G2: *Let´s dig it !* Combining plateau models and surface erosion

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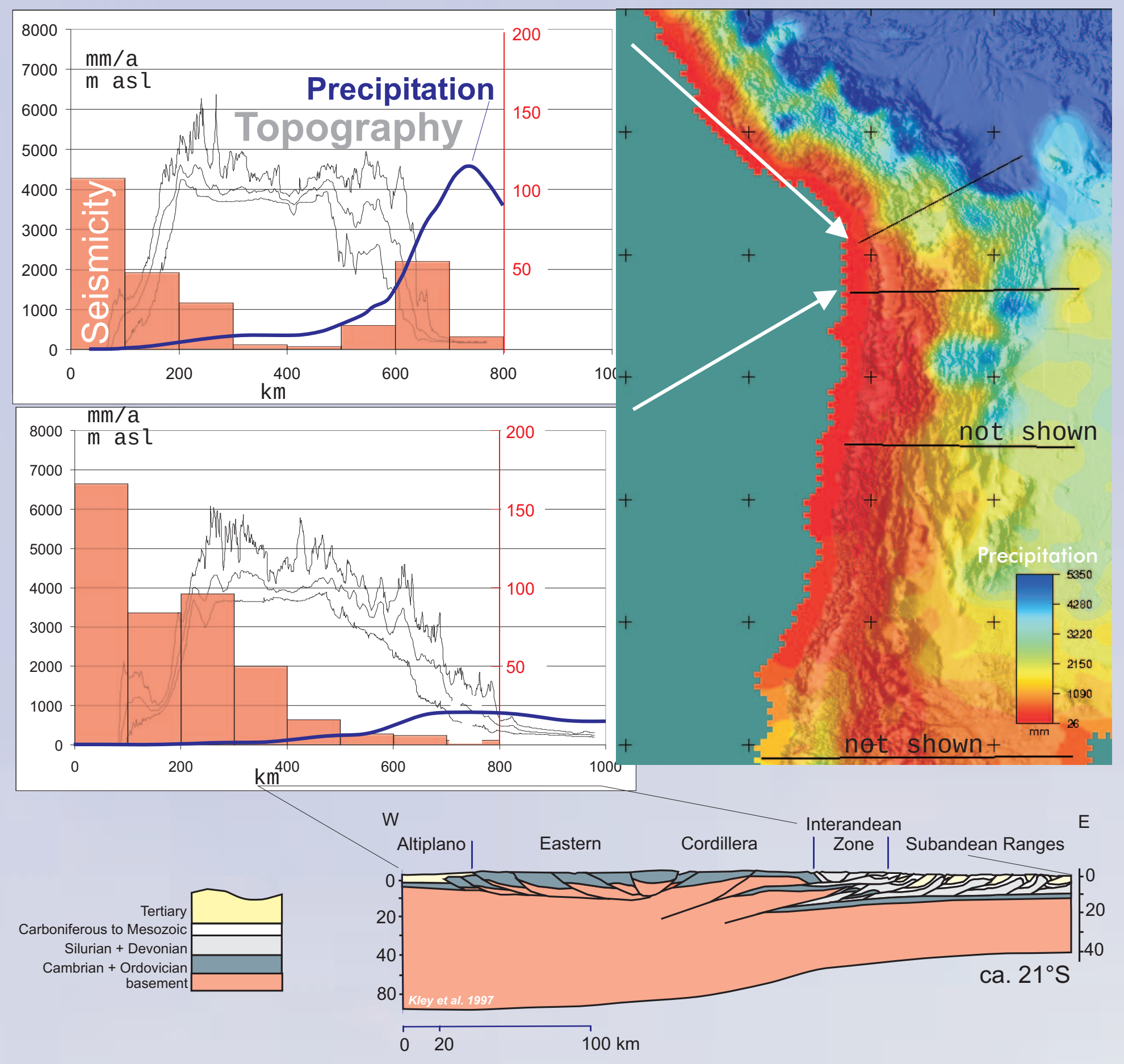
From wet to dry: the Altiplano rim



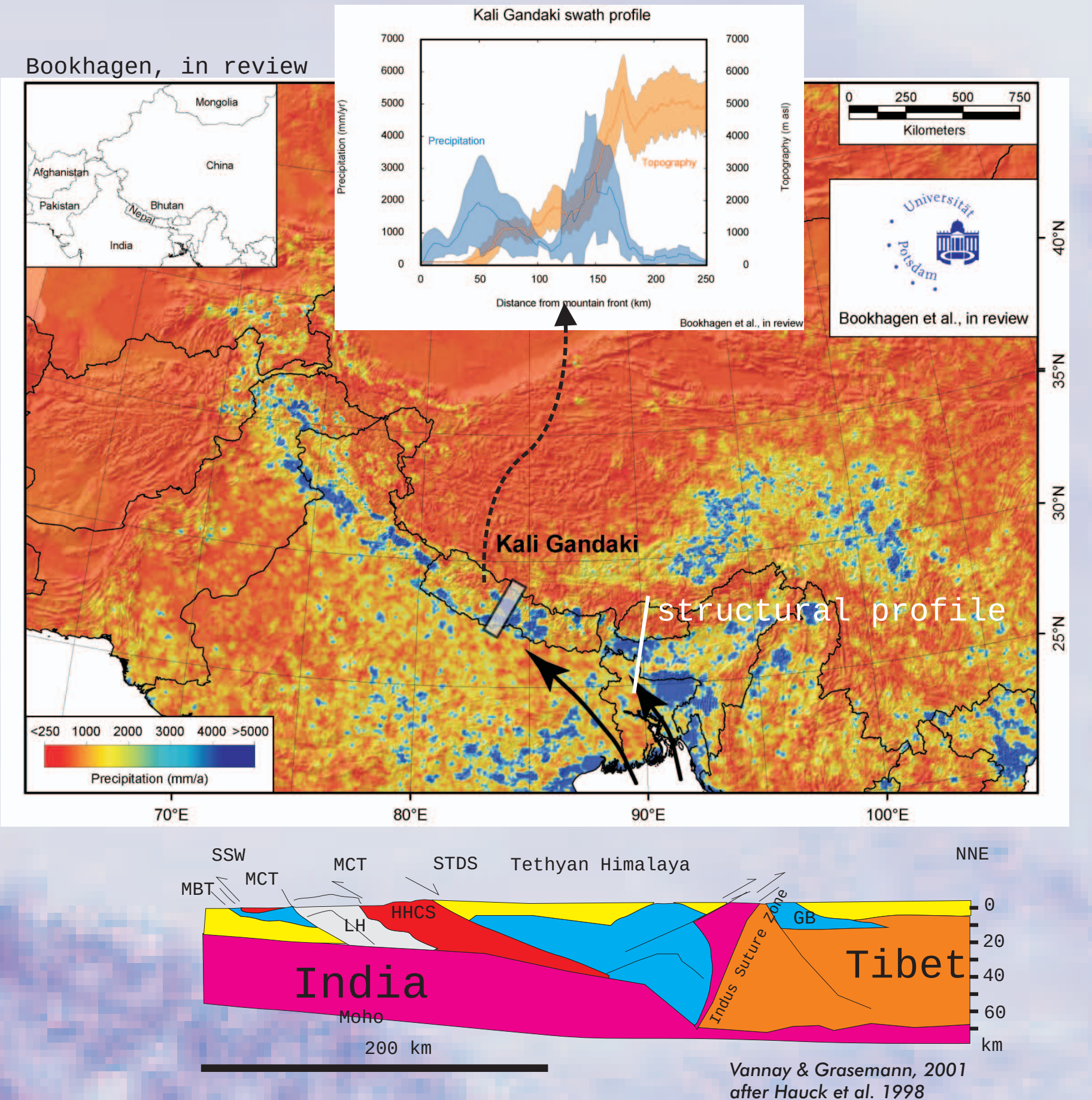
Goal

In a series of numerical experiments we show how different erosion rates affect the structure of the plateau rim, the thickening evolution of the interior of the plateau and the distribution of exhumation patterns across the plateau edge.

Introduction

Erosion rates and exhumation depth differ strongly along the strike of the Andean Orogen. South of the Santa Cruz elbow not more than 3 to 5 km of rock have been removed in the Eastern Cordillera since 10 Ma . In contrast, along the northeastern edge of the Eastern Cordillera in the La Paz area 10 km of overburden have been removed since about 10 Ma. Both areas show significant difference in structural style, for example the Subandean is a lot wider in the dryer southern region than in the northern one. Even stronger precipitation and deeper exhumation with higher rates are oberserved in the Himalayas that border the Tibet plateau. Here, exhumation of mid-crustal rocks at the plateau edge has started in the lower Miocene. In this preliminary study we test endmember models and point out some indicate similarities with the Andean and Tibetan plateau flanks.

The Himalayas: Monsoon climate



LH: Lesser Him.; HHCS: Higher Him. Cristalline Sheets, MBT: Main Boundary Thrust; MCT: Main Central Thrust, STDS: Southern Tibet Detachment System

Modelling method

We use a fully coupled 2-D marker-based thermo-mechanical finite element code. The explicit lagrangian time-marching calculation scheme allows for strong non-linearities. We employ both Maxwell visco-elastic rheology with stress-dependent viscosity as well as Mohr-Coloumb elasto-plasticity with softening.

Tectonic model

Starting configuration includes a plateau, composed of felsic, pre-heated and pre-thickened crust, and a colder, and hence, stiffer foreland composed of three crustal layers: sediments, a felsic layer, and a mafic layer. In some models sediments are subjected to strong plastic softening (drop of the internal friction angle by ten-times at 2% deformation).
Kinematic boundary conditions that push the foreland towards the plateau at 1cm/yr drive the experiments.

Erosion model

Erosion is driven in two different ways by the local slope.
(1) An algorithm that simulates fluvial erosion calculates the erosion rate by:

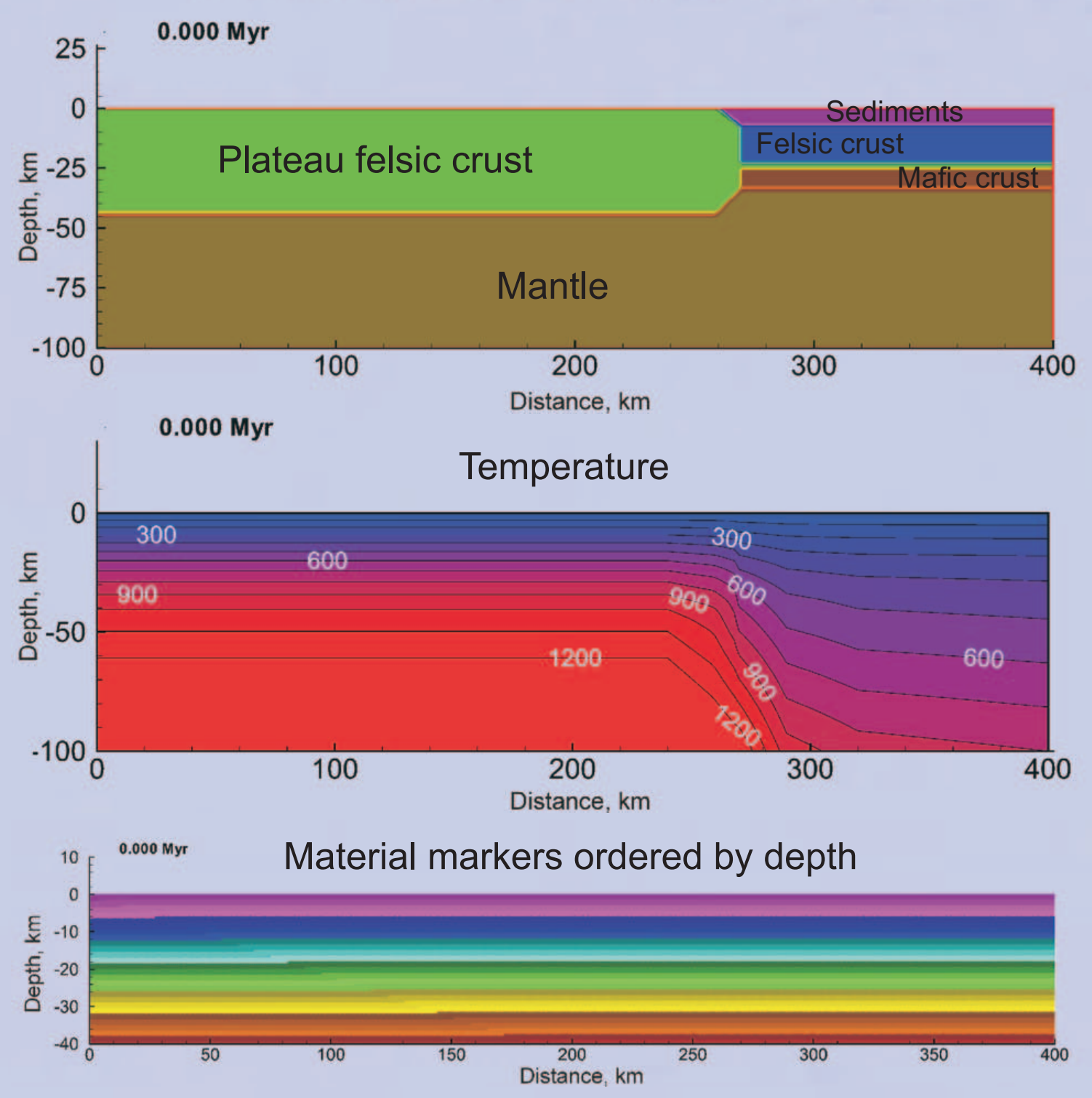
$$dh/dt = K_f * dy/dx * |x-x_r|$$

here dy/dx is local slope, $|x-x_r|$ - absolute distance from the drainage divide, K_f - erosion coefficient. We employ two values of the K_f: 10^{-13} referenced as "high" and 10^{-12} referenced as "low".
(2) Landsliding erosion rates are:

$$dh/dt = K_l * d^2y/dx^2$$

K_l also takes two values: 10^{-5} referenced as "high" and 10^{-6} as "low".

Initial state of the model



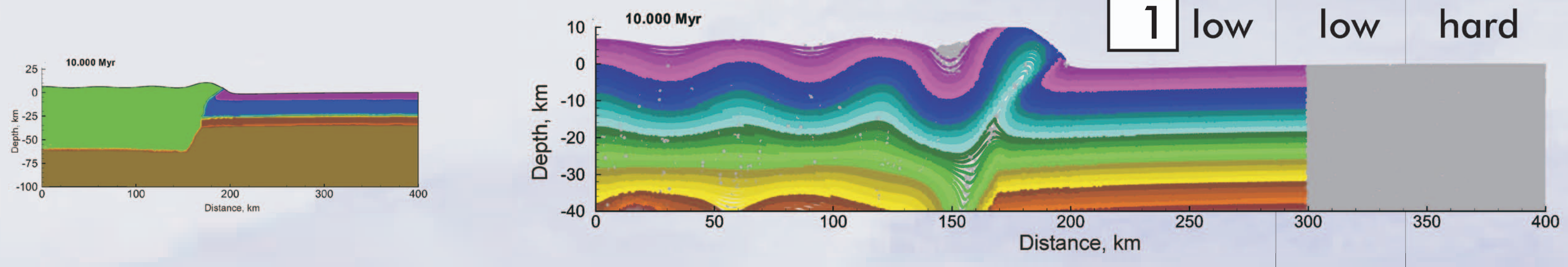
Summary
Surface erosion strongly affects structural style and deformation localization at plateau margins. Low erosion rates favour deformation of the internal parts of the system (model 1). Deformation in the external parts of the orogen including the formation of wide foreland thrust belts are favoured by soft foreland sediments (4) and require low to moderate erosion rates. High fluvial erosion rates generally lead to localized deformation along single, steeper thrusts and generate the deepest exhumation (2,5).

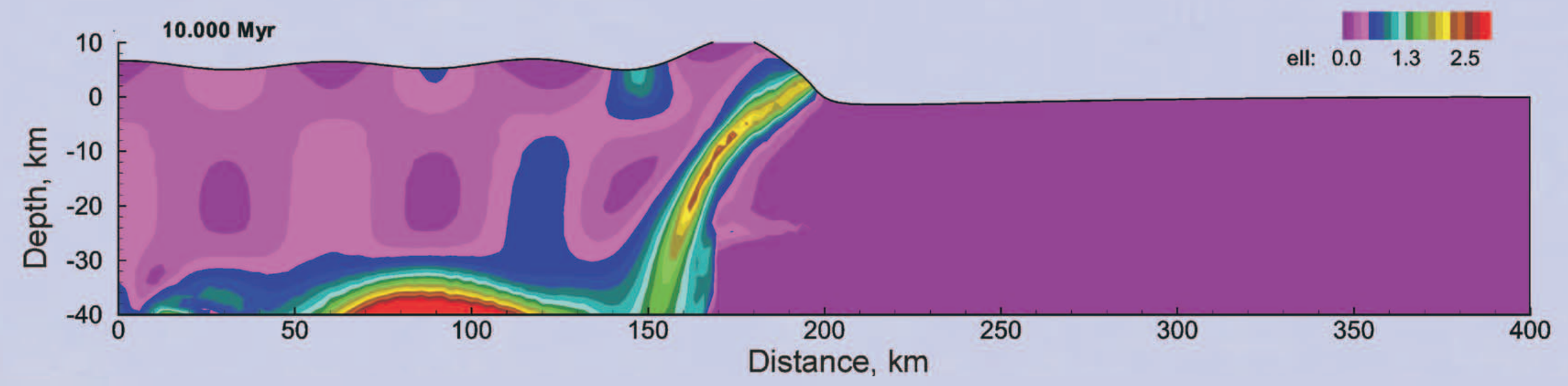
The Andes can be considered to have a rather weak foreland which consequently leads to the formation of a wide thrust belt in the Subandean range. However N of the Santa Cruz elbow increased fluvial erosion may help to inhibit the formation of a wide FTB.

Along the Himalayas the precipitation rates are locally even higher than north of the Santa Cruz elbow. However, only mid-crustal levels are exhumed. The discrepancy to our model, which exhume lower crust as well, may be due to the fluvial erosion law we use, that erodes most efficiently at the base of the slopes. In contrast, FT-ages along the Himalaya slope are genereally youngest between 2000 and 4000 m. Moreover, the initial strength distribution of our model may need some refining.

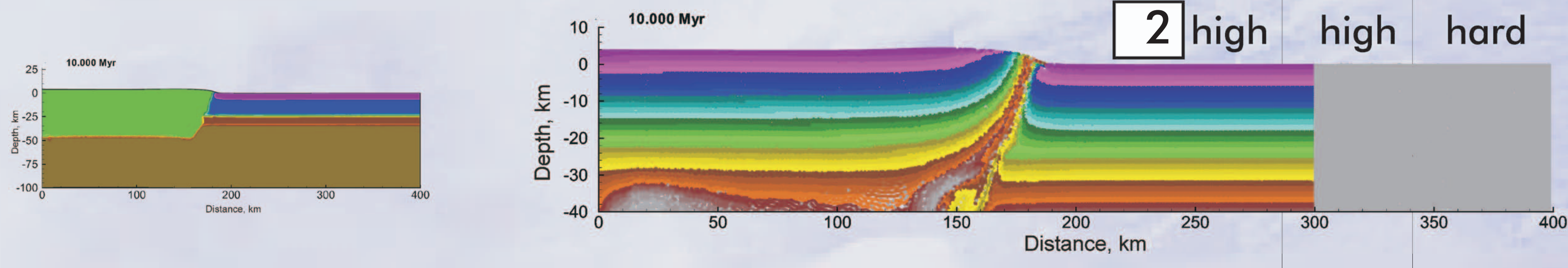
	Fluvial erosion	landslide erosion	foreland rheology
1	low	low	hard
2	high	high	hard
3	low	high	hard
4	low	high	soft
5	high	high	soft

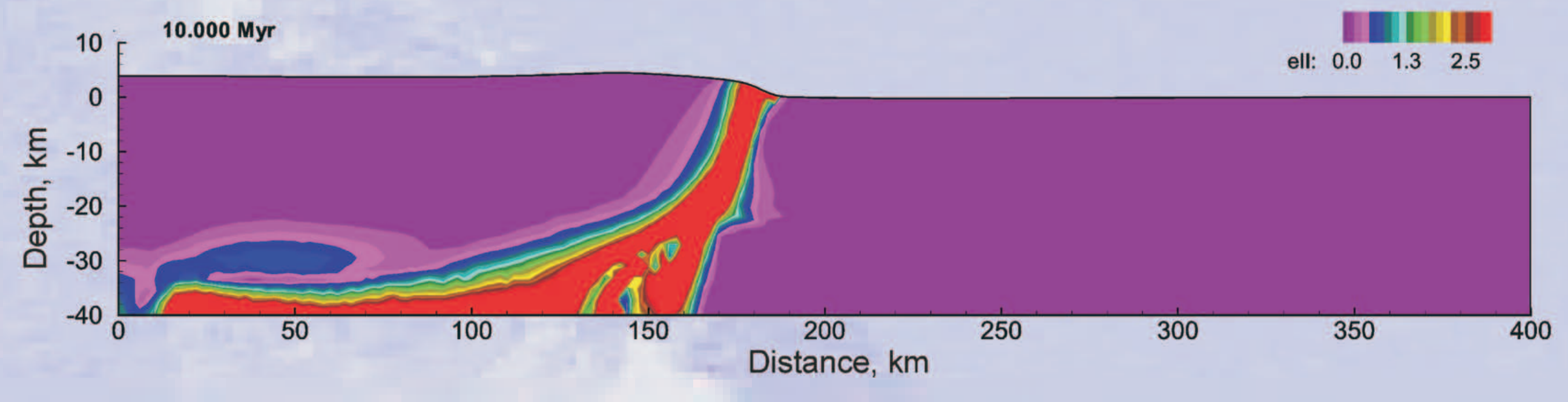
Final strain (second invariant of strain tensor)



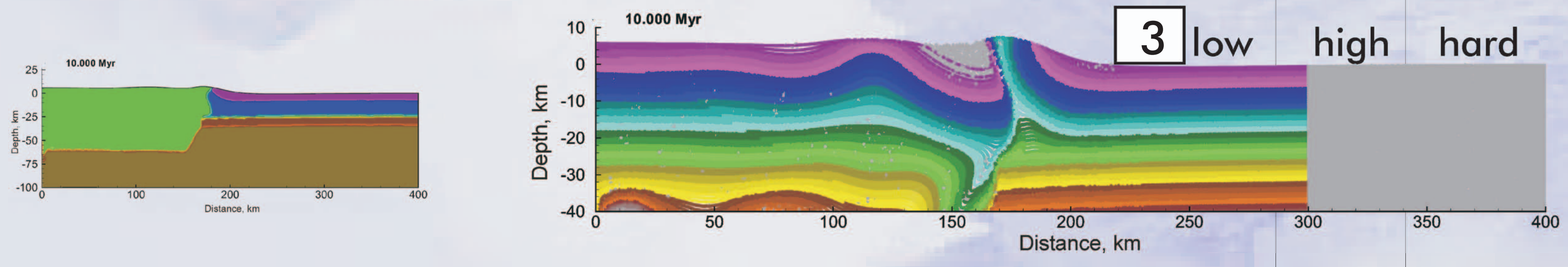


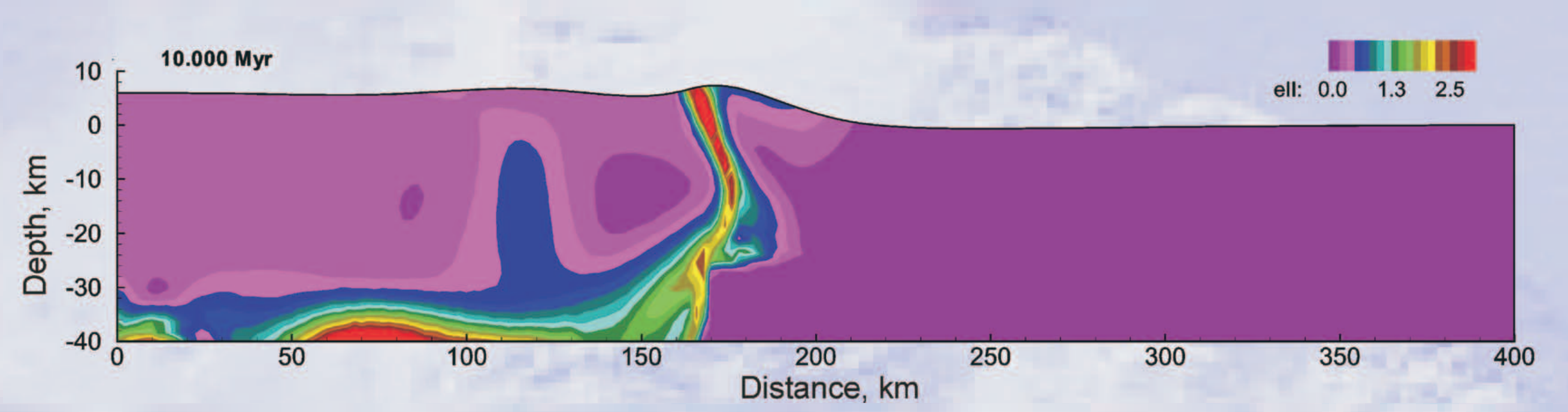
As a reference we use the case with low overall erosion. The thermally weakened plateau region localizes the deformation. Exhumation is very low. The plateau thickens throughout the test.



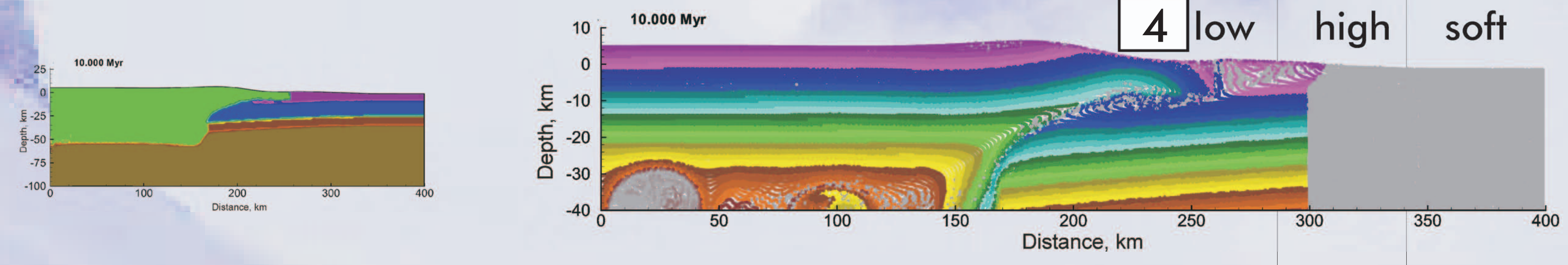


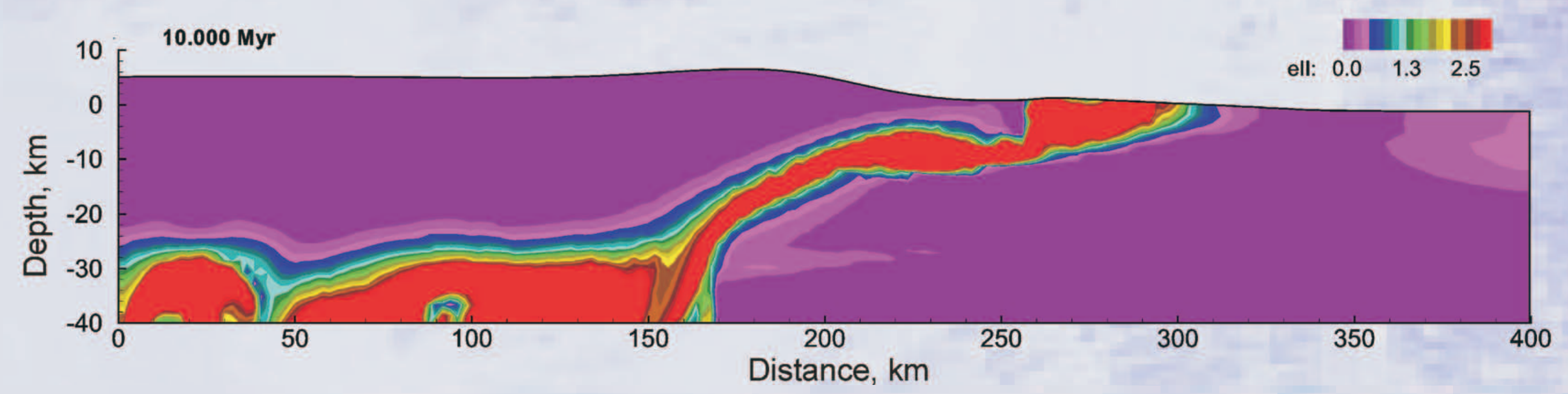
Switching on both erosion mechanisms leads to extremely deep exhumation. Deformation becomes effectively localized on a single shear zone (see finite strain distribution on the right-hand panel). Note the vertical exaggerateion that gives the thrust zone a steeper appearance. The plateau is not thickened in this experiment, that illustrates the high efficiency of exhumation.



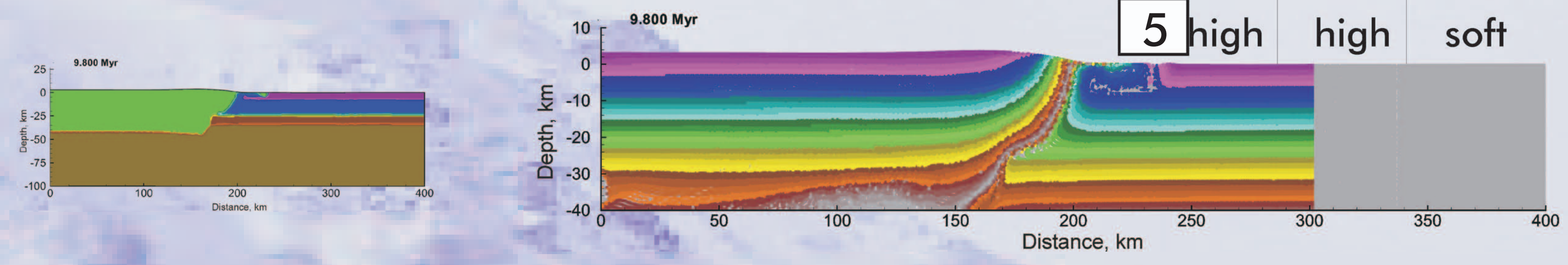


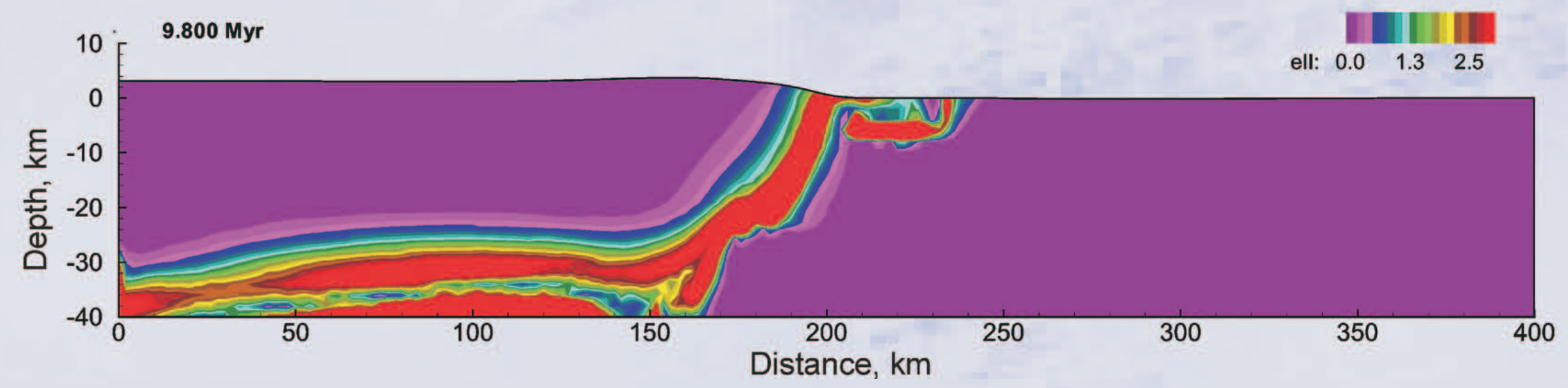
The landsliding unloads the hanging walls of the thrusts at the steepes surface slope. The steepest landscape always appears near the top of the plateau rim, hence the unloading favours thrusting towards the plateau.





The introduction of soft foreland sediments enables long overthrust which are additionally favoured by exhumation of the hanging wall, which, in turns, unloads the thrust.





Switching-on of the high fluvial erosion combined with soft sediments again suppresses long overthrusting. Erosional super-fault effectively accomodates tectonic shortening. The evolving anticline is rapidly eroded and deeply exhumed. Again, as in case 2, plateau loses a lots of material through erosion (no apparent thickening of the plateau).