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Expanding the "Active Layer"

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COMMENTARY

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Key Points:

- The terminology for the active layer for fluvial bedload transport can be expanded to encompass a "morphological active layer"
- In laterally unstable (e.g. braiding) rivers the morphological active layer has significant lateral extent and varying morphology
- The form of active later in a river type distinguishes differences in bedload dynamics

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Expanding the "Active Layer": Discussion of Church and Haschenburger (2017) What is the "Active Layer"? *Water Resources Research* 53, 5–10, Doi:10.1002/2016WR019675

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Abstract Church and Haschenburger (2017, https://doi.org/10.1002/2016WR019675) make helpful distinctions around the issue of defining the active layer, with which we agree. We propose expanding discussion and definition of the "active layer" in fluvial bedload transport to include the concept of the "morphological active layer." This is particularly applicable to laterally unstable rivers (such as braided rivers) in which progressive morphological change over short time periods is the process by which much of the bedload transport occurs. The morphological active layer is also distinguished by variable lateral and longitudinal extent continuity over a range of flows and transport intensity. We suggest that the issue of forms of active layer raised by Church and Haschenburger opens up an important discussion on the nature of bedload transport in relation to river morpho-dynamics over the range of river types.

Church and Haschenburger (2017) raise a fundamental issue in fluvial bedload and morphodynamics by identifying the need to consider what is meant by the "active layer." Church and Haschenburger (2017) conclude that the term has been applied to two categories of active layer. One category is the dynamic active layer or exchange layer (sometimes referred to as the Hirano layer) and its variants used in sediment transport modeling and referring to the layer of continual particle exchange between the bed and near surface and bedload. The second category is the "event" active layer or "disturbance layer," referring to the sediment layer that can be scoured or filled during a bedload transport event (or multiple events), or during the passage of bedforms such as dunes. We agree that these differences have not been recognized in typical usage and we support the distinction made by Church and Haschenburger (2017). Here we aim to expand the discussion in two ways. First, by addressing these active layer categories in light of observations in braiding rivers (and other laterally-unstable rivers), and second, by connecting active layer characteristics to the nature of the bedload transport process in rivers of different morphology and particularly gravel-bed rivers.

The differences identified by Church and Haschenburger (2017) are partly related to defining bedload as a primarily hydraulically-driven, surface-based, grain scale exchange process on a stable bed, or as a morphological process in which bedload and progressive changes in channel form are closely connected at small time steps. The relative importance of surface-exchange or morphological transport differs between river types and scale (Ashmore & Church, 1998), and therefore an essential element of this discussion is extent to which the characteristics of the active layer reveal and distinguish the nature of the bedload transport phenomenon between river types.

For the most part, bedload in gravel-bed rivers has been analyzed as surface-based particle exchange over a stable bed morphology. In addition, much of the current usage reviewed by Church and Haschenburger (2017) refers to stable single-bed channels (particularly in the case of gravel-bed rivers) which generally have little topographic development during transport or limited local scour and compensating fill during mobilizing events, or are dominated by the passage of meso-scale wavy bedforms such as dunes. In laterally unstable and morphologically dynamic rivers, such as braiding rivers, one can envisage another form of active layer: the "morphological active layer" (Leduc et al., 2015) referring to the volume of sediment reworked by the river over a specified time interval. In morphologically dynamic rivers transporting bedload, a large area and depth of the bed sediment layer is mobilized as part of the transport process in short time periods related to channel-forming processes such as channel avulsion, bend and confluence scour, bar migration, and channel pattern reconfiguration. These channel-forming processes occur at bankfull and lower discharges and increase in magnitude with increasing discharge in a given river. As a result, at

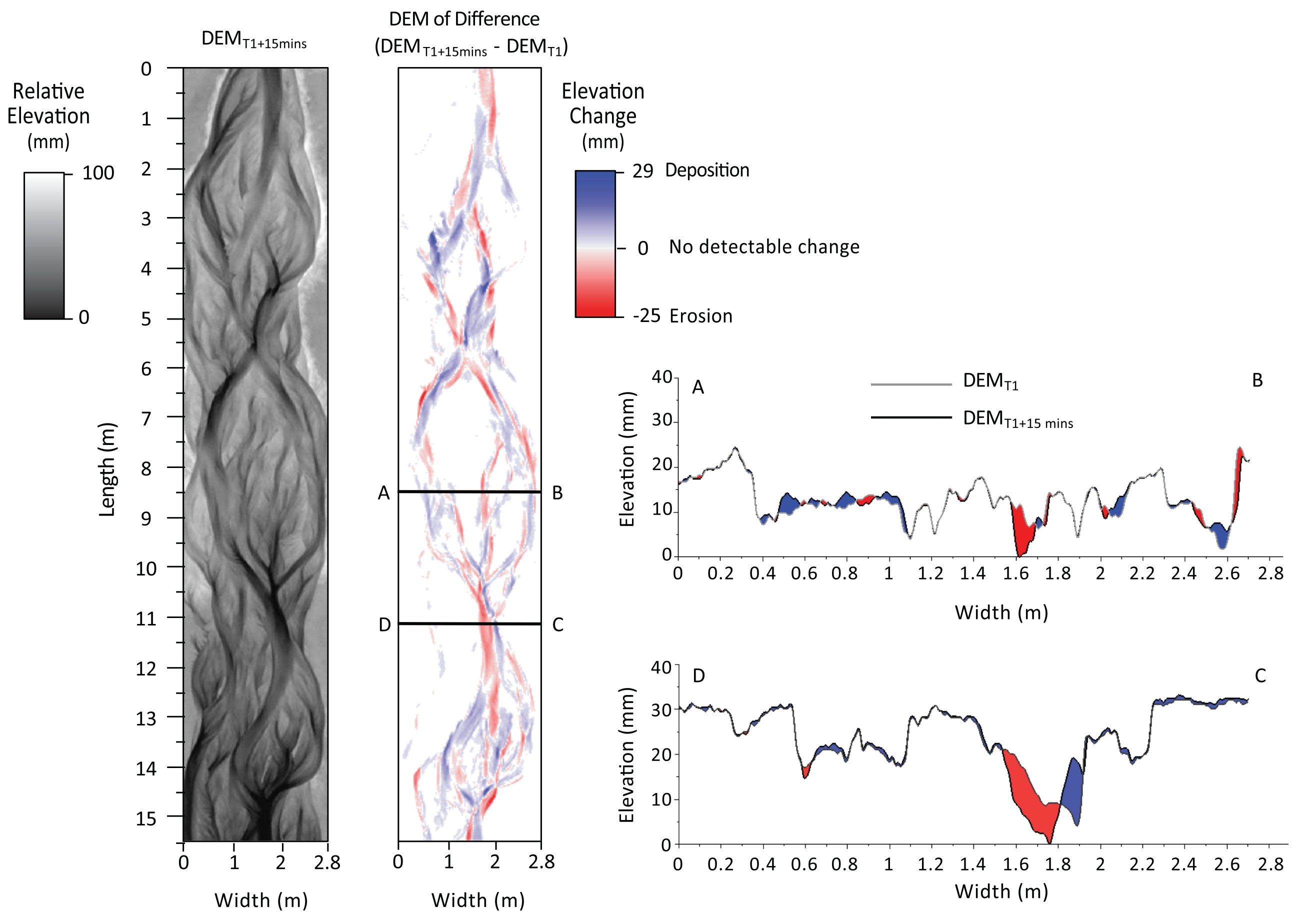

Figure 1. (left) Digital elevation models from a Froude-scaled physical model of a braiding channel were used to generate (middle) DEMs of difference (DoD) by comparing the elevation differences between DEMs over time. (right) The planform view of the DoDs demonstrate differences in the morphological active width spatially, while the cross sections illustrate some of the variability in the morphological active depth at a given time step.

channel-forming discharge and high bed material mobility, the rate of morphological turnover of bed-material increases (Wheaton et al., 2013). Expansion of this morphological active layer with increasing flow occurs both laterally, through the expansion of the morphological active width (Ashmore et al., 2011), as well as vertically via increasing morphological active layer depth. Lisle (1995) also discusses the "active layer thickness" as a morpho-dynamic characteristic of gravel-bed rivers varying with bed sediment mobility. The maximum morphological active layer depth in gravel-bed and sand-bed rivers is equivalent to the amplitude of the topography across the whole river. This may be 20–30 D_{50} in gravel-bed rivers (Ashmore et al., 2011; Wheaton et al., 2013; Williams et al., 2016), and has equivalent vertical extent in sand-bed rivers when scaled by the topographic amplitude of the river bed (Lane et al., 2010; Parker et al., 2013). The morphological active layer is also the sedimentological active layer: the layer in which the dominant scale of sedimentary structures and grain sorting develop within the fluvial deposit (Leduc et al., 2015; Parker et al., 2013).

We propose that in relation to bedload transport processes, the "morphological active layer" can be adopted to refer to the entire layer of fluvial sediment subject to channel scale morphological re-working, from which the channel forms, and through which the channel functions as a bedload movement system. Specifically, this refers to the bed sediment that produces progressive development (i.e., active braiding and morphological change) in laterally-unstable rivers, rather than the compensating scour and fill found in stable, single-thread gravel bed channels. Figure 1 demonstrates this with an example of morphological development in Froude-scaled physical models of gravel braided rivers in which the extent of the morphological active layer extent was calculated by DEM differencing. Additional characterization of the morphological active layer reveals that it varies in width and depth with discharge (commensurate with differences in bedload transport rates) and cannot be represented as a uniform "sheet" of mobilized sediment (Leduc et al., 2015). In addition to being laterally and vertically variable, significant active layer turnover can occur in very short time periods at high flows (Ashmore et al., 2011) so that large proportions of the channel area can be re-worked in a single event (Parker et al., 2013; Williams et al., 2016) or at sub-event time scales at higher (near bankfull) discharge. These active layer dynamics have been observed in real time over periods of much less than an hour and as small 15 minutes in small-scale models (equivalent to less than an hour at full scale) (Ashmore et al., 2011; Lindsay & Ashmore, 2002). Furthermore, observations from small-scale models run with constant channel-forming discharge indicate that the extent of re-working of this morphological active layer increases with the time interval, signifying that it is a continuous process of morphologically-connected transport.

In their paper, Church and Haschenburger (2017) distinguish the "dynamic" and "event" active layers in terms of scale (time and length). The morphological active layer that we have described in braiding rivers is most similar to the "event" active layer. We note that in very dynamic rivers the morphological change defining the active layer is, in effect, equivalent to the active bedload (Ashmore & Church, 1998; Vericat et al., 2017) but it will be useful to provide clear information on the time period for which it is defined and measured in any particular case. In addition, the morphological active layer in braiding and similar river types has significant lateral extent. In contrast to previous discussion and characterization that has focussed mainly on the vertical extent of the active layer, the morphological active layer in many braiding rivers is a three-dimensional phenomenon. The extent of the morphological active layer is spatially and temporally variable laterally and longitudinally, with highest continuity and contiguity at higher discharges (i.e., higher bed material mobility) (Figure 1). Variation in lateral extent may be much greater than variation in vertical extent over a range of discharge The three-dimensional characteristics is a significant element of the morphological active layer and its direct connection to morphodynamics of the entire channel in relevant river types at a range of time scales.

An important corollary of this active layer discussion is that analysis and modeling of bedload transport, in relevant river types, should extend from purely grain-scale, surface-based mechanics to larger scale processes of channel morpho-dynamics. Therefore, beyond considerations of definition alone, we suggest that the analysis of the active layer may provide insight into the differences in bedload transport processes and channel morpho-dynamics in rivers of different types and at different spatial and temporal scales. It is likely that more extensive morphological active layers are associated with gravel-bed rivers with greater relative bed material mobility and this may also be tied to absolute river scale as well as river type and flow stage (Lisle, 1995). Church and Haschenburger's (2017) review therefore opens up the possibility of expanding the discussion of the active layer to thinking about differences in bedload transport process, and to relations between bedload and channel morpho-dynamics, across the spectrum of river types.

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