7 Deformation versus erosion

A recent debate has centred on the chicken or egg question (England and Molnar, 1990), i. e., whether erosion controls deformation or vice versa. Based on the insight gained during the course of this study, we follow Hodges et al. (2004) and consider both processes not as antagonists, but as part of one dynamic system - the orogenic wedge. Additionally, field and experimental data indicate that the degree of sensitivity of a bivergent wedge with respect to kinematic boundary conditions and to surface processes may depend on the scale and on the object of observation.

As outlined in chapter (3), bivergent orogens show several common features, which have been used to constrain the CCW concept (Davis et al., 1983). Given the wealth and variability of tectonic and climatic pre-conditions of orogenic evolution, it follows that specific kinematic boundary conditions or surface processes are not needed for these phenomena to emerge. This is consistent with an observation of Montgomery and Brandon (2002), who pointed out that all mountain belts, despite their specific tectonic context or climate zone have a similar local relief, ranging between 1 and $2\,km$.

The scale invariance of these phenomena additionally underlines their independence on specific boundary conditions and allowed the use of sandbox experiments to simulate bivergent wedge-evolution. We showed that neither the implementation of different kinematic boundary conditions nor the simulation of erosion has hindered the bivergent sand-wedges to follow a four staged evolutionary pathway. In addition, deformation in all experiments was controlled by the accretion cycle with its three phases. These observations highlight once again the robustness of bivergent wedges to kinematic boundary conditions or to surface processes. Further support for this prediction is derived from the good agreement between results of this study and previously published work, which involves other methodological approaches (e. g., Willett, 1999; McClay and Whitehouse, 2004).

There are however, some trends within the experimentally derived data, which deserve discussion. As demonstrated in section (5.3.7), the evolution of the height and the width of the pro-wedge can be well described with a power law, which is consistent with theoretical predictions (Dahlen, 1990). We further found that the scatter of the power-law coefficients, related to the height of the pro-wedge, is higher for the first experimental series than for the second one (Table 7.1). Thus, power law coefficients of the erosion experiments are very similar to the one observed in experiment 9.05, which has the same kinematic boundary conditions but lacks erosion. This would indicate that changes of the kinematic boundary conditions would have a more profound effect on how the wedge grows vertically than erosion (Table 7.1). A likewise observation can be made for the out-of-sequence indexes calculated for each experiment. The respective scatter is again higher for the first experimental series (Table 7.1) and the OOSD indexes of the erosion experiments are again very similar to the one of the reference experiment. There is, however, a prominent exception. Focused pro-wedge erosion has resulted in a continuous unloading of the deformation front, which inhibited the activation of the internal glass-bead layer to serve as a detachment. This observation suggests that a certain erosion mode can determine the active detachment level.

In more general terms, we postulate that kinematic boundary conditions such as flexure, mechanic stratigraphy, basal and internal properties of the incoming layer and the orogenic wedge, as well as fluid pressures determine the active detachment level, the spatio-temporal propagation of deformation and thus the ratio between piggy-

Experimental series	Experiment	OOSD	Lateral growth of pro-wedge	Height above singularity
1^{st}	9.15	0.62	$y = 0.79t^{0.48}$	$y = 0.85t^{0.29}$
	9.05	3.73	$y = 1.06t^{0.44}$	$y = 1.03t^{0.26}$
	9.20	8.1	$y = 0.80t^{0.50}$	$y = 0.76t^{0.33}$
	9.35	3.95	$y = 1.80t^{0.32}$	$y = 0.48t^{0.42}$
	9.25	0.46	$y = 0.97t^{0.43}$	$y = 1.00t^{0.23}$
2^{nd}	9.05	3.73	$y = 1.06t^{0.44}$	$y = 1.03t^{0.26}$
	9.06*	3.42	$y = 1.17t^{0.40}$	$y = 1.12t^{0.24}$
	9.09†	4.16	$y = 1.08t^{0.37}$	$y = 1.10t^{0.19}$
	9.10§	0.97	$y = 1.34t^{0.30}$	$y = 1.00t^{0.24}$
	9.11‡	3.16	$y = 0.90t^{0.47}$	$y = 0.92t^{0.27}$

* Distributed retro-wedge erosion.
† Distributed pro-wedge erosion.
§ Focused pro-wedge erosion.
‡ Focused retro-wedge erosion.

Table 7.1: Selected indexes

back thrusting and internal deformation. With respect to the influence of erosion, two scenarios can be envisaged. If erosion changes only the ratio between piggy-back thrusting and internal deformation, the orogenic wedge is thought to be still driven by "kinematics". If however, erosion changes the detachment level and thus modifies the volume of material accreted to the orogen, we argue that erosion has taken the lead. Following this view, an erosion-induced slowdown or halt of the propagation of deformation towards the foreland, as observed for the Himalayan orogen during the last $10 Ma$ (Thiede et al., 2005), does not necessarily mark the transition from a tectonically to an erosionally controlled orogen. Further evidence with respect to changes of the detachment level would be required to address this question.

The above considerations indicate that surface processes and kinematic boundary conditions can evoke similar phenomena. Thus, the ascription of certain observations to changes of the local to regional climate or to changes of thrust-kinematics, hundreds of kilometers away – or even on the other side of a bivergent orogen, remains difficult, but should be taken into account. Within this respect, we note that these far-field interactions bear some importance for either landslide or seismic hazard assessment studies.

Feedback processes provide an additional challenge, since an originally tectonic signal might be converted into a climatic one (e. g., rain shadow), which finally may convert to a tectonic signal again (e. g., propagation of deformation). Such a scenario might explain the observed oscillatory filling and excavation of the Quebrada del Toro basin in NW Argentina (Hilley and Strecker, 2005). Time series analysis, in conjunction with detailed regional to orogen-wide studies, may provide insight, but are still left with the challenge, to decide, whether two observations occur coincidentally or causally linked. In order to address these issues, we propose that a stronger integration of field and simulation studies is required, and that time series from the former should be used to constrain the latter. This raises the need to provide more testable predictions from simulation studies and we hope that we have made a step toward this direction.