Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2018-35-SC1, 2018

Earth Surface Dynamics Discussions

ESurfD

Interactive comment

Interactive comment on "Clast imbrications in coarse-grained sediments suggest changes from upper to lower flow regime conditions" *by* Fritz Schlunegger and Philippos Garefalakis

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Received and published: 30 May 2018

Commentary from Paul A. Carling

The authors are to be congratulated for addressing the process controls related to the development of imbrication in coarse-grained sediments. Surprisingly, despite the availability of suitable flume-based equipment in recent years to study the process and hydraulic regimens in detail, relatively few experimental data have been published on the subject (Qin et al., 2012) and nothing substantial on the mechanics of particle orientation during the imbrication process. Although laser scanning is now being applied to investigate particle packing in the field (e.g. Hodge et al., 2009: Millane et al., 2006), there is little consideration of the flow regimens related to the formation and preservation of imbrication. Much of the field-related imbrication literature makes little or no reference to the associated flow regimens which reworked the gravel beds, so in some instances they could have been subject to both super-critical and sub-critical flow regimens (e.g. Kauffman & Ritter, 1981; Smart et al., 2004), whilst for other beds only sub-critical flows were likely (Sengupta, 1966; Hodge et al., 2009: Bury Green Brook). The issue of flow regimen and imbrication has relevance to the process of armour development which was a topic of considerable interest in the 1980s (e.g. Bray & Church, 1980; Carling, 1981) but which largely has been neglected until the last decade. Rather than present an exhaustive (and largely positive critique) of the draft manuscript, below I make some general observations that the authors might consider in any revision of their work.

I note that in the manuscript the various upper-stage bed states are not clearly defined, nor delimited, in terms of the hydraulic conditions that pertain to each bed state. Neither standing waves nor hydraulic drops are clearly distinguished. Also upper-stage plain beds and hydraulic jumps are not considered, although particles can imbricate on the beds below all four of these flow states. In the same vein, it is not made clear why lower-stage bed states cannot be associated with imbrication when there are field examples from such flows, as noted above. Although the authors suggest Grant (1997) indicated that super-critical flows in rivers are rare, a careful reading of Grant (1997; see also Tinkler, 1997a&b) demonstrates that such flows cannot be sustained for long, nor over substantive distances which allows for such flows in principle to occur frequently, such as in the case of breaking standing waves. If super-critical flows are rare, as the authors suggest, then imbrication should also be rare, which is not the case.

The manuscript does not state explicitly, but it implies, that imbrication occurs only at the transition from upper to lower flow regimen. In itself this observation might reflect the fact that imbrication is more likely to be stable and observable beneath lower-stage flows or on a bed that is dry after flow cession (subsequent to such a transition). In contrast, the bed may be both difficult to observe and may be unstable when flow transitions from lower to upper stage, such that the identification of the presence and persistence of imbrication is less assured.

As noted above, laboratory studies are few that consider the detailed hydraulic conditions. Johansson (1963) examined the roll of gravity and turbulence on initial motion in sub-critical experimental flows as well as a transitional flow and locally-developed standing waves. In sub-critical flows, Johansson noted particle vibration (see also Tipper, 1989), before entrainment by rolling and sliding, and reported that all three modes of motion contributed to imbrication once particles came to rest. Significantly, Carling et al. (1992) reported on initial motion of various particle shapes from different pebble-roughened and cobble-roughened fixed beds which included observations of in situ particle rotation and imbrication of different shaped particles. The significance of this particular study is that all the experimental flows were sub-critical. The detailed observations of Carling et al. (1992) show that although imbrication may occur from sliding of a particle 'in situ' (i.e. within the immediate vicinity of the bed pocket), particles tend to be entrained into transport by rolling. These results indicate that when a mobile particle comes to rest, it is likely to imbricate and stabilize by sliding rather than by rolling.

From the above, Schlunegger and Garefalakis's description of imbrication as a product of rolling, but not sliding, of clasts is rather oversimplified. Actual clast motions over the bed are quite complex and irregular as Carling et al. (1992) present in some detail. The role of clast shape in mediating initial motion, style of motion and in the degree of imbrication is also relevant, as has long been known. Although here I do not develop this aspect, steep imbrication angles for suitably-shaped clasts are more often reported for high-velocity flows than for low velocity flows, such that the influence of flow regimen on particle attitude would be worth exploring further.

The authors have established an approximate relationship between the occurrence of clast imbrication and the presence of upper flow regime flow (Froude > 0.9, approxi-

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mately). However, this is not the necessarily the same as the upper to lower regime transition (as claimed in the title and abstract). The authors should check for possible circularity in their calculations; they appear to derive flow depth from the Shields equation, having substituted for τ (the bed grain shear stress) after first arbitrarily fixing τo (the critical bed grain shear stress.

A more nuanced approach to rewriting this manuscript would lead to a useful contribution on the probability of imbrication occurring under different flow regimens.

Acknowledgements

I thank Mike Church for suggestions that contributed to shaping this commentary and to Rob Ferguson for checking the derivation of the equations presented by Schlunegger and Garefalakis.

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