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Development of a clay-rich interval above a limestone substrate in the Condroz region of southern Belgium

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ABSTRACT

A profile comprising a limestone substrate overlain by a clay-rich interval, which represents a common sequence, was studied with the objective of determining the relationship between substrate and cover. The profile was characterized by various types of mineralogical and chemical analyses, and by a micromorphological study. The mineralogical and chemical data demonstrate that the cover is unrelated to the parent rock, including all horizons below the loess-derived Ap horizon. Thin section observations show that the basal C3 horizon is largely composed of illuvial clay, deposited around claystone fragments, resulting in a fabric that, together with profile position, relates the interval to so-called beta horizons. In higher parts, up to a level recognized as a lithological discontinuity based on mineralogical composition, the profile largely consists of fragments of clay coatings and disintegrated claystone fragments, with an overall upward increase in degree of pedoturbation. The source of the clay is assumed to be Cenozoic deposits that are known to occur in the region. The main conclusion of this study is that clay intervals overlying limestone can have a complex mode of development, to be studied by a combination of methods, and with implications for the valorization of existing soil maps.
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1. Introduction

The nature of clay-dominated intervals above calcareous substrates has been the subject of a large number of studies. Various hypotheses have been invoked for their development, as exemplified by discussions regarding widely investigated formations of this type, such as clays overlying chalk in France ('argile à silex') and England ('Clay-with-Flints') (e.g. Quesnel et al., 2003). For this specific example, the main proposed hypotheses are surface alteration of the limestone bedrock, subsurface limestone dissolution, and accumulation of illuvial clay, the latter derived from a clayey sediment cover or from overlying loess (e.g. Catt, 1986; Dewolf, 1976; Mathieu, 1975; Thiry and Trauth, 1976).

In the Condroz region of southern Belgium, the limestone substrate is commonly covered by reddish clayey material, which is generally considered to be the non-carbonate residue of the limestone (Buurman, 1972; Buurman et al., 1970; Marechal, 1958; Thorez and Bourguignon, 1973). The clay interval is usually overlain by a silt-dominated cover, regarded as a loess deposit. In order to test these hypotheses, the present study compares the nature of the non-carbonate fraction of the limestone with that of the overlying clay interval, and the composition of the surface interval with that of the loess deposits of central Belgium. Variations in composition and fabric were also studied to understand the relationship between other profile units, including a prominent silt wedge.

The study was initiated in the late 1970s, as part of a broader study of the genesis of soils of various types in Belgium. A preliminary interpretation was later presented at a conference (De Coninck et al., 1990), but the full results were subsequently never published.

2. Setting and field characteristics

The physiographic region of the Condroz, southern Belgium, forms an elongated zone, directed WSW–ENE, between the Ardennes in the south and the extensive loess area of central Belgium in the north. On a regional scale, the Condroz has a geological substrate consisting of Upper Devonian sandstone and Lower Carboniferous limestone.

The studied profile is situated near the town of Dinant, along a road cut at the intersection of the N94 and N97 roads (50°14′26″N, 4°57′56″E, 288 m asl; Fig. 1), close to the top of a flat hill. At the moment of sampling, the parcel behind the road cut was a cultivated field with cereal crops. The bedrock in the study area consists of limestone, dolomite and calcareous shale, assigned to three Upper Tournaisian to Lower Visean formations (Waulsort, Leffe and Molignée Formations) (Delcambre and Pingot, 1993). At the sampling site, the bedrock is composed of limestone. Sampling was carried out under the flat upper part of a small hill. The limestone substrate has an irregular surface, with the

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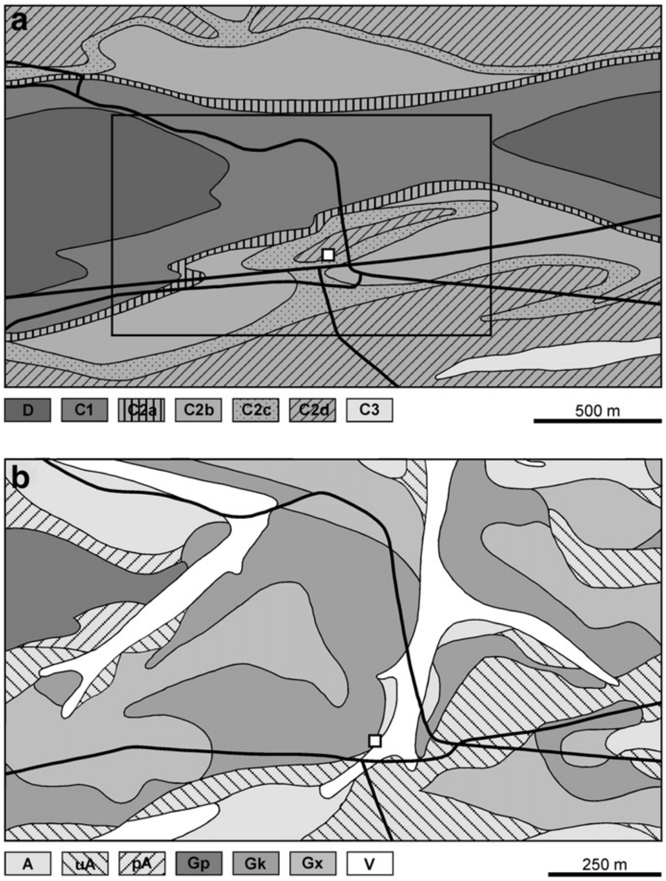

Fig. 1. Location, geological setting, and soil types. a. Geological map, after Delcambre and Pingot (1993) — D: Devonian (Ciney Formation), C: Carboniferous, with C1 Lower Tournaisian (Hastière to Maurenne Formation), C2: Upper Tournaisian to Lower Visean (C2a Bayard Formation, C2b Waulsort Formation, C2c Leffe Formation, C2d Molignée Formation), C3: Visean (Neffe Formation). b. Soil map, after Bourguignon (1966) — A: loamy soils with Bt horizon (Aba, Aba (b), Aca, Ada), uA: loamy soils with Bt horizon and with clay substrate at shallow depth (uAba, uADa), pA (sA): loamy soils with Bt horizon and with sandstone (or sand) substrate at shallow depth (pAba, sAba), Gp: loamy soils with sandstone fragments and with Bt or Bw horizon (Gbap, Gbbp), Gk: loamy soils with limestone or claystone fragments and with Bt or Bw horizon (Gbbk, GbBK), Gx: loamy soils with chert fragments and with Bt horizon (Gbax, Gdax), V: valley soils on loamy material with/without rock fragments (A-Gbp).

top at a minimum depth of 1.70 m beneath the land surface and dropping to levels below the base of the exposure in other parts (>2.70 m) (Fig. 2). The bedrock is penetrated by deep irregular narrow dissolution pockets, roughly parallel to its subvertical stratification (~70°).

From base to top, the profile comprises unweathered dark gray limestone (R2), lined by a weathering rim (R1). The overlying clay interval is dark reddish brown (5YR 3/3) with black ped cores (5YR 2/1) in the lower part (C3). In higher parts, it consists of yellowish red clay (5YR 4/6) (C2), followed by yellowish red (5YR 4/8) silty clay with abundant clay coatings and common Mn oxide coatings (C1). For all C horizons, clay coatings along ped faces are recognized in the field. The overlying Bt2 and Bt1 horizons contain common clay coatings and are overall heterogeneous in terms of color, with red and more brownish to yellowish red patches (2.5YR 4/6 vs 5YR 4/3 to 4/8). Their texture is clayey, with a higher silt content in the upper part (Bt1). The surface horizons (Ap1, Ap2) consist of dark yellowish brown (10YR 3/4) silty loam to clay loam, with scattered chert fragments. The profile is crossed by a subvertical wedge structure, reaching a depth of 2.3 m, filled with a yellowish brown (10YR 5/6) silt deposit, with a somewhat higher clay content at the level of the Bt1 horizon (SW1) than in lower parts (Bt2

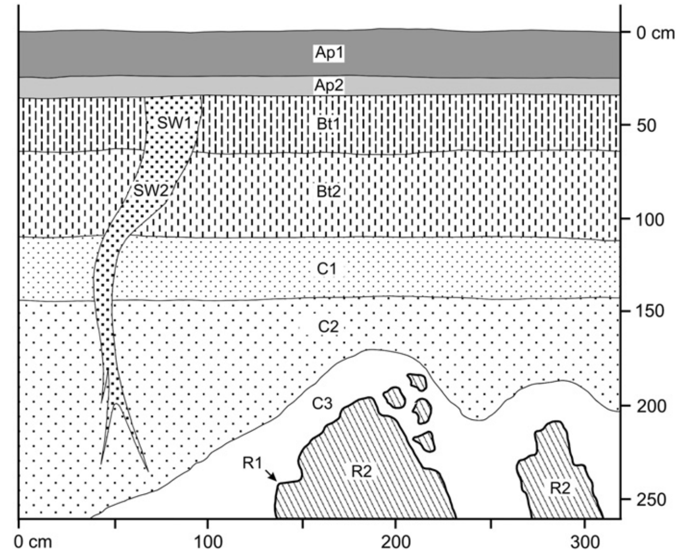

Fig. 2. Schematic representation of the studied profile, with silt wedge at left.

level, SW2). Relevant soil-structural features are the conchoidal vertical faces of large prismatic peds in the C1 and C2 horizons, and the well-developed platy to lenticular structure in the upper part of the silt wedge, extending into the surrounding Bt2 material.

According to the soil map for the region (Bourguignon, 1966), the soils in the study area have a silt to silt loam texture, determined by the presence of a loess cover, and they commonly include rock fragments derived from a substrate that occurs at shallow depth (Fig. 1). Soil development is described as mainly consisting of clay illuviation and structure development or color change. One of the reported soil types, corresponding to the soil at the site of the studied profile, is characterized by a clay substrate occurring at shallow depth (uAba series), interpreted to have formed by alteration of limestone (Bourguignon, 1966). In terms of the WRB soil classification system (IUSS Working Group WRB, 2007), the profile comprises an argic subsurface horizon and shows an abrupt textural change and lithological discontinuity at shallow depth (see further), resulting in a general designation as Abruptic, Clayic, Cutanic, Profundic Luvisol. According to the United States soil classification (Soil Survey Staff, 2010), the soil has an ochric epipedon and an argillic subsurface horizon, and the profile qualifies as a Typic Paleudalf.

3. Methods

Profile descriptions and soil horizon designations were made or revised according to FAO guidelines (FAO, 2006). Color annotations refer to moist material, using standard soil color charts (Munsell, 2000). Particle size distribution was determined after H_2O_2 treatment and using sodium hexametaphosphate as dispersant; the pipette method was used for grain size analysis of the silt and clay fractions (2–50 μm, <2 μm). The silt and clay fractions were separated for other analyses by successive sedimentation (Na_2CO_3 dispersant, pH ~ 9.5). Chemical analysis involved lithium carbonate fusion for Si, Al and Ti, and acid digestion for all other elements; concentrations were measured by colorimetry (Fe, Ti) and atomic absorption spectrometry. For the parent rock, the chemical composition was determined for the residue remaining after removal of carbonates with (i) cold 1 N HCl and (ii) an acetic acid (HOAc) buffer solution (pH 5) followed by H_2O_2 treatment. For the profile samples, the pH was determined in H_2O and in KCl (1/1 ratio), and CEC was determined using 1 N ammonium acetate at pH 7. Free iron and aluminum determination was done by analysis of extracts obtained by reaction with a Na dithionite–citrate–bicarbonate (DCB)

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