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WAVE IMPACTS ON CLIFFS: FROM THE FIELD TO THE LABORATORY

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1 INTRODUCTION

Rock coasts occupy over 50% of the global shoreline and many sandy beaches are underlain by coastal platforms and rocky cliffs. The problem of wave-driven cliff erosion is of great societal importance, with many coastal communities located on top of cliffs that are at risk from erosion. Continuing global mean sea level rise and changes in storminess are generally expected to exacerbate the erosion of coastlines (Hurst *et al.*, 2016), as larger waves can reach the cliff toe without breaking offshore. However, the science underpinning wave-induced cliff erosion is still at a relatively early stage. Even the relative contributions of waves to cliff erosion, which include hydraulic forces, impulse pressures and abrasion, are not well resolved.

Most insights into wave impacts on cliffs come from field observations of coastal ground motion during storm events (e.g. Young *et al.*, 2011, Huppert *et al.*, 2020). These field investigations demonstrate the dependence of large wave impacts on both water levels and wave conditions, and in some cases the correlation of periods of large ground motion with increased erosion (Earlie *et al.*, 2015). Unsurprisingly, although large impacts generally occur at high tide during storms characterised by large significant wave heights, the largest impacts occur when tidal levels and storm surge combine to provide water levels that are conducive to the incident waves breaking on the cliffs (Thompson *et al.*, 2019; 2022). Larger wave heights or shallower water levels tend to lead to breaking further offshore, with a broken wave interacting with the cliff, while smaller wave heights or deeper water levels may preclude strong wave breaking on the cliffs.

There have been relatively few experimental studies into wave-driven cliff erosion; these were generally undertaken under very idealised wave conditions (e.g. Sunamura, 1977) and using materials that were either too soft to approximate natural rocks (e.g. Sunamura, 1977; 1982) or too hard to be eroded (Hansom *et al.*, 2008). Although these experiments have informed the development of rocky coast evolution models, their results have not been replicated or verified, and rigorous scaling laws to link laboratory erosion rates to field time scales are currently lacking. However, considering cliffs as steep or vertical (natural) coastal structures, a large body of experimental work has been undertaken to investigate impact pressures and their implications for the failure of engineered structures (e.g. Peregrine, 2003, Bullock *et al.*, 2007). These investigations are complicated by the inherent variability of the wave impact pressures, even within controlled experiments undertaken with highly repeatable incident wave conditions (Raby *et al.*, 2022).

Although field and laboratory data are valuable, it is still very challenging to quantify wave contributions to cliff erosion due to the relatively short durations and variable conditions of most field records. On the other hand, most controlled laboratory investigations have typically focused on loads on non-erodible engineered structures such as seawalls. The current project seeks to advance understanding of the fundamental mechanisms and timescales of wave-driven erosion on rocky cliffs, which will be vital in improving assessments of cliff erosion hazard in high-energy wave environments as sea levels rise.

2 AIM OF PRESENT PAPER

This paper aims to describe a series of physical experiments to investigate wave impacts on cliffs and their erosive mechanisms. These experiments will be informed by the re-analysis of data from a field investigation into wave impacts on cliffs (Thompson *et al.*, 2019) and the thorough classification of wave-by-wave impact classes using video records of approximately 7500 individual impacts (Thompson *et al.*, 2022). Here we present further wave-by-wave analyses that reveal the properties of the waves that create these different impact classes. Using time series data, our results provide new insights into the details of the most impactful waves.

The physical experiments described in this paper will focus on the potential of sediment abrasion and breaking wave impacts to contribute to cliff erosion. Using a highly repeatable setup, the sediment abrasion mechanism is investigated through repeated interactions with a bore representing a highly turbulent broken wave (illustrated in Figure 1), an erodible cliff and the sediment of a beach in front of the idealised cliff. Regular scans of the erodible cliff face provide a detailed understanding of the development of the eroded notch and its evolution in response to the incident bore impacts and subtle changes in the beach profile. The sediment-laden bore impacts are characterised according to their water levels and velocity fields, as well as the approximate concentrations of the entrained sediment in the impact zone. The breaking wave impact experiments use a similar setup to that of Raby *et al.* (2022), considering the sensitivity of the impacts (characterised using impact pressures and accelerations) to small changes in water level and incident wave properties (e.g. phase), and comparing these focused wave results to the largest impacts observed during irregular wave experiments.

The paper will present the methodology and preliminary results of the two sets of physical experiments (abrasion and impacts), including a discussion on the mechanisms, timescales and scaling challenges associated with modelling wave-driven cliff erosion.

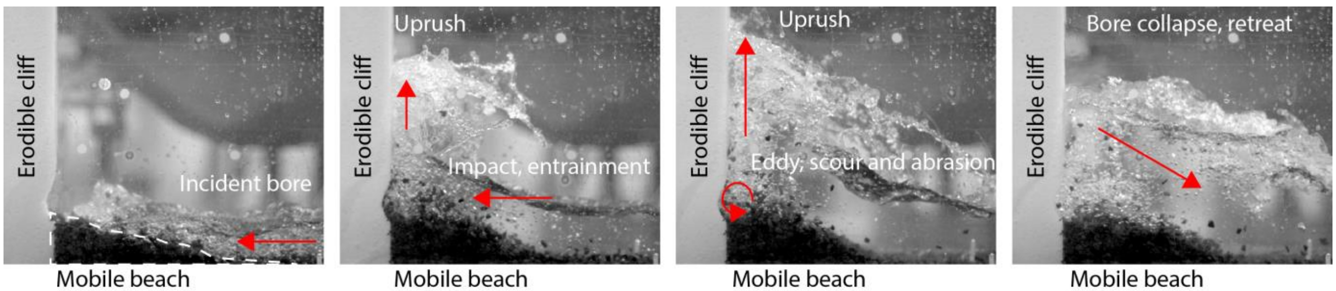

Figure 1. Snapshots from bore abrasion experiments, showing the bore approach towards the mobile beach (shown with dashed lines in the first image), the impact and uprush of the sediment-laden bore, the counter-rotating eddy at the beach toe responsible for sediment suspension, scour and abrasion, and the bore collapse and retreat.

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