

Gray et al., 2018, Off-fault deformation rate along the southern San Andreas fault at Mecca Hills, southern California, inferred from landscape modeling of curved drainages: *Geology*, <https://doi.org/10.1130/G39820.1>.

Movie DR1

Sensitivity analysis and parameter space exploration

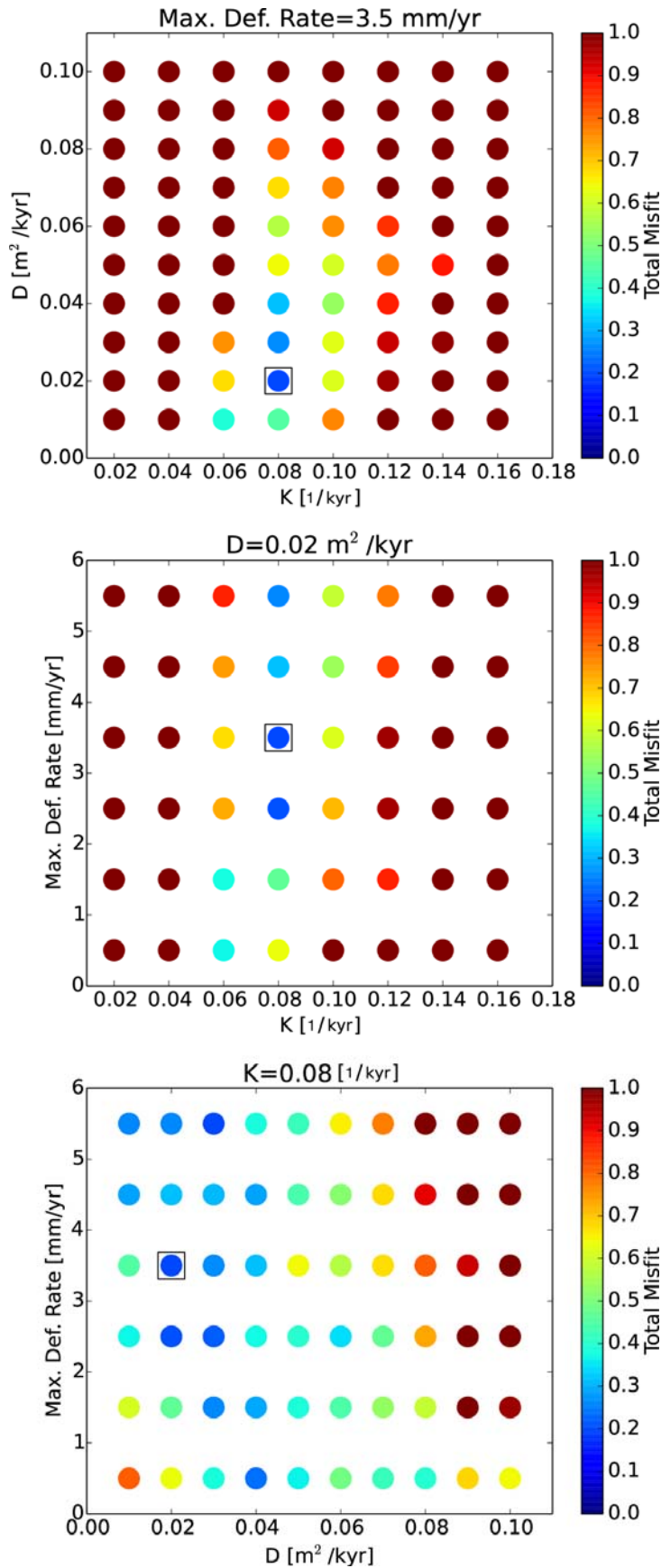
Rather than assign *a priori* arbitrary values for the parameters K (fluvial erodibility) and D (hillslope creep coefficient), which are not well constrained for this field site and have several orders of magnitude of variability (e.g., Fernandes and Dietrich, 1997; Harel et al., 2016), we derived K , D , and deformation rate simultaneously using a comprehensive, three-dimensional parameter study. We used this parameter study to find the combination of K , D , and deformation rate that best match our study landscape. Our parameter study consisted of 480 model realizations, in which each realization was a unique combination of three parameter values. We tested value combinations from the following parameter ranges: K from 0.02 to 0.16 kyr^{-1} in increments of 0.02 kyr^{-1} , D from 0.01 to 0.1 m^2/kyr in increments of 0.01 m^2/kyr , and deformation rate from 0.5 mm/yr to 5.5 mm/yr in increments of 1 mm/yr.

To compare model results with our study landscape, we developed a goodness-of-fit metric based on three morphologic variables: B_R (an aspect metric described in the main text), mean elevation, and total relief. For a model realization to be considered representative of the study landscape, and therefore to provide a potentially valid deformation rate, it must match all three of these metrics reasonably well. We developed a measure of total misfit that includes all three metrics to streamline model-landscape comparison:

$$\text{Total Misfit} = \frac{|B_{Rm} - B_{Rl}|}{B_{Rl}} + \frac{|E_m - E_l|}{E_l} + \frac{|R_m - R_l|}{R_l} \quad (1)$$

where B_{Rl} is the aspect metric, E is mean elevation above base level (used in both the field measurements and model calculations), R is total relief, m subscript denotes a modeled value and l subscript denotes a value measured from the study landscape. Higher values of *Total Misfit* denote a larger misfit between model and landscape, and vice versa. We calculated *Total Misfit* for each of the 480 model realizations. As reported in the main text, the parameter combination of $K = 0.08 \text{ kyr}^{-1}$, $D = 0.02 \text{ m}^2/\text{kyr}$, and deformation rate = 3.5 mm/yr yields the lowest total misfit (0.196). This supports the claim in the main text that 3.5 mm/yr is the best model-derived estimate of deformation rate. We show below in the sensitivity analysis section that this best-fit parameter combination is not simply an anomalous point in the parameter space, but that goodness of fit declines as K , D , and deformation rate deviate from the values we have reported. Note that this analysis shows the *sensitivity* of the model to the changes in deformation rate whereas the analysis in the main text describes how we assess the relative likelihood that a given deformation rate is occurring given the landscape.

One important question to ask is whether this best-fit parameter set is simply an anomalous place in the parameter space, or whether the model incurs progressively more misfit as parameter values deviate from the best-fit set. Because we sampled a three-dimensional



parameter space (K , D , and deformation rate), visualization of the entire parameter study dataset to answer this question is not straightforward. Instead, we have chosen to break the parameter space up into three two-dimensional slices, with each slice shown at a constant value of the third parameter. For example, we show the response to changing K and D at a constant value of deformation rate, and so forth. Together, the three two-dimensional plots show that substantial deviation from the best fit parameter set in any of the three parameters produces increasing misfit between the model and our study landscape (Figure DR1).

Figure DR1: Two-dimensional slices of the three-dimensional model parameter space, each with the third parameter held constant. Dot colors indicate the total misfit (sum of misfits of B_R , mean elevation, and total relief) between the model and our study landscape. Best-fit model realizations are outlined with black rectangles. This parameter study shows that the best-fit parameter set inhabits a minimum total misfit region of the parameter space, and that substantial changes in any of the three model parameters result in large increases in model-landscape misfit.

In the top panel of Figure DR1, shown for $SR = 3.5$, any deviations in K and D from the best-fit values lead to progressively increasing misfit. In the middle panel, a deformation rate of 2.5 mm/yr provides nearly as good a misfit value (0.204) as 3.5 mm/yr (misfit of 0.196), indicating that 2.5 mm/yr is also a possible deformation rate. This is evaluated further using the analysis in the main text. However, for all other changes in K or SR , misfit increases substantially. In the bottom panel, again a deformation rate of 2.5 mm/yr appears to be a possibility, but model-landscape misfit increases beyond the 2.5-3.5 mm/yr range. It is important to note that misfit becomes high as D increases, which supports the use of a low diffusivity for this landscape.

Model set-up and initial conditions

The landscape evolution model represented by Equation (1) is implemented via standard landscape evolution methods (Duvall and Tucker, 2015) using the Landlab 1.0 modeling toolkit (Hobley et al., 2017). The landscape is initiated as a plane of zero elevation on a rectangular grid seeded with random noise to initiate drainage network formation. We use standard D8 flow routing and a depression mapper and filler component within landlab to simulate flow across the landscape (Hobley et al., 2017).

Because we do not what the initial conditions of the curved basins, such as the exact time of initiation of uplift, or the exact form of the landscape prior to uplift beyond the regional drainage pattern, we take a probabilistic approach to compare the modeled landscape to the field site. We run multiple model runs to collect the data in Fig. 3B in the main text. Multiple runs are performed and averaged to avoid any potential random fluctuations due to the random noise seeded at the start of model runs. The model run time of 2 Ma is chosen as this is a large enough span of time to gather enough data to produce a stable average B_R value.

B_R miscellaneous aspects

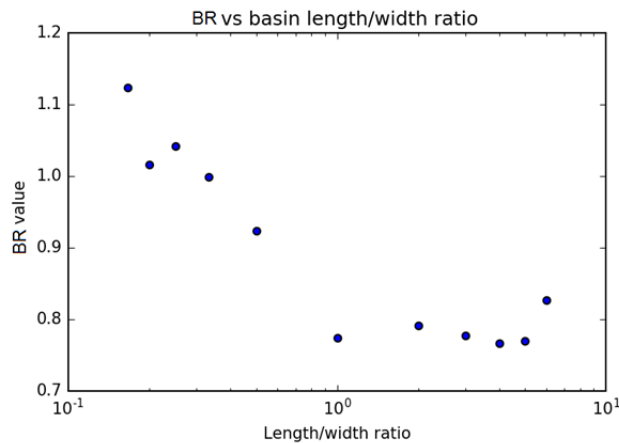


Figure DR2: Comparison of the length/width ratio of a basin with an outlet at the middle of the lower boundary and the B_R metric at topographic steady state.

To test whether the B_R value depends on basin length, we performed model runs in which the length to width (L/W) ratio of the model was repeatedly increased and the B_R metric at topographic steady-state was recorded. The model was constructed with a single outlet at the middle of the lower boundary, thus forcing the model to create a single rectangular drainage basin with a given L/W. We examined length/width ratios of 6:1, 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5, and 1:6 (Figure DR2). We find that the B_R metric is sensitive to L/W ratios below 1 and approximately constant for ratios between 1 and 5. For our study area, the L/W ratio is approximately 3, which is typical for drainage basins generally (Montgomery and Dietrich, 1992). We conclude that the B_R metric is appropriate for the basins in this study.

Sensitivity to grid resolution

In our landscape evolution model, we use a cell size of 5 m, which is also the approximate width of the highest-order channels in the study area. We test cell-size effects by running a model with a set 5 mm/yr deformation rate and a fixed domain size, and observing the mean and standard deviation of B_R (Figure DR3). The metric value is insensitive to grid cell size when cell size is less than or equal to 30 m.

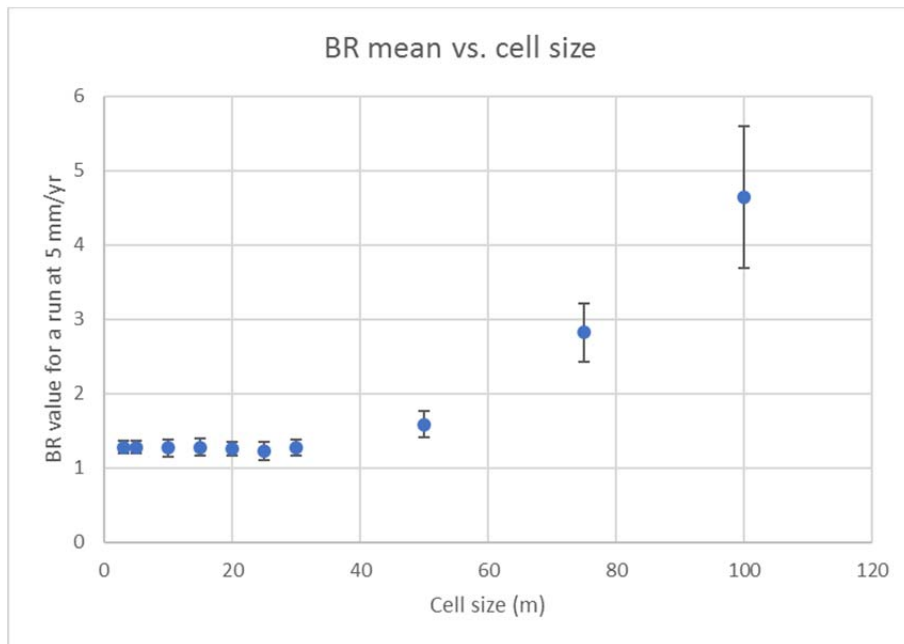


Figure DR3: Comparison of multiple models at the same deformation rate of 5 mm/yr. Cell size effects are present at cell sizes greater than 30 m. We use a cell size of 5 m based on the average width of the highest-order channels. The 5 m pixel size is far lower than the apparent onset of cell size effects.

Impact of a linear shear profile

Additionally, we run a linear OFD profile in our landscape evolution model and produce the landscape seen in Figure DR4. Linear profiles do not recreate the curvature seen in the field site.

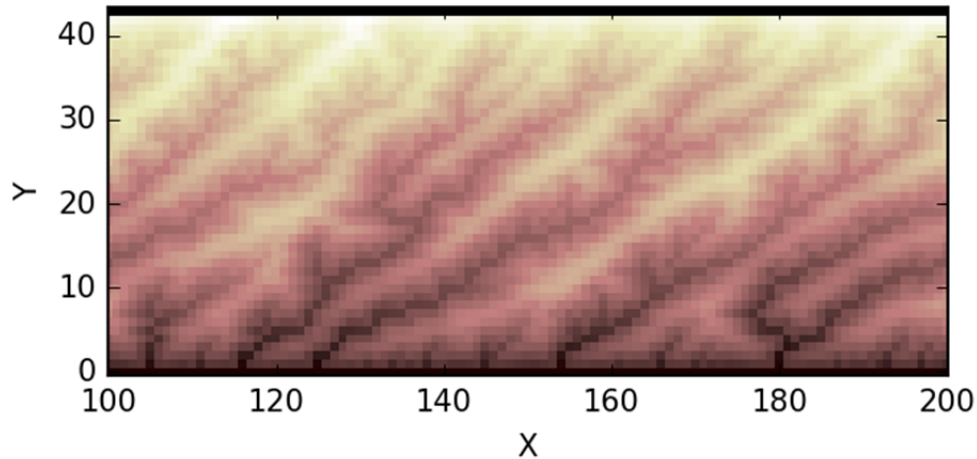


Figure DR4: Example of the use of a linear OFD profile. The resulting drainage basins do not have the ridgeline/channel curvature observed in the field area.

Supplemental References:

Fernandes, N. F. and W. E. Dietrich (1997) Hillslope evolution by diffusive processes: The timescale for equilibrium adjustments, *Water Resour. Res.*, 33 (6), 1307-1318.

Harel, M.-A., S. M. Mudd, and M. Attal (2016), Global analysis of the stream power law parameters based on worldwide ^{10}Be denudation rates, *Geomorphology*, 268, 184-196.

Montgomery, D. R., & Dietrich, W. E. (1992). Channel initiation and the problem of landscape scale. *Science*, 255(5046), 826-830.