Possible environmental effects on the stratigraphic architecture of the Swiss Molasse Basin: state of the art and further research needs

Schlunegger Fritz

Exogene Geology Group, Institute of Geological Sciences, University of Bern, Baltzerstrasse 1-3, 3012 Bern, Switzerland, schlunegger@geo.unibe.ch

The availability of a high-resolution temporal framework for foreland basin deposits has allowed to reconstruct the causal relationships between the geodynamic evolution of mountain belts and the sedimentary response in the adjacent foreland basins for the time scales of single structures and of whole orogens. This is especially the case for the Oligo-Miocene evolution of the Swiss Molasse basin located north of the Alpine orogenic wedge. For this foreland basin, high-resolution magnetostratigraphy in combination with mammal biostratigraphy allowed to determine ages for changes in the pattern of facies, subsidence rates, dispersion directions, petrofacies and the fossiliferous record of plants (Kuhlemann & Kempf, 2002). These data, in turn, yielded the basic information to reconstruct the sedimentary response in the basin to Alpine tectonic events, climate variabilites, and modifications in the lithological properties of the exposed bedrock (Schlunegger & Simpson, 2002). As a consequence, it is now generally accepted that the basin width, the dispersion direction, the pattern of subsidence rates and hence the location of the topographic axis is controlled by the ratio between rates of deep crustal processes leading to crustal thickening, and surface processes resulting in redistribution of mass from the orogen to the adjacent foreland. Specifically, identation and crustal growth between the Eocene and Late Oligocene caused an increase in the rates of crustal accretion and surface erosion. As a result, the basin became overfilled as indicated by the stratigraphic change from marine to terrestrial conditions (evolution from UMM to USM). However, because the response time of erosional processes to crustal dynamics is in the range of several Ma, the orogen experienced a net growth until the Late Oligocene. As a result, the Molasse basin subsided at high rates causing the topographic axis to shift to the proximal basin border. In addition, km-thick alluvial fan deposits with dm-large gravels established at the proximal basin border. During the Aquitanian, however, ongoing erosion and downcutting in the hinterland caused the ratio between the rates of rock uplift and erosion to decrease. As a result, the topographic axis shifted towards the distal basin border, and the pebble size of conglomerates at proximal positions decreased to the cm- scale.

This relationship between crustal dynamics and surface erosion was modulated by a shift towards a more continental climate in the Aquitanian and by exposure of the crystalline core in the orogen. This modification of climate is indicated by a shift from the predominance of deciduous trees in the Late Oligocene strata to an abundance of fragments from pines, poplars, and legumes in Early Miocene rocks (Berger, 1992). Similarly, the geochemical record of caliche nodules shifted towards lighter oxygen and heavier carbon isotopes, respectively. This change supports the interpretation of a more continental climate with a veldt-like vegetation cover. Exposure of crystalline rocks in the hinterland together with the shift towards a more continental climate resulted in a decrease in the erosional efficiency of the Swiss Alps and hence in a decrease in sediment discharge to the Molasse Basin towards the end of the Aquitanian (Kuhlemann et al., 2001). As a result the basin became underfilled and marine conditions of the OMM established.

The decrease in erosional efficiency as outline above played an important role in the initiation of a major phase of lateral orogenic growth (deformation of the Southern Alps, and the Jura Mountains some Ma later). Simpson & Schlunegger (2002) suggested that although topography of the Alps grew in response to indentation in the Early Oligocene, erosion during this period was efficient enough to prevent the orogen from attaining a mechanically critical geometry. This scenario is reflected by progressively increasing sediment discharges, by the progradational nature of the stratigraphic record and by the rapid vertically directed exhumation. However, this situation changed in the late Aquitanian as an increasingly greater proportion of rock with low erodibility was exposed to the surface, and as the palaeoclimate became more continental. The result of these two effects was to change the deformation of the orogen from vertically- to mainly horizontally directed extrusion as indicated by lateral orogenic growth at ca. 20-18 Ma and the decreased sediment fluxes from the orogen.

In summary, the available chronological record allows to interpret possible causal links and feedback mechansims between Alpine geodynamics, climate, exposed bedrock lithologies and sedimentary processes at large spatial and temporal scales. However, pending questions require a more detailed chronological and spatial framework for the Molasse deposits that is currently available. These comprise the search for possible controls on the stratal architecture at the outcrop scale. For instance, there is a consensus that the stacking pattern of lithofacies was controlled by lateral shifts of distributary channels in terrestrial and marine environments. However, it has been unclear whether these shifts have been driven by local instabilities in sediment flux (autocyclic control), or by climate-driven variations in the relative importance of sediment production by weathering on hillslopes, and sediment export in channels (allocyclic control). Specifically, studies in Central Peru imply that the latter processes potentially result in substantial variations in sediment flux to basins at the time scales of orbital cycles. Also, there is a lack of high-resolution sedimentological information that allows to determine water discharge in channels during deposition of the Molasse strata. Specifically, the inferred climate change at the Late Oligocene-Early Miocene boundary should be seen by an equivalent modification in the channel geometries. These more detailed information are required to enhance our understanding about the nature and the rates of processes that resulted in the formation of the stratal achitecture of the Molasse. This implies a substantical down-scaling of both space and time during further research activities.

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