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Space-for-time substitution and the evolution of submarine canyons in a passive, progradational margin.

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40% of submarine canyons worldwide are located in passive margins, where they constitute preferential conduits of sediment and biodiversity hotspots. Recent studies have presented evidence that submarine canyons incising passive, progradational margins can co-evolve with the adjacent continental slope during long-term margin construction. The stages of submarine canyon initiation and their development into a mature canyon-channel system are still poorly constrained, however, which is problematic when attempting to reconstruct the development of passive continental margins.

In this study we analyse multibeam echosounder and seismic reflection data from the southern Ebro margin (western Mediterranean Sea) to document the stages through which a first-order gully develops into a mature, shelf-breaching canyon and, finally, into a canyon-channel system. This morphological evolution allows the application of a space-for-time substitution approach. Initial gully growth on the continental slope takes place via incision and downslope elongation, with limited upslope head retreat. Gravity flows are the main driver of canyon evolution, whereas slope failures are the main agent of erosion; they control the extent of valley widening, promote tributary development, and their influence becomes more significant with time. Breaching of the continental shelf by a canyon results in higher water/sediment loads that enhance canyon development, particularly in the upper reaches. Connection of the canyon head with a paleo-river changes evolution dynamics significantly, promoting development of a channel and formation of depositional landforms. Morphometric analyses demonstrate that canyons develop into geometrically self-similar systems that approach steady-state and higher drainage efficiency. Canyon activity in the southern Ebro margin is pulsating and enhanced during sea level lowstands. Rapid sedimentation by extension of the palaeo-Millars River into the outermost shelf and upper slope is inferred as the source of gravity flows driving canyon evolution. Canyon morphology is shown to be maintained over the course of more than one fall and rise in sea-level. Our model of canyon evolution is applicable to other passive margins (e.g. Argentine continental margin).