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Genesis and architecture of sequences of Quaternary coral reef terraces: insights from numerical models

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The variety of existent morphologies of coral reefs highlights their elevated sensitivities to several forcings. This diversity is equally represented in the fossil counterparts, which stack in accordingly diverse sequences of reef terraces or barriers. The current scarcity of observations and datings does not allow yet the general conceptualisation of behaviour laws, but this difficulty can be overcome by numerical modelling. We devised a numerical approach to unravel the significance of these spatial and temporal variability, that accounts for sea-level oscillations, vertical land motion, initial slope, wave erosion, and reef growth. We benchmark our model on the well-documented subsiding sequence of Hawaii and on the original sequence of Wangi-Wangi (Sulawesi) that has the particularity of exhibiting active barrier reefs in an uplifting setting. According to common theories, barrier reefs are supposedly archetypical of subsiding settings, but this example discards this common assumption. We set out to test the impact of a range of parameters on the development of sequences of coral reef terraces, and take advantage of the flexibility of our model to expand our analysis towards a parametric study. In order to treat the full range of simulations that encompass the considered parametric windows, we propose that sequences of coral reef terraces form barcodes, described by extracting a few geometrical characteristics (number, width and height of terraces, presence of barriers). This comprehensive yet compact description of the sequences can conveniently be used to compare the sequences. We find that geological factors are prominent controls on the architecture of reefal sequences, and suffice to explain the variety of observed sequences, to the first order, regardless of ecosystemic processes that impact their development only to the second order. Vertical land motion and slope of the foundations are the prime parameters at the scale of the sequence. The potential growth rate of the reef itself only plays a minor role. Barriers may develop both in uplift and subsidence mode, although they are more frequent on subsiding coastlines. Whether sequences preserve their barriers -either active or fossil- efficiently informs on the wave erosional power. We thus reappraise the genesis of sequences of coral reefs in a unified theory. The joint effects of the parameters at play, including local idiosyncracies, imply that terraces may correspond to unexpected event: major events can be poorly represented, some episodes of sea-level fluctuations may be over-represented by several terraces, or conversely absent, and reoccupations can lead to composite terraces representing multiple events. Consequently, we propose a change of paradigm. We contend that sequences should not be considered as stacks of fossil reefs formed during discrete events of sea-level oscillations, sea-level highstands, but instead form during a continuous process throughout the whole eustatic variations, and that the commonly assumed bijective relationship between sea-level highstands and terraces shall be abandoned.