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Role of discontinuities in spatial pattern of sea cliff erosion: case of a seaward dipping flysch cliff (Socoa, Basque Country, France)

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Sea cliff shapes and erosion rates are controlled by several factors. Among them, rock resistance, whose strength results from lithology and rock structure, are pointed as major factors. Erosion is expected to focus on discontinuities where the rock mass is weakest (faults, fractures, joints and strata bounds), but understanding the control of discontinuities on the spatial and temporal pattern of erosion remains challenging. To analyze and quantify how rock structures control erosion, we monitored the evolution of a 400-m-long stretch of well-structured sedimentary cliffs: the Socoa cliff (Basque Country, France). The rock, known as the Socoa flysch formation, is a 45°-seaward-tilted, shore-parallel-striking, decimeter-thick repeating sequence of sandstone, mudstone, marl and limestone beds. Cliff-face erosion was observed and quantified using 6 ground-based Structure-from-Motion (SfM) surveys, spanning 5.7 years between 2011 and 2017. To compare with longer term data, a multi-decadal (54 years) cliff-top retreat rate was also assessed using SfM-orthorectified archive aerial photographs spanning the period 1954-2008. During the ground-based survey, the 13 250 m² cliff face released 4500 blocks larger than $1.45*10^{-3}$ m^3 for a total rock volume eroded of 170 m^3. This rock lost volume equates to an average cliff retreat rate of 3.4 mm/yr. It is slightly slower than the 54 years-average cliff top retreat rate of 10.8 ± 1.8 mm/yr. In elevation, the maximum erosive activity is positioned about 2 m above high spring tides. The geographic position of rock scars is controlled by tectonic discontinuities. Alongshore, hot-spots of erosion are focused where major faults cross-cut the cliff face. Around these geographic hotspots, the depth of detached blocks is controlled by bed thickness, removing one or several beds at once. The surficial extent of detached blocks on the cliff-face is controlled by orthogonal secondary tectonic joint sets. These joints do not stop on lithological bed limits but rather on mechanical limits encompassing several lithological beds at once. As a process, we explain block detachment and cliff collapse by a cycle of erosion nucleation on discontinuities, radial erosion propagation around the nuclei and finally, cliff collapse crisis affecting the cliff top. We demonstrate that block production is concentrated around faults (nucleation) that focus erosion and allows for the radial development of sea caves close to cliff foot. Then, block production occurs mainly around those caves by radial detachment processes at free edges or fractures (propagation). It may lead, exceptionally, to high-magnitude events, during which slab collapse can affect the cliff from base to top (crisis).