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Discussion

Reply to comment on "How plausible are high-frequency sediment supply-driven cycles in the stratigraphic record?" by Jasper Knight

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1. Introduction

The comment by Jasper Knight on "How plausible are high-frequency sediment supply-driven cycles in the stratigraphic record?" (Castelltort and Van Den Driessche, 2003) mostly tries to defend that rivers and their stratigraphic record show a complexity across many spatial and temporal scales that we would have overlooked in our paper. This would have made our work, based on the sedimentary system concept, "narrow in approach and outlook", and lead us to "conceptual weaknesses". Jasper Knight then claims proposing "some alternative ways at looking at the operation of river sediment systems".

In fact, Jasper Knight only enumerates some geological truisms about fluvial systems, erosion and sedimentation, whereas in our paper we made it clear that the concept of macroscale sedimentary systems on geological timescales "is aimed at distilling the first-order characteristics and dynamics of real systems from their natural complexity". This leads him, through a superficial reading, to a complete misunderstanding of our paper.

In this reply, we will briefly explain why there is no contradiction between our results and the different aspects of river systems that Jasper Knight points out. By the way, we will try to clarify our results and our philosophy.

2. The operation of fluvial sediment systems

We acknowledge that rivers are very complicated systems with a lot of factors playing in concert, but as we stated in our paper, following the well known works of Schumm (1977) and Allen (1997), our approach based on the sedimentary system concept was "aimed at distilling the first-order characteristics and dynamics of real systems from their natural complexity". Therefore, our work should be read having in mind this perspective, with its advantages and limitations that we also made clear elsewhere in the paper.

Jasper Knight develops that "erosion and deposition take place throughout the length of a river system" at a variety of space and time scales, and that the path of sediments inside a river over time is complex, i.e. made of temporary storage and remobilisation, again at a variety of space and time scales.

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We say nothing different when we state that sediment supply variations at the entrance of sedimentary basins "may not necessarily be tied in a straightforward way to allogenic changes in the erosion zone", or that "the sediment flux (...) has to be transported from its production zone to the deposition zone, which is unlikely to be instantaneous".

Jasper Knight writes that "it is likely that most erosional products never make it to a terminal site of deposition (i.e. a river mouth), but are stored within a river's transfer zone over timescales of 10^3–10^5 years" and that "as such there is an imbalance between sediment input and output which will be overlooked if studies are based (...) on the catchment as a whole (e.g. C and VDD)". This is exactly our point! The temporary sediment storage on such timescales and the imbalance between sediment input and output are, respectively, the expression and result, of the buffer effect we argue for.

Jasper Knight states that: "the long response times (scale of 10^5–10^7 years) of river systems to allogenic forcing, calculated by C and VDD, suggest that rivers are insensitive to changes operating at a frequency higher than Milankovitch-driven glacial-interglacial cycles". Firstly, our calculated response times are of the order of 10^3–10^6 years. Secondly, we stated clearly in our text, based on Paola et al. (1992) and Beaumont et al. (2000), that "the response time (or equilibrium time), is the time needed to return to equilibrium after a change in boundary conditions", and that "if they (the boundary conditions) vary rapidly compared to the response time, the response will not be in equilibrium with the forcing". This lead us to the main conclusion that "in detrital accumulations fed by the way of intermediate to large transfer subsystems, as large deltas for example, high-frequency ($\leq$ 100 ka) sediment flux oscillations may not occur in equilibrium with allogenic changes in the source area. Therefore, high-frequency stratigraphic cycles cannot be an equilibrium response to such allogenic changes". In contrast with the way Jasper Knight interpreted our response times, the buffer effect illustrated in our work is an evidence that rivers are sensitive to high-frequency oscillations.

Let us now answer to each point used by Jasper Knight to argue that our response times are "meaningless": (1) "They compare rivers from different physical and climatic settings and with different geological histories". This is one major mean by which you can find a common descriptor, and understand something about the general behaviour of rivers. (2) "They imply a single period of allogenic forcing followed by system response". This is wrong. The calculated response times are independent from the number of allogenic forcing periods. (3) "They do not consider the effects of shorter-period allogenic forcing or different scales of forcing". This is obviously interesting, but complexifying the problem was not our aim. Everyone is free to go further our work and to do this for example. (4) "They do not consider that allogenic forcing (and thus river response) may be focused on some river reaches rather than others". We made it clear in the paper that "we consider macroscale sedimentary systems (e.g. schematic mountain–river–delta or catchment–fan systems) on geological time scales". Allogenic forcing that would focus to some river reaches rather than other would be tied de facto to smaller scale allogenic forcing and smaller scale sedimentary systems. This is beyond the scope of our work, but does not invalidate in any way our results in the framework we stated first. (5) "They do not consider the role of temporary storage (and therefore possible equilibrium) within the river's transfer zone (although this is highlighted as important)". Again, we made it clear in our work by explicitly stating that "the sediment flux (...) has to be transported from its production zone to the deposition zone, which is unlikely to be instantaneous". Therefore, this is not only highlighted as important, it is crucial. If rivers act as buffers for sediment supply variations coming from the source area, this is because they temporary store sediments along their course. In this way, temporary storage, and alluvial terraces, are the stratigraphic expressions of the buffer effect.

Jasper Knight then refers to the study of Macklin et al. (2002) in order to give an example of synchronous response of different catchments to a same allogenic forcing. This study deals with the recognition of fluvial aggradation events preserved in the Mediterranean basin during the last 200 ka (Macklin et al., 2002). Again, this does not contradicts our results, as stated by Jasper Knight, but better strongly reinforces them because such aggradation events inside those transfer zones are the witnesses of temporary storage, i.e. of the buffering effect of those transfer zones for sediment flux variations coming from upstream zones at high-frequencies.

3. Conceptualising river systems' response to allogenic forcing

Whereas an image represents a given object (for example, a given river), the concept represents all the objects of a same family (rivers in general). Therefore, the concept helps in understanding the characters of an extended number of objects.

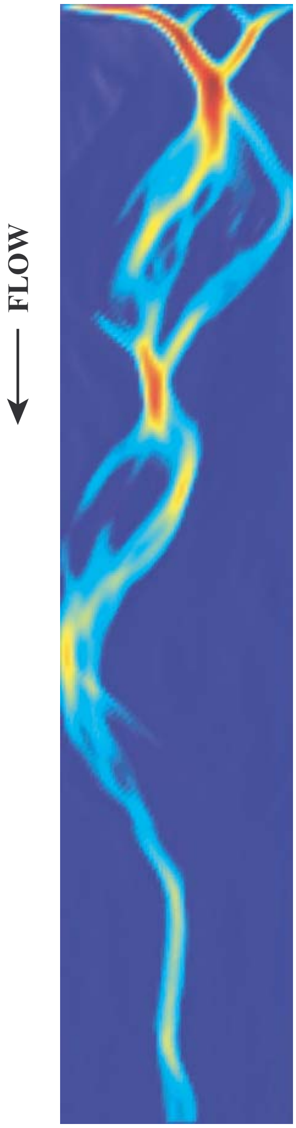

Fig. 1. Example of a simulated braided river. Warm colors indicate increased sediment load in the water at flow convergences and cold colors indicate smaller sedimentary loads at flow divergences.

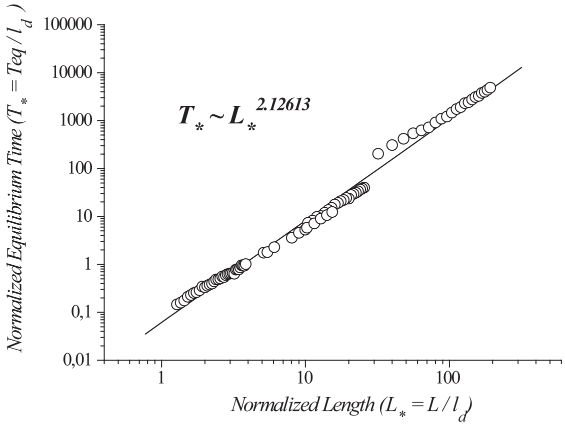

Fig. 2. Evolution of equilibrium time of simulated rivers with their length. The equilibrium time T_{eq} and the length L are normalized to the transport length of sediments l_d. When l_d is less than the system's length (L_*>1), the sediments can be temporarily stored in the system, which is the case of alluvial rivers. The graph shows that the equilibrium time scales well with the squared system's length, which is indicative of a diffusive behaviour.

When Jasper Knight states that "it is more useful to consider the transfer zone as comprising a shifting mosaic of temporary sediment storage areas which change in location and importance over time and which respond to different forcing factors on different scales'', he argues for a broader consideration of rivers complexities, but this is not conceptualising. In our paper, we conceptualise river systems' response by embodying most of rivers' complexities in an average diffusive behaviour.

Our assumption of a Fickean diffusive behaviour of rivers could have appeared strong to some, even if it was already supported by several works (e.g., Dade and Friend, 1998; Humphrey and Heller, 1995; Métivier, 1999; Métivier and Gaudemer, 1999; Paola et al., 1992). Indeed, if grains were transported in a purely advective way, i.e. at water velocity (1 m s^{-1} on average), the time constant for sediments to travel through a river of 1000 km long would be of the order of 10 days, whereas our calculated response times are better of the order of 100 ka on average. Such a large difference would therefore suggest that the real behaviour of rivers may be better somewhere between advection and diffusion, and the real response times between those extrema.

By using the numerical model Eros (see Crave and Davy, 2001 for details of the model), which fully incorporate advection and diffusion for the transport of sediments, we recently simulated (Fig. 1) the formation of alluvial rivers (Castelltort et al., 2003). In the model, vertical incision is a function of discharge and slope, and sedimentation is proportional by $1/l_d$ to the sedimentary load in transport, with l_d defined as a characteristic transport length of sediments (Crave and Davy, 2001; Davy and Crave, 2000). We showed that the small scale (in time and space) advective transport of sediments in alluvial rivers can be averaged as a diffusive behaviour on the long term (Castelltort et al., 2003), because the response times of those simulated rivers scale with their squared length (Fig. 2). This reinforces the diffusive assumption made in our paper and supports our results.

The traditional approach in stratigraphy, which is mostly interested in a sum of details, as illustrated by the view of Jasper Knight in his comment to our paper, has long confined stratigraphy to an "unstructured science, preoccupied with description" (Sloss, 1962).

We better agree with the research philosophy of Kirkby (1999) when he states that: "the variety of fluvial forms described in this book ('Varieties of Fluvial Form' by Miller and Gupta, 1999), and the generally light level of analysis that has been possible within these case studies, illustrate the very limited way in which detailed fluvial research has been able to contribute to a broad understanding of rivers and channelways. It is time to draw conclusions from all that has been learned in the last 50 years, and apply them, in a suitably simplified way and at relevant scales, to entire fluvial systems, and to studying how such systems have evolved over time".

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