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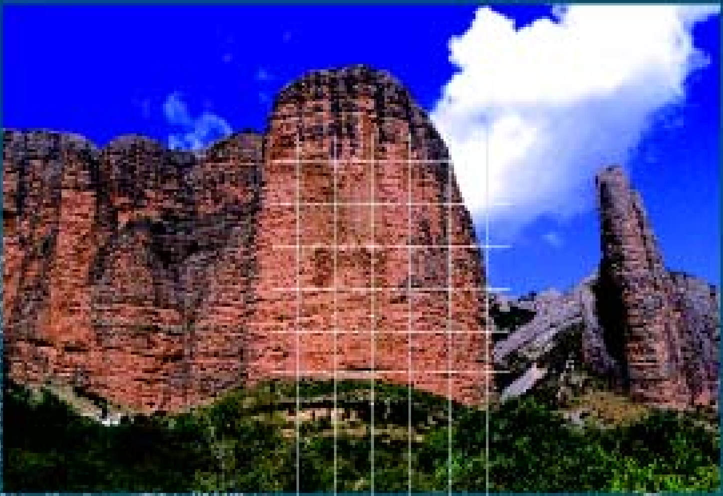
LARGE MASS MOVEMENTS IN RELATION TO DEGLACIATION IN THE PYRENEES

J.M. Garcia Ruiz; C. Marti Bono; B. Valero Garcés and P. Gonzalez Samperiz



FIELD TRIP GUIDE

B-5

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FIELD TRIP GUIDE - B5

LARGE MASS MOVEMENTS IN RELATION TO DEGLACIATION IN THE PYRENEES

José M. García-Ruiz, Carlos Martí-Bono, Blas Valero-Garcés and Penélope González-Sampériz
Instituto Pirenaico de Ecología, CSIC, Campus de Aula Dei, Apartado 202, 50080-Zaragoza, Spain
E-mail: humberto@ipe.csic.es Phone: 976 716025 Fax: 976 716019

1. Introduction to the geology and geomorphology of the Pyrenees

The B5 field trip will take us to the headwaters of the Gállego Valley, where some of the best examples of large mass movements in the Pyrenees occur. In the same valley a glacial tongue of more than 30 km in length developed and many examples of glacial forms and deposits can be found. In some cases, a relationship between glacial features and mass movements has been established, especially in the uppermost part of the valley.

The Gállego Valley is located in the Central Spanish Pyrenees. It runs from north to south, crossing the geological structures in which the Pyrenees can be divided:

The Axial Pyrenees occupies the central part of the range. It corresponds to the oldest sector and it is composed of Paleozoic shales, quartzites, limestones and schistes, affected by regional and contact metamorphism (i.e. the marbles of the Infierno Peak). These materials were folded during the Hercinian movements (Carboniferous), resulting in a very heterogeneous relief according to the differential resistance of the lithology. Thus, the limestones tend to evolve into isolated, small massifs limited by vertical scarps and affected by karstification. The quartzites also produce cliffs, although they do not evolve into individual massifs. On the other hand, shales and schistes result in areas with smoother gradients, large valleys and hillslopes affected by mass movements of different scales (García-Ruiz, 1989). This is the case of some of the Pyrenean valleys, as the Hecho, Aragón an Gállego valleys. The Axial Pyrenees do not appear along the whole Pyrenees, since after the Hercinian orogeny, Paleozoic formations were eroded and covered by continental (Permian and Triassic) and marine (Jurassic, Cretacic and Eocene) sediments.

Several pre-Stephanien granodioritic intrusions are located within the Axial Pyrenees (Panticosa-Cauterets, Posets, Eriste, Perdiguero, Maladeta, Andorra, Albera). They form the highest peaks in the Range characterized by high topography, sharp divides (related to an intense glacial erosion in cirques) and strong gradients, as well as the resmains of older erosion surfaces. The highest peaks in the Pyrenees are located in the divides of these intrusions: Aneto Peak (3404 m), Posets (3375 m).

The post-hercynian sedimentary cover was deposited during the Mesozoic and the first half of the Tertiary (Eocene and Oligocene). The sedimentary formations were continental at the beginning (Triassic), with conglomerates, sandstones and clays of a typical red-wine colour, and, later, marine, with limestones (Jurassic, Cretaceous and Eocene), marls and sandstones (Cretacic and Eocene). Both, the Paleozoic aqnd Mesozoic formations were affected by the the Alpine orogeny, resulting in the Alpine Pyrenees.. Several units can be distinguished from north to south: The Inner Sierras, The Flysch Sector, The Inner Depression and the Outer Sierras.

The Inner Sierras are a large overthrusting anticlinorium whose axis is oriented from west to east. They are relatively narrow in the western part and wider in the central-eastern areas, especially between the Cinca and Segre Rivers, due to the development of several overthrusting tectonic structures. Limestones and sandstones result in an abrupt relief in which vertical cliffs alternate with small platforms intensively karstified. The highest peaks are located in Monte Perdido Peak (3355 m), Collarada Peak (2886 m), Telera (2764 m) and Tendeñera (2853 m). The rivers cross this unit creating deep and narrow canyons. In general, the relief is controlled by the geological structure: the verticality of the cliffs is only interrupted by small marly outcrops or by large debris taluses (screes). Some *cuestas* characterize the highest divides and allows the identification of perched synclines.

The Flysch formation is composed of alternating thin layers of sandstones and marls. It is characterized by relatively smooth relief, with rounded divided that decrease regularly in height from around 2000 m to 1000 m, showing the remains of Tertiary and Quaternary erosion levels. The hillslopes, covered by coarse, matrix-supported colluvium, are regularized, with gradients of around 40%. The flysch was intensively folded and faulted during the Alpine tectonics. Deep mass movements, shallow landslides and water erosion contribute to the torrentiality of rivers and ravines (García-Ruiz and Puigdefábregas; Lorente et al., 2002). Some of the best terminal areas of the Pyrenean glaciers are located within the Flysch Sector, leaving lateral, well-preserved deposits. The contact with the Inner Depression is by an overthrusting fault.

The Inner Depression is a long valley oriented from west to east, except for some north-south structures (i.e. the Boltaña anticlyne) that break its continuity. This depressed area is related to a large outcrop of Eocene marls, and the fluvial activity that has “voided” the original relief, due to the erodibility of the marls in seasonally contrasted climates. Pediments (glacis) and fluvial terraces prevail in the bottom of the Depression, whose borders easily evolve into badlands.

The southernmost part of the Inner Depression is covered by Oligocene continental deposits of deltaic and fluvial origin (conglomerates, sandstones, clays and marls), organized in a synclinorium developed after the main phase of the Alpine tectonics. A new uplift phase folded slightly this area, which has evolved into very regular *cuestas*.

Finally, the Outer Sierras constitute the front of the overthrusting structures of Gavarnie and Cotiella-Montsec. They form a large anticlinorium with a faulted contact with the Ebro Depression. The materials are very similar to those of the Inner Sierras, although the peaks rarely are higher than 1500-1600 m (except in the case of Tozal de Guara: 2077 m). Even so, the relief is very craggy, with cliffs, *cuestas* and very deep and narrow canyons. Karstification processes are very intense.

2. The Gállego Valley

The B5 field trip focuses on the headwaters of the Gállego River (Fig. 1), in one of the most humid sector of the Spanish Pyrenees. The average annual precipitation is around 2000 mm (García-Ruiz et al., 1985), mainly concentrated between October and June, with a slight decrease in January and February. Most of the precipitation reflects the Atlantic influence, with fronts coming from northwest and west. The modern snow equilibrium line is at 2805 m asl. During the Little Ice Age, the snow equilibrium line was at 2618 m asl (López-Moreno, 2000), reaching 1900 m during the maximum glacier extent of the last glaciation. (García-Ruiz et al., 2000).

The whole valley shows evidence of human disturbation. Under 1500 m, most of the south facing slopes were cultivated with bench terraced fields. Since the beginning of the past century, farmland abandonment has affected to all the hillslopes, which have been re-colonized by shrubs and relatively dense forests. Farming is only active in the Gállego Valley floodplain, although the increasing urbanization (tourist resorts) and the construction of reservoirs has reduced the more and more the cultivated area. Besides, some of lateral perched flats, corresponding to glacial dammed deposits are partially cultivated (Aso de Sobremonte, Yosa and Betés, especially.

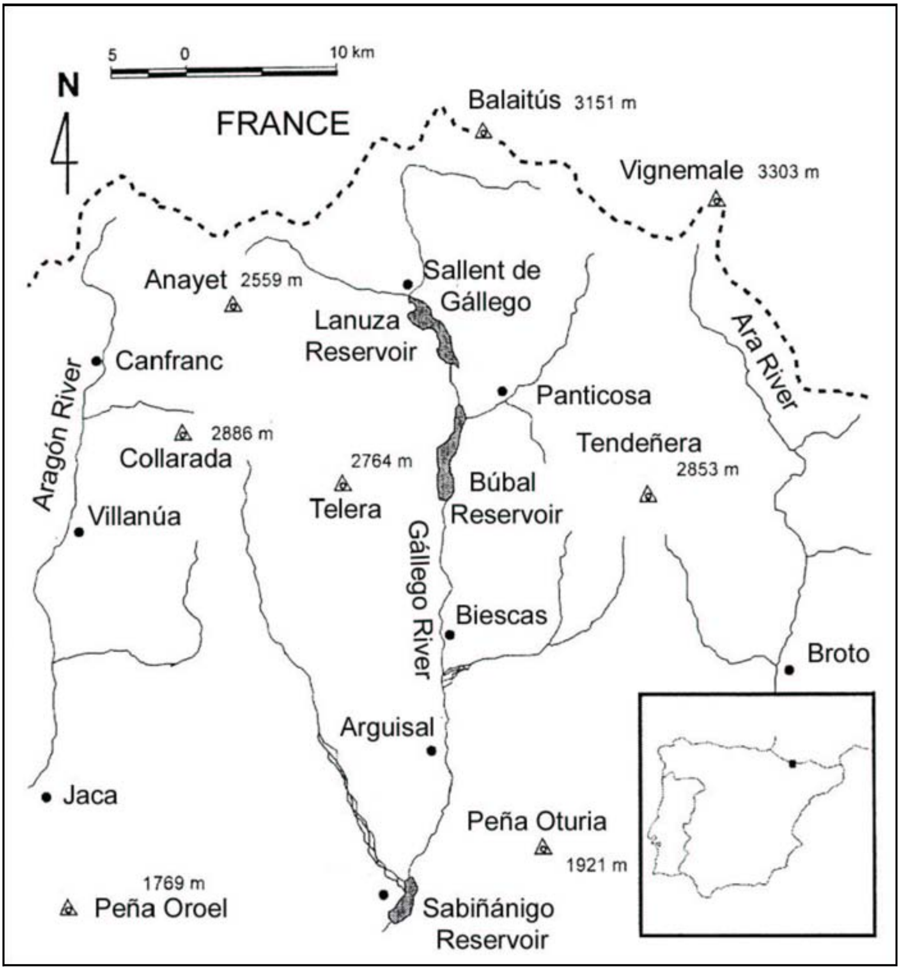

Figure 1.- General situation of the field trip area.

Above 1600 m many of the natural forest were burnt in the Middle Age, as Montserrat (1992) demonstrated in his study of the sediments from the Tramacastilla Lake. Now the deforested areas have evolved into subalpine grasslands, grazed by sheep and cows in summer. Deforestation was responsible for a sudden increase of erosion rates, as well as the triggering of shallow landslides (debris flows, translational slides) and solifluction (García-Ruiz et al., 1990). Höllermann (1985) underlined that, after deforestation of the upper forest belt, the solifluction belt lowered some hundred of metres. Nevertheless, no relationships have been found between deforestation and deep mass movements.

The B5 field trip begins in the Sabiñánigo-Senegüé basin, located on the flysch formation. This basin is characterized by a wide alluvial plain, where the Gállego River develops a braided-like channels. Some large alluvial fans occupy the lateral areas of the alluvial plain; they have been built by the main tributaries of the Gállego River, transporting sediments especially from the lateral moraines. The fans have been active until relatively recent times. One of them, the Arás fan, close to Biescas, was the responsible for the so-called Biescas catastrophe, a flash flood that occurred on 6 August, 1996 (White et al., 1997). The versants are densely forested, especially the north facing slopes, occasionally affected by some scattered debris flows.

After the Flysh Sector, the Inner Sierras appear as a dramatic limestone wall that suddenly rises up to more than 2600 m. The south versant corresponds to the front of an overthrusting anticline, with small glacial cirques, glacial tills, periglacial screes and exo- and endo-karst (lapiaz, dolines, subterranean rivers, caves and wells) The north facing slope shows a craggy relief, with vertical scarps, large cirques, tills of different glacial stages and avalanche channels with their corresponding fan-like talus accumulations. The Gállego River crosses the Inner Sierras throughout a short and deep canyon (Santa Elena) that corresponds to a subglacial gorge.

The Axial sector occupies most of the Gállego River headwaters. The area is very heterogeneous due to the lithological diversity and the geological complexity derived from the activity of both the Hercinian and Alpine tectonics (Julián et al., 2000). Two units can be distinguished: The Paleozoic areas and the Panticosa-Cauterets granitic massif.

The most important factor in the evolution of the relief in the Upper Gállego Valley is the distribution of small limestone massifs within the large shale outcrops. The former have evolved into relatively high relieves, surrounded by vertical scarps, sometimes forming in-cuesta relief. Peña Foratata (2295) is the best example of limestone isolated massif. Shales appear as smooth relieves, with rounded divides and relatively disorganized fluvial networks, due to the occurrence of large mass movements. Some remains of Stephanien volcanism appear as isolated peaks, due to their greater resistance (andesites) (Anayet, Campo de Troya and, more dramatically, the Midi d'Ossau, in the French side of the range. In the contact with the granitic massifs, a contact metamorphism produces another abrupt relief (corneanes, quartzites and marbles of the Infierno, Punta Zarra, and Argualas peaks).

The granitic massif is characterized by a massive morphology with steep gradients and sharp divides. It is crossed by many fractures and dykes that guide the course of ravines and even glacial valleys. The cirques, very well defined, are affected by avalanche channels and debris taluses. The bottom of the cirques is covered with chaotic accumulations of blocks and, in some cases, rock glaciers. At a detailed scale, nerviations and pseudo-gnammas are the evidence of postglacial weathering. Locally the granite appears intensively polished, with *roches moutonnées* in the glacial thresholds.

3. The main glacial features of the Gallego Valley

Landforms in the Gállego Valley, as in most of the Pyrenees, derive from the structural organisation, lithological contrasts and glacial erosion. Excellent examples of glacial cirques can be found in the granitic massifs, as well as in the north facing slopes of the Inner Sierras. U-shaped valleys developed especially in granites and even in shales.

The main glacier started in the Respomuso cirque, located in the Balaitús massif (Aguas Limpias Valley), in the Respomuso cirque, received some important tributaries at the moment of the maximum extent (Arrieles, Pondiellos, Escarra and Caldarés-Ripera), passed through the Inner Sierras and ended at the Sabiñánigo-Senegüé terminal basin. The maximum extent of the Gállego glacier is represented by some disperse deposits close to Sabiñánigo, during the so-called Aurín Stage. Many other deposits are present throughout the valley, the most important ones being those located in the lateral valley-walls of the end basin.

The study of glacial landforms and deposits in the Gállego Valley started at the end of the 19th century (Penk, 1883) and continued along the 20th century (Panzer, 1926; Fontboté, 1948; Barrère, 1966; Martí-Bono, 1977). Lately, Montserrat (1992), Martínez de Pisón and Serrano (1998), Serrano (1998), García-Ruiz et al. (2003) and Peña et al. (2004) have focused their studies in the Gállego Valley; besides, Martí-Bono and García-Ruiz (1994), Martí-Bono (2000) and Chueca et al. (1998), among others, have contributed to understand the evolution of Upper Pleistocene glaciers in the Central Spanish Pyrenees.

According to the available 14C and OLS dates, and to therelative chronology based on the topographical position of different glacial tills, the following chronology has been proposed for the Central Pyrenees (García-Ruiz et al., 2003):

(i) The maximum extent of the glacier occurred most probably at around 60,000-65,000 years BP. At this stage, at least three episodes are represented in lateral moraines, both in the main valley and in the Escarra Valley. The most internal episode probably corresponds to the Senegüé end moraine. Later, the tongues retreated very much, though there are no evidence of the location of the glacier front for thousands of years.

(ii) Around 20,000-25,000 years BP, coinciding with the coldest period of the Upper Pleistocene (Late Glacial Maximum) a new re-advance occurred, but the length of the ice tongue was much shorter than before. Most of the main tributaries did not connect with the main glacial tongue (Serrano, 1998; Chueca et al., 1998).

(iii) Several frontal arcs and their lateral ridges evidence a short re-advance during the Oldest Dryas. This is the “Upper Valley Glacier Phase” defined by Bordonau (1992) and dated between 16,000 and 15,000 years BP (end of the last pleniglacial).

(iv) Rock glaciers and debris-covered glaciers confirm the occurrence of a short period with cold temperatures and a high activity of gelifraction in the cirque backwalls with a large debris input (14,000-13,000 years B.P.?) (Bordonau, 1992; Copons and Bordonau, 1997).

(vi) Many cirques have a final morainic arc close to the cirque backwall, that represents the last stage of glaciation, attributed to the Younger Dryas. Nevertheless, fresh morainic arcs are present at the front of actual small glaciers in the Infierno Peak and Balaitús massif, deposited during the Little Ice Age.

Besides, remains of an older glaciation, dated by OLS between 150,000 and 200,000 years BP have been found in the Aragón Valley (15 km westward). The 60 m fluvial terrace of the Gállego River close to Sabiñánigo also corresponds to this previous glacial phase (Peña et al., 2004) as well as some sparse granitic boulders in the Cotefablo area.

4. Mass movements

Many examples of both shallow and deep mass movements can be found in the Spanish Pyrenees. Some of them are located in the Upper Gállego Valley, especially in the Flysch Sector and in the Paleozoic shale outcrops of the Axial Pyrenees. In the first case, slumps tend to appear above all in the overthrusting contact between the Flysch and the marls of the Inner Depression. Some disperse earthflows are scattered randomly, most probably related to the presence of faults. Debris flows, very abundant in the Flysch Sector, locate especially in south facing slopes, between 1100 and 1400 m, in areas affected by strong human pressure in the past and then abandoned (García-Ruiz and Puigdefábregas, 1982; Lorente et al., 2002). Close to the divides, translational planar slides occur in deforested, subalpine areas (García-Ruiz and Puigdefábregas). Nevertheless, some of large mass movements located in the valley walls of the Gállego main glacier would be related to deglaciation (see Stop 2).

The shale outcrops in the Axial Pyrenees are the best place in the Spanish Pyrenees to study deep mass movements. They have a large, subcircular scar and a tongue up to 1 km in length, corrugated and laterally limited by levees. They affect clearly the rock substratum. The greatest frequency of these earthflows (although in some cases they can be defined partially as slumps) appears in the uppermost part of the valley, between the ski resort of El Formigal and the mountain pass of El Portalet. Nevertheless, some of the largest examples are located in the Pondiellos ravine and close to the La Sarra reservoir (Julián-Andrés et al., 2001). Most of them seem to be scarcely active, though others show evidence of recent small and slow movements. The continuous instability of the road is a proof of this activity (García-Ruiz, 1989), and it maybe related to lateral erosion of the Gállego River. However, close to the Upper Gállego Valley, a large mass movement occurred in 1982 in Eaux-Bonnes, Aubisque mountain pass, French Pyrenees (Besson, 1996).

These deep mass movements have a clear lithological control, since in the Axial Pyrenees they only occurred in the shale outcrops. The reasons for this control are obvious: shales are affected by an intense and deep network of fault and tectonic structures that facilitates a deep weathering and the percolation of water in springtime (snowmelt and frontal rainfalls). Besides, deglaciation would have reduced the pressure over the valley walls, and the consequent relaxation would have been a key factor for triggering mass movement (Corominas, 1990; Bordonau and Vilaplana, 1986). For instance, in the case of *sackungen* (deep-seated rock creep in slopes on foliated bedrock), most of authors suggest the removal of the load and lateral support in glacially oversteepened slopes after the retreat of ice tongues as the main triggering factor (Agliardi et al., 2001). Nevertheless, studies carried out by Gutiérrez Santolaya et al. (in press) in the Benasque Valley (Central Spanish Pyrenees) have demonstrated that the occurrence of *sackungen* seems to correspond to the Holocene, several thousand years after deglaciation. According to these results, Gutiérrez-Santolaya et al. (in press) stated that "glacial erosion and the subsequent debutressing of the valley sides generated slopes predisposed to *sackung* development, but did not initiate the lateral spreading phenomena". In the Gállego Valley, the chronology of some mass movements offers further evidence of the relationships between deglaciation and landsliding.

* * *

During the B-5 Conference Field Trip several stops will show examples of morainic deposits, different glacial phases, and the possible relationships between deglaciation and the triggering of large mass movements.

Stop 1. Senegüé: the end basin of the Gállego glacier

The end basin of the Gállego glacier is one of the best examples in the Pyrenees, where both lateral and frontal deposits well preserved. When the glacier left the Inner Sierras and arrived to the Flysch Sector, its tongue was at least 400 m thick, leaving large lateral moraines in the junction with its tributaries, that remained dammed at the moment of maximum glacial extent. For that reason, most of the tributaries lodge glaciolacustrine deposits, perched some hundred of metres above the valley bottom.

Two are the end moraines located in this basin (Fig. 2). The most important one is the Senegüé moraine, that forms a large transverse hill that reaches up to 35 m over the Gállego River. The south facing slope of the moraine connects with a large proglacial plain that corresponds to the 20 m terrace. A trench within the moraine shows the typical matrix-supported subglacial till, with sub-rounded blocks of granite, sandstones and limestones. Likewise, there is a small void infilled by a lacustrine deposit (rhythmites), most probably caused by the melting of an internal ice block (kettle).

About 2 km downstream, close to the Aurín River (a tributary of the Gállego River), small morainic remains scarcely raise up over the alluvial plain. They have been eroded by the Gállego River, and the melting waters during the Senegüé stage. These are the outermost morainic rests in the Gállego Valley. Nevertheless, Peña et al. (2004) underline the existence of a polished sandstone outcrop at Sabiñanigo, although its glacial attribution is uncertain. Most of the city of Sabiñánigo has been built over a deposit with large sub-rounded, glacial-origin blocks. The origin of this deposit is uncertain (glacial, fluvial), since the blocks could have been transported for some hundred of metres by the Gállego River from the end moraine.

In the Sabiñánigo-Senegüé basin, the oldest dates have been obtained from a fluvioglacial terrace of the Gállego River, located 60 m above the present channel (155,800 years BP) (Peña et al., 2004), which would correspond to the stage M1 in the Aragón Valley. The proglacial outwash of the Aurín moraine has been dated in 69,000 ± 8,000 years BP (Peña et al., 2004), an age relatively similar to that of M2 in the Aragón Valley. Finally, the Senegüé moraine has an OLS age of 35,700 years, that is a clear retreat stage. Here, as in the case of the end Aragón Valley basin, the Isotope Stage 2, corresponding to the Late Glacial Maximum, is absent. Glacier deposits related to the MIS 2 have been found several kilometres upstream, confirming that the maximum extent of the Pyrenean glaciers occurred earlier than in the north of Europe (García-Ruiz et al., 2003).

Stop 2. Molino de Escuer: The Biescas slump

The Biescas-Arguisal slump is located on the right margin of the Gállego Valley, within the Flysch Sector. The substratum is composed of alternating thin beds of calcareous sandstones and marls. The area corresponds to the Senegüé-Sabiñánigo glacial end basin, where the Gállego glacier left abundant lateral tills at decreasing altitude above the valley bottom: the ice tongue had 400 m thickness in Biescas, 200 m in Escuer, 200 m in Arguisal, and it ended close to Sabiñánigo.

Average annual precipitation at Biescas is 1116 mm, although extremely intense events are relatively frequent (White et al., 1997). Mean annual temperature is 10.3 ºC. Current vegetation is dominated by reforested pines with disperse submediterranean oaks.

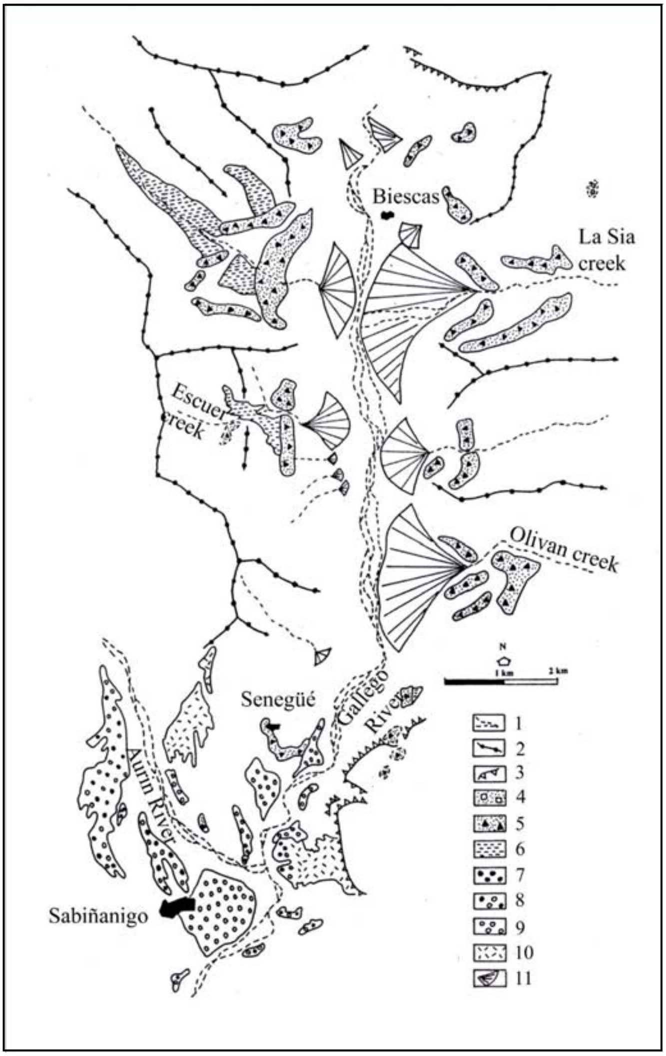

Figure 2.- Geomorphological scheme of the terminal morainic complex in the Gállego Valley (Sabiñánigo-Biescas basin): **1,** Rivers and creeks; **2,** Smooth divides; **3,** Cuesta front; **4,** Glacial deposits previous to the Phase of Maximum Extent; **5,** Moraines deposited by the Gállego glacier; **6,** Lateral obturation glaciolacustrine deposits; **7,** Terrace of 100-110 m; **8,** Main level of terraces (50-60 m); **9,** Terraces of 15-20 m; **10,** Main level of glacis; **11,** Alluvial fans.

Fig. 3 shows some of the most outstanding features of the slump. In the upper part it affects the hillslope for about 2 km. At the foothill, the large slid mass is about 900 m in length, and it is crossed by small ravines that end in alluvial fans. At the north side of the slump, the Escuer ravine develops a partially active fan, after crossing the right lateral moraine of the Gállego glacier. The moraine outcrop is suddenly interrupted toward the south since it has been dismantled by the slump. The upper part of the scar is at 1400 m and the lowest part at 820 m.

The presence of other minor, intermediate scarps, and of small lakes located backwards indicates the existence of rotational movements. At present, the lakes are completely infilled of sediment.

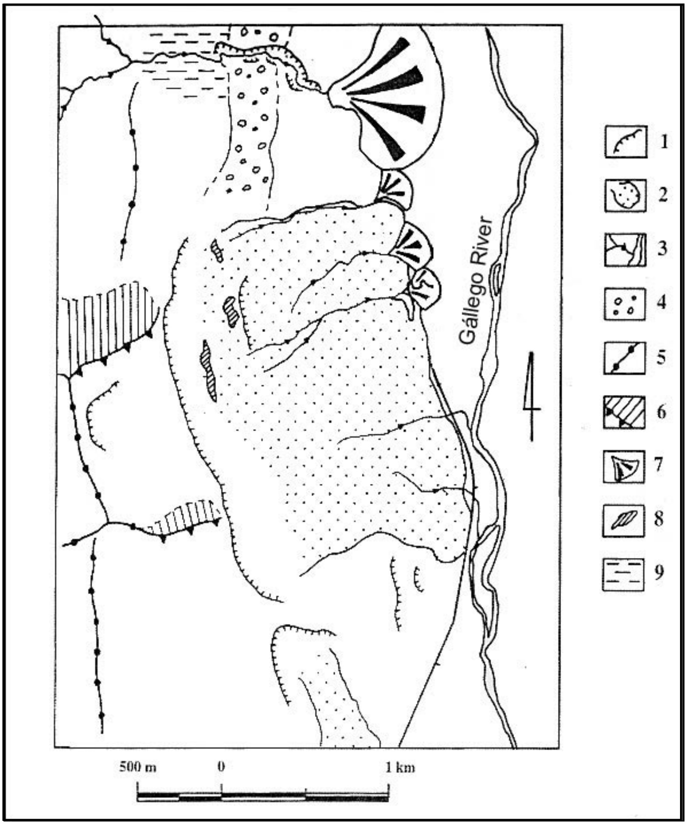

Figure 3 Geomorphological scheme of the Biescas-Arguisal slump: **1**, Scars; **2**, Slipped deposits; **3**, fluvial network; **4**, Morainic deposits; **5**, Smooth divides; **6**, Structural reliefs, front of cuesta; **7**, Alluvial fan; **8**, Depressed areas, with lacustrine siltation; **9**, Glacilacustrine sediments.

Fig. 4 shows two possible interpretations of the Biescas-Arguisal slump. The first one suggests that there are two sliding planes: one is the responsible for the main slide, including the rotation that explains the location of the lakes; the second one developed immediately below the lake. An alternative interpretation considers that there are also two sliding planes, although with different signification. A first big slide would occur, probably without rotation, and later the scar would undergone a new, rotational movement. From a chronological point of view both interpretations lead to different situations. In the first case all the slid mass moved at the same time, whereas in the second one the slump in which the lake locates is clearly posterior to the main slid body.

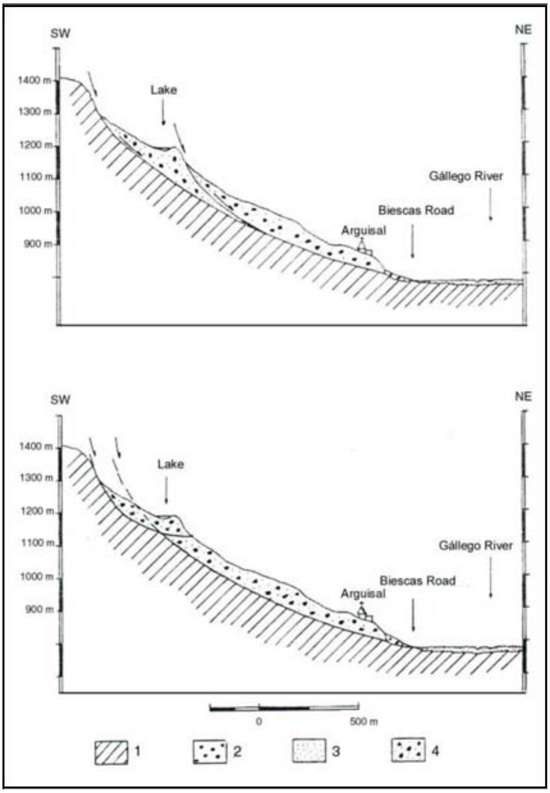

Figure 4.- Alternative interpretations of the Biescas-Arguisal slump: **1**, Non slumped terrains; **2**, Alluvial fan; **3**, Terraces and alluvial plain of the Gállego River; **4**, Slumped material.

A sediment core was taken from one of the lakes. Strong fluctuations in pollen concentration are interpreted as changes in the sedimentation rate, related to more intense rainfalls. Dating from pollen concentration and charcoal were not useful due to the presence of frequent inversion of dates and contamination. Some of the samples gave recent dates, and others, close to 20,000 years BP, probably contaminated by the presence of dinoflagelates from the Eocene flysch. The analysis of the pollen diagram indicates that the infilling of the lake occurred during the Late Holocene. (i) there are no relevant changes in the pollen spectrum that would suggest a transition between Upper Pleistocene and Holocene; and (ii) from the bottom of the deposit the pines dominate in the composition of the vegetation, together with other arboreal *taxa*, typical from the actual landscape. Nevertheless, these results do not reject the existence of relationships between deglaciation and landslide triggering. The main body of the landslide could be very old, whereas the slump in which the lakes locate could be relatively recent.

Stop 3. Tramacastilla Lake: Deglaciation and mass movements

A complete sequence of glacial stages since the maximum expansion of the glaciers until the Younger Dryas can be found in one of the right-margin tributaries of the Gállego glacier in its headwater: the Escarra Valley. A field trip through the valley allows direct observations of several deposits corresponding to different glacial, Würmien stages.

The basal date of the lacustrine sediments from a glacial-origin lake (Tramacastilla lake) located in the divide between the Escarra and the Lana-Mayor valleys was 29,400 ± 600 years B.P. (Montserrat, 1992)., suggesting once again that the maximum extent of the glaciers in the Southern Pyrenees was reached earlier than the LGM. The Escarra glacier would have diminished much in size at about 30,000 years B.P., since tills belonging to the maximum extent are located at least 100 m above the Tramacastilla lake.

The sediment core of the Tramacastilla lake provides a reconstruction of landscape and paleoclimate evolution for the last 30,000 years. Until the beginning of the Holocene, lake sediments are characterized by the presence of massive fine silts ("Blue Clays" facies) with low percentage of organic matter, relatively low quartz and feldspars, and high carbonate content. An abrupt re-organization of the local surface hydrology occurred between 18,000 and 20,000 years B.P due to changes in the drainage area of the Ordecito creek. As a consequence, carbonates are absent in the sedimentation and a slight increase in the grain size occurred. An expansion of forest after the Bolling period greatly reduced watershed erosion, and sedimentation in the lake became dominated by organic material during the Holocene. Coarser sands were deposited during a short interval at about 4,000 years B.P. and correlate with a short opening of the vegetation (maybe a first man-induced fire due to livestock management?). During the last 1000 years sedimentation has become coarser, organic-poor and clastic, with a much higher rate of sediment accumulation. Increased conted in charcoal suggests a clear and generalized period of fires aiming to the enlargement of subalpine grasslands. The consequence was an increase of soil erosion and sedimentation (García-Ruiz and Valero-Garcés, 1998).

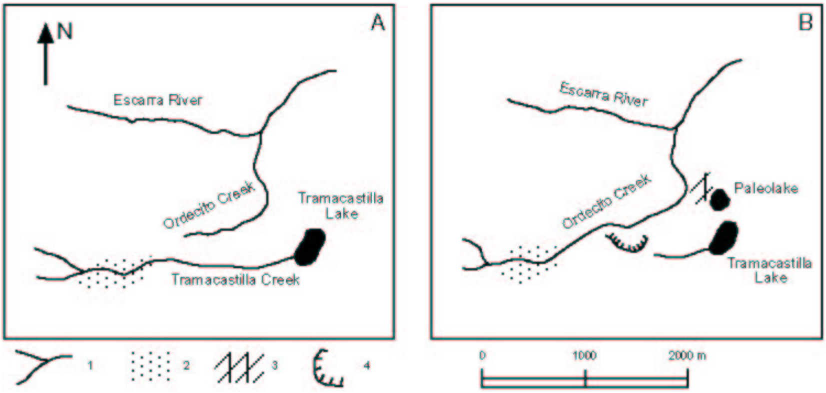

Figure 5.- Capture of the Ordecito Ravine, at about 20.000 yrs BP. (A) Pre-landslide situation; the Tramacastilla creek directly fed the Tramacastilla Lake. (B) Post-landslide situation; the upper reach of the Tramacastilla creek is captured by the Ordecito Ravine and the lower reach is isolated from the headwaters. Other landslides north of Tramacastilla lake block the outlet from this lake and create another lake (the northern Tramacastilla paleolake): **1**, fluvial network; **2**, moraines with limestone clasts; **3**, landslide accumulation; **4**, Ordecito landslide scar.

For the field trip purposes the most interesting topic is the presence of other lacustrine sediment crop out immediately northward of the Tramacastilla lake. They were deposited in a lake that was drained and partially eroded. This lake was dammed to the north by several small, rounded hills that correspond to outcrops of Paleozoic shales. They are part of the landslide that changed the course of the Ordecito creek (Fig. 5). The changes in the surface hydrology induced by the landslide apparently were responsible for both the origin of this small lake and the changes in sedimentary conditions in Tramacastilla lake. The AMS 14C date from the pollen concentrate at one of the levels of the lake sediments was 20,600 ± 170 years BP (García-Ruiz et al., 2003), coinciding with the maximum expansion and the beginning of the retreat of the Escarra glacier during the Late Glacial Maximum. The pollen spectrum of the lake sediment indicates a cold steppe dominated by non arboreal taxa.

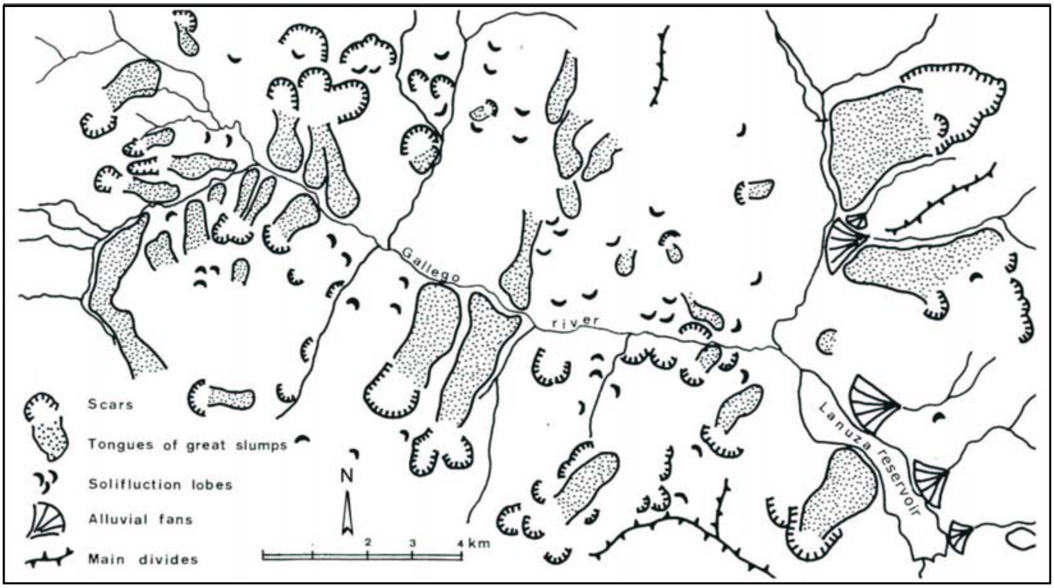

Figure 6.- Large mass movements in the headwaters of the Gállego Valley.

Stop 4. The Lanuza earthflow

In front of the Lanuza village a large earthflow developed with the scar on schistes and shales and a large tongue that reached the valley bottom. The front is now in contact with the Lanuza Reservoir (Fig. 6). This earthflow has undergone a recent reactivation that affects the main road to France. A small landslide occurred in the eighties in one of the margins, as well as some cracks in the uppermost part. Ayala et al. (1988) suggested that this reactivation has been encouraged by the uprising of the water table due to the construction of the Lanuza Reservoir. Between the Formigal ski resort and the El Portalet mountain pass, the road is also affected by local mass movements, although they are probably activated by incision and lateral erosion of the Gállego River.

Stop 5. El Portalet: The Corral de Las Mulas earthflow and peatbog

The Corral de las Mulas peatbog corresponds to an old lake in the Formigal area. A large earthflow dammed the Gállego River and developed the lake, until the Gállego River cut the front of the mass movement forming a small stretch of rapids. Part of the landslide crossed the river valley and reached the left margin of the river.

The landslide is covered by a surface accumulation of large, non-rounded blocks, partially forming transverse ridges somewhat similar to those of a rock glacier. Nevertheless, neither the location nor other characteristics coincide with those required by a rock glacier. It seems that the earthflow occurred at the same time that a debris avalanche from the upper part of the scar, and for this reason the blocks located on the surface can be organised in arcuate ridges. The date of the basal sediments deposited in the lake is 20,150 ± 150 years BP. The sediments are carbonate-poor, and for this reason a hard-water effect in unlikely. This date demonstrates that at that time the upper Gállego glacier in The Formigal sector had already melted and probably restricted to the cirques and maybe very small tongues. The pollen spectrum indicates a cold steppe environment similar to the northern Tramacastilla sequence (Stop 3), and dominated by non-arboreal taxa.

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ROAD LOG

Zaragoza- Upper Gállego Valley- Zaragoza.

Departure 9th September, from the Conference Hall, at 8:30 a.m.

Road N-330 (133 Km), Zaragoza-Huesca-Senegüé. **Cofféе stop** and **Stop 1** (10-10:45 a.m.)**.** General view of the terminal basin of the Gállego glacier. Frontal moraines. Thirty minutes walking are required.

Road N-330 (4 Km), Escuer. **Stop 2**, Biescas-Arguisal slump. General view (11-11:30 a.m.).

Roads N-330 and A-131 (20 Km). Tramacastilla. Field road (track) (12 Km) up to the Lake of Tramacastilla (**Stop 3, optional**). Lacustrine deposits as indicators of slump ages. (If the field road conditions were not suitable for coach traffic the day of the Field Trip, we will skip Stop 3). (11:30 a.m.-14 h).

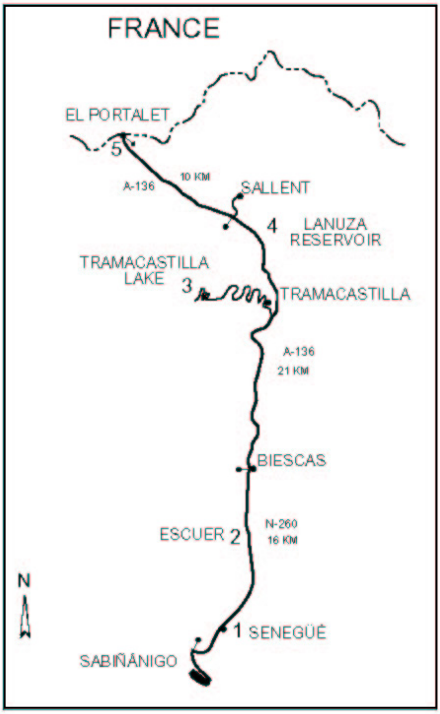
Road A-131 (8 Km). Stop for lunch at Restaurante Mingo (14:15-16:15 h).

Road A-131 (4 Km), **Stop 4**, Lanuza reservoir. Earthflow besides a reservoir (16:30-16:45 h).

Road A-131 (12 Km), Portalet de Anea (**Stop 5**), Earthflows (17-18 h).

Return to Zaragoza (18-20:30 h).


FRANCE
EL PORTALET
10 KM
A-136
SALLENT DE GALLEGO
21 KM
BIESCAS
N-260
16 KM
SABIÑÁNIGO
N-330
55 KM
N
HUESCA
N-330
72 KM
ZARAGOZA


FRANCE
EL PORTALET
5
A-136
10 KM
SALLENT
4
LANUZA RESERVOIR
TRAMACASTILLA LAKE
3
TRAMACASTILLA
A-136
21 KM
BIESCAS
ESCUER
2
N-260
16 KM
N
1
SENEGÜÉ
SABIÑÁNIGO