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50-year of pedogenesis and element dynamics in Technosols developed on spoil tips of the Nord–Pas-de-Calais coal-mining basin (France)

EMILY LLORET[1], YENSINGA BAFOUNGA[1], JERÔME DIBONGUI[2], MARION DELATTRE[2], ANNETTE HOFMANN[2] AND FRANCK BOURDELLE[3]

[1]Université de Lille - LGCgE
[2]Université de Lille - LOG
[3]CY Cergy Paris Université - ISTeP

Spoil tips of the Nord–Pas-de-Calais coal-mining basin (northern France) are anthropogenic landforms composed mainly of carboniferous black shales. Since mine closure, many of these deposits have undergone spontaneous revegetation by pioneer herbaceous species (e.g., *Glaucium flavum*, *Iberis umbellata*) or by surrounding forest communities (e.g., *Betula pendula*, *Quercus spp*). These colonization processes have given rise to emerging ecosystems supported by the development of Technosols whose pedogenesis remains poorly documented in this region.

This study provides the first detailed physico-chemical, mineralogical, and geochemical characterization of Technosols formed on three representative vegetated spoil tips: Ostricourt, Sabatier Nord, and Ledoux Lavoir. Sampling was conducted along slope transects, with particular attention to mid-slope profiles where interactions among erosion, vegetation, and hydrology most strongly drive soil formation. Analyses included particle-size distribution, bulk density, pH, major and trace elements (ICP-MS), total and organic carbon and nitrogen, Rock-Eval® pyrolysis, and X-ray diffraction.

Although these soils are young (< 50 years), they already show clear pedogenetic structuring with up to four horizons (OL/OF/OH, Az, Bz/Boxz, Zt). Oxidative weathering features - jarosite and Fe-oxyhydroxides - are widespread, reflecting acid mine drainage (AMD) generated by pyrite oxidation. Soil pH varies significantly (3.6–7.5) depending on vegetation cover, horizon depth, and drainage. Chemical Index of Alteration (CIA) values (70–80) indicate moderate weathering, marked by depletion in Ca, Na, and K and enrichment in Fe and S. Forested slopes show pronounced accumulation of As, Pb, Zn, W, Cu, Sb, Mo, and Ge, consistent with retention through Fe-oxide precipitation, clay adsorption, and organic complexation.

Results show that vegetation-induced AMD initiates early pedogenesis, while the coupling of shale weathering and organic-matter incorporation drives rapid differentiation of horizons, reaching 20–40 cm in 30–50 years.

Overall, despite steep slopes (30-50 %) and an altered oceanic climate that limits soil stability, these spoil tips exhibit rapid pedogenesis and the emergence of increasingly mature Technosols. These findings support the ecological management and restoration of post-mining landscapes.