



Pedogenesis and Properties of Soils Formed on a 800 ka Sequence of Quaternary River Terraces in the Spanish Pyrenees

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In the Ebro basin (Spain) and adjacent Pyrenees, we have examined time-related trends in soils formed on well-dated sequence of fluvial terraces formed along the Rio Cinca and Rio Gállego in northern Spain. The soils have formed on fluvial deposits (largely glacial outwash) and include up to ten regionally distinct terrace surfaces mapped as Qt10 (lowest) to Qt1 (highest). Soils were described on both former cobble-gravel fluvial bar positions and former channel positions with up to 2 m of silty-sand overbank deposits overlying cobble-gravel alluvium. Terraces and glacial deposits have been dated using radiocarbon, luminescence, magnetostratigraphy, and nuclide depth profiles using cosmogenic Be10. The ages obtained from glacial deposits indicate glacial periods at about 85 ka, 64 ka, and 36 ka (from glacial till) and 20 ka (from loess). The fluvial drainage system fed by glaciers, developed extensive terrace systems which have approximate average dates of 11 ka (Qt9), 45-47 ka (Qt8), 61-68 ka (Qt7), 97 ka (Qt6), 151-178 ka (Qt5), 395-430 ka (Qt3), and > 740 ka (Qt2). The modern climatic regime is Mediterranean with precipitation ranging from ~125 mm/yr at the lower elevations to ~250-350 mm/yr at the higher elevations. The lithologic composition of the soil parent material (fluvial sediment) is siliceous igneous and metamorphic rocks (~75% of the deposits) and secondarily of carbonate marine rocks (~25% of the deposits).

General trends in soil development in the arid part of the chronosequence show strong time-related trends in pedogenic accumulation of calcium carbonate (from 15 to 75-85% wt.), weak trends in iron oxides (0.5 to 1.8% wt. total extractable Fe), the type and degree of carbonate cementation (carbonate stage I to V; Bwk to Bkm), and soil development index values (SDI) ranging from about ~5 (Qt10) to ~90 (Qt3). By comparison, trends in soil development in the semi-arid to sub-humid part of the chronosequence have stronger overall accumulation of clay and iron oxides (0.5 to 3.8 % wt. total extractable Fe), minimal pedogenic carbonate (0 to 22% wt.), SDI values from ~ 15 (Qt9) to ~ 120 (Qt3), and greater profile depths relative to the soils in the arid localities. Maximum soil developed occurs on the ~ 400 ka Qt3 surface. Only weakly developed soils are present on the older Qt1 and Qt2 surfaces, reflecting the erosional degradation of the two oldest terrace remnants. Soil morphology, especially development of soil Bkm and Bt horizons, strongly reflects the original bar-and-channel depositional topography. Soils formed at bar positions have higher gravel content, stronger developed Bkm horizons with carbonate cemented gravel (III-IV+ carbonate stage morphology), relative to soils formed at channel positions. Soils formed at channel positions have low gravel content (parent material is primarily overbank and loess deposits) and Btk horizons with scattered to abundant carbonate nodules (I-II carbonate stage morphology).