Click to view movies.
Movie 1 (Bedload, Trinity River) Movie 2 (Turbidity current) Movie 3 (Internal delta)
Movie 4 (Bedload transport) Movie 5 (Upstream migration) Movie 6 (Gravel front)
Movie 7 (Downstream migration)

Controls on Gravel Deposits in Deep-Water Reservoirs; Bedload Transport and Bedforms Associated with Turbidity Currents*

Octavio Sequeiros[1], Benoit Spinewine[2], Rick Beaubouef[3], Tao Sun[4], Bruno Savoye[5], Marcelo Garcia[6] and Gary Parker[6]

Search and Discovery Article #40516 (2010)
Posted March 25, 2010

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*Please refer to the companion article, Search and Discovery Article #40480 (2010) entitled "Secondary Flow in Meandering Channels on Submarine Fans: Implication for Channel Morphodynamics and Architecture."

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Abstract

Outcrops show features indicating that turbidity currents transport both sand and gravel as bedload (in traction). In addition, both outcrops and the modern seafloor show evidence for a variety of bedforms, including dunes, antidunes and cyclic steps. Lacking better information, most researchers have interpreted these features using relations based on rivers and experimental models of fluvial flow. Here the results of a series of experiments on bedload transport by saline underflows and turbidity currents are presented. In the case of the saline underflows, dissolved salt is a surrogate for fine mud in suspension that does not easily settle out. The experiments indicate that the relation for bedload transport for such currents is very similar to that obtained for rivers. In addition, the experiments revealed four regions for bedforms: plane mobile bed, upstream-migrating antidunes, downstream-migrating antidunes and dunes. These results are applied to an outcrop showing sediment waves in gravel, as well as gravel waves on the modern seafloor. They are of particular relevance to the interpretation of gravel-bearing hydrocarbon reservoirs.

References

Fukuoka, S., K. Okutsu, and M. Yamasaka, 1982, Dynamic and kinematic features of sand waves in upper regime: Proc. Jpn Soc. Civ. Eng., v. 323, p. 77–89 (in Japanese).

Meyer-Peter, E., and R. Müller, 1948, Formulas for bed-load transport: Proceedings of International Association for Hydraulic Structures Research, Stockholm.

Nakajima, T., and M. Satoh, 2001, The formation of large mudwaves by turbidity currents on the levees of the Toyama deep-sea channel, Japan Sea: Sedimentology, v. 48, p. 435–463.

Pirmez, C., and J. Imran, 2003, Reconstruction of turbidity currents in a meandering submarine channel: Marine and Petroleum Geology, v. 20, p. 823-849.

Sequeiros, O.E., B. Spinewine, M.H. Garcia, R.T. Beaubouef, T. Sun, and G. Parker, 2009, Experiments on wedge-shaped deep sea sedimentary deposits in minibasins and/or on channel levees emplaced by turbidity currents. Part I. Documentation of the flow: Journal of Sedimentary Research, v. 79. p. 593-607.

Wilson, K.C., Bed-load transport at high shear stress: Proceedings of American Society of Civil Engineers, Journal of Hydrology Division HY 6.

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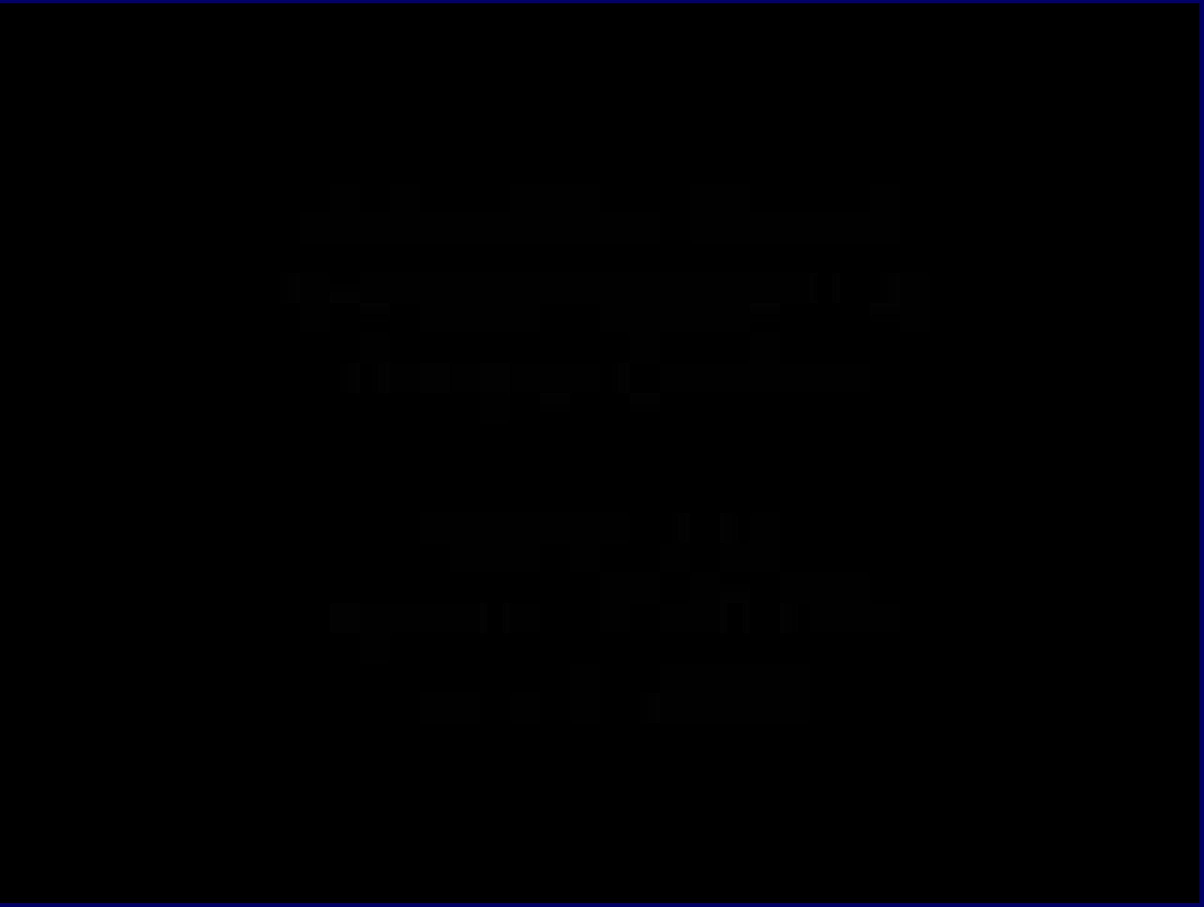
Controls on Gravel Deposits in Deep-Water Reservoirs; Bedload Transport and Bedforms Associated with Turbidity Currents

AAPG Annual Convention & Exhibition

Octavio Sequeiros, Benoit Spinewine, Rick Beaubouef, Tao Sun, Bruno Savoye (deceased), Marcelo Garcia* and Gary Parker*
June 9, 2009

THE TOPIC OF INTEREST

Turbidity currents are similar to rivers in that they can transport sediment as:
• bedload (rolling or saltating along the bed), and
• suspended load (wafted high into the flow)



Trinity River, California
Cour. A. Krause

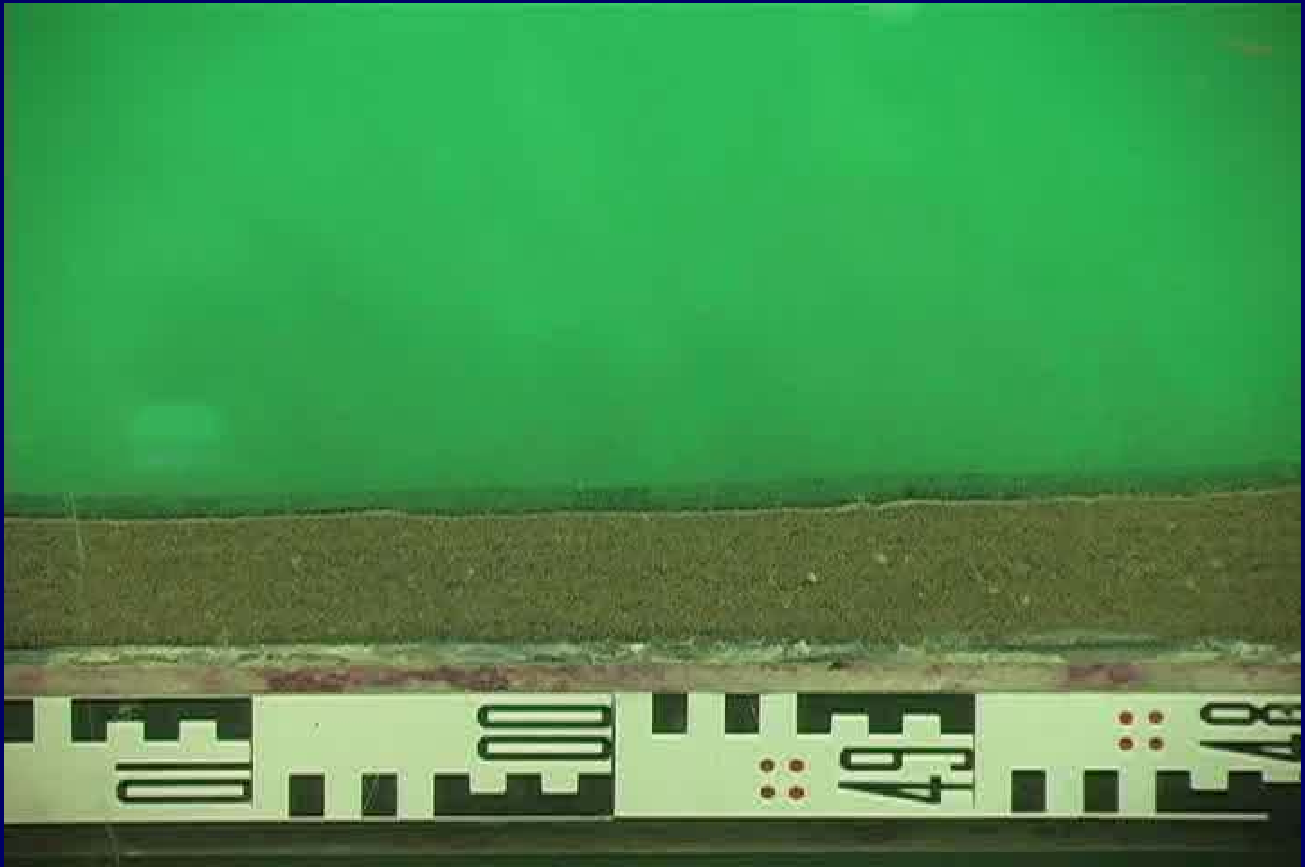
(Click black rectangle to view movie)

THE TOPIC OF INTEREST

The driving mechanism of turbidity currents differs from rivers.

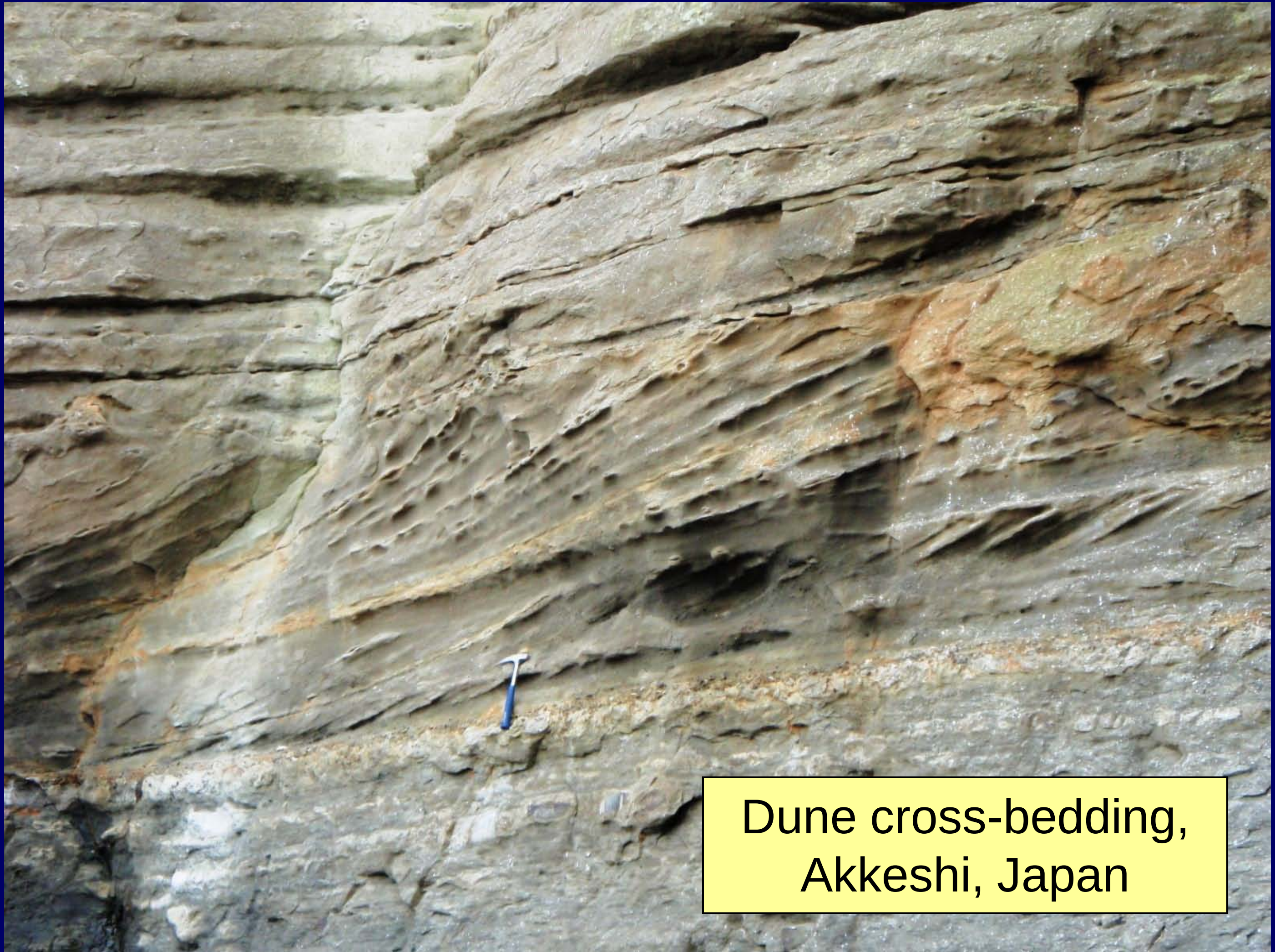
- **River: gravity pulls the *water* downslope, water drags the sediment.**
- **TC: gravity pulls the *suspended sediment* downslope, suspended sediment drags the water, which then drags the bedload.**

(click image to view movie)



THE TOPIC OF INTEREST

We can study bedload-dominated river deposits in outcrops,



Dune cross-bedding, Akkeshi, Japan

THE TOPIC OF INTEREST

But we can go and look at rivers any time we want.

THE TOPIC OF INTEREST

In the case of bedload-influenced deepwater deposits of turbidity currents, however,
there is no practical way to observe the formative currents.

Gravel megawave, Cerro Gordo, Patagonia

BEDLOAD AND BEDFORMS IN RIVERS

What have we learned from rivers?

Las Vegas Wash, USA

BEDLOAD AND BEDFORMS IN RIVERS

Some key dimensional parameters:

H	=	depth (river), flow thickness (saline/turbidity current)
U	=	mean flow velocity
g	=	gravitational acceleration
ρ	=	water density
ρ_s	=	sediment density
D	=	grain size
R	=	$(\rho_s/\rho) - 1$ (submerged specific gravity: 0.53 for plastic, 1.65 for quartz
τ_b	=	bed shear stress
F_e	=	fractional excess density of flow above ambient fluid = 1 for river (under air), << 1 for turbidity current
q_b	=	volume bedload transport per unit width
ν	=	viscosity of flowing fluid (mostly water)

BEDLOAD AND BEDFORMS IN RIVERS

Some key dimensionless parameters:

$$\mathbf{Fr}_d = \frac{U}{\sqrt{F_e g H}}$$

Froude number:

$Fr_d > 1 \rightarrow$ supercritical (shooting)
$Fr_d < 1 \rightarrow$ subcritical (tranquil)

$$\tau^* = \frac{\tau_b}{\rho R g D}$$

Shields number: scales sediment mobility

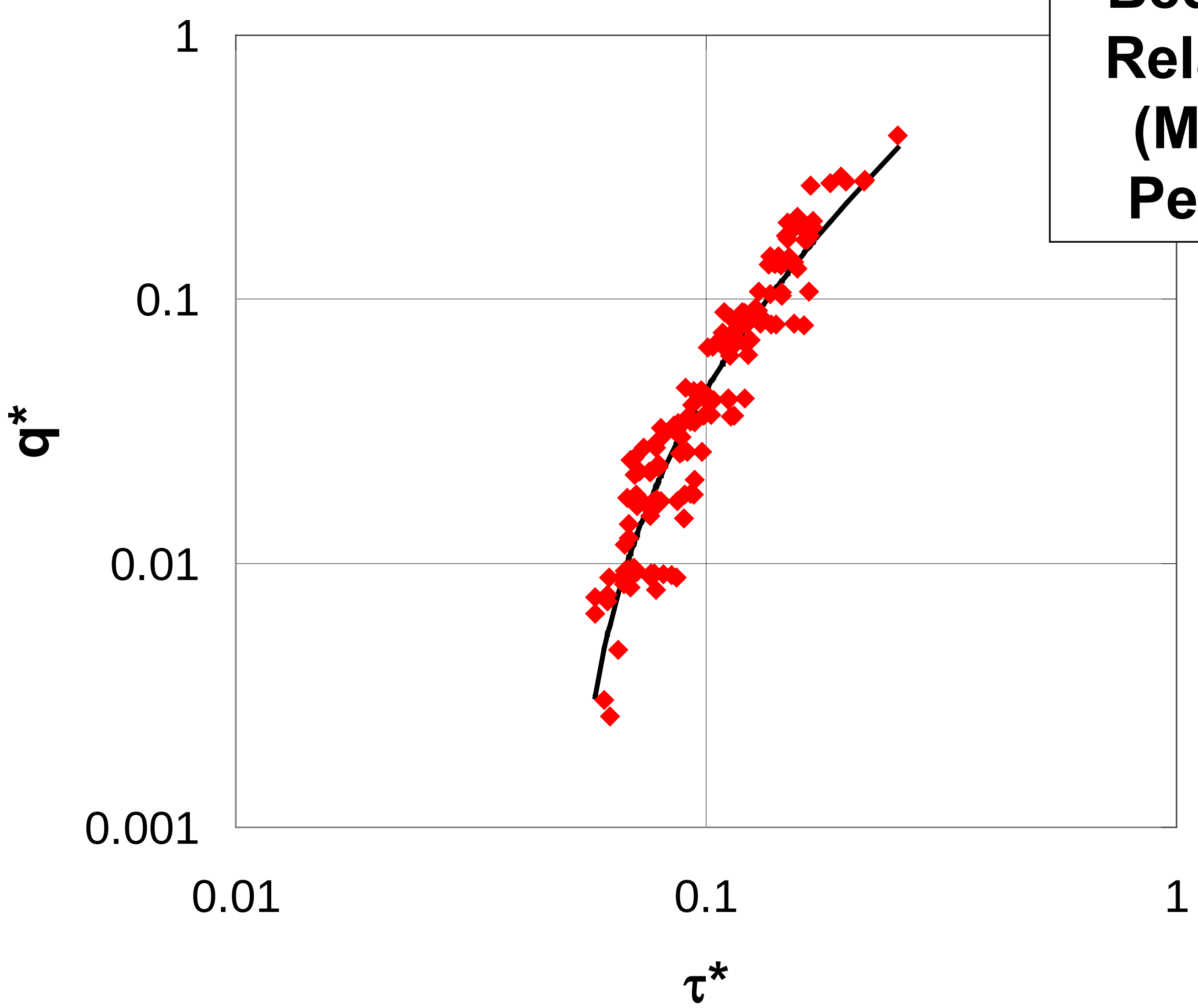
$$q^* = \frac{q_b}{\sqrt{RgD}\,D}$$

Einstein number: scales bedload transport rate

$$\mathbf{Re}_p = \frac{\sqrt{RgD}\,D}{\nu}$$

Particle Reynolds number: scales particle size

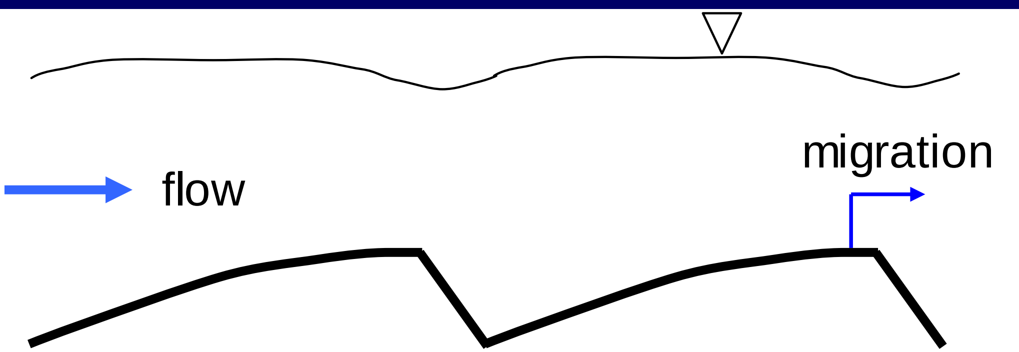
BEDLOAD AND BEDFORMS IN RIVERS

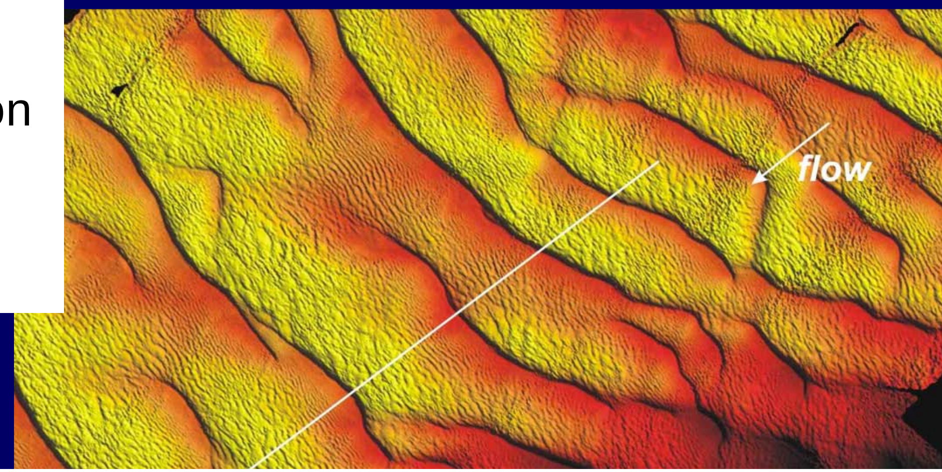


Bedload Transport Relation for Rivers (Modified Meyer-Peter and Müller)

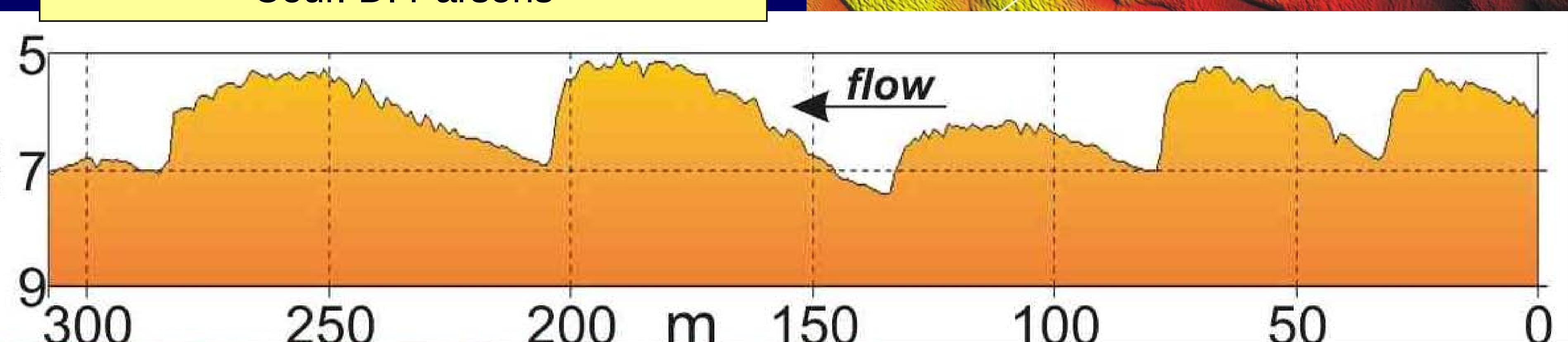
BEDLOAD AND BEDFORMS IN RIVERS

Dunes:
subcritical ($Fr_d < 1$)
water surface weakly out of phase with bed
migrate downstream





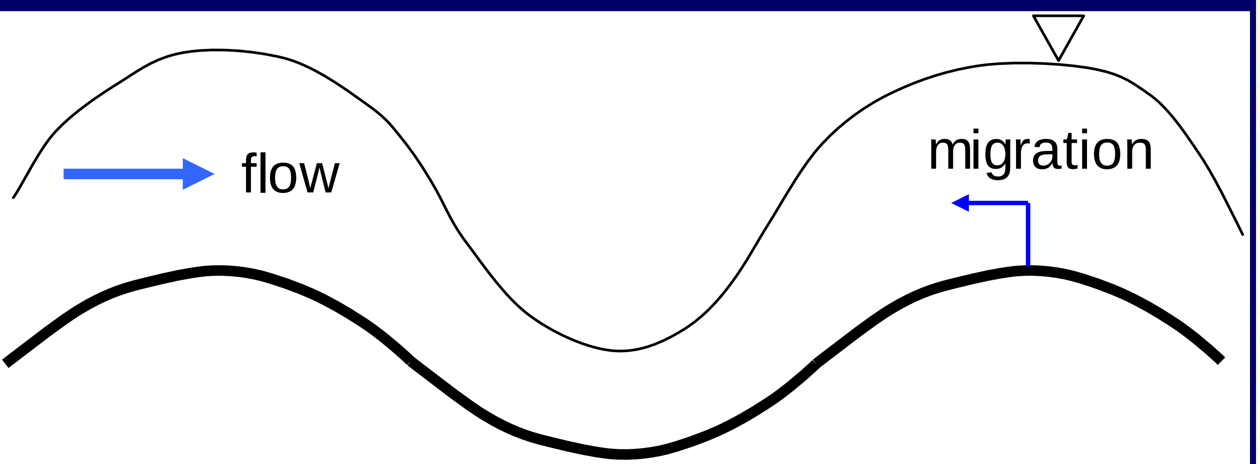
Paraná River, Argentina: 1 – 2 m high
Cour. D. Parsons

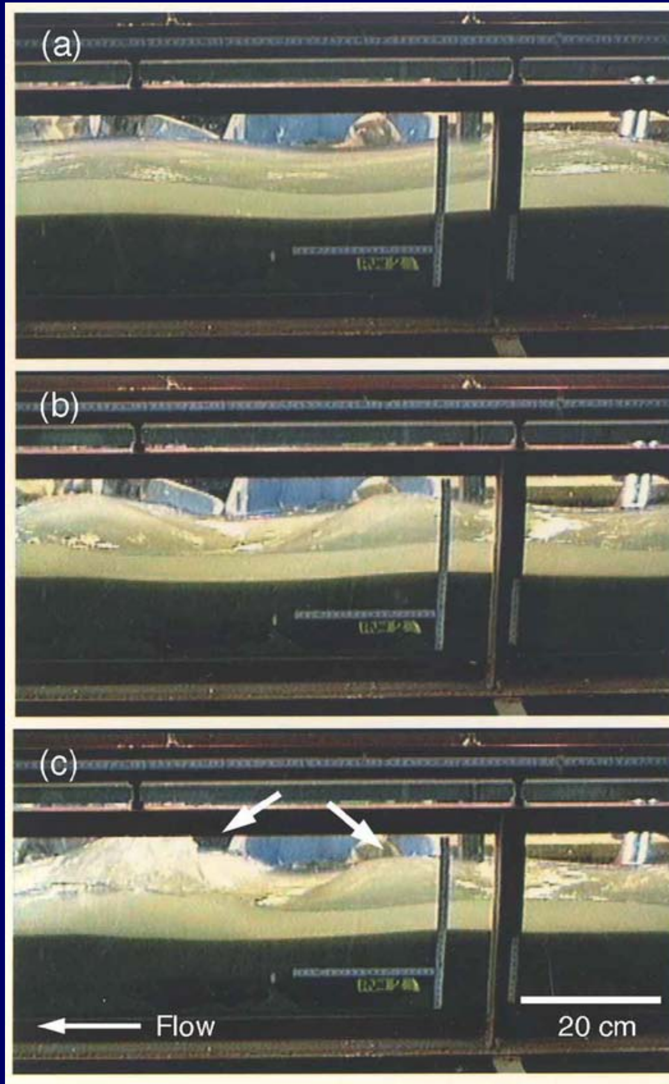


BEDLOAD AND BEDFORMS IN RIVERS

Cour. M. Yokokawa

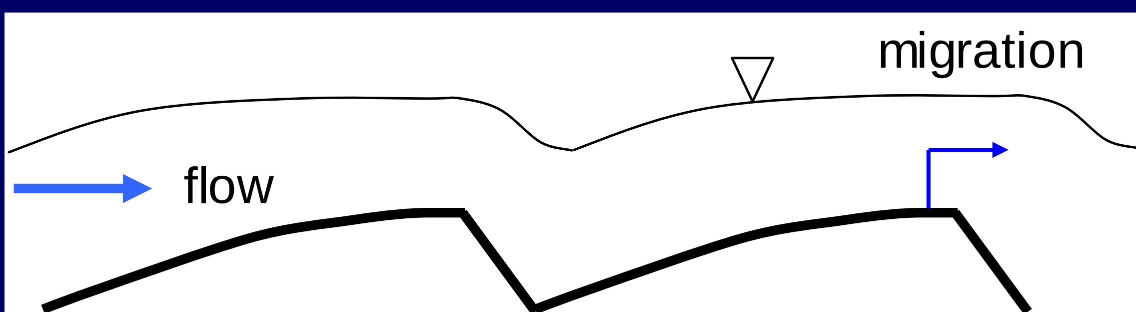
Upstream-migrating antidunes:
supercritical (Fr_d > 1)
water surface strongly in phase with bed
migrate upstream



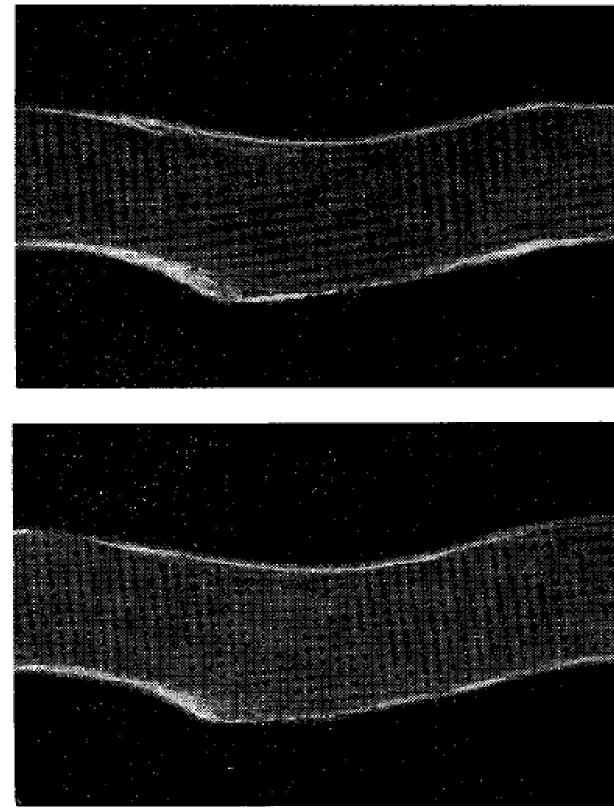


BEDLOAD AND BEDFORMS IN RIVERS

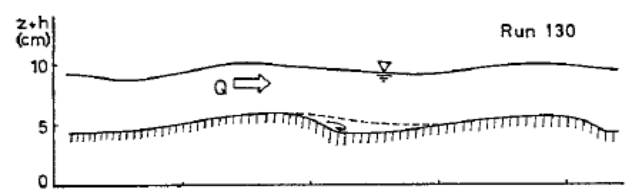
Downstream-migrating antidunes:
supercritical ($Fr_d > 1$)
water surface strongly in phase with bed
migrate downstream



Fukuoka et al. (1982)

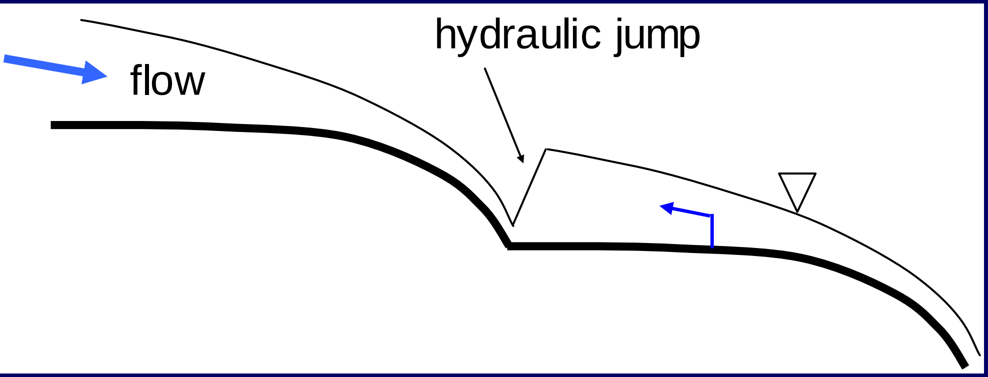


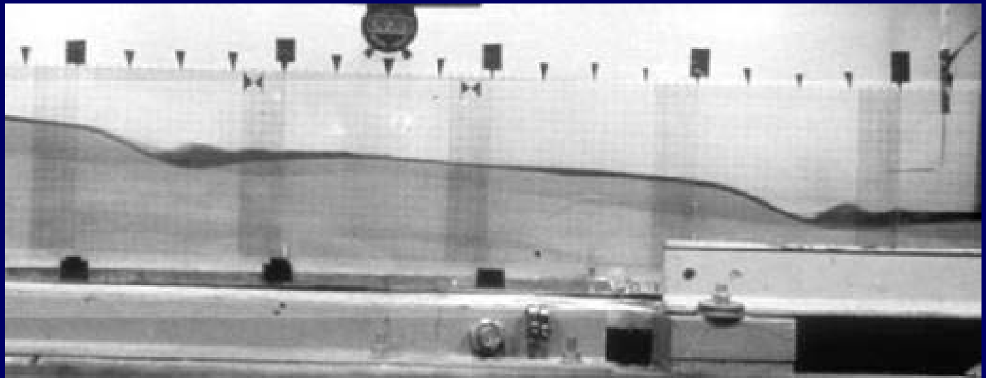
写真—5　アルミ粉末による剥離領域の可視化



BEDLOAD AND BEDFORMS IN RIVERS

Cyclic steps:
Highly supercritical
Punctuated by
hydraulic jumps
Migrate upstream



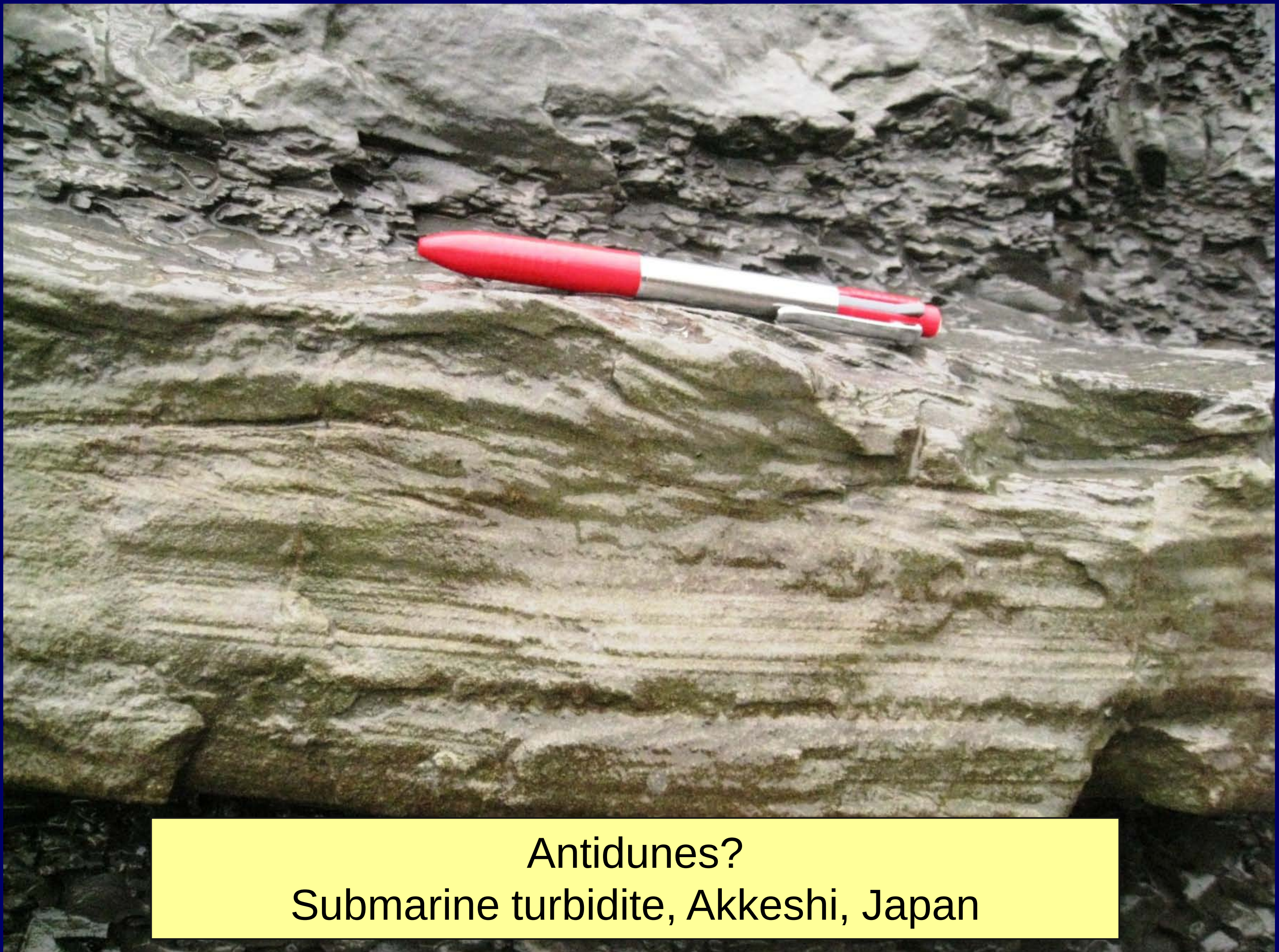


Tailings fan-delta
Lake Wabush, Labrador

WHAT ABOUT TURBIDITES?

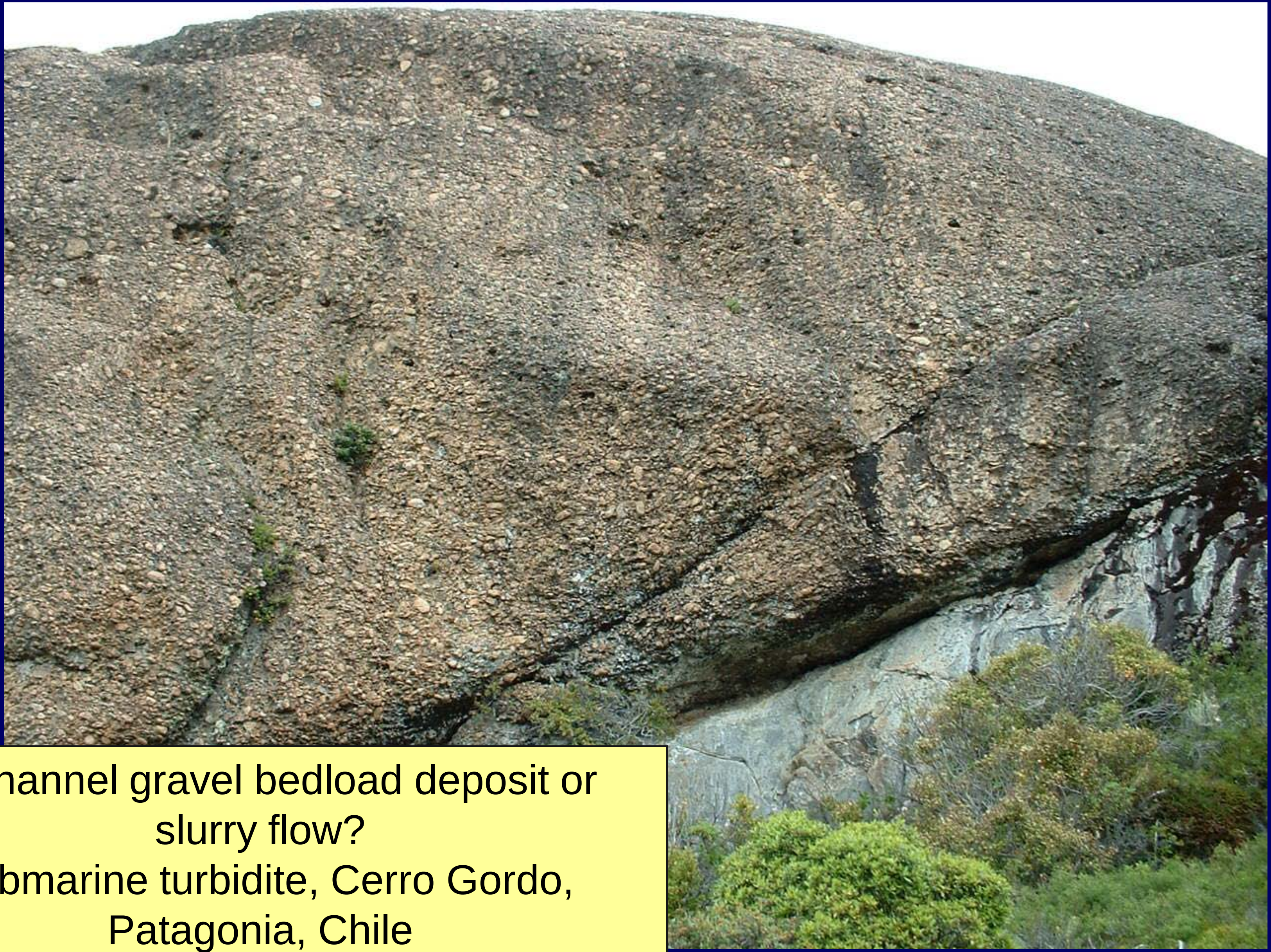
Dunes?
Submarine turbidite, Ainsa, Spain

WHAT ABOUT TURBIDITES?



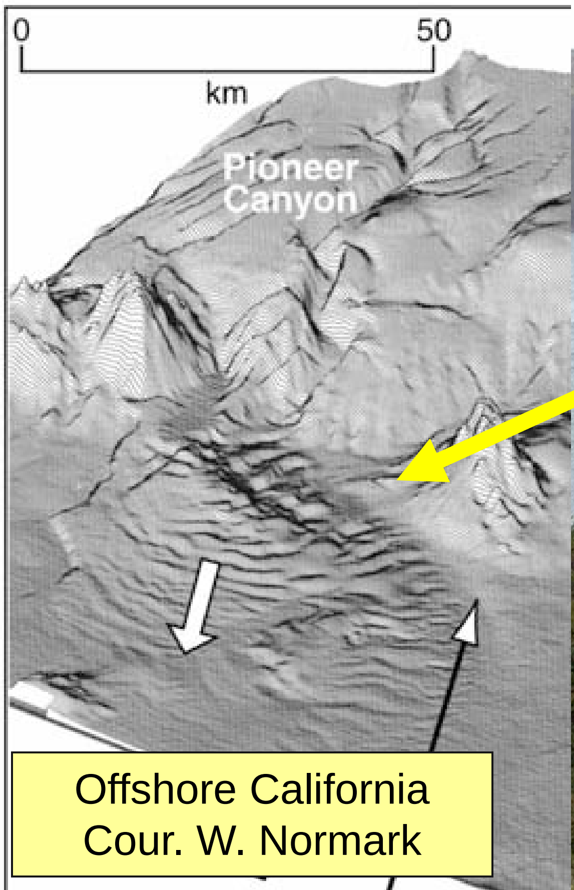
Antidunes?
Submarine turbidite, Akkeshi, Japan

WHAT ABOUT TURBIDITES?

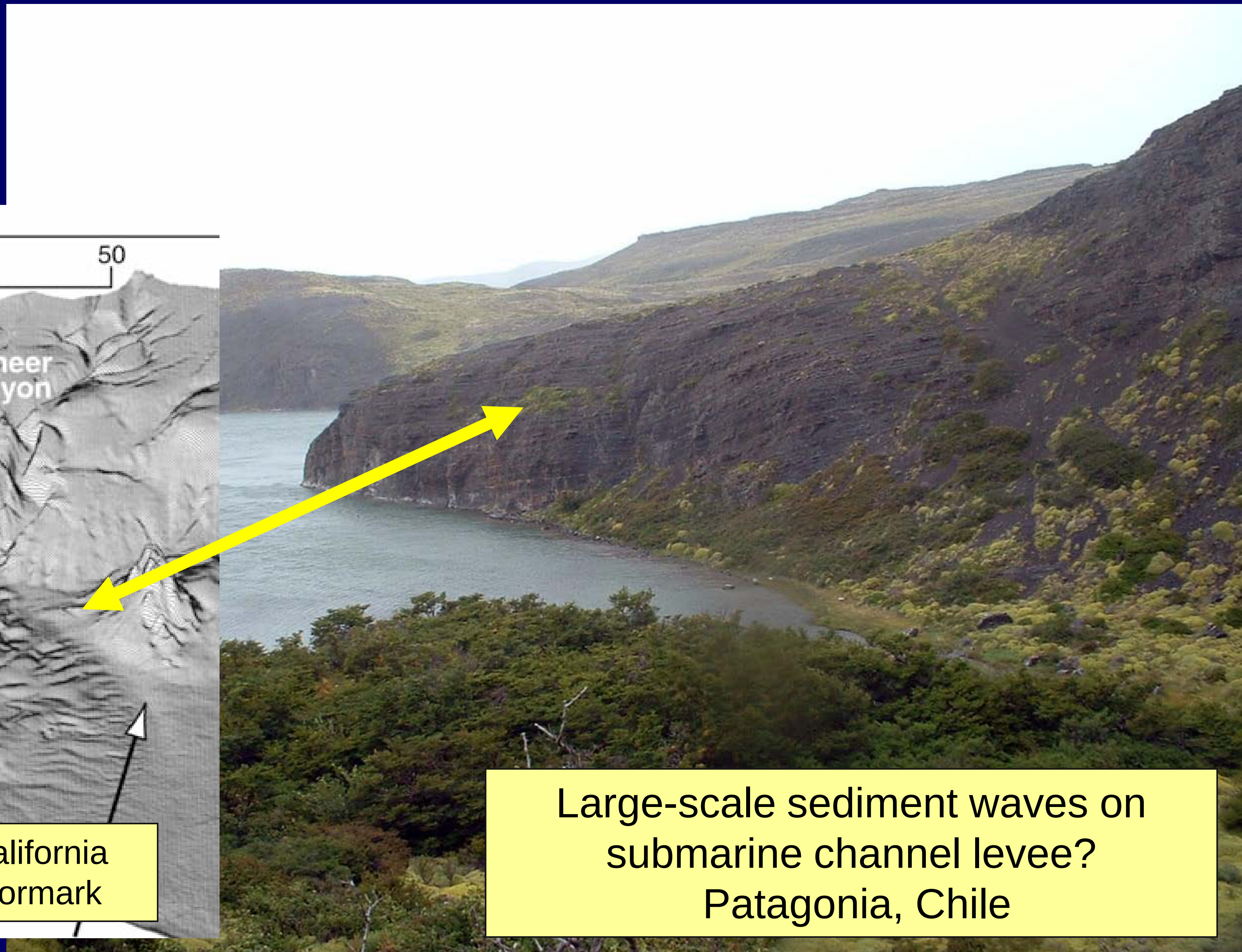


In-channel gravel bedload deposit or slurry flow?
Submarine turbidite, Cerro Gordo, Patagonia, Chile

WHAT ABOUT TURBIDITES?



Offshore California
Cour. W. Normark



Large-scale sediment waves on submarine channel levee?
Patagonia, Chile

EXPERIMENTAL SETUP

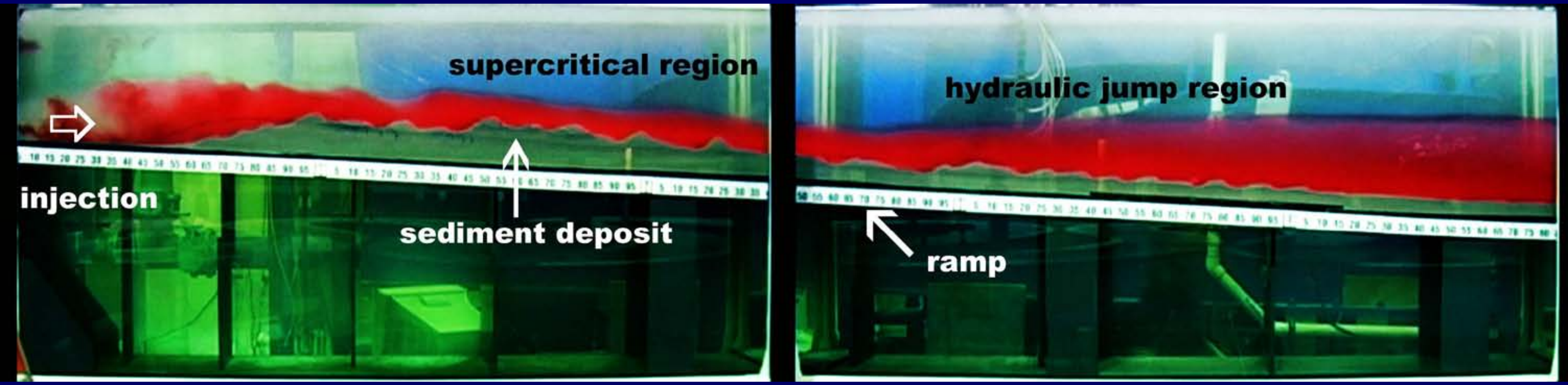
There is one more tool in our arsenal to understand turbidity currents, turbidity morphodynamics and turbidites: EXPERIMENTATION.

EXPERIMENTAL SETUP

The repatriated Garcia Tank, Ven Te Chow Hydrosystems Laboratory. **(click image to view movie)**

15 m long, 0.45 m. wide, 14 m. deep:
Designed for sustained turbidity currents (up to 1 hour)

EXPERIMENTAL SETUP



We ran saline underflows, hybrid underflows/turbidity currents and turbidity currents over a lightweight plastic granular bed (0.25 to 2.9 mm, s.g. = 1.5).

We obtained, for the first time, comprehensive data on
- **bedload transport and**
- **bedforms for**
- **Froude-supercritical and**
- **Froude-subcritical currents**

Dissolved salt serves as a good surrogate for fine-grained sediment in suspension that drives turbidity currents.

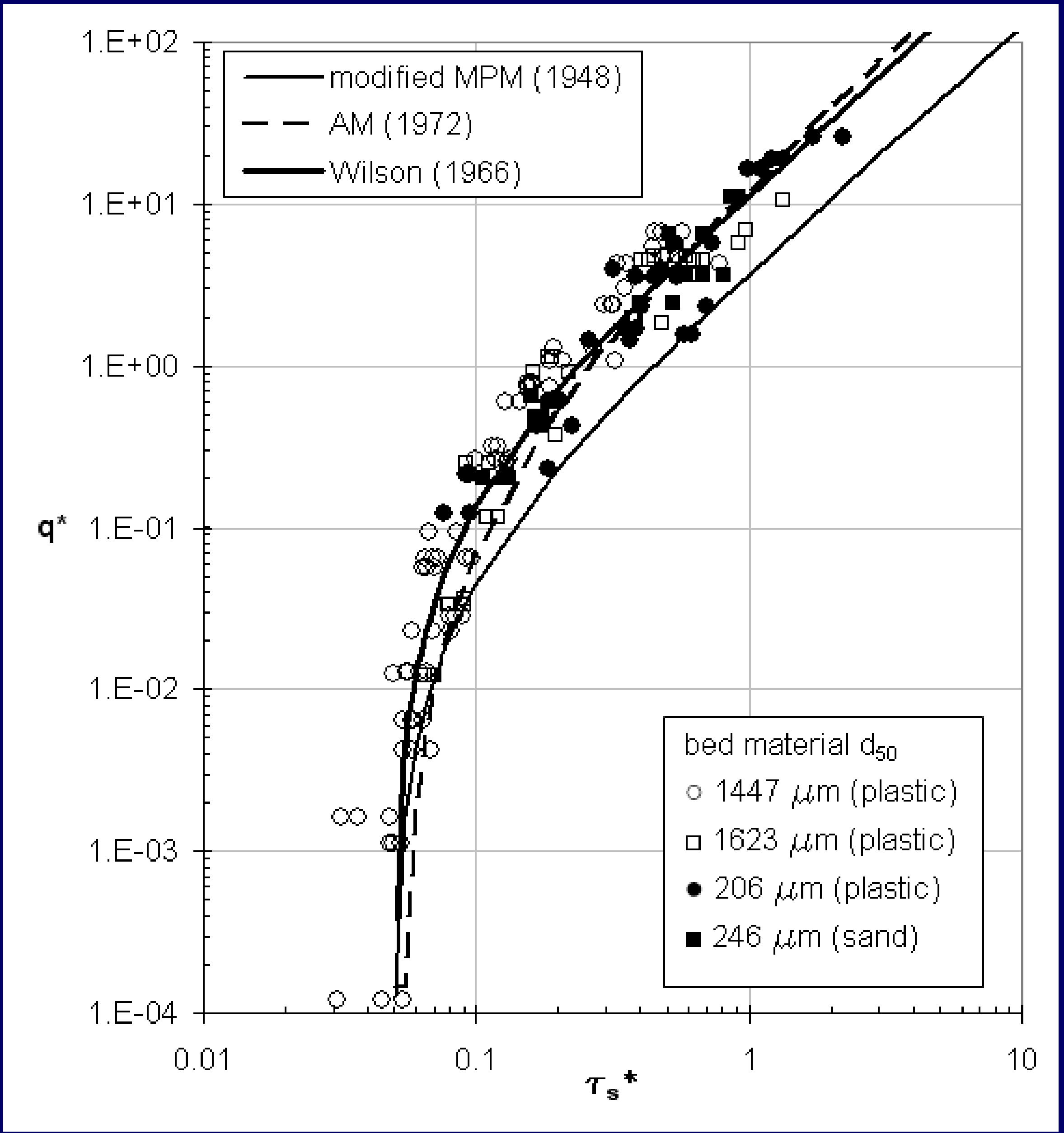
EXPERIMENTAL RESULTS

Bedload transport

(click image to view movie)

EXPERIMENTAL RESULTS

Bedload transport relation:
Our data fit existing fluvial relations



EXPERIMENTAL RESULTS

Plane bed
Frd = 0.71

Dunes
Fr_d = 0.67

EXPERIMENTAL RESULTS

Upstream-migrating antidunes

(click image to view movie)

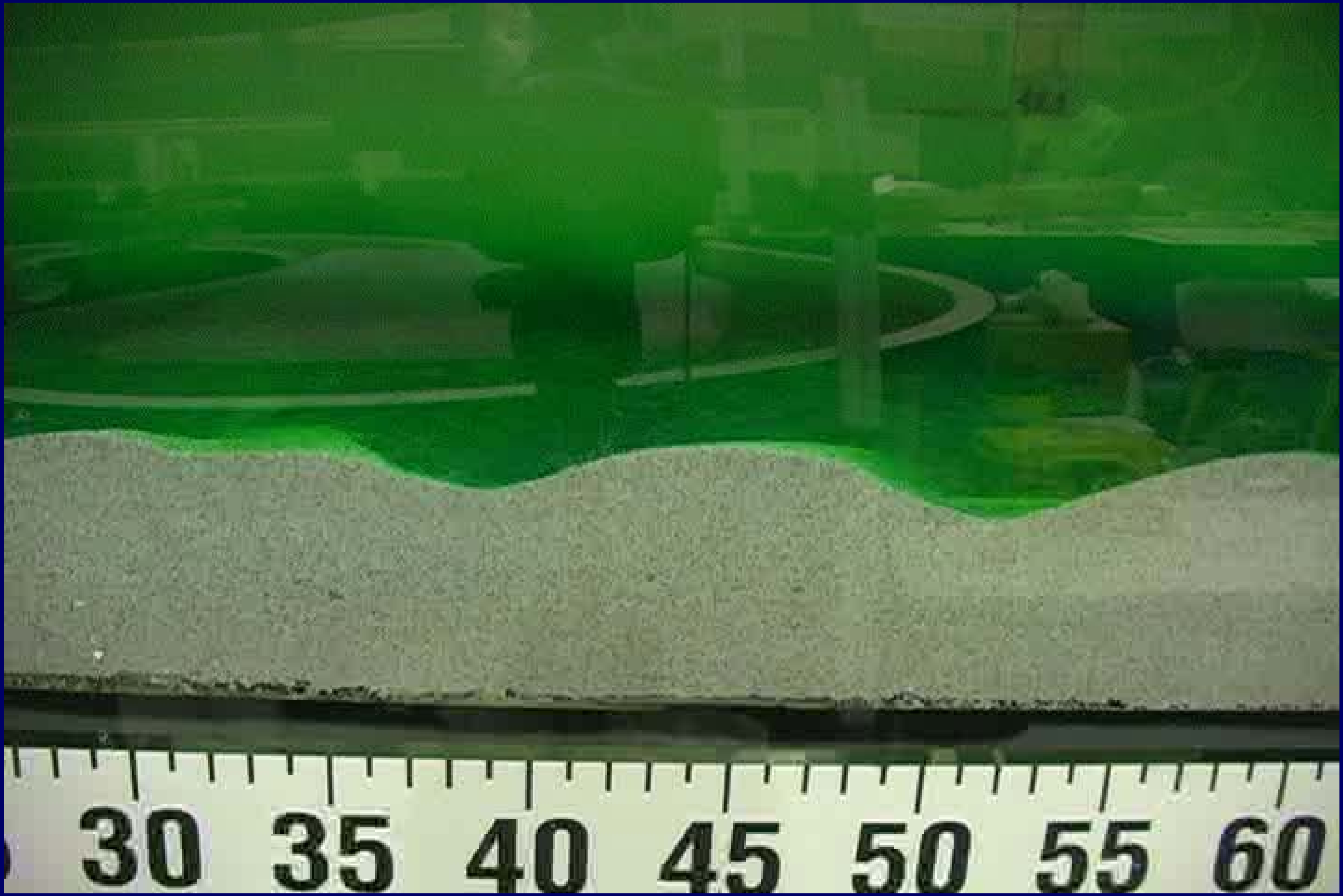
EXPERIMENTAL RESULTS

(click image to view movie)

EXPERIMENTAL RESULTS

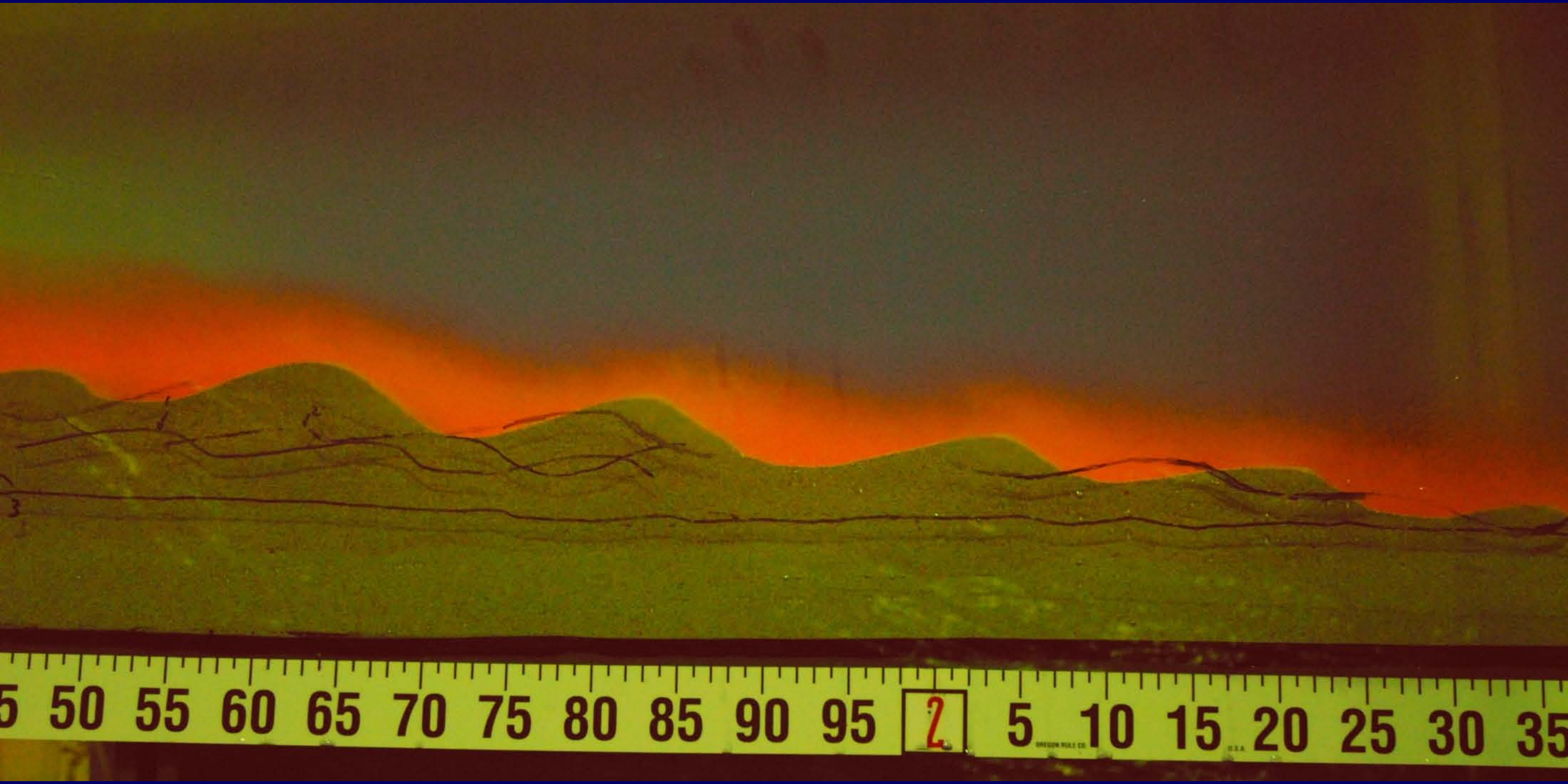
Downstream-migrating antidunes

(click image to view movie)



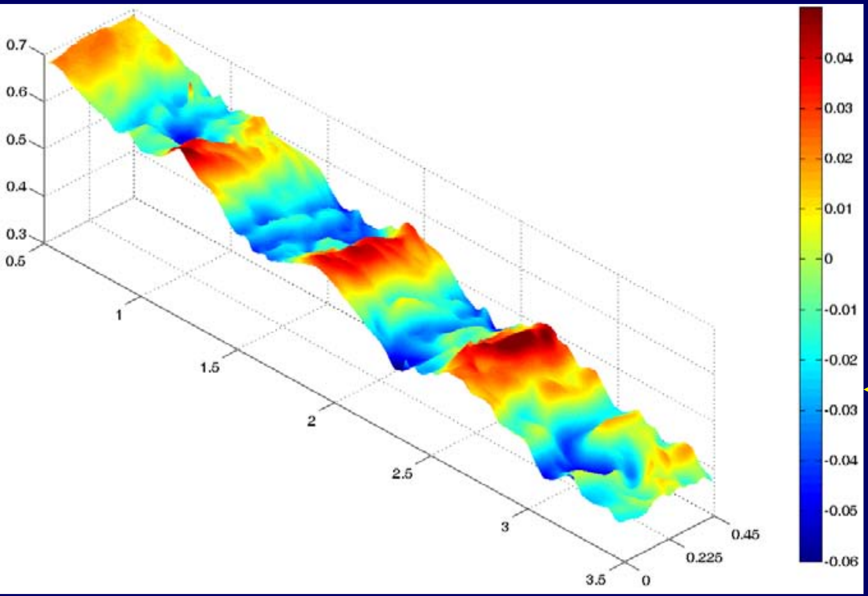
EXPERIMENTAL RESULTS

Downstream-migrating antidunes:
bed and interface are in phase



EXPERIMENTAL RESULTS

Cyclic steps/sediment waves (some suspension required)

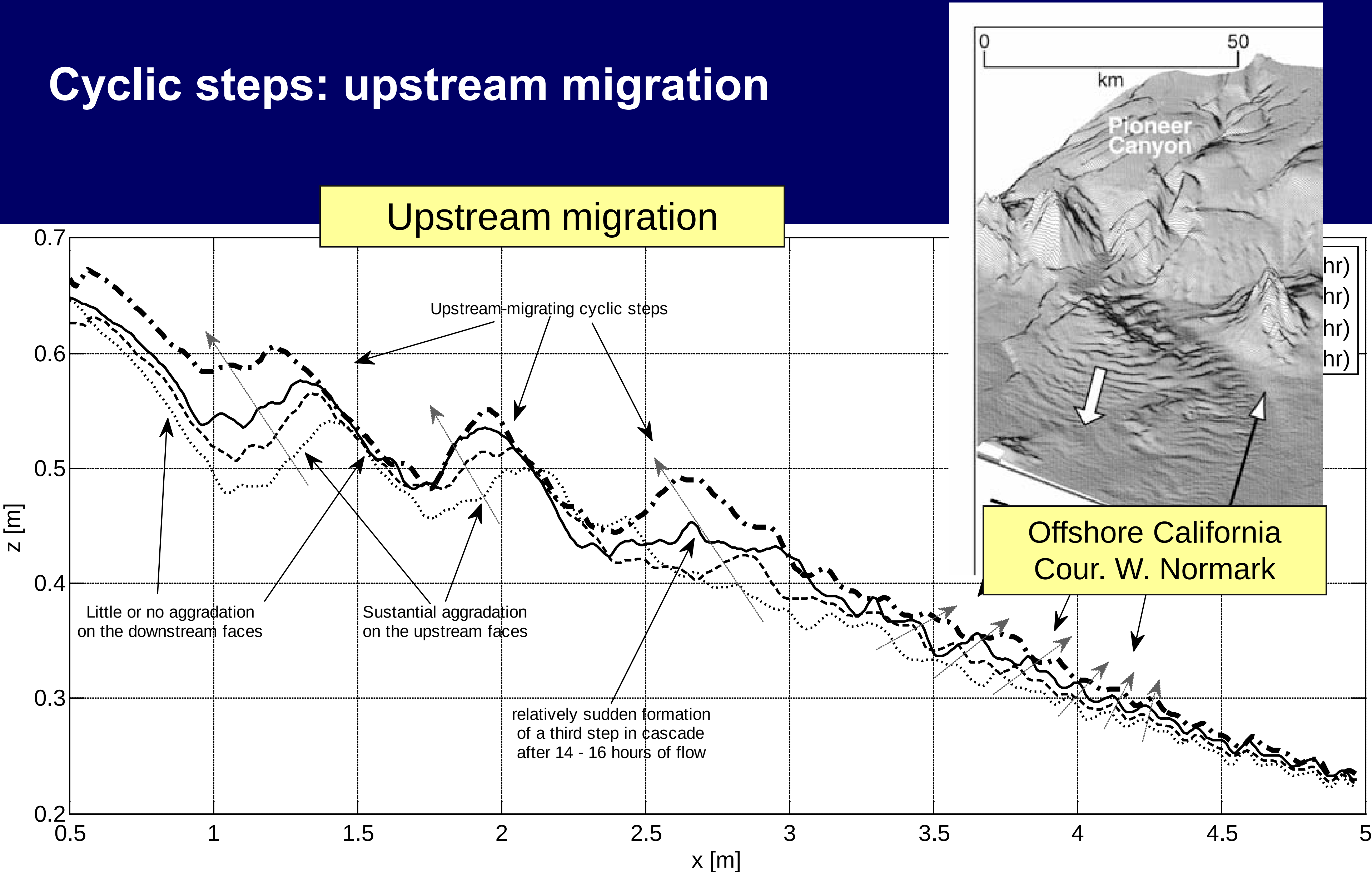


The above experiment can be considered to be a model of levee overflow.

on cover of August, 2009, JSR (Sequeiros et al.)

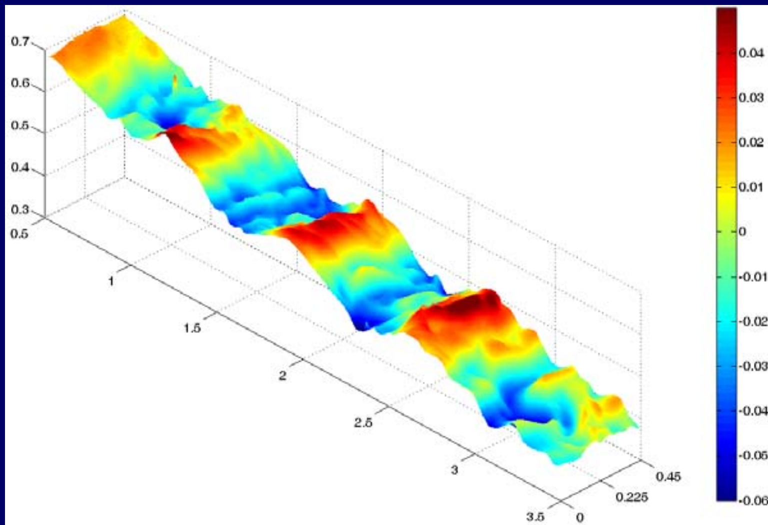
FIELD APPLICATION: SEDIMENT WAVES

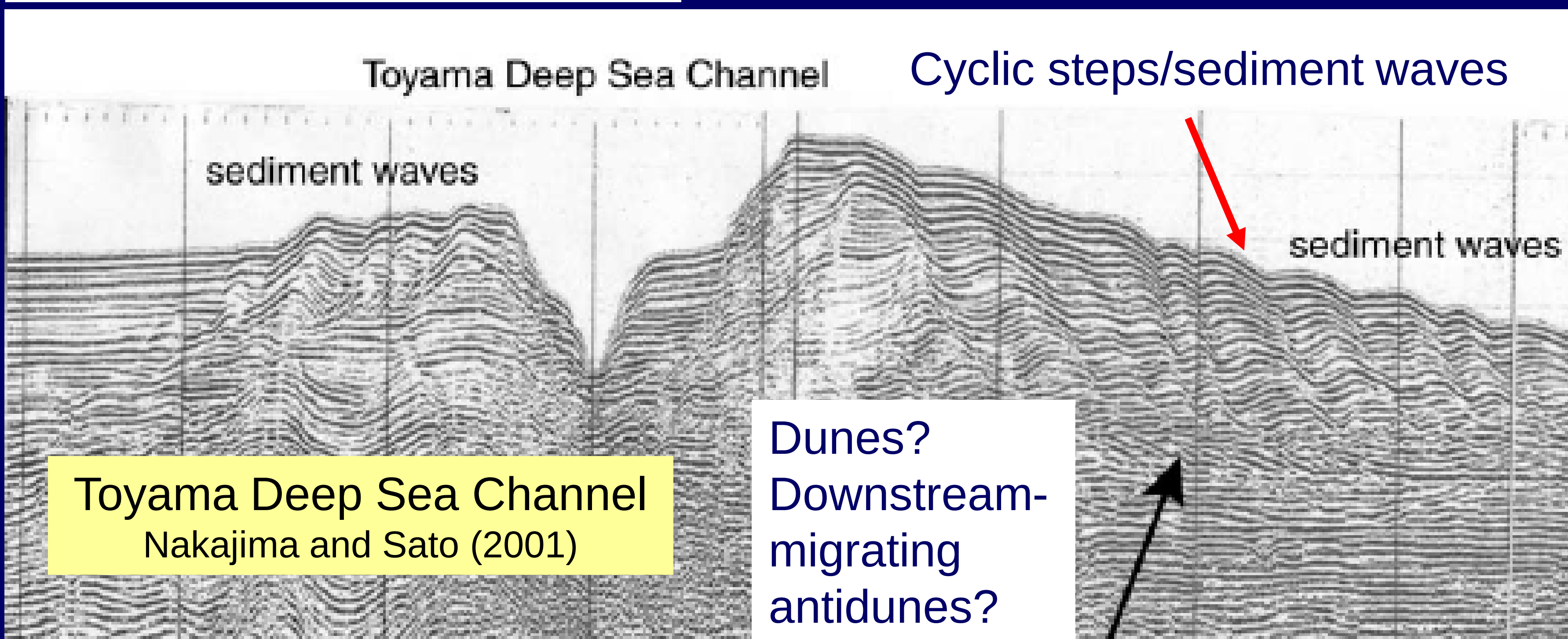
Cyclic steps: upstream migration



Offshore California
Cour. W. Normark

FIELD APPLICATION: SEDIMENT WAVES

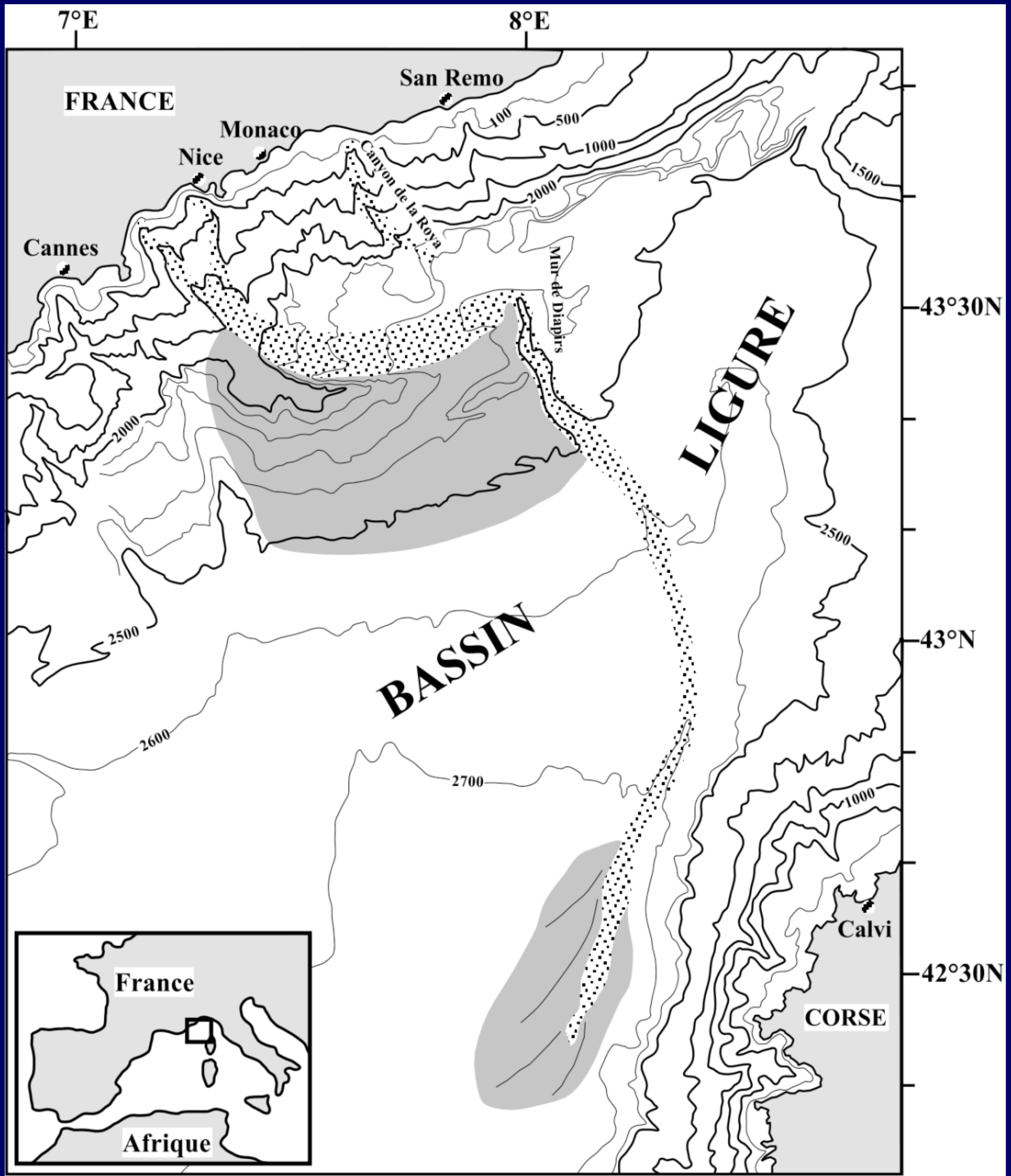




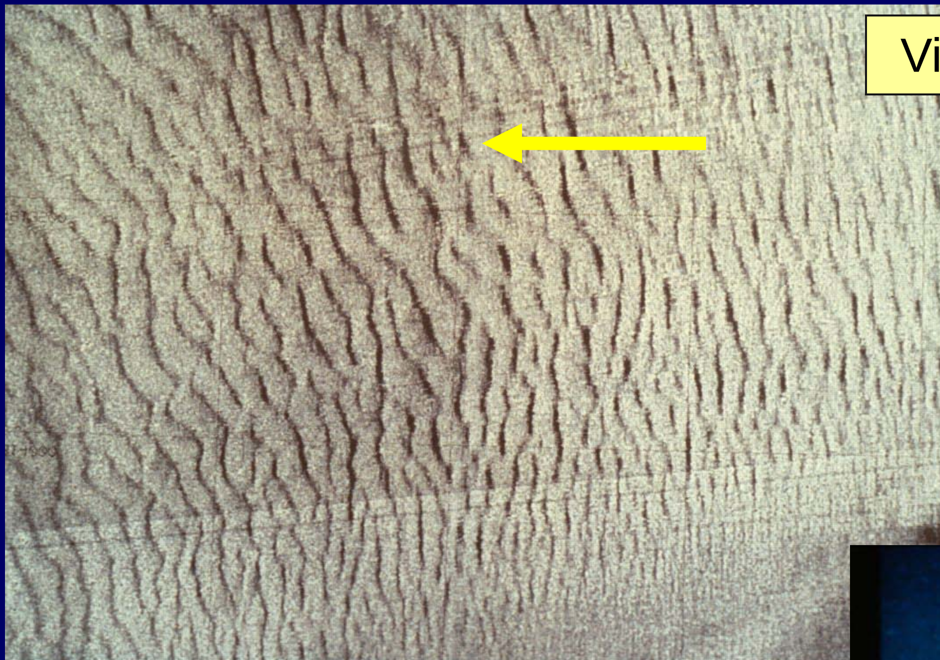
FIELD APPLICATION: GRAVEL MEGAWAVES

Var Submarine Canyon-Fan System off Nice, France

Cour. B. Savoye



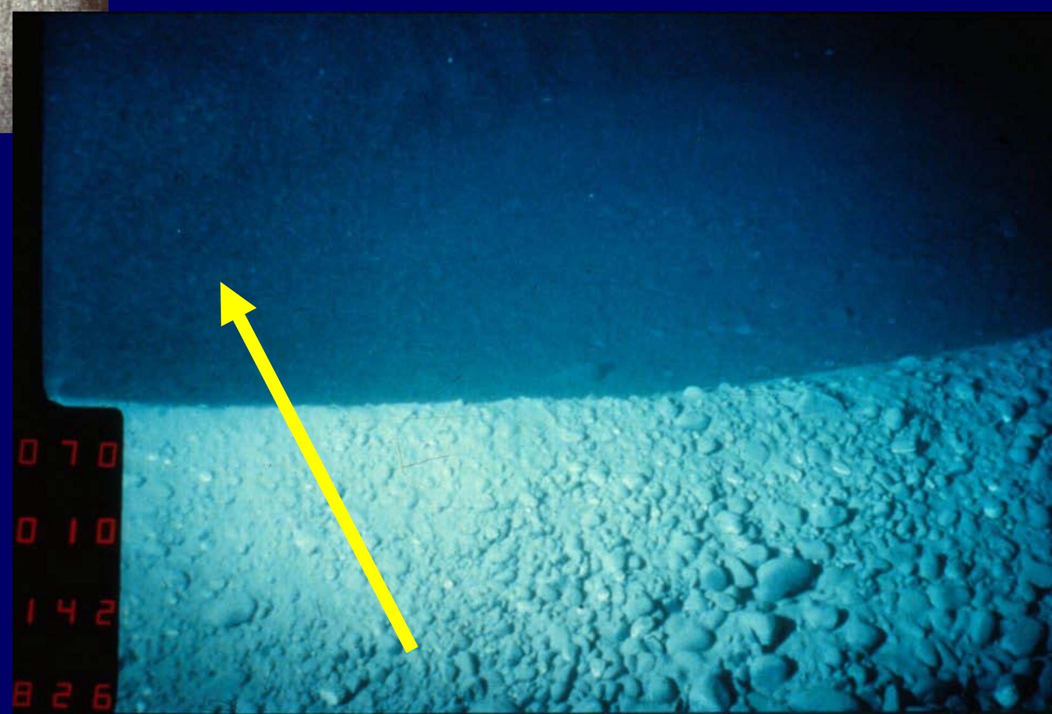
FIELD APPLICATION: GRAVEL MEGAWAVES



View looking down

Cour. B. Savoye

View over crest



Gravel megawave field in the Var Submarine Canyon near Nice, France

h = 2-3 m (max 10 m)
L = 30-40 m (max 120 m)
S = 0.03
D ~ 100 – 200 mm?

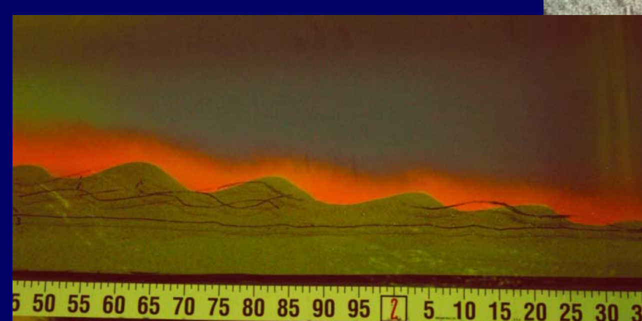
FIELD APPLICATION: GRAVEL MEGAWAVES

These are downstream-migrating antidunes.

	Horizontal scale: 1:			100	
	Vertical scale: 1:			100	
		Model		Prototype scaleup	
Bed slope	S	0.05		0.05	
Wave height	Δ	0.03	m	3	m
Wavelength	λ	0.3	m	30	m
densimetric Froude no	$\mathbf{Fr}_d$	1.8083		1.8083	

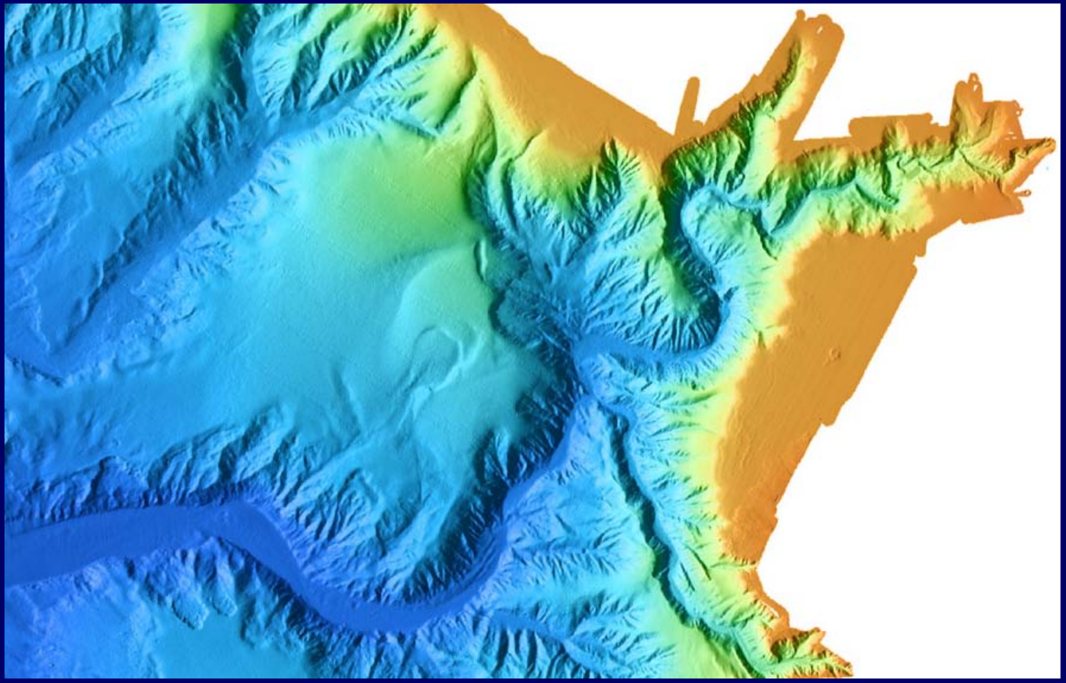
Gravel wave fields in the Var canyon

h = 2-3 m (max 10 m)
L = 30-40 m (max 120 m)
S = 0.03



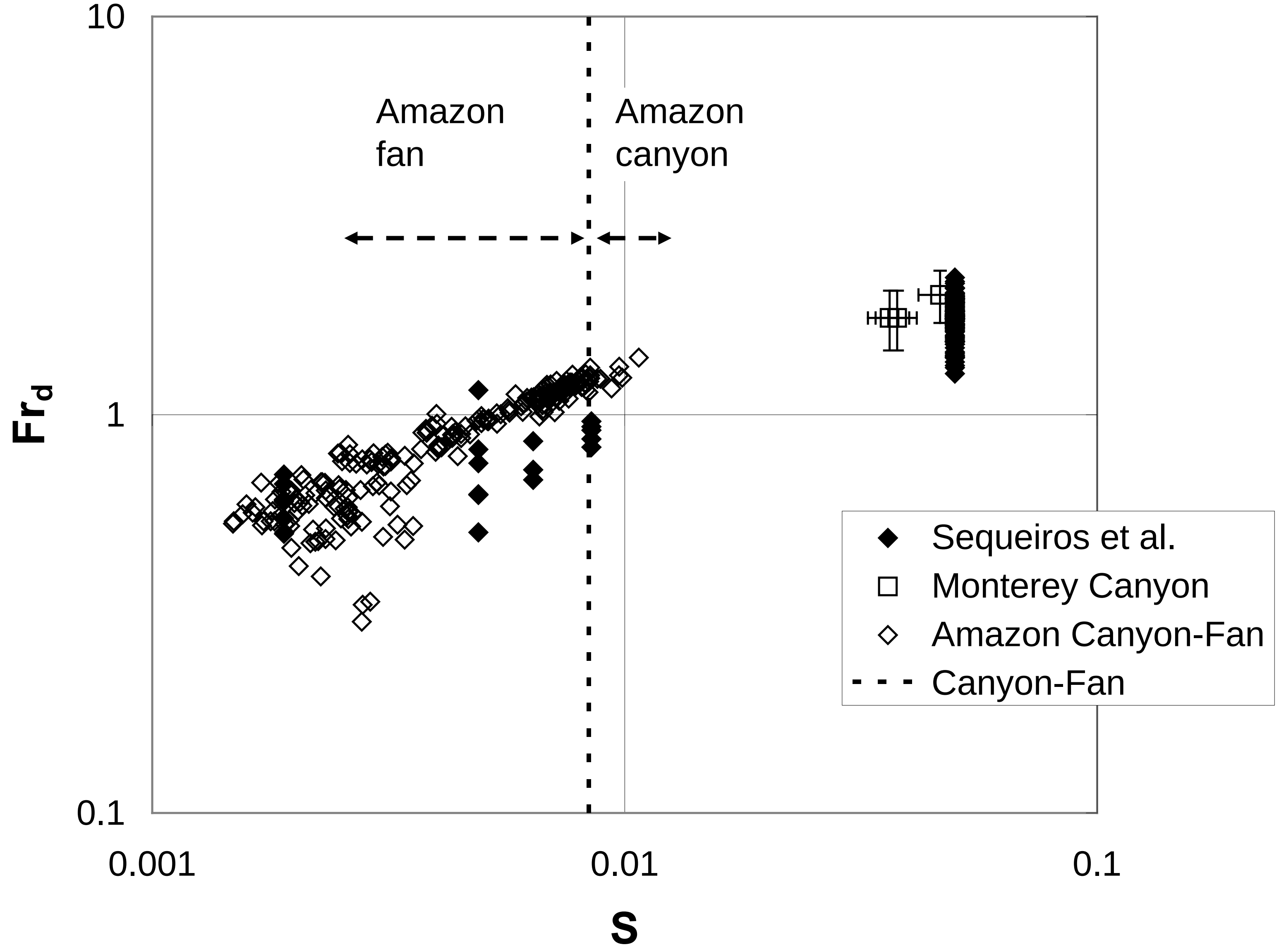
FIELD APPLICATION: AMAZON CHANNEL

Channel on the Amazon Submarine Fan
Pirmez and Imran (2003)



Monterey Submarine Canyon
Image cour. MBARI

FIELD APPLICATION: AMAZON CHANNEL



THANK YOU FOR LISTENING

San Julian, Venezuela: image cour. J. Lopez