

The Influence of Grain Size on the Nature of Oscillatory-Flow Bedforms: Experimental Results Using Very Fine and Coarse Sand*

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Search and Discovery Article #50227 (2009)

Posted November 30, 2009

*Adapted from oral presentation at AAPG Convention, Denver, Colorado, June 7-10, 2009

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Abstract

Workers have long believed, based on outcrop studies, that the bed configurations created by purely oscillatory flow are different in fine and coarse sand, but few experimental studies have been undertaken to determine the influence of grain size. Our experiments using very fine sand and coarse sand in a wave tunnel show that large, oceanic-scale waves (orbital diameters 1-4.5 m) produce very different bed configurations.

In very fine sand, a greater diversity of bedforms is possible. Small, generally straight-crested, size-invariant (anorbital) ripples (wavelengths ~ 10 cm, heights < 1 cm) occur exclusively in very fine sand at low oscillatory velocities. Large, 3D orbital ripples with wavelengths (λ) that scale with orbital diameter (d_o) according to the relationship $\lambda \sim 0.6 d_o$ appear as oscillatory velocities increase and coexist with anorbital ripples over a range of intermediate velocities. The large orbital ripples become more subdued and rounded as oscillatory velocity increases, with flank slopes of 5-15 degrees. Aggradation of these bedforms would generate structures resembling hummocky cross stratification.

Small anorbital ripples and round-crested large orbital ripples are absent from coarse sand. The only bedforms consist of large, straight-crested, orbital ripples that scale with orbital diameter according to the relationship $\lambda \sim 0.4 d_o$. These large coarse-grained ripples are distinctly steeper than their counterparts in very fine sand, with flank slopes of 15-22 degrees. If such ripples were formed

in the presence of even a weak unidirectional current, they would generate cross stratification that could be mistaken easily for the deposit of a current-generated dune, leading to the potential for significant misinterpretation of the environmental setting.

References

Cheel, R.J. and D.A. Leckie, 1992, Coarse-grained storm beds of the Upper Cretaceous Chungo Member (Wapiabi Formation), Southern Alberta, Canada: *Journal of Sedimentary Petrology*, v. 62, p. 933-945.

Cummings, D.I., S. Dumas, and R.W. Dalrymple, 2009, Fine-grained versus coarse-grained wave ripples generated experimentally under large-scale oscillatory flow: *Journal of Sedimentary Research*, v. 79, p. 83-93.

Leckie, D.A., 1988, Wave-formed, coarse-grained ripples and their relationship to hummocky cross stratification: *Journal of Sedimentary Petrology*, v. 28, p. 607-622.

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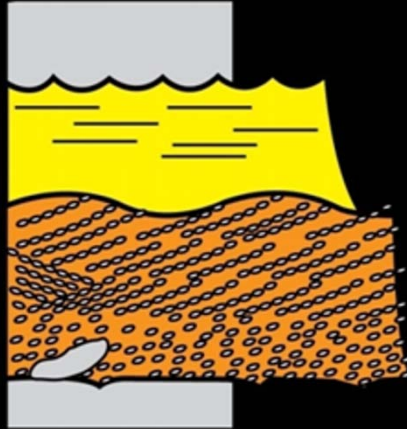
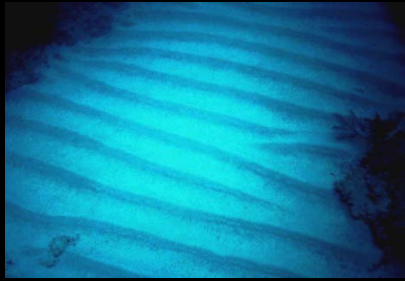
Can you get HCS
in coarse sand?

Hummocky cross- stratification (HCS)

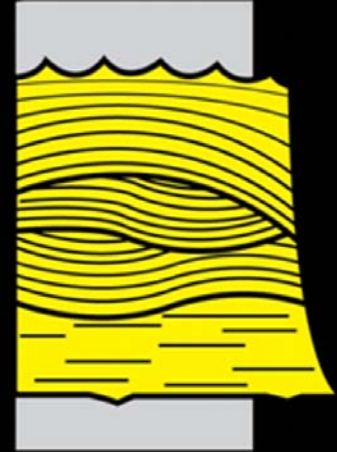
Book Cliffs (photo by J. Southard)

Hypothesis

(Leckie, 1988; Cheel & Leckie, 1992)



Coarse sand and gravel

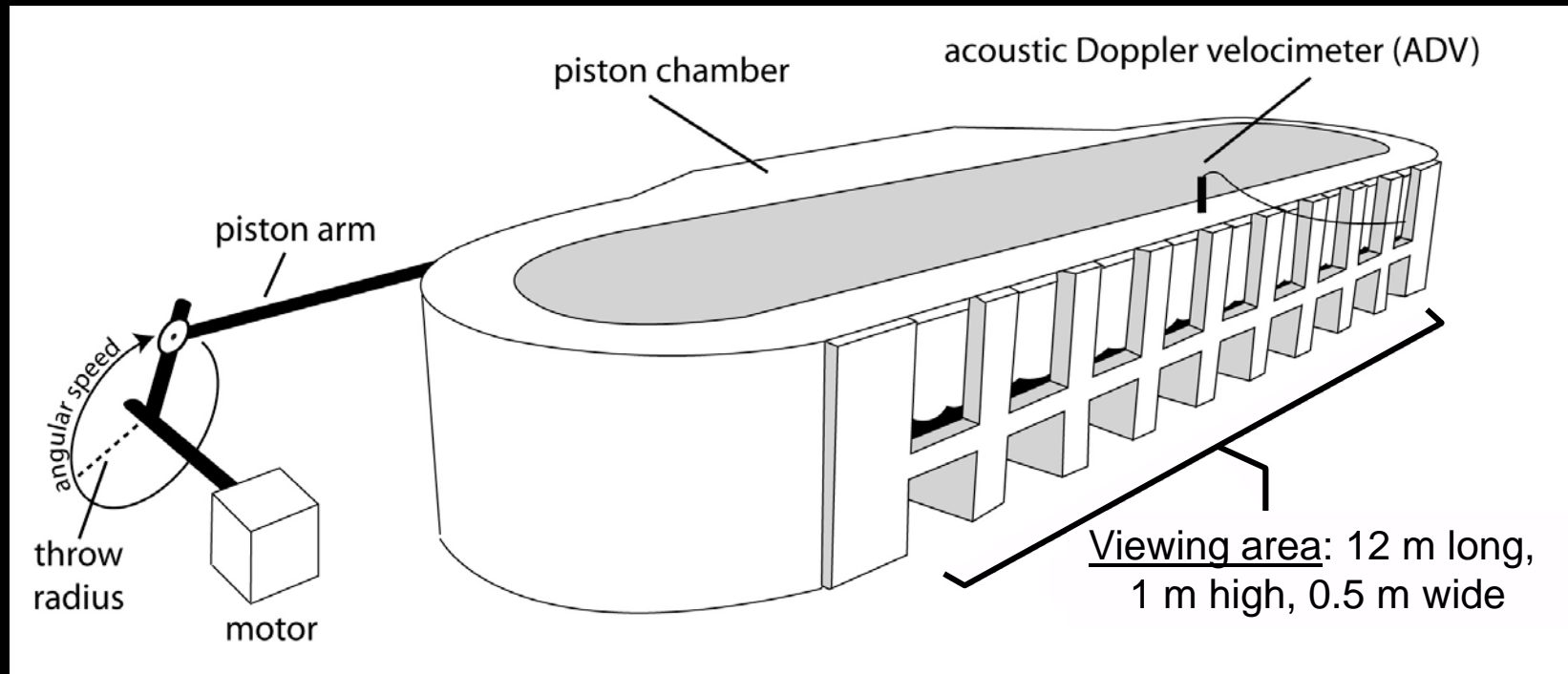


Fine and very fine sand

Based on a review of data from modern & ancient environments, Leckie (1988) suggested that wave-ripple morphology and stratification differ substantially in coarse grained and finer grained sediment.

This study was conducted to test this hypothesis explicitly in a controlled laboratory setting.

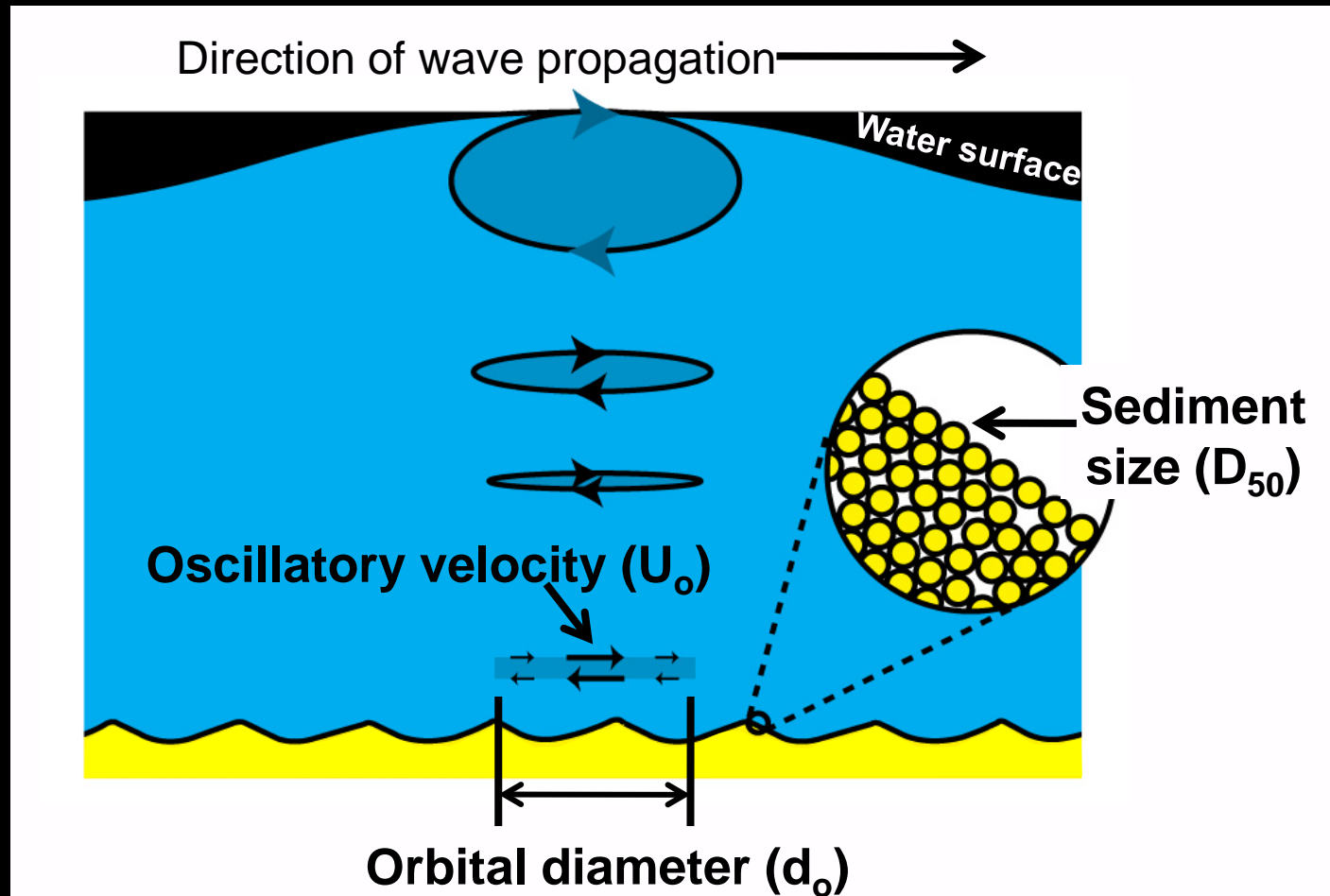
The study of storm-generated wave ripples is logistically difficult. In modern settings, equipment tends to break or be displaced during storms. Flumes cannot be used because they must be prohibitively long to generate the requisite long wave periods (> 6 s). One successful solution has been the use of **wave tunnels**, which can simulate near-bed oscillatory water motion during storms.



Racetrack- shaped wave tunnel

Coastal Engineering Laboratory, Queen's University

Three main variables control the geometry of wave ripples

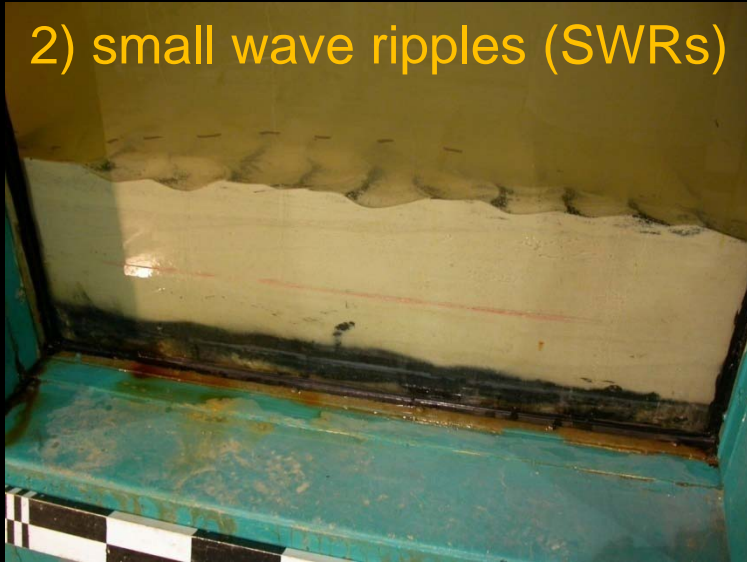


Experimental conditions: D_{50} — 0.12 mm and 0.8 mm
— $95 \text{ cm} < d_o < 450 \text{ cm}$
— $20 \text{ cm/s} < U_o < 140 \text{ cm/s}$
— $4.5 < T < 12 \text{ s}$

Five bed configurations were observed

1) no motion

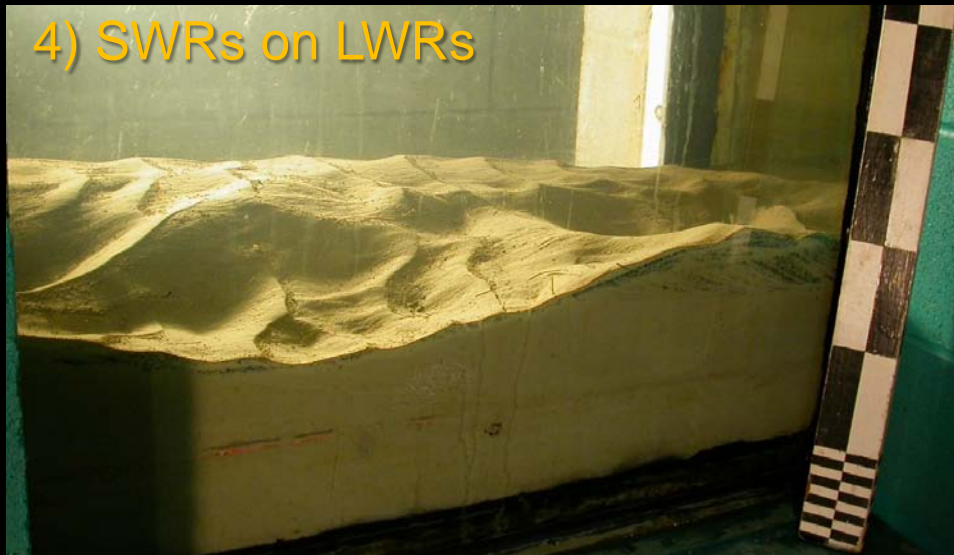
2) small wave ripples (SWRs)



3) large wave ripples (LWRs)

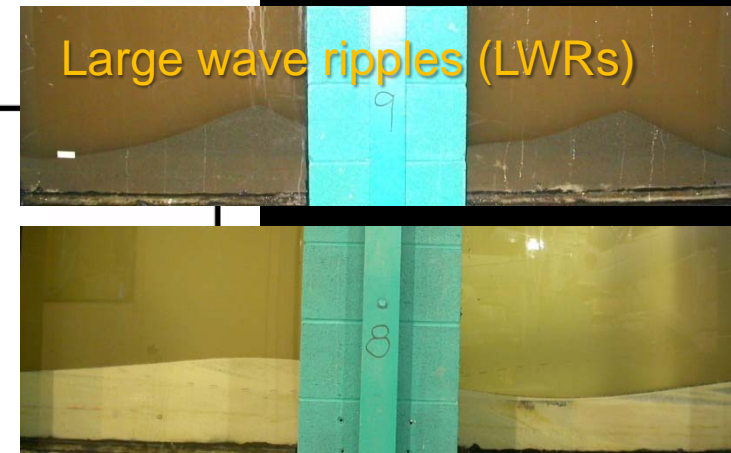
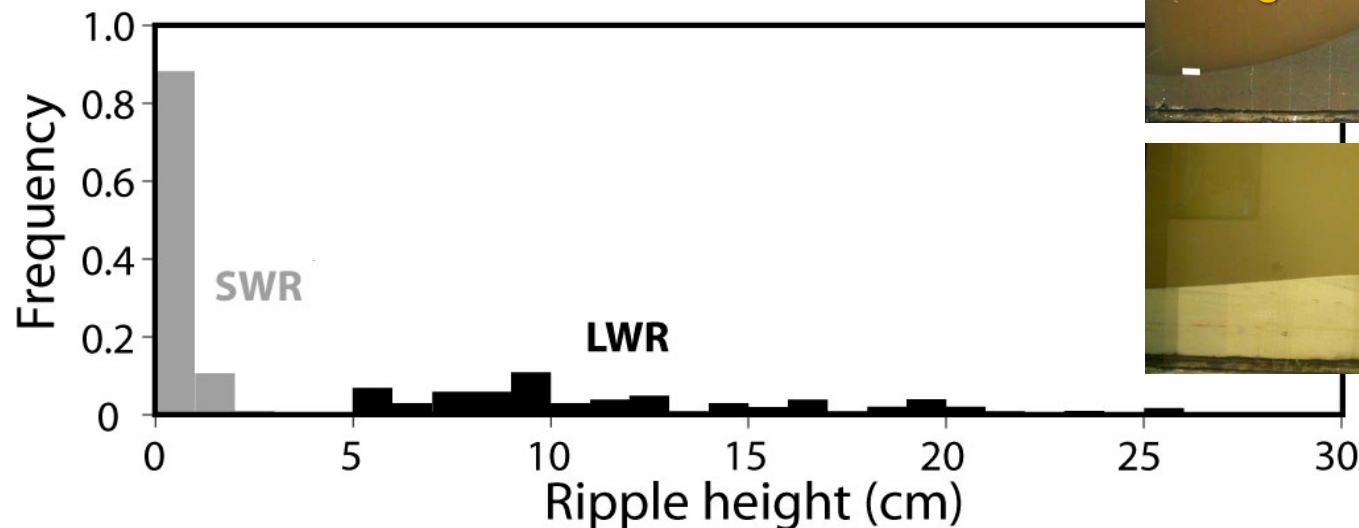
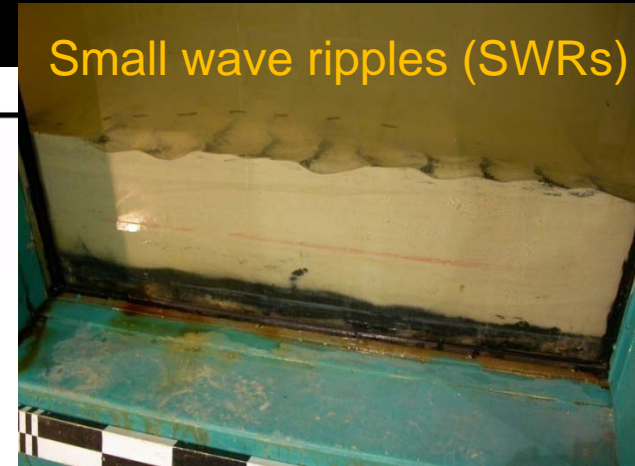
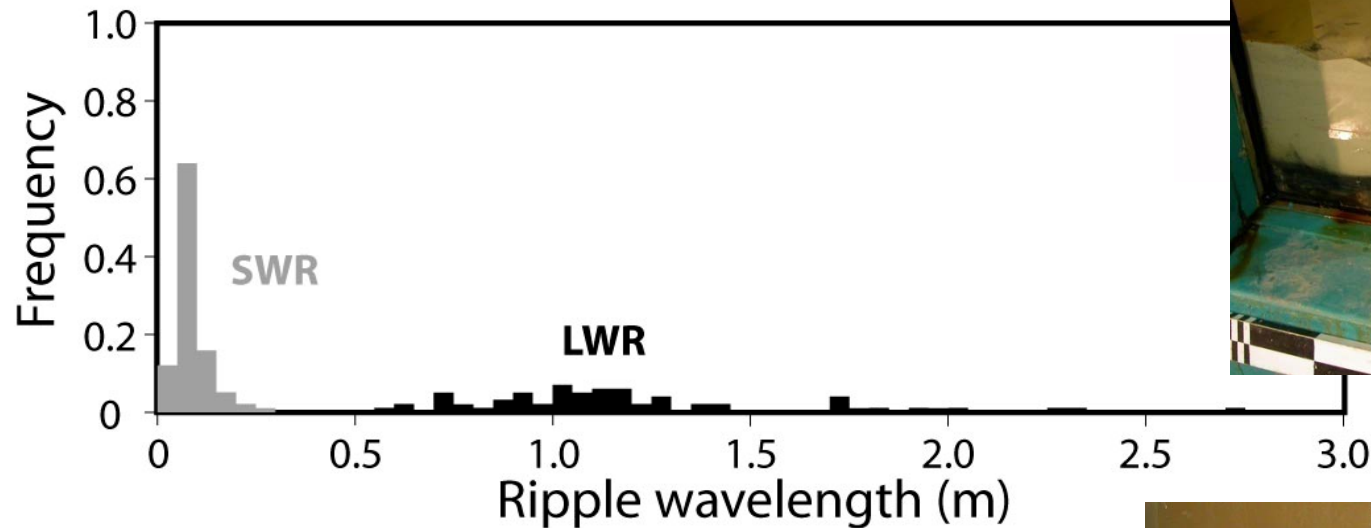


4) SWRs on LWRs

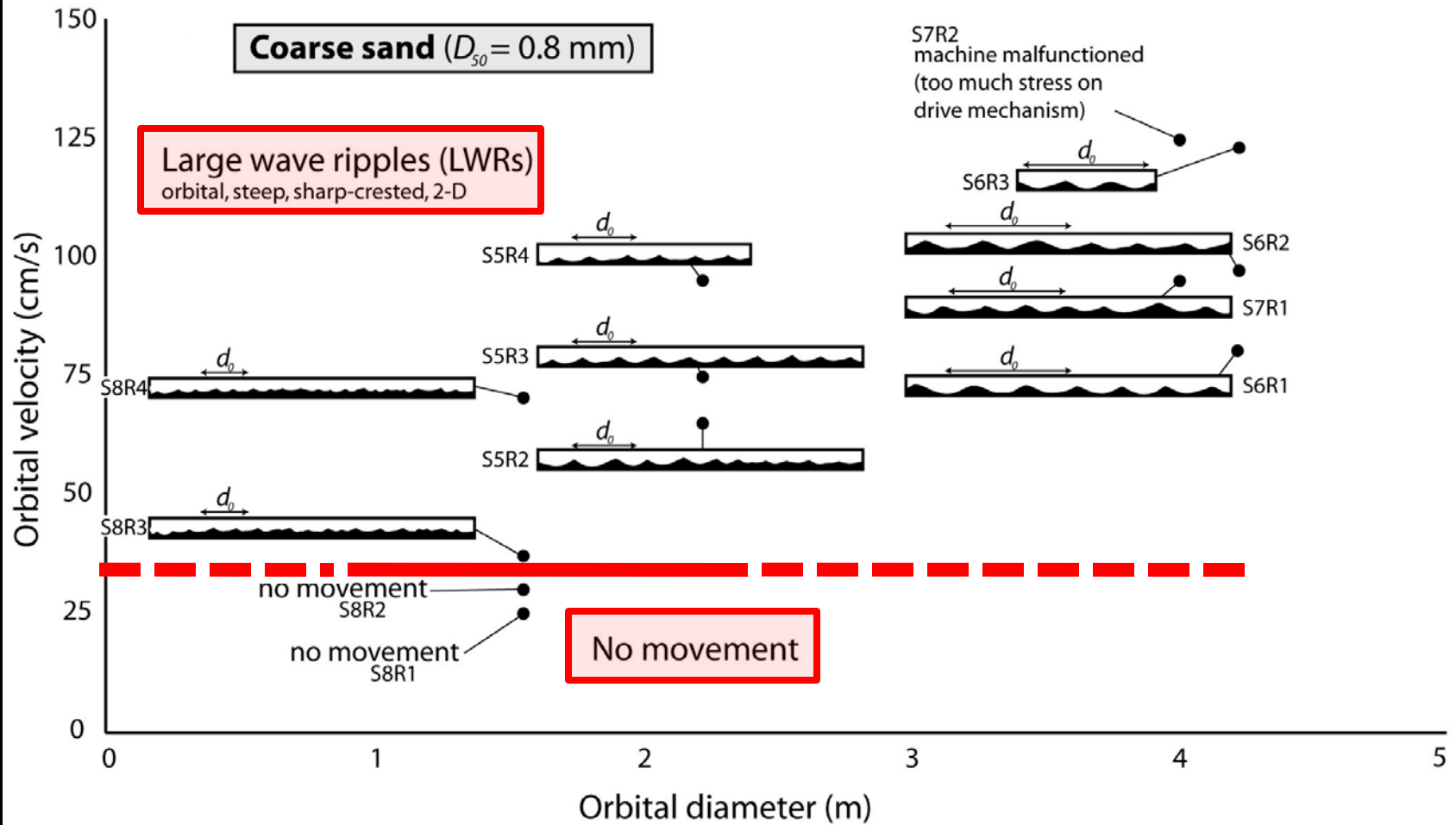


5) upper plane bed

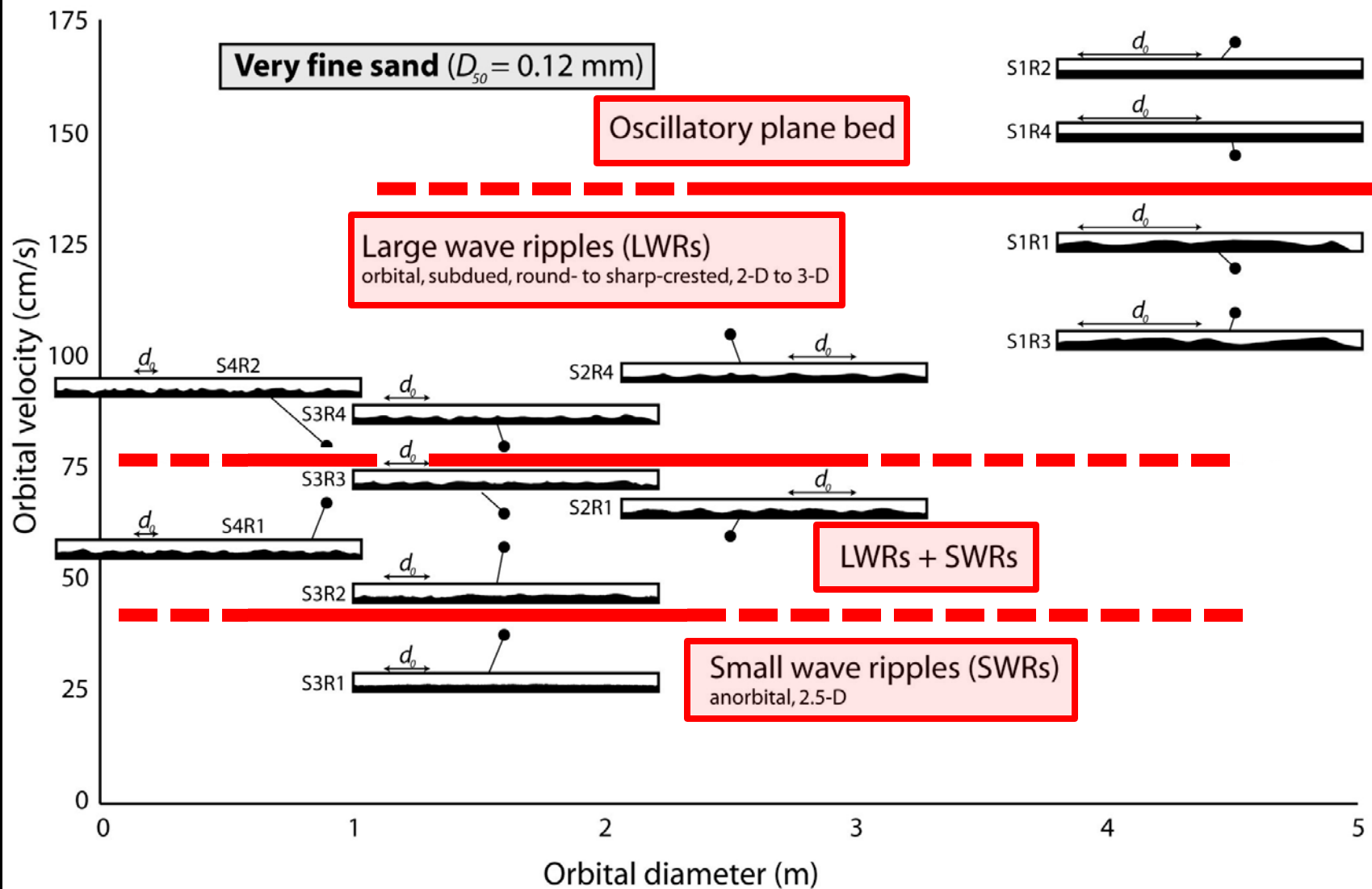
Small wave ripples and large wave ripples are morphologically distinct.
They also have different grain-size occurrences.

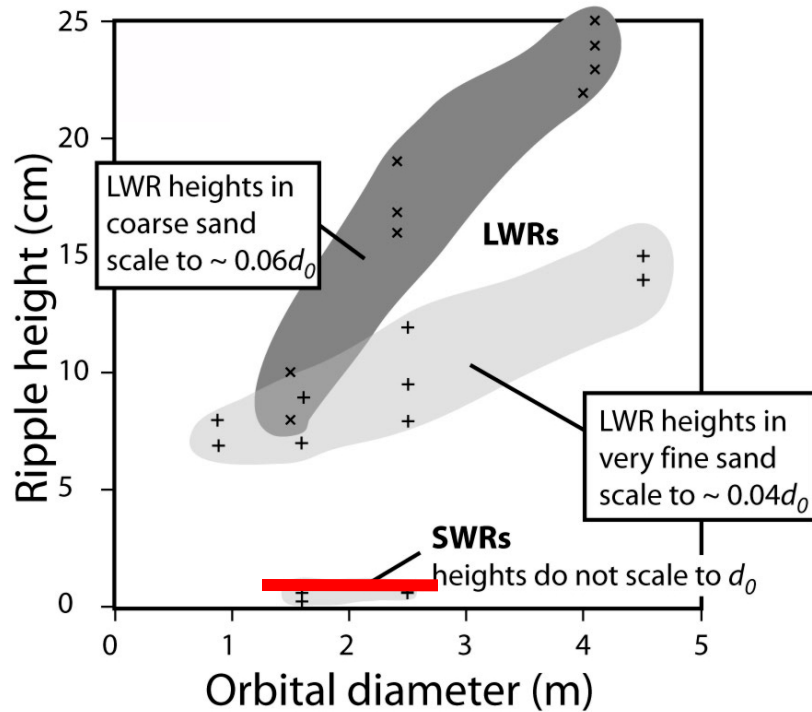


Bedform phase diagram for coarse sand

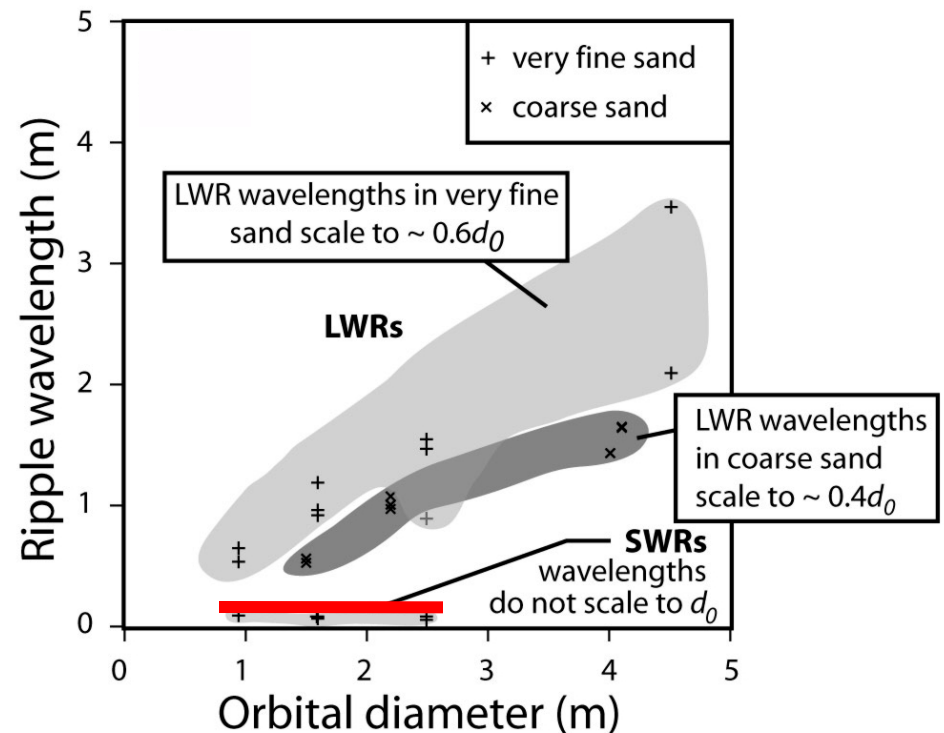


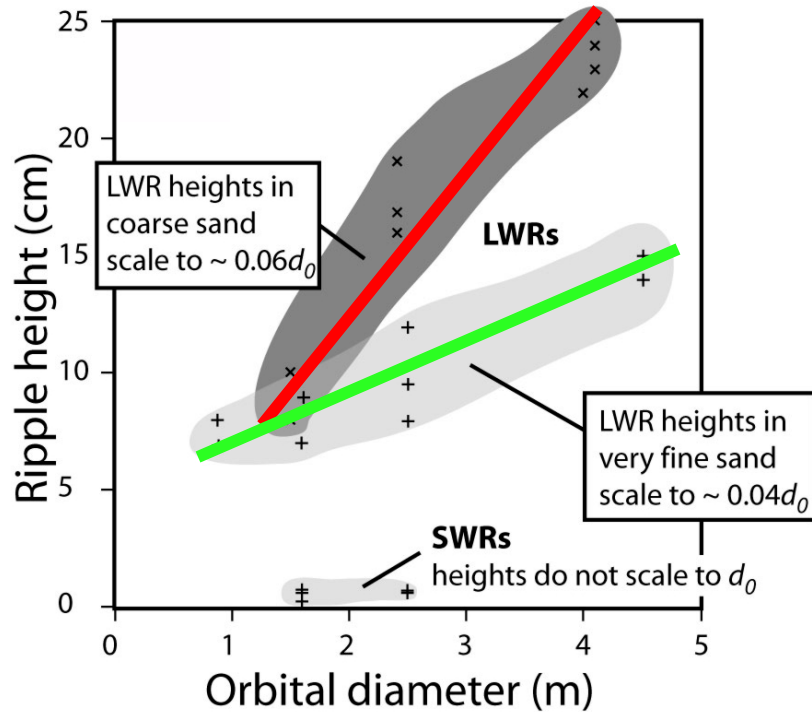
Bedform phase diagram for very fine sand



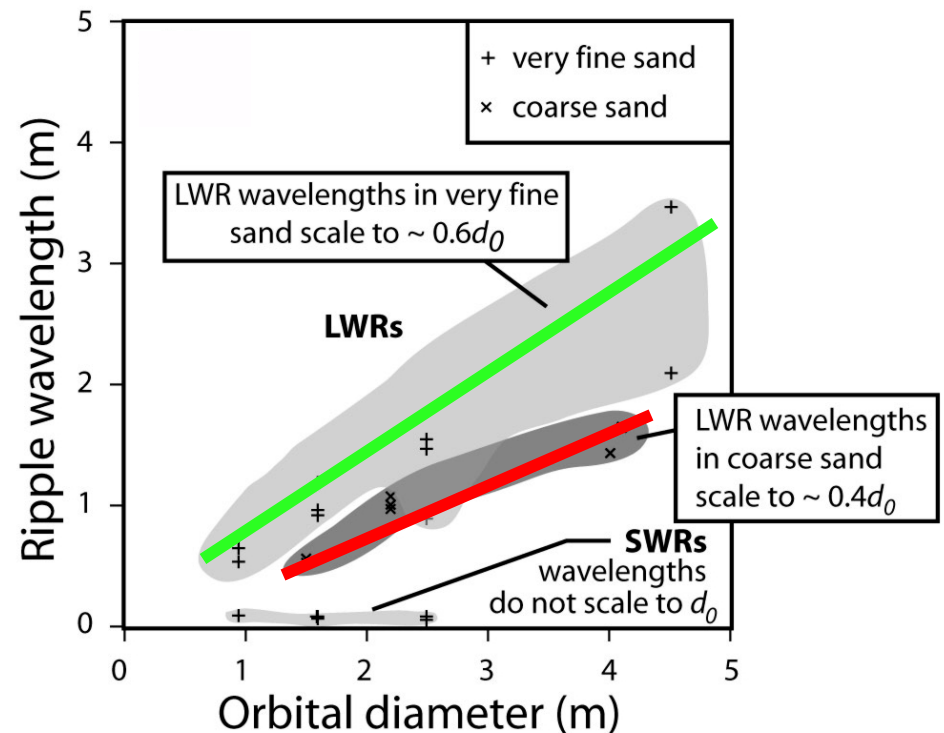


Small wave ripples do not scale with wave size. They are "anorbital ripples".



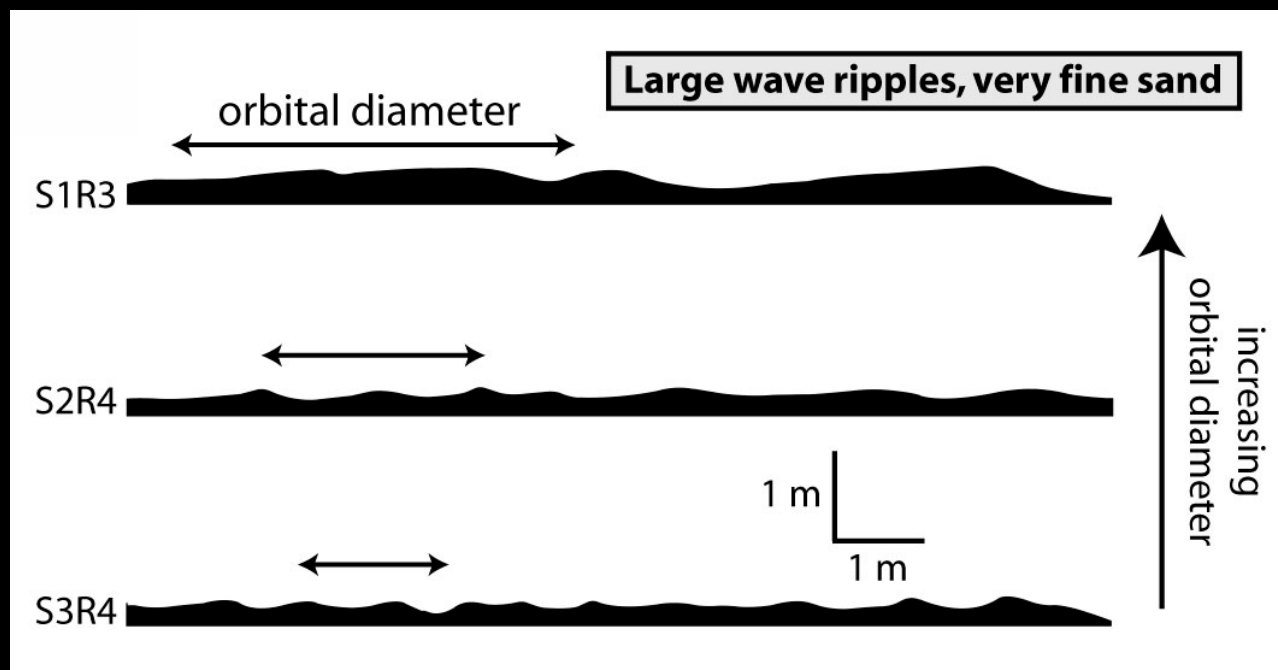
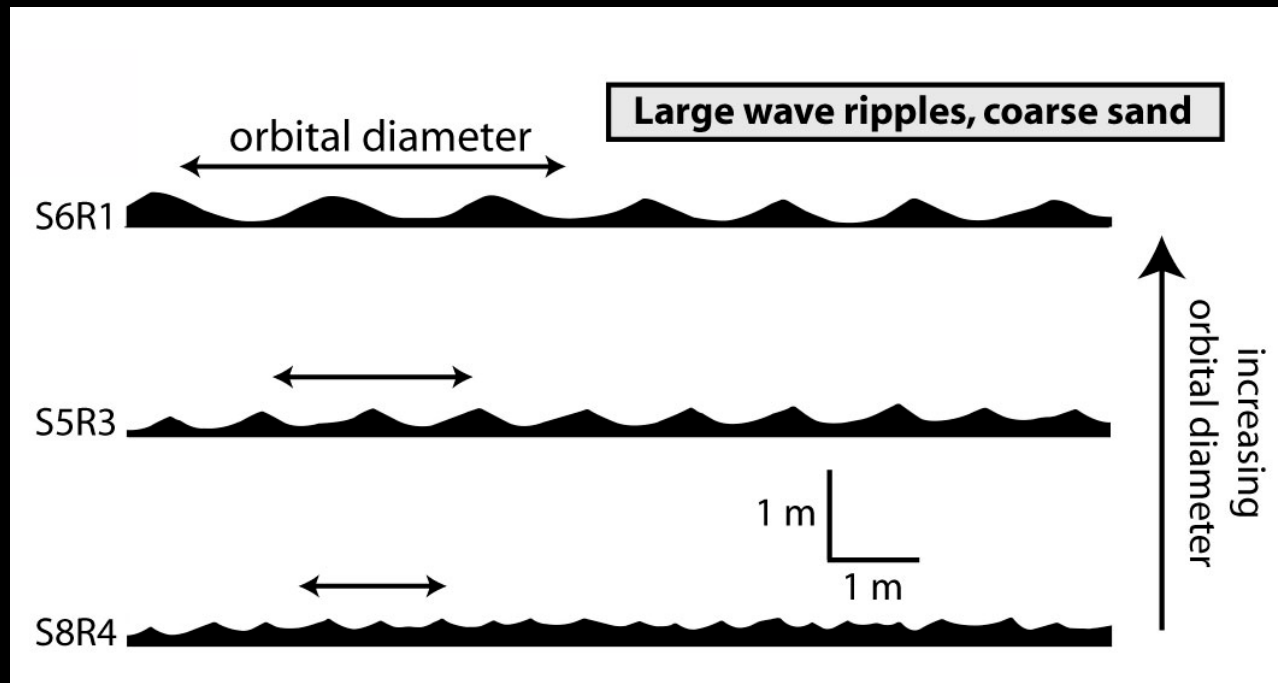


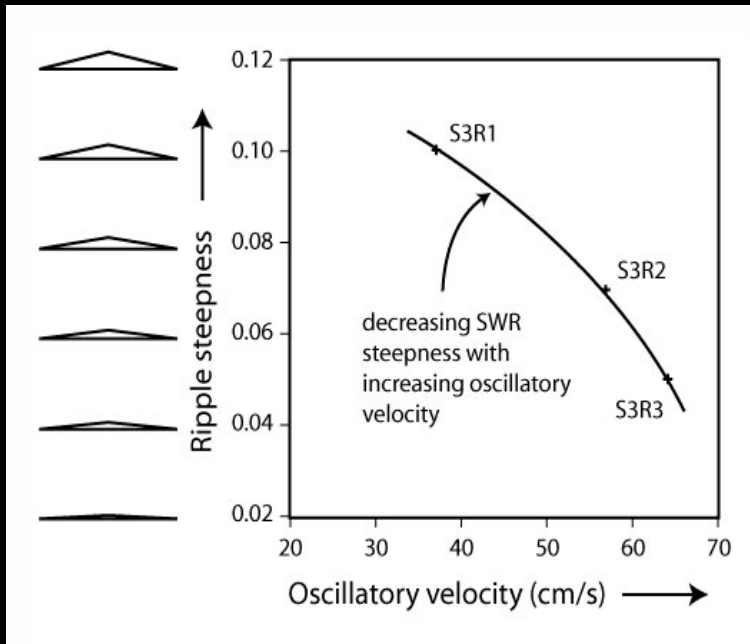
Large wave ripples scale with orbital diameter. They are “orbital ripples”. For the same orbital diameter, wave ripples in fine sand are flatter but longer wavelength than those in coarse sand.



— coarse sand
— very fine sand

The scaling with orbital diameter can be seen in these bed traces from 6 different flume runs.

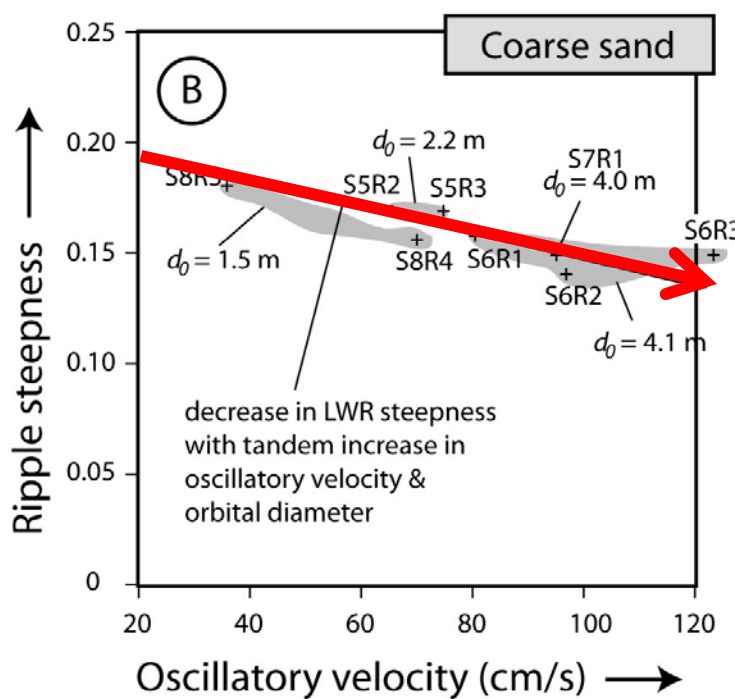




Small wave ripples become flatter and more subdued as the oscillatory velocity increases.

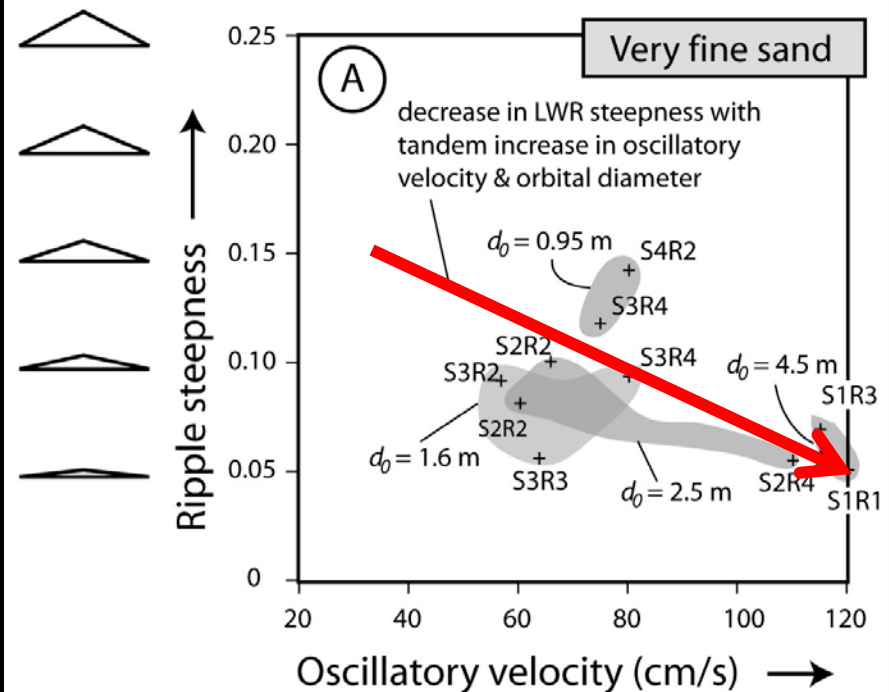
[Steepness = height/wavelength]

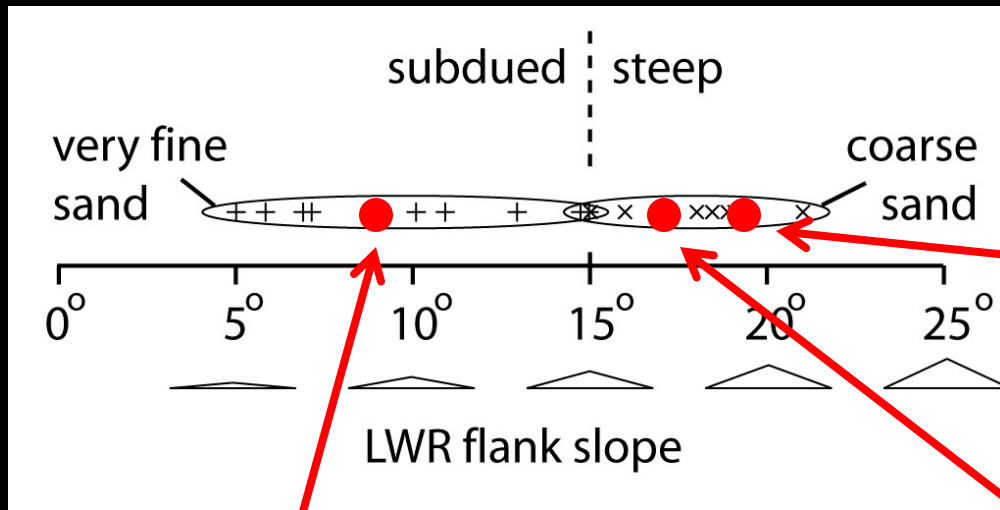




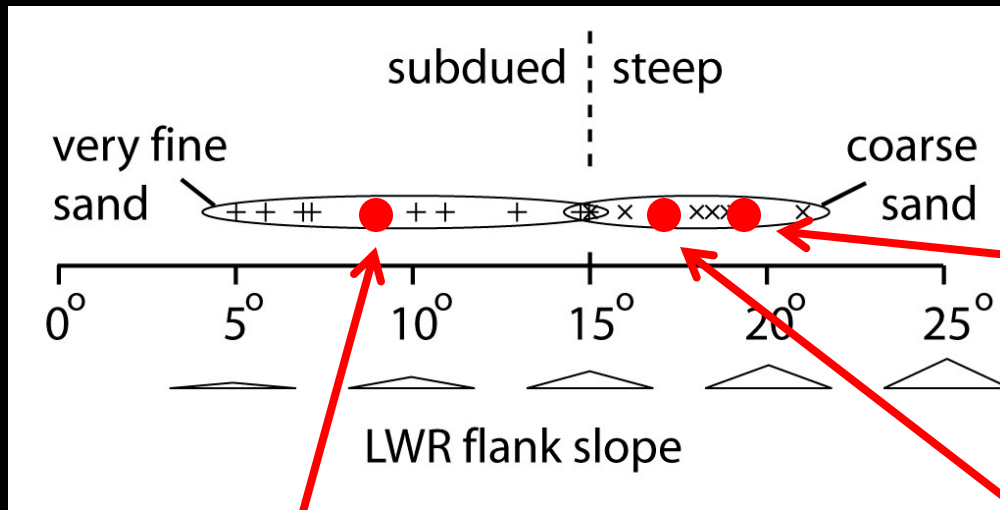
Large wave ripples also become flatter and more subdued as the oscillatory velocity increases. This trend is more pronounced in very fine sand.

[Steepness = height/wavelength]



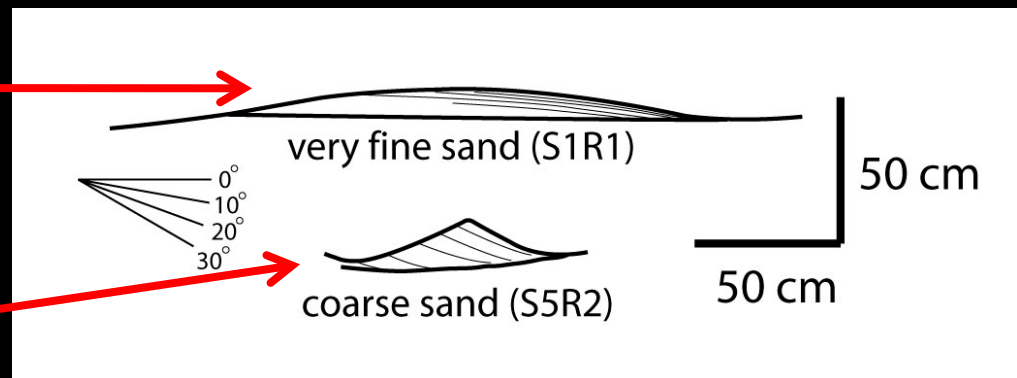


There is a continuum of steepness for large wave ripples, from flank slopes $> 20^\circ$ to $< 5^\circ$. Large ripples in coarse sand were all 2D, whereas large ripples in very fine sand were commonly 3D.



HCS

"Cross bedding"



CONCLUSIONS

1. Grain size has a strong influence on the nature of wave ripples:
 - small, anorbital ripples only occurred in very fine sand
 - large, orbital ripples occurred in both sand sizes
 - large wave ripples are sharp crested and steep in coarse sand
 - large wave ripples are commonly hummocky in very fine sand
2. Orbital diameter determines the size of large wave ripples:
 - large ripples in very fine sand increase in wavelength more rapidly than large ripples in coarse sand
 - there is continuum between micro-hummocky and normal hummocky ripples
3. Oscillatory velocity influences the steepness of the both small and large wave ripples:
 - wave ripples become more subdued and flatter as the oscillatory velocity increases, especially in very fine sand

FUTURE RESEARCH

- For large ripples, there appears to be a continuum of shape between steep, sharp-crested large ripples in coarse sand and flatter, rounded large ripples in very fine sand.

What is the real lower limit of hummocky cross stratification?

- The phase diagram for wave-generated bedforms remains very poorly constrained for long-period waves with large orbital diameters.

For more information, see:

Cummings, D.I., Dumas, S., and Dalrymple, R.W., 2009, Fine-grained versus coarse-grained wave ripples generated experimentally under large-scale oscillatory flow. *Journal of Sedimentary Research*, v. 79, p. 83-93.