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Colluvial legacies of millennial landscape change on individual hillsides, place-based investigation in the western Pyrenees Mountains

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ABSTRACT

We detect transition to agropastoral land use in a mountain landscape by radiocarbon dating physical signatures (sedimentation rates, charcoal concentrations, magnetic susceptibility) of conversion from native forest to pasture contained within colluvial stratigraphic sections. Focus is on two study sites located on toeslopes directly beneath zero-order hollows draining several hectares in the commune of Larrau (Pyrénées Atlantiques, France) along the international drainage divide of the western Pyrenees. Sample sites maximize likelihood of spatially and temporally uniform slopewash sedimentation. This constitutes a place-based approach to decipher the chronology of agropastoral activities within individual fields, which is applicable to other mountain ranges of the world. Stratigraphic columns were augured in contiguous 10 cm sample levels, which produced temporal resolution of decades to several centuries. We interpret relatively high concentrations of charcoal, rapid sedimentation, and magnetic susceptibility patterns as evidence of the intentional use of fire to transform forests into pastures. Results indicate that intentional burning and clearing probably were initiated by the Late Neolithic (ca. 5000–6000 cal. BP). However, intense burning, extensive forest clearance, and erosional degradation occurred later during the Bronze Age at one site, and during the Iron Age at the other site. This non-synchronous pattern of charcoal abundance and sedimentation rates is consistent with human agency of land clearance driving the chronology rather than paleoclimatic drivers. Stratigraphic zones of rapid sedimentation at both sites constitute "legacy" sediment of great antiquity. Our results are consistent with similar shifts in fire regimes and vegetation assemblages derived from direct association with anthropogenic proxies (e.g. pastoral pollen taxa, fungal spores of sheep dung, and archaeological sites) elsewhere in the Pyrenees and other European mountains. Consequently, our method may provide a good indicator of human presence and land-use activities for mountainous areas where paleoenvironmental records from bogs, lakes, and archaeological sites are limited.

1. Introduction

We present multi-proxy physical stratigraphic evidence from deposits of colluvial slopewash that are indicative of mid-Holocene transformation of forest to pasture along the continental drainage divide between France and Spain in the western French Pyrenees Mountains. Regional pollen and charcoal records from lakes and peat bogs have established that agriculture, pastoral activities, and animal husbandry first appeared in the western Pyrenees circa 7500 cal. BP with notable expansion by 6000 cal. BP (Galop, 2006; Mazier et al., 2009; Rius, 2009; Rius et al., 2012; Galop et al., 2013; Perez-Díaz et al., 2015). This evidence also indicates that human use of fire was instrumental for creating and maintaining pastures.

The prime-mover explanations were once favored for the expansion of domestication in Europe (Ammerman and Cavalli-Sforza, 1984), but are yielding to evidence that the Neolithic transition was relatively abrupt and included both local adoption and independent domestication (Crubézy et al., 2006; Zeder, 2008; Rowley-Conwy, 2011). The initial insights leading to this shift in understanding the Neolithic transition were concentrated in highly

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evolved, low-gradient riverine environments (Dotterweich, 2008; Hoffmann et al., 2008; Berger, 2011), and rely on paleoenvironmental records derived from pollen, spores, and charcoal preserved in wetland and lake sediments at lower elevations. These windblown and fluvially transported microfossils represent watershed and regional scales of vegetation change having coarse spatial resolution. Interpreting the human capacity to transform earth processes over the Holocene by reference to a single activity (i.e. grazing) and using a fossil archive (i.e. pollen) can lead to simplistic and deterministic accounts that are no different than earlier prime-mover explanations (Moe et al., 2007; Ejarque et al., 2011; Cunill et al., 2013).

Agropastoralism is the primary means by which humans modified European mountain landscapes over the course of the Holocene (Moe et al., 2007; Ejarque et al., 2011; Cunill et al., 2013; Bal et al., 2015), but the geomorphic, topographic, climatic, and vegetative heterogeneity of these landscapes means that results obtained in one region may not be valid for interpreting mountain landscapes elsewhere (Mazier et al., 2009; Brun, 2011; Ejarque et al., 2011). Accumulating evidence furthermore indicates that human land use over the Holocene in mountain landscapes was largely decoupled from climatic/temperature gradients (Ejarque et al., 2010, 2011; Cunill et al., 2013). Numerous studies now confirm that mountain landscapes are the result of climatic and anthropic pressures exerted and interrelated in a variable manner over the course of the Holocene (Kaal et al. 2008a,b; Ejarque et al., 2010; Bal et al., 2011; Pelachs et al., 2011; Vannière et al., 2001).

While traditional paleoenvironmental archives convincingly portray how nascent Late Neolithic agropastoralism expands into extensive pastoral land use during the Bronze Age in mountainous terrain, they lack resolution on past human activities within individual fields. Consequently, little is known about the exact timing of past land-use changes at the spatial scale of individual hillsides, especially on high drainage divides. Here we test the idea that the Holocene chronology of landscape change from native forests to pastures is preserved in slopewash colluvium that accumulated on toeslopes of individual mountain hillsides. This place-based approach relies on changes in sedimentation rates, charcoal concentrations, and magnetic susceptibility to reconstruct activities of the first shepherds in the western Pyrenees.

2. Material and methods

2.1. Study area and sample sites

We focus on two colluvial sites at 1350–1600 m elevation in the ethnically Basque commune of Larrau (12.7 km^2, Department of Pyrénées Atlantiques, France, Figs. 1 and 2). A single stratigraphic section was sampled from each site with auger borings of contiguous 10 cm sample intervals (4.5 m deep hole at the Ihitsaga site and 1.8 m deep hole at Vallon de Mulhedoy). The southern boundary of the commune abuts the completely treeless international drainage-divide between France and Spain (Fig. 2). Bedrock consists of well stratified Mesozoic mudstone, shale, dolostone, and limestone that is steeply tilted and folded (Moores and Fairbridge, 1997) and capped by a thin mantle of noncalcareous silty to clayey yellowish-brown residuum. The residuum ranges from 0 to about 2 m thick, consisting of Alfisol type soils that tend to be more organically enriched in present-day pastures (Leigh et al., 2015).

The climate is humid oceanic (Atlantic) on the French side of the Pyrenees, with a mean long-term (AD 1956–2010) annual precipitation ~1700 mm and a mean annual temperature ~13 °C supporting mesophyllous vegetation. Native woodlands currently are dominated by beech (*Fagus silvatica*) that is often intermingled with fir (*Abies pectinata*) and oak (*Quercus* sp.). Most south facing slopes and both sides of the continental divide are covered with grasses and herbs, primarily bentgrass (*Agrostis* spp.), fescue (*Festuca* spp.), nard (*Nardus stricta*), and bluegrass (*Poa* spp) intermingled with various sedges (Family Cyperaceae) and legumes (e.g., *Trifolium alpinum*). These herbaceous communities are regularly maintained by intentional burning (Coughlan, 2013) and would revert to woodlands without such human intervention, whereas the north facing slopes below 1300 m are largely forested (Fig. 2). No trees currently exist above ~1700 m, but the ecotone of the natural treeline would actually be around 2200–2300 m and ranged up to ~2400 m during portions of the Holocene (Cunill et al., 2012). Native vegetation throughout the Holocene would have consisted almost entirely of woodlands if not for human alteration (Perez-Díaz et al., 2015).

This research relies on two intensively studied colluvial depositional sites (Ihitsaga and Vallon de Mulhedoy; Figs. 1 and 2) that capture overland flow and slopewash sediment from entirely pastured hillslopes of zero-order drainages (i.e. no fluvial channels). These colluvial depositional sites comprise relatively flat toeslopes favoring sedimentary accumulation of slopewash, and lack mass-wasting deposits (landslide, slump, or debris flow deposits). Such flat toeslopes are relatively unique, as most backslopes drain directly into stream channels bypassing hillslope deposition. Nonetheless, the two colluvial sites studied capture sediment that is representative of the character of most of the sloping pastureland currently in use.

The sampled colluvial sections are small hollows that collect sediment from zero-order watersheds with drainage areas of 12 ha for Ihitsaga and 4 ha for Vallon de Mulhedoy (referred to simply as "Mulhedoy" henceforth in the text, tables, and figures). The Ihitsaga site (1355–1590 m elevation) accumulates slopewash in a small trough or swale situated on a bedrock bench so that the flow from upslope converges somewhat into the trough. The Mulhedoy site accumulates slopewash on a bedrock bench that allows somewhat more divergent flow than at Ihitsaga. The Mulhedoy site was the object of a previous investigation (Leigh et al., 2015), but many new radiocarbon dates have been obtained and analytical techniques have been modified and improved since that study was conducted, comprising a new data set.

2.2. Methodology

A 7.6 cm diameter bucket auger was used to retrieve a contiguous column of 10 cm sample increments from each site. Samples were bagged, oven-dried at 105 °C, and saved for laboratory analyses. Entire samples were gently disaggregated to pass an 8 mm mesh to avoid crushing large charcoal fragments, and subsamples were subjected to particle size, magnetic susceptibility, and charcoal analyses.

Particle size analysis determined the weight fractions of gravel (>2000 μm), sand (2000-63 μm), silt (63-2 μm), and clay (<2 μm). Gravel is reported as the percent of the whole oven-dried sample. Sand, silt, and clay are reported as weight percentages of the <2 mm mineral soil following destruction of organic matter with hydrogen peroxide, wet sieving the sand through a 63 μm mesh, and then obtaining the silt and clay percentages by the hydrometer method of Gee and Bauder (1986).

Subsamples crushed to pass a 2 mm mesh were measured for their low-frequency (0.46 kHz) mass-specific magnetic susceptibility with 10.0 g samples contained within 20 ml plastic vials. Each sample was measured on two separate occasions with a Bartington™ MS3 magnetic susceptibility meter with the reported value being the average. Twenty-five replicates of one sample indicate a standard deviation of 0.001057 $\times$ 10^{-6} m^3 kg^{-1} or 0.70 percent of the mean sample value of 0.150448 10^{-6} m^3 kg^{-1}.