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The evidence of lateral podzolization in sandy soils of Northern Poland

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ABSTRACT

Evidence of slope-scale element translocation (lateral podzolization) has been documented in sandy areas of Northern Poland. Accumulative soils enriched with organic matter, iron, aluminum, and manganese (Entic Podzols) have been found at the bottom of closed, small depressions in inland-dune fields and undulated surfaces of glaciofluvial terraces. Together with the surrounding weakly or moderately developed podzolic soils (Albic Arenosols, Haplic Podzols) Entic Podzols form regular toposequences, and seem to be geochemically linked. In the light of chemical, micromorphological and SEM-EDS analyses, the whole solum of the soils under study exhibit diagnostic features of the illuvial *spodic* horizon; however, they do not have an eluvial *albic* horizon.

Landscape position and features of the studied soils suggest inter-pedon translocation of organic matter, iron and aluminum as the concept of Entic Podzol genesis. Furthermore, high values of Fe_d/Fe_t and Fe_o/Fe_d ratios in their solum can be interpreted as evidence of allochtonous character of iron accumulation. The results of this study show that the lateral podzolization process can be common even along slopes built from loose, permeable sandy deposits, where one would not expect any effective intra-layer solution flow. Organic matter and compounds illuviated to the Bhs horizon are the probable factors limiting percolation and modifying the direction of solutions movement. On slopes of more complex morphology, small closed depressions act as geochemical traps, where compounds leached from the upper slope soils can accumulate. Radiocarbon dating carried out on a buried Entic Podzol found in one of the profiles shows that the process has continued for more than 1200 years.

1. Introduction

The phenomenon of lateral podzolization has been described in granite and sandstone areas of the Scharzwald (Black Forest) Mountains in Germany (Sommer et al., 2000, 2001), however it is known also from other Podzol-dominated areas (e.g. Glazovskaya, 1968; Karavayeva, 1968). It has been defined as the landscape scale process responsible for variability of Podzols on 10^2–10^3 m long steep slopes built from weakly permeable rocks. Lateral, inter-pedonal movement of solutions leads to the formation of soils differing by thickness of eluvial and illuvial horizons: 'E-Podzols' in upper parts of slopes and 'Bs-Podzols' in lower slope positions.

Other mechanisms controlling the diversity of Podzols in slope sequences are also known from numerous studies. The most obvious is the influence of ground water at the foot of the slope (e.g. Dzięciołowski, 1976; Prusinkiewicz, 1961; Seibert et al., 2007). In this case, according to higher moisture, soils in lower topographical positions show more expressed effects of podzolization than soils located upslope: more contrasting E and B horizons and better developed B horizons.

In the Podzol-dominated landscape of the inland-dune area of the Toruń Basin (Northern Poland), specific accumulative soils enriched with iron, aluminum and organic matter in the whole solum were found in small depressions surrounded by 10^1–10^2 m long slopes (Jankowski, 2001). Until now the occurrence of such soils was known from a limited area. New field investigations carried out in recent years confirm a much wider distribution of such soils on dunes of the Toruń Basin, and also their occurrence in other sandy areas of Northern Poland.

According to a lack of contact with groundwater and a lack of substantial topoclimate variability on such short slopes, lateral movement of solutions can be the presumed factor causing the formation of these soils. Since they developed in loose, highly permeable sands, the question of whether intra-layer solution flow can be effective in this case raises doubts.

The objective of this paper is to characterize these accumulative soils occurring in Podzol-dominated landscapes in the context of their distribution patterns, basic properties and classification, as well as an attempt to explain their genesis — referring to the concept of lateral podzolization.

2. Regional settings

Widely spread sandy areas formed according to deglaciation of the last Pleistocene continental ice-sheet are characteristic for Northern

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Poland and the whole European sand belt (Zeeberg, 1998). Field studies were conducted in three regions of such origin (Fig. 1):

1. The Toruń Basin, a huge area of inland-dunes developed on surfaces of glaciofluvial terraces in the Toruń–Eberswalde ice-marginal stream valley, contemporarily drained by the Vistula and Noteć rivers (Galon, 1961). The relief of these dune fields is undulated or even hilly, with regular patterns of parallel, bow-shaped dunes and complex dune hills built by merging several single forms, reaching 30–45 m in height (Mrózek, 1958).
2. The Brodnickie Lakeland and 3. Bory Tucholskie, represent glaciofluvial outwash-plains, contemporarily drained by the Skarlanka and Wda rivers, respectively. The land surface in both regions is generally flat; however, in places it is diversified by subglacial channels, kettle-holes, melt-water depressions or depressions of depositional origin.

Glaciofluvial terraces of the ice-marginal stream valley as well as outwash plains are built from sandy, permeable deposits which are several meters deep.

The whole study area lies in the range of the Poznań (Frankfurt) phase (18.8 ka; Kozarski, 1995) of the last glaciation (Weischselian/Würm), although glaciofluvial sands were deposited at the foreland of the ice sheet of the Pomeranian phase (16.2 ka; Kozarski, 1995). Dune forming processes are dated to cold phases (the Oldest-, Older- and Younger Dryas) of the Late Glacial (14–10 ka BP; Nowaczyk, 1986; Jankowski, 2003).

The three study regions form a triangle with 100 km long sides. The Bory Tucholskie and the Brodnickie Lakeland are in the north and the Toruń Basin lies more to the south (Fig. 1).

The whole area lies in the zone of humid, temperate climate, of the transitional type between oceanic and continental. The mean annual temperature is 6.9–7.7 °C with the hottest month July (16.6–18.0 °C) and the coldest January (−3.0 to −2.5 °C; Wójcik and Marciniak, 2001). The mean annual precipitation does not exceed 600 mm, with the maximum in summer (April–September: 65%).

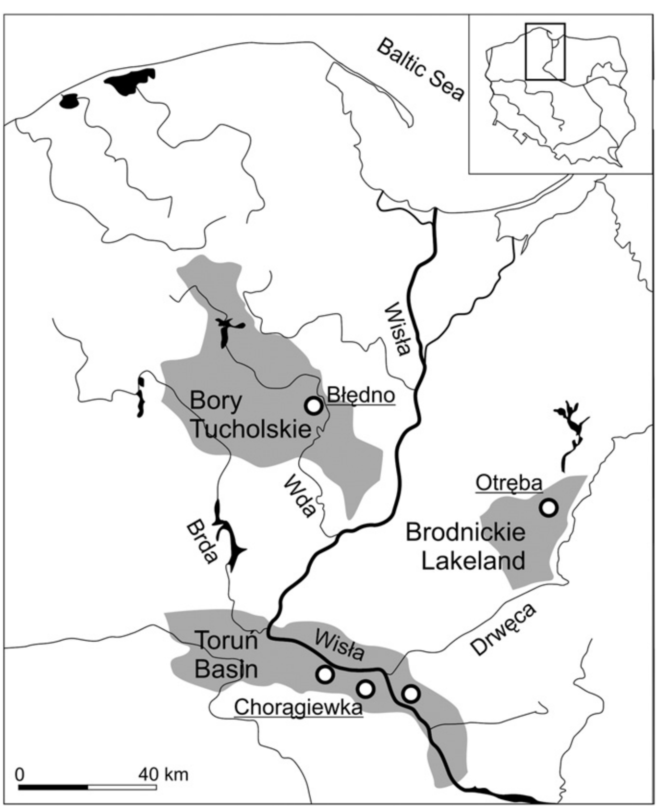

Fig. 1. Location of the study area.

Pine forests (*Peucedano-Pinetum*) are presumed to be the potential, natural vegetation on the dunes of the Toruń Basin (Matuszkiewicz, 1995). Glaciofluvial sands are habitats for poor deciduous — oak–lime–hornbeam forests (*Tilio-Carpinetum*) or pine–oak mixed forests (*Querco roboris–Pinetum*); however, all study sites are currently overgrown with artificial pine plantations (*Peucedano-Pinetum*).

3. Methods

Reconnaissance field works allowed the recognition of places where accumulative soils occur, and also the rules regarding their distribution. 120 drillings and 12 soil pits were made while mapping individual contours and their surroundings in selected areas: the Chorągiewka site (CH — the Toruń Basin), the Otręba site (OT — the Brodnickie Lakeland) and the Błędno site (BL — Bory Tucholskie). Soil profiles were examined with regard to their topographical position, in the following sequence: summit–slope–bottom of the depression. Five profiles were selected to be presented in this work: three profiles representing different variants of accumulative soils in depressions (CH1, CH3, OT2) and two profiles of soils in the surroundings (CH2, OT1). Pairs of profiles CH2–CH3 and OT1–OT2 were located on dune- (CH) and outwash- (OT) slopes and they constitute toposequences.

Soil morphology was described according to standard procedure (FAO, 2006). Soil material was sampled from genetic horizons distinguished in the field and after preparation (drying, separation of roots and fraction >2 mm by sieving) it was analyzed in the laboratory.

Texture was determined by combining the Bouyoucos (1951) hydrometer and sieve method. Bulk density and moisture were quantified by using 100 cm^3 cores dried in oven at a temperature of 105 °C.

Organic carbon (OC) content was determined by the wet dichromate oxidation method, and total nitrogen (Nt) content by the Kjeldahl method. The reaction was measured in H_2O and 1 M KCl in 1:2.5 suspension for mineral samples, and 1:10 suspension for organic samples.

Pedogenic forms of iron and aluminum were extracted: Fe_t with $HClO_4$–HF, Fe_d with sodium dithionite–citrate–bicarbonate (Mehra and Jackson, 1960) and Fe_o and Al_o with ammonium oxalate buffer solution (McKeague and Day, 1966). Their contents were measured using a SEMCO S91E spectrophotometer (Fe_o, and Al_o) and a SOLAAR 699 atomic absorption spectrophotometer (Fe_t and Fe_d).

Accumulative horizons (AB, Bhs) of representative profiles were the subject of more detailed studies. Micromorphological investigations were carried out in undisturbed samples taken in Kubiena's tins (6.5 × 8 cm). After impregnation and being cut into thin sections, they were observed and photographed under a Nikon Eclipse E600 Pol microscope at a magnification of 10–40×.

Spot micro-analyses of uncovered thin sections were conducted by the SEM/EDS technique in the Institute of Hydrogeology and Engineering Geology at the University of Warsaw, Poland.

Elemental composition of bulk samples was determined by a set of methods (ICP, INAA, ICP/MS and XRF) in the Activation Laboratories Ltd., Canada.

4. Results

4.1. Distribution of accumulative soils

Occurrence of accumulative soils is limited to bottoms of small land depressions, closed by slopes from each side. They neither appear in valley-like depressions open from one side, nor in any other landscape position, including depressions influenced by shallow ground water. Surrounding slopes are 10–100 m long and 1–20 m high with inclinations between 5 and 30°. Individual polygons of accumulative soils occupy areas of only 2–10 × 100 m^2. The frequency of