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A unification of channel incision laws in steep, coarse catchments based on high Shields numbers

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Traditionally, river channels have been modelled as either detachment- or transport-limited; in the former case, incision rates are controlled by the stream's ability to erode the bed, in the latter rates are controlled by downstream divergence in sediment carrying capacity. Previous studies have highlighted the expected differences in channel dynamics created by these two end-member scenarios. However, for many coarse, mountainous channels, neither of these simple options is entirely appropriate. If a river is directly loaded by large amounts of sediment supplied by colluvial or other non-riverine processes, and especially if this sediment is coarse, then neither of the sets of assumptions underlying these models is satisfied, since mobilising these sediments may be of comparable difficulty to transporting them away. These situations may include those where channels are directly coupled to hillslopes which are sources of bedrock landslides, debris-flow-prone environments and paraglacial landscapes in which rivers must process large amounts of glacial debris. Instead, for these settings some intermediate case – a "hybrid" incisional system – must be considered.

Previous workers have tended to model such systems on a purely detachment limited basis with a sediment flux term, f(Q_s), modulating erosional efficiency. These approximations show nonlinearity of incision rate with increasing shear stress, τ, on the bed, with peak incision rates occurring at moderate values of τ. However, we show here that a similar response may be expected from a purely transport-limited river where the critical Shields number is very high, with channel-forming discharges close to this threshold. Excess shear stress above the threshold at first creates a strongly non-linear amplification of erosion of the bed, and then with further increases, counter-intuitively starts to actively inhibit incision. This process is driven by a switch in dominance from increasing carrying capacity to increasing difficulty in mobilising enough sediment in high shear stress events; importantly however, no explicit formulation and calibration of a "tools and cover" effect is required. Instead, the form of the incision nonlinearity is an intrinsic property of the incision law, dependent only on the Shields number. Thus this approach may be more parsimonious than those based on the detachment-limited framework when applied in appropriate settings.