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Weathering processes in superficial deposits (regolith) and their influence on pedogenesis: A case study in the Swiss Jura Mountains

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ABSTRACT

The last glacial period left a mantle of freshly reworked sediments covering the European landscape. Glacial, periglacial, fluvio-glacial, and aeolian dynamics enhanced transportation and mixing of materials, generating new superficial deposits in which Holocene soils developed. These assorted surface sediments often differed from the underlying bedrock in their lithological composition and texture, and were delimited by lithological discontinuities. In the Swiss Jura Mountains, the Mesozoic limestone bedrocks are covered by various superficial deposits (moraines, cover-beds, loess deposits, cryoclasts, etc.), which reduce or even suppress the influence of limestone on present-day soil development. In this context, soils and their underlying bedrock no longer present a genetic continuity. The nature and relationships between these deposits is studied within a toposequence of soils, in terms of their mineralogical and geochemical compositions. Three main superficial deposits (limestone bedrock clasts, loess, and non-carbonate moraine), are used as reference materials in order to characterize the complex mixing of sediments through the toposequence. Soils with limestone clasts undergo decarbonation and decalcification processes. Iron-rich Alpine loess deposits, composed of fine silicate particles, enhance brunification process in soils. A non-carbonate Alpine moraine displays the most acidic conditions within the toposequence due to enhanced leaching (clay and ions) processes. Consequently, the reworked surface sediments (including limestone cryoclasts, moraines, and cover-beds) have a prevailing influence on pedogenesis compared to the hard underlying bedrock.

1. Introduction

In the temperate zone of Europe, cyclic Quaternary glaciations had a strong impact on landscape modeling and sediment distributions. During all rhexistasic periods, former soils were eroded and sediments reworked (Erhart, 1967). Various dynamics and sedimentological processes (glacial, periglacial, fluvio-glacial, aeolian, etc.) transported materials and created new mineral deposits. In glacial environments, till and fluvio-glacial deposits are dominant. Periglacial processes, such as frost shattering, gelifluction–solifluction, or cryoturbation, led to the formation of scree slope deposits and cover-beds, which redistributed cryoclasts, aeolian particles, and local weathered material along the slope (Kleber, 1992, 1997). In addition, loess deposits were widespread in periglacial environments but were often reworked and mixed with other materials, and consequently only preserved on flat surfaces or in depressions. A mantle of freshly reworked superficial deposits covered the landscape at the end of the glaciations. Therefore, this surficial sedimentary material was different from the underlying bedrock in terms of lithological composition and texture (rock clasts, fine material). These distinct layers resulted in the formation of lithological discontinuities. Boundaries were generally abrupt and caused by a break in sedimentation or an erosional surface (Schaetzl, 1998; Phillips and Lorz, 2008). However, lithological discontinuities due to sedimentary processes must be discriminated from soil layering caused by pedogenesis, which creates more gradual transitions (Lorz and Phillips, 2006).

Holocene soils developed from the Lateglacial onwards (with a maximal age of about 17,000 cal. years BP in western Switzerland according to the detection of arctic vegetation on the Swiss foreland; Hadorn et al., 2002; Magny et al., 2003), following the withdrawal of the Rhône glacier starting about 19,000 cal. years BP, and sediment reworking by periglacial processes (Mailänder and Veit, 2001; Ivy-Ochs et al., 2004). The post-glacial mineral substrata for pedogenesis varied with the cover of sedimentary deposits lying on the relief, creating a mosaic of mineral microenvironments. Bedrock outcropped on crests or cliffs but was sometimes completely covered by sediments on slopes and flat areas (Campy and Macaire, 2003). In this geomorphological context, what are the impacts of such various mineral substrata on soil development? Clearly, a distinction has to be made between the soil parent material (the material in which the soil develops; it can be outcropping bedrock or any kind of superficial deposit, even reworked),

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and the underlying geological bedrock, which can be totally disconnected from the prevailing pedogenetic processes. As a result, soils and their underlying bedrock no longer present a genetic continuity (Semmel and Terhorst, 2010; Lorz et al., 2011). Autochtonous geological bedrock is relegated to the status of substratum bedrock (Kleber, 1997; Lorz and Phillips, 2006) and allochtonous superficial deposits assume the role of soil parent material for Holocene soil development (Terhorst, 2007; Dewolf and Bourrié, 2008). Therefore, these deposits need to be characterized (their origin, mineralogical and chemical composition, distribution in the landscape, and their possible mixing with other materials) in order to understand Holocene soil genesis in the temperate zone (Schaetzl and Anderson, 2005).

The aim of this study is to demonstrate the major role of superficial deposits on present-day pedogenesis by investigating the way they disturb the simple genetic relationship of soils with their geological bedrock. As a consequence, the impact of weathering of superficial deposits will be discussed. Indeed, these mineral materials play a key role in soil differentiation by potentially orientating pedogenesis towards unexpected evolutionary pathways.

2. General setting and site description

2.1. Geological setting

The study site is located in the Swiss Jura Mountains (Fig. 1). The whole massif is composed of Mesozoic limestone and marls, which were subsequently folded during Alpine orogeny in the Miocene and Pliocene. The resulting Jura Mountains have a crescent-like shape, the inner part (eastern) of which is constituted of alternating anticlines and synclines, and outer part (western) of tabular limestone beds. A local ice sheet (Aubert, 1965) probably covered the southern part of the Jura Mountains during the last glacial maximum (corresponding to the marine isotope stage, MIS, 2 from about 30,000 to 17,000 cal. years BP; Buoncristiani and Campy, 2004; Ivy-Ochs et al., 2008). The ice flow passed over the first crest in the southeast (but did not cover the highest summits) and met the Alpine glacier at the southeastern Jura foot slope, at a maximum altitude of 1200 m a.s.l. (Arn and Campy, 1990; Campy, 1992). A range of mixed till deposits, containing carbonate material brought by the Jura ice tongue and silicate material originating from the Alps, was created as a consequence

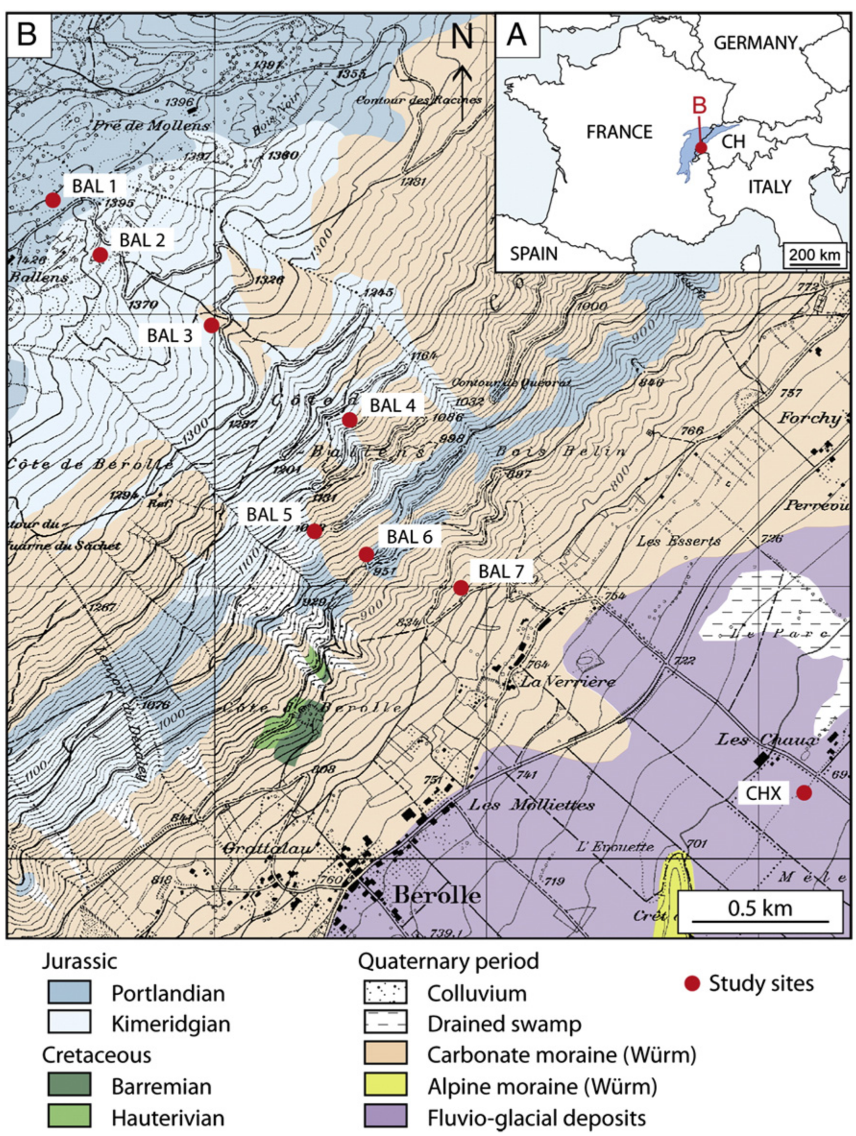

Fig. 1. (A) Location of the Jura Mountains in Europe. (B) Geological map of the Ballens toposequence and localization of the study sites (redrawn after Custer, 1935; Aubert, 1941; Falconnier, 1950; Vernet, 1973).