LANDFORMS AND GEOMORPHOLOGICAL PROCESSES IN THE DUERO BASIN: PLEISTOCENE GEOMORPHOLOGY OF AMBRONA AND ATAPUERCA SITE

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FIELD TRIP GUIDE

C-8
LANDFORMS AND GEOMORPHOLOGICAL PROCESSES IN THE DUERO BASIN. PLEISTOCENE GEOARCHEOLOGY OF AMBRONA AND ATAPUERCA SITES.

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1.- Introduction. The Duero Basin
The Duero basin is one of the two large inland Tertiary depressions of the Iberian Meseta, and is separated from the Tajo basin by the Spanish Central System. This northern meseta covers approximately 50,000Km² and has a mean altitude of 850m, some 150m more than the southern, or Tajo, meseta.

The basin's mountainous margins are: the Cantábrica Range to the N, the Astur-Leonesa region to the NW, the Iberian Range to the E and SE, the Central System to the S, and the Central-Iberian region, or Salmantino-Zamorana peneplain (mean height 700 to 800m), to the W.

A particular feature of this depression is that it is almost entirely drained by one major river, the Duero and its affluents, with the exception of its SE sector Almazán subbasin drained by the river Jalón, an affluent of the Ebro, and by affluent networks of the river Henares.

From the perspective of Pleistocene geology, this basin is not as well-known as the Tajo basin, mainly due to a notable lack of vertebrate fauna and palaeolithic archaeological records in stratigraphic settings. Exceptions are the archaeological sites of La Maya (Salamanca), and Ambroña-Torralba, and Atapuerca (Burgos) archaeo-palaeontological sites, which will be discussed below.

The (Fig. 1) shows the basin's characteristic deposits: piedmonts and fluvial terraces in the N region; fluvial terraces and erosion surfaces, with or without covering surficial deposits, to the S of the river Duero; sandy aelogic deposits in the SE; and erosive-depositional structural surfaces formed in carbonate lacustrine Upper Neogene deposits of the páramos castellanos in the E and central area. At least two erosional surfaces associated with the latter forms have been described and mapped, with numerous dolines, terra-rosa relicts and limestone crusts of Pliocene age.

Stop 1: The palaeo-archaeological sites of Ambroña and Torralba.
The Pleistocene sites of Ambroña and Torralba, some 2.5 Km apart, morpho-structurally belong to the Castilian branch of the Iberian Range (Figs.2 and 3). Physiographically, the area in which both sites are found corresponds to the boundary between three large hydrographical basins of the Iberian Peninsula: the Atlantic basins of the rivers Duero and Tajo, and the Mediterranean basin of the river
Jalón. The headwaters of these three hydrographical basins are drained by the rivers Henares (Tajo basin), Bordecorex (Duero basin) and the Masegar, or La Mentirosa, a small tributary of the river Jalón, upstream from the Medinaceli town.

**Figure 1.** Quaternary deposits of the Duero basin (modification from the Quaternary Map, 1989, and the Geological Map of Spain, 1994, both 1:1,000,000, ITGE). Legend: (1) continental Tertiary, uppermost deposits are lacustrine páramo limestones; (2) Raña piedmont; (3) fluvial terraces; (4) floodplains; (5) erosion surfaces with or without detritic cover; (6) aeolian sands; (7) endorheic depressions; (8) Atapuerca sites; (9) cities: B, Burgos; L, León; P, Palencia; S, Salamanca; V, Valladolid; Z, Zamora.

Ambrona and Torralba have been key sites for research into prehistory. Both archaeological sites along with their Acheulian tools have been scientifically known since the start of the 20th century, most distinguishably for their elephant remains. For decades now, the sites have sustained the idea than human groups systematically hunted during the middle Pleistocene, although Vila et al. (2004)
have found no evidence for elephant hunting in Ambrona. The first to explore the two sites was Enrique de Aguilera y Gamboa, Marquis of Cerralbo, who from 1909 to 1911 excavated approximately 2000 m² in Torralba and between 1914 and 1916 in Ambrona. Years later, from 1960 to 1963, Clark Howell (Chicago University) excavated some 3000 m² in Torralba and over 1200 m² in Ambrona. Then, at the start of the 1980s, Howell and Freeman (1980-1981) and Howell (1983) recommenced the excavation work in Ambrona, until completing a further 1300 m². So far in Ambrona, around 2700 m² of the site’s 6000 m² have been excavated.

Figure 2. Ambrona site in its geographical (A), geomorphological (B and C) and stratigraphic context (D). In D, gravels in cm (mode/larger). Minerals: Q (quartz), F (feldspar). (Pérez-González et al., 2001).
Since the beginning of the 1990s, M. Santonja and A. Pérez-González have organized seven excavation trips (1993-1999), and since the year 2000 have conducted other investigations aimed at completing our knowledge of the genesis and age of the site, as well as evaluating the possibility of transforming the Ambrona site into a museum.

1.- Geology and Geomorphology
Geologically, the two sites occur at the cross-point between the structures of the eastern border of the Central System and the Castillian branch of the Iberian Range, which to the north bounds the Tertiary Almazán basin.

Figure 3. Geological scheme of the Conquezuela-Ambrona-Torralba polje (after the geological maps 434, 435, 461, 462 and own data). Geographical location of Ambrona and Torralba sites. Legend: 1, marls, sands, conglomerates; 2, sandstones, limestones, marls and dolomites; 3, limestones, dolomites, carniolas and marls; 4, marls and gypsum; dolomites and marls; 6, conglomerates, sandstones and clays; 7, anticline; 8, syncline; 9, fault; 10, direction and inclination of bed; 11, normal contact; 12, unconformity contact; 13, rivers, direction and sense of the flow indicated by arrows; 14, altitude in meters; 15, town; 16, archaeological sites of Miño, Torralba and Ambrona; B, Buntsandstein; M, Muschelkalk; K, Keuper; J, Jurassic; C, Cretaceous; Q, Quaternary (Pérez-González et al., 1997a, 1999).
Outcropping materials in this area are of Mesozoic age (Fig. 3) and belong to the siliciclastic facies of the Buntsandstein, carbonated facies of the Muschelkalk and to the mudstones, marls and gypsums of the Keupers, whose top is constituted by marine epicontinental carbonates of the Imón Formation. The Jurassic is formed by the carniolas of Cortes de Tajuña and other limestone formations reaching the upper Lias. The Cretaceous is preserved in a degraded syncline structure in La Ventosa del Ducado, discordantly overlying the Jurassic and spanning from the Albian to possibly the Coniacian.
From a geomorphological point of view, (Fig 4), the sites of Ambrona and Torralba have been related to the development of the conquezuela Ambrona-torralba anticlinal polje (Pérez-González et al. 1997). Three general erosion surfaces were recognised, the oldest (M3, dated Miocene) and topographically highest, lies at an altitude of 1200 m. The most relevant process occurring during the Lower Pleistocene was the chemical and physical degradation of the M1 surface (1159 m). Weathering residues were drained by the Bordecorex river (Duero tributary), whose southern watershed possibly followed the Torralba village parallel, about 5 km south of its current position.

Denudation of the carbonate M1 surface led to the development of an erosion level, which coincides with the stratigraphic contact between the Keuper facies and the dolomite Upper Triassic unit of the Imón Formation.

This level of local erosion at about 1140 m is known as the Surface of Ambrona (SA). The middle Pleistocene saw the accumulation of alluvial fans and lacustrine-like deposits in Ambrona, associated with fauna and early Acheulian industry. In this setting of the Jalón river began its new course, capturing the valley of the Bordecorex river and progressing towards the current watershed, to the north of the village of Ambrona. This process left the Ambrona site at a relative height of 39-40 m above the channel bed of the Masegar river, at an absolute altitude of 1145 m (Fig 2B). The development of the Masegar river valley has followed a polycyclic pattern, with bed-rock terraces at +7-9 m, +15m, +22m, and +35 m, and an alluvial plain at 1 m. The Acheulian site at Torralba (Fig 2C) occupies and intermediate morphological position between the terraces at +35 m, and +22m. It lies about 6-7 m into the +35 m terrace, with its bottom 28 m above the floodplain of the Masegar river, at an absolute height of 1115-1116 m. This means that the Torralba site is younger than the Ambrona site and therefore, they fail show the same stratigraphic formation (Fig 5).
2.- Lithostratigraphy of Ambrona and chronological approaches of the Ambrona-Torralba sites.

Previous stratigraphic works (Butzer 1965, Howell et al. 1995) established two lithostratigraphic units, defined as the Lower and Upper Member Complex, which provisionally includes the top unit AS6, according to the stratigraphic division proposed by Pérez- González et al. (1997-1999). Investigations underway will define a new informal Ambrona Formation, composed of three member complexes (Pérez-González et al., in prep).

The lithostratigraphy of Ambrona presented in Figure 2D, corresponds exclusively to the central site area. In this sector, it is possible to define a stratigraphic column of about 6.5 m that has been subdivided into six members: AS1 to AS6. All the facies described in figure 2D, correspond to fluvial or shallow lacustrine environment. From AS1 to AS2 gravels, sands and clays facies, derived from the NE (AS1) or E (AS1/AS2) represent medial or distal position of alluvial fans in which individual fluvial channels may be identified in AS1. AS3 deposits indicate a less energetic, shallow lacustrine environment, with limits W and NW of the site. AS3 contains abundant *Elephas* fauna and artefacts. The fluvial-lacustrine deposits of AS4 erode the top of AS3, with coarse material derived from the NE, deposited at the stream mouth. Like AS5, AS4 is a fining-upwards succession. AS6 overlies AS5 presenting a stratigraphic discontinuity and is formed by the regular interbedding of two alternating lithologies with abundant gastropods. The top of the sequence is formed by a soil, of vertic type with A, Bw and 2Cg horizons.

<table>
<thead>
<tr>
<th></th>
<th>AS1</th>
<th>AS1/2</th>
<th>AS2</th>
<th>AS2/3</th>
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<th>AS4</th>
<th>AS5</th>
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<td>14</td>
<td>14</td>
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<td>339</td>
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*Figure 6.* Stone artifacts by level. Artifacts showing no signs of edge rounding (edge rounding = 0) in AS3 are in brackets (Santonja and Pérez-González, 2001).

Faunal and Acheulian artefacts indicate middle Pleistocene age. Geomorphological correlations with travertine terrace sequences of the upper Jalón and upper Henares valleys, indicate that Ambrona is older than the terraces at +20-25 m, aged ca. 200Ka (Howell *et al.* 1995). Moreover, given its
geomorphological position prior to the construction of the +30-35 m terrace, it must be over 350 Ka old, although at present it is not possible to establish its age with greater precision (Fig 5).

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<th>%</th>
<th>NSIP</th>
<th>%</th>
<th>NSIP</th>
<th>%</th>
<th>NSIP</th>
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<td>25</td>
<td>100.00</td>
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<td>57.53</td>
<td>227</td>
<td>49.35</td>
<td>190</td>
<td>49.74</td>
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</table>

Figure 7. Number of remains and percentage by taxa in each level (Soto et al., 2001).

Stop 2. General valley profile in the Duero river.

Terraces of the river Duero in the Almazán basin
The valley of the river Duero has a small number of terraces in its source area—the Mesozoic mountains of Urbión—and in the Palaeozoic area of Zamora and Portugal (which we will visit in the last days of this trip). In contrast, terraces overlying the materials of the Tertiary basin are much more developed.

Traditional concepts restricted the fluvial terraces of central Spanish rivers to three or four levels (Hernández-Pacheco, 1928) by associating them with Quaternary glacial and interglacial dynamics, with heights ranging from +10 to +105 m above the level of present channels. This criterion was applied to the Duero (Hernández-Pacheco, 1932), even up until fairly recently (Hoyos et al., 1973, 1974; Delgado, 1988).

Particularly in the Almazán basin, gravel deposits corresponding to the highest terraces were systematically interpreted as Plio-Pleistocene “rañas”, or the last alluvial fan deposits of the Tertiary basin infill before Quaternary fluvial entrenchment; the plains produced by these deposits were considered structural forms in resistant levels (Ferreiro, 1991; Carral et al., 1993) or stepped, erosive glacis systems (Delgado, 1988; Valverde, 1991). Carral et al. (1993) argue we could be dealing with a first generation of overlapping high Quaternary terraces.

However, as pointed out by Pérez-González (1982), main fluvial arteries have left behind in the Meseta (Central Spanish plains) a large number of terraces. In the case of the Duero, 14 terraces occupy its central stretches of Valladolid-Castronuño, reaching heights of up to +144 m above the present channel level. An intermediate number of terraces of 6 to 8 only appears when specifying particular features of the valley such as a substrate of lithologies that are karstifiable or resistant, in which incision processes dominate over lateral deposition.
In the Almazán basin, 21 levels have recently been described (Rodríguez García & Pérez-González, 2002) at heights of up to +180 m above the present channel level. However, in this revision the highest level is reinterpreted as part of a Miocene unit, so that these 20 levels reach a maximum of +170 m (Fig. 8).

2. Chronology
Given the lack of palaeontological data, age estimates for the Duero terraces have been tentatively based on the lithic artefacts they contain. The following chronological interpretations have been proposed by Pérez-González (1982) and Santonja and Pérez-González (1984) for the central Duero reaches in Valladolid:

- Terraces at +82 to +144 m – Lower Pleistocene
- Terraces at +18 to +62 m – Middle Pleistocene
- Terrace at +8-12 m – Upper Pleistocene
- Terrace at +3-5 m and the present flood plain – Holocene

For the Almazán basin, we have the study of Rodríguez de Tembleque (1998). According to the presence of Acheulian industries, this author ascribes the terraces at +18-20 m (TDA14) to the late Middle Pleistocene, and those at +40 m (TDA10) to the Middle Pleistocene proper, while arguing the terrace at +60 m (TDA8) should be assigned to the beginning of the Middle Pleistocene or end of the Lower Pleistocene. The stratigraphy of terraces at levels above +60 m (TDA7) has not yielded any lithic assemblages.

Figure 8 shows the relative heights and approximate ages of the terraces, and indicates several archaeological sites of the Duero depression.

<table>
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<tr>
<th>HOLOCENE</th>
<th>TDA</th>
<th>SORIA</th>
<th>TITUEIRO</th>
<th>ALMÁZAN</th>
<th>SÜMA</th>
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**Figure 8.** Terrace levels of the river Duero in the Almazán Basin (TDA) and their relative heights in the different sectors examined. Also indicated are tentative age limits and some archaeological sites of the Duero (according to Santonja & Pérez-González, 1984). B: Burganes. C: Castronuño. M: Monfarracinas, Toro.
The polygenic surface M$_2$ (Upper Miocene-Lower Pliocene), considered the initial geomorphological level from which Quaternary fluvial downcutting commenced, occurs in the Almazán area at some +200 m above the present channel level. The surface is preserved at the southern border of the basin, generally overlying the Miocene lacustrine limestones that mark the overtopping of the Tertiary basin.

Fluvial terraces appear along both valley sides, although in terms of their numbers and surface development, they are larger on the right margin –especially the highest terraces– such that the valley is intensely asymmetric (Figures 9 and 10). The left margin is characterized by the steppening of horizontal limestone resistant beds up from the M$_2$ surface towards the depression axis, where underlying sandy Neogene facies appear.

![Figure 9](image-url)  
**Figure 9.** Geomorphological map of the Duero valley in the central sector of the Almazán Basin. Numbers indicate the TDA level.

This assymmetry is a consequence of the constant and slow uplift of the Northern mountain block (Urbión-Cameros), which caused the progressive channel displacement towards the South during the Quaternary and the creation of the stepped, terraced profile of the valley. On the other hand, the Southern mountain block (Castillian Branch of the Iberian Range) showed a more episodic uplift during the Tertiary, and remains stable probably since Pliocene times.
Stop 2, from the terrace level TDA9 (+47-52 m), allows us to take a general view of the valley: northwards, the terrace flights; and southwards, the Miocene páramo landforms and stepped resistant beds.

The difficulties in investigation and interpretation encountered by previous authors, especially in the case of the highest terraces, are largely due to the dense pinewoods and colluvial material covering the area, such that the terraces and slope materials can be easily misinterpreting as a single thick gravel formation. However, among the different terrace levels, the Tertiary substrate corresponding to different tectosedimentary basin infill units can be identified through detailed studies. The gravel deposits of the terraces are of indisputable fluvial origin, and show similar characteristics and thicknesses across levels. Terrace levels are arranged as steps like hanging levels; only the lowest levels at heights below +10 m overlap each other.

**Stop 3. Characteristics of the deposits.**

Terrace deposit composition is similar for all levels: quartzite pebbles, sandstones, conglomerates and quartz, derived from Wealdian formations of the northern mountainous block and resedimented Tertiary materials. In some zones, there are considerable proportions of limestone pebbles from Mesozoic or Miocene carbonate areas.

Some of these features indicate a certain degree of temporal evolution: from the highest to the lowest terraces, mean clast sizes increase (2-5 cm in high terraces; 5-12 cm in low terraces where blocks also appear) and there is a tendency towards clast flattening (Ferreiro, 1991; Carral et al., 1993). Nonetheless, the mean clast size of the alluvials is also strongly influenced by the local bedrock, so that in terraces developed over proximal facies of Tertiary alluvial fan units (e.g. Soria-Viana de Duero sector) block-sized clasts are plentiful.

In terms of the characteristics of its deposits, overall, the system is a *braided* gravel system, in which *longitudinal bar* structures (Gm) with decimetric sand intercalations (St) predominate. In the lowest terraces, we also find *point-bar* structures, indicating an increase in the sinuosity of the fluvial system.

In this stop we can study some gravel quarry trenches in a low terrace of the Duero (+8-10 m), showing the exposed general features.
1. Fluvial morphometry and tectonics
A longitudinal profile of the terraces and the present alluvial plain is shown in Fig. 11. Also indicated are the M2 planation surface, as well as the channel sinuosity and valley slope parameters in different sectors. Notice the continuity of the levels all along the profile.

![Figure 11. Longitudinal profile of the river Duero and its terraces and the M2 planation surface, in the Almazán basin. Channel sinuosity (P) and slope gradient in ‰ (S) along the valley are also indicated. The four reaches marked on the upper part of the figure correspond to the name and number of different sheets of the 1:50.000 National Topographic Map.](image)

Longitudinal variations of sinuosity and gradient are indicators of variations in bedrock lithology and structure. A general tendency towards gradient decrease can be distinguished, ranging between 1.11‰ in Soria and 0.68‰ in Osma, the lowest sector. The sinuosity is broadly constant, about 1.2.

Two areas show a steeper slope: these are Gormaz and Soria-Los Rábanos, where the river is entrenched in both Cretaceous karstic limestone blocks. In the latter, the relatively high sinuosity (up to 1.2), does not fit with the bedrock lithology, and is a consequence of the incision of meanders previously developed over upper clastic Tertiary units.

But the most interesting area is undoubtedly that of Viana de Duero, that shows abrupt transitions in gradients and sinuosity, ranging respectively from 0.31‰ and 1.00 upstream, where is also a channel tendency to anastomose, to 3‰ and 1.23 downstream. These variations can also be noted in the terraces and are not presumably a consequence of changes in bedrock lithology, but neotectonic activity. Following the models exposed by Schumm et al. (2000) or Burband & Anderson (2001) it is deduced a deep thrust of the Northern block (Urbión-Cameros) over the basin central area, as is marked on the figure. Such a structure agrees with the river Duero southwards displacement during the Quaternary and the present valley assymetry.

Stop 4. The Langa Anticline.

1. Introduction
From a geological standpoint, the area examined occupies the eastern margin of the Tertiary Duero Basin, and more specifically the so-called corredor de Aranda de Duero-Burgo de Osma (Pérez-Gonzáleze et al., 1994), a passage connecting the SE region of the Duero Basin with the Almazán...
Basin. To the north, east and south respectively, the area is bounded by the Mesozoic Sierra de Cameros, the northern Aragonian Branch and southern Castillian Branch of the Iberian Range, and the Palaeozoic deposits of the NE extreme of the Central System. The most widely represented deposits of the study area, essentially of Neogene age (Miocene), are the characteristic continental sediments of an endorheic basin, with alluvial fans at the margins, and fluvial and vast shallow lacustrine environments in the central regions, along with Quaternary covers mainly associated with fluvial deposits.

Most outcropping Cenozoic sediments correspond to the Miocene, and have been divided into the two informally described units (Nozal & Montes, 2004): Lower Páramo Sequence (middle Miocene) and Upper Páramo Sequence (middle-upper Miocene). calcareus levels appear at the top of both sequences and are designated Calizas del Páramo Inferior (Lower Páramo Limestones) and Calizas del Páramo Superior (Upper Páramo Limestones), respectively. With the exception of the Langa Anticline, these sediments show a simple structural arrangement of subhorizontal layers that are practically non-deformed, or slightly SW dipping.

Physiographically, the region occupies the valley of the Duero, which is the main river crossing the region. Its relief is generally gentle within the range of heights (1080-820 m) formed by “páramos” intensely dissected by incised valleys that confer the landscape a morphology of tablelands stepped by the abrupt escarpments typical of the region.

Highest altitudes occur south of the Duero, in the “upper páramos” of Quintanas Rubias (1092 m), Morcuera (1084-1046 m) and Alto de Ayllón (1086-1027-1019 m). Immediately north of the Duero, “páramos” are lower and not as well defined since they are delineated by the “Langa limestones” folded in the anticline, the most outstanding benchmarks being Castildediez (1024 m), Chozo (996 m) and Torquillas (999 m). To the north of the anticline, the Upper Páramo Limestones once again configure true “páramos” (Peñalba de Castro) at heights of 1039-1018 m.

According to the morphological units of the northern Meseta described by Pérez-González et al. (1994), the region belongs to the SE Sector of the Duero Depression including the Almazán Depression, in the so-called region of “calcereous páramos”.

The region’s morphology is the result of significant erosion, which since the end of the Miocene was mainly exerted by the fluvial network (fluvial morphogenesis) acting on a substrate of alternating materials of varying competence, structurally organized as subhorizontal or inclined (folded) layers. Most of the region is therefore dominated by a well-characterized structural-type relief.

Among the elements comprising this structural relief, tablelands forms predominate with two levels or main elements of reference. On one hand, we find the summit plateaus (Upper Páramo Limestones) associated with the final construction stage of the Neogene piedmont, thus occupying the highest topographical positions (1090-1020 m), and on the other hand, the Lower Páramo Limestones level comprises moderately high plains (980-960 m) flanked by intermediate level changes scarped to a greater or lesser extent.

Besides these two obvious reference elements, intercalated in the series are several others, which are also competent but of less entity and/or continuity, that provide numerous small derived forms: shoulders, benches, scarps, mesas buttes etc. Of these levels, the most significant are the calcareous level(s) of the base of the Langa series (Langa limestones), stratigraphically located beneath the
Lower Páramo Limestones, but owing to their deformation, they show different dips and occur at varying heights (1024-840 m).

Areas in which the heterogeneity and different lithological competence are not as marked have developed more gentle rolling forms, with structural flats sometimes appearing at the expense of more compact or cemented levels such as conglomerates and caliches.

To the north of the Duero lies the anticlinal structure of Langa de Duero, where in fold crest zones, the Langa limestones attain similar heights to the stratigraphically highest units (Upper Páramo) found both to the north of this structure and to the south of the Duero.

The Langa anticline is a unique structure within its setting and even with respect to the entire Duero Basin. It is a large fold (cartographic scale) that affects lower-middle Miocene deposits, related to a compressive stage that is perfectly defined in time and manifests in the basin, in the middle of the corredor. Its peculiar location and synsedimentary development gave rise to an intrabasin relief that conditioned sedimentary systems and therefore the palaeogeographic evolution of the region along with its current configuration.

The mapping undertaken shows the Langa fold as an asymmetric anticlinal structure of direction ESE (N 110) and vergence SSW, which extends for more than 25 km between the towns of Guma, in the NW extreme, and San Esteban de Gormaz to the SE. The northern limb is well-developed and gently dippig while the southern limb is much shorter and shows dips of up to 30°.

According to the zone’s tectonic setting and the structures, present and inferred, at the northern border of the basin (Gimerá et al., 1995), the anticline could be a Mode-I fault-bend fold (Suppe, 1983; Jamison, 1987). Fold development (ramp stage, Vergés & Riba, 1991) has generated in both its limbs syntectonic unconformities in the Tertiary succession, with rotative onlap on the fold of most recent horizons as fold growing decreases.

Along the southern limb, in a band some 2 km wide between the towns of Langa de Duero and Alcozar, a simple progressive unconformity (Riba, 1976) may be observed in the Tertiary succession, produced by growth of the anticline, as the layers became folded while being deposited on the flanks. This unconformity is comprised of sedimentary levels that wedge towards the most active limb to form a fan of beds open towards the south. At the height of Langa, given the slope of the layers, the syntectonic fan angle is around 30°.

“Fossilization” of the structure is cartographically revealed by calcareous levels interpreted as “Lower Páramo” in the Alcozar sector (Atalaya II 983 m, Barraganes 986 m). The term fossilization is used in the tectonic sense (ceasing of fold growth) and does not refer to its total burial, since the structure protrudes beyond the top of the Lower Páramo Limestones. The Langa anticline developed during the lower-middle Miocene and became fossilized by the Lower Páramo Limestones dated as late-middle Miocene (Aragonian MN 7).

The anticline’s northern limb, extends in the Sheet of Peñaranda across nearly 10 km with very gentle dip (3°-5°) in a NNE direction. Layer wedges and their onlap on the structure are discretely perceivable in the field (SW of Bocigas de Perales), but easily distinguished from the cartography.
In terms of its morphostructure, the Langa anticline comprises a unit of folded structure on the right-hand bank of the river Duero, mainly developed at the point where it joins the river Perales, defining a contrasting landscape with platforms and well-developed structural flats gently inclined towards the N and NW in the long limb, while in the short more inclined limb, a discrete but patent cuesta relief develops as south-facing slopes.

This unit shows the typical morpho-structural elements of a structural fold relief.

In this case, the reference lithostratigraphical element would be the third of those mentioned above, that is, competent levels developed to a greater or lesser extent (“Langa limestones”, “Portillo caliche”...) stratigraphically intercalated in the series below the Lower Páramo.

The crest of the vergent Langa anticline is intensely eroded such that it forms an anticlinal valley elongated in the fold direction, which gives rise to inversion of the relief (breached anticline). The secondary fluvial network runs in a direction transverse to the structure, adopting a consequent parallel position on both limbs.

In the shorter, more pronounced (≤30°) southern limb, the Langa limestones and other competent, albeit more discrete, levels immediately above them, give rise to a cuesta relief showing several different forms such as crests or hog-backs with chevrons and smaller scale ridges (Fig. 12). As strata lose their inclination towards the crest zone in sites in which they are preserved, they give rise to energetic buttes (Castildediez, 1024 m), or to narrow buckled benches pronounced to a greater or lesser extent (to the N and NE of Langa).

Figure 12. Cuestas to the NW of Langa de Duero.

On this limb, the incision of the secondary network has progressed vigorously and in the same manner, its retreat at the headwaters gives rise to consequent transverse valleys with their respective “cluses”. These cut the limb (cuestas), along which materials from the hinge were emptied, and when
adjacent interfluvial zones disappear give rise to a depression or anticlinal longitudinal valley (combe).

The northern limb, long and with moderate dip (≤5°) gives rise to a gentle ramp dipping N developed on the Langa limestones and on a thick caliche (El Portillo) situated approximately 20 m above the limestones. Both calcareous levels give rise to flats or páramos gently inclined northwards. The hillfront (scarp) formed towards the combe shows one or two marked ridges of fairly irregular and wavy course. The secondary drainage system, whose main collector is the river Perales (subsequent), appreciably imposes upon the ramp of gentle slopes (consequent streams), and develops an arborescent network that gives rise to many cataclinal valleys (ruz) and fingers in the flats forming the reverse side of the cuesta.

2. Interpreting the geological development of the Langa fold setting.
During the middle Miocene (Aragonian) sedimentation took place in alluvial plain and palustrine-lacustrine environments. Fluvial facies reflect systems of low sinuosity with vast exposed lutite plains that promote the development of caliches. Palaeocurrents indicate a SE origin, trending WNW towards the basin’s innermost zones.

This set of materials was likely involved in the deformation experienced by the Langa fold. Anticline growth was synchronous with this sedimentation, generating syntectonic unconformities on its limbs, most appreciable on the southern limb where the array of layers (Langa series) indicates alternating fluvial and palustrine environments. Simultaneously, a sandy, slightly sinuous fluvial system approaches from the west with palaeocurrents trending N-NE, indented by a braided fluvial system with episodic ephemeral currents arising in the east (Ramos Martín & Alonso Gavilán, 1990). Both these deposits are covered by the Lower Páramo Limestones.

The growth of the Langa anticline produced a whale-back relief in the centre of the corredor, diverting the courses of channels flowing towards the corredor centre, which bordered the fold to later converge in the NE extreme as a wide meandriform fluvial system known as the “Aranda detritic series”.

The sequence ends with a predominance of carbonate deposits that give way to the Lower Páramo Limestones, of upper Aragonian age and marked expansive character, which partly fossilize the Langa fold, reflecting a stage of tectonic stability. The distribution of lacustrine environments is very clearly conditioned such that two lacustrine depocentres form to the north and south of this threshold (Sheets of Peñaranda and Ayllón), the latter being the most significant. Towards the SE border of the palustrine environments, these pass to mud flats with caliche facies (Atauta and Valparaíso páramos).

Overlying this level, a new sedimentary sequence starts with the installation of a low-sinuosity, fluvial network that is clearly entrenched, at least in these sectors, running in an ESE-WNW direction. On the southern border, alluvial fan fringes of carbonated clasts and scarce transporting capacity appear, while towards the NE, gravel and quartzite sand deposits arise from a large alluvial fan rooted in the northern border. During the rest of the Miocene, this fan was to impede or displace lacustrine environments towards the S and W (Sheet of Peñaranda).

In some areas, fluvial environments intercalate with palustrine-lacustrine episode(s) to culminate, also with an expansive character, with the sedimentation of the Upper Páramo Limestones,
corresponding to carbonated shallow lakes with palustrine facies developed to a lesser or greater extent.

The presence of the anticline continued to condition the distribution of sedimentary environments since, although not active, it comprised a relief that protruded the corredor centre such that two lacustrine basins arose. One to the north, between the anticlinal fold and the Mesozoic border of La Demanda, represented by the upper páramos of Peñalba de Castro (1022 m), El Salterio (1020 m) and Mata Verde (1039 m). The other depocentre was emplaced south of the Duero, and was mostly expressed in the páramo called the Alto de Ayllón. On the regional level, the tectonic stability of this epoch is reflected in the expansive nature of the Upper Páramo Limestones on marginal alluvial fan fringes or even on Cretaceous border reliefs. The age of the “inter-limestone” series of the páramos is upper Aragonian-lower Vallesian, although there have been no direct datations of the Upper Páramo Limestones in this region. Provisional palaeomagnetic data obtained from the Piquera de San Esteban section (Peñas Rodadas, 1055 m) point to the base of the upper Vallesian.

**Stop 5. Upper Páramo of the Alto de Ayllón.**

The sector considered here is found at the SE border of the Duero Depression, in contact towards the SE with the NW end of the Iberian Range (Sierra de Pela), and also close to the northern foothills of the Central System (Sierra de Ayllón), immediately to the south.

The relief is generally moderate to abrupt although with no great height changes and is constructed from end-Neogene piedmont, defined by two elements: the sedimentary plain corresponding to the limestones platforms of the Upper Páramo or by the border’s detritic deposits (of similar age), and a ramp or pediment developed on the Mesozoic border (Iberian Range). The drainage network downcuts both these elements; fluvial modelling being the morphogenesis responsible for the Meseta landscape.

Topographically, this region can be considered as a high plain sloping SE to NW, intensely incised by the Duero and Riaza rivers and their inflowing secondary systems. The topographically highest zones occur along both the interfluvial Riaza-Duero zone and the southern border itself, with peak heights ranging from 1242-1050 m.

According to purely descriptive relief criteria, like the folded unit described previously, the sector corresponds to the region of “calcareous páramos”. The classic physiographic units of the great Castillian depressions may be quickly and easily discerned (Pedraza et al., 1986): Páramos, Campiñas (open land), Vertientes (slopes) and Vegas since they constitute a transition (or border) zone, or ramp-type piedmont.

Its morphology is the result of fluvial morphogenesis acting –on the one hand– on a substrate of homogenous, detritic, inconsistent materials practically restricted to the SE sector –and on the other hand– on an alternating set of lithologies of varying competence with subhorizontal structural arrangements in the basin, tilted slightly (folded) at the border and occupying the rest of the zone.

The first of these morphogenetic processes gives rise to the Campiñas and Vegas. The Campiñas constitute a landscape of rolling plains that extend towards the SW, with the Campiñas de Campo de San Pedro and Boceguillas developed between the foot of Somosierra and the Honrubia structure. Their eastern boundary is the tabular structural unit.
The campiña is characterized by gentle interfluvial zones and flat-bottomed valleys—the Vegas— with asymmetrical wide slopes that steadily lose height towards the SW. These generate a landscape of transition from an inverted relief, where terrace remains occupy high plains flanked by scarped level changes in erosive slopes (right margins), and to a gently rolling terrain constructed over the easily eroded sediments of the Neogene infill.

The páramos, Vertientes and ramp-type piedmont develop on the second lithological group. In these, a well-characterized structural type relief dominates, where, in addition, the fluvial system is markedly entrenched, clearly superimposed upon the underlying Mesozoic and Tertiary sediments.

This aclinal tabular structural relief (tableland) is the consequence of differential erosion between resistant layers (limestones and caliches, conglomerates and cemented sandstones) and poorly consolidated clays and silts. Structural forms are therefore the most significant of the region and confer interfluvial zones the morphology of páramos and stepped horizontal flats and benches on slopes.

Structural flats are subhorizontal since they are constructed over rock strata with this same arrangement, and show excellent development in this unit. Their construction occurs at the expense of the two main reference lithostratigraphic elements. Thus, the limestones of the upper Miocene (Vallesian) constitute the structural surface with erosive features (slightly retouch) of the so-called Upper Páramo, represented by the extensive páramo of Alto de Ayllón in the SW area (Fig. 13), the stylized mesa of Cuevapalo-Muela to the north, and the páramos of Morcuera and Quintanas Rubias to the SE. The limestones of the middle Miocene (upper Aragonian) or Lower Páramo, define flats of smaller size and lower height (Cojo 981 m, Rostrocodo, Las Alforjas, Monte del Cubo), shoulders and stepped benches at mid height, some 20-40 m below the Upper Páramo. Further away and almost isolated appear the lower páramos of Atauta, Valparaiso and Llano de San Juan. Both the reaches of the river Pedro and those of the streams Monte and del Prado, downcut in the shape of moderate canyons into the Lower Páramo, forming structural scarps and narrow benches (960-940 m) at the respective margins.

Competent levels of less entity (caliches, limestones, sandstones), intercalated at different heights in the series give rise to the same shapes but on a smaller scale, and to others of less entity such as castle hills, pinnacles, fungiform overhangs etc. Structural scarps limit the larger páramos, although given the thinness of Tertiary strata, the level changes produced are discrete (10-40 m). Benches of hard layers are mostly due to the more compact layers, whose presence originates in the small steeped slopes.

Overlying the Alto de Ayllón páramo limestones appear well-preserved red sediments comprised of sands, silts and clays topped by quartzite gravels; these same materials also occur closer to the border (NW of Liceras) on both degraded (levelled) Mesozoic sediments and the cemented Miocene calcareous conglomerates of the border. They are organized on a karstified surface in the shape of spectacular hollows (dolines) 3-4 metres in depth, filled with red clays arising from the dissolution of limestone banks. The clay fraction is mainly composed of illite-micas and kaolinite.

Towards the NW and NE, there is a rapid reduction in thickness, probably because of the wedge (fan) morphology of the deposit itself.
These red sediments, especially in the lower clay-silt stretch, are interpreted in near-by areas according to their mineral and sedimentological properties (García del Cura, 1974; Ordoñez et al., 1976) to be the consequence of dismantling of thick profiles of red soils developed at Palaeozoic and Mesozoic borders, transported and deposited by mud-flows. Sands and quartzite gravels are thought to correspond to gravel bars deposited by more diluted laminated flows, although with an abundant fine sediment load. Both types of sediment would have been deposited by alluvial fans rooted to the S and SE in the reliefs of the sierras of Ayllón and Pela.

The quartzite gravels lying on red series in the Alto de Ayllón páramo eventually directly onlap the erosion surface developed on the Mesozoic border. Here, with a thickness of over 4 m, they correspond to proximal facies, with well-rounded quartzite pebble and boulder (inherited from the Bunt base) and sizes of up to 40 cm. The deposits of both sectors are equivalent and we attribute them to the rañas, representing top deposits and thus the last sedimentary episode in the elaboration of the piedmont (raña R₀, sensu Martín-Serrano, 1991).

Their age of this karstified surface is difficult to establish because of the lack of palaeontological remains and they have been traditionally assigned to the Pliocene based on their morphological position. They fossilize the Upper Páramo Limestones (classically ascribed to the Vallesian-Turolian) and are covered by raña deposits, also considered Pliocene, or more specifically, Plio-Quaternary, although they have not been specifically dated.

The erosion surface is essentially the one (S₂) defined by Gracia et al., (1988, 1990) in the central sector of the Iberian Range and the NE border of the Duero basin, where these authors consider the end of its elaboration to correspond to the Turolian-Pliocene (an age accepted at that time for the limestones of the Upper Páramo). Based on its the development, characteristics and age, the surface has been correlated with the Main Erosion Surface of the Iberian Range, of lower Pliocene age (Peña...
et al., 1984) Similarly, its morphological and mineralogical features associate it with the upper surface of Molina & Armenteros (1986), ascribed to the Pliocene by these authors.

At the foot of Somosierra, Raña de Riaza is similarly a characteristic quartzite, conglomerate deposit that, with its morphology of an extensive fan (currently very incised), occupies the interfluvial Riaza-Riaguas region. At the headwaters, its deposits fossilize the pediment, or ramp, of the northern border of the Central System (Fig. 14). The alluvial fan spreads towards the north from Riofrío de Riaza, its apex (1.300 m) extending to Fresno de Cantespino, where it is currently topographically hanging (1.080 m) by the fluvial downcutting and the highest terrace of the Riaza river. The lower stretch of the fan has a mean slope of 1.06%, which steadily increases southwards to 2.5% at the apex.

![Figure 14. Ramp of the northern border of the Central System to the SE of Cerezo de abajo.](image)

The fan’s deposits shows numerous outcrops in the badlands that appear along its entire eastern scarpment, among which we could mention those of Los Terronales, SSW from Fresno de Cantespino (Fig. 15). In the sections, the fan deposits of thicknesses between 2 and 3 m clearly stand out owing to a flat contact overlying the lower unit, the Miocene red clayey silts. These appear as quartzite gravels (quartzite and quartz), loose and washed on the surface with an ochre sandy-silty matrix. Being the most distal facies, grain size is generally small, with sizes smaller than 15 cm, although they can surpass 50 cm at the headwaters. The *raña* shows a characteristic ochre colour and beneath it an ochre alteration may also be observed deep in the 3-5 m of substrate, decolouring, or “ochrerizing”, the red detritic deposits of the upper Miocene.

The *rañas* of Liceras-Alto de Ayllón and of Riaza represent the top of the piedmont, from which the hierarchy and entrenchment of the fluvial system commence. However, according to correlations with dated deposits (upper Turolian) that are lithologically similar, though morphologically entrenched over the Upper Páramo Limestones in the basin’s central sectors and considered to be already exorheic (Mediavilla *et al.*, 1996), they could be interpreted as coeval.
The surface defined by the top of the Upper Páramo Limestones, in large measure practically corresponds to a structural surface with erosive features, but when observed in more detail overlying the Alto de Ayllón, it becomes clear that the surface slopes towards the N and NW, cutting different levels of Upper Páramo limestones. The higher limestone strata are karstified, yielding residual mounds and irregular vertical cavities filled and covered with terra rossa, and detritic materials including red clayey silts and quartzite gravels.

At the border corresponding to the Iberian Range, overlying the Mesozoic cover and even the Palaeozoic basement, a degraded surface or ramp pediment (erosion surface), appears, rooted in the northern foothills of the Sierra de Pela and perfectly connects with the sedimentary plain of the basin’s Upper Páramo (Fig. 16). On this pediment, some isolated residual forms standout: El Cerro Matilla (1.242 m), overlying Palaeozoic quartzite materials, and La Cuesta del Gallo (1.235 m), on limestones of the upper Cretaceous.
Gradients range from 2-1.3%, generally facing NW, and occupy topographical positions spanning from 1.240 m in the southern sector, where it currently hangs, up to 1.110 m at its northern extreme, where it appears fossilized by red detritic deposits and/or quartzite conglomerates of the raña de Liceras (Mayabril, El Corral de la Mata...), whose deposits extended to the Alto de Ayllón páramo. The final building of this surface is determined by the age of the most recent sediments that fossilize it. Hence, assuming the correlation proposed above with equivalent dated sediments of the basin centre, we propose it could be assigned to the upper Turolian.

Figure 17. “Intra-Miocene” erosion surface in the left bank cut of the Pozo Moreno stream, WNW of Liceras.

Moreover, west of Corral de la Mata, the intense entrenchment of the Pozo Moreno stream shows –in cross-section– an erosion surface that bevels the strata tablets and folded Jurassic dolomites and limestones of the Cuevas Labradas Formation. This surface is fossilized by cemented, calcareous conglomerates corresponding to the proximal facies of the Upper Páramo Sequence (Fig. 17); in this section, it undoubtedly represents the intra-Miocene Surface (S1), but it may also be noted how the surface steadily gains height in a southwards direction towards the border, until it becomes fossilized by the rañas or as a denuded erosion surface, indicating the surface’s period of development was sometime between the upper Aragonian and upper Turolian.

Figure 18. End-Neogene erosion surface at the eastern end of the Honrubia anticline (Sierra de Pradales), NNW of Maderuelo.
It is therefore a polygenic, heterochronic erosion surface that started development during the time of Lower Páramo Sequence, and was modelled during that of the Upper Páramo Sequence, whose marginal detritic sediments fossilized it by onlap. Its maximum would be reached during sedimentation of the Upper Páramo Limestones that constitute its base level, with which it is perfectly leveled (Fig. 18). Subsequently, the surface would have been reworked during the time of the red series and rañas, probably by now with a lower base level due to the capture and exorheic nature of the basin.

I Geological and geomorphological interpretation of the tableland Unit

The Duero Basin constituted a well-individualized domain throughout the course of the Neogene. Towards the end of the cycle, a lacustrine environment became the general setting, at least in a large part of the basin and specifically in the sector considered here. This setting is represented by the Upper Páramo Limestones, which are clearly expansive at the periphery, such that towards the borders the calcareous sedimentary plane levels (onlap) with more or less extensive pediments, but which are always well-developed on the border’s Mesozoic materials, to make up the so-called End-Neogene Erosion Surface (that had been previously forming).

This model would indicate great tectonic stability in the mountainous periphery with no level changes generating relief and, at the same time, constitutes the last clear sign of the basin’s endorheic stage. Subsequent to the development of these carbonated lacustrine environments, they underwent drying and subaerial exposure under a humid climate that promoted marked alteration and karstification processes over the limestones. Simultaneously, at the border and at the mountainous periphery, red soils developed in what was likely a biostatic stage (Ordóñez et al., 1976).

From this time on, and given this “end-Neogene pediplain” defined by an erosion surface degrading a calcareous sediplain, and its linked gentle piedmont plain, we can assume a change in geodynamic conditions dominating different processes that were to transform this landscape.

A change towards damper and rainier conditions would result in the rapid dismantling of alteration profiles in the pediments and neighbouring reliefs (foothills of Sierra de Pela and NE end of the Sierra de Ayllón) dragging them towards the basin and depositing them in the form of red silty-clayey alluvial fans and quartzite rañas prograding towards the interior of the basin (upper Turolian?). This fossilized the karstification surface built over the Upper Páramo in those areas where alluvial offlap occurred, yet maintaining across the rest of the surface the conditions of subaerial exposure, and therefore, of dissolution and karstification.

On top of the red clayey silts were deposited alluvial “sheets” of quartzite gravels, traditionally designated rañas, that form the top of the piedmont, and are therefore previous to the fluvial incision of this sector; they are the product of confined clear water flows of high transport capacity. These gravels would arise from sedimentation in the form of bars within shallow, braided channels, indicating a clear tendency towards wetter conditions.

Previous or simultaneous to the onset of the humid, rainy conditions that gave rise to this set of peripheral alluvial fans, the capture of the Duero Basin by the retreat of the Atlantic network must have taken place (Martín-Serrano, 1988a,b), facilitated by an increase in discharge and thus a greater erosion and transport capacity.
Thus, the rañas, or at least those considered here as such (rañas of Liceras, of the Alto de Ayllón páramo and of Riaza), could be coeval with the capture process without being morphologically entrenched. Further, Martín-Serrano argues that it is unfeasible to assume a synchronous end-Neogene landscape, since the progression of the fluvial network cannot reach all places at the same time. This hypothesis establishing the heterochronicity of the raña, would also explain the different degrees of dissection of the sectors of the basin.

Traditionally, the start of fluvial entrenchment would mark the Neogene-Quaternary transition (Aguirre, 1989), but as argued before, what we are looking at is a progressive process at the basin level such that it refrains from being a precise chronological limit and might be better described as one of heterochronicity in the basin setting.

The start of fluvial glyptogenesis saw the end of the Duero Basin’s endorheic cycle and the beginning of its erosion and emptying in an Atlantic direction along the main artery from which it takes its name. The currents of water provided by the alluvial fan system constructing the rañas, were probably collected immediately to the north by a main collector (palaeo-Duero?) and by secondary ones running north-westwards towards the “captured” zones of the basin, that is, zones with a lower base level.

Hence, coevally or subsequent to the rañas of this basin sector, the downcutting of the palaeo-Duero was initiated already as an exorheic course. Throughout this process (which was to span the entire Pleistocene), the present fluvial system developed as the Tertiary infill became dismantled and the different forms were modelled. The result was a structural-type relief, given the lithological characteristics of the Mesozoic and Neogene series and their architecture, giving rise on the one hand to several competent levels previously levelled by the Erosion Surface to generate the ridges of the Mesozoic cuesta reliefs of the border, and on the other hand, to flats forming a series of isolated and/or stepped horizontal platforms, or páramos, from the piedmont top.

**Stop 6. Dune – humid zones complex of Lastras de Cuéllar.**

1. Introduction

The aeolian deposits of the southeast Duero basin, along with those associated with the basin of the river Guadiana in Extremadura and those of the plain of La Mancha, are the three most outstanding aeolian complexes of the inland Iberian peninsula (Borja Barrera and Pérez-González, 2001). Of these, the dunefields and sand sheets of the Duero basin are the largest, spanning hundreds of Km², from the central sectors of the basin to almost the foot of the Central System. Crossing the provinces of Ávila, Segovia and Valladolid, they cover areas of both open country and the high páramos of the basin’s interior. The deposits mainly occupy the natural province of Tierra de Pinares, whose name refers to the presence of a more or less continuous wood of *Pinus pinaster* and in smaller measure of *Pinus pinea*. These pinewoods, autochthonous in principle (Allué et al., 1995) and present at least during the last 9000 years (Franco-Múgica et al., 2005), underwent substantial expansion owing to repopulations initiated in the second half of the 19th century (Cortazar, 1877 and 1891), and especially so after the 1940s (ICONA, 1995). Besides having been a major source for the resin industry, these pinewoods have played an important ecological role, helping to fix the dunes.
Figure 19. Gemorphologic synthetic map of southeast of Duero basin with Lastras de Cuéllar and Nava de la Asunción stops. Legend: 1-Dunefields; 2-Aeolian sand-sheet; 3-Flood plains and lacustrine areas; 4-Flood plains and terraces of river Duero and Pisuerga; 5-Fluvial terraces; 6-Pediment deposits; 7-Highlands and structural plains; 8-Mesozoic Sepúlveda massif; 9-Paleozoic and Mesozoic bedrock: erosion surfaces and residual landforms.
The extensive sand deposits of the Duero basin, well-known since the middle of the 19th century (Casiano de Prado, 1854 and 1862; Cortázar, 1891) were attributed a fluvial origin, and it was later that Hernández-Pacheco (1923 a-b) ascribed their formation to wind action. The sands forming the aeolian system are comprised mainly of light minerals, with a mean composition of 62.5 % quartz, 35 % feldspars and 2.5 % rock and mica fragments, Their heavy mineral fraction is defined by the association turmaline-garnet-andalucite in mean proportions of 35, 25 and 12 % respectively (Alcalá del Olmo, 1972-74; Casas et al., 1972). These sandy deposits have lately been interpreted as a product of aeolian remobilisation, by southeasterly and easterly winds, of the less coarse materials of Quaternary terraces and Miocene arkoses (Pérez-González, 1982). The textural features of the deposits are highly variable and essentially depend on their source areas. Thus, sands from fluvial deposits are better sorted and of medium grain sizes, while those mainly arising from Tertiary arkosic facies are poorly sorted and mean grain sizes are coarser.

2. The aeolian system of Tierra de Pinares.

Sands of aeolian origin cover terraces and complex Plio-Quaternary surfaces, several types of Tertiary sediments (conglomerate, sandy, silty and marl facies) and Mesozoic and Palaeozoic materials (slates, schists, quartzites, granitoids, dolomite sandstones, limestones and marls) of the satellite massifs of the Central System. The aeolian system is characterized by two main morphosedimentary environments, sand sheets and dunefields (Fig. 19). The geomorphological features of both are described below.

Sand sheets covering some 1.500 Km² are the most abundant deposits of Tierra de Pinares. These are sand deposits with flat or slightly rolling surfaces that cover irregularities in the terrain or substrate; thicknesses ranging from a few centimetres to 4-5 m. In these deposits, we may find isolated dune bodies generally of little significance morphologically, or devoid of avalanche faces, thus defined as deflation depressions of varying size. Deposits forming sand sheets are usually of medium to fine grain size (0.350-0.060 mm) in the páramos. In contrast, open areas show medium to coarse grain sizes (0.350-0.700 mm) predominantly in western zones, and medium-fine (0.500-0.125 mm) sizes in easternmost deposits. In different sections, we can see parallel-subparallel stratifications and slightly undulated and crossed very low angle stratifications, all large scale, with lamination thicknesses ranging from millimetric to centimetric sizes.

Dunefields comprise groups of dunes of different size and morphology. Throughout Tierra de Pinares appears a series of dunefields developed both on páramos and on open zones, the most outstanding of which in terms of extension are those of Arévalo and Sanchonuño-Lastra de Cuéllar (Bernat Rebollal, M. et al., 2003). Most abundant depositional forms in Tierra de Pinares are simple and complex parabolic dunes. The former arose from blowouts, while the latter were the result of the joining of simple forms moving at different speeds. Other recognizable forms include transverse, barchan, dome and longitudinal dunes. The sands forming these deposits show variable grain sizes, with medium-fine sizes predominating in the easternmost dunefields and páramos, but these also have laminations of coarse to very coarse sands, particularly in the westernmost part of the aeolian system of Tierra de Pinares. There is a predominance of crossed-planar large-scale stratification of low and high angle. At the base of some high-angle laminations, deformation structures associated with avalanches appear. As in the sand sheets, lamination thicknesses vary from millimetric to centimetric, and orientations and slopes of lamination indicate wind transport directions consistent with effective palaeowinds inferred from dune morphologies. These dunefields have interdune spaces, these areas consist in topographically depressed zones of low relief between dunes that have
the same morphological and sedimentological characteristics as the sand sheets, and, depending on
the presence or not of transient or permanent wet zones, are defined as wet or dry interdune areas.

Figure 20. Geomorphological setting maps at stops 1 and 2. Legend: 1-Eolian sand-sheet an interdune areas; 2-Dune and indication of slipface; 3-Climbing dune; 4-Dune crest; 5-Blowouts and wind-furrows; 6-Fluvial cliff; 7-River channel; 8-a: Fluvial terrace, b: flood plain or valley bottom; 9-Nava (Endorheic wetland); 10-Lake; 11-Structural scarpment and plain; 12-Slope on Terciary bedrock (arkosic sands and limestones); 13- Terciary bedrock (arkosic sands and limestones)

The stop 6 is a set of wet dunes and interdune depressions appearing at the NE margin of the
dunefield known as Dunas de Sanchonuño–Lastras de Cuéllar, on the right bank of the Cega river,
which divides the dunefield in two zones. Interdune lows and associated lake bottoms occur relatively
close to the river Cega, but at a much higher topographical level (55 m difference). This is the result
of the as yet immature regional drainage network, which has not extended or incised sufficiently to
reach or drain the lake base, in turn protected by dunes of heights up to 24 m (see Fig. 20: Lastras de
Cuéllar). The Carrizal lake is bounded on the NE by a sand sheet that extends towards Tertiary
slopes of marls and clays close to Hontalvilla, while towards the SE it borders with a parabolic
compound dune formed by the joining of two or more simple forms such that it has a more or less
rectilinear front in the contact zone with the lake and a peak height of 18 m. This permanent lake
occupies a larger wet bottom (Nava) that becomes transiently flooded. Currently, the bottom-lake
complex is affected by exploitation of the aquifer that feeds the lake, providing water by direct
pumping of the lake water and peat. Three hundred metres towards the SE of the Carrizal lake there
is an interdune zone elongated in an NW-SE direction, whose SE border is comprised of a transverse
dune of slightly sinuous course and 24 m peak height. This transverse dune has a scarcely degraded
crest and down- and upwind slopes of 15-20° and 3-6° respectively. It is therefore one of the best-
preserved large dunes of Tierra de Pinares. The interdunar zone is of the wet type and contains a
transient pond (Tenca lake). Temporary flooding occurs mainly in autumn-spring. These wet
interdune zones are the consequence of a subsurface water table that temporarily or permanently
outcrops in the most depressed zones. The water table is linked to a free aquifer formed in the
Quaternary detritic materials that cover the impermeable Tertiary substrate composed of the marls
and clays of Cuestas facies outcropping in nearby eastern slopes. According to Temiño et al. (1997),
changes in the water table conditioned the development of the aeolian system. Thus, in wet periods with a high water table, sands and dunes would stabilize, while in dry periods, when the water table is low or absent, the system would reactivate. Recent sedimentological-palynological and chronological analyses in the Carrizal lake (Franco-Múgica et al., 2005) indicate a lacustrine sedimentation with no aeolian sand supply for the last 9500 years, such that the cessation of dune advance and aeolian activity must have occurred before this time. Finally, downwind slopes from the dune complex examined trend NE and E such that the winds responsible for these dune forms were clearly SE and W, which also prevail today.

Figure 21. Slipface (dip: 15-20º) of crescentic dune (20 m high) and wet interdune area with pond development (Tenca lake). The first plane of the picture shows the upwind face (dip: 3-6º) of another crescentic dune. Sanchonuño-Lastras de Cuéllar dunefield.

Stop 7. Isolated dune of Nava de la Asunción.
This is a parabolic dune formed downwind from an arkosic area surrounded by a thin sand sheet (20-30 cm). It is a hemicyclic, very open, or lunate, type dune (length-width ratio 0.45) such that its constructing winds were of highly variable direction, between WSW and S components. The dune (Fig. 20: Nava de la Asunción), of maximum height 6 m, length 750 m and maximum width 100 m, has a flattened crest and up- and downwind faces are of gentle slope, 3-5º and 6-10º respectively. It is therefore a relict form that has suffered the effects of wind and water. The inner structure of the dune can be observed along a cut made to enlarge a nearby crop field. The deterioration of a good part of the deposit may be observed. Stratification (see Fig. 22) is crossed-planar with subhorizontal wedging towards areas downwind from laminations. In its western arm, measured lamination planes indicate a maximum inclination of 19–22º in N and NE directions, confirming the palaeowinds inferred from dune morphology as constructors. Laminations are millimetric and centimetric in thickness, showing great textural variability amongst each other but with a predominance of sands of medium and coarse grain sizes, including sets containing very coarse sands and micro-pebbles of quartz and feldspar. The morphologies of the largest grains are angular and subangular, which along with their large diameter
of up to 7 mm, indicates the proximity of the source area, as well as the high speed of the gusts of wind that transported them by reptation, estimated as some 85 Km/h according to Bagnold’s sand transport equations (1941).

Detailed stratigraphic columns around 2 m long have been obtained. So far, textural variations and lamination thicknesses have not yet indicated any type of cyclicality in the formation process that might suggest a fixed pattern of transport-sedimentation. Further, the dune shows a high degree of soil development including the formation of horizons E (20-30 cm), clayey Bt (1-1.5 m and 20 % clays), and Ck (3-3.5 m) with carbonate nodules. Similar soils have only been observed on dunes in the most western zone of Tierra de Pinares, specifically on the Arévalo dunefields and dunes close to Adanero. Soil development must have been subsequent to deposit formation (there is no intercalated soil) and during a relatively wet period, allowing leaching of the clay. The age of the deposit has been estimated by thermoluminescence at 12.68 ± 1.3 ka BP (13.98 to 11.38 ka BP). According to GRIP sequence nomenclature (Walker et al., 1999), this would situate it in the GS-1 isotope event or Younger Dryas (12.6-11.5 ka BP) but it could have first formed at the end of the GS-2a event or Older Dryas (15.5-14.5 ka BP). During both these periods, climatic conditions were colder and more arid than the present.

Figure 22. Picture of Nava de la Asunción quarry in a parabolic dune with edaphic evolution (E, Bt and Ck horizons). It can also be observed centimetric laminations with wedge planar cross bedding. Lamination surfaces indicate transport stream flux from south and southwest.

Stop 8. Sites of the Sierra de Atapuerca.

1. Introduction
The Sierra de Atapuerca, 15 Km east of Burgos (Fig. 23), is a NW-SE trending Mesozoic anticlinal, in which the Edelweiss Group have mapped 3700 m of a system of cavities known as the Cueva Mayor-Cueva del Silo, with two current openings. Sima de los Huesos (Fig. 2) located in one of these
caves (Cueva Mayor) is where T. Torres discovered the remains of human fossils in 1976. At present, over 3000 fossils corresponding to some 30 hominids of both sexes and different ages have been found. These hominids are interpreted as ancestors of Neanderthals and have been dated as previous to 300 ka BP by uranium series and electron spin resonance (ESR) (Bischoff et al., 1997). More recent estimates (Bischoff et al., 2002) based on new radiometric data, indicate an age older than 350 ka and even 400-500 ka.

On the south side of the Atapuerca anticline, an abandoned railway trench has exposed several caves (the Elefante, Galería and Dolina) overtopped by allochthonous elasic sediments from 15 to 25 m thick. These deposits contain rich faunal associations of micro- and macromammals, birds and reptiles. In level TD6 of the Dolina cave in the “Aurora” Stratum, 20-25 cm thick, lithic artefacts and almost a hundred human fossil remains belonging to at least six individuals have been recovered (Carbonell et al., 1995). The “Aurora” Stratum has been palaeomagnetically dated as belonging to the Matuyama Chron (> 0.78 Ma BP) by Parés and Pérez-González (1995) and Falgueres et al. (1999) using a combination of ERS and U-series applied to fossilized ungulate tooth enamel. The human bones have been ascribed to a new species, *Homo antecessor* (Bermúdez de Castro et al., 1997). Cutmarks on some of the human bones have been interpreted as evidence for cannibalism.

2. Geology and geomorphology of the Sierra de Atapuerca
The Mesozoic Sierra de Atapuerca approaches the boundary of the hydrographic catchment areas of the rivers Duero and Ebro. This limit artificially coincides with the geological Tertiary depressions that bear the same name.

Because of its geographical location, the Sierra de Atapuerca belongs to the large interior Tertiary basin of the Duero, its north-east border limiting via the La Bureba corridor with the Ebro Meseta’s external depression (Fig. 23).

Structurally, the Sierra de Atapuerca is an overturned anticline with a NE vergence and Iberian NNW-SSE direction (Olivé et al., 1990). This structure forms a mont relief of upper Cretaceous limestone, dolomites and calcarenites (Turolian to Santonian). Atapuerca’s karst sites developed at the expense of dolomites and limestone, sometimes oolitic, of the middle Turolian-Coniacian, which represent a regressive internal marine platform episode of a thickness around 45 m (Olivé et al., o.c., Pineda and Arce, 1997). Oligocene limestone conglomerates and red clays outcrop on both sides of the Atapuerca anticline in unconformity and erosive discordance.

The most recent Tertiary beds, of Miocene age, is arranged horizontally or subhorizontally, although the dip may be a few degrees when overlying the residual relief of the Sierra de Atapuerca. Lithologically, it is comprised (in ascending order) of marls, clays and gypsum (“Cuestas Facies”),
over which are superimposed up to 20 or more metres of limestones and marls with large silex nodules (“Lower Páramo Limestones”). According to the aforementioned authors, these carbonated, stratigraphically-upper layers would belong either to the Aragonian or to the middle Vallesian. Stratigraphically above the “Lower Páramo Limestones”, we can still find the clays, sands, marls and limestones that give rise to the “Upper Páramo Limestones” probably of upper Turolian age (Pérez et al., 2001).

The landscape around the Sierra de Atapuerca is made up of shallow valleys with slopes sometimes formed by stepped, smooth-edged terraces or structural overhangs of the sedimentary unit “Lower Páramo Limestones”. This landscape is dominated by the mont residual relief of the Sierra de Atapuerca, whose heights approaching 1080 m (San Vicente, 1079 m, Matagrande 1078 m) render an erosion surface designated S0 by Zazo et al. (1983, 1987).

This erosion surface (S0) has its correlative formation in the Oligocene-Lower Miocene conglomerates which, in unconformity and erosive discordance, rest on the upper Cretaceous, carbonated-detritic materials. To a certain extent, the Sierra de Atapuerca must have already been a positive relief at that time, successively pushed up by tectonics during the Miocene and Pliocene. During the whole of this period, the Atapuerca Mesozoic anticline was a differentiated relief, emerging in the continental Tertiary basin. In addition, Benito Calvo (2004) detected the remains of a further 2 erosion surfaces in the flanks of the Sierra de Atapuerca (Fig. 25 and 26). The most ancient surface (SE2) is of middle Miocene age and the youngest (SE3), of the upper Miocene (Turolian), would correspond to the sedimentary cycle of the “Upper Páramo Limestones”.

The fluvial dissection is, however, the conspicuous Pleistocene landscape of the Atapuerca surroundings. Benito Calvo (o.c) has mapped up to 14 levels of stepped terraces of the river Arlanzón, with heights ranging between +2-3 m relative to the river channel with the highest at+92-97 m and undisputable of lower Pleistocene age. It is likely that the middle-lower Pleistocene boundary corresponds to the terrace at+60-67 m, and the upper Pleistocene to 4 or 5 levels with relative heights up to +13 m (Figs.25 and 26).

The river Arlanzon’s fluvial deposits are formed by clast-supported textures mainly made up of quartzites and shales of sizes mostly between 4 and 6/7 cm. The shales are percentage–wise more abundant in sizes less than 2-3 cm longest axis. Tertiary limestone clasts can be accounted for in the current riverbed bars but they, nevertheless, seem to be absent from the upper terraces. The facies recognised represent bars and channel fills, with thicknesses of not more than 4-5 m observed. At present, the Arlanzón is a braided, low sinuosity river.

The origin of the Sierra de Atapuerca karst is phreatic (e.g., Cueva Mayor). It is a covered karst (Torres, 1976) whose main development stage, according to Zazo et al. (1983, 1987, o.o.c.c.), coincides with sedimentation of the top limestones of the Aragonian or middle Vallesian. These authors argue that the Cueva Mayor and the trench cavities could be senile forms, at least from the +60 m terrace of the river Arlanzón. It was thus during the Quaternary that vadose phases and partial reactivations of the karst due to climate changes, and drops in the base level of the Arlanzón started. The Galería, Gran Dolina and Elefante sites represent this phreatic-vadose scheme and its development, controlled by bedding planes and fracture systems, until their current forms.

The preferential directions observed in the conducts are NNE-SSW, WNW-ESE and NW-SE (Eraso et al., 1998; Ortega et al., in press).
Figure 25. Sierra de Atapuerca geomorphological sketch (Benito Calvo, 2004).
3. Lithostratigraphy of the Elefante, Galería and Gran Dolina infills

In the abandoned railway trench of the Sierra de Atapuerca, the best-known infills from S to N are those of the Elefante, Galería and Gran Dolina. The “Sima del Elefante” (TE site) is a substantial cave infill with a stratigraphic succession 25 m thick and 15 m wide. The exposed section has been divided into 21 lithostratigraphic units defined by major unconformities. The lower lithostratigraphic units contain a rich faunal assemblage and a set of flint stone tools of lower Pleistocene age (Matuyama Chron >780 ka).
These 21 stratigraphic units are further grouped into three sedimentary stages (Rosas et al., 2004): a lower stage spanning from the sequence bottom to unit TE14; a middle stage comprising units T15 to T19 and an upper stage including units TE 20 and TE 21 (Fig. 27). Sedimentation is allochthonous in these three differentiated stages and essentially comprised of mudflows and gravitational sediments (debris flows), along with bat guano in the lower stage. Stalagmite floors and hydric traction deposits appear in the intermediate state. Stage 3 is represented in the southern sector of the Elefante section and is composed of fall debris and terra–rossa.

Five clastic fill phases (G1 to GV) and a soil relict (GV1) have been distinguished in the Galería site (Fig. 28). Unit GI is comprised of interior facies, and units GII to GVI correspond to allochthonous facies.

The lower GI unit of Galería with a maximum thickness 5 m, shows lutite-sandy dominant lithofacies and also speleothems at the bottom and top. The Matuyama-Brunhes boundary occurs in the upper third of GI.

Unit GII overlies GI in angular and erosive discordance. As for the subsequent lithostratigraphic units, GII comprises exterior deposits with N and S points of entry in the excavated stratigraphic section of Galería (Fig.28). These deposits are clastic facies of gravel sizes and occasionally of fall blocks of the walls and roof of the cave with clayey-silty reddish matrices (5YR 5/8). The GI deposit medium is mainly hydric in GII, GIII and GIV, and gravitational or hydric deposits may be found. The GV unit are debris facies, typically entrance ones, and GVI, is a soil with A, Bt, Bk and Ckm horizons classified as a Petrocalcic Palexeralf.

In the sediments overtopping Dolina (or Gran Dolina, TD), like in Galería, interior facies appear in the basal units TD1 and TD2, while allogenic or exterior facies span from TD 3-4 to TD11 (Fig 29). There is, however, the odd level, such as TD9, in which the entrance of clastic elements from the outside is restricted.

Unit TD1 is composed of clayey, laminated sediments, and TD2 is formed by blocks and limestone angular gravels derived from the walls and roof of the cavity. These clastic facies are covered by a thick speleothem. Units TD3-4 to TD6, 7 m thick, are comprised of sandy lutites (7.5YR 5/8) and limestone blocks and gravels of scarce clayey matrix (clast-supported). The Aurora stratum, some 20 cm thick, occurs at the top of TD6. Ascribed to the lower Pleistocene (Matuyama Chron), this layer contains silex and quartzite artefacts, as well as the hominid remains that gave rise to the new species H. antecessor (Parés and Pérez-González, 1995; Carbonell et al., 1995; Bermúdez de Castro et al., 1997).

Unit TD 7 contains breccias and calcarenites, the Matuyama-Brunhes boundary being located at its top. TD8, 3 m in thickness, is a debris-flow facies of gravels and blocks with hardly any matrix. While TD9 constitutes resedimented bat guano facies 0-40 cm thick, this unit fossilizes an ellipsoid-shaped vertical tube overtopped by clayey silt deposits (Fig. 29). Unit TD10 represents a clear time of opening towards the outside, with the entry of clastic and other wall fall elements along with clayey reddish flows (5YR 5/8). This level is very rich in fauna and lithic tools. Excavations underway are uncovering significant anthropomorphic activity in this level. TD11 is the clastic lithostratigraphic unit that overtops Gran Dolina. At its top, we find residual terra-rossa deposits (2.5Y 4/6) that infill small cavities and joints.

4. Dating the infill of the railway trench

It is highly probable that overtopping of Elefante, Dolina and Galeria took place towards the end of the middle Pleistocene and that allochthonous sedimentation started a million years ago (Falgueres et al., 2001; Rosas et al., 2004). The lower-middle Pleistocene boundary is found in unit TD7 of Dolina and G1 of Galería (Parés and Pérez-González, 1995; Pérez-González, et al., 2001). Allochthonous sedimentation in the trench cavities seems to have continued some 800,000 years, and perhaps somewhat more in Elefante.

In terms of the palaeoenvironment, existing pollen data (García Antón, 1995) and estimates based on micromammal assemblages (López Antoñanzas and Cuenca Bescós, 2002), point to changes from
cold, dry climates at the Dolina sequence base, to interglacial periods with fluctuations in relative humidity in the lithostratigraphic units that overtop Dolina.

Figure 29. Magnetostratigraphy of the Dolina site (Parés and Pérez-González, 1995).
Stop 9. The river Duero
Besides being the main collector of the north Meseta, the river Duero has the greatest discharge of the rivers in the Iberian Peninsula and drains the peninsula’s largest hydrographical basin, covering 98.375 km² (Masachs, 1952). Flowing entirely E-W, the initial half of its course runs along a “soft” Cenozoic substrate and its final portion cuts down into the Iberian basement. Its main supplies are received by this initial stretch as it runs along the Duero depression, which is fed by water from the Cantabrian Range and northern half of the Iberian Range to the north, and from a large part of the Central System to the south (Fig. 30). The heights of these mountains, often above 2000 m, determine that the main tributaries of both these margins have pluvionival regimes. With the exception of the Tormes, southern tributaries, which are irregular and with intense seasonal rhythm, show relative and absolute discharges that are considerably lower (by half) than the northern feeding tributaries.

Figure 30. Hydrographical system of the Duero depression.

The river Duero longitudinally divides the Duero basin into two, and its unequal supplies in the past are also clearly manifest by the presence of terraces. Its main watershed is drained by two branching systems of triangular base: the Esla in the western half and the Pisuerga in the eastern section. Largest alluvial deposits in the northern piedmont are morphologically well-defined, from their initial head points to the elaborate and numerous sequences of terraces linking them to the current course. These two triangular systems become strangled close to the main channel but not before dragging large volumes of Tertiary sediments in the central-northern area of the depression. In the basin centre, the fluvial network shows intense interference due to the calcareous mesas of the “páramos de los
Torozos”, extending east-northeastwards. The reaches of the southern half constitute a perpendicular network dividing in a parallel manner a mainly arkosic poorly-defined piedmont sector interrupted by elevated basement blocks (Pérez González et al., 1994).

The river Duero cuts the central sectors of the depression leaving behind a morphology of steps of calcareous “páramos” and fluvial terraces.

Its peculiar longitudinal profile comprises two continuous profiles, both close to their equilibrium level, whose reaches coincide in the Cenozoic basin and Variscan basement (Fig. 31). As the Duero passes through the city of Toro, it is in the last stretch of its course through the Cenozoic depression, 30 km from its final entrenchment in the Iberian basement in Zamora. In this last stretch through the basin, the course of the Duero crosses Palaeogenic and pre-Palaeogenic materials, i.e., the basin’s eldest stratigraphic record which outcrops at its SE corner. Although entrenched, its already sinuous channel indicates its position at the end of its first longitudinal profile, with the previous site being the reference for the regional base level.

**Figure 31.** Longitudinal profile of the river Duero according to Valentín Masachs (1952).

**Stop 10. Appalachian palaeorelief of the western border. Origins and chronologies.**

The landscape of the large expanses of the Iberian Massif is defined by discrete mountain alignments trending NW-SE, transverse to its main reliefs. Island mountains, or *inselbergs*, arise as elongated residual reliefs, and when materials of varying resistance to erosion are repeated by folding, magnificent Appalachian or pseudo-Appalachian relief forms appear.

The alpine faults that modify the large peneplains of the Massif elevate, sink and also displace these types of relief. These palaeoreliefs are previous to the formation of the large alpine mountains and their associated troughs, since they are truncated by them and buried by the Cenozoic deposits that fill them. Generally they are previous to the main alpine deformation stages, even to the Cenozoic record. There are conclusive examples such as the SE extreme of the Massif, where the palaeoreliefs are buried by Triassic formations (Nozal, in litt.) or the present Zamora border of the Duero basin fossilized by deposits, attributed to the Cretaceous or to the lowest Palaeocene (Blanco et al., 1982; Molina et al., 1989).
From Sanabria to Sayago, the relief is defined by two peneplain inlets of the Duero depression as an extension of its main high plain, separated by a narrow, tortuous mountainous band. This relief is basically differential, and fairly unaffected by the level changes produced by recent tectonic events. Its shape is given by two contrasting main elements: long, levelled elevations of Armorican quartzite comprising the flanks of regional megastructures and vast flattened zones forming the nucleus of these structures. These latter regions, which constitute Solé’s main peneplain of Zamora (1958), are in detail a confusing model composed of several erosion surfaces (Martín-Serrano, 1988). The tight, isoclinal folds of the most intense deformation stage during the Variscan orogeny give rise to morphological elements of smaller order and a differential nature. For this reason, large mountainous volumes become defined in detail as a function of the Palaeozoic lithostratigraphy in a broken relief in alternating hillocks and small quartzite sierras, and slatey depressions of variable surface extension. It is therefore the structural features of the two Variscan stages that condition relief on two different scales. Hence, orography is based on the varying resistance to erosion of the basement materials. Through levelling of the sierra summits, this differential modelling is of an Appalachian nature but also has its own particular features imposed by the structural complexity of its Variscan geology (Martín-Serrano, 1988).

Figure 32. Location of the siderolithic outcrops of Zamora and main observation points.
In the past, it was difficult to admit that these types of relief could be exclusively linked to resistance. The authors of the time proposed a mixed genesis including the resistant nature of the rock or stratum along with tectonic elevation through fracturing in a direction parallel to stratification. Many quartzite sierras were interpreted as horsts (Ribeiro, 1941; Llopis, 1958). The interpretation accepted today evokes genesis through differential erosion induced by regional rejuvenation. This refers to the effects of cumulative differential erosion based on the resistance of quartzites and on the erosionability of weathered slates. The result is an enhancement in orographic contrasts between the two types of material (García Abbad and Martín-Serrano, 1980).

Figure 33. Model for the morphogenesis of the Appalachian reliefs of the Iberian Massif. Key: 1, non-weathered basement; 2, alteration layer; 3, siderolithic sediments; 4, etch surface; 5, initial surface; 6, successive topographical profiles.

The exceptionality of the differential reliefs of Appalachian character of the Iberian Massif can be illustrated by a few examples of geological interest, some panoramic and others related to given outcrops of a stratigraphic and mineralogical nature. In Montamarta (Zamora), next to the Ricobayo water reserve of the river Esla, we find one of the best outcrops of the stratigraphic record; the most complete and ancient of the western border of the Duero basin (Fig. 32). The siderolithic nature of the bottom of this record (Bustillo and Martín-Serrano, 1980), probably of the Cretaceous, the weathered layer affecting the fossilized basement and its clear relationship with the palaeorelief, confer a particular interest to these deposits, namely, the possibility of dating this landscape. Among the palaeorelief, we may still find the remains of what must have been a considerable kaolinitic meteorization layer and given their nature, these remains can be correlated with the siderolithic deposits that constitute the bottom of the sedimentary record of the western border of the Duero basin.
(sandstones of Zamora and Salamanca) that these immediately fossilize. If this correlation is associated with the principal elements of the relief itself, that is, the summit line and etch surface, it may be argued that it was the destruction of a preceding landscape (end Mesozoic?), flat and with thick alterite layers, that gave rise to the relevant palaeorelief (García Abbad and Martín-Serrano, 1980). Notwithstanding, the base of this irregular palaeorelief (general topography surface) also preserves the remains of a significant weathering layer of kaolinic nature that may be correlated with the basal siderolithic deposits that quickly fossilize it. This correlation, interrelated with the main elements of this landscape, the summit line and etch surface (proper of the palaeorelief), prompts the hypothesis that all these elements belong to a single past landscape, which was flattened and with significant alterites, whose destruction gave rise to today’s orographic configuration (Fig. 33).

Figure 34. Stratigraphic sequence of the Zamora-Salamanca region (sedimentology and cementations). Key: 1, intense ferrugenizations, dark purple; 2, purple marmorizations; 3, red ferrugenizations; 4, red marmorizations; 5, ochre ferrugenizations; 6, ochre marmorizations; 7, ferrugenizations with Liesegang rings; 8, pisolites; 9, silicifications; 10, carbonates; 11, bioturbation; 12, pedotubules.
The only alterites preserved are the roots of some profiles that disappeared through erosion. However, it is still possible to clearly appreciate part of the regolith, a clayey material produced by the transformation of most of the slate to kaolinite, containing quartz veins affected by retraction phenomena that give rise to fissures infilled with ferruginous sandstone from the overlying deposits. The sedimentary record that fossilizes it is a thick detritic formation (gravels, conglomerates, sands, and silt and clay levels) whose main components are quartz and kaolinite. The three members into which it is subdivided (here basically the two lower ones appear) are related to the nature of their cementation: basal or of the ferruginous crust with extensive iron deposits, Montamarta with iron and some silicon, and Zamora with intense silification. From bottom to top and in a general manner, the formation shows petrological and mineralogical features arranged inversely to the sequence derived from a lateritic alteration profile: a steady decrease in quartz, kaolinite and opaque minerals (iron oxides), and increased labile minerals, such as micas and feldspars, and rock fragments. This behaviour is particularly evident in Montamarta (Fig. 34).

**Stop 11. Fluvial incision: Arribes del Duero.**
The fluvial network is deeply incised and mostly affects westernmost areas of the Iberian Massif. In the current situation, the Portuguese basement is almost fully entrenched. Two thirds of the channels of the rivers Sil and Miño are entrenched, the incision of the Duero and Guadiana reaches the border zone, and the Tajo, which has progressed the most, runs entrenched until the centre of the Madrid basin (Fig. 35).

*Figure 35.* Main entrenchments of the fluvial system of the Meseta. Key: 1, Iberian Massif; 2, 3 and 4, Mesozoic and Cenozoic, 5, main elevations of the Iberian Massif, 6, fluvial network; 7, gorges.
Although it is certain that Quaternary eustatic changes have had their repercussions throughout the entire peninsula, most physiographic features of the rivers that cross its ancient basement are witness to a relatively long geological past. During the Tertiary, the alpine rejuvenation experienced by the Iberian massif reactivated its role as a source area such that fluvial incision processes were enhanced and prolonged to the present. The consequence is the rising erosion of rivers to reach the interior peninsula and thus also access its large continental Cenozoic basins, in an effort to recover the oceanic base level, upset by the substantial alpine morphostructural reorganisation occurring since the end of the Mesozoic. The likelihood, however, of establishing a reasonable age for this phenomenon is practically null because of the lack of references, whether geochronological, chronostratigraphical or simply stratigraphical.

Thus, the deepening of the most western Iberian rivers is a geodynamic tendency that continues to the present, induced by the alpine orographic changes occurring during the Oligocene and Miocene. The sequellae of this geographical past, although appearing throughout the entire hydrographic network, are restricted to a few sites, which owing to their outstanding features and beauty merit special attention. Among the most spectacular of these is without a doubt Las Arribes del Duero, a deep gorge almost 100 kilometres long that defines the boundary between Spain and Portugal. This impressive canyon fashioned out of granite with vertical cuts longer than 400 metres downcuts some 800 metres into the main peneplain of the Meseta. Longitudinally, it defines a very significant step that connects the Atlantic to the interior peninsula, since along this stretch, the river Duero bridges a level change of 520 metres, from the 630 m of Zamora to the 110 m of Barca d’Alba.
References


Hernández-Pacheco, F. (1932) Las terrazas cuaternarias del Duero en su tramo medio. *Boletín de la Real Sociedad Española de Historia Natural*, 32. 479-487


Landforms and geomorphological processes in the Duero Basin


Nozal, F. (in litt.). *Cartografía Geológica y Memoria (Geomorfología) de la Hoja de Siles (865). Mapa Geológico de España a escala 1:50.000 (MAGNA)*, IGME.


Wohlfarth,(1999). Isotopic events in the GRIP ice core: a stratotype for the Late Pleistocene. Quaternary Science Reviews, 18, 1143-1150.


ROAD-LOG

Stop 1: Local from Torralba to Ambrona. Road SO-P 4164, at 3 Km.
Stop 2: Road C-116 (Burgo de Osma-Almazán), km 44.
Stop 3: Local road from Almazán to Cubo de la Solana, km 1.8.
Stop 4: Road N-122, Km 16.800
Stop 5: Road N-110, Km 88
Stop 6: Road SG-212, Km 15
Stop 7: Road SG-342, Km 6
Stop 8: Atapuerca. Road BU-V 7012, at 4 Km from Santovenia de Coca village.
Stop 9: Road N-122. Toro town.
Stop 10: Road N-630 Km 291.5
Stop 11: Miranda do Douro (Portugal), Road ZA-324, at 40 Km from Villalcampo (Zamora, Spain).