

Imbricated coastal boulder deposits are formed by storm waves, and can preserve a long-term storminess record

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Supplementary information:

Includes

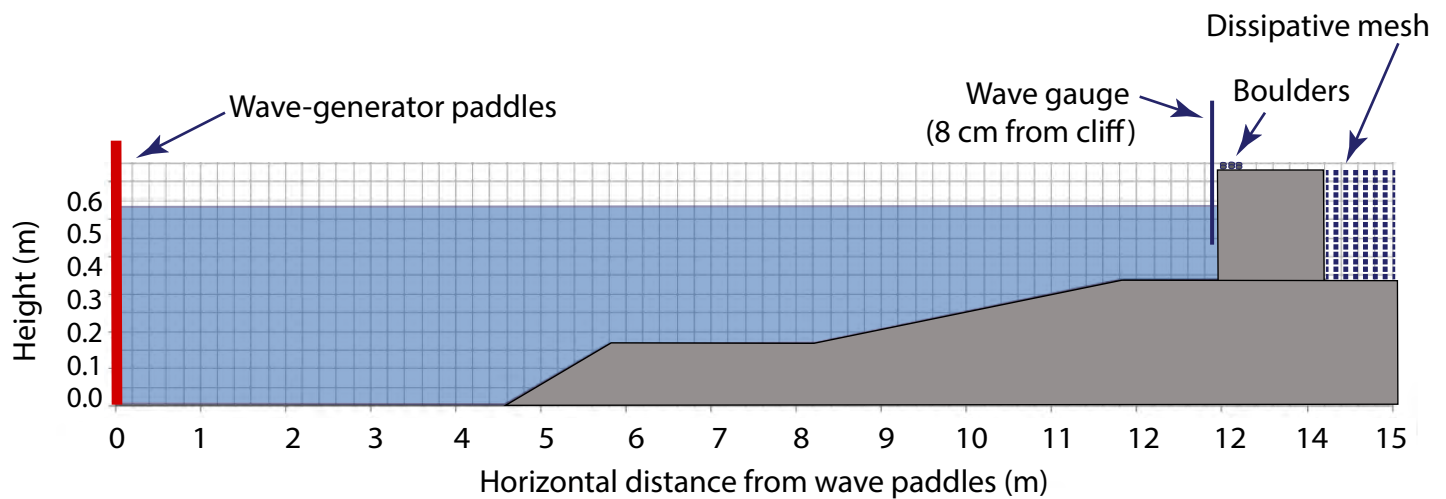
Captions for Movie 1, Movie 2, Movie 3, and Movie 4

Supplementary Figure S1

Supplementary Figure S2

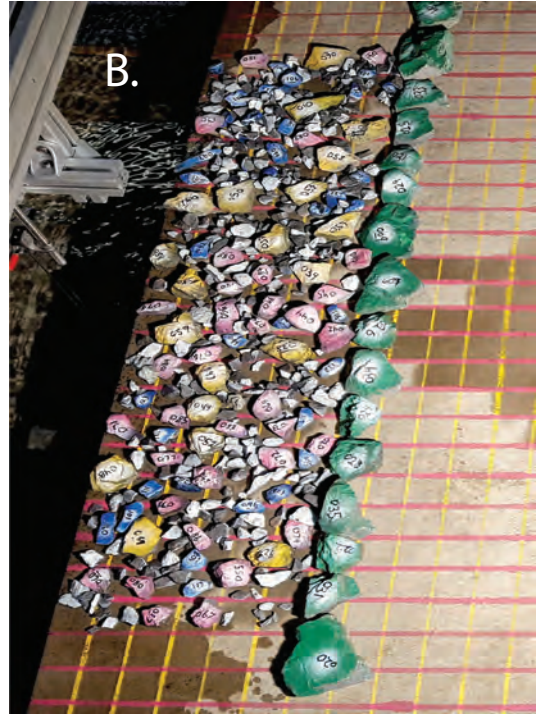
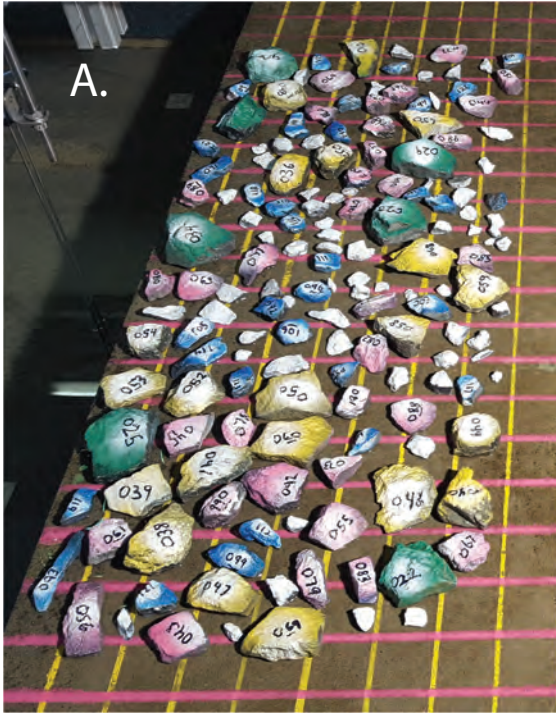
Supplementary Table S1

- Movie 1** GoPro footage showing the first storm segment run in test “Unrestricted 2” (there were fifteen subsequent runs in this test: Table 1). The thin metal rod extending into the water near the cliff (middle of the field of view) is the wave gauge at which the wave trace in Fig. 4 was recorded. Note the relatively small number of cliff-overtopping waves, and also the size-independent stability of boulders positioned right at the cliff edge.
- Movie 2** Sequence of GoPro stills taken at the end of each of the fifteen runs during test “Unrestricted 3” (Table 1), showing the progressive evolution of the deposit. Note that after several runs the core of the main cluster reaches an equilibrium configuration. Small clasts continue to move through and over the deposit, and the scattered boulder field grows; but the main cluster stops migrating inland (larger storms might reactivate it). At the seaward edge of the cluster, flow is competent to move some of the large clasts, which are transported laterally.
- Movie 3** GIF generated from stills taken after each run during test “Backstop 2”. The closeups were taken to document boulder configurations at the end of each storm segment. The sequence highlights some of the different modes by which boulders were stacked within the deposit. Pink arrows show how partial insertion of a small dark (i.e. overturned) clast beneath yellow boulder 010 facilitated uplift of the seaward edge, leading to 010 being tilted vertical. The wedging clast was subsequently transported onto the ridge, leaving 010 balanced at the ridge edge. The yellow arrow tracks the simple overturning of yellow clast 054, which becomes stacked on other clasts. And the red arrows track yellow clast 04, which becomes uncovered half-way through the series. A small grey clast wedges beneath 04, causing it to overturn onto other clasts in the ridge, both narrowing and steepening the deposit. The action of the large overturning clast causes the superjacent small blue clast to also overturn, migrating upward and inward.
- Movie 4** GoPro movie showing the first storm segment test “Cliff Edge 6” (Table 1). The yellow clasts used in these tests all moved readily during the main series tests, when their initial positions were further inland. This test included a further three storm segments, at the end of which the two overturned clasts had reached approximately 55 cm and 60 cm (=55 m and 60 m) inland; one other clast had been transported 50 cm (without overturning); four clasts had been dislodged and fell into the ocean; and three clasts remained unmoved on the cliff edge. Similar results were seen in other tests.



Supplementary Figure S1

Cross-section of wave tank setup, using measurements of Ward⁸⁹, showing configuration used in this study. Note the 4x vertical exaggeration of the Y axis. Water was 54 cm deep (54 m prototype equivalent) in the deepest part of the tank, adjacent to the wave generator, and shallowed progressively across ramps and flats to a near-shore depth of 20 cm (=20 m) adjacent to the cliff. The cliff rose 10 cm (=10 m) above the still-water level. Model boulders were arrayed on the cliff-top platform, which extended 120 cm (=120 m) from the cliff edge. The platform was level for some tests, and sloped seaward (at 3°-7°) for others, as is the case on the Aran Islands. A dissipative mesh behind the platform ensured that overtopping flow was not reflected back; backwash was driven only by gravity.



Supplementary Figure S2

Boulder population setup for (A) unrestricted and (B) backstopped platforms. The 5 cm grid on the platform top represents 5 m at full scale. Clast numbers and colours correspond to Supplementary Table S2

Supplementary Table S1. Catalogue of model boulders used in tests. Individual entries for clasts 10-500g. The smallest clasts (5-10 g) were not weighed individually and are not included in this catalogue. ID numbers and colours in Figs. 5, 6, and 8 correspond to entries in this table. Only the upper surface was painted, so clasts appearing grey in photographs were overturned in transport.

| ID number | Colour | Mass (g) | X axis (cm) | Y axis (cm) | C axis (cm) |
|------------------|---------------|-----------------|------------------------|------------------------|------------------------|
| 018 | green | 475 | 10.9 | 7.7 | 3.3 |
| 019 | green | 317 | 9.2 | 7.3 | 2.7 |
| 020 | green | 507 | 9.5 | 7.7 | 3.2 |
| 021 | green | 168 | 5.5 | 5.2 | 3 |
| 022 | green | 108 | 5.5 | 5.3 | 2.3 |
| 023 | green | 141 | 5.2 | 4.7 | 2.8 |
| 024 | green | 102 | 6.3 | 3.4 | 2.3 |
| 025 | green | 156 | 7.4 | 5.3 | 1.9 |
| 026 | green | 112 | 6.3 | 6 | 1.8 |
| 027 | green | 203 | 6.8 | 5.6 | 2.9 |
| 028 | green | 135 | 6.5 | 6 | 2.5 |
| 029 | green | 138 | 6.3 | 4.9 | 2.3 |
| 030 | green | 257 | 7.2 | 5.5 | 3.9 |
| 031 | green | 154 | 5.9 | 5.2 | 2.9 |
| 032 | green | 198 | 6.1 | 5.3 | 3.8 |
| 033 | green | 191 | 7.3 | 6.8 | 2.1 |
| 034 | green | 243 | 8.5 | 4.9 | 3.4 |
| 035 | green | 172 | 8.7 | 6.1 | 1.8 |
| 036 | yellow | 79 | 5.8 | 3.9 | 1.9 |
| 037 | yellow | 69 | 5.4 | 4.1 | 1.8 |
| 038 | yellow | 84 | 6.6 | 4.4 | 2 |
| 039 | yellow | 60 | 4.8 | 3.8 | 1.7 |
| 040 | yellow | 88 | 5.3 | 3.7 | 2.5 |
| 041 | yellow | 74 | 6.2 | 4.2 | 1.6 |
| 042 | pink | 49 | 4.4 | 4.3 | 1.3 |
| 043 | pink | 38 | 3.6 | 3.5 | 1.5 |
| 044 | pink | 40 | 4.2 | 3.7 | 1.1 |
| 045 | pink | 36 | 4.4 | 3.2 | 1.3 |
| 046 | yellow | 71 | 6.4 | 6 | 1.4 |
| 047 | yellow | 60 | 5.5 | 3.6 | 1.7 |
| 048 | yellow | 82 | 5.9 | 5.3 | 1.8 |

| ID number | Colour | Mass (g) | X axis (cm) | Y axis (cm) | C axis (cm) |
|-----------|--------|----------|-------------|-------------|-------------|
| 049 | yellow | 62 | 4.7 | 4.5 | 1.6 |
| 050 | yellow | 75 | 6.5 | 5.1 | 1.4 |
| 051 | pink | 32 | 3.7 | 2.2 | 1.8 |
| 052 | yellow | 57 | 4.9 | 4.1 | 1.5 |
| 053 | yellow | 56 | 5.3 | 3.3 | 1.4 |
| 054 | yellow | 68 | 4.3 | 3.5 | 2.5 |
| 055 | pink | 44 | 4.1 | 3.8 | 1.6 |
| 056 | pink | 36 | 6.8 | 2.7 | 1.1 |
| 057 | yellow | 66 | 6 | 3.4 | 1.6 |
| 058 | yellow | 74 | 5 | 4 | 1.8 |
| 059 | yellow | 76 | 5.9 | 4.4 | 1.8 |
| 060 | pink | 32 | 4.1 | 3.4 | 1.3 |
| 061 | pink | 33 | 3.5 | 3.4 | 1.4 |
| 062 | yellow | 75 | 4.7 | 4.7 | 1.4 |
| 063 | pink | 32 | 3.8 | 3.2 | 1.2 |
| 064 | pink | 31 | 4.3 | 2.7 | 1.1 |
| 065 | pink | 31 | 3.7 | 3.4 | 1.6 |
| 066 | pink | 34 | 4 | 2.6 | 1.7 |
| 067 | pink | 32 | 3.6 | 3.4 | 1.5 |
| 068 | yellow | 76 | 5.5 | 4.5 | 1.7 |
| 069 | yellow | 73 | 5.5 | 4.2 | 1.6 |
| 070 | pink | 22 | 3.6 | 3.1 | 1.1 |
| 071 | pink | 25 | 4.7 | 2.8 | 1.1 |
| 072 | pink | 23 | 4.8 | 3.7 | 0.8 |
| 073 | pink | 21 | 2.5 | 2.1 | 1.4 |
| 074 | pink | 21 | 4.7 | 2.9 | 0.8 |
| 075 | pink | 22 | 2.8 | 2 | 1.9 |
| 076 | pink | 24 | 3.4 | 2.4 | 1.6 |
| 077 | pink | 25 | 3.8 | 2.1 | 1.6 |
| 078 | pink | 24 | 3.6 | 2.4 | 1.4 |
| 079 | pink | 25 | 5.4 | 2 | 1.3 |
| 080 | pink | 22 | 3.2 | 2.5 | 1.2 |
| 081 | pink | 22 | 3.4 | 2.3 | 1.5 |
| 082 | pink | 23 | 3.9 | 3.3 | 1.2 |
| 083 | pink | 24 | 3.6 | 1.8 | 1.7 |
| 084 | pink | 22 | 3.6 | 3.4 | 0.9 |
| 085 | pink | 22 | 3.7 | 2.9 | 1.1 |
| 086 | pink | 25 | 4.8 | 1.8 | 1.5 |
| 087 | pink | 26 | 3.6 | 3.2 | 1.7 |
| 088 | pink | 23 | 3.8 | 3.6 | 0.8 |

| ID number | Colour | Mass (g) | X axis (cm) | Y axis (cm) | C axis (cm) |
|-----------|--------|----------|-------------|-------------|-------------|
| 089 | pink | 28 | 3.1 | 3 | 1.9 |
| 090 | blue | 12 | 3.2 | 1.9 | 0.8 |
| 091 | blue | 20 | 4.9 | 1.8 | 1.1 |
| 092 | blue | 18 | 3 | 2.1 | 1.4 |
| 093 | blue | 18 | 7.6 | 1.2 | 1 |
| 094 | blue | 15 | 3.1 | 2.5 | 1 |
| 095 | blue | 11 | 2.5 | 2.1 | 1.2 |
| 096 | blue | 12 | 3.1 | 2.3 | 1.1 |
| 097 | blue | 13 | 2.7 | 2.2 | 1.4 |
| 098 | blue | 17 | 3 | 1.5 | 1.3 |
| 099 | blue | 19 | 4.6 | 2.4 | 1 |
| 100 | blue | 20 | 3.8 | 2.4 | 1.4 |
| 101 | blue | 20 | 4.7 | 1.8 | 1.2 |
| 102 | blue | 14 | 3 | 2 | 1.1 |
| 103 | blue | 18 | 2.7 | 2.3 | 1.5 |
| 104 | blue | 17 | 3.5 | 2.4 | 1 |
| 105 | blue | 15 | 3.8 | 1.4 | 1.2 |
| 106 | blue | 16 | 3.1 | 2.6 | 0.9 |
| 107 | blue | 15 | 3.1 | 2.8 | 0.9 |
| 108 | blue | 17 | 2.8 | 2.3 | 1.5 |
| 109 | blue | 11 | 2.7 | 1.4 | 1.2 |
| 110 | blue | 13 | 2.9 | 1.9 | 1.3 |
| 111 | blue | 11 | 2.7 | 2.2 | 0.8 |
| 112 | blue | 11 | 3.3 | 1.5 | 1.2 |
| 113 | blue | 14 | 2.8 | 1.8 | 1.3 |
| 114 | blue | 19 | 4.8 | 2.8 | 0.7 |
| 115 | blue | 14 | 3.1 | 2 | 1.2 |
| 116 | blue | 11 | 3 | 2.4 | 0.9 |
| 117 | blue | 13 | 3 | 2 | 1 |
| 118 | blue | 12 | 3.9 | 2 | 0.8 |
| 119 | blue | 14 | 3.4 | 1.5 | 1.3 |
| 120 | blue | 14 | 3.4 | 2 | 1 |
| 121 | blue | 19 | 2.5 | 1.9 | 1.6 |
| 122 | blue | 20 | 3.3 | 2.6 | 1.1 |
