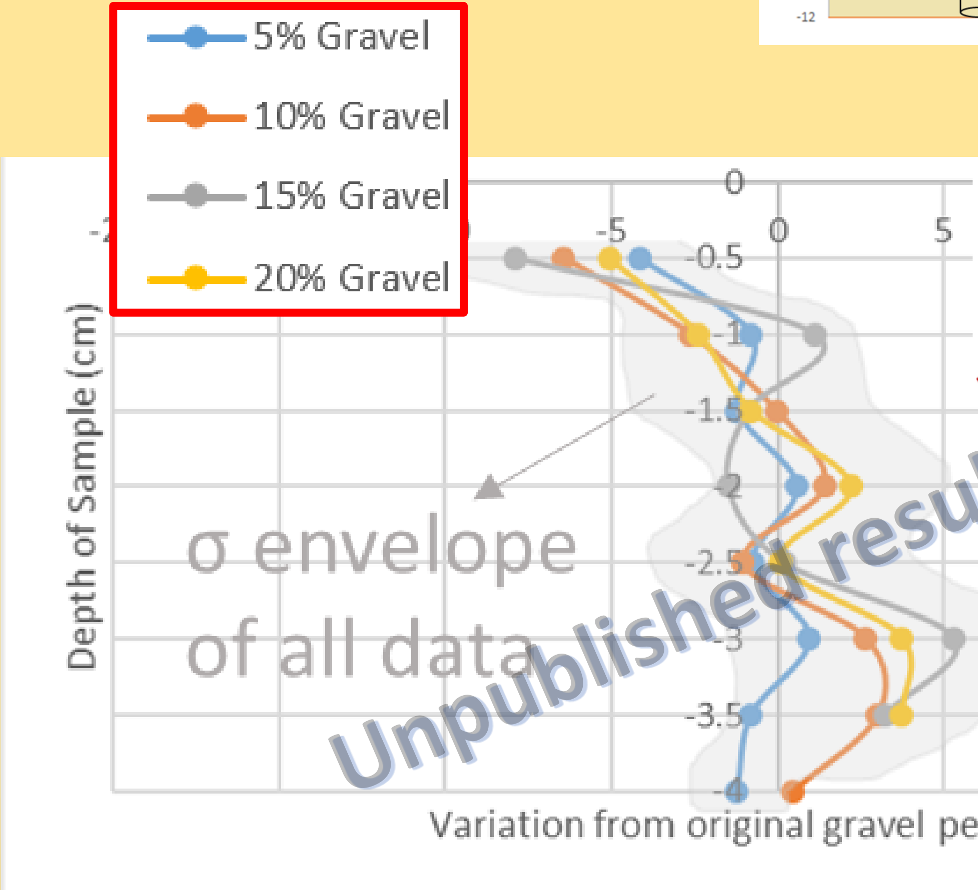


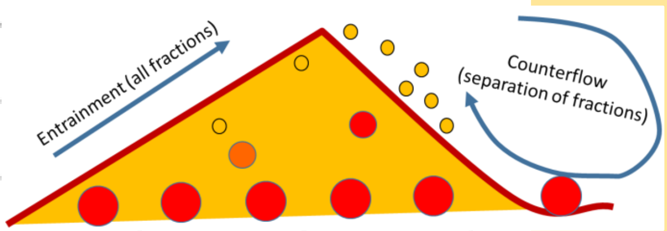
Laboratory analyses: down-core particle size analyses



Down-core gravel % in cores taken from initial flat bed varies only -0.5% to +1.3% from original mixture in bag (n=4):







?

Differently mixed beds => differently sized ripples:

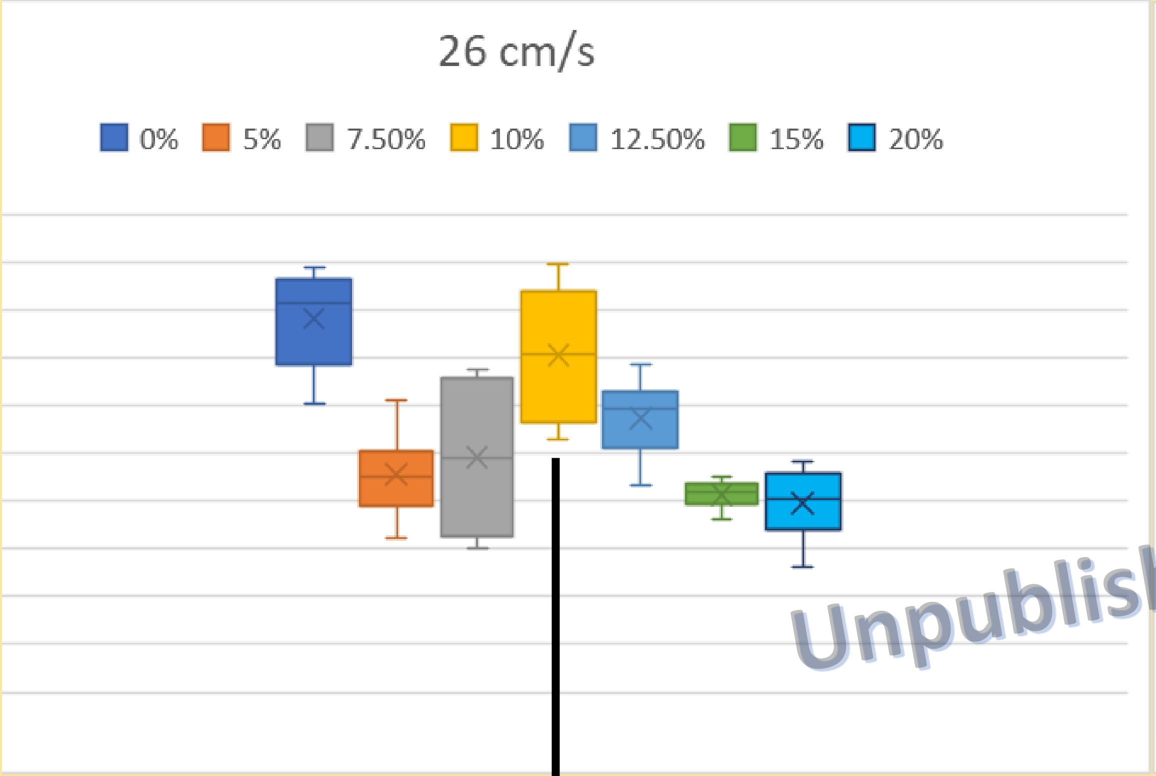
⇒ No direct comparison of internal structure possible from this plot

⇒ Plot potentially shows depth of mobilisation: **deepest samples vary from initial mixture: entire bed mobilised?**

Laboratory analyses: Ripple migration rates as indicator of bed mobility

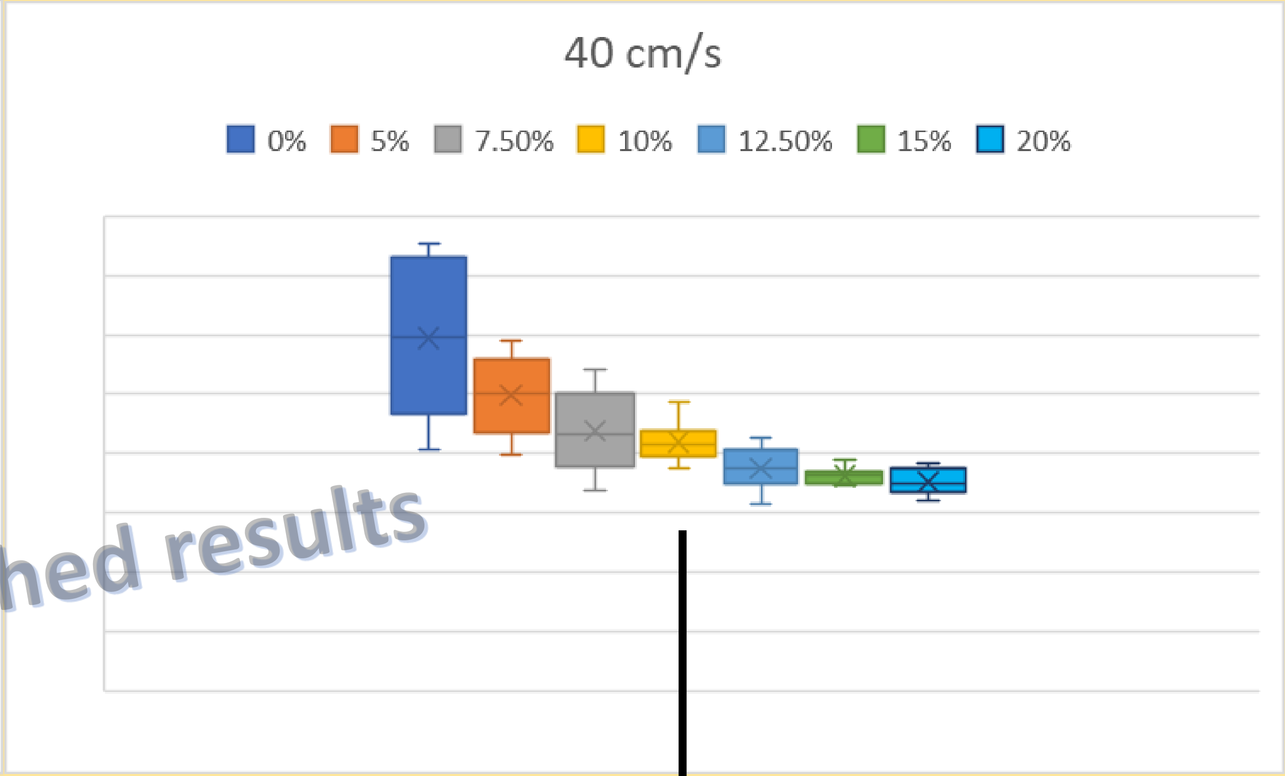
"only sand should be mobilised"

same scale



Mobility of mixtures highest at 10% gravel:
Gravel mobilised despite current well below that needed for threshold of motion?
(Cf. independent modelling results by Connor McCarron (in prep))

All sediment mobilised



Let's fit a line through those…

Laboratory analyses: Ripple geometry as indicator of bed mobility

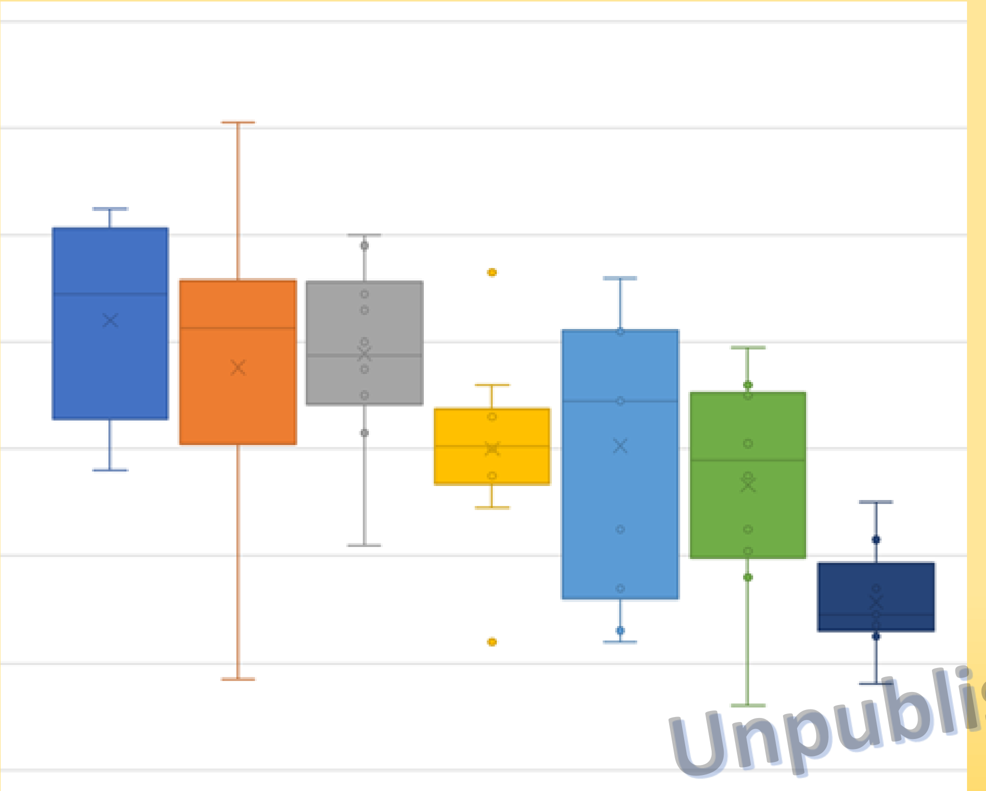
26 cm/s

% gravel in sand-gravel mixture

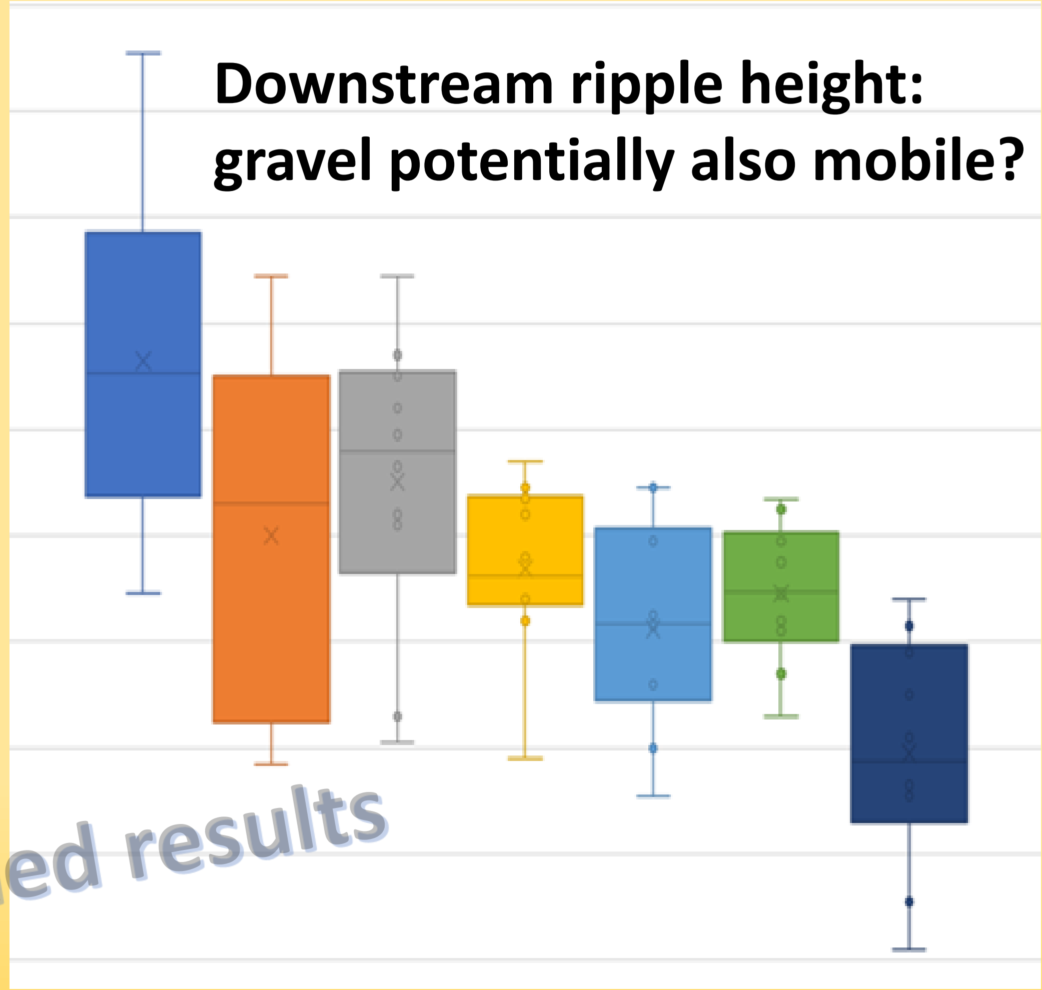
0% | 5% | 7.5% | 10% | 12.5% | 15% | 20%

Upstream ripple height: only sand mobile

same scale



Downstream ripple height: gravel potentially also mobile?



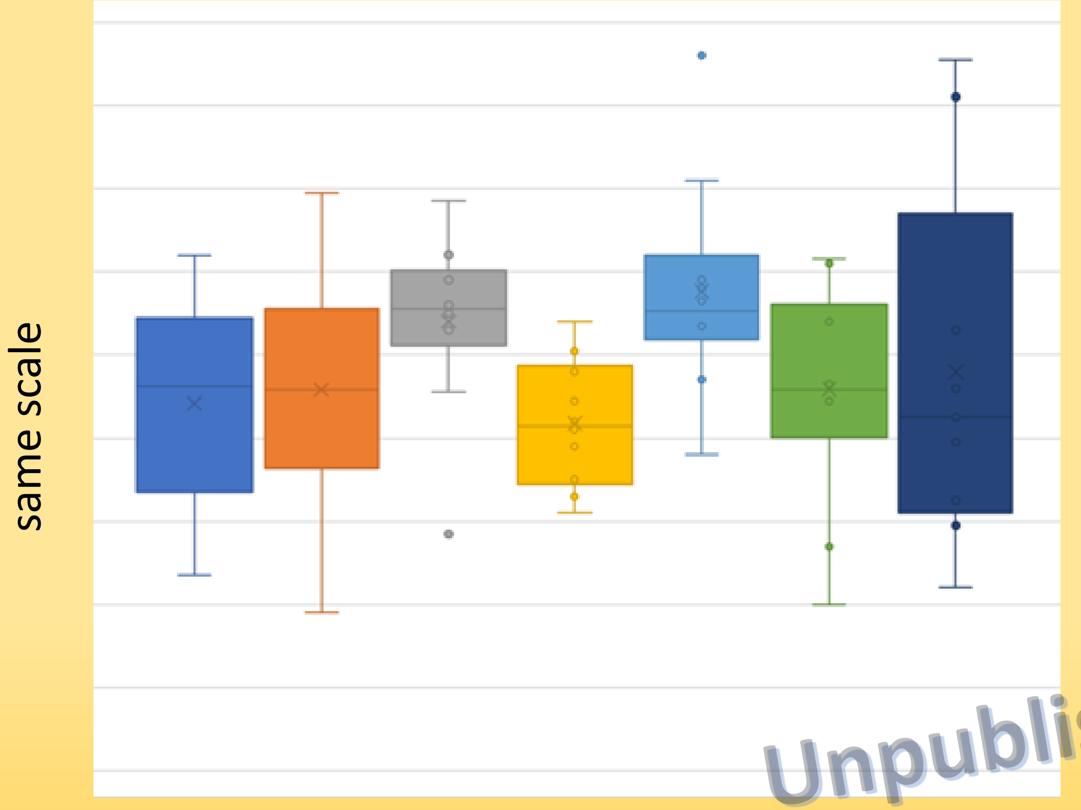
Laboratory analyses: Ripple geometry as indicator of bed mobility

26 cm/s

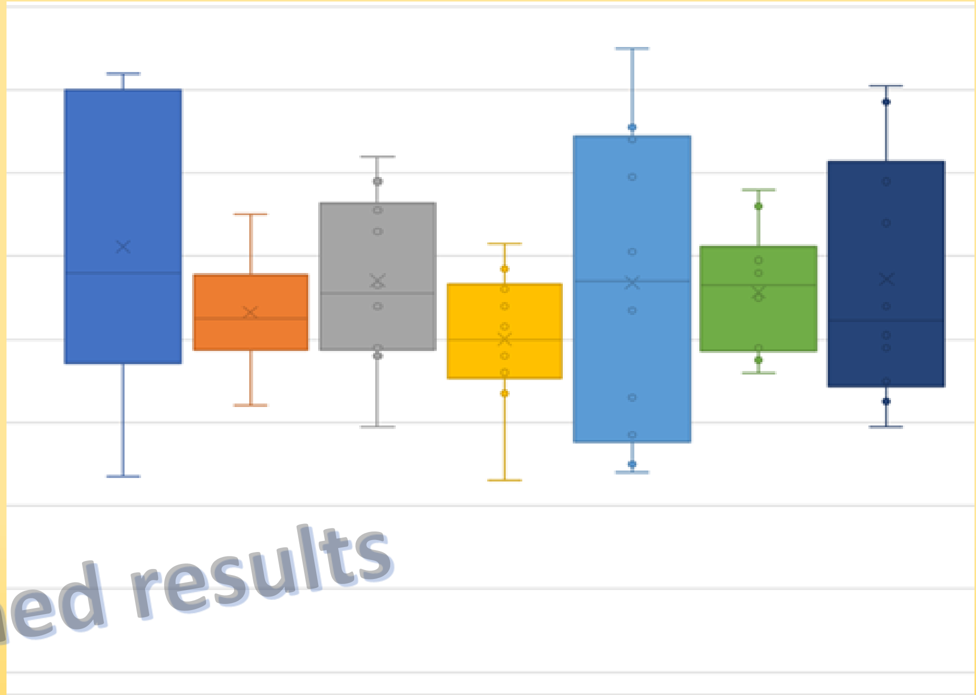
% gravel in sand-gravel mixture

0% 5% 7.5% 10% 12.5% 15% 20%

Upstream ripple length: only sand mobile



Downstream ripple length: gravel potentially also mobile



Laboratory analyses: Ripple geometry as indicator of bed mobility

To address major uncertainties in forecasting short- and long-term bed morphodynamic behaviour (around objects) in non-uniform sedimentary environments common in palaeo-glaciated shelf seas, we have:

- **Quantified Hiding-Exposure effect for bimodal mixtures**
- **Revised bedload transport formulae and perform sensitivity tests**
- **Monitored bed dynamics for different sediment mixtures in laboratory flumes and offshore**

So far, we find that:

- **10% gravel in a sand mixture is more mobile than other mixtures (sometimes even more mobile than pure sand if current speeds mobilise both fractions). This translates itself in faster moving ripples, but not in changing geometry.**
- **The active layer of the bed may well be much deeper than ripple base; depth related to gravel percentage?**

Research is ongoing (credit to Irinios Yiannoukos)…

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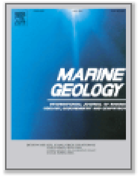

The hiding-exposure effect revisited: A method to calculate the mobility of bimodal sediment mixtures

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Article | Assets | Peer review | Metrics

Review article

A synthetic map of the north-west European Shelf sedimentary environment for applications in marine science

Robert J. Wilson, Douglas C. Speirs, Alessandro Sabatino, and Michael R. Heath

Sources cited in this presentation

McCarron, C.J., Van Landeghem, K.J.J., Baas, J.H., Amoudry, L.O. & Malarkey, J. (2019) The hiding-exposure effect revisited: A method to calculate the mobility of bimodal sediment mixtures. Marine Geology 410, 22–31: Open Access

Wilson, R.J., Speirs, D.C., Sabatino, A. and Heath, M.R. (2018) A synthetic map of the north-west European Shelf sedimentary environment for applications in marine science. Earth Systems Science Data 10, 109–130: Open Access