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Identification of facies models in alluvial soil formation: The case of a Swiss alpine floodplain

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Abstract

This paper describes different conceptual facies models intervening in alluvial soil formation in the case of the Sarine River floodplain, a partially embanked floodplain situated in the northwest of the Swiss Alps. Alluvial soils are submitted to processes of deposition and erosion and exhibit various characteristics reflecting the composition and properties of the material transported. Moreover, these processes of sedimentation and erosion vary in space and time and contribute thus to the heterogeneity of the whole floodplain system. Detailed analyses of the different soil layers permit a precise description of the variability and complexity of soil formation. In addition, the vertical succession of the horizons is useful to reconstruct the different natural or artificial events that occurred in this alluvial valley since the nineteenth century. On a larger scale, this study aims to contribute to floodplain management by identifying zones for restoration. The investigation was undertaken using data from 109 auger borings carried out in the Sarine River valley. Several morphological attributes of the different horizons and of the different profiles were first reduced in number and then grouped by a hierarchical agglomerative clustering. Profile factors were analysed by means of correlation analyses as well as other data summaries. The results showed positive correlations between several factors, particularly between the total profile thickness and the number of horizons found in the profile. Four facies models of alluvial soil formation are then proposed to illustrate and explain the variability of alluvial soil formation in the Sarine floodplain. Finally, these facies models are placed into the context of the Sarine floodplain scale case, according to the levels of organization of the alluvial system.

Keywords: Facies models; Alluvial soil; Soil formation; Hierarchical levels; Floodplain; Switzerland

1. Introduction

Floodplains are ecotones forming a transition between aquatic and terrestrial environments. They are characterized by complex ecological systems and are dynamic spatial mosaics, more or less connected with the active channel of the river. These lateral connections are essential for the functioning and integrity of a floodplain (Thoms, 2003), and the various landscape patches induce a hierarchical system that can be considered at different levels. Thoms (2003) also reported that many floodplain management strategies often fail to provide scientific knowledge at the appropriate scale. The approach described by Petts and Amoros (1996) is based on the fluvial hydrosystem. This one is defined as an eco-complex forming by different environments that are dependent to a greater or lesser degree on connectivity with the active channel of the river, just like the character of this main channel also depends on interac-

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tions with those environments. In other words, the fluvial hydrosystem may be viewed as a nested hierarchy of subsystems with different levels controlled by different rates and types of processes. Five distinct levels are then described:

– the drainage basin, delineated by a topographic divide (the watershed) that results from geological processes and climatic changes;
– the functional sectors, delimited by changes in valley width and gradient due to different flow, water-quality and sediment regimes draining subbasins of different geological, climatic and biogeographical character;
– the functional sets, defined as sections of typical ecological units associated with specific landforms (e.g. major cutoff meander, aggrading floodplain, main channel);
– functional units, characterized by a typical animal and plant community that is indicative of the habitat conditions at the site that are generally arranged in spatial successions along topographic gradients; and
– the mesohabitats, subdivisions of functional unit that are particularly sensitive to variations of the control variables and may change from year to year.

The integrity of the fluvial hydrosystem depends then on the dynamic interaction between hydrological, geomorphological, and biological processes. The exploration and analysis of the multivariate and spatial data found in these ecological attributes of floodplains are commonly explored by standard methods such as correspondence analysis or clustering and are widely used by ecologists.

In this complex ecological system, alluvial soils are characterized by sediment transport and deposition, as well as by soil formation (Gerrard, 1987), and could be identified at the level of functional units. In fact, these particular sequences evolve from a single origin by progressive changes over time-scales of 10^{-1} to 10^{2} years and the processes involved include sedimentation or organic matter accumulation for example (Petts and Amoros, 1996). Thus, this combination of geomorphic and pedologic processes is the main property of alluvial soils providing good elements for the interpretation of past environmental changes (Daniels, 2003). Moreover, alluvial soil morphology varies according to landscape position and overbank lithofacies (Autin and Aslan, 2001), but also from river modifications through time, such as embankments and dam constructions. These geomorphic processes produce a landscape mosaic reflected by abrupt juxtapositions of soils of different ages and degrees of profile development (McAuliffe, 1994).

Stratification, formed by the alternation of pedological layers and layers with new material, is a particular characteristic of alluvial soils (Gerrard, 1987). New deposition may bury a pre-existing soil and move it away from the zone of active pedogenesis (Daniels, 2003). Alluvial soils are good models to estimate the part of pedogenesis illustrating periods of stability with development of pedogenic features and pedoturbation, representing the overlay of sediments or instability periods (Paton et al., 1995) in high or low energy depositional environments. High energy deposition contains coarse sediment deposited by traction currents, whereas low energy deposition is characterised by fine-grain sediment deposited by suspension settling.

The process of soil cumulization is particularly important in a floodplain context because all floodplains are subject to pedogenesis during the intervals between periods of sediment deposition. These vertical successions of overbank deposits and pedogenic features are defined as paleosols by Kraus and Brown (1988) and are generated by slow and sporadic aggradation and soil modification interrupted by more rapid deposition. Paleosols can be identified as buried soils determined by five groups of soil-forming factors: climate, organisms (including man), relief, parent material, and time (Bronger and Catt, 1998). They can also be regarded as polygenetic soils if they contain features formed during two or more periods of different environmental conditions and they demonstrate moreover an inverse relationship between soil maturity and sediment accumulation. But, paleosols are not restricted to alluvial context, so the term *pedofacies* is mainly preferred in order to delimit the lateral changes of adjacent packages of sedimentation rock when they vary in their ancient soil properties as a function of their distance from areas of relatively high sediment accumulation (Kraus and Brown, 1988). According to these last authors, the concept of pedogenic maturity is used to infer sediment accumulation rates at different locations in ancient floodplain environments: weak soil development is assumed where sedimentation rates are rapid and strong development is presumed where sediment accumulation is slow. In a semiarid cut-and-fill floodplain context, Daniels (2003) defined three alluvial pedofacies. These three identical soils are shown to have developed different pedogenic features through time as a result of different aggradation rates. Daniels (2003) also defined A horizons as soil-stratigraphic markers and indicators of relative aggradation rates. Thus, identification of the different horizons present