Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2019-24-AC1, 2019

Earth Surface Dynamics Discussions

Interactive comment on "Geomorphic signatures of the transient fluvial response to tilting" *by* Helen W. Beeson and Scott W. McCoy

Helen W. Beeson and Scott W. McCoy

hwbeeson@gmail.com

Received and published: 18 June 2019

Thank you so much for taking the time to provide such a thorough comment. You raise good points that we will try to address or clarify in our revisions. Below are some initial thoughts organized around the headings in your comment with italicized subheadings added by us. We will respond more formally to each comment when we complete the revisions.

First, we would like to clarify that our main goal in this paper is to illustrate the first-order fluvial geomorphic signatures of the transient response to a punctuated tilting event, not to prove that the Sierra Nevada has experienced a tilt in the late Cenozoic. Our goal in showing data from the Sierra is twofold: 1) to show that the first-order

Printer-friendly version

Discussion paper

signatures of a punctuated tilting event can be seen in a real landscape that has been proposed by many to have been tilted (though the timing and magnitude of this tilt are still debated), and 2) to demonstrate how the signatures of tilt that we show with the models can be applied to a real landscape to estimate timing and magnitude. We hope to convey that our estimates presented in this paper of both timing and magnitude of tilt in the Sierra are rough estimates (in part because of how roughly we constrain model parameter values and in part because of how we limited the topographic analysis to just a few rivers in this paper), but that, because these estimates are consistent with many previously published estimates made from multiple independent methods, the signatures could now be applied in a thorough and systematic way in attempts to extract tectonic histories from landscapes that have experienced a punctuated tilting event. We will try to clarify these objectives in a revised version.

Response to comments on the Northern Sierra Nevada Yes, we have analyzed the Rubicon River, which is the longest tributary to the Middle Fork American River. When doing the analysis for the entire Sierra, we used a naming convention in which we called each profile by the fork of the major river that the analyzed tributary drained into. In most cases the largest tributary has the same name as the fork it drains into for much of its length, but in this case you're right that it doesn't and that there is another, smaller tributary named the Middle Fork American River. We will put a channel head marker, a blue line for the river on the DEM, and call the river Rubicon/Middle Fork American to clarify which river was analyzed.

Variable incision depths and Cenozoic volcanics near to the modern river level

Thanks for bringing up the excellent field observations of extremely variable incision depths in adjacent river basins and Cenozoic deposits not far above modern river elevation on many Sierra rivers. These are the exact observations that initially drew us to studying Sierra rivers and ones we are trying to show can be explained if these river profiles are viewed as in a transient state with nonuniform erosion rates. We show a chi plot of the Rubicon / Middle Fork American and it is far from the characteristic form of an equilibrium chi plot in which all river channels collapse on a single straight line and there are large changes in channel steepness that do not correspond strictly to rock type. We suggest that because the disequilibrium profile form of the Rubicon/Middle Fork American is consistent with a transient state of adjustment to a short-lived tilting event, only the profile downstream of the mainstem knickpoint should be a robust recorder of rock uplift that occurred in the punctuated episode of tilting. In the 1-D simulation of a transient response to a punctuated tilting event, incision depth varies from near-zero at the mountain front (at the tilt axis), increases linearly up to the mainstem knickpoint (the portion of the profile that has incised through all the rock uplift due to punctuated tilt) and decreases back to near-zero at the channel head (the portion of the profile where incision is less than rock uplift). In the simulations, maximum uplift occurs at the crest, but this is exactly the point where incision has been limited because the small drainage area limits the erosion rate and the main tilting-induced knickpoint is still far downstream. With the additional complexity of heterogeneous lithology in the 1-D model, incision depths can become highly variable upstream of the mainstem knickpoint. Rock with anomalously low erodibility can stall mainstem knickpoints and lead to little incision at that location, but still have significant incision downstream where the mainstem knickpoint has propagated and upstream where another knickpoint has kicked off in more erodible rock (see Fig. 4 and check out the simulations on Figshare at https://doi.org/10.6084/m9.figshare.8111498.v1). We suggest that the transient response to tilting modulated by heterogeneous lithology is a mechanism that can explain how incision histories can vary widely both among neighboring basins and within an individual basin. In our revised version of this paper, we will make sure to highlight this conclusion and to emphasize that, when interpreting tectonic histories from incision depths in real landscapes, it is important to analyze spatial gradients of incision rather than isolated measurements and further, that only incision downstream of the mainstem knickpoint directly records the magnitude of rock uplift that occurred in the punctuated episode of tilting.

Also, since these canyons have been deep for a long time, knickpoints along the profiles of their tributaries cannot be used in the manner adopted here to provide evidence of recent uplift-driven incision.

We don't follow the logic of this comment and hence are not sure how to respond. Our results would suggest that if the mainstem had indeed incised long ago, tributary knickzones formed in response to that incision should have propagated much greater distances than are observed.

Streampower framework begins with the assumption that there is uplift to be detected and thus this technique cannot be used to determine whether or not there was uplift because it already assumes that U is not zero.

By employing the stream power model of bedrock river incision we make no assumptions regarding the value of rock uplift. In the governing equation (equation 1) rock uplift can be any value, including zero. If rock uplift is zero, equation 1 says the time rate of change of elevation will be equal to the river incision rate, which in this case we assume scales with stream power. If one is interested in equilibrium channel steepness, k_{sn}, (that is, the channel steepness at which rock uplift is perfectly balanced by river incision) one can use equation 5. Uplift can be zero in equation 5, it just predicts that at equilibrium, zero channel steepness is needed to balance a rock uplift rate of zero. But yes, in order to have any channel steepness and fluvial relief at equilibrium, uplift (or base level fall) must be actively occurring. One can, however, model a transient declining state in which uplift has occurred in the past but is then reduced to zero.

Heterogeneous lithology

Thanks for pointing out that our approach could be made clearer in the methods section – we will revise it in a future version. We intentionally assume uniform lithology when calculating chi in the Rubicon/Middle Fork American although we know this to be false because this approach reveals whether changes in channel steepness (the slope of the chi plot) correspond to lithologic boundaries or whether changes in steepness occur independent of rock type and might thus be a result of temporal changes in boundary conditions. Figure 10 shows that the biggest change in steepness (at chi of 75) does not occur at a lithologic boundary. The other big change in steepness (at chi of 140) does approximately correspond to lithologic boundaries and is consistent with the transient response to tilting in a band of more erodible rock upstream of the mainstem knickpoint.

Methods used to obtain model parameter values

In response to our choice to use the incision rate from the Stanislaus as a proxy for modern uplift rate in our calculation of K: Our aim is simply to present a back-of-the-envelope calculation of K for the Sierra in an effort to show that timing can be calculated using these methods *if K can be constrained*, not to provide a robust estimate of tilt timing using the rough estimate of K. Given that the Sierra Nevada appears to be in a transient state, it is tricky to use equation 5 to estimate K given that only isolated portions of the river network has equilibrium steepness. Unfortunately, there are no published erosion rates for basins that have reached equilibrium to modern boundary conditions (i.e., near the mountain front) and thus no great proxy for modern uplift rate. We chose to use the incision rate from the Stanislaus River as a proxy for modern uplift rate in the lower Rubicon/Middle Fork American because 1) it is a measurement from a mainstem river (like the Middle Fork American), and 2) it measures incision over a short, recent time period of 1.6 Myr (rather than longer term measurements made from cosmogenic nuclides) and thus is possibly closer to modern boundary conditions. Yes, the cave occurs in metamorphic rock and the lower section of the Rubicon/Middle Fork American (where the rate in question is used as a proxy for uplift rate) runs almost exclusively through metavolcanic and metasedimentary rock. We will justify our choice to use this incision rate in a revised version and also clarify that we do not think k_{sn}

from a single basin and an incision rate from a transient river is a robust way to estimate K and hence, our estimates of timing for the Sierra are only presented as an example that, with rough parameterization, results in timing that is consistent with published research.

Response to comments on the Southern Sierra Nevada: Thanks for pointing out that we are missing crucial information in this section. The method we present for estimating tilt magnitude from azimuth-gradient relationships in the modern river network seems to overestimate tilt magnitude and thus gives maximum values because gradient continues to increase for millions of years following a punctuated tilting event. We will clarify that our estimate of 2.3 degrees is a maximum and a known overestimate and is thus consistent with the estimate you present of 1.1 degrees. Despite rapidly overestimating tilt magnitude, we will highlight that we think application of this method is still useful in that it demonstrates that a signature of tilt is recorded in a real modern river network in the manner predicted by a 2-D model and the existence of this signature is consistent with a recent tilting event.

Response to comments on modeling: We simulate the end-member scenario of instantaneous tilt with zero internal deformation as the first step to investigate first-order signatures of the transient response to rapid tilting. The transient response to this simple scenario is quite complicated on its own and we wanted to fully explore it before adding additional complications such as more realistic nonuniform uplift fields. We are not trying to exactly simulate the Sierra or any particular landscape with the 2-D landscape evolution model and for that reason we use the simplest possible model. We agree that adding more realistic flexural deformation, such as described in Martel et al., 2014, would be a great next step. To show that our end member of instantaneous tilt likely applies to more realistic tilting scenarios in which tilting occurs over a time period that is short relative to knickpoint travel times we will add an additional simulation to the supplement in which the same tilt magnitude is achieved over a finite amount of time such as 5 or 10 million years.

We aim to show that the observed azimuth-gradient relationship in the modern stream network in the Sierra Nevada is consistent with the first-order signatures predicted with a simple 2-D landscape evolution model. We will add discussion points on the timescale of tilt and internal deformation in the discussion on the limitations of the model.

Response to comments on connections with previous work: In a revised version we will try to provide a more balanced review of the debate and make it clear that the debate surrounding the timing and magnitude of tilt in the Sierra is active and unresolved. The tectonic history of the Sierra is not the focus of this paper and thus a thorough review of all published evidence for and against late Cenozoic tilting would be out of place. Our primary goal in this paper is to present robust, first-order signatures of the transient fluvial response to a punctuated tilting event and our use of the Sierra is simply to show that, in a landscape that many have argued has been tilted, these signatures exist.