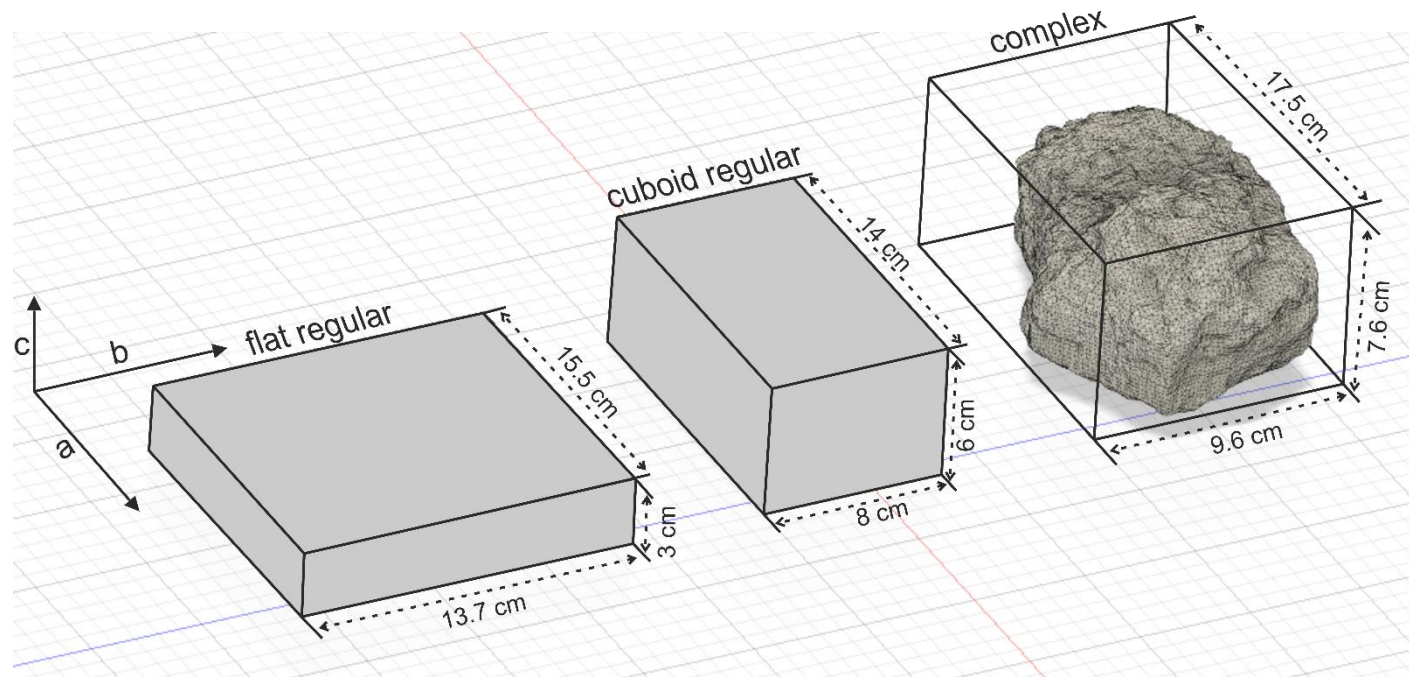


Significance of boulder shape for the transport of boulders by tsunamis



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Introduction



Large tilting flume at IWW, RWTH Aachen University
(Photograph by Peltzer, 2015)

Study scope

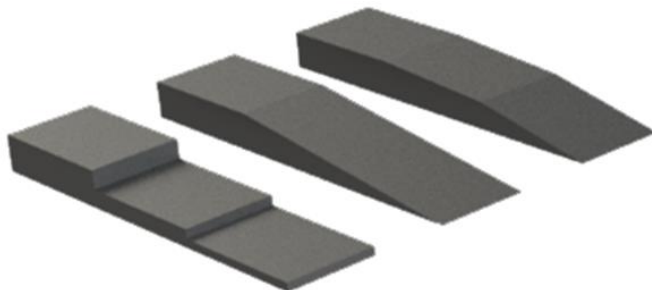
Investigations on the influence of boulder shape, shore shape, boulder submergence and boulder alignment on tsunami induced boulder transport

■ Methods

- Application of a downscaled natural boulder
- Well controlled physical experiments
- Video analysis
- Flow measurements (height and velocity)

■ Key results

- Significant influence of boulder shape
- Highly sensitive boulder behaviour
- Confirmation of results from previous studies
 - Three phases of transport
 - Slightly delayed mobilization after impact
 - Sliding predominant transport mode



■ Experimental setup

■ Pump-driven dam-break like wave

- Tilting flume, IWW, RWTH Aachen University, Germany

■ Three submergence setups

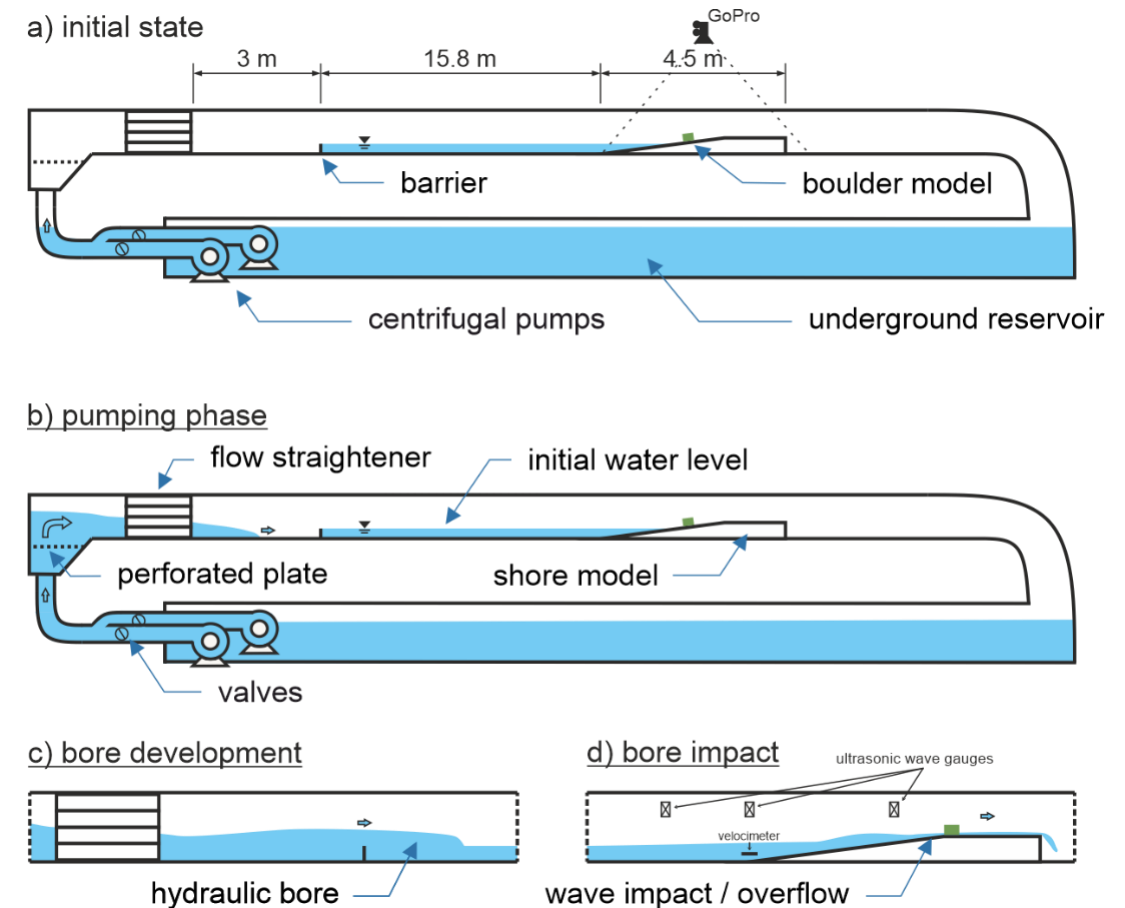
- Submerged, partially submerged, subaerial

■ Three boulder alignment

- 0° (short boulder face perpendicular to the flow)
- 45°
- 90° (long boulder face perpendicular to the flow)

■ Three boulder shapes

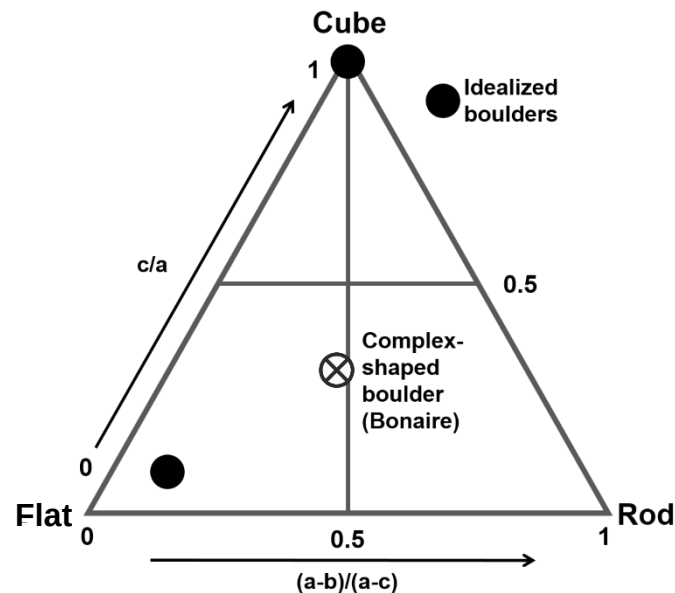
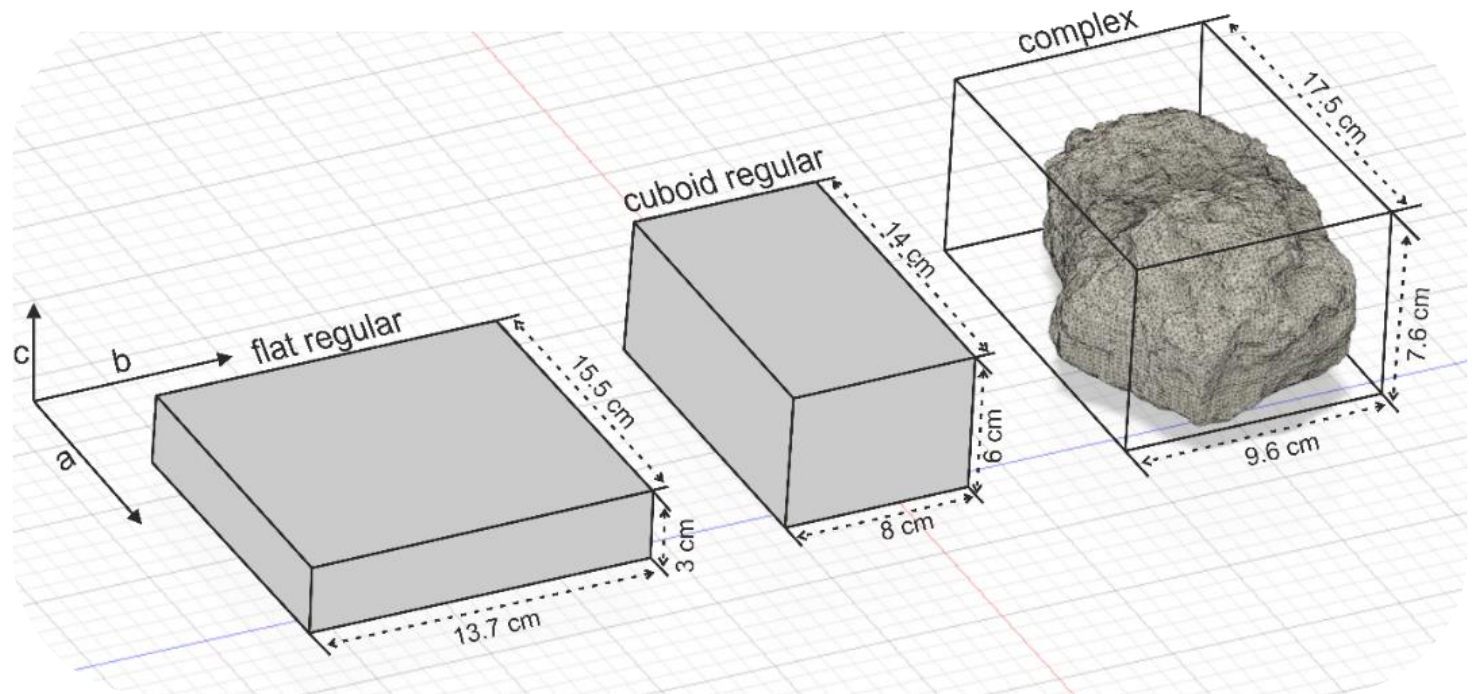
- Cuboid regular
- Flat regular
- Complex shaped (natural)



general experimental setup

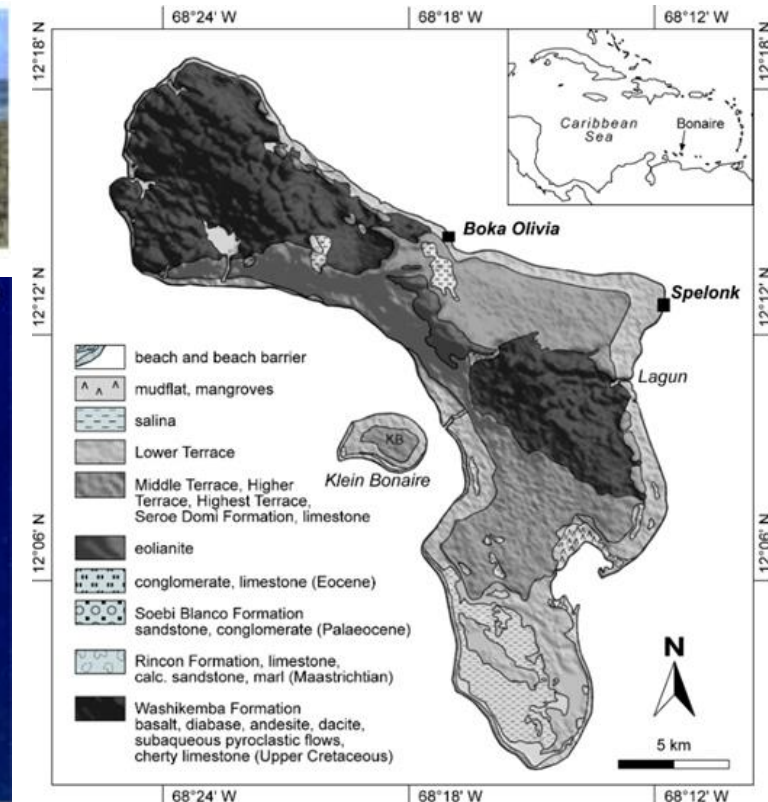
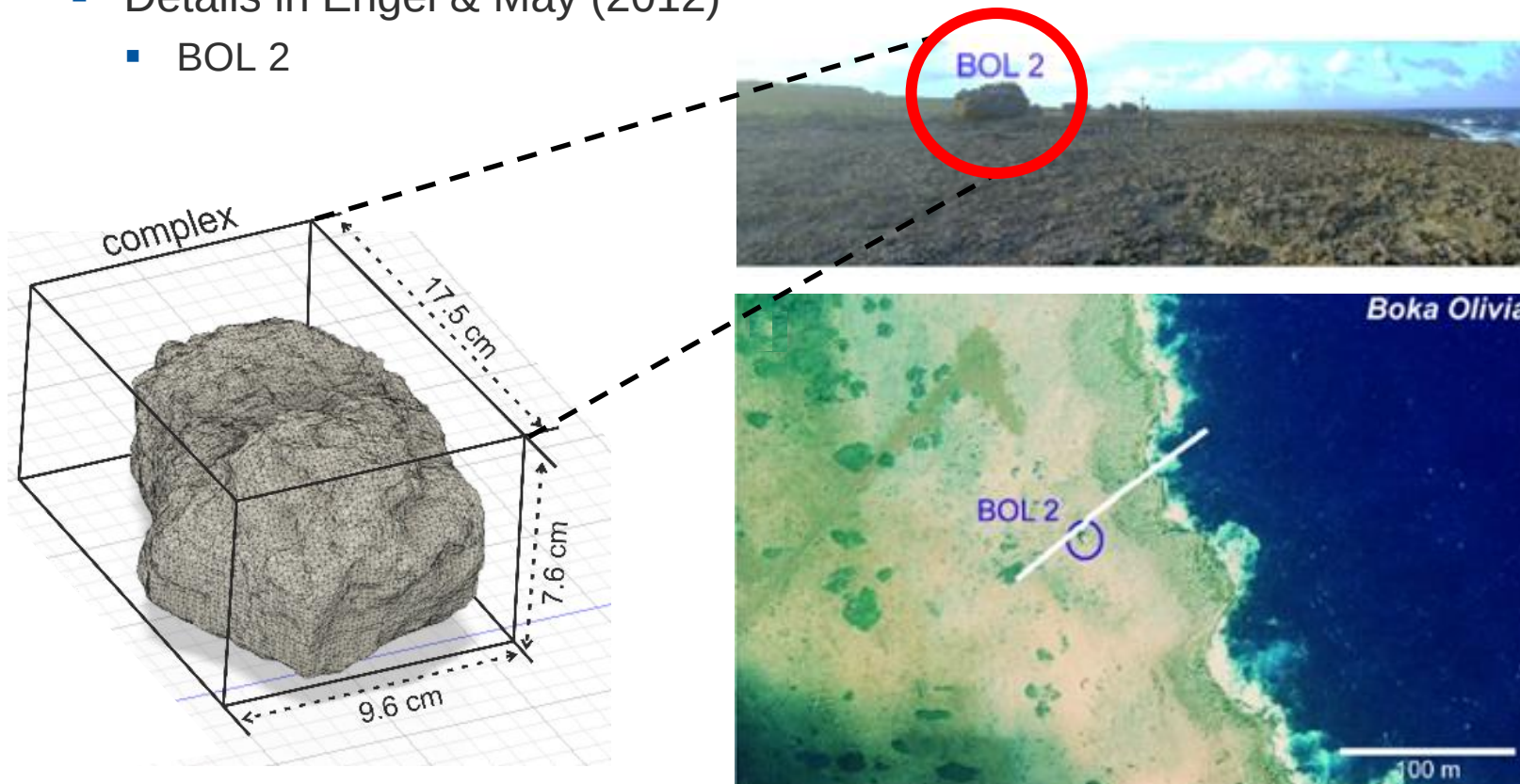
■ Applied boulder models

- Flat regular
 - Cuboid regular
 - Complex (natural)
- Identical density
 - 2.2 g/cm^3
 - Similar total surface area

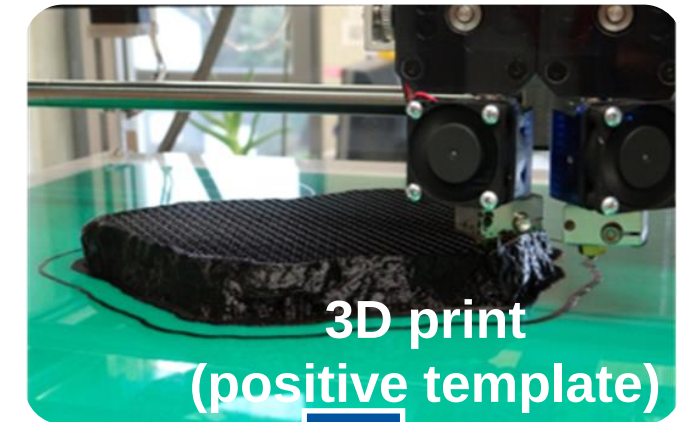
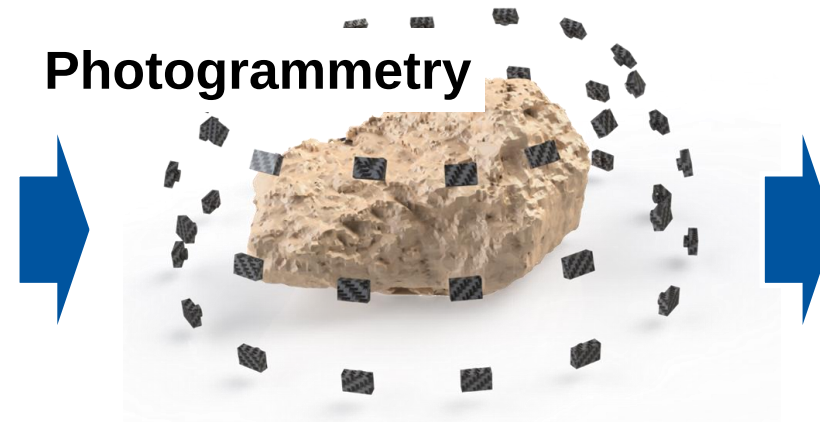
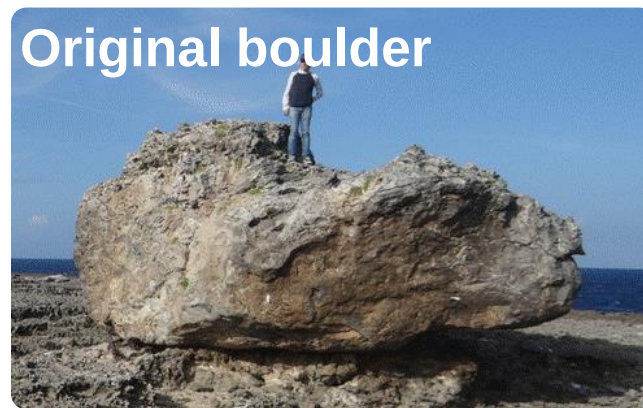


■ Original complex boulder

- Origin: Boka Olivia on the island of Bonaire (Caribbean Sea, lesser Antilles)
- c. 2.2 g/cm³
- c. 170 t
- Details in Engel & May (2012)
 - BOL 2

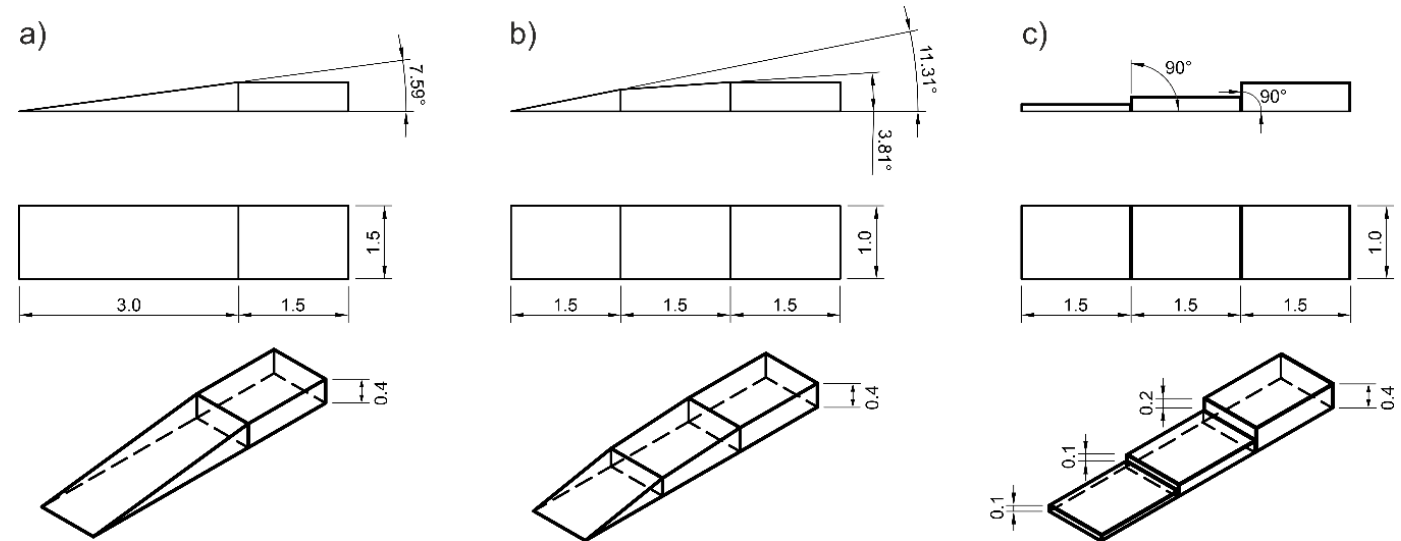


- **Complex boulder**
 - Downscaling procedure



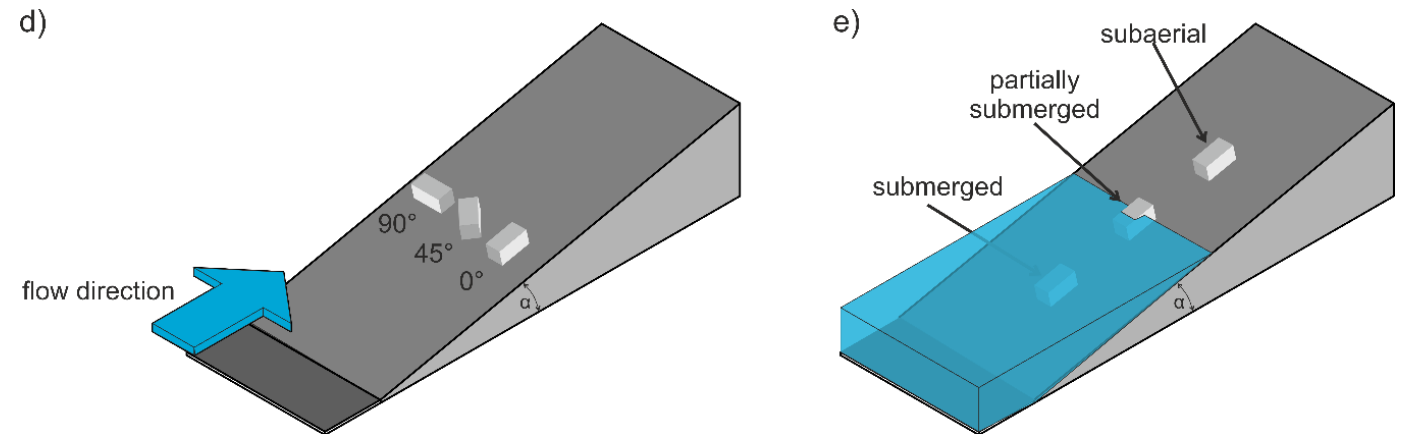
■ Shore models

- Uniformly inclined (type 1, a)
- Non-uniform inclined (type 2, b)
- Stepped (type 3, c)



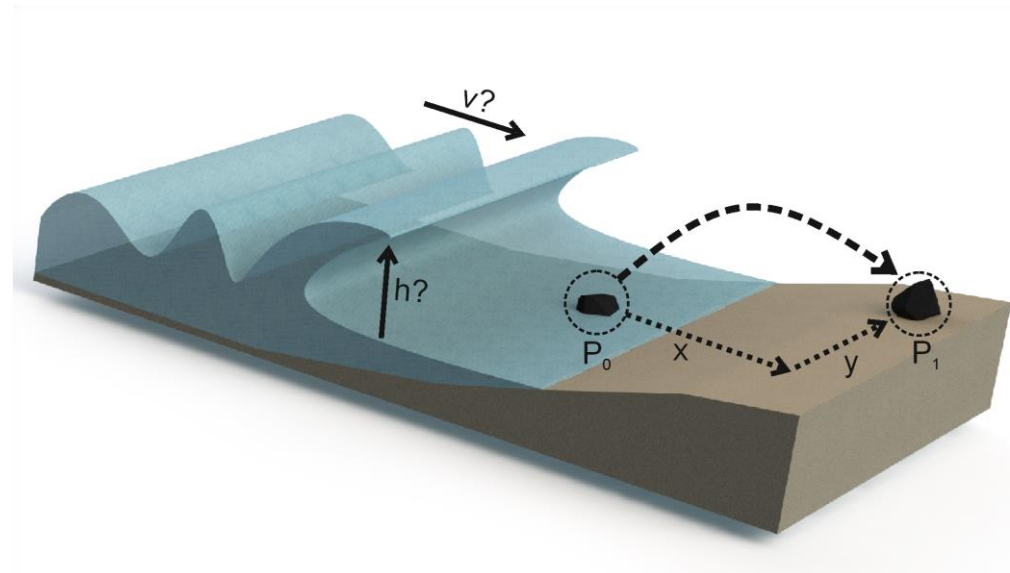
■ Three boulder alignments (d)

- Orientation of main axis to the flow 0° , 45° , 90°



Applied shore models (a, b, c) and setups (d, e)

Results



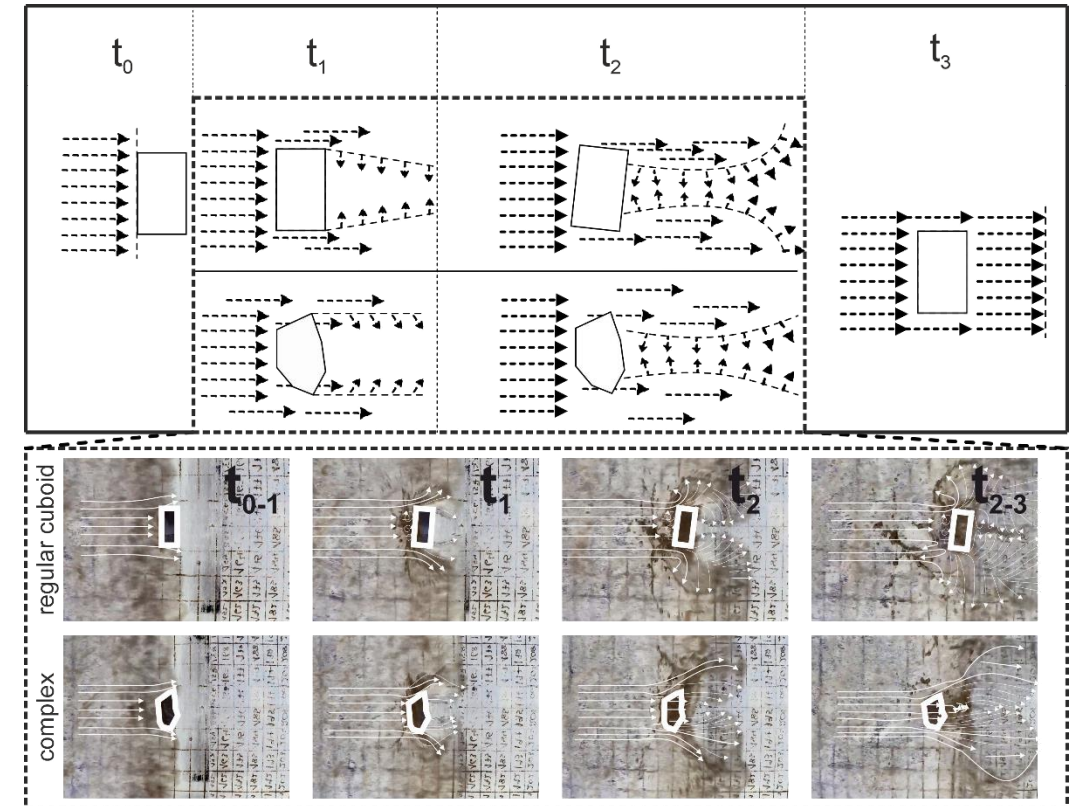
■ Flow fields after flow impact

- Closing app. 0.1 s after impact
- Less flow disturbance in case of the complex boulder

➡ **Less force transfer**

■ Transport

- Mobilization app. at 50% of the max. flow velocity
- Three phases (in accordance with Liu et al., 2015)
 - Acceleration
 - Steady (constant boulder velocity)
 - Deceleration
 - (Rest)



Flow impact and acceleration phase.

(Time interval between states is 0.1 s; design from Nandasena and Tanaka, 2013)

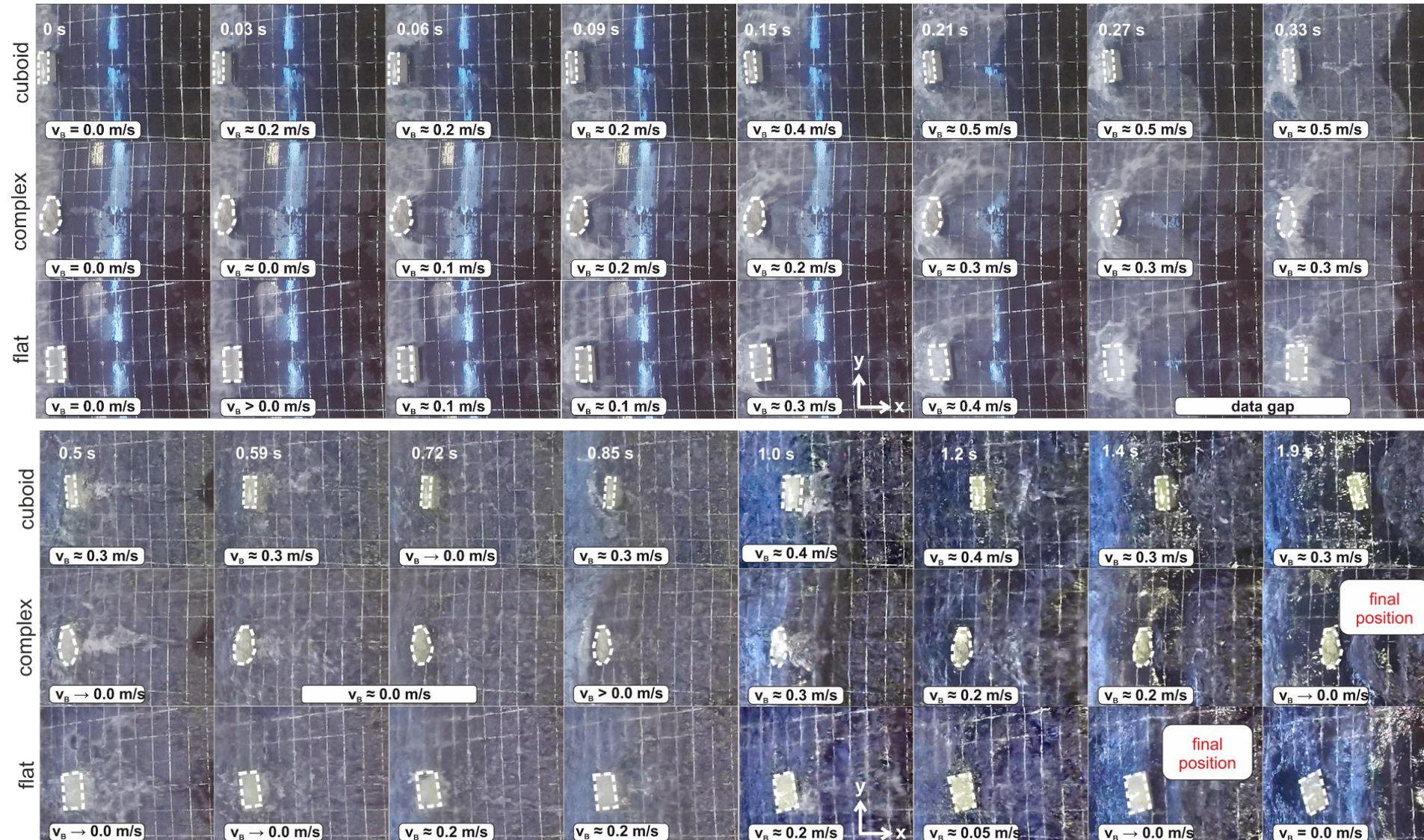
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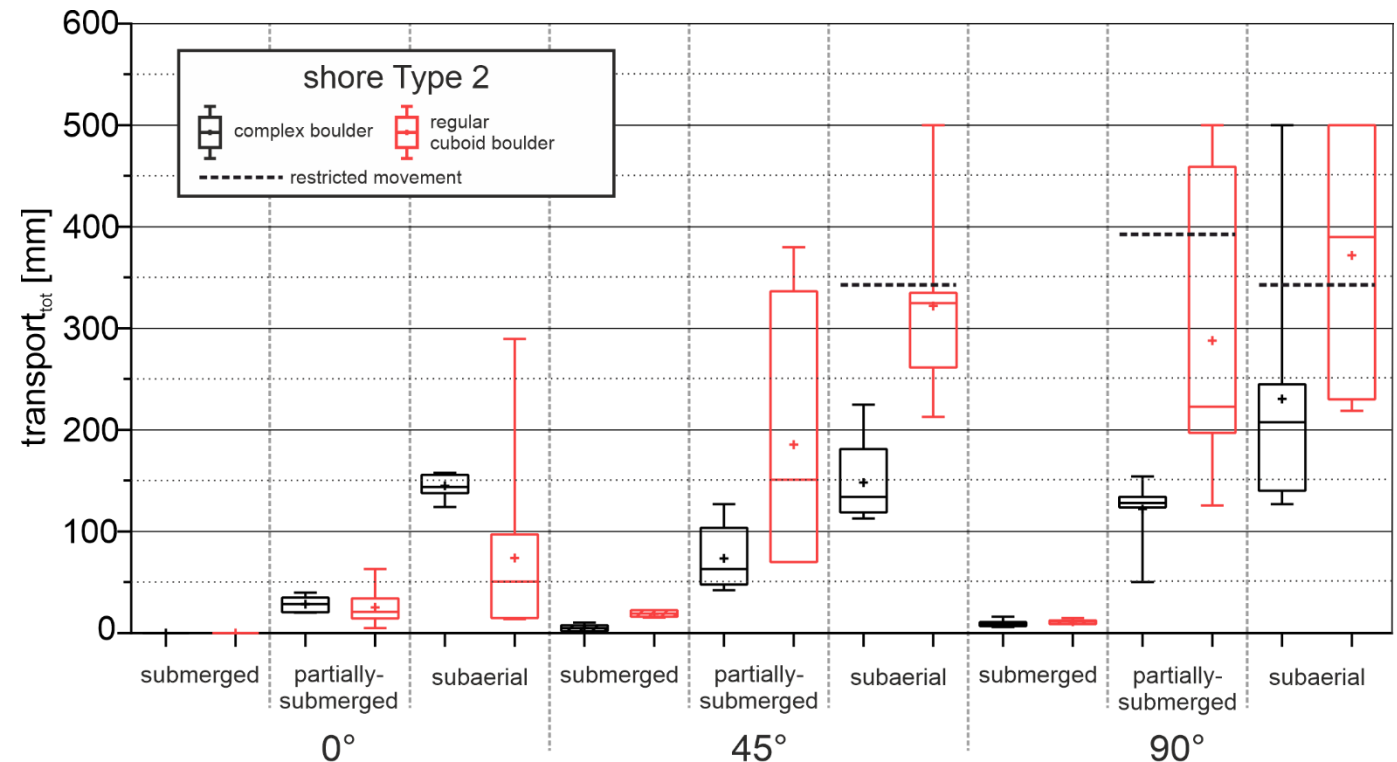
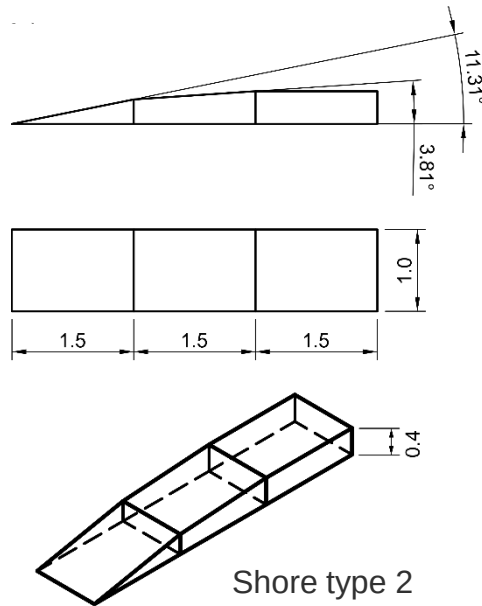


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Representative experimental run (v_B = boulder velocity)

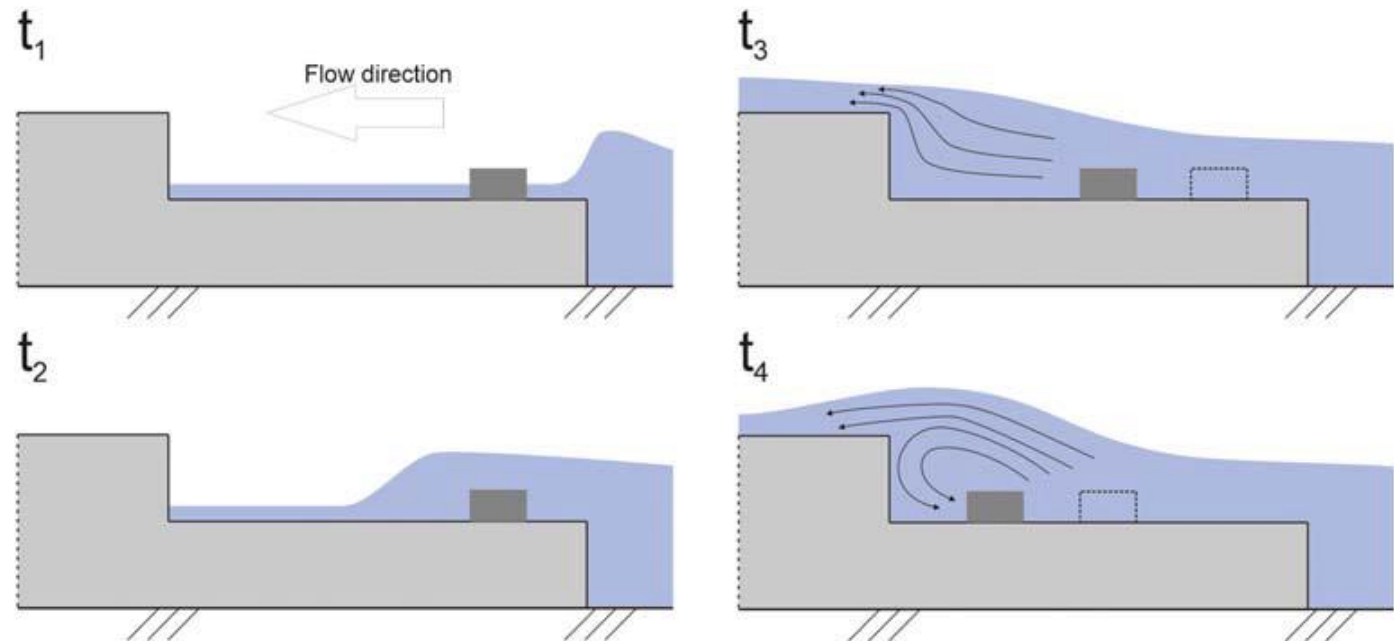
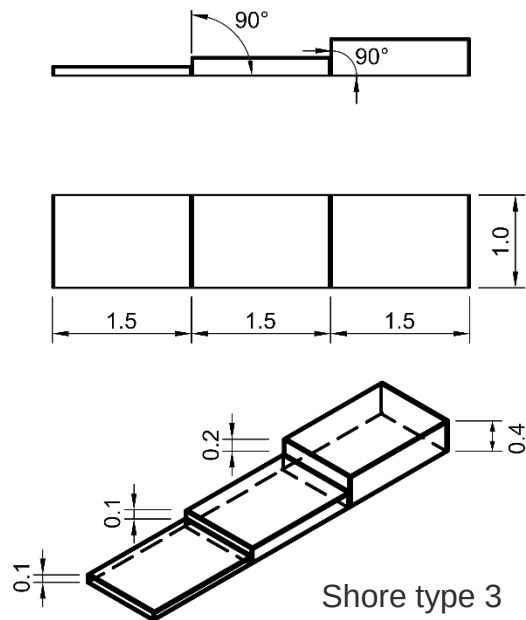
- **Transport distances on shore type 2**
 - Total transport distance increases with
 - Decreasing submergence
 - $0^\circ < 45^\circ < 90^\circ$
 - Flat < complex < cuboid



Range of transport distances on shore type 2 for the cuboid and complex boulder

■ Transport distances on the stepped shore type (type 3)

- Strong influence of wave reflection
 - Boulder deceleration
 - Re-mobilization in opposite direction
 - No transport on the next step in all cases

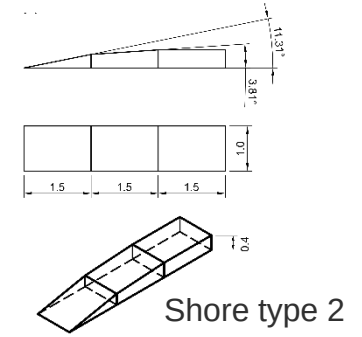


Influence of wave reflections on shore type 3

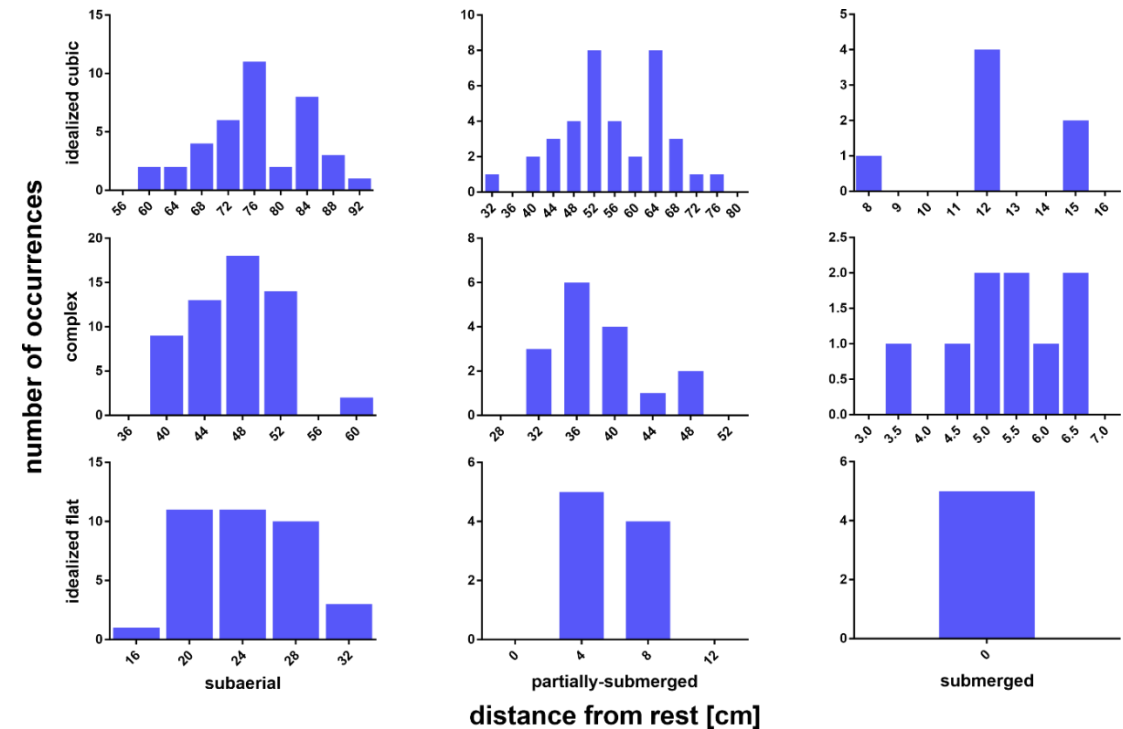
Experimental sensitivity

- Highly sensitive boulder behaviour
- Sensitivity increases with mean maximum transport distance

➔ Number of runs for normally distributed transport distances increases



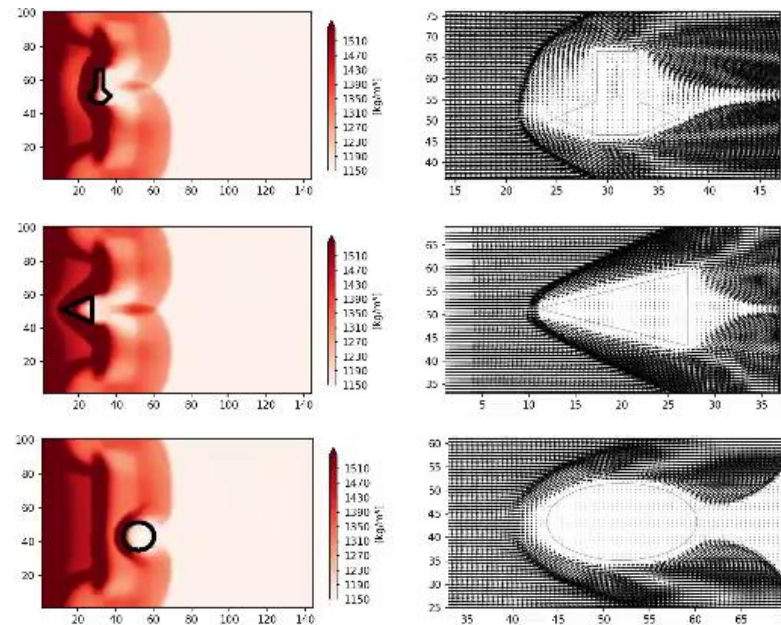
	idealized		complex		flat	
	sa	ps	sa	ps ¹⁾	sa	ps ¹⁾
Transport distance [cm]						
25% Percentile	71.55	49.04	43.2	34.65	21.33	4.136
Median	75.61	54.23	47.25	36.12	24.78	5.339
75% Percentile	83.27	63.18	50.27	41.61	26.95	7.92
Maximum	90.32	76.28	59.49	49.24	31.28	9.755
Mean	76.21	55.67	47.05	38.12	24.27	5.896
Std. Deviation	7.85	9.971	4.664	5.236	3.622	2.347
Std. Error of Mean	1.257	1.639	0.6233	1.309	0.6037	0.7823
Lower 95% CI of mean	73.66	52.34	45.8	35.33	23.05	4.092
Upper 95% CI of mean	78.75	58.99	48.3	40.91	25.5	7.7
normality test	<i>D'Agostino & Pearson omnibus normality test</i>					
	K2	0.8351	0.2841	0.7559	1.985	0.6327
	P value	0.6587	0.8676	0.6853	0.3706	0.7288
	Passed?	Yes	Yes	Yes	Yes	Yes
	<i>Shapiro-Wilk normality test</i>					
	W	0.9716	0.9821	0.9807	0.9298	0.9762
	P value	0.4185	0.8032	0.507	0.2424	0.6176
	Passed?	Yes	Yes	Yes	Yes	Yes
	<i>KS normality test</i>					
	KS distance	0.1084	0.1352	0.07712	0.1972	0.1118
	P value	> 0.1000	0.0853	> 0.1000	0.0969	> 0.1000
	Passed?	Yes	Yes	Yes	Yes	Yes



Statistical results for the experiments on shore type 2

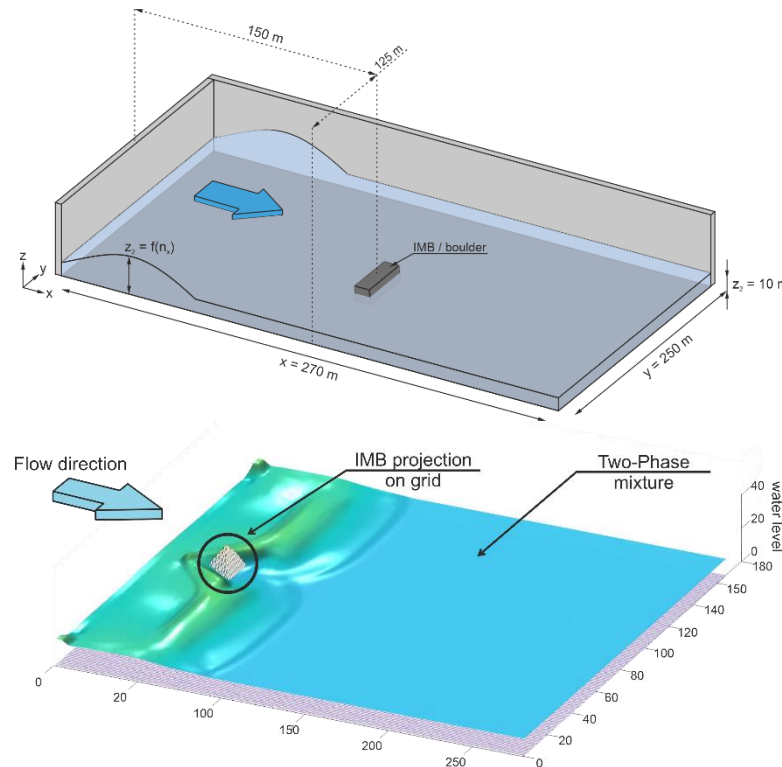
Distribution graphs for reached distances from the boulder origin on shore type 2

Outlook

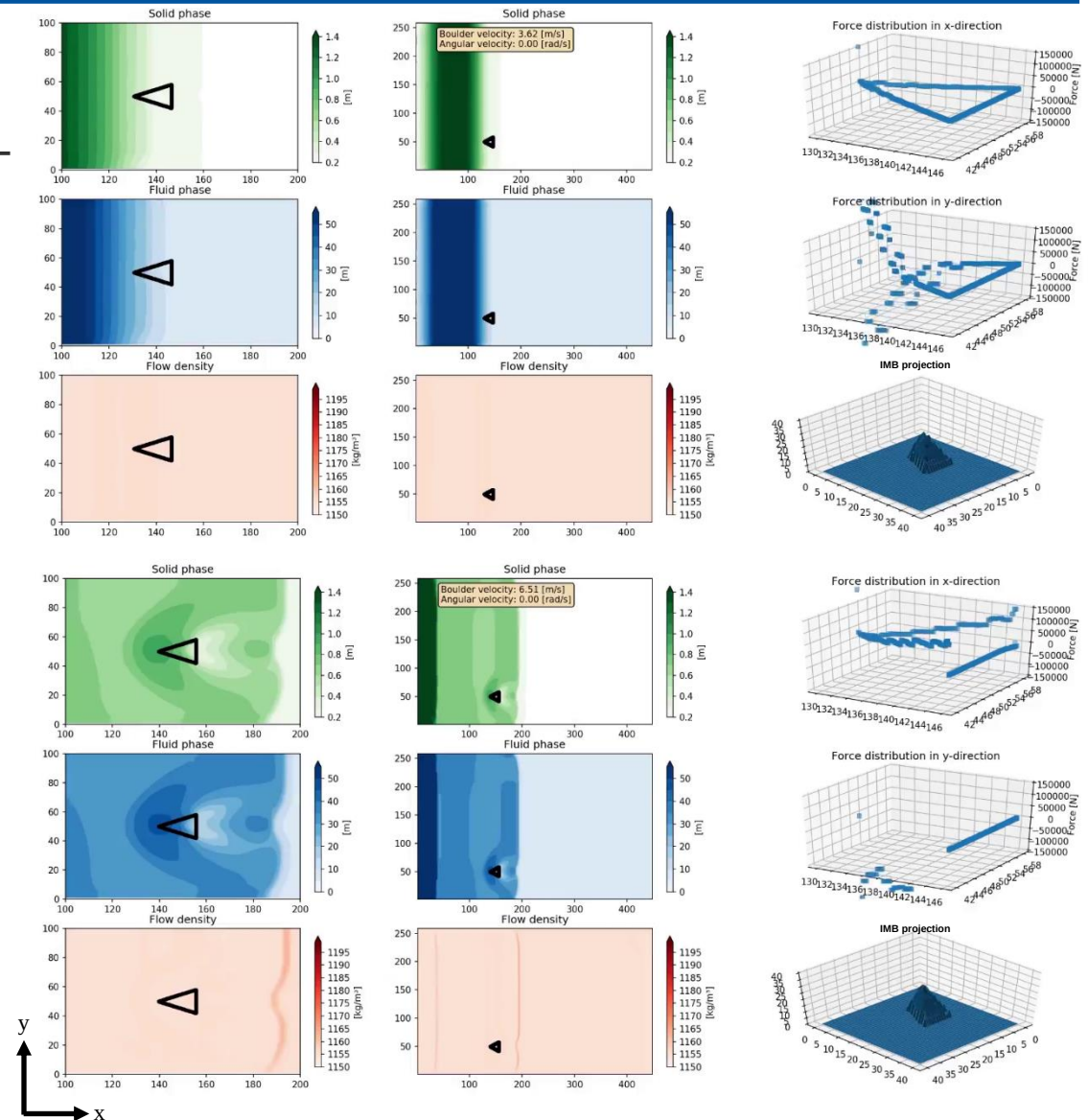


■ Numerical investigations

- Coupled Immersed Boundary Method with the Two-Phase Flow model of Pudasaini (2012)
- 2D depth averaged
- Adjustable boulder shape



Basic numerical setup



Modelling with coupled Two-Phase Flow and IMB

■ Improved knowledge base

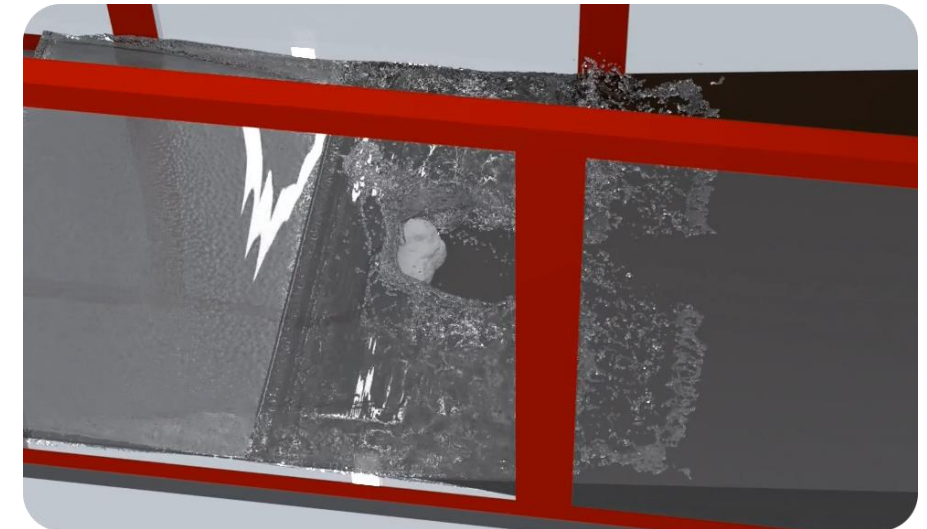
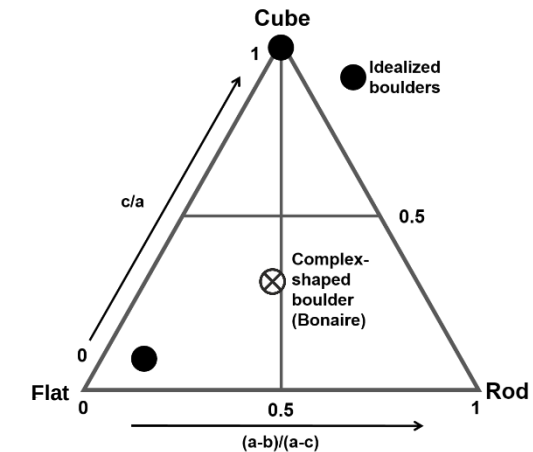
- Exemplary:
 - Systematically defined and scaled experimental conditions
 - Normalized measurement procedure

■ Systematic shape investigations

- Incrementally altered shapes (e.g., cube $\rightarrow$ transition shapes $\rightarrow$ sphere)

■ Full threedimensional numerical modelling focussing on wave boulder interaction

- Detailed force investigations
- e.g. Smoothed Particle Hydrodynamics



Modelling of the complex boulder by SPH
(DualSPHysics)

For further information:

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Significance of boulder shape, shoreline configuration and pre-transport setting for the transport of boulders by tsunamis

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