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External controls on formation and preservation of fluvial terrace staircases in the Southern Pyrenees foreland

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The fluvial network of the Southern Pyrenees is an example of transverse drainage systems in young (alpine) mountain belts and it features well preserved fluvial terrace records. Some of the major Southern Pyrenees tributaries, like the Cinca and the Gallego, have been studied previously and have some age controls on their fluvial terrace levels. We extend these records to the largest drainage system of the Southern Pyrenees, the Segre river system, presenting new GIS and field data, as well as exposure ages obtained from *in situ* produced ^{10}Be cosmogenic nuclides.

The terrace staircase of the Segre River is built up by cut and fill type terraces, ranging from 112 to 3 meter above the present-day riverbed. Gravel deposits have commonly thicknesses of 2 to 7 meter over bedrock. Locally they have extensive thicknesses of up to 20 meter and show evidence for the impact of ongoing tectonics (i.e. gypsum doming, tectonic basin) featuring faults and folds as primary features.

The terrace record can be subdivided into four groups of terraces that are separated by large incisive steps of about 20 meter: I) old extensive single terrace surfaces (TQ1, $\sim$112m), II) terraces of limited extent preserved as remnant hills (TQ2, $\sim$80m), III) two extensive terrace levels (TQ3 and TQ4, 60-45m), and IV) a well-preserved and extensive lower terrace complex (TQ5-TQ7, 30-3m). The staircase morphology (extent and elevations) of the Segre River shows analogies with other streams of the Southern Pyrenees indicating regional scale causes for the formation of terraces.

The terraces TQ1, TQ2,TQ3 and TQ4 have been sampled for *in situ* produced ^{10}Be cosmogenic nuclides. Our results show preliminary minimum ages of Middle to Late Pleistocene terrace abandonment: TQ1: 274 ka (MIS 9a), TQ2: 135 ka (MIS 5e), TQ3: 106 ka (MIS 5c), and TQ4: 65 ka (MIS 3), and erosion rates of 0.3 cm/ka (TQ1, TQ4), 0.45 cm/ka (TQ3), and 0.73 cm/ka for TQ2. The obtained ages indicate a causal relationship between terrace abandonment (incision) and interglacial periods, and point to a terrace formation (aggradation) related to glacial periods in the Pyrenean headwaters. Sedimentological outcrop observations corroborate a cold-climate based genesis of the terraces and present numerous braided channels, ice rafted boulders and frozen sand clasts. Morphologically, the extensive terraces surfaces point to a more than 4km wide presumably braided river system during formation of TQ1 and TQ2.

The longitudinal terraces correlation reveals a downstream diverging trend along the lower reaches (foreland stretch) which is most likely base-level controlled. We link the divergence of the Segre terraces to the downcutting history of the Catalan Coastal Range that borders the Ebro foreland basin to the Mediterranean Sea. The stepped morphology with several topographic levels at the breach record the downcutting history of the Catalan Coastal Range. Our longitudinal Segre terrace profiles point to a base-level of about 200m a.s.l. at the begin of terrace formation at the Segre and indicate gradual incision since at least the Middle Pleistocene. We argue, that the Catalan Coastal Range functioned as a local base-level upstream the sea outlet presumably until the Late Pleistocene.

Hence, the preservation of terrace staircases at the Southern Central Pyrenees does not require tectonic uplift (although it can not be excluded) and can be explained by base-level mechanisms, while the terrace formation is climate triggered and the result of glacial-interglacial-cycles in the Pyrenees.