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GEOMORPHIC DOMAINS IN THE EASTERN ALPS -- INSIGHTS FROM SURFACE PROCESSES MODELLING

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Introduction

The Eastern Alps, being a target of geoscientific research for centuries, have also attracted the attention of geomorphologists. Based on the spectacular plateau-like geomorphic features and summit levels, there is a long-lasting debate on the post-Oligocene geomorphic evolution. Some authors suggested numerous planation surfaces, while some others consider the observable paleosurface relicts as stages of only a few denudation/sedimentation phases. (Frisch & al. 2000 gives an overview on this issue.). The situation is complicated by the increased uplift rate in the Quaternary and the effect of the glaciation.
Indeed, the complexity of the geomorphic features, including elevated flat-lying or tilted plateaus, U-shaped deep valleys with hanging valleys on the sidewalls, discrete summit level groups and elongated drainage pattern, needs to be explained in detail. Beside of the tectonic dismembering through strike-slip motions and nappe formation, a possible argumentation can be based on the wide variety of lithologies present in the region. Commonly, the different geomorphic characteristics of an area are attributed mainly to the diverse erodibility properties of the underlying rocks. On the other hand, our earlier results based on statistical analysis of DEM of the recent topography showed that the Eastern Alps can be divided into different characteristic domains (Frisch & al. 2000). These domains correspond to tectonic units with similar uplift history, but the units themselves show lithological heterogeneity suggesting that the lithology plays a secondary role, assuming that the uplift rate is moderate or high (Székely & al., 2002).
In the last decade, owing to the exponentially increasing computer power, major advancements have been made in the understanding of surface processes through the development of the Surface Processes Modelling (SPM). Beside the classic geomorphic methods, this digital modelling technique became available to analyse the dynamics of the surface evolution.
Here we present some results of a few simplistic SPM-model settings and evaluate the resulting geomorphic patterns.

Methodology

To have some insights concerning the role of the erodibility contrast and the uplift rate, numerical simulation of the erosion and uplift was carried out with the help of the SPM code CASCADE (generously provided by the author, J. Braun, Canberra). This code is a TIN-based one allowing dynamic remeshing (under certain conditions), i.e. reshaping the net of nodes. It is especially advantageous if tectonism plays a major role.
The various model settings have three common features: (1) a thrust front (representing the boundary of the Eastern Alps and the Molasse zone), (2) a depositional basin (corresponding to the Molasse zone), and (3) an assumption concerning the dewatering of the area. The first two conditions are almost self-explanatory, but the third assumption needs to be explained in some extent.
It is generally accepted that the topographic evolution in Eastern Alps were different in the various tectonic units, most importantly the Western part of the Eastern Alps was mountainous already in the Late Oligocene, while the Eastern regions were rather hilly. Their separating feature, the Inn valley is considered as a major tectonic line with a lifetime over

several tens of million years (e.g. Frisch & al. 1998) playing a major (now declining) role since the Late Oligocene. Such a feature determines the hydrological evolution of the region, dewatering large areas and somewhat fixing the drainage network, since it is difficult to reorganize the drainage if there is an established trunk channel in the area continuously incising lowering the base level for the catchment.
Therefore, all of our models include a fault system (modelled by a linear zone of weak lithology) running obliquely to the thrust front, which initially governs the evolution of the drainage pattern. The difference between the test runs are the erodibilities of the different blocks, and sometimes the prescribed (differential) uplift rates.

Results and discussion

According to our model results the lithological difference (here: erodibility contrast) may determine the evolution of the drainage system if the uplift rate is relatively low (in the order of 0.1-0.3 mm/a). If, on the contrary, the uplift rate is high (>0.5 mm/a) in a part of the model space, it seems that the lithological contrast plays only a secondary role, because the surface adapts to the high uplift rate. In the erodible area a somewhat smaller relief builds up, but valleys cut through the erodible region and lower the base level for the less erodible zone, too. If the erodibility contrast is not so high (less than a factor of 2) the different zones show similar surface properties.
Results show that a stable situation can be maintained if the uplift rate is smaller than 0.5 mm/a (with an erodibility contrast factor of 5). Otherwise the zone plays a role in the dewatering and deflects the path of the evacuated sediments, but it is not always the main trunk channel. This result implicitly supports the idea based on other observations, that the uplift rate could not be so high for long time as it is presently measurable or deducible from the glaciation-induced sediment evacuation during the Pleistocene. Thus, results suggest the glaciation induced relief enhancement in the Eastern Alps, too.
Concerning the sediment production, the high uplift rate implies slow onset of sediment output, because surface uplift in the initial phase buffers the incoming material flux and postpones the increase of the sediment production. The consequently high relief provides capacity of temporary sediment storage. Time by time, this capacity is used by the sediments en-route to the sedimentary basin, i.e., the sediment output flux becomes volatile. Accordingly, the outflux curve reaches more slowly the dynamic equilibrium level and fluctuates more strongly around it, than in the case of low uplift rates.
The model runs dedicated to pure differential uplift provided a very interesting result. These tests were constructed to replace the effect of lithological contrast with differential uplift. Solely the narrow weak zone (representing the Inntal Fault) was included as lithological contrast, the other areas were made of the same rock type. The concluding remark of these runs is that the differential uplift can also produce domains, like the contrasting lithologies, if the uplift rate is moderate or high. This conclusion is in accordance with the results of DEM analysis mentioned in the introduction.
A further interesting behaviour can be observed, if the model contains differential uplift: sometimes a slowly uplifting part temporarily will be covered by the sediments being transported to the main depocenter, if the evacuation routes are partly or completely blocked by the products of the high uplift rate. Thus, some temporal intermontane basin-like areas may develop, despite their uplifting trend. Later, when the sediment evacuation paths reopen or the sedimentary cover overfills the bordering scarps, the previously existing paths may be reestablished, or in the case of overfilling, new paths may come into existence. This scenario seems to be plausible for the relict intermontane basins in the Eastern Alps.
Assuming differential uplift of several tectonic units, it is possible to get results resembling to the present topography of the Eastern Alps. However, the presently available modelling

techniques do not model correctly the effect of the glaciation, therefore further studies are required to include the glaciation-induced relief enhancement as well.

Outlook

At the present level of modelling technique the spatial resolution of the model space is very low. This hampers the construction of more detailed models and does not allow the study of the behaviour *within* the tectonic domains. A further improvement could be to extend the modelling with submarine deposition; this could extend the modelled time frame.
As it was mentioned above, unfortunately there is no working two-dimensional glacial erosional model, which would be very important to understand the formation of the U-shaped valleys and the glaciation-induced relief enhancement.

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