Effect of Froude Supercritical Flow on Fluvial Facies, Geometries and Architecture*

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Abstract

Froude subcritical flow is considered the geomorphically formative flow in rivers, as reflected in fluvial facies models, morphodynamic river discharge and sediment dispersal models, flood mitigation strategies, and in how we read the stratigraphic record. Froude supercritical flow is commonly assumed a transient occurrence, or limited to steep bedrock rivers with shallow flow. Yet, the sedimentary record of modern and ancient rivers with highly variable discharge displays an abundance or even dominance of Froude supercritical flow deposits.

This article shows that Froude supercritical flow may exert first-order control on river morphodynamics, such as the nature of the small- and large- scale bedforms and thus the resultant stratigraphy, as well as on sediment transport mode and rate. Such rivers characteristically lack well developed barforms, as supercritical flow is not advected by bars and bar migration thus not maintained. Transition to Froude supercritical flow significantly increases the proportion of sandy and gravelly sediment carried in suspension. Suspension transport critically increases downstream sediment transport rates, as bedload transport rates are linked to downstream bedfrom migration rates that are only a small fraction of the mean flow velocity. This article discusses the effects of supercritical flow on small- and large-scale bedform migration and the resultant depositional architecture in rivers where supercritical flow is the geomorphically formative flow.

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Effect of Froude Supercritical Flow on Fluvial Facies, Geometries and Architecture

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Problem:

- Froude supercritical flow (Fr>1) sedimentary structures abundant on some
    - Deepwater slopes
    - Deltas
    - Rivers

- But Fr>1 flow commonly considered a transient occurrence in a shallow flow and very high slopes

- How come we see an abundance or dominance of Fr>1 features in some settings = geomorphically formative flow in some systems?

- What difference does it make?

Sub- vs supercritical flow

What difference does it make?

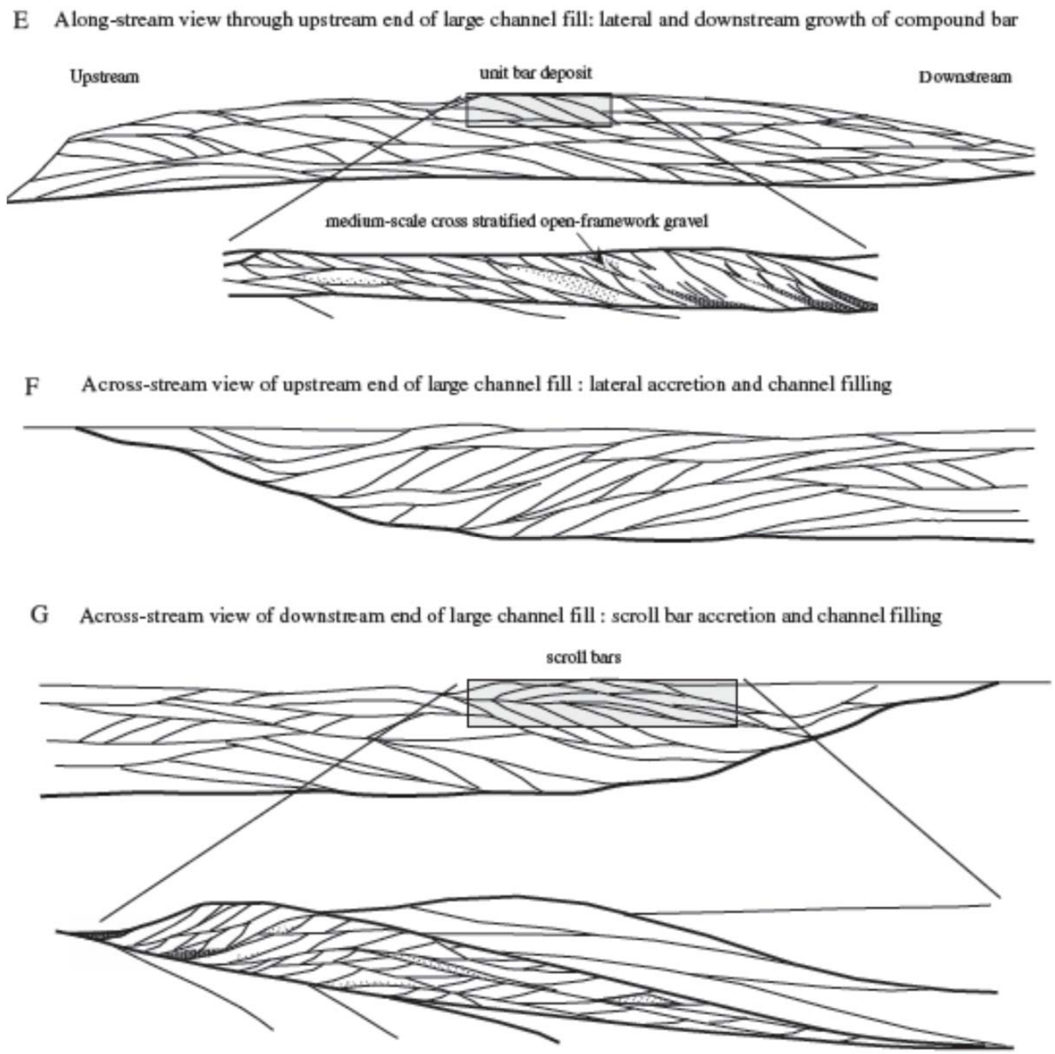
Subcritical flow Fr<1

www.**youtube**.com/watch?v=cJo0fTpJypg

- Slow, stable flow
- Bedload transport
- Equilibrium conditions for bedform migration (ripples, dunes, bars)
- Downstream bedform migration with steep (angle of repose) foresets
- Sediment transport rates depend on bedform migration rates and lengths

What difference does it make?

Subcritical flow Fr<1



- Various scales of cross lamina and strata
- Indicate the downstream migration and lee side preservation of steep foresets

Lunt et al., 2004

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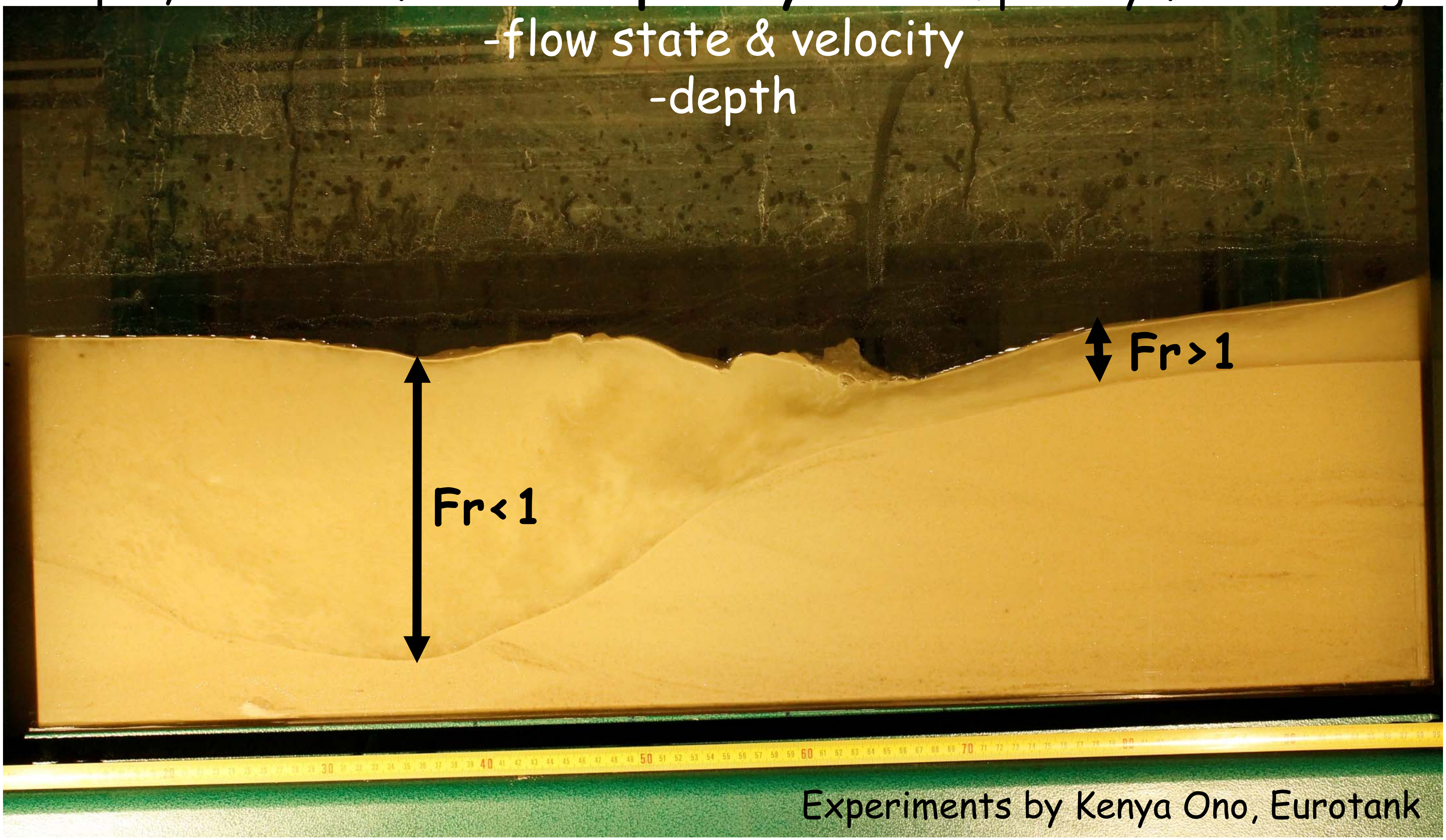
What difference does it make? Supercritical flow Fr>1

Experiments by Kenya Ono, Eurotank

- Rapid, unstable flow with highly fluctuating flow state, velocity and Fr nr
- Suspension transport of sand and gravel
- No equilibrium conditions or sustained bedform migration: deposition and erosion intermittent
- Up – or down-stream migration or vertical aggradation
- Sediment transport rates not linked to bedform migration rates or length

Unstable (large Fr variability) flow

Rapid, unstable flow with **spatially** and temporally fluctuating
- flow state & velocity
- depth

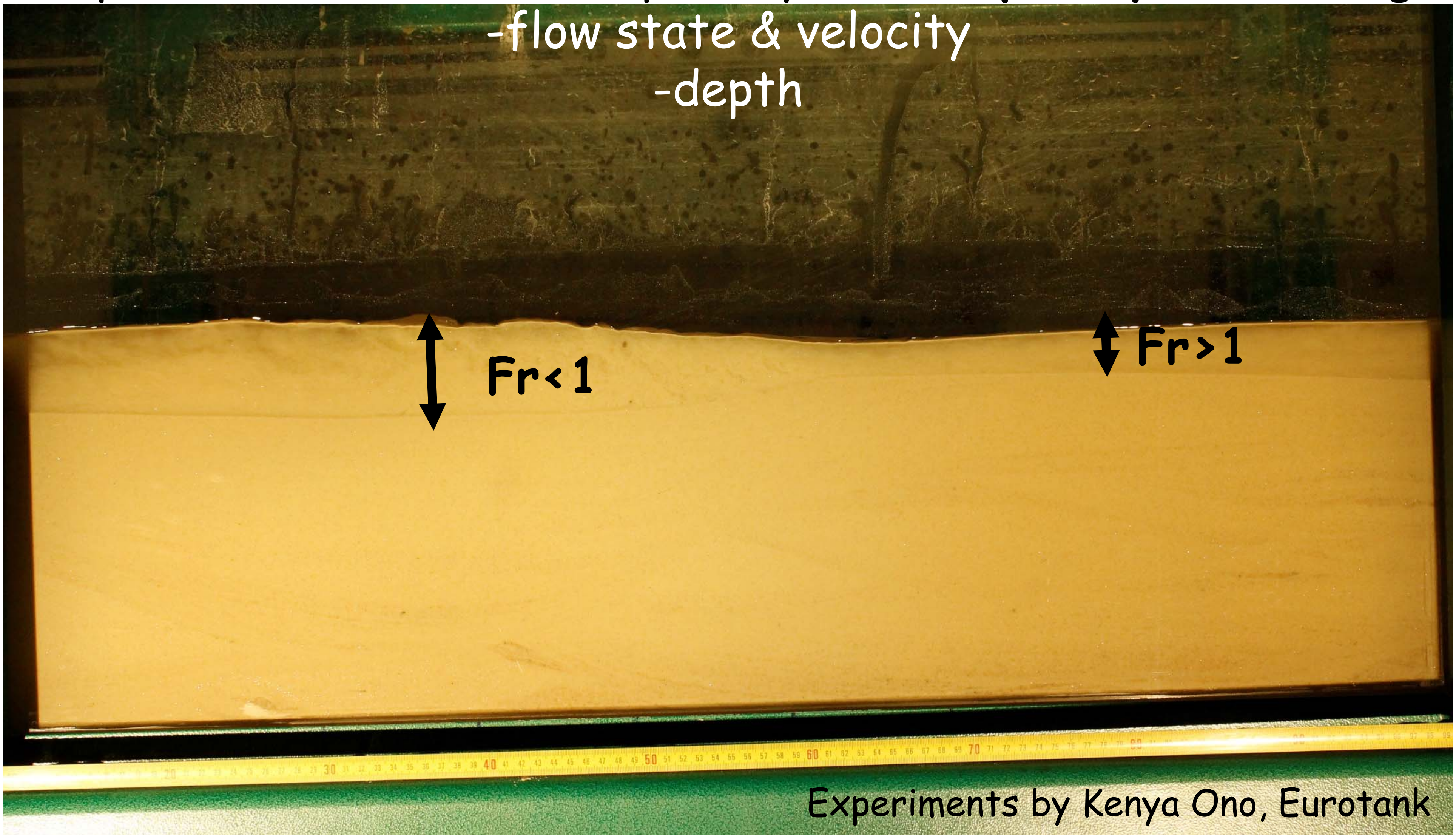


Unstable (large Fr variability) flow

Rapid, unstable flow with spatially and **temporally** fluctuating

-flow state & velocity

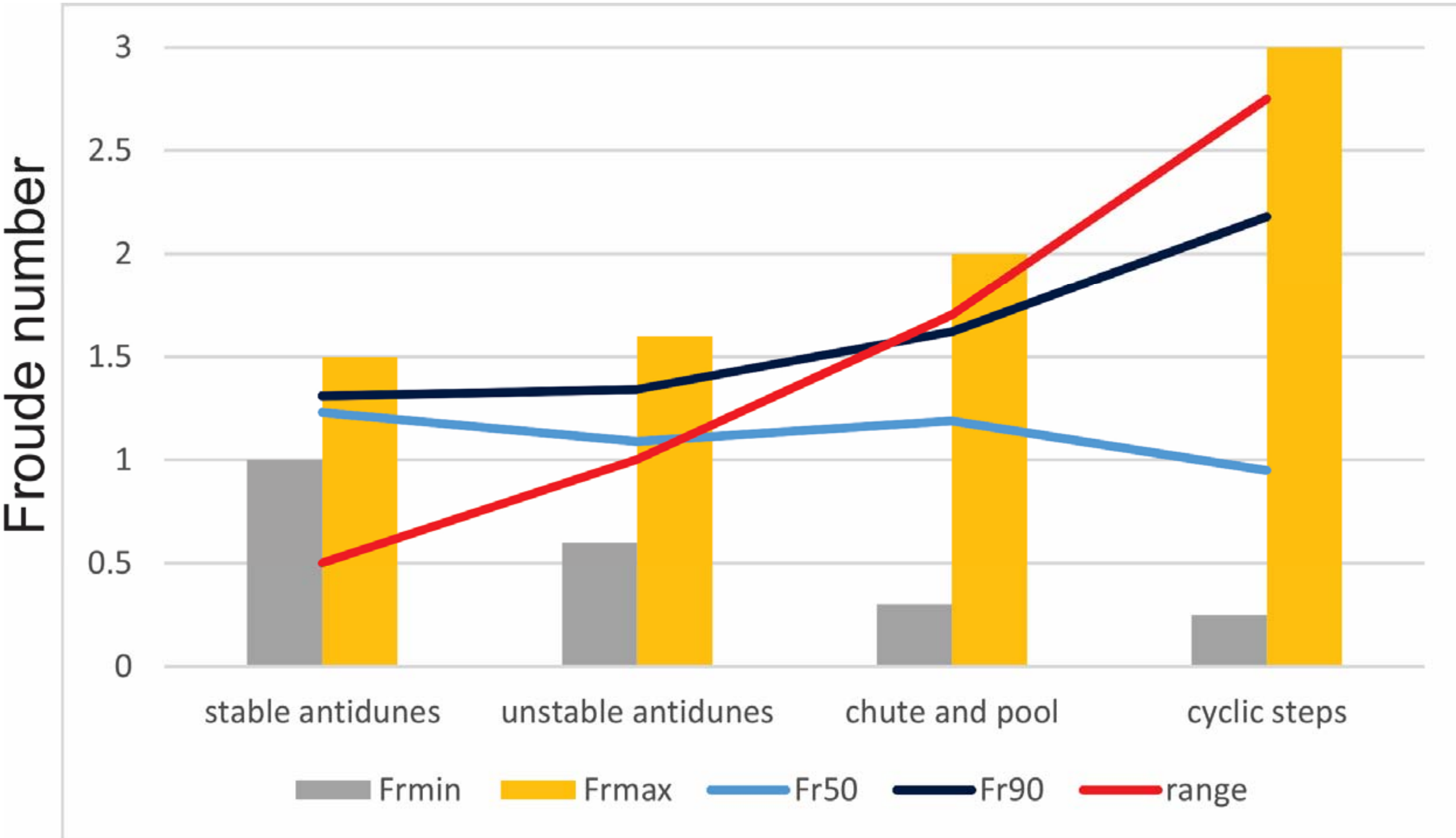
-depth



Experiments by Kenya Ono, Eurotank

Unstable (large Fr variability) flow

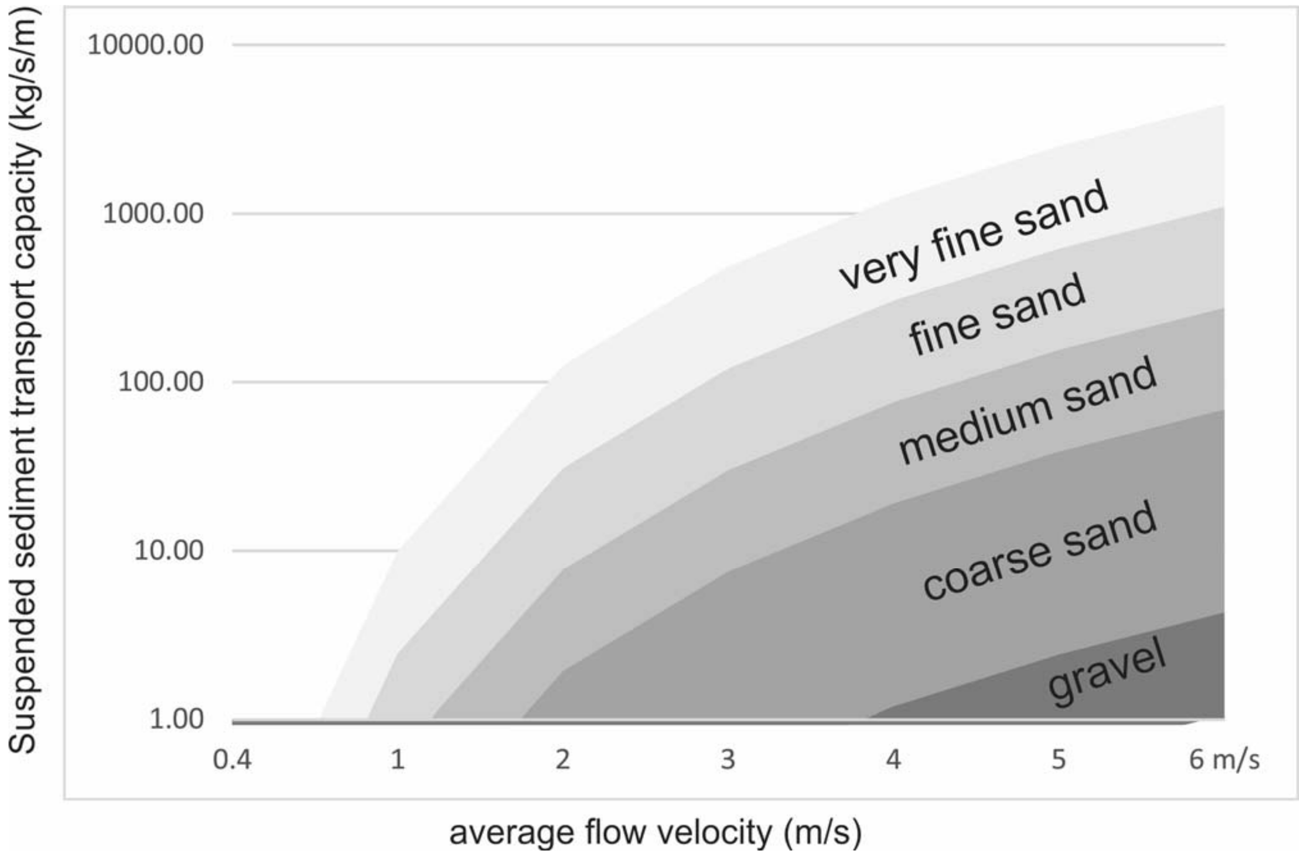
Increasing instability with increasing Fr_{90} = Fr_{max}- Fr_{min} increases



Data from Cartigny et al., 2014

So what?

Effects: Suspension transport



Van Rijn, 2007

Effects: Fr>1 sedimentary structures

Specific Fr>1 sedimentary structures are difficult to interpret in some cases as they are not formed as sustained equilibrium bedforms but rather by intermittent deposition and erosion (except perhaps cyclic steps)

Planar laminations

Convex-up low-angle strata

Scour and fill

Effects: “Poorly developed bars”

Fr>1 flow not adverted around bars: low-angle downstream accreting sheets with lee-side erosion and backset bedding

Effects: "Poorly developed bars"

Erosionally based, low-angle sheets

Effects: Bars

Erosionally based, low-angle sheets

Experiments by Kenya Ono, Eurotank

Effects: “Poorly developed bars”

No sustained lateral accretion:
oblique downstream to vertical accretion and no upward fining

Effects: "Poorly developed bars"

Fr>1 flow not adverted around bars: upward coarsening

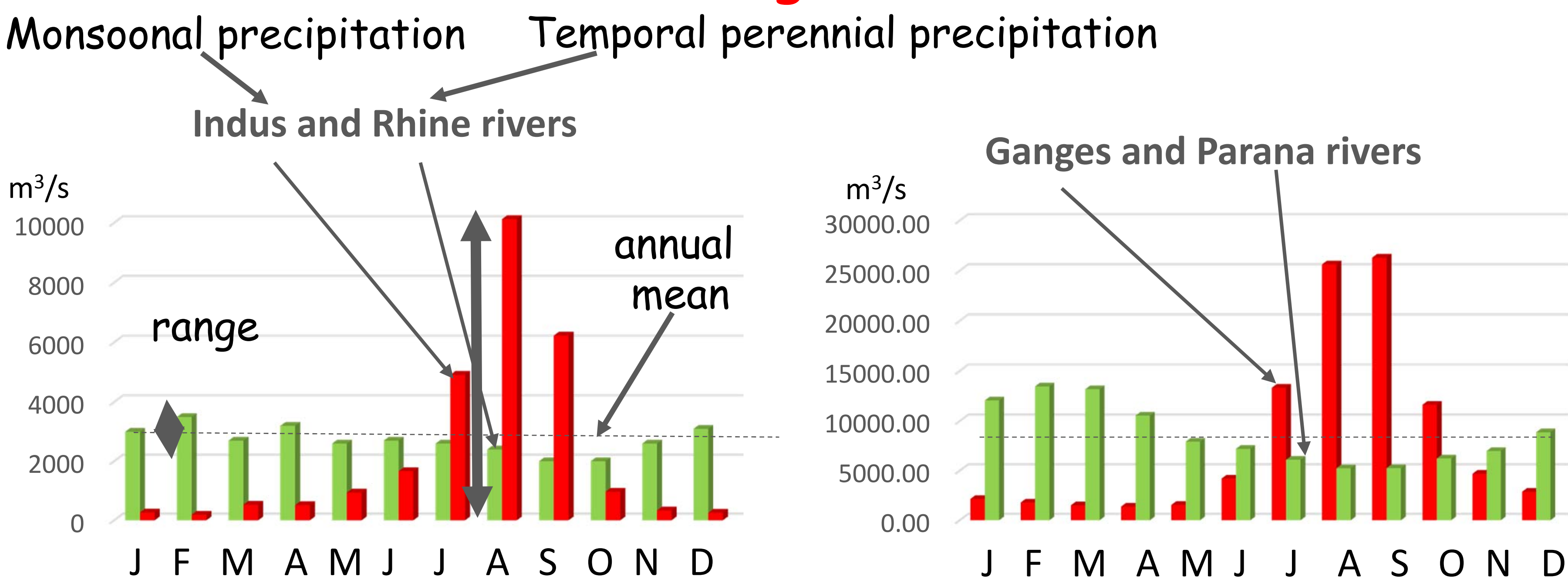
Effects: Architecture

Flow instability and high local deposition rates promote avulsions rather than channel migration

Effects: Architecture

At what conditions is Fr>1 flow geomorphically formative?

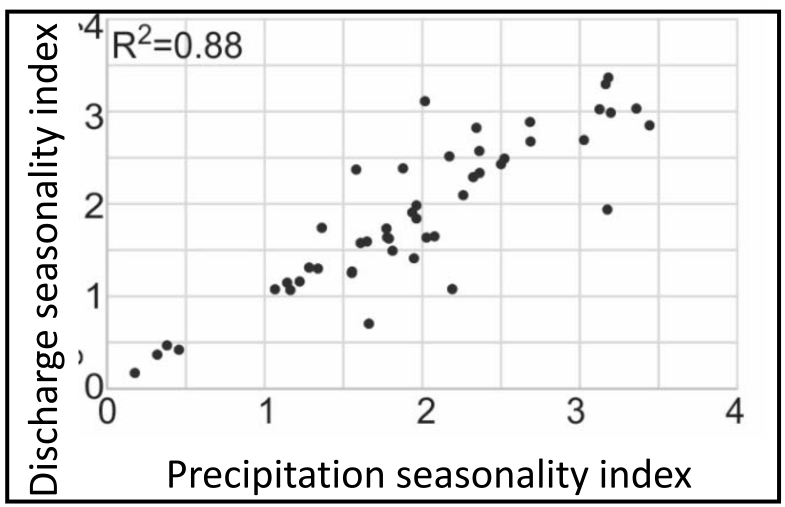
Unstable FR>1 flow formative flow in some variable discharge rivers



Precipitation vs discharge seasonality index

Precipitation seasonality index:

$$\frac{P_{max}-P_{min}}{P_{mean}}$$



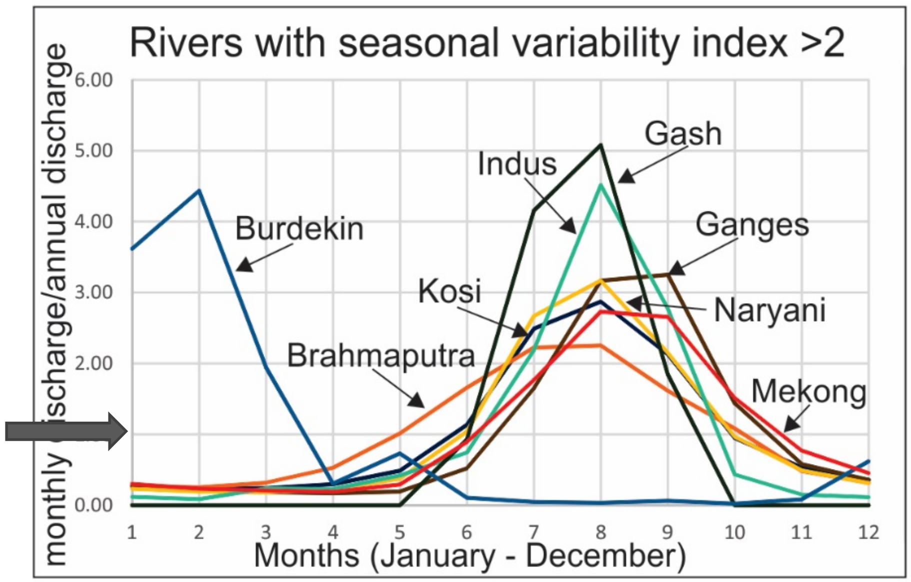
Discharge seasonality index:

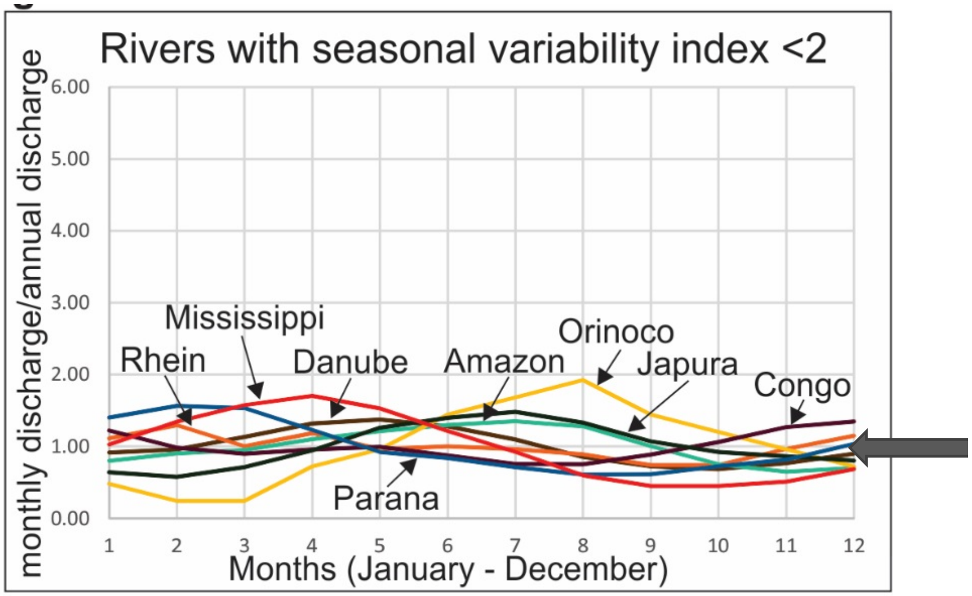
$$\frac{Q_{max}-Q_{min}}{Q_{mean}}$$

Plink-Bjorklund, 2015

Variable discharge

Perennial precipitation zone





DVI>2

DVI<2

Qmax >800% of Qmean

Q90 >500% of Qmean

Q50 ca 50% (0-10%) of Qmean

Qmax <180% of Qmean

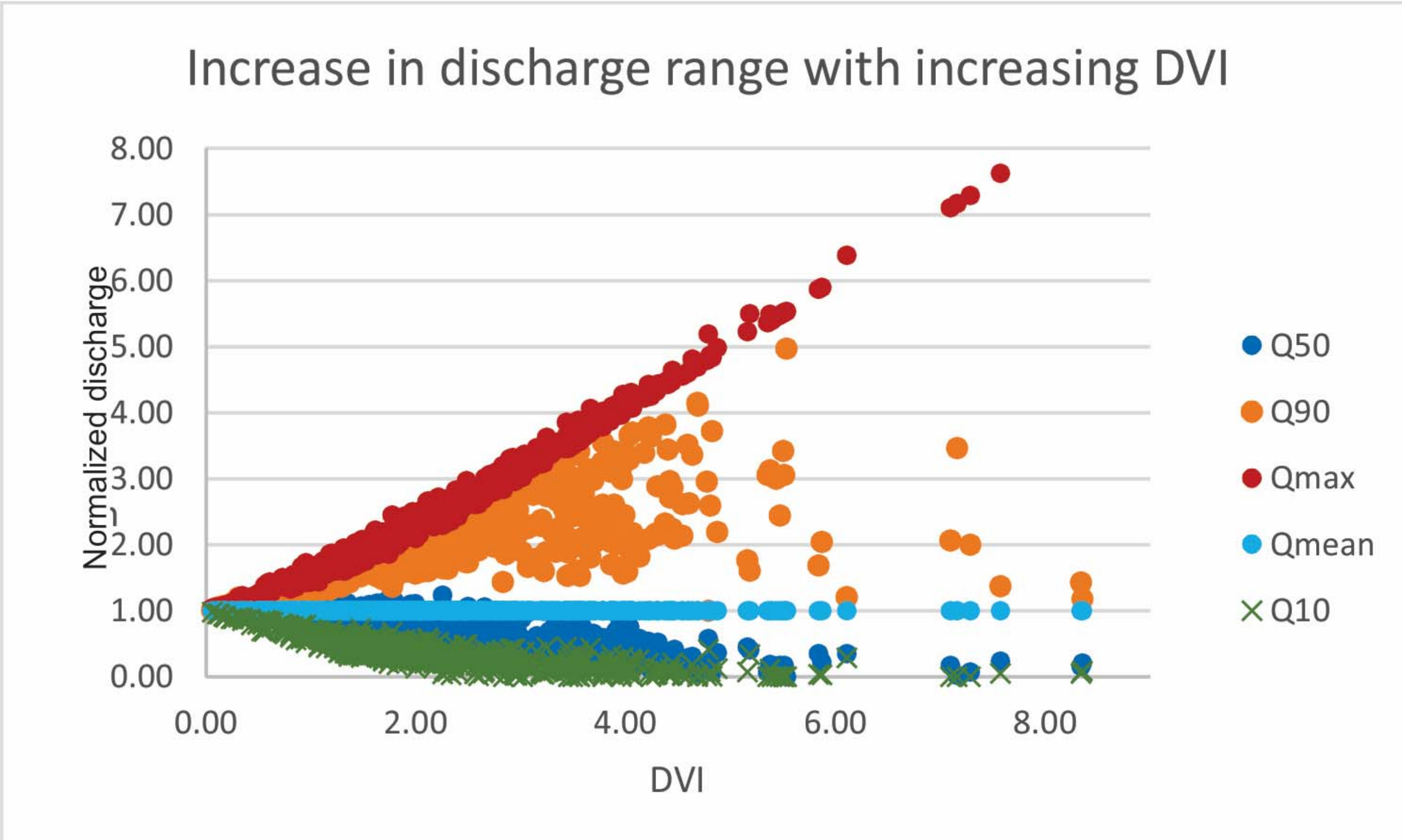
Q90 <160% of Qmean

Q50 within 92% of Qmean

Q10 within 40-70% of Qmean

Increased discharge range in variable discharge rivers

Monthly discharge data of 497 rivers http://www.sage.wisc.edu/riverdata



Plink-Bjorklund, 2017

Persistent discharge rivers:

Base discharge = ca Qmean

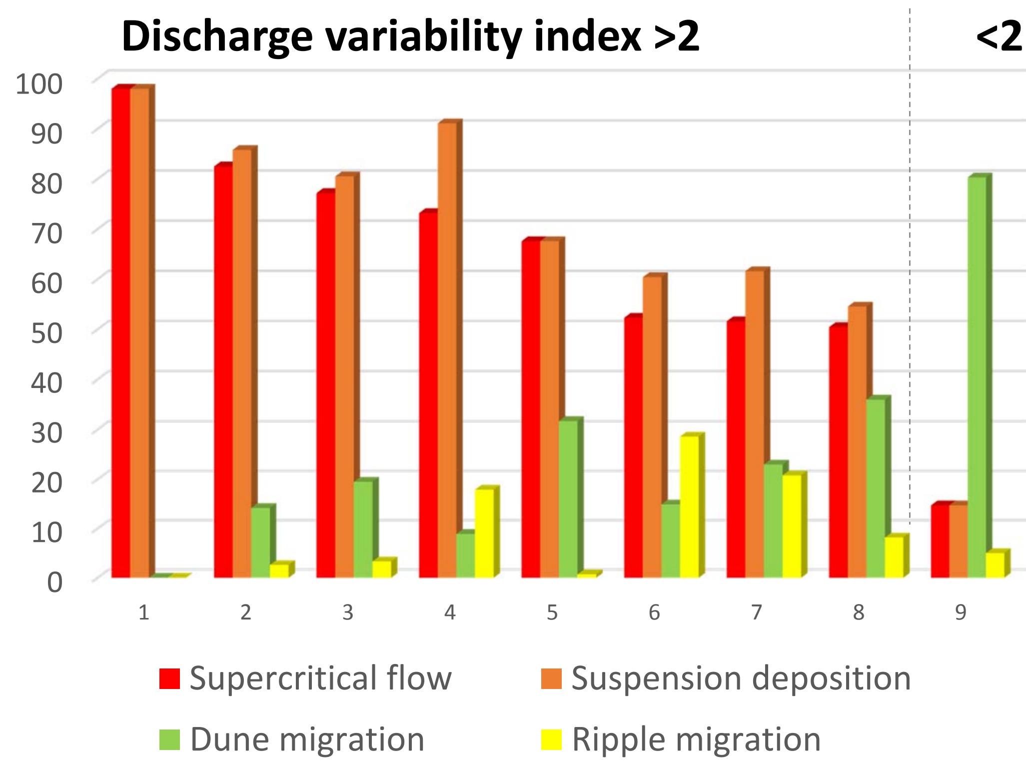
Flood discharge = ca Qmean

Variable discharge rivers: Base discharge <<Qmean

Variable discharge rivers: Flood discharge >>Qmean

Base flow = geomorphically inefficient
Flood discharge (Fr>1) = short duration but the formative flow

Persistent perennial precipitation zone rivers

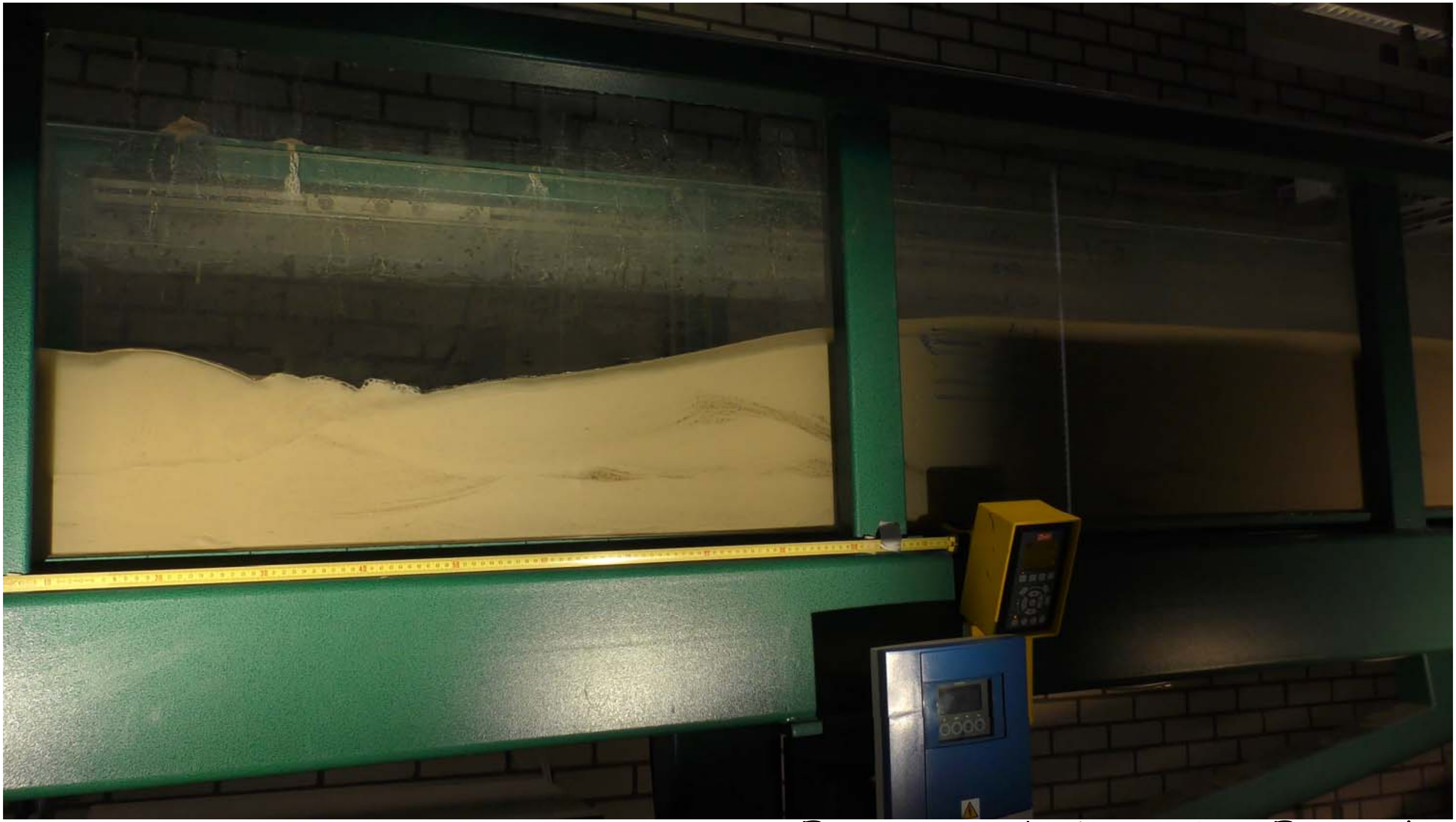


Plink-Bjorklund, 2015

Other things to consider?

Water depth? **Advection length & sediment transport rates?**

Environmental signal propagation? **Autogenic processes?**



Experiments by Kenya Ono, Eurotank

Conclusions

- Both the Fr>1 and the large Fr range define the flow characteristics
- Fr>1 in transient events, most deposition due to hydraulic jump and drop to Fr<1 conditions: should be termed unstable or variable flow rather than Fr>1 flow?
- Where it is the geomorphically efficient flow, it affects morphodynamics: not just sedimentary structures, but the transport mode, downstream sediment transport rate, mode of deposition, flow depth, advection lengths, autogenic processes, environmental signal transfer …
- We need more than just new facies models …