THE GUADARRAMA MOUNTAINS (SPANISH CENTRAL SYSTEM): GEOMORPHOLOGY, LANDSCAPE AND ENVIRONMENTAL PROBLEMS

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FIELD TRIP GUIDE - C7
1. Introduction

The fundamental aim of this excursion is to present a summary of the knowledge that currently exists regarding the Geomorphology of the Guadarrama Mountains and, by extension, the Spanish Central System. Furthermore, and given that these mountains are located in the vicinity of a large city such as Madrid, special attention is given to the problems generated by the demand for leisure areas and other resources (countryside, water, land, etc), with a discussion of the implications that said process has for the conservation of this natural environment.

The contents of this guide mainly consist of a summary of the research work that we have carried out in the Spanish Central System over the last few decades. Logically, we have also used the work of other researchers who have dealt with this subject and mainly work in the universities of Madrid (the Geography and Geology Faculties of the Complutense and Autónoma Universities), as well as the Spanish Geological and Mining Institute.

Each specific contribution will be reflected as it appears in the text, however we must highlight that the basis of the latter is formed by the excursions that were carried out, with a similar subject matter, as part of the 4th Spanish Geological Conference (Pedraza et al., 1996) and the 6th National Geomorphology Meeting (Pedraza et al., 2002). Additionally, as you will see throughout the guide, there are many quotes regarding the contribution of scientists who could be considered pioneers in their understanding of the Guadarrama Mountains. These allusions are not just historical references since, in many cases their contributions continue to be of scientific interest, despite the passing of time.

In order to obtain an overview of the geomorphological context of the area to be visited, the guide contains an initial introductory section which provides a brief summary of the characteristics of the Guadarrama Mountains within the setting of the Iberian Peninsula’s Central System: Intraplate mountains which are structured in blocks and originate from the tectonic reactivation of an Ancient Massif (the Hesperian/Iberian Massif) during the Alpine Orogeny, whose morphology is defined by a system of piedmont stairways (piedmonttreppen) which were reshaped by diverse processes (glacial, periglacial, fluvial, fluvio-torrential and slope) during the Quaternary period.

The second section of the guide talks about the Guadarrama Mountains landscape, which form the central-eastern sector of the Central System, and provides a summary of the characteristics of their natural environment and problems, as well as their physiognomy or “physiographic units”. These units are those that have traditionally been used as a referential basis for territorial management and landscape studies.
Lastly, the third and final section contains specific observations regarding each of the programmed stopping points. To a certain extent, these represent a summary of the contents described in the previous sections, since the stops have been organised into a cross-cutting itinerary which allows the visitor to observe all the morphological units of the mountain range. At each stopping point, a description is provided of the most significant features of the unit or units that are being visited.

2. The Guadarrama Mountains in the context of the Central System

2.1. Introduction: Geographical and geological aspects

With a NNE-SSW orientation, the Guadarrama Mountains are one of the great orographic units or “sierras” that form the Central System; intraplate mountains originating from Alpine tectonic reactivation and located in the Hesperian or Iberian Massif of the Iberian Peninsula. The “sierras” into which the Central System is divided are separated by prominent morphotectonic alignments and, from East to West, they are: The Somosierra-Ayllón Mountains, with an average altitude of 1700 m and a maximum of 2262 m (El Lobo); the Guadarrama Mountains, with an average altitude of 1800 m and a maximum of 2430 m (Peñalara); the Gredos Mountains, with an average altitude of 1900 m and a maximum of 2592 m (Almanzor); the Gata-Peña de Francia Mountains, with an average altitude of 1500 m and a maximum of 1723 m (Peña de Francia); and the Estrela Mountains, in Portugal, with an average altitude of 1750 m and a maximum of 1998 m (Estrela) (Fig. 1).

![Diagram showing the geomorphic units ('sierras') of the Spanish Central System (Gata-Peña de Francia, Gredos, Guadarrama and Somosierra), and its location within the Geological Iberian Regions (a, Hesperian or Iberian Massif; b, Alpine Mountain Ranges; c, Cenozoic Basins). Some important morphotectonic alignments are indicated by numbers: 1, 2, 3, 4, 5 (see Fig. 3).](image-url)
Despite being an average mountain range in terms of altitude (the maximum is 2592 m, the average height of its peaks varies between 2200 and 1400 m, depending on the sector, and the height difference that separates the peaks from the piedmonts varies between 1500 and 600 m), the Central System is one of the great water divides of the Iberian Peninsula, since it separates the Duero and Tajo drainage basins.

Furthermore, the presence of this mountain range has meant that, in the interior of the Iberian Peninsula, dry Mediterranean plain environments coexist with the sub-humid environments that are convergent with Atlantic Iberia and characterise the mountain areas; this coexistence is represented by a characteristic plant succession which, from the piedmonts to the summits, consists of: Holm oaks (*Quercus ilex*), Pyrenean oaks (*Quercus pyrenaica*), Scots pine (*Pinus sylvestris*), Provence broom (*Cytisus purgans*) and graminea grasslands (*Festuca indigesta*). This botanical succession has been greatly modified by man, since he has caused widespread deforestation and thereby forced the forests to retreat.

Like the rest of the Central System, the Guadarrama Mountains are located on terrains which once formed part of the European Hercynian (or Variscan) mountain chain and currently forms one of the main geological regions in the Peninsula, namely the Hesperian or Iberian Massif (see Fig. 1). Tectonics, metamorphism, magmatism and other features developed during Hercynian (or Variscan) times helped Lotze (1945) to establish the initial geostructural zoning of the Hesperian or Iberian Massif; these zones were later specified by Julivert *et al.* (1974). According to the latter, the Central System belongs to the Central-Iberian zone and is characterised by the following geological features: Unconformity between the Lower Ordovician Armorican Quartzite and the Cambrian and/or pre-Cambrian series; Hercynian (or Variscan) polyphasic tectogenesis; highly varied regional metamorphism, from epizonal to catazonal; and an abundance of plutonic intrusions, which are the rocks that produce the most outstanding morpholithological contrasts, creating granitic topographies such as La Cabrera (*Stop 1*) and La Pedriza de Manzanareas (*Stop 10*). As far as post-Palaeozoic material is concerned, the Mesozoic or Cenozoic sedimentary cover is located in certain interior depressions (*Stop 7*) and the more recent Quaternary deposits are to be found along the entire length of the massif, in intermittent outcrops (Fig. 2).

Bearing in mind the effect of these petrological and structural features on the current morphostructure of the Spanish Central System, the latter has been divided into three dominions: One central and two border areas (Pedraza, 1994a). The Guadarrama Mountains belong to the first group, in other words, the central dominion.

The “central dominion” includes practically all the Guadarrama and Gredos Mountains (see Fig. 1). It is characterised by an abundance of granitic and gneissic materials in which a fragile deformation structure predominates, thereby conditioning the tectonic reactivation process to create a “Germanic” topography, in other words, *horst* and *grabens* (currently interpreted as “*pop up*” and “*pop down*”; Ribeiro, 1988 and Warburton & Álvarez, 1989). In the border dominions (Somosierra, Gata- Peña de Francia), there are many metamorphic materials with a low degree of transformation and a ductile deformation that favours the generation of differential Apalachian reliefs.
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Figure 2.- Geological sketch map of the Spanish Central System and its location within the Hercynian Massif. Granite types of the legend are: AG-type (biotitic granites with local incidental amphibole); BG-type (biotitic granite *sensu stricto*); CG type (biotitic granites with incidental cordierite). Key to plutons: 1, Ventosilla; 2, Villacastín; 3, La Cabrera; 4, Hoyo de Pinares; 5, Navas del Marqués; 6, La Pedriza; 7, Cabeza Mediana; 8 Atalaya Real; 9, Cardeñosa-Ávila; 10, Hoyos del Espino; 11, Navalosa; 12, Pedro Bernardo; 13, Bejar; 14, Corneja. (From Villaseca and Herreros, 2000).

Although the overall orientation of the Central System is NE-SW, its sectorial organisation is more complex. In general, there are two dominant directions, NNE-SSW and E-W, whose relation or interaction gives the Central System’s ridges the appearance of a series of dissymmetric H’s, leaning towards the east with horizontal bars compressed between the oblique lines. This structure helped to develop the hypothesis of the involvement of horizontal movement (not only vertical movement, as was initially considered) during the tectonic relief reactivation process (Pedraza, 1976); a hypothesis that was confirmed by later works (Vegas *et al.*, 1990; Carrasco *et al.*, 1991). The greatest horizontal movements took place along the strike-slip fault systems which create “morphotectonic corridors” that separate the different sectors or mountain ranges that form the Central System (Fig. 3).

This interpretation of movements at a general level also becomes evident in detailed observations. This is true for the layout of certain divides, such as the curving suffered by many ridges, particularly in the Gredos Mountains. These phenomena, together with other data on the deformation of Quaternary alluvial deposits (Pedraza, 1976; Carrasco *et al.*, 1991), have allowed Quaternary neo-tectonic activity with morphological repercussions on the topography.
The southern and northern limits of this mountain range are varied in nature. In the western sector of the Central System, the piedmonts of the elevations continue on from the large flattened plains that define the average altitude or level of the territory within the Hesperian Massif and the “sierras” are limited by topographical contrasts. Other geological features appear on the plateau, close to topographical limits, due to contact between the terrains of the Hesperian Massif and the adjacent depressions of the Duero and Tajo rivers, in other words, Mesozoic border cover and reverse faults overthrusting on Neogene deposits. It must be highlighted that the Neogene deposits correspond to the filling of basins, which are progradant on the massif and contemporary to the tectonic reactivation of the terrain. In some areas, they have been partially levelled and the massif-basin contact is irregular and shows exhumation. Lastly, another possible limit is a result of the recent fossilisation of ancient piedmonts developed on basement materials (during the Pliocene or Plio-Pleistocene); these are piedmont fans with conglomeratic materials or “raña” (literally scrubland) formation, in Spanish geological terminology. The characteristics of such limits may be observed during the 1\textsuperscript{st} stop.

2.2. Morphostructure: Evolutionary phases and the organisation of current topography
As in all reactivated Ancient Massifs, the general layout or lines of the Central System’s topography are a legacy from events which took place prior to its formation period.
The starting point is the great European Hercynian (or Variscan) Range which originated from a pluriphasic orogeny: Several phases of regional metamorphism and magmatic intrusions and several phases of tectonic deformation (folding and fracturing). These antecedents brought about a parallelepipedic arrangement of the blocks, establishing clear topographical limits, in other words, a block mountain.

Furthermore, the continuous succession of levelling phases served to create a large surface of “peneplain” erosion which would be the “generatrix” of the current topography (dachfläche): The morphogenetic processes which later modelled and transformed it serve to provide a reference point for explaining many of the Central System’s morphological features.

At the end of the Mesozoic era and the start of the Cenozoic era, the process which some call “Tertiary inversion” took place: Mesozoic “extension” was succeeded by Cenozoic “compression” and this created the current topography of the Iberian Peninsula.

With regards the Central System, once the influence of the opening of the Central Atlantic had decreased, its tectonic reactivation depended on the Pyrenean and Betic orogens: The forces created in these active margins of the Peninsula were transmitted towards the interior of the Iberian plate and various belts of moderate intraplate deformation appeared: The Central System is one of these (Vegas, 1974; Capote et al., 1990; Vegas et al., 1990; De Vicente et al., 1994). It is important to highlight that the association between the Betic-Rif orogen and the origins of the Central System is a long-established theory described in many works (Macpherson, 1901; Schenzner, 1937; Solé Sabarís et al., 1952; Birot & Solé Sabaris, 1954; etc.).

In detailing the sequence of tectonic reactivation movements, certain phases or stages have been established which are described according to the creation of topographical features, tectonic structures or stress fields and have a local, regional or global reference base, depending on the case in hand.

For many years, the “Alpine” sequence used by Schenzner (1937) was followed, in accordance with the thinking of the “German school” (German geologists who frequently worked in Spain), in other words: Sávica, Staírica, Rodánica, Rodánica II, and Waláquica.

Besides these global references, recent research has provided new data and different terms which are more specific to the sector in which the phenomena have been detected. This is the case of the Castellana and Neocastellana tectonic phases or stages (Aguirre et al., 1976), Extremadura (Martín Escorza, 1977), or Ibérica, Torrelaguna, Altomira y Guadarrama (Capote et al., 1990) or the “evolutionary cycles” (tectonic, morphogenetic and sedimentary) that are termed pre-arkosic, arkotic and post-arkosic (Pedraza, 1978).

If we base our approach on these “evolutionary cycles”, as far as topographical origins are concerned, the Central System possesses unmistakable signs of “differential tectonics” which may be divided into three sequences (Pedraza, 1978, 1981; Pedraza & Carrasco, 1999; Pedraza et al 2002):

The first sequence corresponds to a widespread bulging which begins to lift and undulate the plateau, thereby creating depressed and raised areas which, in the long term and following restructuring, will form consolidated basins (from the former) or mountain ranges and platforms...
(from the latter). These represent the final moments of the “pre-arkosic cycle” (during the Palaeogene) and can be associated with the Pyrenean phase or stage. At this time, and in accordance with findings in other similar areas (for example, the Jerte Valley), one may presume that there was horizontal movement in the great faults that limit the elevations and that this initiated the formation of interior depressions as compensatory basins associated with said movement (Carrasco and Pedraza 1991; Carrasco et al. 1991; Carrasco 1999); basins that have been interpreted as pull-apart features in certain areas (Capote et al. 1996).

The second sequence is the sequence of great vertical displacements which establishes the relationship between mountain ranges undergoing uplift and their associated subsident basins that act as sedimentary store or bolson. This could involve a continuous and accelerated uplift (the relief gradually bulge until forming individualised blocks), however it could include stable periods that are compensated for by greater basin subsidence which ensures that topographical dynamism is maintained. The end of this sequence, which leads immediately on to the next, involves a significant readjustment of the axial blocks which causes a series of massifs to appear in the Central System, rising above the plateau that previously occupied the highest position. This is the “arkosic cycle” (from upper Oligocene to middle Pliocene) and can be associated with the Altomira and Betic-Guadarrama phases or stages or the classic phases termed Sávica (at the beginning), Stairica, Rodánica, Rodánica II and Waláquica (at the end).

During this period, the main divides of the Central System appear and the evolution of the intermountain depressions is complex: Some are cancelled and rise with the massif (as proved by the absence of Neogene sediments at their centre) and others are transformed into small pit basins of variable subsidence (the bottom is full of Neogene materials).

The third sequence begins with the aforementioned readjustment of the axial blocks (which remain and are consolidated during this phase) and is characterised by considerable “distension” which causes the rapid subsidence or “collapse” of some intermountain depressions and marginal basin (adjacent to the massif). These phenomena have continued until modern times in the form of subsidence located in prominent areas. This phase corresponds to the “post-arkosic cycle” (essentially the Quaternary period) and its beginnings may be associated with the compressive phase which, according to classic terminology, would correspond to the Waláquica phase.

Although certain signs seem to indicate the maintenance of features that require a current uplift in topography (scarps, facets, ridge movement, incisions and cuts in the drainage network, etc), so far no data has been found to demonstrate that any significant effect of the compressive process is maintained and coexists with the distensive process.

The final result of these events is a topography that is defined by one main mountain range, sometimes two, other secondary ranges which stand more or less parallel to the latter and several subsidiary ranges which lie perpendicular to these, to a greater or lesser degree. All these ranges are separated by depressions, fracture corridors and intermountain basins (see Fig. 3).

On an individual scale, each of the main mountain ranges can be described as a symmetric voussoir structure: A system of blocks which stand adjacent to one another, descending on each side of the highest to form stair-like benches. This appearance is characteristic of many mountains whose origins lie in the tectonic reactivation of ancient massifs and was given the term piedmont
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stairways (piedmonttreppen) by W. Penck (1924). In the Central System, and more specifically the Guadarrama Mountains, this was initially described by Schwenzner (1937).

The secondary mountain ranges can also be described as voussoirs, although they tend to be dissymmetric: One side is formed of stair-like benches, whilst the other faces a depression with a continuous hillslope. They may consist of tectonic blocks, inselberg residual topography or mixed topography. Good examples of these three cases are, respectively, the San Vicente or Piélago Mountains (located in the Gredos Mountains), Las Cabreras (located in the transition sector between the Gredos and Guadarrama Mountains) and the Cabrera Mountains (located in the Guadarrama Mountains and explained at the 1st stop). The main and secondary mountain ranges are separated from each other by fracture corridors or true tectonic depressions.

The subsidiary mountain ranges are different orographic structures to that presented by other ranges. The blocks which form subsidiary ranges may be highly fragmented by tectonics and form smaller stairs with a “step slope” structure (this is true of La Pedriza de Manzanares and is mentioned at Stop 10). In other cases, they are reduced to mountain shoulders due to the combined action of erosion and tectonics (fluvial incisions which form gorges and tectonic unevenness, generating depressions adjacent to the main voussoir; a good example of this are the southern slopes of the Carpetanos Mountains which face the graben of El Paular or Alto Lozoya, which will be mentioned at Stop 7).

The earliest origins of these subsidiary mountain ranges are to be found in the presence of longitudinal faults (more or less parallel to the main and secondary mountain ranges) and transverse faults (more or less perpendicular to said ranges). The action of the transverse faults is particularly significant and, as a result, small depression-corridors are formed perpendicular to the main and secondary mountain ranges which are used by the hydrographic network to carve gorges, often of considerable size. This whole system of voussoirs, stairs, rock spurs and perpendicular depressions or gorges creates a characteristic appearance which is known as “keyboard-like topography”.

In those cases in which the voussoir is symmetrical, in other words, the stairs and the keyboard effect appear on both slopes, the area acquires a particular physiognomy which is termed “fishbone” (referred to at times using the German word, schollengebirge): One main mountain range created by the voussoir and other subsidiary ranges created by the keyboards.

These basic topographical features serve to define the main lines or “architecture” of the landscape. They have conditioned and still condition many of the environmental characteristics of the terrain and, for this reason they also represent a basic reference point for establishing management units, as will be mentioned at various stops.

2.3. Morphological sculpture

If we consider the morphological sculpture of a terrain to be all the visible physiognomic features derived from the action of exogenous processes, we can refer to two main morphological sequences in the Central System: Planation surfaces and recent morphological sculpture. The first are the result of successive levelling phases, of varying magnitude, and the second is the result of processes which, due to their recent establishment in the area, have been unable to create morphologies with a geometric and genetic importance comparable to that of the surfaces and their most obvious effect is an erosive action upon said surfaces.
2.3.1. Planation surfaces
When analysing the origins of the Central System’s topography, one highly controversial subject is the age and origin of the primary peneplain (that which was compartmentalised into blocks during tectonic reactivation, the so-called “primärrumpf” of German authors) and the nature of its relationship with the fundamental surface of the plateau (that which forms the majority of the terrain of the Hesperian Massif) and the piedmont plains (the bottom of intermountain depressions and ramps that border the mountainous massif).

For Schmieder (1915) and many other German authors, including A. Penck, the ramps (base plains upon which the elevations stand) are tectonic blocks rather than true levelled piedmonts. Similar theories are defended by E. Hernández-Pacheco (1923) and Garzón (1980), and they all consider a *finicretácia* surface (end of the Cretaceous) to form the foundations of the current topography. By contrast, other authors (Schwenzner, 1937; Solé Sabarís et al., 1952; Birot, 1937; Birot & Solé Sabarís, 1954; Pedraza, 1978, 1994a, 1994b) believe that several morphogenetic sequences explain the levelling and they clearly distinguish between summit plains and piedmont plains.

Schwenzner (1937) talks of an intra-Tertiary peneplain (from the pre-Tortonian age) as the primary surface (primärrumpf) which currently consists of the summits and forms the summit level (*gipfelflur* or *dachfläche*). The other surfaces are stair-like benches (*mesetafläche*), contemporary to the uplifting of the terrain during the Tertiary period (from the Oligocene to the end of the Pliocene), according to a genetic model of cycles with successive tectonic pulsations (uplifting and isolation of the previous piedmont plains) followed by other stable periods (the erosion and creation of piedmont plains). This author differentiates between three stair-like benches: The highest M₃, whose average height varies between 1400 and 1700 m, depending on the zone; the intermediate M₂, whose average height varies between 1000 and 600 m, depending on the zone, and the lowest M₁, whose average height varies between 900 and 500 m, depending on the zone. Regardless of the genetic approach, the organisational understanding of the Central System’s topography described by Schwenzner (op. cit.) is the one which best defines the morphographic and physiognomic characteristics of the topography of these mountains.

Solé Sabarís et al. (1952) and Birot & Solé Sabarís (1954) believe that widespread levelling took place throughout the entire Hesperian Massif, ending with the creation of a peneplain. The latter presents very different concluding epochs (different authors talk of surfaces from the pre-Triassic, Triassic, Intra-Cretaceous and Eocene periods, amongst others) and is therefore classified as heterochronal. This approach defends the end-Miocene age as the context for the last levelling and, therefore, for the fundamental surface of the plateau, which is also the primary surface (primärrumpf) of the Central System and currently consists of the summits of the latter and forms the summit level (*gipfelflur* or *dachfläche*). On the basis of the ideas of Birot (1937), the piedmonts (*mesetafläche* M₂ and M₁) are considered as pediments produced during the Pliocene in a new morphogenetic cycle in a semi-arid environment.

Pedraza (1978) works with both models and also details another one, to a certain degree intermediate to the two, which considers three basic stages in the morphogenesis of the Central System’s plains (Fig. 4). In this case, an explanation is given mainly regarding the differences between a widespread morphogenesis and one that is localised in spatial and temporal terms: The widespread version is capable of forming a large plain on a general scale (throughout the entire
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Hesperian Massif) whereas the localised one only forms regional plains (in each sector or reactivated terrain) and piedmonts, in particular. Widespread morphogenesis is associated with a polygenic peneplanation phenomenon (as described by certain authors with regards other Ancient Massifs, it results from several morphogenetic systems and cycles, in which fluvial action still predominates; see Cholley 1950 and Klein 1973, 1985) which is heterochronal (it began once the Hercynian topography had been formed and continued throughout the Hesperian Massif wherever the sediments of subsequent cycles did not fossilize the terrain and may even continue to evolve in modern times, as in the case of the Extremaduran peneplain described by Gómez Amelia, 1985). Localised morphogenesis is monogenetic (it is a border plain produced by the destruction or erosion of weathering profiles, basically an etchplanation) and isochronal (it occurs in all zones throughout the Tertiary and is contemporary to tectonic reactivation).

In accordance with the above, in the morphology of the Central System there exists only one type of plain which possesses the category of a true planation surface. It is a polygenic and heterochronal peneplain, gradually disrupted by tectonics throughout the Tertiary period, and correlatable to the large plains of the Hesperian Massif. It is, therefore, the fundamental surface of the plateau and also the primary surface (primärrumpf) which has been disturbed by tectonics, causing it to occupy the summit level (gipfelflur) and the first bench of the plateau (mesetafläche M3).

The other plains, those which form the piedmonts (mesetafläche M2 and M1), must be considered as lesser plains which are contemporary to tectonic reactivation and associated with a variety of morphogenetic cycles. In the first of these cycles or sequences (the “arkosic cycle”, between the Upper Palaeogene and the Mid-Pliocene; see Section 2.2), an etchplanation is produced in environmental conditions similar to those of the modern-day savannah. This represents the main phase of tectonic reactivation and involves the filling of the Tertiary Duero and Tajo basins by alluvial fan and playa lake deposits. This is deduced from an analysis of morphological sculptures in the Massif and the facies of the correlative sediments of sedimentary basins (see, for example, Gutiérrez Elorza & Rodríguez Vidal, 1978; Pedraza, 1978; Vaudour, 1979; Alberdi et al., 1985; Friend & Dabrio, 1996). At the start of the second cycle or sequence (the post-arkosic cycle; from Middle Pliocene to Lower Pleistocene, see Section 2.2), the plateau shifts towards the West, the current hydrographic network begins to take shape and the etchplain is redeveloped to form a semi-arid pediment. Lastly, during the rest of this second cycle (during the Quaternary), a new morphogenesis takes place as a result of recent processes (current and subcurrent), which tends to cause a deterioration in previously generated morphologies.

2.3.2. Recent morphological sculpture

The influence of ancient morphogenesis is a determining factor in the current configuration of the Central System and, for this reason almost all geomorphologists have coincided in generally classifying it as a block mountain. This is the case because, despite their erosive effect upon previous configurations, recent processes have not developed their own morphologies, categorised as units, to replace the preceding ones. They are therefore elemental forms which are superimposed upon the older ones. This is true for the morphological sculpture that is due to mass movements and fluvial, torrential, periglacial and glacial processes.
Figure 4.- Schematic cross section from the Central System to the Toledo Mountains (see figures 1 and 3 to identify the
topographic and geomorphologic units) showing the main evolutionary stages of the origin and formation of the Central
System mountains: stage 1, the primary “peneplain” is formed (at the end of Cretaceous Period); stage 2, the “peneplain”
deformation and Paleogene basins are formed due to the first tectonic impulses (at the beginning of the Paleogene); stage
3, the processes of elevation-subsidence, etchplanation-fan sedimentation and mountain range-bolson type sedimentary
basin formation starts because of the important tectonic activity (the upper Paleogene time ?); stage 4, the piedmont
mountain etchplain is formed and a bolson-type sedimentary basin is filled, the former “peneplain” appears now at the
mountain summits (during the Miocene to middle Pliocene ?); stage 5, tectonic, pedimentation, and fluvial processes (the
most important) define the actual relief (from upper Pliocene ? to actual times) (from Pedraza, 1978).

Legend: 1, faults; 2, metamorphic and granitic rocks (Paleozoic and pre-Paleozoic); 3, “prearkosic cycle” sediments
(Cretaceous and Paleogene); 4 to 8 “arkosic cycle” sediments (from upper Paleogene to middle Pliocene) (bolson
sedimentary facies: 4, 5 and 6, proximal, middle and distal alluvial fan deposits; 7 and 8, playa-lake deposits); 9,
“postarkosic cycle” sediments (“raña” fanglomerate and fluvial deposits).

Sp, summit plains; M₁, intermediate plains in the Central System and summit plain in the Toledo Mountains; M₂ and M₃,
piedmont plains (upper and lower ramps in the Central System and Toledo Mountains) and “paramos” (upland plains)
and “campiñas” (rolling lowland plains) in the Tajo and Duero basins; R, “raña” fanglomerate
— The **fluvial and torrential morphological sculpture** that is characteristic of this phase consists of fluvial incisions in the form of gorges, whilst notable fluvial terraces appear only at the bottom of certain intermountain depressions. Several facts must be taken into account when analysing the current hydrographical network, namely:

1) Regarding the possible relationship between ancient fluvial networks (from the *arkosic cycle*) and the current fluvial network, we may only highlight the fact that some present-day channels follow a route which coincides with that of the apex of ancient alluvial fans.

2) The presence of ill-defined drainage networks with a highly mature appearance on upper plains contrasts with the fluvial incisions that form gorges on piedmont plains and certain hillslope sections.

3) The existence of hillslopes barely sculpted by the hydrographic network or, at most, compartmentalised by preferential adjustments along large fracture lines but without the generation of dendritic interconnections. This clearly faceted physiognomy, together with data regarding recent neo-tectonic activity on the edge and in the interior of the massif (Pedraza, 1976; Carrasco *et al.*, 1991), indicates that topographical energy is at least being maintained due to tectonic causes.

4) The slopewash, highly incisive in sectors with dry environments, has led to the erosion of weathered materials (regolith), in a process that is convergent with the etchplanations that are typical of the *arkosic cycle*.

The influence of human activities upon this process has been analysed in various studies regarding the Guadarrama Mountains (Bodoque *et al.* 2001, 2002) and, more specifically, the effects of leisure activities will be discussed at **Stop 6** and along the journey towards **Stop 7**.

— The importance of **mass movements** in the sculpting of slopes was barely noticeable until a few years ago (Carrasco & Pedraza, 1992). Research indicates that slides and flows (combined with falls, geliffuction and creep, mentioned since time immemorial) largely determine the detailed morphology of the slopes and, together with other phenomena, may have been responsible for the appearance of certain fluvial networks and certain glacial basins.

Regarding this same subject and in relation to the repercussions of the growth of urban settlements on the stability of slopes, the specific case of the city of Segovia will be mentioned at **Stop 4** (Díez Herrero & Martín Duque 1993).

— **Periglacial morphological sculpture** is due to nival processes and frost cycles which are the most widespread actions in both space and time. The most notable phenomena that appear as a result of these processes include rock fall, which accumulates to create diverse morphological features (talus slopes, protalus ramparts and rock cones); gelifluction and creep, giving rise to bench slopes and asymmetric valleys; and slopewash, creating debris cones and grèzes litées.

As far as erosion morphology is concerned, the most common features are tors, sharp crests, nivation hollows and rillwash erosion morphology.
With regards detailed forms, the structured soils are equally noteworthy: Sorted stone circles, stone garlands, stone pavements, etc.

All these processes were most active during the Pleistocene and are associated with cold periods, with or without glacial activity, during which permafrost is presumed to have developed (Fränzle, 1959; Brosche, 1978; Bullón Mata, 1988; Sanz Herraiz, 1988; Pedraza, 1994c).

— Glacial morphological sculpture is limited to specific sectors whose altitude and morphology were suitable for the accumulation of snow: They are mountains whose peaks measure almost or over 2000 m.

Although glacial morphologies are present in almost all sectors of the Central System (Somosierra, Guadarrama, Gredos, Estrela), they developed to the greatest degree in the Gredos and Estrela Mountains. In other sectors, it is only possible to find morphological sculptures resulting from ancient cirque glaciers or, at most, slope glaciers, however in Alto Gredos, the Nava and Béjar Mountains (Gredos Mountains) and the Estrela Mountains, there also exist morphologies which correspond to ice caps and valley glaciers.

The most outstanding glacial morphology of the Guadarrama Mountains is located in the Peñalara Massif (Stops 7 & 8), a study of which led to one of Spain’s pioneering works on this type of process. It was written by Obermaier & Carandell (1917) and here we shall highlight that, on the basis of the well-developed external and internal moraine complexes originated by the ancient glacier of La Laguna Grande, they assigned this glaciation with a chronology equivalent to that of the Riss and Würm Alpine phases. Given the absence of precise dating, this chronology continues to be applied to all the glacial morphologies of the Spanish Central System. Nonetheless, we must draw attention to the fact that a later work (Fränzle, 1959) limited glacial activity to the Würm phase. There are also recent studies of the Gredos Mountains which argue that their glacial development was more complex and attempt to describe all the phases (pleniglacial, stabilisation phases, advance or retreat pulsations), assigning each one with a chronology that is established through correlation with other regional processes (Carrasco 1999).

3. The Guadarrama Mountains

3.1. The natural environment and its problems
As indicated in Section 2, the Guadarrama Mountains form the central eastern sector of the Central System, covering a length of 110 km between the depression corridors of Somosierra, to the East, and Alberche, to the West (see Figures 1 & 3). The excursion mainly visits the central sector of the Guadarrama Mountains because this contains the range’s two highest massifs (Peñalara, 2428 m, and Cabeza de Hierro Mayor, 2380 m) and, as is clearly shown in Fig. 5, has a very well-defined serial block morphostructure (horst and grabens). These blocks are responsible for the main topographical contrasts (morphological, morpho-topographical and morphographic) and, together with vegetation and land use, provide a referential basis for delimiting the environment’s different physiognomies and landscapes.
Figure 5.- Geologic cross section from the Duero basin to the Tajo basin through the Guadarrama Mountains.
Legend: 1, faults; 2, granitic rocks (Carboniferous); 3 metamorphic rocks (gneiss, schist; Cambrian-Precambrian); 4, sands, marls, limestone and dolomite (Upper Cretaceous)-conglomerate, sands and marls (Paleogene); 5, conglomerate, arkoses and sands (Upper Paleogene to Middle Pliocene); 6, sands, silts and marls (Upper Paleogene to Middle Pliocene); 7, silt, marls and gypsum (Upper Paleogene to Upper Miocene); 8, limestone (Upper Miocene to middle Pliocene).
In accordance with the biogeographical region in which it is located (the Mediterranean), the Central System possesses a Mediterranean continental mountain climate. This means that the dry period has a definite influence and, despite having a sub-humid environment (rainfall varies between 500 mm/year on piedmont terrains and 1500 mm/year on the peaks), which contrasts with the driest of both sub-plateaux, the vegetation must withstand water shortages for at least one month a year. The average annual temperature varies between 14ºC in piedmont areas and 5ºC on the peaks. The environment is therefore cool in the summer and cold in the winter and approaches the nival zone at altitudes of over 1900 m.

Within the Mediterranean region, the central sector of the Guadarrama Mountains is located in the Guadarramense sub-sector of the Guadarrámico sector of the Carpetano-Ibérico-Leonesa province (Rivas-Martínez, 1987). In accordance with these biogeographical conditions, the vegetation series are as follows (Fig. 6):

- **Crioromediterranean** belt: The formation of pasture meadows (*Festuca indigesta*) on the peaks (at heights of over 2000 m).

- **Oromediterranean** belt: Formations of Provence broom (*Cytisus purgans*) and dwarf junipers (*Juniperus nana*) on the peaks and upper slopes (from the peaks to 1900 m) and the formation of Scots pine forests (*Pinus sylvestris*) in the mid-upper slope sections (from 1900 m to an average lower height of 1700 m, under natural conditions).

- **Supramediterranean** belt: The formation of oak or Pyrenean oak woods (*Quercus pyrenaica*) on mid-slopes and, in certain cases, in the hillslope-piedmont transition section (to an average lower height of 1200 m) and the formation of holm-oak woods (*Quercus ilex*) in lower hillslope and piedmont sections (to an average lower height of 650-700 m).
These vegetation series form the sequences that one might expect, given the ecological conditions of the terrain (rock, soil, humidity, sunshine, evolutionary status, etc), however, they have been modified by anthropic actions and, in certain cases natural processes (fires, prolonged drought, general or local climate change, specific lithological substrata, etc). At the moment, and considering these natural and anthropic factors, the most evident changes or effects are:

- The presence of relict plant formations (savins, birches, yews, etc) which coexist with those arising from recent evolution.

- Riparian vegetation (river bank or gallery forests) which dissect the vegetation belts, following the routes of river courses, and generate fertile plains, ash woods or copses and, in some cases, pasture lowlands.

- Changes or distortion in the natural vegetation (essentially on hillslopes) which has favoured the development of certain species rather than others. The most significant case in the Guadarrama Mountains involves the expansion of Scots pine forests, to the detriment of oak or Pyrenean oak woods and holm-oaks.

- Deforestation as a result of the exploitation of woodlands (wood for fuel, construction and industry), both on hillslopes and piedmonts, has led to the development of herbaceous formations (pastures) to the detriment of arboreal formations, thereby generating regression phases in which woodland gives way to scrubland (*Cytisus, Carex, Cistus, etc.*) or pastures (*Festuca, Stipa, Agrostis, Poa, etc.*).

- Widespread deforestation to create farming land, essentially on piedmonts, has created areas of arable land (farm land on which cereals, vines, olive trees and other fruit trees are grown) and irrigated land (pasture land and vegetable gardens).

- The expansion of traditional urban settlements and the creation of new ones, together with the exploitation of resources (hydrological, mineral, construction materials, etc) and leisure activities, has led to the appearance of various infrastructures (housing estates, reservoirs and water channels, roads, paths and motorways, ski-resorts, recreational areas, quarries, etc) which have considerably modified the vegetation cover.

This issue, the elimination of vegetation cover, brings us to the last landscape factor to be considered: The anthropic influence. Like all Mediterranean mountains, the Guadarrama has been subject to anthropic intervention since time immemorial. This may be summarised as an economy of primary agrosilvopasture uses which is responsible, to a large degree, for the first significant changes in the landscape, transforming it from ‘natural’ to ‘anthropised’.

These changes may be described as historical and more or less gradual until the start of the 1960’s, when the large-scale expansion of Madrid began. In general, the first changes were associated with agrosilvopasture practices, whilst the second were associated with the consolidation of an urban lifestyle and the growth of secondary and tertiary activities that appeared in the rural setting due to the influence of the large city.

This whole process is now clearly visible in the landscape, with varying levels of impact: Areas where anthropic activity has largely blended in with the natural environment (copses, fertile
plains, meadows, protected countryside or areas with controlled silvicultural activities, etc) contrast with other areas which have suffered obvious deterioration (massively deforested hillslopes, large conifer plantations, urbanisation, etc) and intermediate cases (deforestation for crops and pasture meadows, small engineering works, etc).

When talking about the Guadarrama Mountains and their transformation, the main referent is the city of Madrid. Indeed, the great changes that have taken place in the mountain landscape are due to the actions of the inhabitants of Madrid (see Valenzuela, 1977).

As happened in other European mountain ranges, at the start of the 20th century, the Guadarrama Mountains began to attract many inhabitants of the large city. Initially, it was a scientific, sporting and, in general, cultural phenomenon among a minority of the population. Thus, the Friends of the Guadarrama Society was formed in 1876, promoted by its leading member, the educationalist Francisco Giner de los Ríos. The activities of naturalists, teachers, hikers and mountaineers (who were one and the same, at the time, and performed almost identical activities), coexisted with another more sedentary form of leisure, ‘summer holidays in the mountains’, from which a few outstanding detached houses or “villas” still remain today.

Following a request made by the members of the first mountaineering club created in Spain, ‘Peñalara: The Twelve Friends’ (founded in 1913), the National Parks Central Committee decided to introduce the protected status termed ‘Natural Site’ and to declare as such La Pedriza del Manzanares, Pinar de la Acebeda, and El Circo y Lagunas de Peñalara. All this took place in 1930.

After the Spanish civil war (1936-1939), these activities were forgotten, largely due to the forced absence of many of its leading figures who went into exile. During the decade of the 1960’s, due to the urban growth associated with the industrial transformation, the Guadarrama Mountains came to the fore as an environment that was located extremely close to Madrid and offered highly ‘appealing’ resources for a large city: Countryside, water, climate, construction materials, nature, etc. As a result of this new vision of territorial uses, considerable changes occurred:

- The hiking and cultural leisure activities that began at the end of the 19th century and, above all, at the start of the 20th, gave way to a massive influx of what some have scornfully called ‘domingueros’ or ‘Sunday sightseers’ (weekend visitors with a very low involvement in cultural and sporting leisure activities).

- The traditional summer villas have been ‘flattened’ to create housing complexes offering holiday homes (and also main homes, more recently), in a process by which the city of Madrid has been extended towards the mountains.

- The capital’s original water supply (the well-known ‘viajes’ of Arab origin) was replaced by an external system which transports water via the ‘Canal de Isabel II’ (whose first phase was constructed between 1851 and 1866). This canal currently has such a volume that it draws water from several hydrographical basins (Alberche, Guadarrama, Manzanares-Lozoya-Jarama) and its continued growth is envisaged (Stops 1, 2 & 3).

- Traditional quarrying (of which there remains little or very little) has given way to industrial quarrying which uses sophisticated machinery to extract large blocks.
The minority activity of early ‘skaters’, practiced on unaltered land, has given way to ski-resort infrastructures which attract a massive influx of visitors (Stop 8).

These developments, being the most significant, have considerably altered the landscape of the Guadarrama Mountains. The expansionist frenzy has been difficult to control. We need only recall that, back in 1975, the Administration drew up a Special Plan for the Protection of the Physical Environment of the Province of Madrid (Gómez Orea 1975), whose indications have barely served any purpose whatsoever. We must also point out that, despite protests from environmentalists and other citizen’s groups, new housing estates and infrastructures have been and are being built (motorways linking Ávila and Segovia with the A-6 motorway, the Madrid-Valladolid railway line, etc) and the latter involve the construction of two new tunnels through the Guadarrama mountain range (the third tunnel of the A-6 motorway and that of the Madrid-Valladolid “fast-train” which is approximately 30 km long).

With regards protected areas, there existed a considerable vacuum from 1940 onwards, due to changes in the legal and administrative system. With the enactment of the new Law on Protected Natural Areas in 1975 (the original law dated back to 1916), all Natural Sites had to be reclassified (i.e. adapted to the new law) or, failing that, removed from the list (eliminated from the network of protected areas). The latter occurred in the case of Pinar de la Acebeda, however La Pedriza de Manzanares (Stop 10) came to form part of the Regional Park of the Upper Manzanares Basin (declared as such in 1985). The process was slower and involved considerable controversy in the case of Peñalara, until the decision was taken in 1990 to create the Nature Reserve of the Peñalara Summit, Cirque and Lakes, in accordance with the new law (Stop 8).

In order to conclude this brief overview of the management of these natural areas, we must highlight that a project is currently underway to declare part of the Guadarrama Mountains a National Park.

3.2. General summary: Geomorphological and physiographic units in environmental management

The division of territories into portions or units which possess a certain homogeneity and are suitable for cartographical representation, is one of the basic working procedures of all the sciences that contain a geographical component. In association with this activity, which compartmentalises territories according to the specific methods of each thematic area of knowledge, another complementary activity appears which aims to provide a summary of the general characteristics of the environment. This involves classification by means of integrated units which are referred to, in general, as either geographical or physiographic units, depending on the degree to which elements of human (productive) activity are incorporated into their definition.

In Spain, the first physiographic classifications were carried out by Dantín Cereceda (1912) and E. Hernández Pacheco (1934) and followed the conceptual basis and procedure of those that were being developed at the time in other countries (for example, those of Salisbury, 1907, or Fenneman, 1928), even though human activities (primary land uses) have been of great importance in Spain, due to the way in which the land has been modified since time immemorial.

Following these methodologies, a new phase in the development of territorial classification began in the second half of the 20th century and the Guadarrama Mountains is one of the areas to which this was applied. The basis for classification consisted of geomorphological units and plant
formations and it was intended for use in territorial management studies that followed procedures and methods similar to those being developed at the time (see, for example, Godfrey, 1977; Christian & Stewart 1968). The structure of the classification varied according to its scale and objectives, namely: general methodological classifications (Pedraza & Garzón 1978; Martín-Duque, 1997), prospective regional classifications (Pedraza et al 1986; Martínez de Pisón 1977) and applied regional classifications (Martín-Duque et al. 2003).

Given that the objective of this excursion is to obtain a general overview of the Guadarrama Mountains and their problems, we shall present the summarised or integrated units that are of regional importance (they are applicable to the whole Guadarrama mountain range and may be correlated throughout the entire Central System) and are established on the basis of geomorphological or morphotopographical units. We will refer to these units at several stops and they are as follows (see Fig. 3):

— Summit plains
These mark one of the reference levels of the mountain landscape (the other corresponds to the piedmonts) and they form the horizon.

They have a very smooth rolling physiognomy in which smooth hills, plains and passes follow on from one another. Their average width is no more than 500 m and the absolute average height is around 2000 m, although this is surpassed by some higher massifs.

From a geomorphological point of view, they are summits which correspond to the remains of the ancient erosion plain that was raised to its current position by tectonic activity. After this geological event, which finished towards the end of the Neogene (or ‘Tertiary’) and the start of the Quaternary, the summits underwent periglacial and glacial remodelling which excavated lowland-type depressions, smoothed the rock, exaggerated certain passes and contrasted certain outcrops.

The anthropic modifications introduced on these terrains have, to all extents and purposes, been minimal. The typical environment is an attenuated nival environment, with grass ground cover (above all on the mountain passes), gelifraction and gelifluction lithosols and some boulders. What are particularly significant, and serve as good indicators to be taken into account when establishing the current activity of periglacial processes, are the forms (stone garlands, terracettes, stone micro-polygons, stone grooving) that are visible in the proximities of Pico de Peñalara and its southwestern slope, towards Dos Hermanas, at heights of over 2100 m.

— Intermediate high plateau plains and associated topography
This unit appears in different situations. In the most characteristic example, that of Llanos de la Morcuera, it is a high plateau or plain adjoining the voussoir at mid-slope. In some cases, it forms the highest point of rather isolated hills, such as Cabeza Mediana, and in others it forms the culmination of blocks that create dividing ridges or ranges on a smaller scale than those defined by voussoirs (a good example is the Espartal-Cachiporrilla ridge). Lastly, they may be reduced to lesser benches which appear mid-slope to form mountain shoulders, spurs, etc.

Their absolute average height varies between 1400 and 1800 m, depending on the sector in which they are located. Like the summit unit, they also have a very smooth rolling physiognomy, as they
are the remains of an ancient peneplain that has been lifted to its current position by tectonics. Despite such similarities, it is very clear that they constitute plains (high plateaux). This geomorphological characteristic has conditioned the anthropic use of the sites: It is on this land that the region’s largest human settlements have been established (towns, residential areas or agricultural and cattle-farming activities) and they were traditionally used for cattle-breeding purposes, making use of the numerous meadows that are to be found in the depressed areas (lowlands), in which it was difficult for woodland to survive (or the creation of meadowland through deforestation was very easy). These circumstances, together with the practice of charring (the manufacture of charcoal) meant that deforestation was intense. Some of these areas have subsequently been reforested with various pine species.

An important point to highlight is the similarity between these plains and the piedmonts. They consist of benches which are often located at the foot of scarp slopes and, as a result, the latter have provided and still provide them with recent discharge materials (alluvial, colluvial or mixed surface formations) which allow the development of deep soils that are suitable for farming. This is what has allowed human settlement and the development of a productive system characteristic of Mediterranean mountains, namely the agrosilvopasture system.

Lastly, as one would expect of a high plateau, it has an extremely harsh climatic environment which is cold and highly exposed to wind action and frost cycles.

— Hillslopes

These are scarp slopes which link the aforementioned plains with each other and the piedmont. Depending on the development of the intermediate or high plateau plain, the hillslope forms a continuous or almost continuous scarp slope (only interrupted by benches and mountain shoulders) or two clearly separated scarp slopes (upper and lower slopes). In the first case, the scarp slope may have a length or height difference of over 1000 m (from 1000-1100 m at the valley bottom to 2000-2200 m, or even 2400 m, at the peaks). In the second case, the height difference is around 300-400 m on the upper slope (this can sometimes reach 500-600 m, as in the case of the Peñalara Massif) and 600-700 m on the lower slope.

As is normal on any mountain slope, there exists an altitudinal zoning of the environments to be found along its length. As far as geomorphological processes are concerned, one could say that in the upper section there is an attenuated nival dominion which favours rill wash (one of the most significant erosive features in places where imbalances may be caused by anthropic action), as well as mass movements of flow (debris-flow), solifluction (or gelifluction) and rock fall from the scarp slopes and cuts in the rock walls of ancient glacial basins. In the intermediate section, fluvial incisions predominate and, given the terraced morphology which allows stabilisation benches, this is where one may find colluvial and glacial accumulations (tills or moraines), lowland bottoms and peat depressions on ancient glacial beds, etc. In the base section, the fluvial incisions are much clearer and, for this reason, there exist many gorges. However, it is above all characterised by having a foot or base at which protalus ramparts (colluvions) and fluviotorrential discharge fans or cones are generated.

Plant serialisation is defined by the criò, oro and supramediterranean belts (see Fig. 6). Extensive cattle-farming and forestry are the most common primary uses and in certain places there are expanses of forest which have been fairly well preserved (for example, the pine forests of Valsaín
and Rascafria, **Stops 6 & 7**). However, deforestation has been intense in the areas where said activities have been inappropriately managed.

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**Piedmont plains**
These form the base for elevations and may be divided into two types:

- **Depressions.** These are intermountain valleys and their foundations consist of a plain that may have developed on base materials, Mesozoic and Cenozoic (Palaeogene and Neogene) sediment cover or a mixture of the two (part base materials and part cover). In all cases, there exists a large quantity of recent deposits (Quaternary surficial deposits) and alluvial formations tend to dominate. This abundance of alluvial formations which are suitable for agricultural use, combined with the morphology of the terrain and less extreme climatic conditions, have meant that the depressions have been extensively colonised. In general, there are many lowland areas, ash woods or copses, sometimes highly fertile plains which are devoted to pasture meadows and even horticultural crops. In recent years, these activities have been displaced by those associated with urban development and leisure activities (**Stop 8**).

- **Ramps.** These form the transition between the mountain ranges and the basin plains (Duero and Tajo basins) and therefore have varying features. In general, they are erosion plains (either recent or exhumed) established on base materials. At their internal borders (adjacent to the hillslope), they converge with intermountain piedmonts: They have a milder climate and there are many forests, lowlands and ash woods, which make forestry and cattle-farming possible. The external borders (in contact with the basin) converge with the basin plains or external basins: the climate is warmer and drier, with highly marked seasons and low water periods, and dry farming is frequent (cereals, fruit trees, vines, etc) (**Stops 1 & 5**).

### 4. **STOPS**

As indicated in Section 1, the itinerary has been organised with the objective of giving an overview of the geomorphological characteristics and environmental problems of the Guadarrama Mountains (Fig. 7). We also consider it interesting to give certain explanations during the journey from Zaragoza to the Guadarrama Mountains (this will help us to situate the Central System in relation to other geological units in the Iberian Peninsula) and also during the journey from the Guadarrama Mountains to the city of Madrid (in this case, we will observe the scope of the metropolitan area, due to the expansion of the city of Madrid). Information regarding these routes and further complementary information about some of the stops made during the excursion (historical or detailed facts about infrastructures and monuments, complementary maps and graphs, official leaflets on protected areas, etc) will be given to the participants during the excursion.
Figure 7.- Schematic lithologic map of Guadarrama Mountains and nearby basins (Duero and Tajo) showing the itinerary and stops.
Legend: 1, Roads; 2, roads’ fieldtrip route, 3 to 9 they are the location of the stops; 3, cities.
- Lithology of the basins (Duero, Tajo and intermountain basins): 4 and 5, fluvial deposits (alluvial plains and terraces; Quaternary); 6, piedmont fan deposits (alluvial conglomerates; “raña” fanglomerate, upper Pliocene to young Pleistocene); 7 debris alluvial fan deposits (proximal, middle and distal alluvial fans facies; upper Paleogene to Middle Pliocene); 8 chemical and evaporitic playa-lake deposits (upper Paleogene to Middle Pliocene); 9, fluvial and lake deposits (conglomerate, sands and marls; Paleogene); 10, fluvial and marine deposits (sands, marls, limestone and dolomite; Upper Cretaceous).
- Lithology of the massif (Guadarrama, Somosierra and Santa María de Nieva): 11, granitic rocks (Carboniferous); 12, metamorphic rocks (quartzite, slate; Ordovician-Silurian-Devonian); 13, metamorphic rocks (gneiss, schist; Cambrian-Precambrian).
4.1. **Stop 1: Guadarrama mountain and Tajo basin.**

- **Location:** The observation site is located at the 34.8 km point on the road from Guadalajara to Torrelaguna (CM-1002); in geological terms, we are on the Northern border of the Tajo Basin (hydrographic sub-basin of the Jarama River) on a “raña” plain.

- **Aspects to consider:** General appearance of the Guadarrama Mountains and their topography, observation of the orographic and physiographic units in this transition zone between the Guadarrama and Somosierra Mountains; characteristics of the southern ramps; characteristics of the southern Cenozoic basin or the Tajo Basin and sedimentary sequences in this area; types of contact between the Ancient Massif and the Cenozoic basins; infrastructures for supplying water to the city of Madrid.

4.1.1. **The Guadarrama Mountains**

The main objective of this stop is to present the geographical, geological, geomorphological, scenic and environmental characteristics of the Guadarrama Mountains. As described in Sections 2 and 3, the Guadarrama Mountains form the central-eastern sector of the Central System; an intraplate mountain range which originates from the tectonic reactivation of an Ancient Massif during the Alpine Orogeny (see Fig. 1). Its morphostructure is typical of a **block mountain** (a *pop up* and *pop down* system) with a Germanic or Apalachian physiognomy and is organised into a system of piedmont stairways (*piedmonttreppen*), which provide the referential basis for classifying the topography and establishing the main physiographic units; units which are defined by also taking into account recent morphological sculpture and other environmental aspects such as natural vegetation, land use, climatic processes, etc (see Section 3.2).

4.1.2. **Transition topography between the Ancient Massif and the Sedimentary Basin: ramps in the Cabrera Mountains and at the northern edge of the Tajo Basin.**

**The ramps or southern piedmont of the Cabrera Mountains**

The topography of the Cabrera Mountains is formed by a granitic **stock** embedded in metamorphic materials (gneisses and schists) by two phases of magmatic intrusion and is composed of biotitic granites (first intrusive phase) and leucogranites (second intrusive phase) (see Figure 2 and Section 4.10, which describe the Hercynian plutonism of the Central System in greater detail). The southern ramp, which we can see, shows all the features of a surface exhumed by etchplanation and later compartmentalised by tectonics and modified by other geomorphological processes. The signs of this sequence are: greater residual relief of the **inselberg** type, already indicated by P. Birot (1937) as one of the characteristics that differentiate the surface of piedmonts or ramps from that of higher plains; fault-line scarps which form the slopes of this topography and its contact with the piedmont; and lesser residual relief, in terms of position and resistance, due to subsequent morphological sculpture cycles during which different erosion levels were caused (**pediment** or **glacis** benches and lowland depressions).

**The Tajo Basin**

The Tajo Basin is one of the great Cenozoic sedimentary basins of the Iberian Peninsula (see Fig. 1), formed during the tectonic reactivation of the Peninsular’s interior terrain. During that period, it behaved like an “intermountain endorreic basin” with a subsidence process that was...
contemporary to the “uplift” of the surrounding topography (Central System, Toledo Mountains, Iberian Mountain Range).

The main subsidence phase occurred during the course of the Miocene (arkosic cycle) and, during this period, the basin accumulated the materials that were deposited by the alluvial fans systems of the surrounding elevations, then subject to an etchplanation process. The sedimentation process expanded over the Massif and features a serialisation that is typical of alluvial fans-playa lake sedimentary systems. From the borders or Massif contact area (where the tips of the emerging fans were located) to the centre of the sedimentary basin (where ephemeral lakes appeared) one may observe a transition in the facies. These are, very briefly, as follows: proximal (thick detrital deposits with abundant large block formations revealing the presence of high density flows or mud flow), middle (detrital deposits of fluvial currents in which braided channels predominate), distal (fine detrital facies with abundant edaphized levels, high secondary clay content and the intercalation of chemical and evaporite facies; these are essentially flood plain and channel-fill deposits) and playa-lake (chemical and evaporite facies characteristic of sedimentation in temporary lakes); it is these materials that filled sedimentary basins to form sedimentary plains. Their subsequent evolution corresponds to the post-arkosic cycle during which two main processes stand out: new tectonic pulsations which raise the Massif’s axial blocks, create new intermountain depressions, deform the sedimentary plain and shift the plateau towards the west, and the gradual definition of present-day fluvial networks which start off highly dispersed, generating piedmont plains on the Massif and correlative plains in the Sedimentary Basins (these are the M₂ and M₁ plains; see Sections 2.2 and 2.3) and end up being hierarchical, creating fluvial incisions and terracing systems.

The 1st stop is located on one of the borders of the Tajo Basin and is, therefore, in the area in which alluvial fans emerged during the main phase of the tectonic reactivation of the Central System’s topography. They are, therefore, proximal facies composed of conglomerates of large blocks and an arkosic matrix (lythic sand with different facies, depending on whether the original area was of granitic and gneiss or schist and slate materials). What is interesting about this observation point is that, together with formations that were contemporary to the main phase of uplift-subsidence (arkosic cycle), there are also formations from the previous period and its transition to the main period (pre-arkosic cycle) and from the subsequent period and the transition to said period (post-arkosic cycle) (see Sections 2.2 and 2.3). There are obvious signs by which to recognise these phases and formations on the terrain: Type of contact, unconformity between different sedimentary formations, planation surfaces and detailed morphology (slope system, badlands, gorges and fluvial terraces, etc) (Fig. 8).

4.1.3. Anthropic activity: Water supplies for the city of Madrid

The city of Madrid was traditionally supplied with water by means of a catchment system formed by underground galleries which were channelled to public fountains (locally referred to as ‘viajes’) and dated from the Arab period (11th century). This system was gradually replaced (some of the old fountains continued to function until the middle of the last century) by the current channel system which transports water from the rivers that drain the Guadarrama Mountain region.

The first infrastructures of the new supply system were built between 1851 and 1866 and consisted of the Pontón de la Oliva reservoir on the Lozoya River and the corresponding channel by which water was diverted to the city of Madrid, which had a population of 240,000 inhabitants.
at the time. The first fountain in Madrid to be supplied by the new system was inaugurated in the year 1858. These infrastructures were called the “Canal de Isabel II”, in honour of the then Queen of Spain, and this name was adopted by the company entrusted with the task of managing Madrid’s water supplies (Stop 2).

Since then, the reservoir and channel system has continued to grow and currently supplies a population of around 6 – 6.5 million people (Madrid City, the surrounding metropolitan area and other municipalities within its sphere of influence). This volume of water requires the collection and diversion of water flow from several river basins which originate in the Central System (the Alberche, Aulencia, Guadarrama, Manzanares, Guadalix, Lozoya and Jarama rivers), with a network of hundreds of kilometres of interconnected channels and 13 reservoirs. The El Atazar reservoir marked a notable change in the supply process for Madrid, due to its technical and political significance (Stop 3).

4.2. Stop 2: Pontón de la Oliva Dam
-Location: This observation point is located in the small gorge that is formed where the Lozoya River meets the Tajo Basin.
-Aspects to consider: The main objective is to observe the Pontón de la Oliva reservoir, its engineering characteristics, history and geomorphological environment.

The Pontón de la Oliva dam consists of a gravity wall which is founded on Cretaceous materials (dolomites and sands) and constructed using masonry materials (stone). It is 72.4m long, stands 31.3m high, as measured from the base of the foundations, and the reservoir has a capacity of $3 \times 10^6 \text{ m}^3$.

The dam took four years to build (from 1851 until 1855), however it took another three years (until 1858) to seal the bottom as water loss made it impossible to fill the reservoir. As part of the waterproofing work, a 50 metre-wide and 35 metre-deep ditch was dug, involving 1700 labourers (1500 of whom were convicts) working full days (day and night). The objective was to seal all the galleries of the karstic dolomite system (a system which included the El Reguerillo cave, in which a great deal of vertebrate fauna from the Pleistocene has been found). Despite this work, they never succeeded in sealing the terrain well enough in order for the reservoir to function and it was therefore decided that two small retaining structures (the Navalejos and La Parra reservoirs) would be built upstream of the Pontón de la Oliva dam, on the Massif (on slate substratum from the Middle Ordovician), and these were used to provide the first water supplies to Madrid.

4.3. **Stop 3: El Atazar Dam**
-Location: The observation site is located at the 14.5 km point on the local road from Torrelaguna to El Atazar, on the Ancient Massif.

-Aspects to consider: The main objective is to observe the El Atazar reservoir and its engineering characteristics; also, the geomorphological setting of the transition topography between the Guadarrama and Somosierra mountains.

The El Atazar reservoir is located in the mid-section of the Lozoya river gorge, on the limit between the Buitrago depression and the ramps of the Somosierra Mountains. The dam (or reservoir cut-off wall) stands on metamorphic materials (slate from the Middle Ordovician) and has a double-curved vault. It is built of concrete and has the following dimensions: Width 7 m (at the top), 36 m (at the base) and 45 m (at the foundations); height 134 m (from the base to the foundations) and 128 m (from the riverbed); length 484 m (at the top) and 150 m (at the base).

The reservoir has a capacity of $426 \text{ hm}^3$, which represents 46% of the overall capacity of the reservoirs located in the Region of Madrid and 20% of the capacity of all the reservoirs that supply Madrid. At its maximum level, it covers a surface of 1069 ha and is 17 km long. The construction of the reservoir (the work began in 1965 and ended in 1972) suffered many technical problems due to the instability of the hillslope material upon which the dam supports rest. Given the fact that it was to be built upon highly fractured slate and the supports in this kind of vaulted design must bear a considerable load, the technical recommendations favoured the creation of a smaller reservoir with a normal or gravity dam. However, those in charge wanted to carry out a construction project that would have a considerable political impact: They were aiming to supply Madrid’s water needs until the year 2000, in other words, for a city that would almost double in population.
Given these problems, the reservoir has never been subjected to its maximum stress level (100% of its load capacity) and its performance has been tested over the years by gradually increasing the maximum load as recommended by experts and according to new control and stabilisation techniques. The maximum volume of water retained represents 92% of its capacity and was reached for the first time in 1990.

4.4. **Stop 4: Geomorphology of Segovia city**

-Location: The city of Segovia, in the contact area between the Ancient Massif (Guadarrama Mountains) and the Sedimentary Basin (the Duero Basin)

-Aspects to consider: A route which observes the setting of the city of Segovia and relates its position to the geomorphological and physiographic characteristics of the area.

The city of Segovia stands in the contact area between the ramp or southern piedmont plains of the Guadarrama Mountains and the structural topography of the Mesozoic and Cenozoic covers. The type of contact that exists between these two formations is similar to that observed in the Pontón de la Oliva area (Stop 1-b2; see Fig. 8): the Mesozoic formations (from the Upper Cretaceous) and part of the Cenozoic formations (from the Lower Palaeogene) appear folded due to basement complex faults and they form monocline knee fold structures and box folds which originate structural platforms in the highest zones. The historical (ancient) settlement of the city of Segovia occupies one such platform which was isolated and came to form a small tableland limited by the gorges of the Eresma and Clamores rivers (cataclinal consequent valleys) and the depression at the edge of the Massif. This depression is a morphotectonic mountain range caused by the differential erosion of the hydrographical network along one of the contact faults between the crystalline materials and their sedimentary cover (orthoclinal subsequent depression). In order to overcome this depression and carry the water supply channel from the Guadarrama Mountains to the city of Segovia, an aqueduct was constructed during the period of Roman colonisation. This structure was built using carved granitic stone, without cement, and was carried out between the end of the 1st and the start of the 2nd century A.D.

4.5. **Stop 5: Physiographic units at the Segovia area of the Guadarrama Mountains**

-Location: In the municipality of Zamarramala, 1 km from the city of Segovia, on a platform of Mesozoic border terrain.

-Aspects to consider: View of the ramp or piedmont and the physiographic units of the northern slopes of the Guadarrama Mountains; overall view of the city of Segovia, concluding the observation of the previously-mentioned aspects of its location (Stop 4).

4.5.1. **The Segovia ramp or piedmont**

Compared to the La Cabrera ramp that we saw in Stop 1, the Segovia ramp is notable for the absence of greater residual relief and its contact with the mountain scarps or fronts is gentler. These morphographic features are signs which must be taken into account but they, alone, are not sufficient to establish genetic differences between the two ramps, above all if we consider that the dominant materials here are high-transformation metamorphic rocks (gneisses and schists), whilst it is granitic rock that dominates on the La Cabrera ramp. However, there are two facts which allow the ramp of Segovia to be presented as an example of a “terrain fossilized by Neogene sediments and subsequently exhumed”, namely the presence of the remains of Neogene arkosic material cover on some points of the ramp; the morphographic relationship of the erosion levels
present in the Sedimentary Basin and the Ancient Massif; and the type of contact in nearby eastern areas where the Mesozoic cover materials (sandstone and dolomite formations from the Upper Cretaceous) continue almost to the very slope of the elevations, forming cover piedmonts with a topography of structural tablelands, hills and platforms.

4.5.2. The physiographic unit of the northern slopes of the Guadarrama Mountains
With regards general topography, we can see the northern voussoirs of the Guadarrama Mountains (see Figures 3 and 5) defined by the Carpetanos Mountains (Pico de Peñalara, 2429 m) and the Quintanar Mountains (Osos, 2196 m) which mark the summit level. Next to them, we can see the secondary mountain range of Cerro de las Cardosillas (La Atalaya, 1647 m) and the subsidiary range of Matabueyes-La Camorquilla (Alto de la Camorquilla 1662 m) which mark the M3 plateau level. The physiographic units of the area are arranged around these topographical elements, as described in the corresponding section (see Section 3.2).

In addition to the traditional human activities (agrosilvopasture) that have modified the landscape (most notably through the transformation of forests into farming land and meadows), we must now also mention those due to the expansion of urban settlements (particularly the city of Segovia), water supply infrastructures and communication routes (new reservoirs, motorways and high speed railway).

Landform-based physiographic maps, also called land system inventories, have been widely and successfully used in undeveloped areas in several locations, such as Australia, Western United States, Canada and the British ex-colonies. In 2000, we developed a landform-based ecologic inventory for the land use planning of the Segovia area and its surroundings (Martín Duque et al. 2003). The study focused on the information transfer process, showing how land use decision-makers can use the information developed from these maps to assist them (see Section 3.2).

4.6. Stop 6: Landscape of La Granja municipality and Valsaín valley
-Location: The municipality of San Ildefonso-La Granja, located at the 121 km point on the CL-601 road and right in the contact area between the hillslope and the northern piedmont of the Guadarrama Mountains (Segovia ramp).

-Aspects to consider: Visit to the landscaped complex of the Royal Summer Palace and a presentation of the route towards the El Paular Valley, following the mountain slopes of the area.

4.6.1. La Granja palace and gardens
The name of this municipality (literally ‘The Farm’) originates from an old farm that monks of the Order of St Jerome owned in the town. Felipe V, the first Spanish king of the Bourbon dynasty, bought the aforesaid farm from the monks and ordered a palace and gardens to be built in 1721. Following this, the enclave was used as a summer residence by all his successors until Alfonso XIII.

The gardens of the La Granja Royal Palace were created in the style of those of Versailles and are one of the best remaining examples of 18th century ‘formal’ gardens. They consist of flower beds and copses that are delimited by plant walls and integrated into a setting that is dominated by oak woods and Scots pine forests, with a gradual transition between two highly different natural landscapes.
4.6.2. The Valsaín valley
The Valsaín valley constitutes one of the most emblematic areas of the Guadarrama Mountains due to its landscape and history. An important Roman road ran along its entire length (this is still visible in certain sections) and, in 1552, Prince Felipe ordered the construction of the first palace to be built in this area, although it was later destroyed by a fire in 1682, thereby prompting the construction of the palace that now stands in La Granja.

The landscape is dominated by magnificent oak and Scots pine forests and the organised exploitation of wood resources in this area dates back to the Middle Ages. In 1761, Carlos III acquired the Scots pine forests and lands of Valsaín for the crown, with the aim of controlling the management of this area and supplying fuel to the royal factories in La Granja. In 1987, the forest was declared an Important Bird Area (IBA), due to the presence of large birds of prey, some of which are in danger of extinction (e.g. the Iberian Imperial Eagle). Since 1995, the area has been managed by the National Parks organisation, giving rise to a unique situation in the Spanish state. In the near future, this magnificent pine forest will become one of the areas of greatest environmental interest in the Guadarrama National Park.

4.6.3. Sheet erosion rates determined by using dendrogeomorphological analysis of exposed tree roots
The recreational activities carried out in certain parts of the pine forest (Boca del Asno, Senda Schmidt) have accelerated soil erosion processes (trampling by continuous trekking), resulting in exposed roots. In order to evaluate this process, we are carrying out several studies based on the morphological pattern of roots, defined by the growth ring series of the sampled roots (Bodoque et al. 2002). In order to make the estimations of erosion more accurate, several anatomical indicators were characterised of exposed and non-exposed roots. These indicators included changes in the microscopic structure of Pinus sylvestris roots (tracheid, rings and resiniferous channels). The study entailed a statistical analysis of exposure time and erosion depth. The influence of environmental factors affecting the velocity variation of the erosion processes was also examined. With a significance level of 95%, the mean erosion rates ranged from 1.7-2.6 mm/yr (29-44 t/ha/year) on a popular trail within the Valsaín Forest, the Senda Schmidt, over the last 101 years. Using a multifactor analysis of the variance, we observed a change in the erosion rates as a function of position on the path along Senda Schmidt, with higher rates closer to the parking lots.

4.7. Stop 7: The intermountain depression of the El Paular
-Location: Los Robledos viewpoint in the El Paular or Alto Lozoya depression.
-Aspects to consider: Characteristics of this intermountain depression and the southern slopes of the Carpetanos Mountains.

Throughout the length of the Central System, there are a series of “valleys” (see Fig. 3) which are associated with the main faults. They are of different types, sometimes mixed, but can nonetheless be summarised as follows:

- **According to physiognomy.** Some are long and narrow valleys following the route of the main fault, to which their slopes lie parallel (these have been called “fracture corridors”, Pedraza 1978); others have a wider and more irregular bottom, with a geometrical form that tends towards rhombic and slopes that are associated with two or more important fault systems (these have been called rhombus-grabens; Portero & Aznar, 1984).
According to position. Some are located in the interior of the Ancient Massif, limited by elevations, and are, therefore, true “intermountain valleys”. Others appear on the edge of the Ancient Massif and are associated with the ramps that define the transition towards the basins or pits that limit them (those of the Duero and Tajo rivers), with which they may have a certain degree of connection.

According to evolutionary history. These include two basic groups: The valleys at whose bottom or base there are sediment covers that correspond to the “arkosic cycle” (Oligocene-Miocene) and which, therefore, functioned as sedimentary basins during the tectonic reactivation of the region; and the valleys which do not have such covers and must be considered as recent tectonic depressions (originated during the post-arkosic cycle).

As far as the origins of these valleys are concerned, they have traditionally been interpreted as grabens, in other words, sunken blocks along normal faults in the distensive phases that alternated with compressive phases during the stages of tectonic relief reactivation (Hernández Pacheco 1923; Solé Sabaris et al. 1952; Birot & Solé Sabaris 1954). Over the years, it has been shown that block tectonics is more complex and, together with the subsidence caused by normal faults, one must also consider the subsidence that is associated with strike-slip faults and reverse faults (Carrasco and Pedraza 1991; Carrasco 1999). Some of these depressions have been interpreted as “pull-apart” basins (Capote et al. 1996).

Given the importance of reverse faults and low angle overthrusts along the limits of the Central System and many intermountain basins, Riberiro (1984) and Warburton & Álvarez (1989) proposed a model which explains the geological structure of the Central System as a “pop-up” (double vergence intraplate chain) in which the basement complex appears involved in the deformation (a tectonic movement with crust overthrust transferred from the active collision edge between the African and Iberian plates). This is currently the preferred explanation (see De Vicente et al., 2004) and all negative topographical features (valleys or depressions) are therefore catalogued as “pop-downs”.

The site that we are visiting, the Alto Lozoya or El Paular Valley, presents all the characteristic features of an intermountain basin: It is confined between surrounding elevations, its physiognomy is rhombic, it is controlled by two large fault systems (the northwestern fault of the Carpetanos Mountains and the southeastern fault of the Llanos de la Morcuera plateau) and it presents Mesozoic and Cenozoic sedimentary covers (including recent coverings from the Quaternary period), which indicate prolonged subsidence (Fig. 9).

4.8. Stop 8: The Peñalara Natural Park
-Location: Puerto de Cotos at the 40.7 km point on the CC-6004 road.
-Aspects to consider: Visit to the Peñalara Natural Park Interpretation Centre.

The Peñalara massif is the highest feature in the Guadarrama Mountains and presents outstanding glacial morphology (cirque, lakes and moraine complexes) which are of considerable educational and scenic value (see Section 2.3.2). Both attributes have made this one of the most highly-valued sites in the Guadarrama Mountains, in both cultural and scientific terms and, for this reason, it was included in the network of Protected Natural Areas in 1930 (see Section 3.1).
Figure 9.- Schematic map showing the recent deposits (Quaternary) in the intermountain basin of “El Paular or Alto Lozoya Valley”. The image located in the bottom right of the figure is a hillshading digital elevation model of the valley. Legend: 1, rivers and streams; 2, main orographic alignments (shown by the divides); 3, “glacis” deposits (early Pleistocene); 4, glaciated morphology (Upper Pleistocene); 5, fluvial deposits (alluvial plain and terraces; Quaternary); 6, torrential fans (Pleistocene); 7, debris and talus slopes (periglacial formations; Quaternary); 8, debris-mud cones (periglacial formations; Quaternary). In the hillshading digital elevation model, the underlying pre-Quaternary sediments are shown: 9, Paleogene and Miocene, 10, Upper Cretaceous; the Pinilla dam appears in white colour.

This protected area found itself in an uncertain situation due to the modifications that were made, over the years, to the regulations governing the conservation of unique areas and the proliferation of infrastructures aimed at promoting leisure activities. After several years, controversy between conservationist groups and the promoters of leisure activities (in particular ski-resort developers), the area was reclassified according to the new protection regulations (it was declared a Natural Park in 1990) and later (in 1999) the administration bought the ski-resort land from its owners and decided to dismantle the infrastructures in order to restore the environment. This process is still underway today (see Vielva et al., 2004).

All the aforementioned aspects, together with the geological, geomorphological and botanical characteristics, are reflected in the interpretation centre, which we shall visit, and they will be discussed during the stop.
4.9. **Stops 9a and 9b: The use of granitic stone in buildings and monuments; the Monastery of San Lorenzo de El Escorial and the Basilica of Cuelgamuros Valley (also called the “Valley of the Fallen”).**

The use of granitic rock as a building material in the Guadarrama Mountains dates back to the prehistorical times of human settlement (monuments, refuges and towns). We have seen the Roman aqueduct of Segovia that dates from ancient times and here we have the monument of San Lorenzo, which is an outstanding example from the Modern Age, and the Valley of the Fallen, which represents the current phase.

As far as the granite stone-working and extraction industries are concerned, they followed a parallel development until a few years ago. Initially, the use of these materials was limited to the local and regional sphere, with tradition exploitation methods. This productive sector remained so until the second half of the last century, when it almost disappeared and was subsequently transformed into a highly technified industry which markets the material as an ornamental stone and exports it to several countries.

4.9.1. **Stop 9a. Monastery of San Lorenzo de El Escorial**

Located in the town of El Escorial, the Monastery of San Lorenzo is a monumental building constructed of carved granitic stone which follows the design of Castilian fortresses (rectangular floor plan with four towers, one at each corner) with various styles: The general decoration is neoplatonic, the adjoining palace is Renaissance in style and the church is Tuscan and Doric. The construction work began in 1562 under the orders of the architect Juan Bautista de Toledo (who was a disciple of Miguel Angel during the construction of St. Peter’s Basilica in The Vatican) and it was continued and finished in 1584 by the architect Juan de Herrera, famous for the construction of numerous churches.

The monument was built upon the orders of King Felipe II (1527-1598) and it is officially considered to commemorate his victory in the battle of San Quintín, which took place on the day of St. Lawrence or ‘San Lorenzo’ (10th August 1557). The monument also has significant religious and dynastic connotations: It is a monastery, place of worship, royal burial place, library and school.

4.10.2. **Stop 9b. The basilica of the Valley of the Fallen**

Located in the Cuelgamuros Valley, not far from El Escorial, the monument of the “Valley of the Fallen” (or The Holy Cross of the Valley of the Fallen) is a building constructed on a granitic rock hill. It has a castle-koppies form of residual topography which developed upon the central nucleus of a small stock of late injection Hercynian leucogranites and is therefore similar to what we will see at the next stop, in La Pedriza de Manzanares (see Stop 10).

The construction consists of three fundamental elements: a basilica excavated into the rock, a construction in the form of a cross, located on the top of the hill, and a rectangular building which contains a monastery and lodgings, linked by a central arcaded square. The basilica occupies the main front area and the monastery occupies the rear and the two are connected by an interior passageway or tunnel excavated into the rock. The cross is centred on the dome of the basilica which stands above the alter and there are chapels with funeral crypts on both sides.
The monument was built between 1940 and 1959, during the dictatorship of General Francisco Franco. In order to justify this colossal project, its promoters claimed that it would be a pantheon and monument to all the combatants of the Spanish Civil War of 1936-1939, regardless of the side on which they fought. However, it was surrounded by controversy from the very start, due to both the involvement of political prisoners in its construction and its ideological significance. Indeed, the basilica contains the tombs of both the dictator, Francisco Franco, and the founder of the Spanish Falange, José Antonio Primo de Rivera. It is also true that it contains the remains of around 40,000 combatants of the Spanish Civil War, almost half of whom fought on the “Republican” side (the term used to refer to those that defended the then legally-constituted government).

4.10. Stop 10: The granitic landforms of the La Pedriza de Manzanares

-Location: La Pedriza de Manzanares is located on the southern slopes of the Cuerda Larga Mountains, one of the main ranges in the Guadarrama Mountains (see Fig. 5), next to the municipality of Manzanares el Real; The observation point is located on the Quebrantaherraduras mountain pass, which can be reached by following the road that runs through the Natural Park.

-Aspects to consider: Observation of the granitic morphology of the environment; the stock of La Pedriza within the context of the great granitic batholith; the genesis of its topography and characteristic shapes.

La Pedriza de Manzanares is one of the 100 intrusive units that constitute the great batholith of plutonic rock (with a surface area of approximately 10,000 km²) of the Gredos and Guadarrama mountains, which occupied the site during the Hercynian (or Variscan cycle) in a series of phases which lasted around 40 Ma (see Fig. 2). Three main intrusive phases have been established: an “early” phase which was contemporary to the ductile tectonic deformation stage (sin-cinematic granitoid rocks) and took place between 340-315 Ma BP, a “fundamental” phase which created the most important plutonic mass and was contemporary to the late fragile tectonic deformation stage (late-cinematic granitoid rocks) which took place between 315-298 Ma BP and, lastly, a “posthumous” phase which generated various, disperse stocks in the frontal mass and is clearly subsequent to the main tectonic deformation phases (post-cinematic granitoid rocks) and took place between 298-280 Ma BP (Villaseca & Herreros 2000).

Granitoid rocks predominate in this batholith (gabbroids and intermediate composition rocks are rare) and the original magmas are considered to be the result of a partial fusion of crust materials or a hybridisation between this process and magmas derived from the mantle (Villaseca & Herreros, op. cit.) The main intrusive units are composed of monzogranite rocks (or adamellites) and constitute 75% of the granitoid rocks of the Central System. Locally, they form granodiorites which represent 9% of the granitoid rocks of the great batholith. Lastly, leucogranites also appear as small units (stocks) which intrude in the other granitoid rocks. These represent 16% of all the rocks of the great batholith. As stated earlier, La Pedriza de Manzanares is one such stock.

Due to its geological characteristics, three material types are present in La Pedriza de Manzanares (see Fig. 2): gneisses from the pre-Cambrian age, which produce, in this case, the formation that is intruded by the great plutonic mass; monzogranites and granodiorites which are the intrusive rocks located upon the aforesaid layer and positioned during the batholith’s “fundamental” phase; and lastly, the leucogranites which appeared during the posthumous phases and intrude into the two aforesaid formations. It is these leucogranites that form the stock and define the characteristic topography of the area.
La Pedriza de Manzanares can be defined as a characteristic granite landscape and has benefited from official protection since the year 1930, when it was declared a Natural Site of National Interest, and 1978, when it was reclassified as a Regional Park. Despite this, there are few specific studies of the granitic morphology of La Pedriza. To be precise, we can name only five studies on this subject: Fernández Navarro (1921), Carandell (1928), F Hernández- Pachecos (1931), Sanz Herraiz (1976) and Pedraza et al. (1989).

The general complex of the La Pedriza stands on the slopes of the main block of the Cuerda Larga Mountains and forms a series of step slopes tilted towards the north, following a joints-fault system whose orientation follows this direction and a vergence which is opposite to that of the faults that limit the large topographical blocks. One of these faults divides the massif into two sectors, whilst the other limits its southern face. The joints-fault system introduces a compartmentalisation of the massif and gives it a macromorphology that consists of large cupolas which are separated from each other by narrow depressions (locally referred to as ‘alleys’ and ‘corridors’). Each of these cupolas presents an individual domed shape, both at its summit and on some of its sides; the general asymmetry of the topography and the greater or lesser erosion of these forms has created a variety of domed shapes (vault, bell, whaleback, tile, etc). In areas where fine grain materials are plentiful (aplitic-granitoid rocks), a vertical jointing tendency predominates and the domed shapes are replaced by castle-like forms or “sharp crests”.

If one considers the main forms that are present in La Pedriza and some of the main genetic factors that control them, it is possible to perform a correlated classification, as shown in Fig. 10.

The above classification must be understood as an initial indicative level, since the genesis of these forms is complex and one must also include the whole range of lesser forms that have been described in the specialized literature (pits, gnamas, pseudokarstic micro-relief, tafoni, rille, etc.; see Twidale 1982; Vidal Romani & Twidale 1998). In order to explain its genesis, and regardless of subsequent evolution, one must take into account that in the dominion of the Central System (and that of the Hesperian Massif, in general) a series of phases involving the exhumation-weathering of etch-topography have followed on from one another during the course of the Mesozoic and Cenozoic periods. As far as weathering is concerned, a brief study of this kind of process, according to the secondary clay minerals that are most abundant in each phase, has established the following sequence of regoliths (Centeno, 1987): kaolinite (pre-upper Cretaceous), interstratified smectite and illite-kaolinite (post-middle Palaeogene), smectite and some illite (pre-Miocene), limited illite and scarce presence of kaolinite and smectite (post-Miocene) and illite and kaolinite (Pleistocene). Of all these weathering phases, the one that is recognised as being of greatest importance and intensity is the first, which generated kaolinitic regoliths in warm, humid environments (see Molina & Blanco 1980; Molina 1991). With regards the phases of etch topography exhumation, the most important phase has been repeatedly mentioned in this guide (see Section 2.3.1) and corresponds to the so-called “arkosic cycle” (from the Oligocene to the Pliocene) during which the etchplain of the Central System piedmonts was generated. Nonetheless, the exhumation of “etch-landforms” has been an active process during the “post-arkosic cycle” (the Pliocene to modern day) in areas which have a Mediterranean climate. On the ramps of the Central System, experts have identified medium-sized granitic bornhardt forms, exhumed over the course of the Pleistocene by the action of interfluvial slopewash (Pedraza, 1984).
Figure 10. - Simplified sketch of most common granitic landforms of the Pedriza de Manzanares area.
Legend: 1, regolith plains and lowlands ("navas") with scattered boulders; 2, boulders and tors; 3, nubbins evolving to tors ("pedrizas"); 4, nubbins ("berrocales"); 5, dome landforms or bornhardts ("yelmos"); 6, tower landforms ("torres or galayos"). These morphologies are commonly associated with the following prevailing factor: 1, granite or monzogranite and generalized faulting development; 2, granite and monzogranite and not generalized faulting development; 3 and 4, granodiorite and leucogranite with orthogonal joint pattern development; 5, granodiorite and leucogranite with orthogonal joint pattern development but sheet joint are dominants (3, 4 and 5, can also be considered different stages from granitic dome landforms to tor landforms); 6, dikes or aplitic-granitoid with orthogonal joint pattern, where vertical joint are dominant. T, tor landforms; f, faults.
5. References

5.1. Included in the text


Hernández-Pacheco, E. (1923). Edad y origen de la Cordillera Central de la Península Ibérica. Asociación Española por el Progreso de las Ciencias, Congreso de Salamanca, volumen 2, 119-134.


5.2. Additional references: geological maps


FIELD TRIP ITINERARY (see fig. 7)

First day, 12-09-2005: Zaragoza-Segovia

8:00. Departure from the Conference Hall
8:00 to 13:00. Travel by bus from Zaragoza to Torrelaguna village. The trip follows the Motorway A-2 from Zaragoza to Torrejón de Ardoz village (280 km) and includes a coffee stop. From Torrejón de Ardoz we will take a local road to the Torrelaguna village (35 km). During this route from Zaragoza to Torrelaguna nearby geological and geomorphological features will be commented.
13:00 to 14:15. Stop for lunch at El Torreón de Torrelaguna Restaurant.
14:15 to 14:45. The coach will pick us up at the Restaurant and we will departure following the local road to the “raña plain” where the stop 1 is situated (15 km).
14:45 to 15:00. Stop 1. Placed near a bus stop by the road. From here, we will take a short walk to a suitable viewpoint, from where the main geological and geomorphological features of the Guadarrama and Somosierra mountains, and Tajo basin, can be seen.
15:00. Departure following the local road to El Pontón de la Oliva dam (10 km).
15:15 to 16:00. Stop 2. Historical, geological and engineering features of the Pontón de la Oliva dam. The access from the coach stop to the dam is very easy—a five-minute walk on a dirty road, and then following a visitors’ itinerary.
16: 00. Departure following the local road to El Atazar dam (6 km).
16:15 to 16:45. Stop 3. Historical, geological and engineering features of the El Atazar dam. The stop is located on a viewpoint adjacent to the coach stop, by the road.
16:45. Departure to Segovia (100 km). Comments on applying geomorphology to the ecological restoration of silica sand mines in the Segovia area.
18:00. Arrival to the Hotel Los Arcos, in Segovia.
21:30 to 22:30. For those interested, we will stroll through the historical city of Segovia, following a sightseeing tour by their monuments and outstanding buildings.

Second day, 13-09-2005: Segovia-San Lorenzo de El Escorial

8:30. Departure by bus from the Hotel Los Arcos in Segovia.
8:30 to 9:15. Stop 4. Tour by bus along the outskirts of Segovia, where we will discuss some aspects of the urban and peri-urban geology, geomorphology, land-use planning and environmental problems.
9:15 to 10:00. Stop 5. Located at one of the best viewpoints of the region, near the village of Zamarramala (2 km from Segovia). From this viewpoint, the main geological and geomorphological features of the Guadarrama mountains and the Duero basin can be seen. Besides, a geomorphological and physiographic explanation for the location of the historical settlement of Segovia will be provided.
10:00 to 10:30. Travel by bus to the San Ildefonso-La Granja village (12 km)
10:30 to 11:45. Stop 6. Visit to the gardens, landscape and surroundings of the La Granja Royal Palace. From this place we will speak about the management and environmental problems of the Scots pine forests of the Valsain – La Granja Valley, and about the impact of recreational activities. Particularly, we will explain the determination of sheet erosion rates by using dendrogeomorphological analysis of exposed tree roots.
11:45 to 12:45. Travel by bus from the San Ildefonso-La Granja village to the El Paular Monastery (35 km). Through this route, we will go from the northern piedmont to the southern...
piedmont, crossing the main Guadarrama mountain range (roads CL-601 and M-604) and finishing at the El Paular intermountain valley. During this journey, we will see some of the physiographic units of the Guadarrama mountains, the Valsain Scots pine forest and the Navacerrada ski resort.

12:45 to 14:00. Stop for lunch in the El Paular Monastery.

14:00 to 14:15. The coach will pick us up at the Monastery and we will come back to the same road (M-604) we drove before lunch, up to the El Mirador de los Robledillos (3 km).

14:15 to 15:15. Stop 7. The stop is located, once again, at a panoramic viewpoint—El Mirador de los Robledillos. To get there, we will have to walk ten minutes on a dirty road. The walk doesn’t pose any difficulties. The aim for this stop will be the view of one of the best examples of intermountain valleys in the Central System, and to speak about its geology, geomorphology, landscape and land uses.

15:15 to 15:45. We come back to the Cotos mountain pass by bus (10 km).

15:45 to 16:45. Stop 8. Visit to the Peñalara Natural Park Interpretation Centre.

16:45: Departure to San Lorenzo de El Escorial (36 km).

17:30. Arrival to Los Lanceros Hotel, in San Lorenzo de El Escorial.

Third day, 14-09-2005: San Lorenzo de El Escorial-Madrid

8:30. Stop 9a. Departure from Los Lanceros Hotel. A five-minute walk will take us to the San Lorenzo Monastery. We will make a short tour around the Monastery and we will speak about its history and granite’s architecture. Here, there is the possibility of visiting the monastery indoors, readjusting the timetable of the rest of the day.

9:15. The coach will pick us up at the Monastery parking, and we will departure to the Valley of the Fallen (6 km).

9:30 to 11. Stop 9b. Visit to the monument, indoors (basilica) and outdoors. Here, we will speak about its history and architecture. Quite interesting can be considered the landscape surrounding this site, so that explanations about the geology and geomorphology of the location will be made.

11:00-11:45. Departure by bus to La Pedriza de Manzanares (34 km). During this route, we will see the environmental effects of the growing of traditional urban settlements, and of the creation of new ones.

11:45 to 13:00. Stop 10. The stop is situated on the panoramic viewpoint of the Quebrantaherraduras pass, fitted with a bus-parking. The objective here is to see the best example of granitic landscape in the Central System and to explain its geology and geomorphology.

Before or after the stop 10, we will visit the Natural Park Interpretation Centre, located on the access to the Park.

13:00. Departure by bus from the Quebrantaherraduras pass (or from the Interpretation Centre parking) towards the Manzanares el Real village, where we will have lunch.

14:15. Departure by bus to Madrid (50 km)

15:15. Arrival to Madrid—the field trip ends.