# Distinction between HCS and Antidune Stratification: A Key to Detect Process vs. Product Changes*

**Shuji Yoshida[1], Makoto Ito[1], Yoshinori Nemoto[1], and Ryota Sakai[1]**

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## Abstract

Antidunes can easily be mistaken for hummocky cross-stratification (HCS) or sigmoidal cross-bedding, and are probably fairly common in various siliciclastic environments. Antidunes are difficult to identify because (1) their preservation potential is considered very low, and (2) their study is based on flume experiments and few outcrop studies of siliciclastic deposits (including so-called “HCS mimics”) and pyroclastites.

We have documented outcrops of Holocene antidune-bearing pyroclastites in Ni-jima, Japan and compared the facies achitecture with antidunes and HCS of siliciclastic outcrops in the US and elsewhere. In the pyroclastic outcrops, antidunes occur in a wide range of scales (from 2 cm to 6 m high), forming compound antidunes. In 3-D, these antidunes in all scales have geometry of laterally coalesced domes trending in the strike direction. In 2-D, they have a convex-up geometry with internal upstream and downstream accretion surfaces, remarkably resembling the vertical cross-section of HCS.

# Distinction between HCS & Antidune Stratification: A Key to Detect Process vs. Product Changes

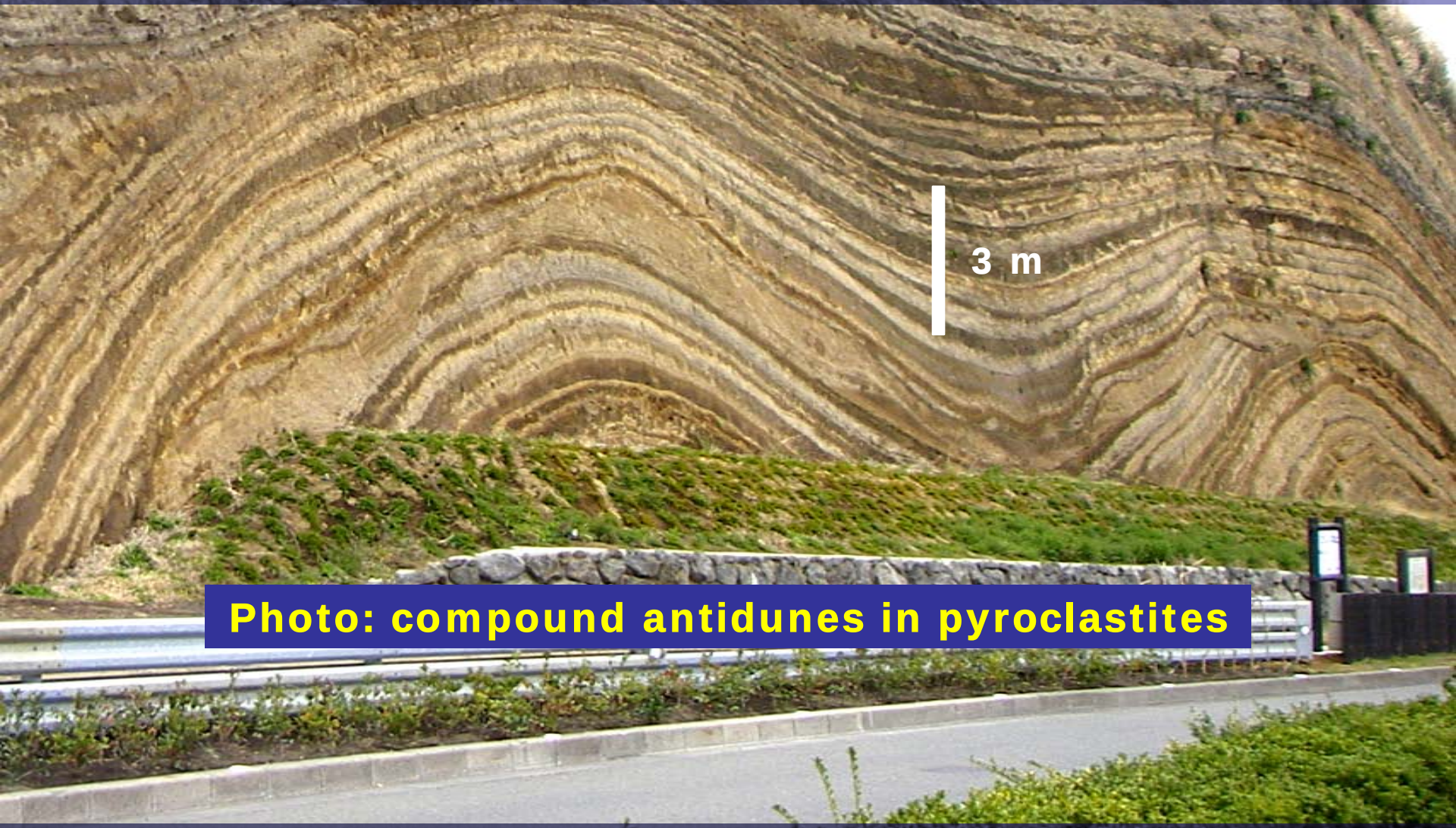


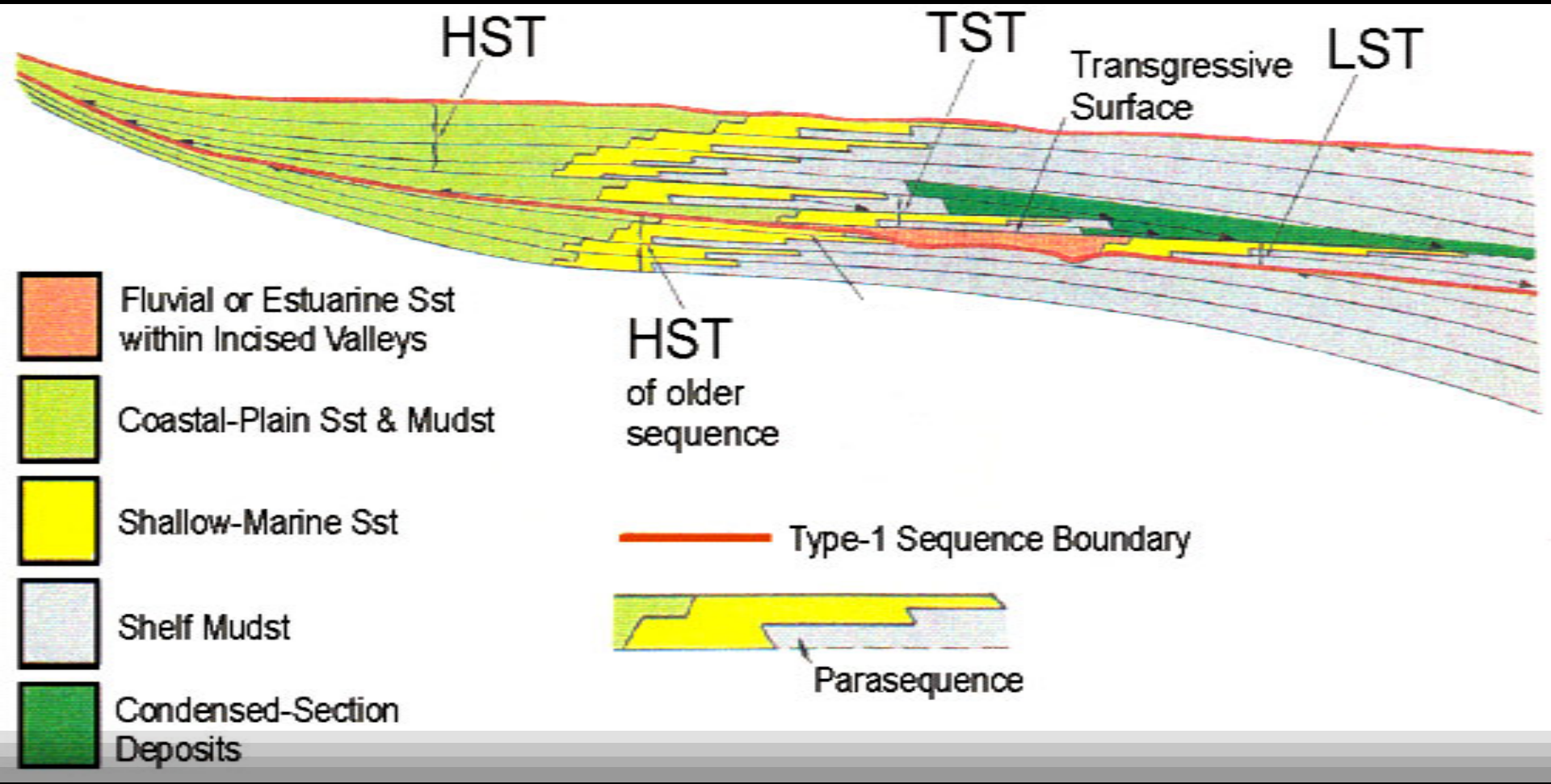

**Photo: compound antidunes in pyroclastites**

Shuji YOSHIDA, Makoto ITO, Yoshinori NEMOTO, Ryota SAKAI
*Chiba University,* Japan

# Outline of Talk

1. **Introduction**
   - Cause of Facies Change within a Sequence-Stratigraphic Framework
   - Distinction between HCS and Antidune Stratification
2. **Antidunes in Pyroclastitites in Ni-jima, Japan**
3. **Discussion : Origin of HCS vs. Antidune Stratification**
4. **Conclusions**

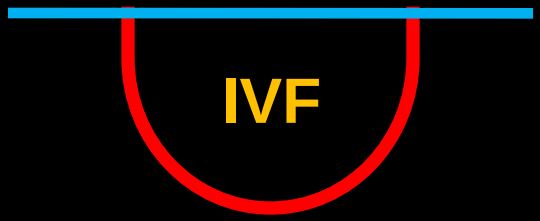
# Early Sequence-Stratigraphic Models

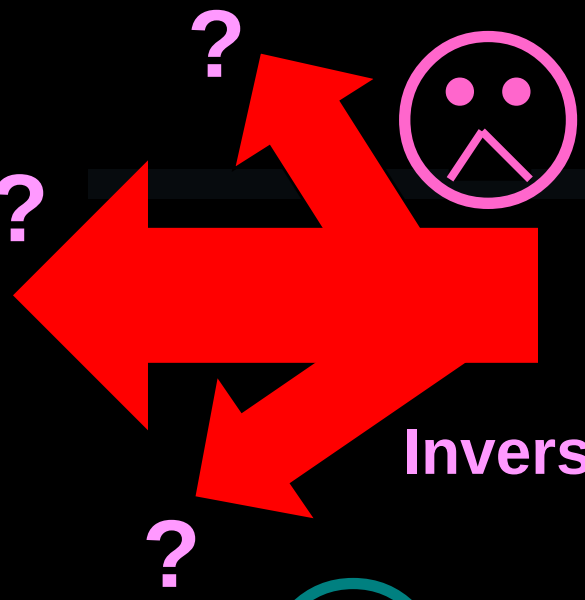

Van Wagoner et al. (1990)

# Inversion Problem: Facies/Sequence Analysis

**Premise / Model**

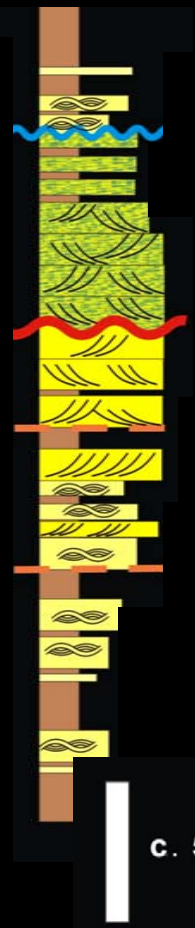



**Traditional view:**
**Incised-Valley FIll**





**Observation**

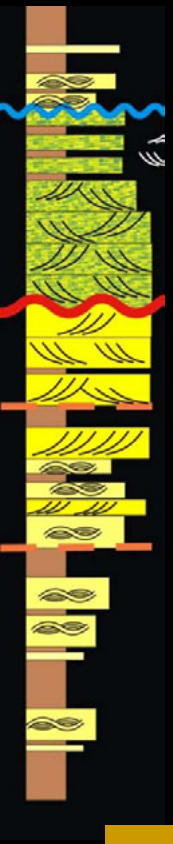



Processes: wave-domination
Product: HCS
Tide significant for IVF

S. Yoshida, R. Steel, & R. Dalrymple, 2007, Changes in Depositional Processes - An Ingredient in a New Generation of Sequence-Stratigraphic Models: *Journal of Sedimentary Research*, v. 77, p. 447-460.

# Origin of Facies Change within a RSL cycle –

## attributable to some *Combinations* of the following 3 factors:



Spatial Change in Locally-Dominant Process

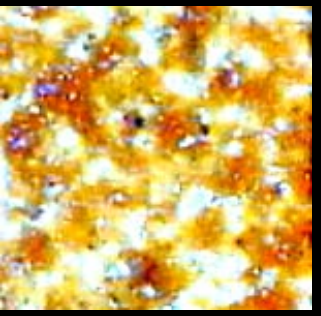
Yoshida, Steel & Dalrymple (2007) JSR, v. 77

Facies Change

Temporal Change in Regionally-Dominant Process

Product Change

# Grain-Size Control on Sedimentary Structures



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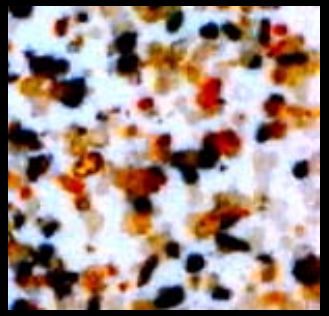
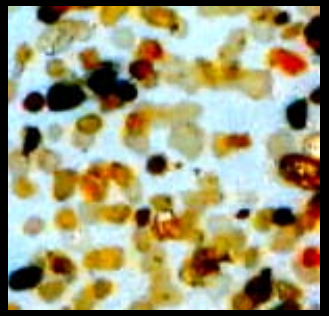


Very Fine



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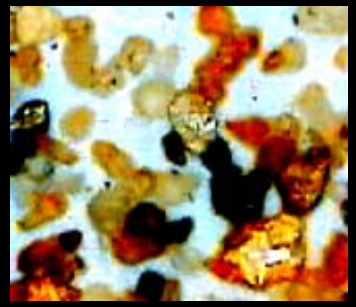
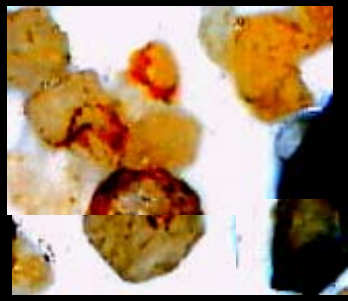


Medium



Coarse

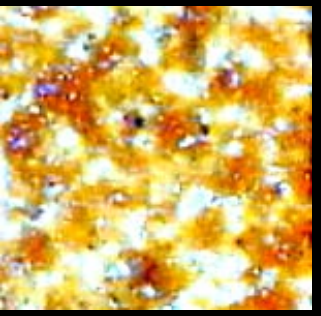
0.15 mm

Sand

Cross Bedding

Hummocky Cross Strata

# Grain-Size Control on Sedimentary Structures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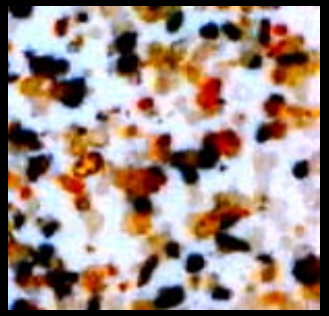
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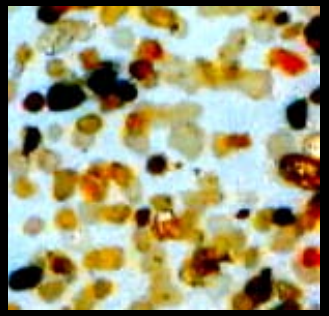
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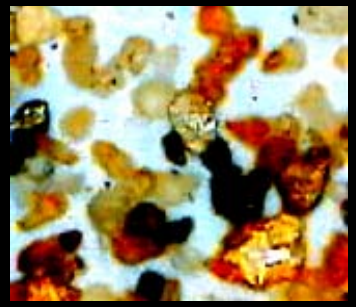
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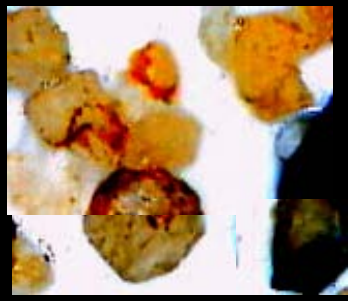
Coarse

Sand

0.15 mm

Cross Bedding

Hummocky Cross Strata

Sand ridges in the US-Canada Atlantic coast

(coarse-grained, cross-bedded)


Dalrymple et al. (1992)

Dalrymple & Hoogendoorn (1997)

Snedden et al. (1994)

# Origin of Facies Change within a RSL cycle –

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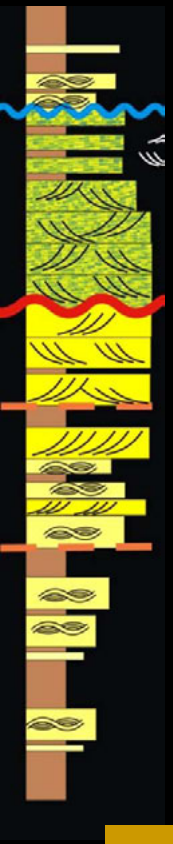

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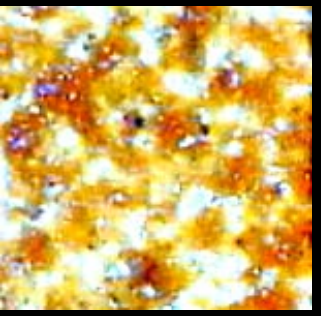

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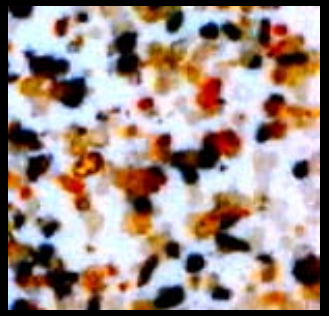

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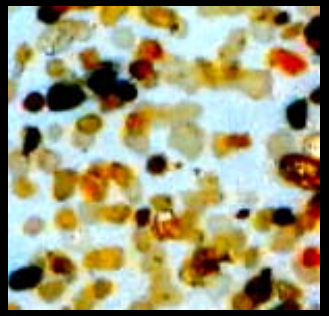

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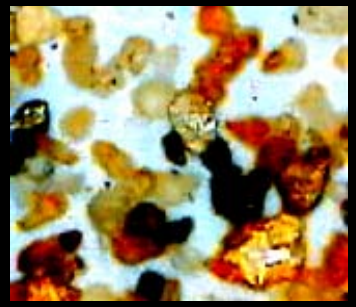

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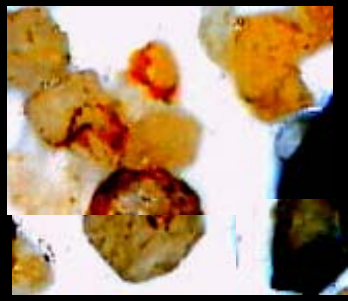


Coarse

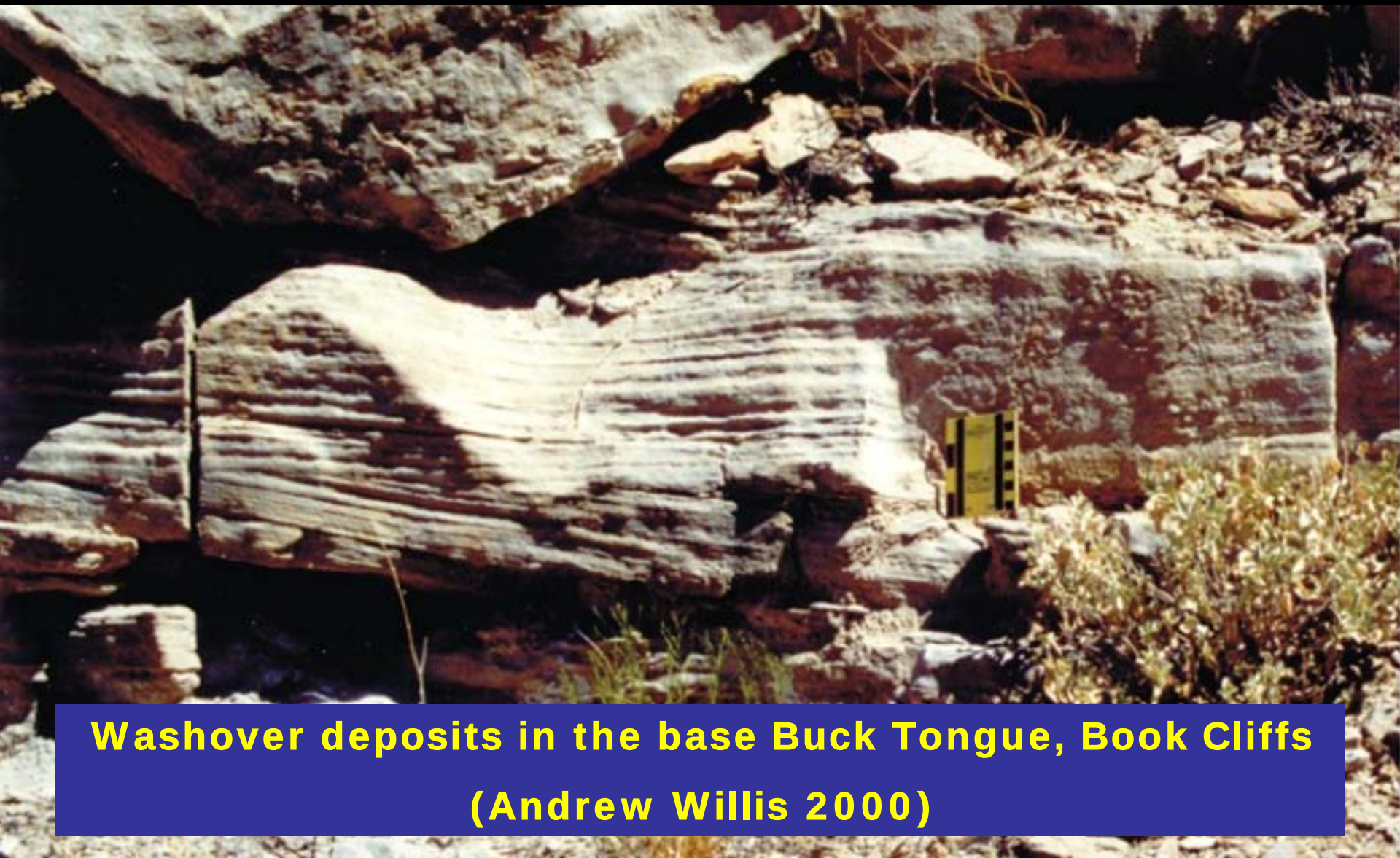
0.15 mm

Sand

Cross Bedding

Hummocky Cross Strata

# HCS Mimics



**Washover deposits in the base Buck Tongue, Book Cliffs (Andrew Willis 2000)**

# HCS Mimics

- **Shoreface-Shelf**
- **Lagoon/estuary (e.g., Washover)**
- **Fluvial (Rust & Gibling 1990)**
- **Precambrian Stromatolites (Hoffman & Schrag 2002)**

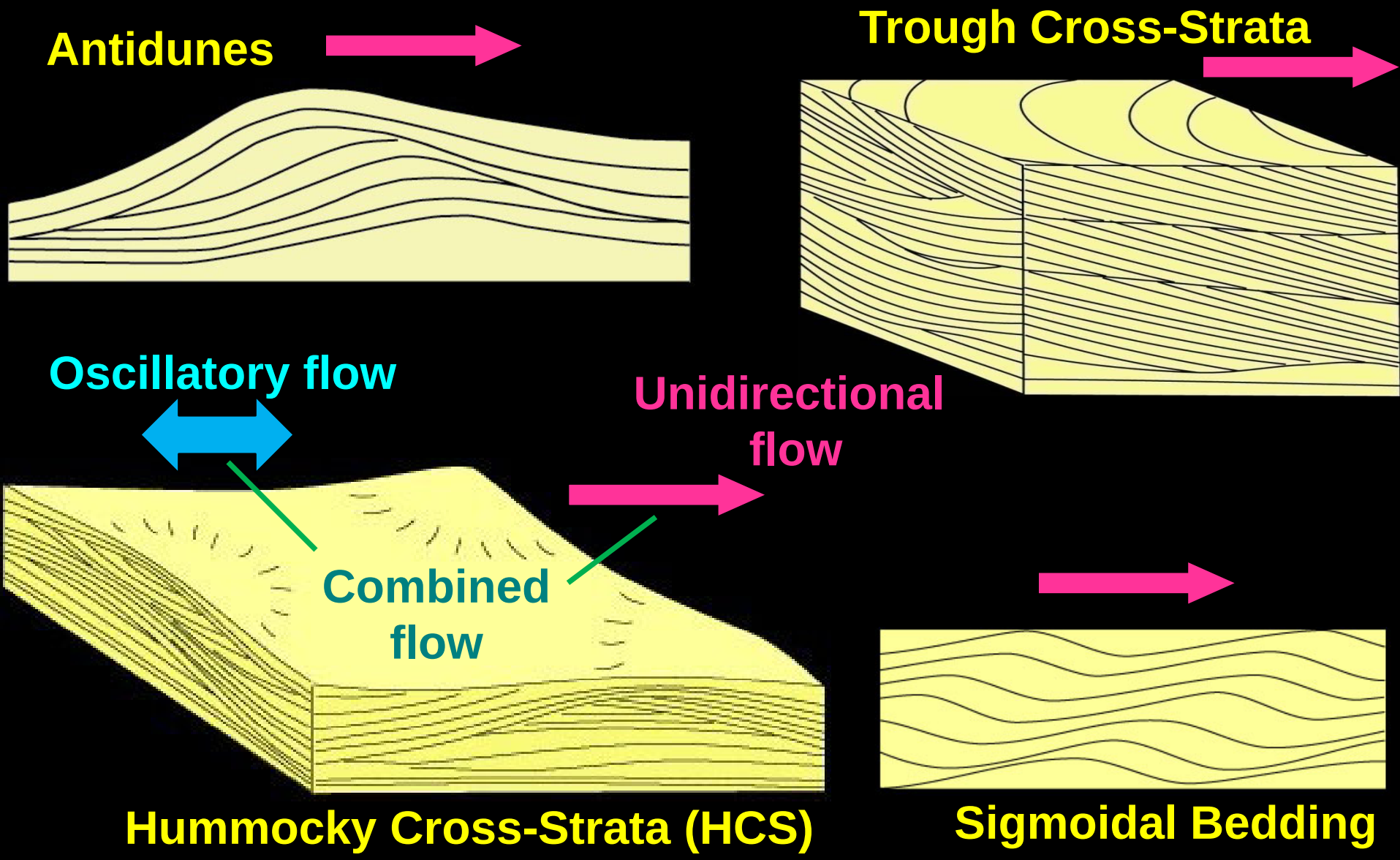
**Alternative Interpretation:**

- **Giant Wave Ripples (Allen & Hoffman 2005)**
- **Antidunes (Alexander, Bridge, Cheel, & Leclair 2001)**

**Medium- to coarse-grained HCS (antidunes?):**

- **Straight/Seaway**
- **Narrow Embayment**
- **Tsunami Deposits**

# Objective: To Better Distinguish between Antidunes and HCS (& other Cross-Strata)



# Methodology

Genuine HCS (Cretaceous, Choshi, Japan)

# Methodology

1. Focusing on Antidune Study

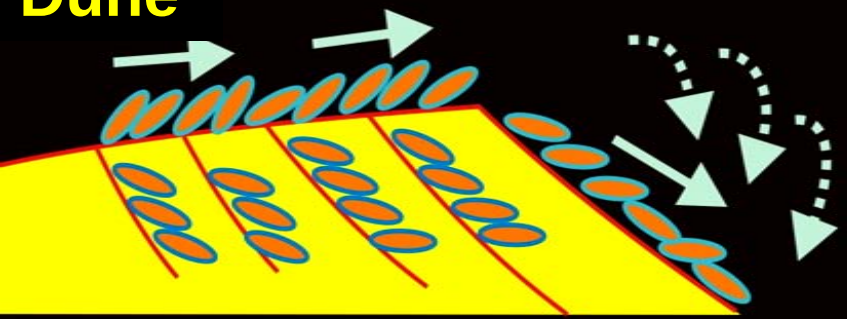
2. Think Out of the Box! Outcrop-Based Study

3. Target Pyroclastic Deposits
   (1) antidunes easier to recognize
   (2) flow direction established by volcanologic studies
   (3) grain-fabric analysis

Grain Imbrications
(Taira 1989)

Antidune

Dune



UFR Plane Bed

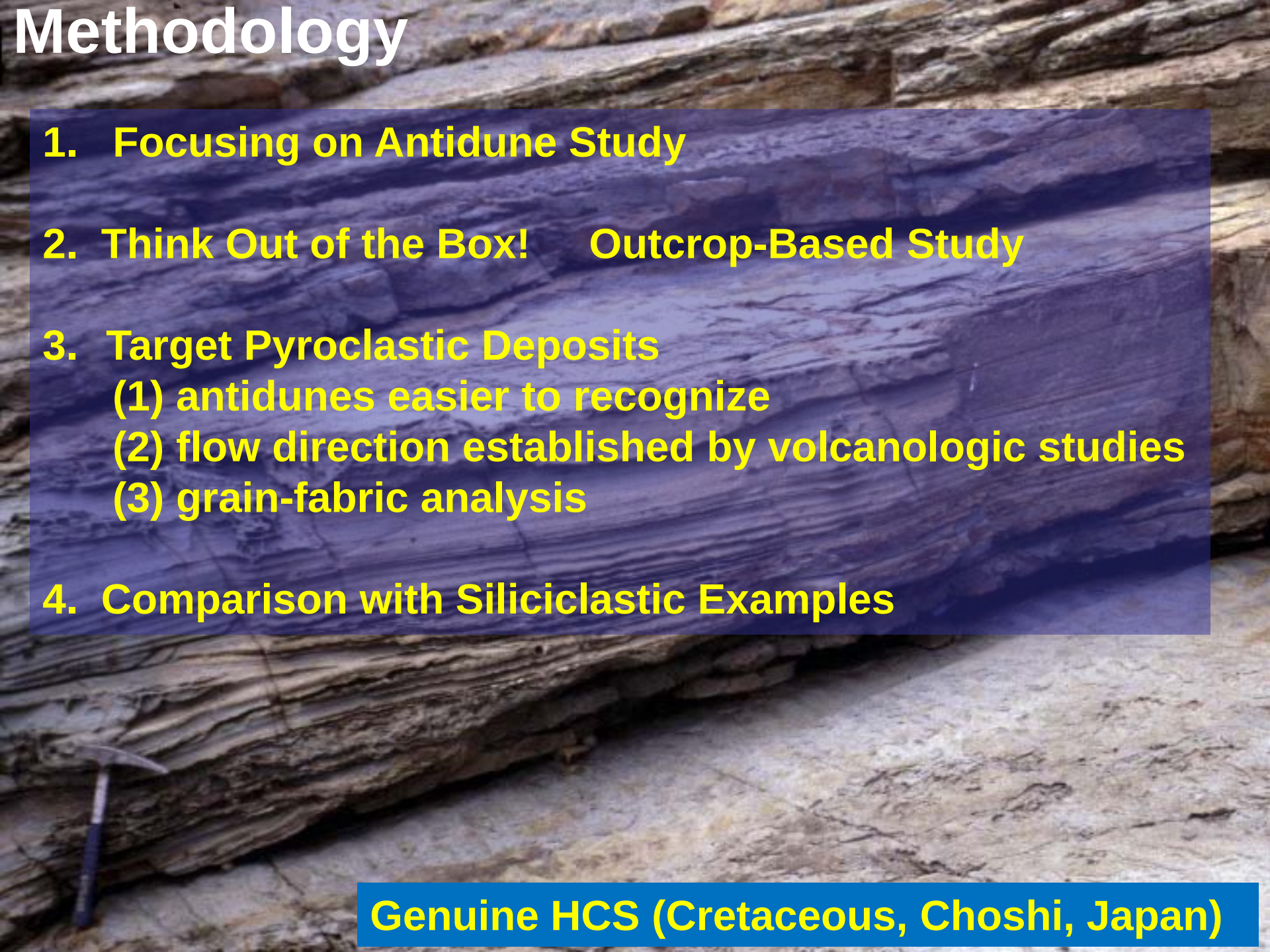
# Methodology

1. Focusing on Antidune Study

2. Think Out of the Box! Outcrop-Based Study

3. Target Pyroclastic Deposits
   (1) antidunes easier to recognize
   (2) flow direction established by volcanologic studies
   (3) grain-fabric analysis

4. Comparison with Siliciclastic Examples



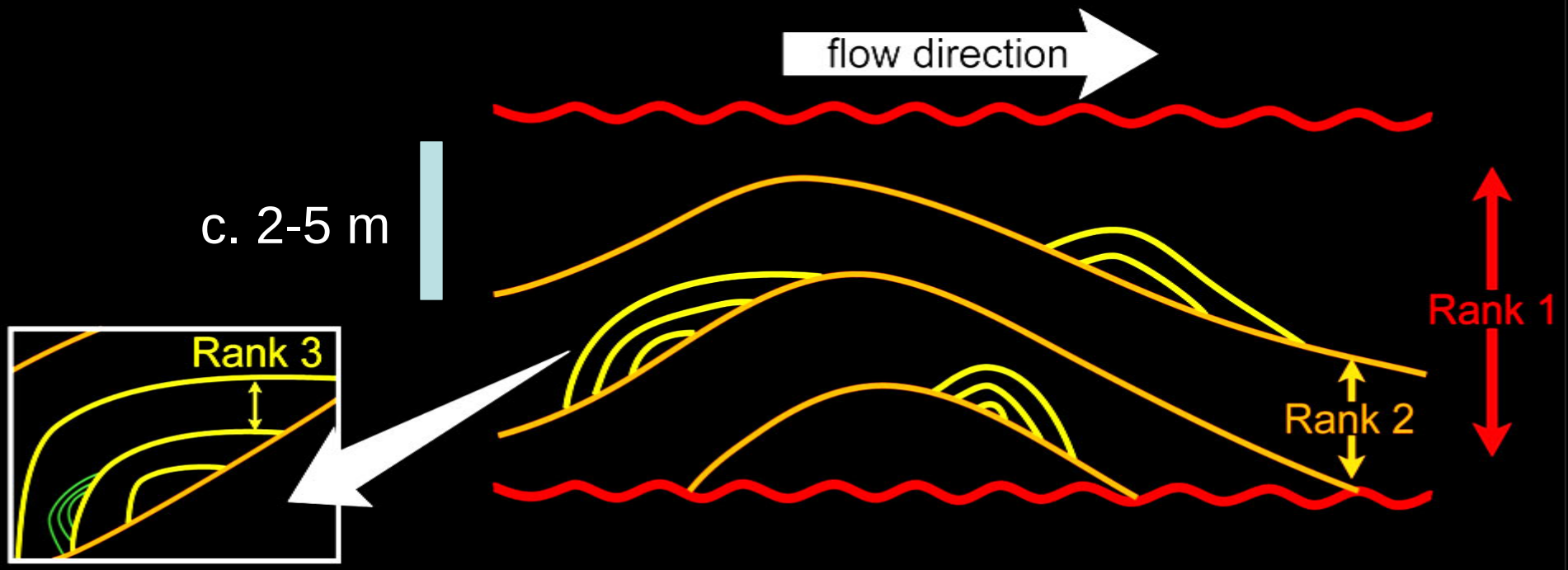
Genuine HCS (Cretaceous, Choshi, Japan)


Study Areas
140° E
36° N
50km
Tokyo
Sagami Trough
Izu-Bonin Trench
Pacific Plate
Nankai Trough
Oshima
Philippine Sea Plate
Nijima
50km

# Study Area 1: Ni-jima Island


Google Earth

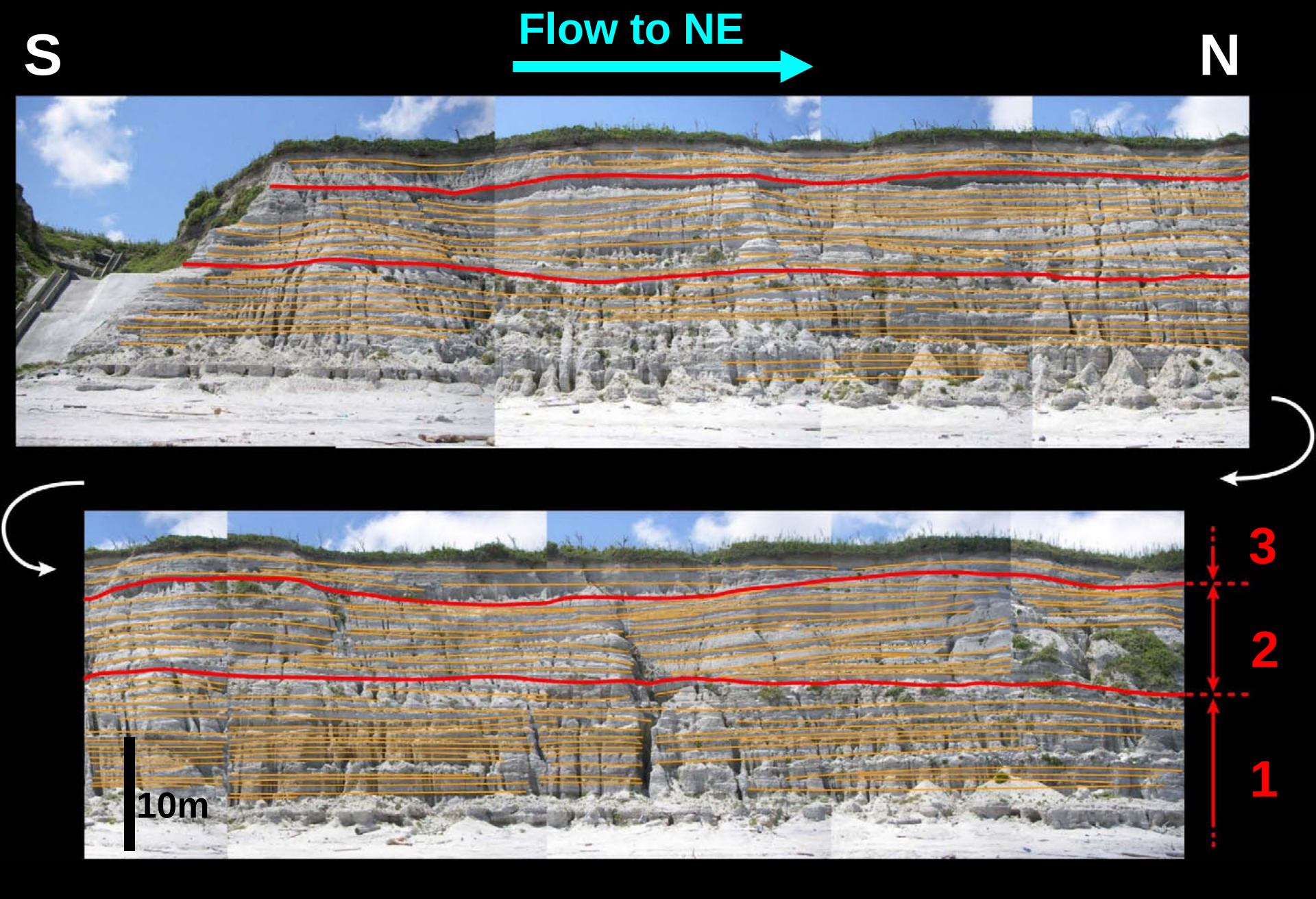
# Compound Antidunes (three-folds +)



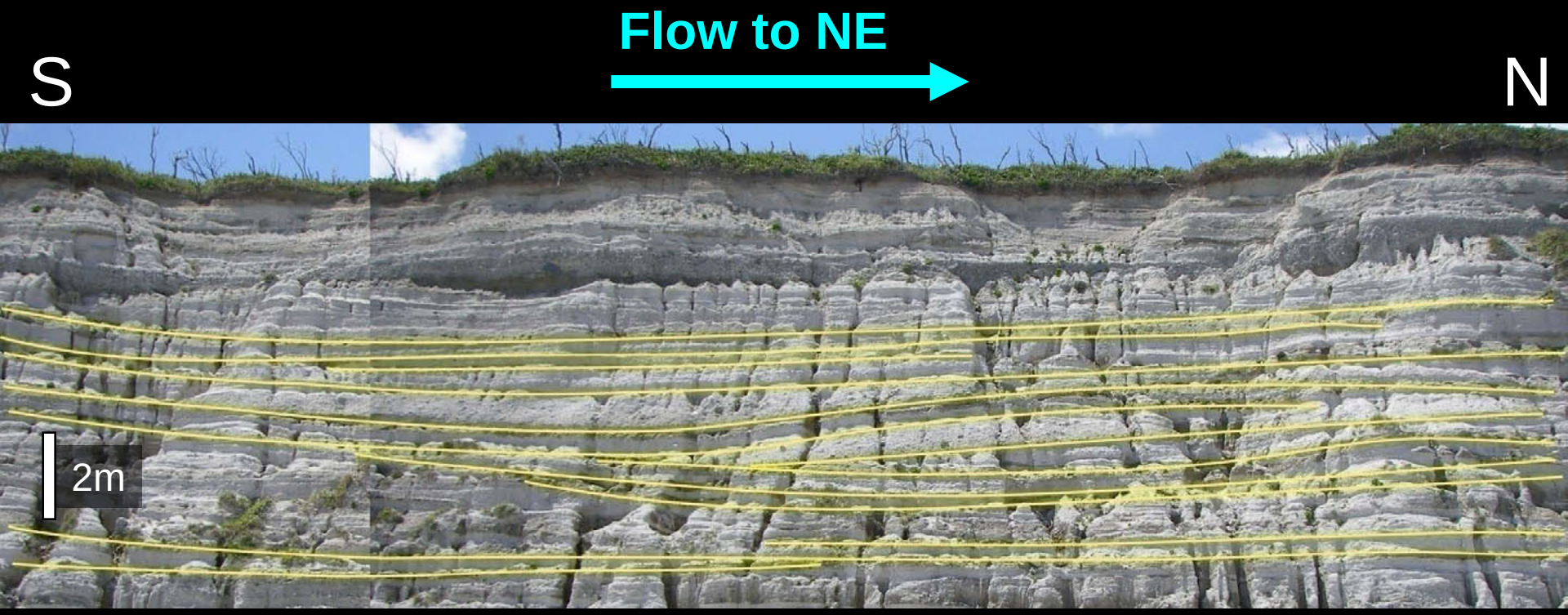

Definition of antidunes:

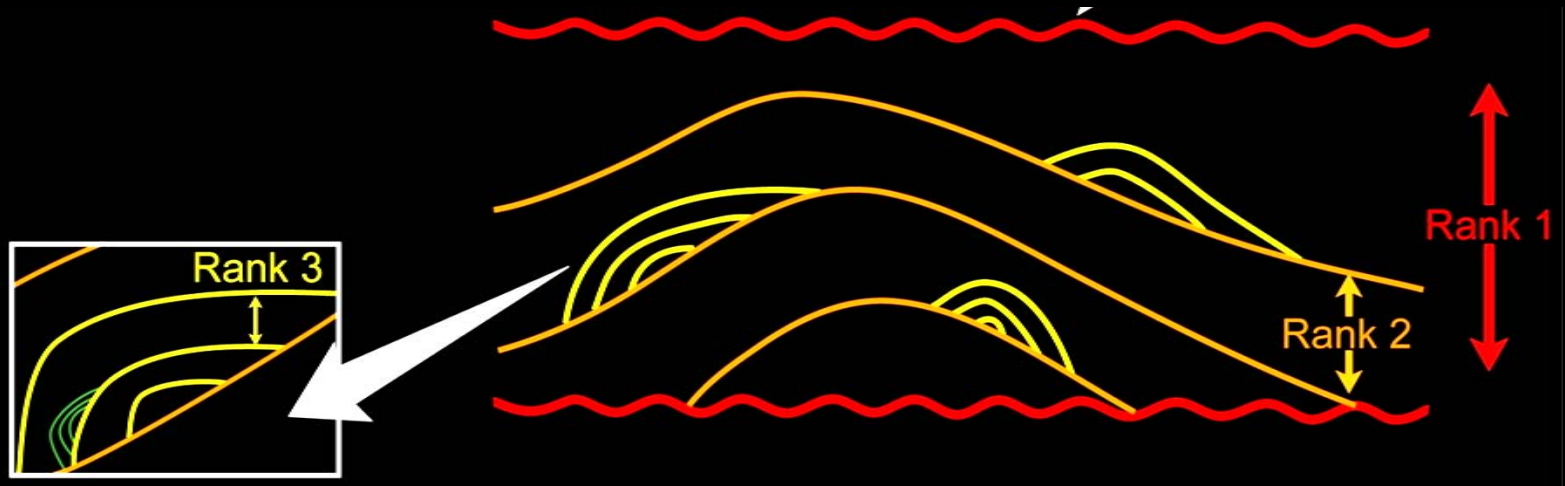
- Traditional sedimentology: Upstream accretion
- Recent flume/engineering communities:
  Upstream and/or downstream accretion (in phase with fluid)

# Geometry of Rank 1 Antidunes

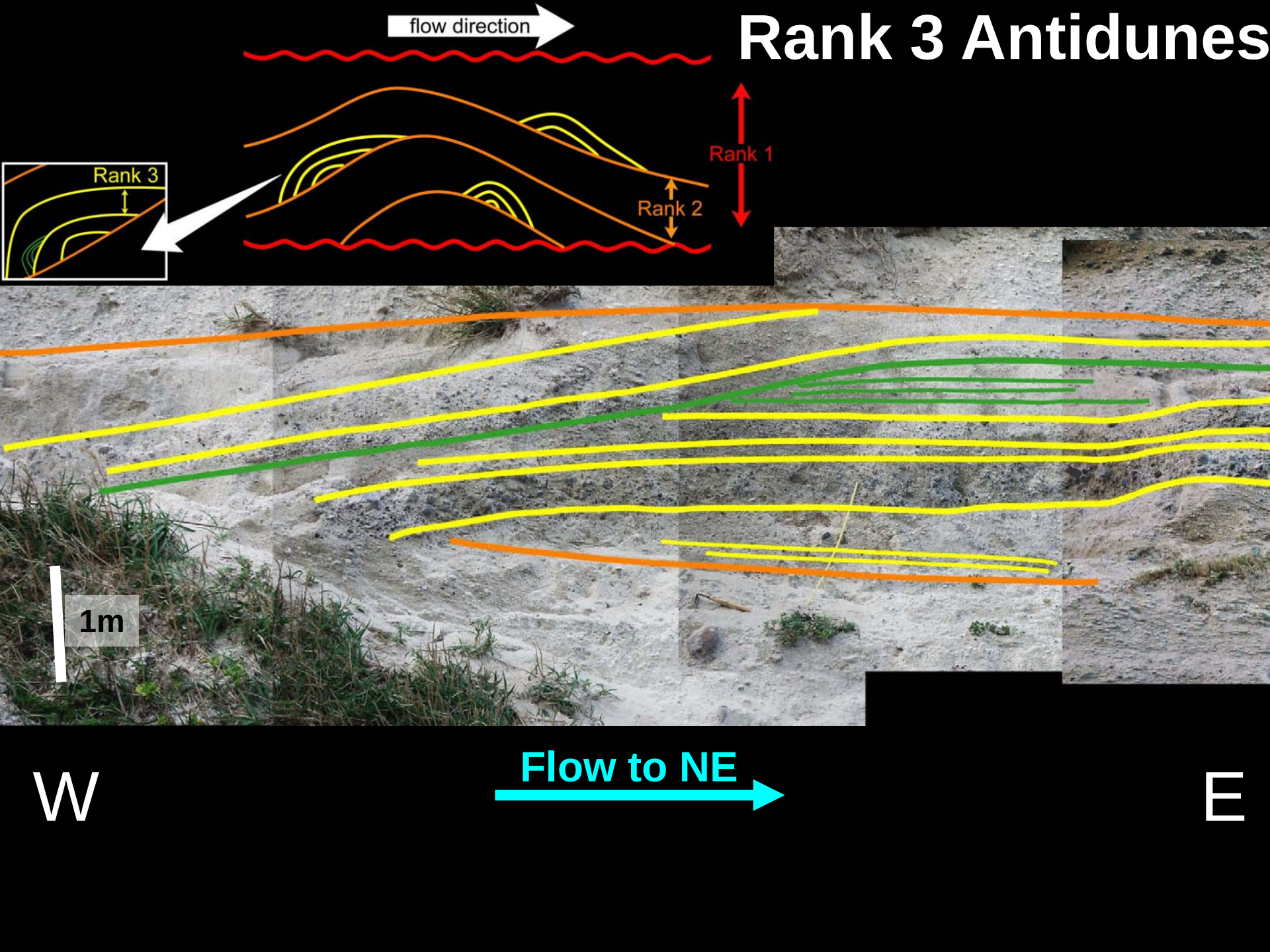


# HCS-like Geometry of Rank 2 Antidunes:



# Rank 3 Antidunes



# Grain Imbrication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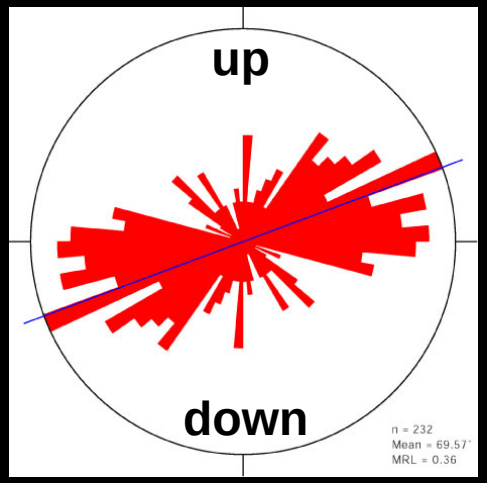



**Flow to NE**

**upstream**

**downstream**

Upstream Accretion

**n = 232**

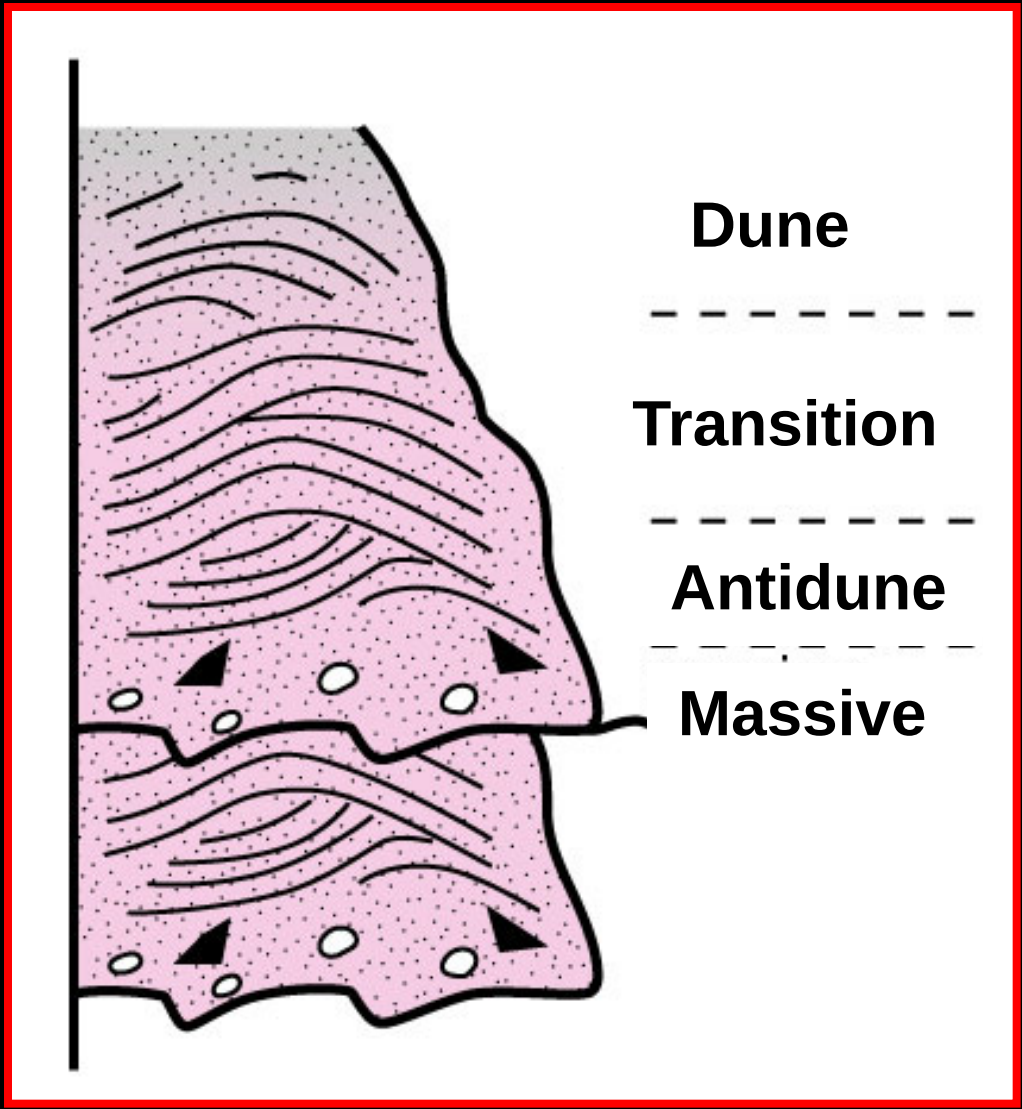
# Trajectory of Vertical Accretion (Rank 2)

N

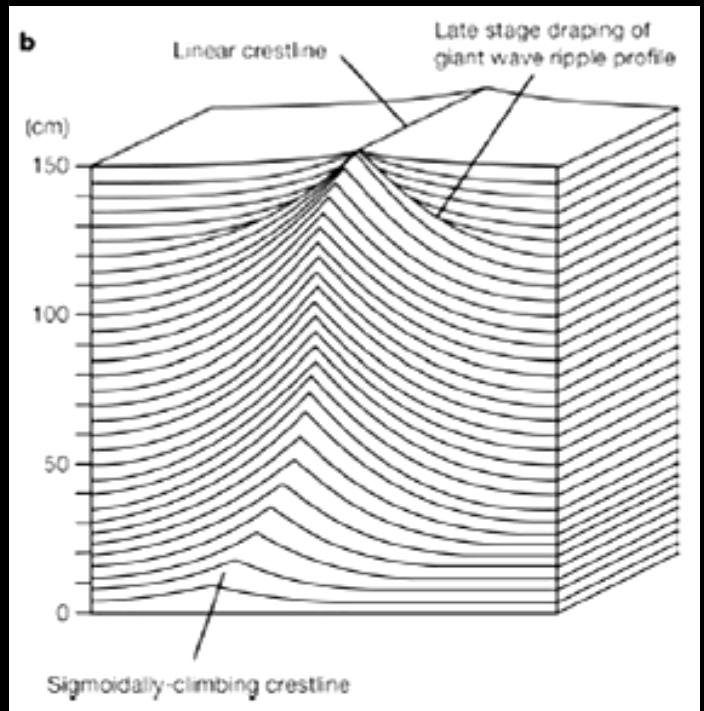
Flow to S

S

# Trajectory of Vertical Accretion (Rank 2)




Allen & Hoffman (2005)

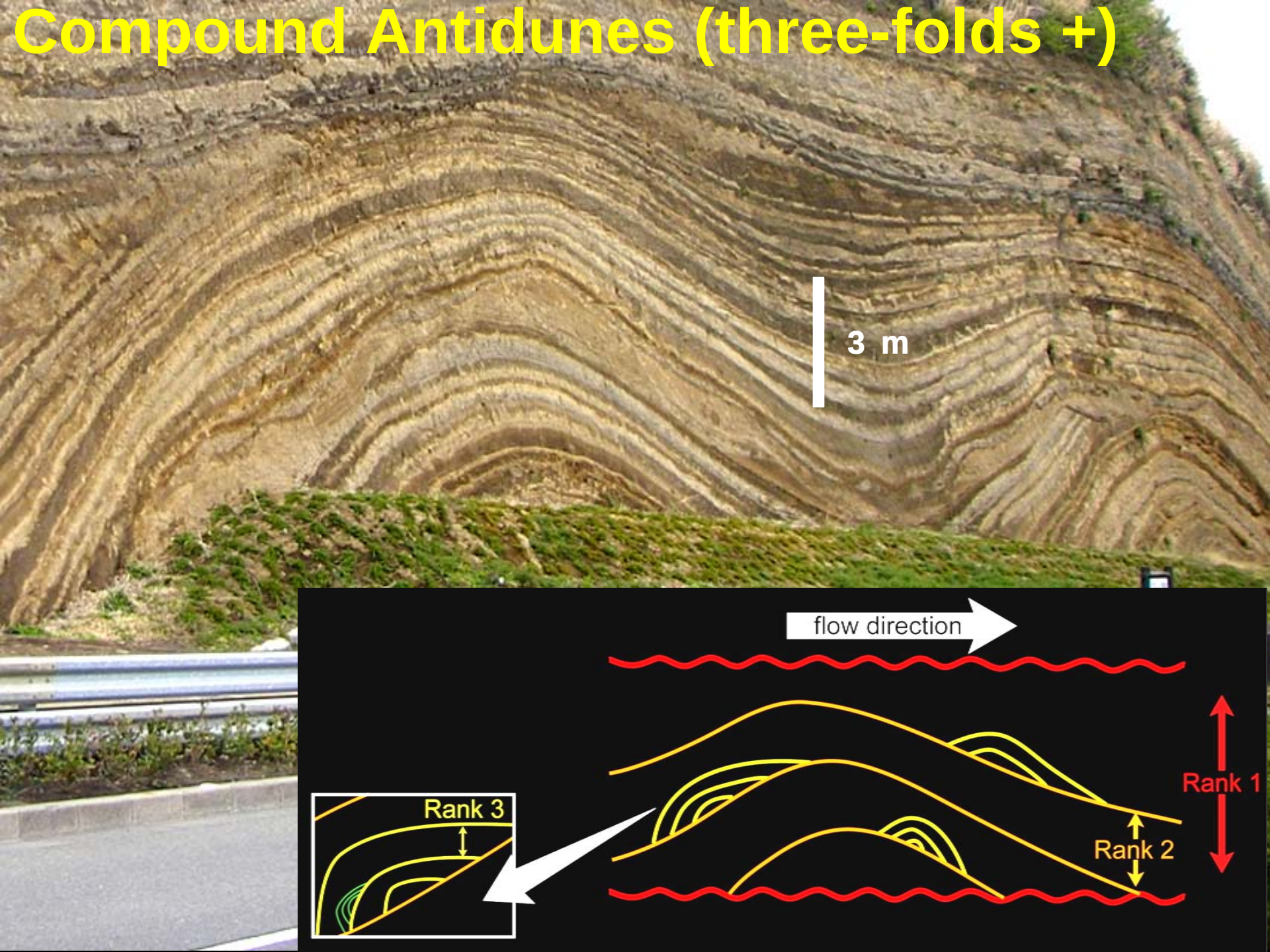

3-D Antidunes (Ranks 2 & 3)
Flow


Study Areas
140° E
36° N
50km
Tokyo
Sagami Trough
Izu-Bonin Trench
Pacific Plate
Nankai Trough
Oshima
Philippine Sea Plate
Nijima

Study Area 2

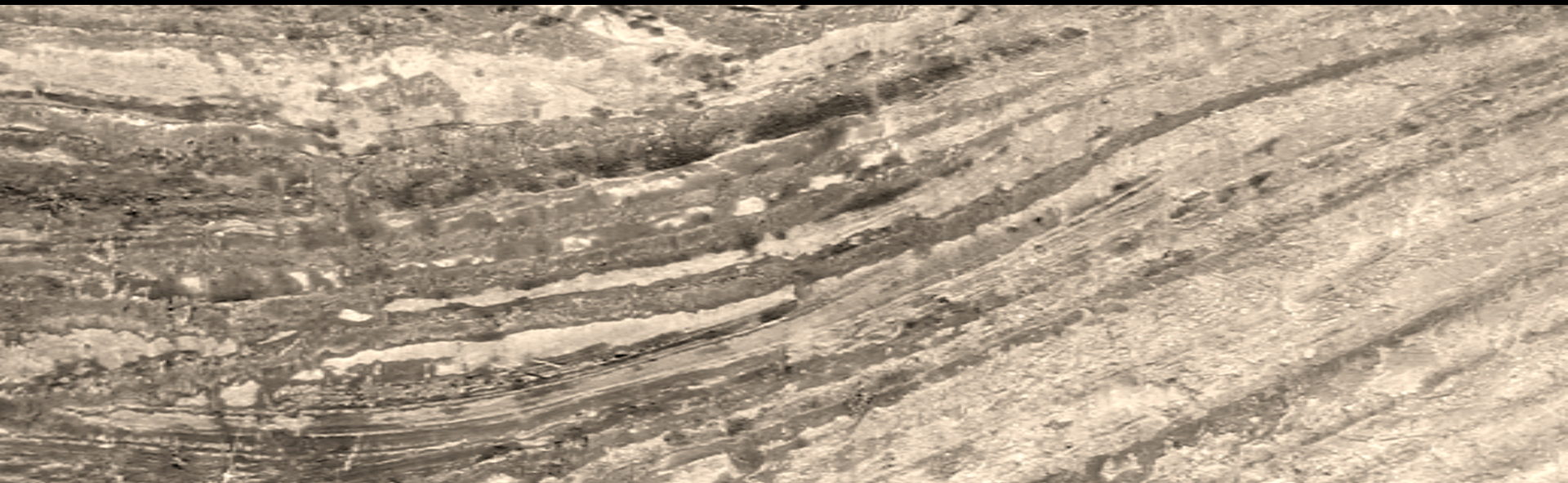
# Oshima Island

# Compound Antidunes (three-folds +)




1 m


# HCS Mimics (Rank 2)



# Discussion

**Origin of HCS and HCS-mimics:**

1. **Combined Flow**
   - **Modern examples (e.g., Indian Ocean)**
   - **Flume**
     - **Fined-grained (Dumas and Arnott, 2006, Geology)**

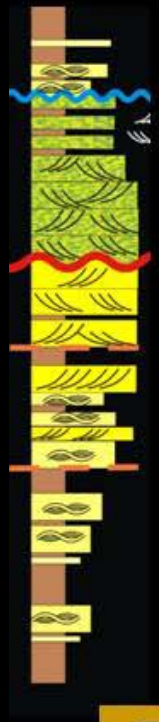
2. **Oscillatory Flow**
   - **Flume**
     - **Very–fine-grained sand (Southard et al., 1990, JSP)**
     - **Medium-grained sand (Takagawa, 2007, Ph.D.thesis)**

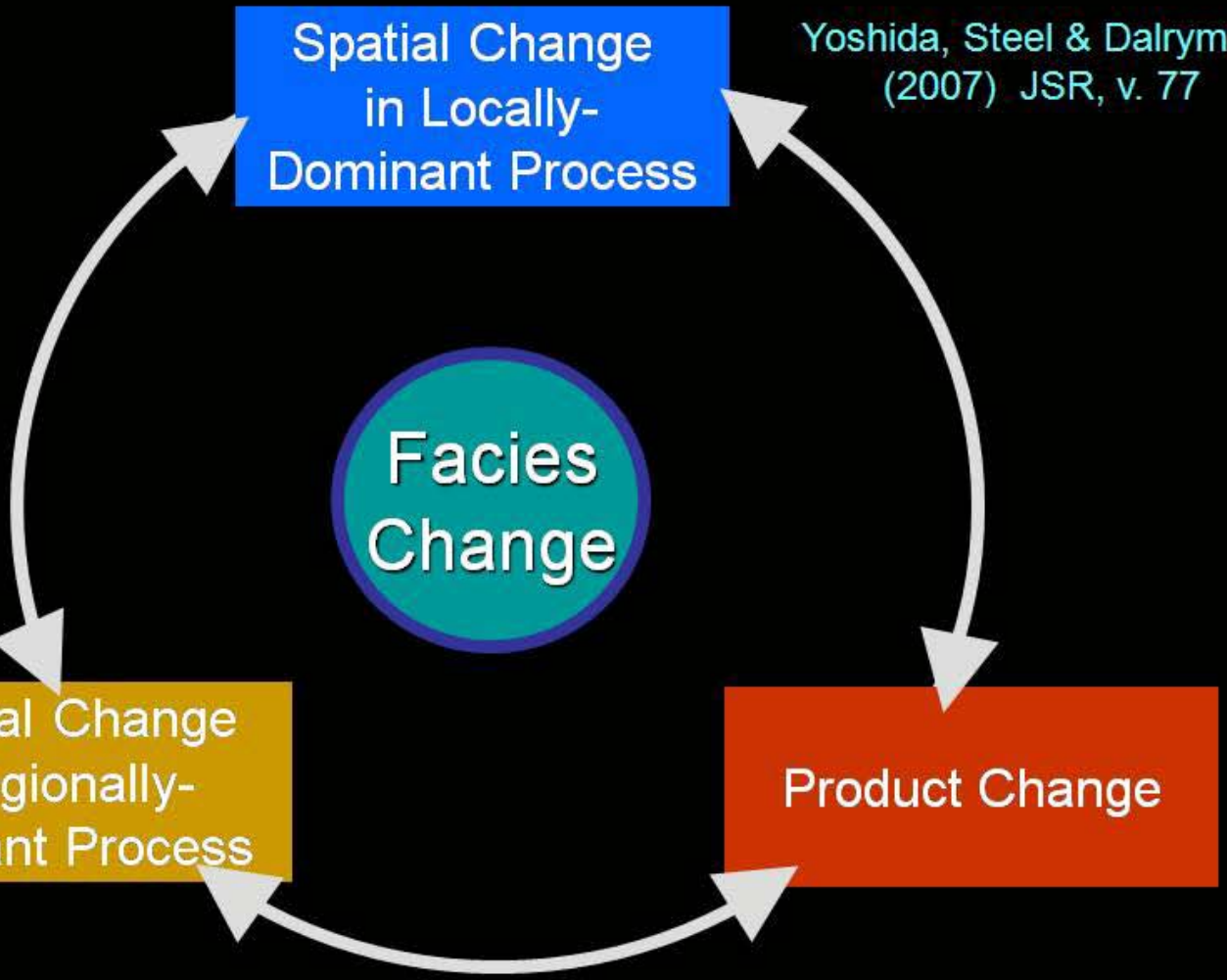
3. **Unidirectional Flow**
   - **Flume: Alexander(2001 Sedimentology) antidune (HCS mimics)**
   - **Fluvial outcrop: Rust & Gibling (HCS mimics antidune?)**
   - **This study: antidune (pyroclastic outcrop)**

# Conclusions



**Cause of Facies Change:**
**Process vs. Product**

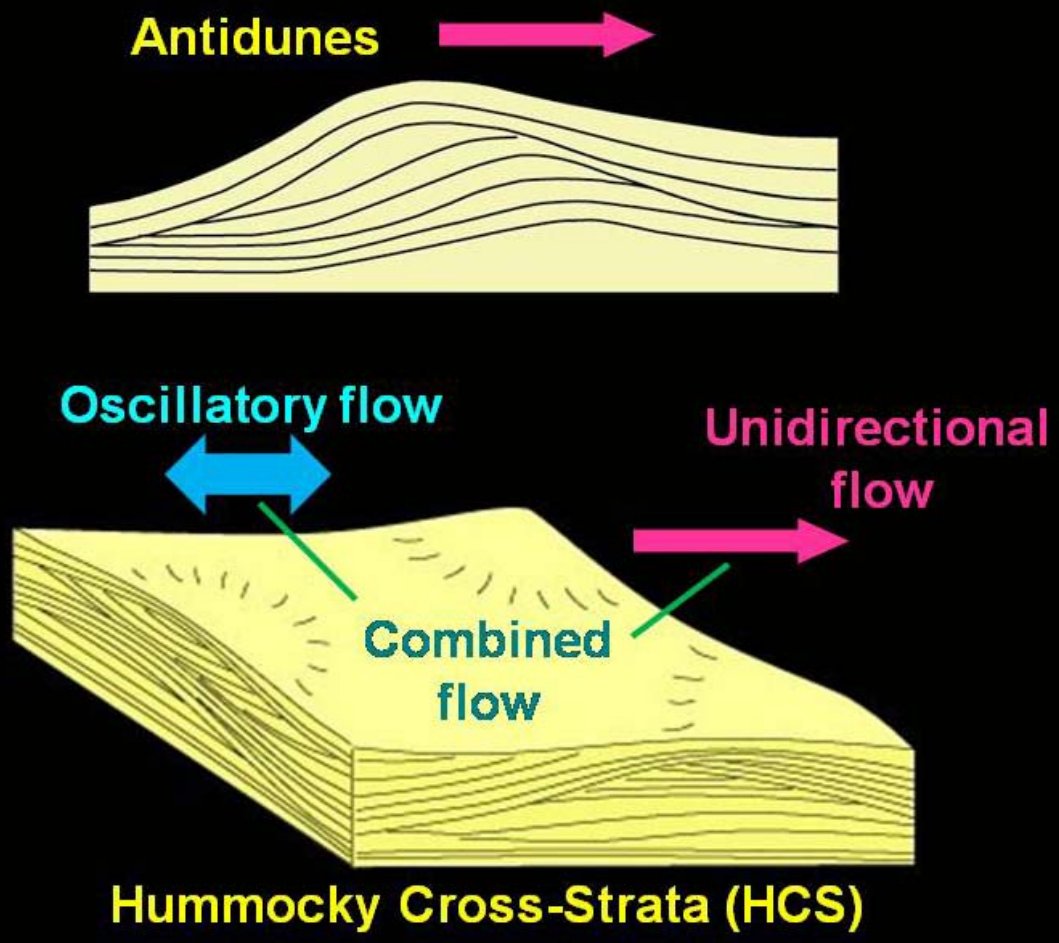




# Conclusions



**Distinction between HCS and antidunes is the key to correctly identify product change.**

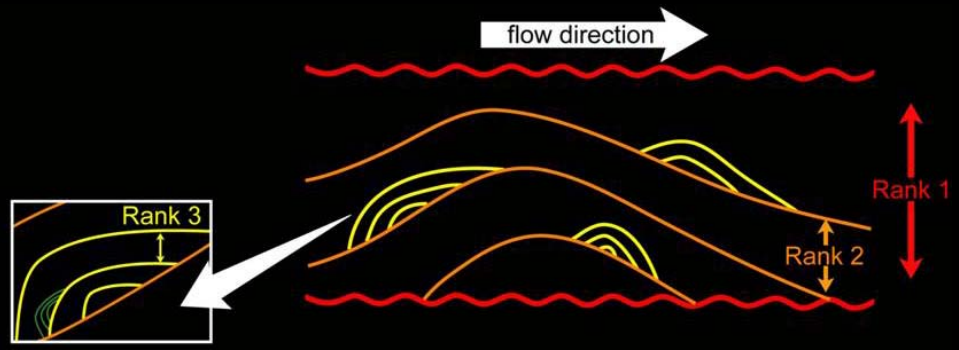


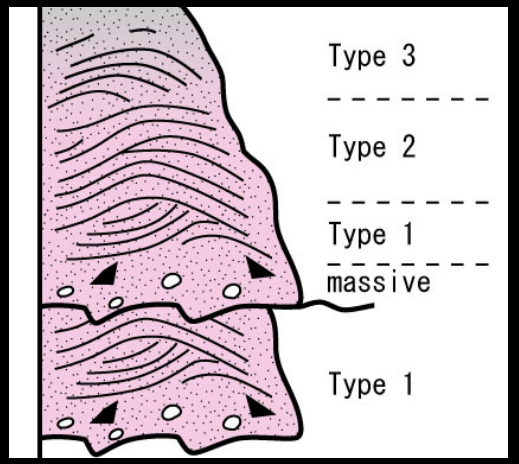
# Conclusions



## Diagnostic Criteria of Antidunes in Ni-jima

- **Nested Geometry** (compound antidunes previously not reported from modern-ancient deposits, or flume/numerical models)

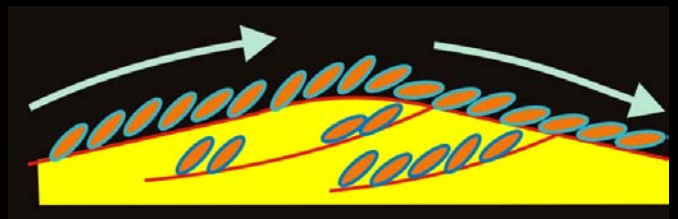



- **Vertical Accretion** (upstream => downstream accretion) **with increasing climbing angle.**

- **Slope** ("fore"set of both upstream & downstream sides) **often exceed 45-50 degrees.**

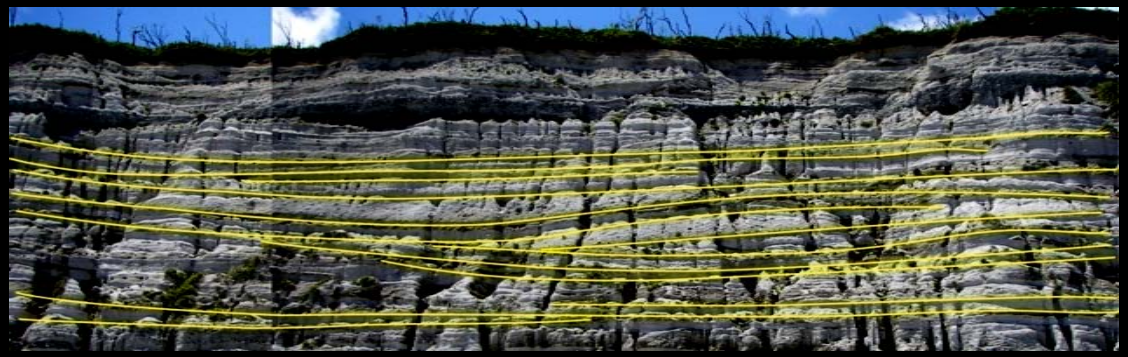
- **Grain Imbrications**



# Conclusions



- **Unidirectional Flow of pyroclastic surge/ flow can produce HCS mimics (3-D antidunes) in a wide range of scales.**



# Conclusions



In combining literature review, HCS or HCS-like sedimentary structures can be formed by

(1) oscillation flow,

(2) unidirectional flow, and

(3) combined flow,

in a certain grain-size range for each. Clear distinction of these products is urgently needed to deduce depositional processes.

# Conclusions

1 2 3 4 5

- Cause of Facies Change: Process vs. Product
- Distinction between HCS and antidunes is the key to correctly identify product change.
- Four diagnostic criteria of Ni-jima Antidunes
- Unidirectional pyroclastic flow/surge produces HCS-like structures
- HCS-like structures form in various hydrodynamic regime. Further study urgently needed.

## Selected References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