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Chronology of geomorphological changes in a valley of Cantabrian Mountains over the last 20,000 years

Cronología de los cambios en la geomorfología de un valle de la Cordillera Cantábrica en los últimos 20.000 años

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Abstract

This is an in-depth study of a mixed deposit of terrace and alluvial fan in a valley of the Cantabrian Mountains that aims to characterize environmental conditions during the period following the Last Glacial Maximum (LGM) at the end of the Pleistocene and the entire Holocene, including human influence to the present day. In this perspective, the lithostratigraphy of different layers was described, the granulometric analysis performed in situ and in the laboratory, the organic bulk sediment dated by radiocarbon and weight, and other empirical studies, such as paleomagnetism were performed. The results reveal a temporal sequence of deposition from around 19.4 ky BP to the present showing different sedimentary environments. Paleoclimatical scientific literature in sorrounding areas complemented the interpretation of the results e.g. pleistocene glaciers, speleothems, palynology and geomorphology. We conclude a completely diferent evolution of studied section between Late-Pleistocene and Holocene. Bottom layers, composed of coarse boulders, are interpreted in the context of a second glacial push after the Local Last Glacial Maximum under conditions of torrentiality. In the upper layers, in the Holocene, there was an increase in sedimentation from slopes through alluvial and colluvial cones, and rivers lost their capacity to transport these sediments. Important environmental changes in the Middle Holocene, 5.5 ky BP, were detected with possible evidence of human action. A decrease from that moment in the deposited sediment caliber was verified.

Key words: Fluvial deposits; Slope deposits; Late Pleistocene; Holocene; Geomorphology.

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Resumen

Este es un estudio en profundidad de un depósito mixto de terraza y cono aluvial en un valle de la Cordillera Cantábrica que tiene como objetivo caracterizar las condiciones medioambientales durante el período posterior al Último Máximo Glaciar (LGM) al final del Pleistoceno y en todo el Holoceno, incluyendo la influencia humana hasta el presente. Con esta perspectiva, se han descrito litoestratigráficamente diferentes capas, se ha realizado un análisis en el campo y en el laboratorio, se ha pesado y datado mediante radiocarbono el sedimento y se han hecho otros estudios empíricos como el de paleomagnetismo. Los resultados revelan una secuencia de deposición desde alrededor de 19,4 ka BP hasta el presente mostrando diferentes ambientes sedimentarios. La literatura científica paleoclimática en áreas cercanas complementa la interpretación de los resultados p.e. glaciares pleistocenos, espeleotemas, palinología y geomorfología. Nosotros concluimos que se ha producido un comportamiento evolutivo completamente diferente de la sección estudiada en el final del Pleistoceno respecto al Holoceno. Las capas inferiores, compuestas por bloques grandes, son interpretadas en el contexto de un segundo pulso glaciar del Último Máximo Glaciar Local bajo condiciones de torrencialidad. En las capas superiores, en el Holoceno, hubo un incremento en la sedimentación procedente de las laderas a través de conos aluviales y coluviales que impidieron que el río perdiera su capacidad de transporte de estos sedimentos. En el Holoceno Medio, 5,5 ka BP, se han detectado cambios medioambientales importantes con un evidencias de acción humana. Desde ese momento se ha verificado un descenso en el calibre de las partículas del sedimento.

Palabras clave: Depósitos fluviales; Depósitos coluviales; Pleistoceno Final; Holoceno; Geomorfología.

1. Introduction

The hydrographic network of the northern margin of the Duero River, derived from the Cantabrian Mountains, has a parallel pattern aligned towards Southwest with common characteristics in the different rivers and interfluves. It is the result of the Cenozoic landfill (Mabesoone, 1959) as an endorheic basin and subsequent dissection following the post-Pliocene opening of the basin to the Atlantic ocean. In the headwaters this process left different paleo river levels as evidenced by the fluvial terraces occupying the piedmont of the Cantabrian Mountains (Mabesoone, 1959; Bertrand and Bertrand; 1984; Fernández-Caballero, 1994) and surfaces of erosion (Gracia-Prieto *et al*., 1990). The headward erosion of the hydrographic network deepened the dissection of the valleys and modelled the relief with a marked erosive character at the head (Bertrand, 1971). Pleistocene cold processes, glacial and periglacial phenomena also completed this morphogenesis to leave landforms and deposits that can be studied for paleoenvironmental reconstruction. The river terraces of the Upper Pisuerga basin were studied by Nossin (1959) in what was an outstanding geomorphological study (Figure 1).

The study of the Holocene record has taken on outstanding interest with the development of Geoarchaeology (e.g., Pérez-Lambán *et al*., 2018), but also with the study of Global Change and Physical Geography. The integration of traditional sedimentological analysis, geomorphology, and the new paleoenvironmental research offers interesting opportunities for the scientific integration of natural and cultural facts with an imprint on the relief. This integration is found in the interface between the hillside and the valley floor where alluvial and colluvial deposits are connected to form a preferential site for the analysis of human alterations of the physical environment (Wohl, 2014).

In this context, the deposits and landforms of the studied area permit the study of the geomorphological sequence between the end of the Pleistocene and the present including

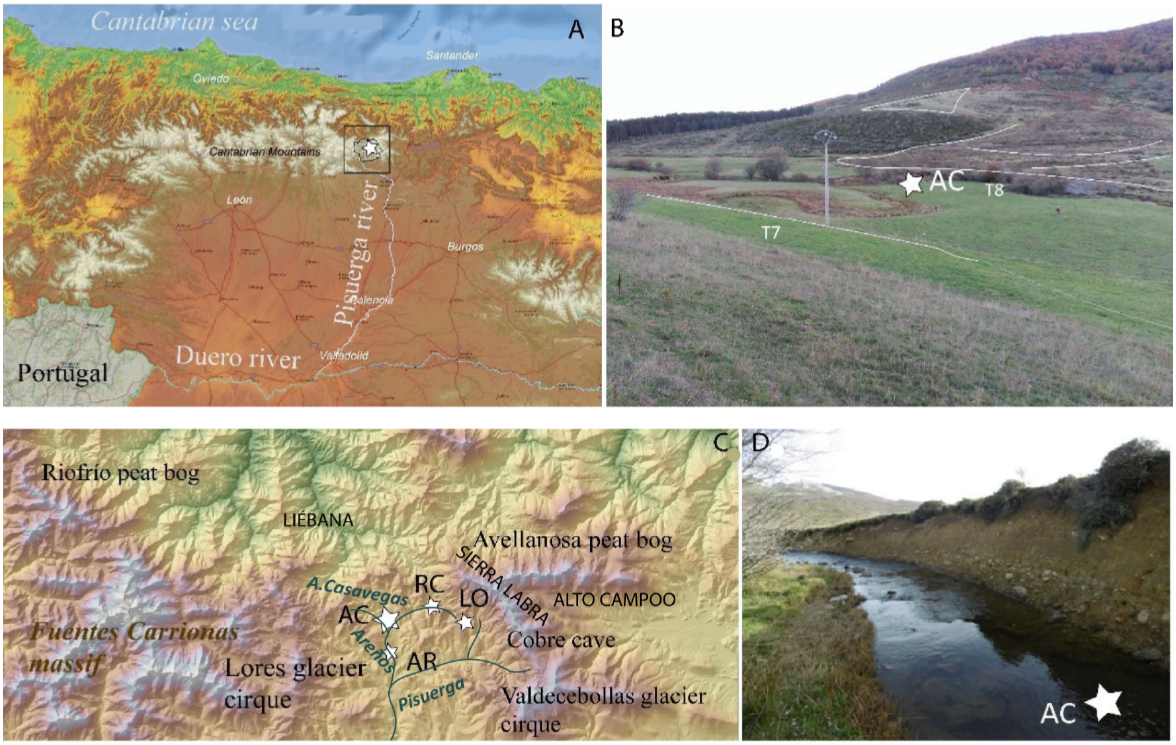

Figure 1. Location of the study site. A) Location of the head watershed of the Pisuerga River, tributary of the Duero river. B) Image of the studied Casavegas valley, tributary of the Pisuerga River. AC, place of the analysed sedimentary profile . T7 and T8, fluvial terrace levels. C) Places mentioned throughout the manuscript. AC, Casavegas deposit: RC, Riocerezo deposit; LO, Lombatero deposit; AR, Areños deposit. D) The investigated section on the right bank of the Casavegas stream (AC).

Figura 1. Localización del área de estudio. A) Localización de la cabecera de la cuenca del Río Pisuerga, afluente del Río Duero. B) Imagen del valle estudiado de Casavegas, afluente del Río Pisuerga. AC, lugar del perfil sedimentario analizado. T7 y T8 son los niveles de terraza fluvial. C) Lugares mencionadas a lo largo del texto. AC, depósito de Casavegas; RC, depósito de Riocerezo; LO, depósito de Lombatero; AR, depósito de Areños. D) La sección investigada en la margen derecha del cauce de Casavegas (AC).

several effects of climate and human modifications. The aim of this paper is to better understand both the relief and environment evolution of a small mountain valley in order to step by step build a research line to understand the evolution of the Duero basin since the LGM.

2. Study site

The northern valleys of the Upper Pisuerga basin (Areños, Casavegas, Camasobres and Riocerezo) are small valleys on the southern slopes of the Cantabrian Mountains in the north of Palencia province. They drain a forest area at an altitude between 1300 and 1700 m and are exposed to the cold and humid air masses from the Cantabrian sea owing to the location of the mountain ranges to the west (Fuentes Carrionas) and east (Sierra Labra).

Four deposits linking the hillsides and the valley bottoms have been detected and four lithostratigraphic columns have been performed. The chosen deposit to be analysed and dated is located in the small valley of Casavegas (Figure 2). The creek flowing here is a tributary at the head of the Pisuerga River just 5 km from the Cantabrian divide. The valley follows a structural corridor located

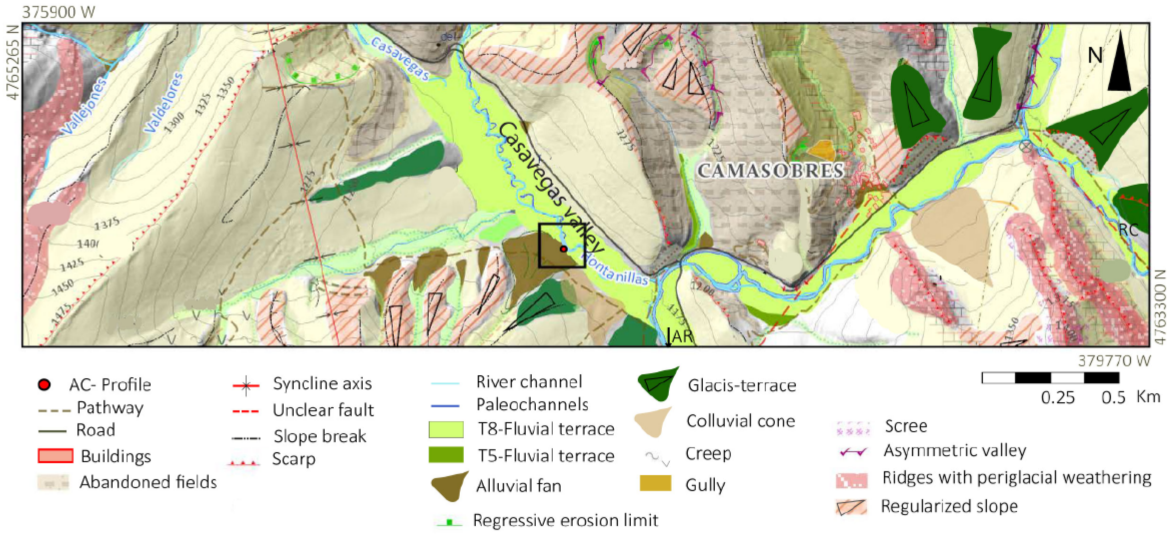

Figure 2. Geomorphological map of the Casavegas valley and the AC-sedimentary profile area.

Figure 2. Mapa geomorfológico del valle de Casavegas y el área del perfil sedimentario AC.

within the core of a large syncline composed of siltstones and shales of Moscovian age (Martín-Merino, 2014; Martín-Merino *et al*. 2014). The valley has an altitude of *ca*. 1200 m and is crossed by a misfit stream. There are sectors saturated with stagnant water due to the filling of the valley bottom by sediments from the slopes, which reach thicknesses of over 3 m. The Casavegas stream follows a flat-bottomed periglacial valley morphology (Ballantyne, 2018) in which intense winter snowfall and the saturation of the slopes by the snow melt (Pisabarro, 2020) produces a flow of water and sediment over fluvial terraces, valley bottom, colluvial cones and alluvial fans on which agrarian activity found favourable conditions. In the center is visible the lowest fluvial terrace (T8), eight of high Pisuerga system (Pisabarro, 2019).

3. Methodology

The Arroyo Casavegas deposit (AC), identified through the field work, is appropiate to the interpretation of morphological changes in the connection between colluvial and alluvial sediments. It is located at 377634W; 4763342N, UTM; 1340 m and has a thickness of 2.6 m. In the field, a lithostratigraphic description of the deposit field was made by dividing it into differentiated layers, taking structure, texture, and shape and sphericity of particles into consideration (Miall, 1996). Based on this analysis in the field, layers were defined from which sediment samples were taken for laboratory analysis. A sample of 300g was extracted from each of these layers.

Granulometry, colour, organic matter content, and magnetic attraction were analysed in the laboratory. The granulometric study of the sandy fraction (2 and 0.063 mm) was made according to the Udden-Wentworth classification (Wentworth, 1922), for which the method developed by Vaudour (1979) was used and statistical parameters were calculated (Folk and Ward, 1957). The method used for sample preparation and to obtain the different granulometric frequency histograms was that defined by Gale and Hoare (1991) following some of the statistical parameters used and reviewed by Blott and Pye (2000). This method, widely used since the 1960s, is sufficient for the needs of this research. In each sample the content of organic matter was calculated by the Loss on Ignition method (Gale and Hoare, 1991), colour was described by the Munsell colour chart and was interpreted following Gale and Hoare (1991).

AMS (accelerator mass spectometry) radiocarbon dating (Libby, 1946) of 4 samples was performed from bulk sediment (<2 mm) with organic matter content after eliminating the surface layer in contact with the atmosphere. In order to know the main sedimentary changes to the deposit, 50g were collected from 4 suitable points. These were processed in the Queens University laboratory in Belfast (Reimer *et al*. 2013). Dataset: intcall3.14c. % enclosed area: 95.4 (2 sigma).

During the treatment process of sediment samples, unusual magnetic behaviour was detected in the upper layers of deposit AC leading to the suspicion that this might be due to the impact of wildfires which increases the magnetic attraction (Gale and Hoare, 1991; Clement *et al*., 2011; Roman *et al*., 2013). A relative measurement of the magnetic response of the fine fraction was subsequently attempted by measuring the attraction of the clays to a magnet.

The scientific literature on the Quaternary at nearby sites helped to mark out some paleoenvironmental milestones to gain a better overall understanding. For this purpose, palynological studies carried out in peat bogs inside glacial cirques within a radius of 20km were helpful (Menéndez-Amor and Florschütz, 1963; Mariscal, 1983). The scope of characteristic Quaternary glacial episodes in nearby areas also had to be taken into consideration (Serrano and Gutiérrez, 2000, 2002; Pellitero and Serrano, 2008; Serrano *et al*., 2013, 2017; Pellitero *et al*. 2019). Moreover, the proximity of karst relief facilitated the paleoclimatic study of the Cueva del Cobre (Muñoz, 2007; Martín-Chivelet *et al*., 2011). In a complementary way and to aid with the discussion, a lithostratigraphic description was made in the field of Areños deposits (AR: 378268W; 4761811N, 1159, UTM); Riocerezo (RC: 379710W; 4763383N, 1145, UTM); Lombatero (LO: 381889W; 4761967N; 1484, UTM) (Figure 1).

4. Results

The analysed sedimentary section was divided into 6 layers (Figure 3; Figure 4; Table 2). The first three layers (AC-1, AC-2 and AC-3) are clearly formed of fluvial sediments belonging to the first fluvial terrace of the valley.

AC-1: This layer is composed of 72% coarse sediment (>2 mm) with up to 60 cm large, rounded and sub-rounded blocks of a fluvial origin. The fine fraction is made up of sand (11%) and silt and clays (17%). The position of the blocks is horizontal without apparent overlapping but defining some stratification. The sandy fraction is highly classified, with 36% very fine sands, 25% fine, 20.5% thick, and 18.5% very thick. The granulometric curve of the sandy fraction is sigmoidal and clearly indicates the torrential origin of the deposit. The dating of 19,621-19,239 cal yr BP (Table 1) indicates that this deposit may be in the context of Local Last Glacial Maximum. The colour of the clay matrix and the 3.67% proportion of organic matter is similar to that of the remaining layers.

AC-2: This layer is composed of 41% coarse fraction, mainly gravels. The fine fraction has 11% of sand and 48% of silt and clays. The grain sizes are poorly classified and heterogeneous with approximately 10% sub-rounded gravels, and gravels in the remaining cases. The sandy fraction of the total has moderately well classified very fine (67%) and fine (24%) sands. However, they are not concentrated around the average; therefore, some heterometry can be seen. There is no structure, and the flow or flows that gave rise to the deposit were of low energy, though somewhat higher than those of AC-4 and AC-6. The deposits respond to a mixed behaviour due to their heterometry. The organic matter content is 3.87%. The luminous and moderately saturated reddish tones 2,5YR 7/6 indicate the presence of hematite in aerobic

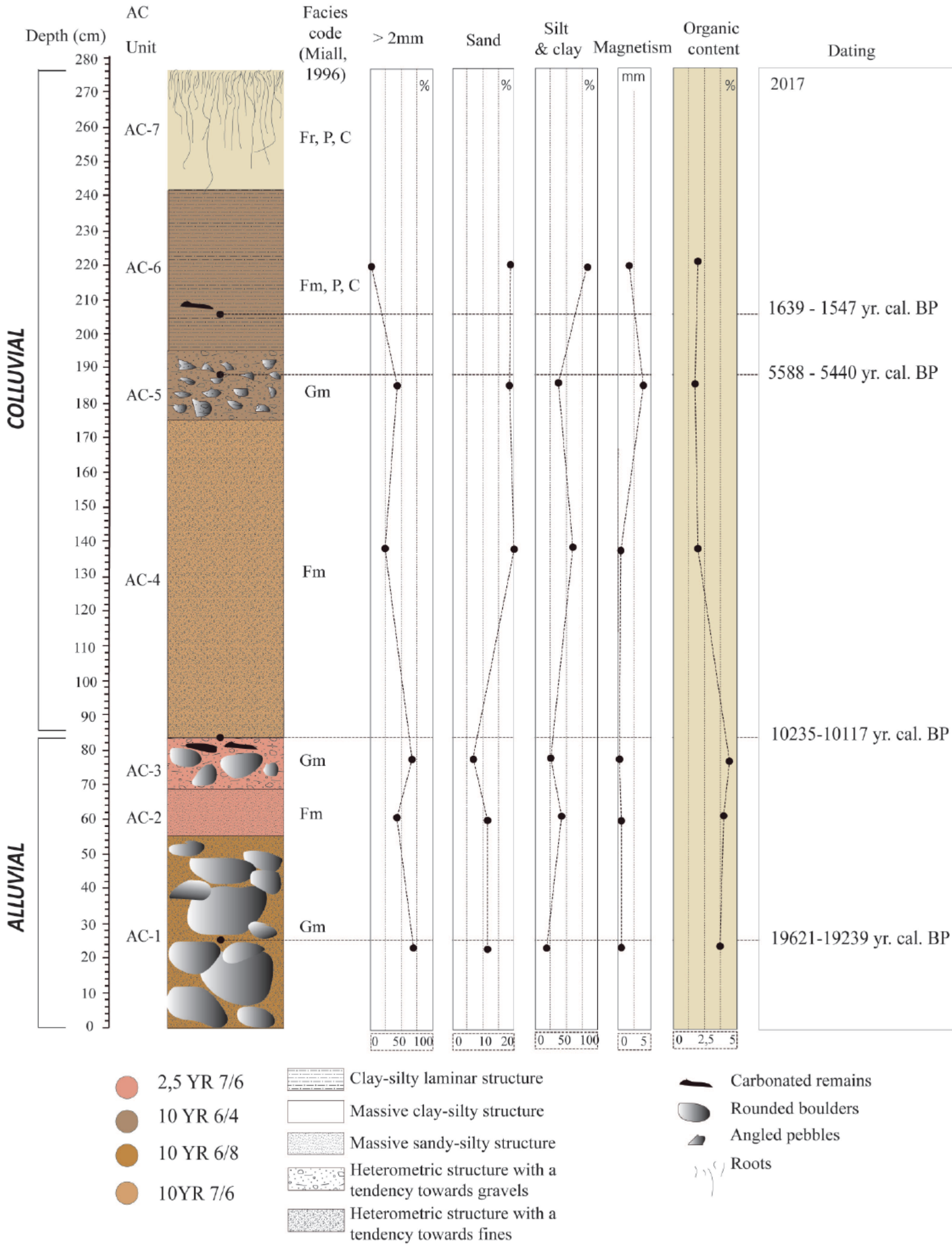

Figure 3. Litho-stratigraphic profile (AC) including sedimentary analysis and samples dated.
Figura 3. Perfil litoestratigráfico AC incluyendo el análisis sedimentario y las muestras datadas.

Lab. Code.	Name	Radiocarbon Age BP	Calibration data set:	% area enclosed cal AD age ranges relative area under probability distribution	
Queen's University. Chrono Centre				68.3 (1 sigma) cal BC	95.4 (2 sigma) cal BC
UBA-34841	AC1	16112 +/- 58	intcal13.14c # Reimer et al. 2013	**17602- 17404 1.000**	17671- 17289 1.000
UBA-34842	AC3	8975+/- 46	intcal13.14c # Reimer et al. 2013	8278- 8199 0.749 8108- 8093 0.074 8039- 8006 0.176	**8285- 8167 0.616** 8121- 7971 0.384
UBA-34843	AC5	4732 +/- 58	intcal13.14c # Reimer et al. 2013	3632- 3560 0.480 3537- 3504 0.216 3428- 3381 0.304	**3638- 3490 0.636** 3470- 3373 0.364
UBA-34844	AC6	1703 +/- 30	intcal13.14c # Reimer et al. 2013	262- 276 0.149 329- 389 0.851	253- 305 0.270 **311- 403 0.730**

Table 1. Information about radiocarbon calibration.

Tabla 1. Información acerca de la calibración de la datación por radiocarbono.

conditions whose tone is usually warm (Lynn and Pearson, 2000; USDA, n.d.).

AC-3: This is a layer with a predominance of coarse fraction, 68%, with mostly rounded blocks and edges, but also subangular, reaching 20 cm in diameter, with a planar and stratified disposition. The rest of the deposit is made up of sand (7%), and silt and clays (25%). The sandy fraction is well classified and has a strong dissymmetry towards fine, in which fine and very fine sands make up 95% of the sample, indicating a slow sedimentation rate of the lacustrine type, which collides with the thick deposits typical of medium-high energy transport. This behaviour may indicate an environment with a contrasted climate in which episodes of water saturation.

by snow melt and high temperatures are combined, given the abundance of hematite (2.5YR 7/6) and torrential river events with some slope contribution. This deposit has been dated at 10,235 - 10,117 cal yr BP.

AC-4: This is a massive layer in which fine sediments are predominant at 75%, of which 59% are silts and clays and 16% sands. The sands follow a clear dissymmetry towards very fine (90 to 63 µm), highly concentrated around the average of 83% of total sands. Inside the thick ones some dropstones appear, indicating the occurrence of low energy mud flows. The hue changes to 10YR 7/6 with a higher content of yellows with goethite, typical of temperate environments (Lynn and Pearson, 2000; USDA, n.d.). The relative thickness indicates greater sediment production in the first stage of the Holocene.

AC-5: In this layer the coarse part makes up 44% of the sample, made up of small rounded stones and heterometric, angular and subangular fragments, the coarsest of which are 15 cm in diameter. These grain sizes clearly indicate a hillside origin. The matrix is made up of a combination of sand (20%) and the remainder consists of silt and clays. Its structure is horizontal with microrhythmic bands, and the sandy fraction contains fine sands.

The magnetic response is disproportionate to that of the lower layers AC-1. The colour combines red and yellow tones (10YR 6/4), the latter tone indicating the presence of goethite, a mineral that is magnetized after flame reduction, and the hematite red magnetized by heating (Lynn and Pearson, 2000;

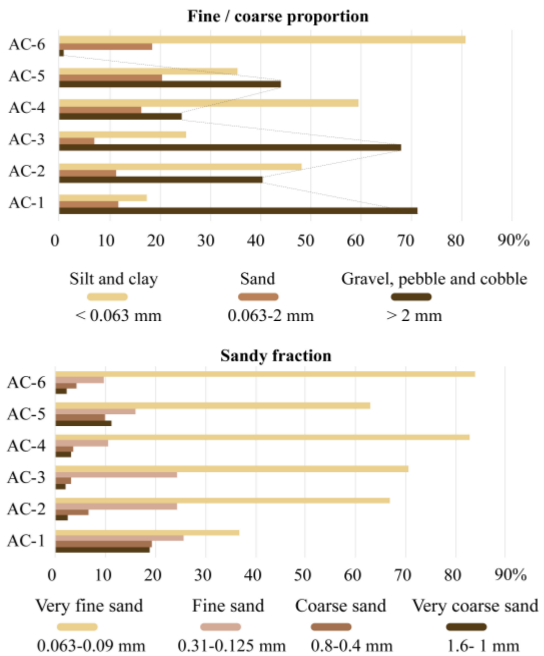

Figure 4. Frequency distribution sediment samples in each layer.

Figure 4. Distribución de frecuencias de las muestras de sedimento para cada capa.

USDA, n.d.). It presents layers with dark coloured coals. Nevertheless, organic matter is 3.68%, very similar to that of the AC-1 layer of the glacial period. The granulometric curve indicates a torrential character in stark contrast to AC-4 and AC-6.

AC-6: This layer is composed of very fine silt and sand without the presence of coarse sedimentation. The structure is in horizontal microrhythmic bands (mm) with some darker stripes and carbonated remains. The absence of coarse and especially fine sedimentation indicates that the frost should have not any influence and also that the deposit had been produced with very low energy in quasi-custard conditions. The observation of episodes of snow melt that produce the flooding of entire valleys with low slope justifies this type of filling (Pisabarro, 2019). The chronology of this layer is eminently historical considering the dating of 1,639 – 1,547 cal. yr BP measured for the base of this layer, which is likely to have formed throughout the Early Middle Ages and part of the Little Ice Age.

Table 2. Synthesis of sandy fraction analysis in each layer of AC deposit.

Tabla 2. Síntesis del análisis de la fracción arenosa en cada capa del depósito AC.

Level	%< 63 µm	Colour	Age cal yr BP	% Org. (LOI)	σi	Q50 (mm)	Mz	So	Ski	KG’	% (>2mm)
AC-6	63.7	10YR 6/4	1,639-1,547	3.68	0.68	0.08	3.45	1.07	1.23	0.0208	0.01
AC 5	40.3	10YR 6/4	5,588-5,440	3.25	1.52	0.09	2.52	1.28	-2.41	0.0198	0.44
AC 4	55.6	10YR 7/6		3.46	0.74	0.08	3.45	1.07	1.23	0.0199	0.24
AC 3	41.7	2.5YR 7/6	10,235- 10,117	4.44	0.69	0.09	3.24	1.12	0.61	0.0207	0.68
AC 2	44.4	2.5YR 7/6		3.87	0.91	0.08	3.12	1.17	0.6	0.0217	0.4
AC 1	22	10YR 6/8	19,621-19,239	3.67	1.57	0.19	1.92	3.24	-1.4	0.02	0.71

Empirical mean: **Mz**= (Q16+Q50+Q84)/3

Typical deviation: σ_i=(Q84-Q16)/4+(Q95-Q15) / 6.6 in ϕ units; [<0.35 very well classified; >4 extremely bad classified]

Trask classification index; **So**= √(Q75/Q25 in ϕ units [1.0-1.1 extremely well classified; 2.7-5.7 very bad classified]

Coefficient of dissymmetry; **Ski** =(Q16+Q84-2Q50) / 2(Q84-Q16) + (Q5+Q95-2Q50) / 2(Q95-Q5); [1 a 0.1 strongly dissymmetric towards fine fraction; -0.3 a -1 strongly dissymmetric towards coarse fraction]

Kurtosis; **KG**=(Q95-Q5) / 2,44(Q75-Q25)*;* KG’= KG / (1+ KG); [<0.4 very platykurtic; >0.75 extremely leptokurtic]; 0.5 for Normal distribution.

AC-7: This ceiling layer consists mostly of roots. It forms the edaphic horizon A. The granulometric analysis was dispensed with due to problems arising from the elimination of so much organic matter.

5. Discussion

The whole investigated section can be simplified into two large different accumulation phases. The first formed the AC-1, AC-2 and AC-3 fluvial deposits, and the second formed AC-4, AC-5 and AC-6 layers linked to the superposition of slope processes.

The AC-1 layer structures the floodplain and has characteristics in common with the base of the river deposits of other surrounding valleys (Figure 5) composed of coarse subrounded boulders (AR, RC and LO). This is interpreted to be a layer corresponding to braided river morphologies with flood channels, channel migrations and oxbows in all

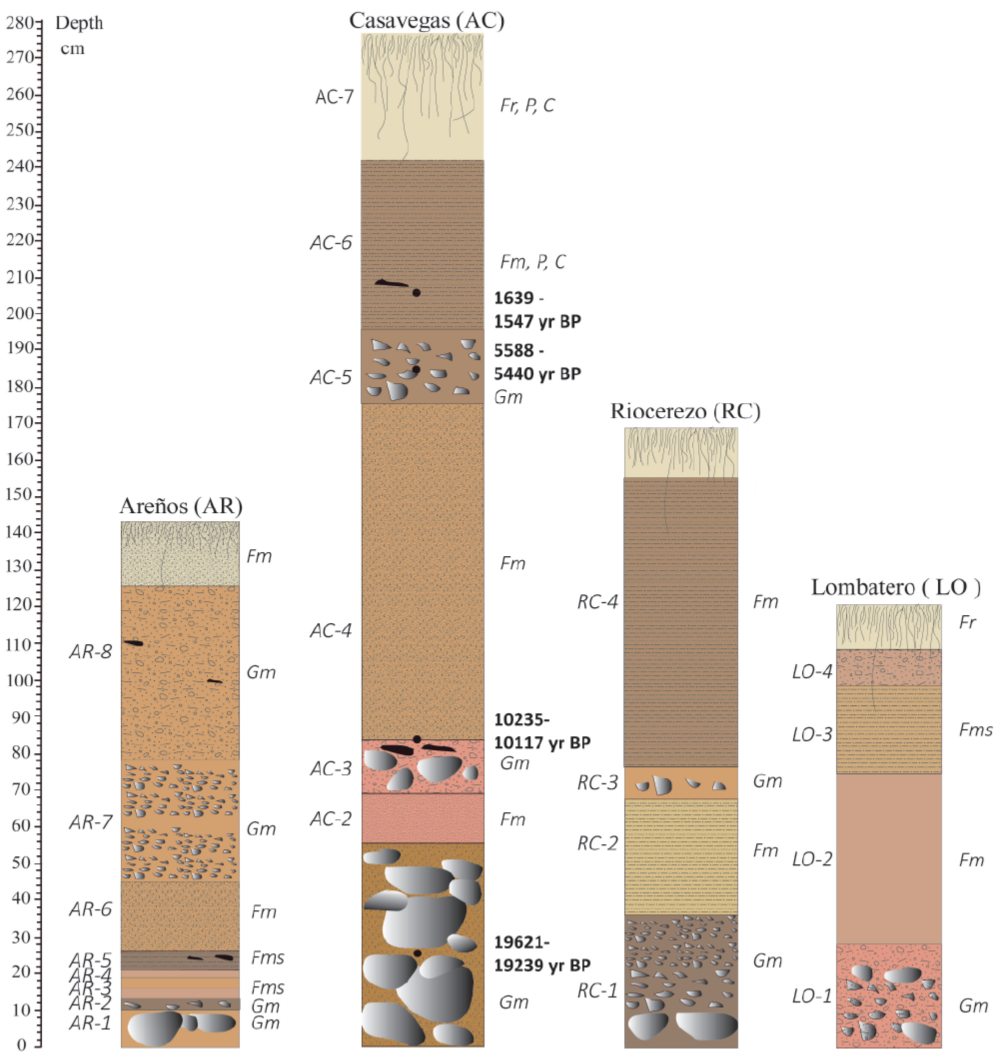

Figure 5. Comparison of AC deposit with other deposits in adjacent valleys (location in Figure 1).
Figura 5. Comparación del depósito AC con otros depósitos en valles adyacentes (localización en la Figura 1).

valleys with greater or lesser caliber depending on competence (Pisabarro, 2019). This layer of boulders covers the current valley bottoms of the headwaters of the Pisuerga River above 1100 - 1200 m.

Fluvial dynamism has been associated with the Late-Pleistocene since the AC-1 layer at its base has been dated 19,621-19,239 cal. yr BP, suggesting a relationship with a glacial environment of high river competence. This age necessarily suggests a relationship with a still cold environment. In the contiguous area of the Fuentes Carrionas Massif, the maximum glacier extension at 36 ky was determined by dating moraine arches (Pellitero *et al*., 2019). This glacier pulse also associates the moraines of the closest glacial cirques in Valdecebollas (Serrano *et al*. 2013) and Horca de Lores (Pisabarro, 2019). A second glacial pulse took place between 19.5 and 18.5 ky BP in a humid environment (Serrano *et al*., 2013, Pellitero *et al*., 2019). For the Cobre Cave, located 10 km to the east, Muñoz (2007) established that after 27 ky BP, the water table has risen, preventing the growth of speleothems. This phase of glacial advance and high fluvial competence coincides in part with the Global Glacial Maximum (Rodríguez-Rodríguez *et al*., 2017; Pellitero *et al*., 2019) and although the complexity of the Iberian climate during glacial stages is high, the climate framework seems to be consistent with the granulometry observed. This episode of high competence could be related to some evidence of gelifluction a few kilometres away, in the Horca de Lores glacier cirque covered with colluvial Holocene deposits (Pisabarro, 2019).

The AC-2 layer is very narrow without a coarse sediments fraction between two layers of coarses (AC-1 and AC-3) possibly linked to a low-energy river bottom environment with hillside interference, although low sediment production indicates low water availability, low torrentiality, or vegetation capable of slowing sediment production. Dating indicates that it includes a very broad period of approximately 10 ky. It can be interpreted that the climate was dry with scarce snowfall from the end of the second glacial advance to the Younger Dryas. The redder colour also seems to indicate warmer conditions that would justify the Bølling-Allerød episode before the Younger Dryas (14.6□12.0 ky. BP) according to ice-cores in Greenland (Rasmussen *et al*. 2014). This warmer conditions were detected between 12.9 and 11.6 ky. BP in the speleothems of Soplao Cave, 30 km to the north (Rossi *et al*., 2018).

The upper layer (AC-3) has smaller boulders that were deposited before the Holocene. This sequence of coarse sediments in a gradation from highest to lowest and with scarce intermediate fines (AC-2) has been observed in profiles from valleys of Riocerezo (RC) and Areños (AR) (Figure 5).

Analysed profiles show similar sequences to the AC-1 (Figure 5). All of them evidence the existence of a sequence formed by a low layer as AC-1 (S-1, Gm facies), a second layer group dominated by fines (S-2, Fm and Fms facies) and a third layer formed by a thin sequence (S-3, Gm facies). The stratigraphic correlation show a Late-Pleistocene age to the S-1, Lower Holocene to S-2, and Middle Holocene to S-3. The complete sequence point a similar evolution to all studied small basins of the Pisuerga valley, and it permits to establish an evolutive empiric model of the Pisuerga headwaters.

The AC-3 layer, included in S-1, would be contemporary to the withdrawal of the last glaciers in the Palentina Mountain (Serrano *et al*., 2013) to move to a humid and warm period between 11.6–8.7 ky BP (Moreno *et al*., 2011).

The layers AC-4, AC-5, and AC-6 form a set with similar sedimentary environments. In all these cases the granulometry indicates a hillside origin. Nevertheless, the greatest thickness of AC-4 points to higher sediment production. This fact may be due to the greater water availability in this period than currently and the end of the Pleistocene. The sandy granulometry, very fine and well classified, indicates that sedimentation took place in a low energy environment, presumably by water saturation of hillsides due snow melt with a humid and temperate climate, which may point to an increase in temperatures with regard to layer AC-3. From the dating of the AC-3 layer it is understood that the AC-4 layer is already clearly part of the Holocene, characterized by warm temperatures and the absence of glaciers in the study area.

The change in environmental conditions with respect to the Pleistocene is notable for the progressive increase in temperatures, which is especially intense from 11.5 to 9 ky BP in the Cantabrian Mountains (Serrano *et al.*, 2015; Rodríguez-Rodríguez *et al.*, 2017). But also, a greater water availability as shown by the floristic changes ocurred during the Upper Holocene (Figure 5), with the expansion of deciduous forests stands out, especially oak and beech trees. This forest expansion would have taken place at the expense of an open landscape composed during the Younger Dryas by herbaceous species mainly of the Gramineae genus (Menéndez-Amor and Florschütz, 1963; Mariscal, 1983).

Despite the fact that temperatures increased, thick and angular particles around 2 mm are observed in the AC-4 layer characteristic of

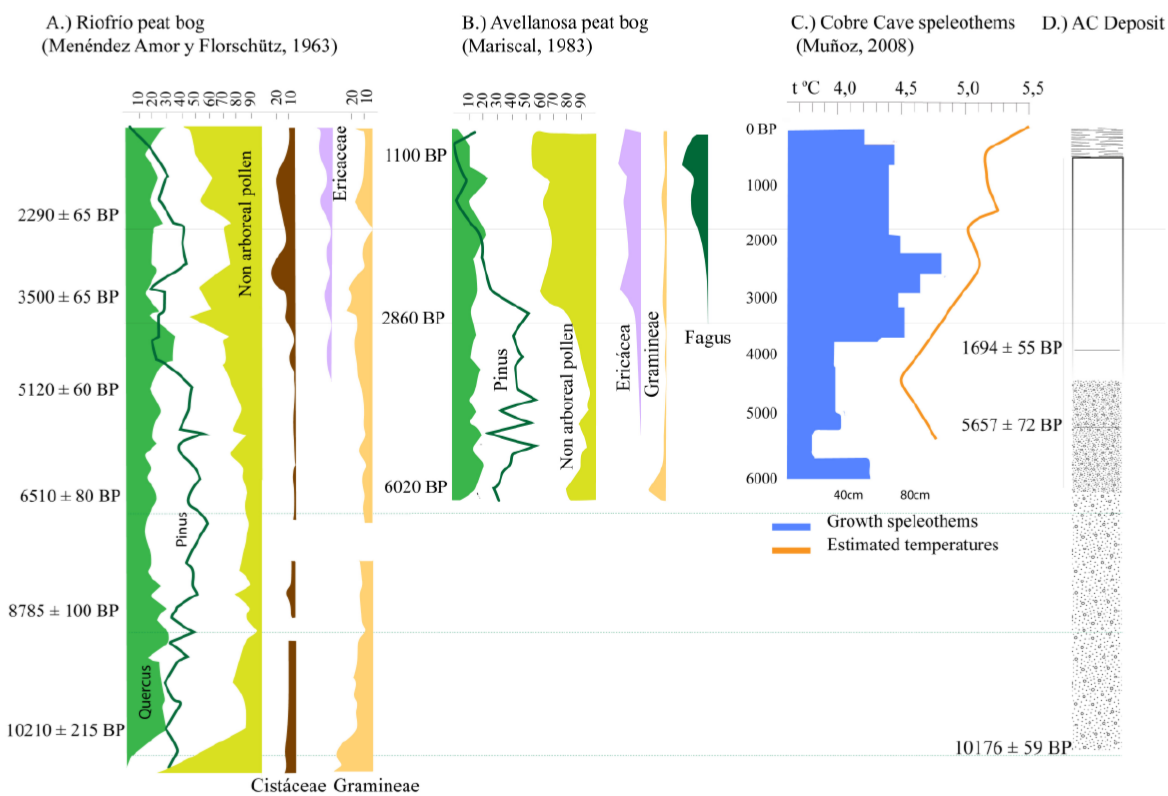

Figure 6. Comparison of the different indirect Holocene indicators in the Alto Pisuerga environment. A) Palynological study of the peat bog of Riofrío (Menéndez-Amor and Florschütz, 1963). B) Palynological study of the peat bog of Avellanosa (Mariscal, 1983). C) Study of speleothems and paleotemperatures in the Cobre Cave (Muñoz, 2007). D) Fluvial deposits in the Casavegas valley (AC). Location in figure 1.

Figura 6. Comparación de los diferentes indicadores medioambientales durante el Holoceno en el Alto Pisuerga. A) Estudio palinológico de la turbera de Riofrío (Menéndez-Amor y Florschütz, 1963). B) Estudio palinológico de la turbera de Avellanosa (Mariscal, 1983). C) Estudio de los espeleotemas y paleotemperaturas en la cueva del Cobre (Muñoz, 2007). D) Depósitos fluviales en el valle de Casavegas (AC). Localización en la figura 1.

freeze and thaw. This indicates that there was still freezing in winter and solifluidal movements linked to the saturation of ground after the snow melt. This reinforce the idea Cantabrian Mountains are characterized by a nival morphogenesis (Nossin, 1959; González-Trueba and Serrano, 2010; Santos-González, 2011; Pellitero, 2014; Pisabarro *et al*., 2017; Pisabarro, 2020), which remained in the Early-Holocene in the north of the Iberian Peninsula associated with westerly winds (Baldini *et al*., 2019).

The 8.2 ky BP event has not been detected, although it has been found several times in the N and NW Iberian Peninsula (González-Amuchástegui and Serrano, 2015; Martínez-Cortizas *et al*., 2020). The homogeneity of AC-4 layer indicates that from 10.2 – 10.1 ky BP. until the mid-Holocene there was a filling of the valley bottoms. The deposits coming from the slopes moved forward and covered the river terraces. The coarse fraction is composed of angular gravels indicating a short transport, and a fraction of very fine sands (90-63 µm), silts and clays that show slow movement. The AC-4 layer do not evidence any human alteration.

The AC-5 layer is very thin and the entire mid-Holocene is included. The texture of both the coarse fraction composed of pebbles and the sandy fraction has a larger size due to a surge in energy that may respond to a change in environmental conditions. Between 5.5 ky BP and a period prior to 1.7 ky BP, there is an episode of cold thermal anomalies or episode 4.2. (Baldini *et al*., 2019; Catalá *et al*., 2019) that would justify the increase in the coarse fraction. Two cold episodes at 5.0-3.7 and 3.0-3.2 ky BP were recognized at Picos de Europa (Ruiz-Fernández *et al*., 2016), and a glacial pulse between 2.8 and 2.7 ky BP in the Sierra Nevada (Oliva *et al*., 2020). At the same time the volume of sediment is reduced in a context of intense drought demonstrated in Castilla La-Mancha between 3.9 and 3.7 ky BP (López-Sáez *et al*., 2014). In the Cobre Cave, the water table also seems to decrease from 6.5 ky BP, as interpreted from the growth of speleothems (Muñoz, 2007).

At this layer, signs of a possible human incidence were detected in the magnetic response of the fine fraction extracted in the sample dated 5.5 Cal ky BP. In general, the period 5.5 – 5.0 ky. BP is the moment when the pioneer livestock societies began to transform the physical environment through wildfires in the Iberian Peninsula (Connor *et al*., 2019). It is consistent with the first occupation of the mountain territory (Campoo, Sejos, Liébana) between the Cantabrian divide and the seacoast (Diez-Castillo, 2011; Ezquerra, 2011; Gutiérrez-Morillo, 1999), the evidence of wildfires in the Cantabrian Mountains (González-Amuchástegui and Serrano, 2015; Ruiz-Fernández *et al*., 2016; Carracedo *et al*., 2018) and also with the appearance of scrubland pollens in peat bogs (Menéndez-Amor and Florschütz, 1963; Mariscal, 1983). These same pollen studies indicate a certain cessation of human activity between 3.5 – 2.8 ky BP., a period similar to the time during which there were no fires in Picos de Europa (Ruíz-Fernández *et al*., 2016) with a slight increase in the genus Pinus (Figure 5) prior to its extinction (Rubiales *et al*. 2008). The confirmation of human presence in the upper Pisuerga was dated in a Copper Age burial site at 3.75-3.45 cal. ky BP (Delibes and Fernández-Miranda, 1981).

Above the AC-5 layer, sedimentation is clearly reduced indicating a runoff decline, during the period close to the base of the AC-6 layer that began around 1,639-1,547 cal yr BP.

The last section of the AC-6 slope deposit occupies the historical period following 1,639-1,547 cal yr BP. From this moment, sedimentation accelerates. We know that accelerated erosion has been mentioned historically: King Alfonso X (1252-1284), for example, promulgated primitive methods of woodland conservation (Klein, 1936). Also, in the AR profile and other highly anthropized valleys nearby, the dynamism of the slopes allows fragments of tiles or bricks to be found at depths greater than 0.5 m (Pisabarro, 2019).

The sedimentation was fine, and without a thick grain size section. Heavy snow cover that characterized the 17th and 18th centuries in the Upper Pisuerga during the Minimum of Maunder and the Maldá pulsation (1780-1790) (Pisabarro, 2019) probably protected slopes. Soil erosion was mainly caused by snowmelt-related solifluction. Nevertheless, the sediment volume did increase as a result of deforestation, sheep-farming, and terrace agriculture, leading to an increase in erosion (Nossin, 1959). From the middle of the 20th century, when aerial photography became available, it was possible to verify how the sinuosity index in several sections of the river decreased – e.g. Areños (AR) section from 1,70 in 1956 to 1,55 in 2016 - (Pisabarro, 2017, 2019). During this period the river evolves into a straighter and narrower planform following the geometry theorical evolution of channels with less water supply (Schumm, 1977) as occurs in Pisuerga headwaters rivers (Pisabarro *et al*., 2019; Morán-Tejeda, 2010). This decreasing could be produced by the combined action of abandonment of agricultural land uses, increased temperatures, evapotranspiration, and reduced snowfall. The revegetation of the hillside would have reduced the sedimentation rate in recent years, so most of AC-7 layer must have occurred before the middle of the 20th century. Even specific pine repoblation allowed some hillsides to stabilize (Figure 1).

6. Conclusions

The deposits of the lowest fluvial terrace (T8) in the northern basin of the Pisuerga river are made up of fluvial boulders and cobbles whose size evidences high competence associated with torrential episodes. Through dating, it has been determined that fluvial deposition of T8 occurred between 20 and 10 ky BP. Coarse sediments in the first layer (AC-1) are similar to other fluvial deposits in the headwaters of the Pisuerga River and would have been deposited under humid and torrential conditions most likely linked to a glacial environment.

Layer AC-4 was sedimented during the Holocene in an environment with very active hillsides. The sediment rate seems to overlap the valley floor with large volumes of fine sediment transported by alluvial fans and coluvial cones. The climate was warmer as marked by the advance of the vegetation, although the winter snowfall was still capable of saturating the ground during snowmelt periods.

In the AC-5 layer, from 5.5 ky BP, there is evidence of human alteration of the physical environment through fires and changes in land cover. Also, a cold peak is visible, possibly linked to a cold episode at 4.2 ky BP, and a later reduction of both human intervention and sediment production until the historical period. Sedimentation in the last 2 ky was much finer, with a complete absence of the coarse fraction, possibly resulting from the combination of a stable climate, low energy, and erosive agrarian practices on the slopes prior to its current abandonment.

As a general conclusion, a Late-Pleistocene and Holocene sedimentary sequence may be evidenced in one of the valleys of the Upper Pisuerga that could provide an initial framework for the Cantabrian Mountains as a whole. Four profiles allows us to establish an evolutive empiric model of the Pisuerga waterhead. They show a three layers sequence formed by a low layer defined by Gm facies and a Late-Pleistocene age; a second layer dominated by Fm and Fms facies and Lower Holocene age; and the third layer formed by Gm facies and a Lower to Middle Holocene age. This framework indicates that floodplain deposits in valleys with aggradation (Pisabarro, 2019) respond to two distinct morphodynamic phases, the first dominated by large-size river transport associated with cold and glacial environment, and a second marked by a humid environment with an overlap of sediments from slopes. In this second phase there is an abrupt change in environmental conditions that appears to be marked by human intervention in the physical environment.

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