



Geomorphology of the northern sector of the Alfambra-Teruel depression (Iberian ranges, NE Spain)

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ABSTRACT

The area of Alfambra (NE Spain) is very representative of the relief evolution of the Eastern Iberian ranges. The geomorphological cartography (Main Map) includes the northern sector of the Alfambra-Teruel Neogene depression and its mountainous surroundings. The cartographic process started by using aerial photographs (1:30000 scale) and fieldwork. The structural reliefs, erosion surfaces, karst landforms, Quaternary pediments and terraces, and fluvial network are represented over a lithological background. The main cartography is complemented with two maps of lithological and geomorphological units. The obtained information enabled the main geological and geomorphological stages of the regional relief to be established.

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1. Introduction

Several geomorphological studies have been made in the eastern sector of the Iberian Ranges in NE Spain since the 1970s. Some of these studies were accompanied by geomorphological maps made to various scales and cartographic systems. A set of PhD theses with black and white maps at 1:50000 scale covered most of this territory. The first maps were made by Ibáñez (1976) in the NE sector, followed by Lozano (1988) in the Gúdar-Maestrazgo Ranges, Sánchez Fabre (1989) in the Alfambra-Teruel depression, Gracia Prieto (1990) to the west in the Gallocanta depression, and Gutiérrez (1988) in the Calatayud and Teruel depressions to 1:25000 scale. The area is also included in geomorphological synthesis maps for the province of Teruel (Peña Monné et al., 1984) and a map of Aragón (Peña Monné et al., 2002) – both edited in color.

The Alfambra-Teruel depression and nearby mountainous area (Figure 1) combine much evolutionary information from the Iberian Ranges. Several studies were made of its Neogene sedimentary history and regional tectonics (Gautier, Moissenet, & Viillard, 1972; Simón, 1983, 1984) and Quaternary accumulations (Burillo, Gutiérrez, & Peña Monné, 1981; Gutiérrez, 1998; Gutiérrez & Peña Monné, 1976; Moissenet, 1985). Its deformations by active tectonics (Lafuente, 2011; Lafuente, Arlegui, Liesa, Pueyo, & Simón, 2014; Simón et al., 2016) show relevant data for the recent evolutionary reconstruction.

Considering these antecedents, it is necessary to develop a detailed geomorphological cartography and

Sheet 542 (Alfambra) was chosen as a representative area. The Alfambra sector gathers enough records of the Cenozoic-Quaternary events to offer a complete evolutionary perspective of the Eastern Iberian ranges within a small area.

2. Regional settings

The Alfambra region is located in Teruel Province, NE Spain. It is the N sector of the Alfambra-Teruel depression, located in the SE part of the Iberian Ranges (Figure 1). The climate is Continental Mediterranean with annual average precipitations between 400 and 450 mm (449 mm in Alfambra) (Peña Monné et al., 2002). The main rainfalls are in spring-early summer and autumn, while the dry season is winter. Average annual temperature is about 10.8°C in Alfambra (1043 m a.s.l.) and descending in the ranges located around the main valley.

The Alfambra River runs across the depression in N-S direction. This river is a tributary of the Turia River that flows to the Mediterranean. As a consequence of the climate and the basin characteristics, the Alfambra River flow reaches an annual average of 1.16 m³/s (Teruel gauging station) (Sánchez Fabre, Ollero, Mora, del Valle, & Ballarín, 2013). The greatest flow is registered in winter and spring, while summer and autumn are very dry. However, torrential flows of over 100 m³/s have been recorded.

From a geological point of view, the Alfambra-Teruel depression is a NNE-SSW oriented graben around

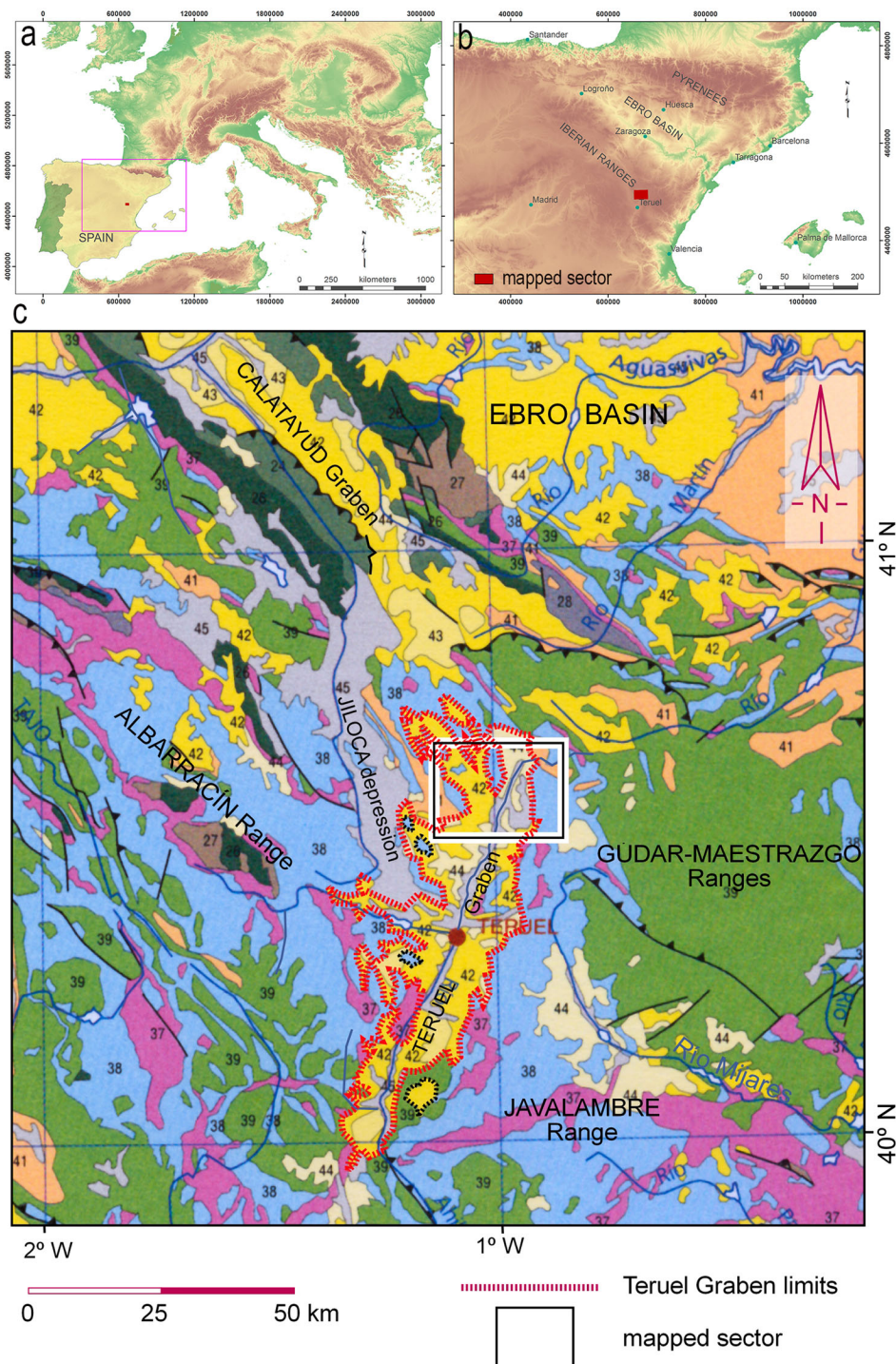


Figure 1. (a) and (b) general situation maps; (c) Location map of the Teruel graben and the mapped area included in the Eastern Iberian Ranges. Cartographic base: Mapa Geológico de España 1:1000000 of the Instituto Geológico y Minero de España (IGME) (24–36 Paleozoic; 37–40 Mesozoic; 41 Paleogene; 42–44 Neogene; 45: Quaternary).

100 km in length from the Galve zone (Teruel) to Mira (Cuenca). It is bordered by a distensive fault system initiated by an Early-Middle Miocene rifting process. The Palomera-Camañas Ranges (1533 m) to the west and Sierra del Pobo (1759 m) to the east are mountainous borders. The Sierra del Pobo is part of the Gúdar-Maestrazgo range. These reliefs are composed of Mesozoic and Paleogene materials folded during the Alpine orogeny and affected by major erosive surfaces (Peña Monné et al., 1984).

The Alfambra-Teruel graben was filled in an endorheic regime from the Early-Middle Miocene with detrital sediments in the proximal areas (composed of conglomerates, sandstones, and clays contributed by the fluvial courses coming from the surrounding ranges). In the distal sectors there are evaporitic and carbonated deposits (*páramos*) composed of limestones, gypsum, and gypsiferous marls deposited in the lacustrine areas of the basin bottom. In this northern area, it is possible to distinguish two *páramos*: the

older of Turolian age (*páramo 1*) and the younger from the Ruscinian (*páramo 2*) (Adrover, Mein, & Moissenet, 1976; Godoy et al., 1983; Olivé, Portero, & Gutiérrez, 1982) and they are separated by reddish detrital layers. In the Late Pliocene, a new distensive phase mostly reactivated the east fault and created a half-graben that uplifted the mountainous massifs (Simón, 1983). The Late Pliocene-Early Quaternary (Plio-Quaternary) is represented by detrital accumulations of the Perales Fm. These have pediment morphology and represent the beginning of the exorheism in the basin (Gutiérrez & Peña Monné, 1976; Gutiérrez-Santolalla, Gracia Prieto, & Gutiérrez Elorza, 1996). The later incision of Alfambra River and the erosive emptying of the basin generated a space where Quaternary pediments and terraces were formed (Gutiérrez & Peña Monné, 1976; Moissenet, 1985). Some of these deposits are showing deformations indicating that tectonic pulses were still present during Quaternary, especially along the contact fault with the Sierra del Pobo (Peña Monné, Sánchez Fabre, & Simón, 1981).

3. Methodology

The **Main Map** has its starting point in the cartographic scheme of the Alfambra-Teruel depression performed by Sánchez Fabre (1989). Black and white aerial photographs of the survey known as American flight B series, 1:30000 scale (1956–1957) were used. In addition, DEM MDT05-LiDAR and the topographic base BTN-25 of the Instituto Geográfico Nacional de España (IGN), especially the contour lines, populations, and river vector layers were used. Although the topographic base over which the first map was made had a UTM Hayford ellipsoid projection and European Datum (1950), the new document was projected to the UTM_Zone 30 system and ETRS_1989 Datum was introduced by georeferencing and digitizing the elements with arctoolbox in ArcGIS 10.1.

The geological information is taken from the corresponding sheet of the Magna series scale 1:50000 (Godoy et al., 1983) of the Instituto Geológico y Minero de España (IGME) in digital format. A synthesis of the lithological and chronostratigraphic information was extracted from this map. The map references for the geomorphological representation were designed following the proposals of Peña Monné (1997) for maps at scales 1:25000/1:50000. A DJI Phantom 4 drone was used to better interpret some areas and improve the cartography. Vertical images were taken flying ~100 m above the areas of interest to obtain detailed geomorphological features (~3 cm/px). It was also used to take oblique photographs to better known difficult access areas, especially of Holocene slopes and dolines. This process was accompanied by a bibliographic and cartographical revisions, as well as new field work that enabled

updating the geomorphological information presented on the final map. The references of the **Main Map** show the represented landforms grouped into four main sections: structural reliefs; erosion surfaces; karst landforms; and Quaternary accumulation forms. Two complimentary maps were drawn containing the lithologic and the morphological units respectively.

4. Results and discussion

The results are described in the same order of the **Main Map** references because it is also related with the evolutionary process of the area.

4.1. Structural reliefs

In the ranges surrounding the Alfambra-Teruel graben, the incision of the fluvial network reveals harder levels of the Mesozoic limestone or Paleogene sandstones and conglomerates. As a result, *cuestas*, *hogbacks*, and *chevrons* are very abundant, as well as elongated morphologies that serves as river divides and isolated hills of structural origin.

At the bottom of the depression, the incision of the Alfambra River and its tributaries over the Mio-Pliocene sediments enable the exhumation of several calcareous layers alternating with softer materials. These show horizontal and sub-horizontal structures (Figure 2(a)). Modeling of the structural platforms (locally known as *muelas*) can be seen at the sides of the main river (Figure 3(a,b)) and these continue until Teruel. The Turolian limestones generated the most important reliefs (Figure 3(a,b)). In the **Main Map**, large platforms are found to the south of Alfambra and opposite Orrios. These platforms have limestone structural surfaces with abrupt scarps. At their bases are concave slopes of clayey materials. Sometimes, when several limestone or conglomerate layers are exposed among the clay layers, the relief becomes stepped. The slopes show a strong regression and this leads to the formation of wide flat-bottomed valleys between the structural platforms. The platforms are sometimes reduced to residual hills, such as at the Alfambra castle (Burillo et al., 1981) (Figure 2(b)). To the north of Alfambra there are wide areas where the detrital sediments are dominant and give place to the formation of a hilly reddish landscape without scarps.

4.2. Erosion surfaces

These relief forms are typical of the mountainous units that surround the depression at Alfambra. The rocky Mesozoic formations of the Sierra del Pobo, as well as those of the Sierra Palomera-Camañas, have had their summits flattened by erosive surfaces. Such summits are dominant features in the nearby mountainous areas such as Sierra de Albarracín (Peña Monné,

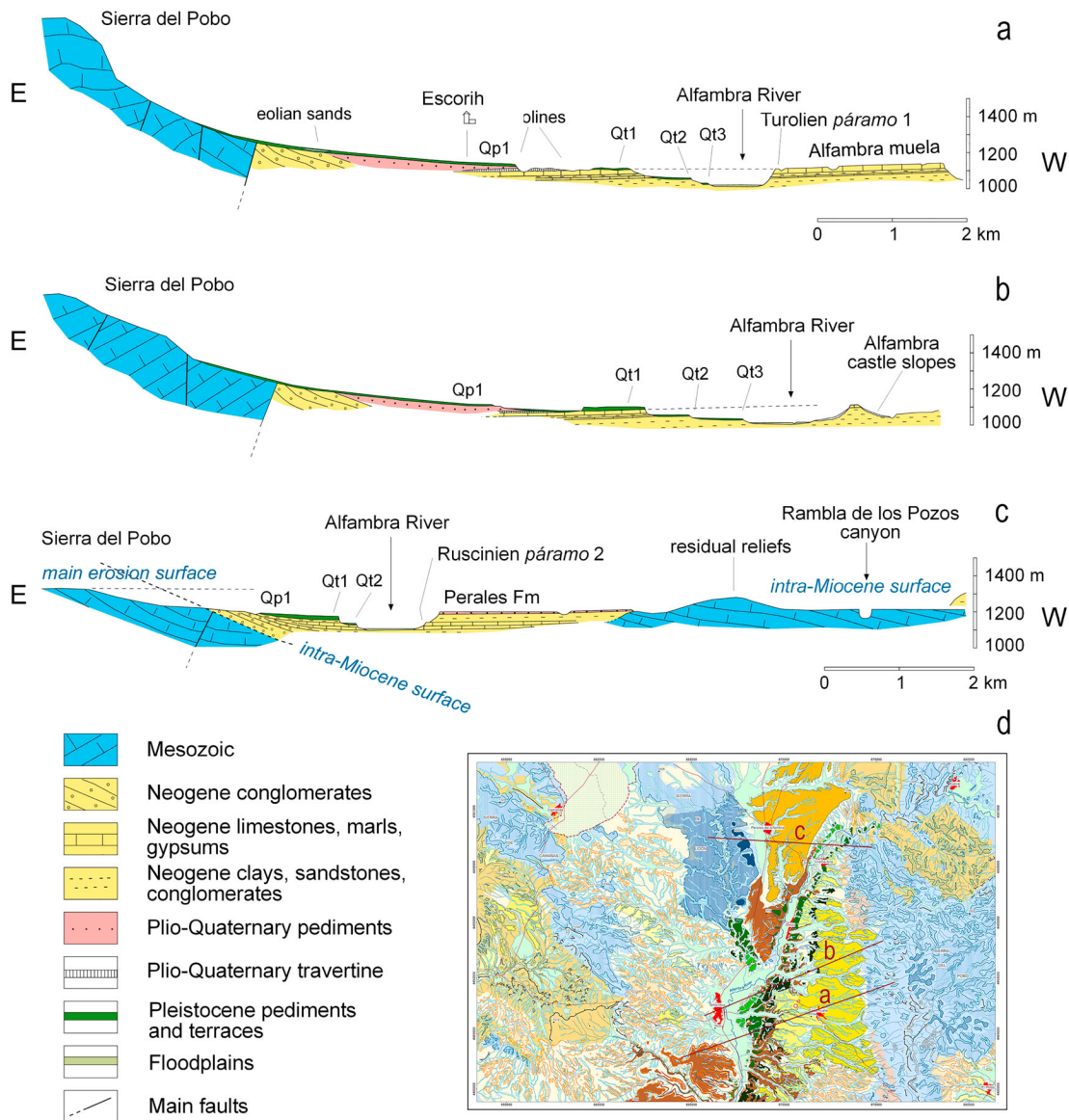


Figure 2. Geological/geomorphological cross-sections of the Alfambra valley and the marginal Iberian ranges; (a) E-W cross section in meridional sector and main features; (b) E-W cross-section in the center-south sector; (c) cross-section in the N sector: erosion surfaces and Pliocene units; (d) location of the cross-sections in the geomorphological map.

Sánchez Fabre, & Lozano, 2010) and Sierra de Gúdar-Maestrazgo (Lozano, 1988), and other sectors of the Iberian Ranges (Gutiérrez & Gracia, 1997). The largest flattening phase is named *main erosion surface of the Iberian Ranges*. (Peña Monné et al., 1984) but there is another older surface called the *intra-Miocene erosion surface* (Gutiérrez & Peña Monné, 1976). These surfaces especially affect carbonated rock, while the siliceous reliefs (Paleozoic and Early Triassic) remain as residual reliefs. Everything seems to indicate that the dissolution processes played an important role during their genesis (Lozano & Peña Monné, 2010). Although they must have initially been continuous surfaces, tectonic evolution later produced deformations and incisions by the river transformed them locally.

In an initial stage, the reliefs that were being created by compressive phases of the Alpine orogeny suffered an initial generalized flattening that corresponds with

the intra-Miocene erosion surface (Figure 3(c,d)). Later, this surface was made uneven by the extensional phases of the Miocene and it is preserved as a residual form in the highest relief of the Iberian Ranges and in the bottom of the resulting grabens (covered by Middle Miocene sediments). This last fact tells us the age (intra-Miocene) of this surface. This old surface can be observed in places where the fluvial network has exhumed it, as in the area of the railway bridge close to Alfambra (middle sector of the geomorphological map) (Figure 2(c)).

These extensional Miocene phases created a significant unevenness that was gradually eroded while the endorheic grabens were filled with these materials. This process gave place to the development of the main erosion surface that supposed the almost complete leveling of the ranges in topographic continuity with the Middle-Late Miocene (Ruscinian) limestone



Figure 3. (a) Neogene platform (*muela*), with resistant limestone scarps (*páramo* 1, Turolien) and slopes in the clayey foots. Holocene accumulations are covering the slopes; (b) scarps of the Ruscinien limestones (*páramo* 2) in Villalba Alta sector; (c) and (d) intra-Miocene erosion surface; (e) main erosion surface of the Sierra del Pobo and Quaternary terraces of the Alfambra River.

levels (*páramo* 2) (Peña Monné et al., 1984). This correlation erosion surface-*páramo* enables its chronology to be established. The surface was later leveled by a new extensional phase that also affected the Ruscinian *páramo*. In the *Main Map*, this surface occupies a large extension in the upper part of the Sierra del Pobo (Figures 2(c) and 3(e)) and in the Sierra de Camañas, with unevenness due to faults.

4.3. Karst landforms

A large volume of limestone together with erosive surfaces and limestone platforms are favorable factors for the development of karst morphologies. There are also gypsiferous marls and gypsums in some Neogene

accumulations that are equally favorable for dissolution processes, although not comparable with the morphologies developed in the south with the gypsums from Villalba Baja and Teruel (Gutiérrez, 1998; Gutiérrez, Sánchez Fabre, & Peña Monné, 1985; Sánchez Fabre, 1989). The main karstic area is in the alluvial dolines of Escorihuela (Gutiérrez & Peña Monné, 1976; Sánchez Fabre, 1989). These dolines were developed over bedrock composed of Miocene gypsum and gypsiferous limestones and marls that were covered by detrital accumulations of the pediments developed in the piedmont of the Sierra del Pobo. The area also has tuff layers, probably from the Final Pliocene age (Moissenet, 1985). The main dolines have a funnel (Figure 4(a)) and pit (Figure 4(b)) shapes generated

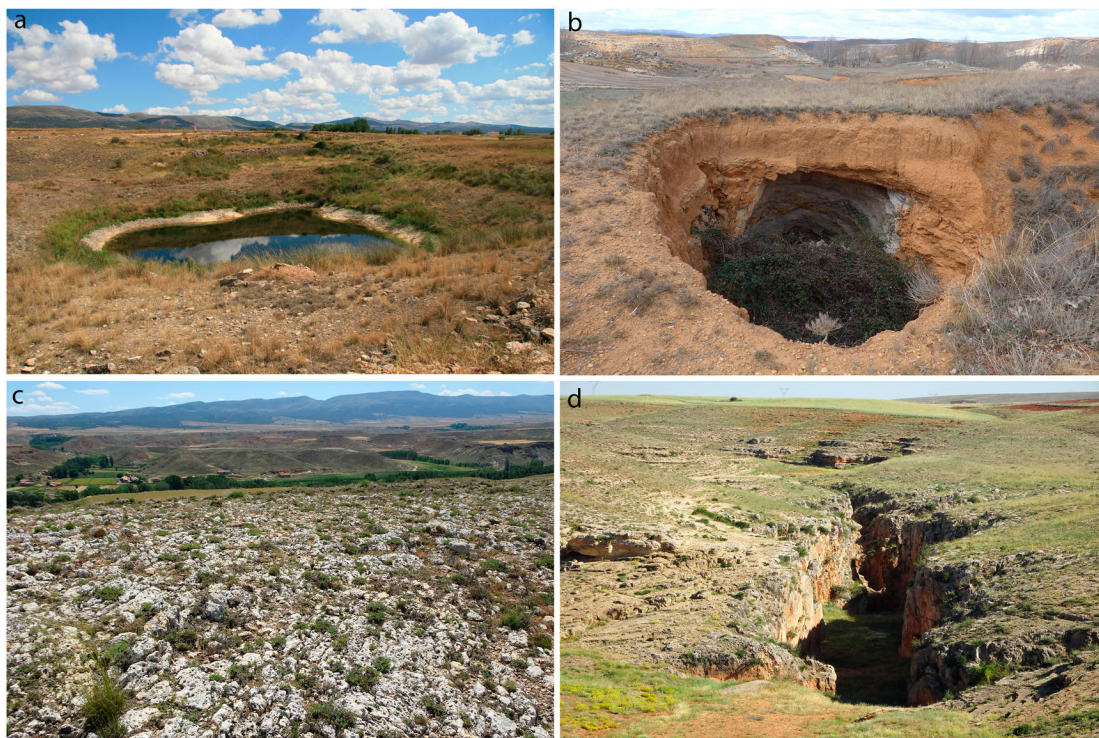


Figure 4. Images of karst morphologies: (a) Funnel shaped alluvial doline of Escorihuela temporarily flooded after intensive rains (September 2011); (b) alluvial pit doline at Los Aljezares of Escorihuela (gypsum quarries). See the Quaternary deposits and the inner cavity in the Neogene gypsums; (c) karren field over the Pliocene limestone platforms (Orrios sector); (d) fluvio-karstic canyon cutting the intra-Miocene erosion surface at Rambla de los Pozos.

by cave collapses (although some are bowl-shaped dolines). The greatest density and karst activity is in the Los Aljezares of the Escorihuela sector.

Moreover, the southern area of the polje of Lidón-Visiedo (Sánchez Fabre, 1989) is to the NW of our study area. The center of this polje is outside the present cartography. These types of fluvio-karstic morphologies are very common in the Eastern Iberian ranges, developed over Mesozoic carbonated lithologies, and favored by the structures created during the late distensive phases (Peña Monné, Jiménez, & Echeverría, 1989).

On the surfaces of the Neogene platforms (*páramo* 1 and 2) the most relevant karst landforms are small bowl-shaped dolines and structural (*Kluftkarren*) and oquerous *karren* (*Holhkarren*) (Figure 4(c)) that are typical of the covered karst by formed karst crytcorrosion processes. Finally, it is necessary to highlight the presence of a fluvio-karstic canyon about 7 km long developed over the intra-Miocene surface and located between Perales and Alfambra. The incision, embedded in the Jurassic limestones, has a meandering shape reaching 20–40 m depth with steep walls (Figure 4(d)).

4.4. Quaternary accumulation forms

The most relevant Quaternary accumulations are located in the Alfambra River valley and in the wide piedmont on its left margin, at the foot of the Sierra

del Pobo. These accumulations started after the Upper Pliocene extensional phase when the exorheism of the graben began together with the incision of the Alfambra River over the surface of the Perales Fm (Figure 2(c)). This incision is currently 110 m deep (Figure 5(a)).

The accumulation is due to a succession of climatic change phases that favor the dominance of accumulation processes on the bottom valley incision while pediments and alluvial fans from the Sierra del Pobo were active. It is also possible that the Sierra del Pobo fault has activated these fluvial dynamics.

The Alfambra River has developed a stepped fluvial terrace system composed of three levels located at +70–80 m (Qt1), +35–40 m (Qt2), and +15–20 m (Qt3) over the present floodplain (Sánchez Fabre, 1989). The complete set of terraces is located between Alfambra and Escorihuela and in the sector between Orrios and Villalba Alta (Figure 3(e)). The terraces are composed of very heterogeneous gravels of varied lithology in a clayey-sandy matrix with sand lenses. The highest and middle terrace is strongly cemented with carbonates forming a compacted and resistant conglomerate.

There are two levels of lateral pediments (Qp1 and Qp2) descending from the Sierra del Pobo that are connected with the upper (Qt1) and the middle (Qt2) terraces respectively. The deposit of the pediments, at 2–6 m of thickness, is composed of angular limestone



Figure 5. Images of the Quaternary forms and deposits: (a) scarp on Pliocene-Quaternary gravels of Perales Fm, N section of the Alfambra River valley (Villalba Alta); (b) deposits of the Qp1, discordant over Jurassic limestones of the Sierra del Pobo; (c) profile of the Escorihuela upper pediment (Qp1). See the aeolian sand lenses with carbonated plant-root structures among the gravel channels; (d) tectonic deformations affecting the Qt1 terrace at Escorihuela; (e) stepped Quaternary pediments and terraces of the Alfambra River in the north sector (Villalba Alta); (f) Qt3 fluvial terrace over reddish Neogene deposits.

gravels. The most extensive pediment (see the [Main Map](#)) is the upper one (Qp1) and whose apical zone penetrates from embayments and erosive surfaces on the sides of the range ([Figure 5\(b\)](#)). Its average surficial gradient is about 4% and it has been significantly hardened by carbonates. One relevant feature is the existence of aeolian sands interbedded among the channel gravels of the pediment. These sands have several carbonated plant-root structures ([Figure 5\(c\)](#)). This disposition is related with a waddi type functioning, as proposed by [Gutiérrez and Peña Monné \(1976\)](#) and [Carrillo and Gisbert \(1979\)](#). The middle pediment (Qp2) is located closer to the Alfambra River and linked with the Qt2 terrace. It has an average gradient of 2% and has carbonated crust levels that form steep scarps over the Alfambra River between Orrios and Villalba Alta. In some valleys it is possible to

distinguish a lower pediment (Qp3), as in the El Pobo locality and to the west of Alfambra. It is also possible to observe large deformations in the accumulations of the pediments and terraces, especially in the Qt1 level, that are affected by faults and foldings ([Figure 5\(d\)](#)) – as well as altitudinal changes due to neotectonics ([Peña Monné et al., 1981](#)). The Qt2 forms a step 35–40 m over the Alfambra River, normally lying on the Neogene limestones or conglomerates ([Figure 5\(e\)](#)). The Qt3 is forming a 15–20 m lower step lying over the Neogene detrital ([Figure 6\(f\)](#)).

Finally, it is necessary to highlight the slope accumulations at the foot of the Neogene limestone scarps, close to the main river. [Biro \(1963\)](#) points to the presence of regularized slopes and associates these with cold Pleistocene stages. The geoarchaeological studies made by [Burillo et al. \(1981, 1983\)](#) in

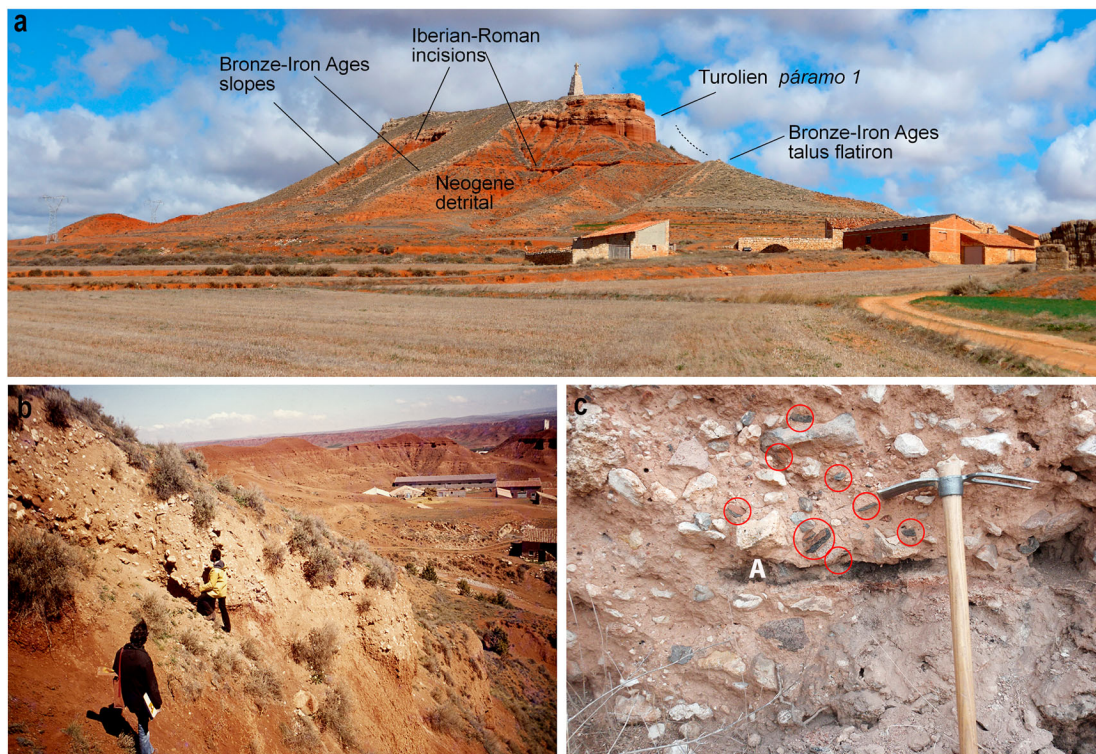


Figure 6. Holocene slopes: (a) Residual hill of the Alfambra castle. Note the slope accumulations after the Bronze and Iron Ages and the subsequent badlands incisions that produce residual talus flatirons; (b) cross-section of the Holocene slope deposits; (c) detail of the archaeological features included in the slope deposit (Bronze and Iron Ages potsherd, in circles, and ash levels: A).

Alfambra castle hill (Figure 6(a)) show that the main slope accumulation phase was the Upper Holocene (Figure 6(b)), specifically the Iron Age Cold Phase as the ceramic content in the accumulations belongs to Bronze and Iron Ages (Figure 6(c)). The presence of residual talus flatirons (Figure 6(a)) suggest that this slope must have previously covered all the slopes. This accumulative stage is generalized in the NE of Spain. It also appears to be affected by later incisions corresponding to a warmer and drier phase starting after the Iberian-Roman Epoch (Peña Monné, 2018).

5. Conclusions: the evolution of the relief

The chronological order of the different components represented in the Main Map enables us to establish the most significant features of the relief evolution. The oldest landforms correspond to those erosion surfaces with good conservation that determine a generally smooth relief only rejuvenated by the incision of the fluvial network (the most scarped features being near rivers).

The compressional phases of the Alpine orogeny (Upper Oligocene-Early Miocene) have folded and faulted the Mesozoic sediments of the Iberian Ranges, and this erosive process has formed the *intra-Miocene erosion surface* whose formation was ended by the Middle Miocene.

A first extensional phase (Middle Miocene) reactivated the faults and compartmentalised the erosive

surface by uplifting the mountainous massifs and forming the Alfambra-Teruel Graben. The resulting topographic unevenness gave place to a cycle of active erosion-accumulation during the Neogene with the formation of a new erosion surface in the ranges (*the main erosion surface of the Iberian Ranges*). At the same time, the infill of the endorheic graben was produced. These infills are composed of the Neogene detrital and evaporitic materials and in this sector they reach until the Middle-Upper Pliocene (Ruscian) (*páramo 2*). The main erosion surface that is laterally linked with the Neogene infill produced a new dominance of flattened forms within the range.

A new extensional reactivation during the Pliocene provoked a new subsidence of the eastern side of the Alfambra graben and so created a semigraben. The Sierra del Pobo was also uplifted by strong tectonic tilting of the main erosion surface. The first sedimentary accumulation indicating the exorheism of the basin is the formation of the pediment of the Later Pliocene Perales Fm.

A fluvial network was incited in the semigraben and started a new erosion-sedimentation cycle during the Quaternary. The fluvial terraces of the Alfambra River and the extended pediments of the Sierra del Pobo piedmont are records of the Pleistocene evolution driven by climatic change, and to lesser degree, by tectonic activity. As the incision progressed, the Neogene platform was modeled and its slopes contain mainly stages of the Holocene evolution.

Software

The **Main Map** was made using ArcGIS 10.1.

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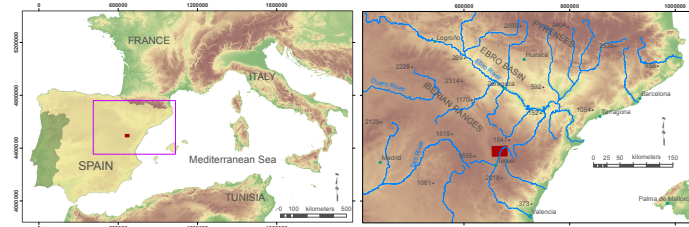
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GEOMORPHOLOGICAL MAP OF THE NORTHERN SECTOR OF THE ALFAMBRA-TERUEL DEPRESSION (IBERIAN RANGES, SPAIN)

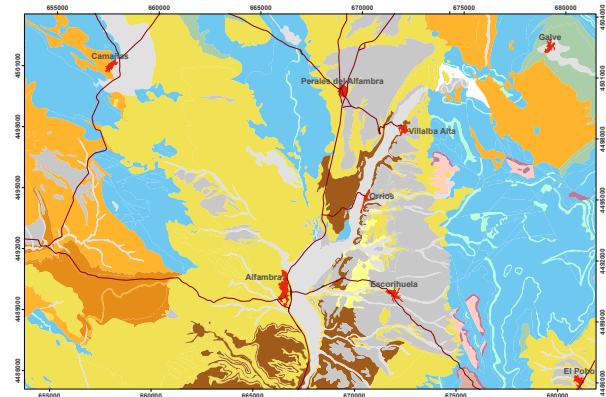
Miguel Sánchez-Fabre, José Luis Peña-Monné and María Marta Sampietro-Vattuone



LOCATION MAP



LITHOLOGICAL UNITS

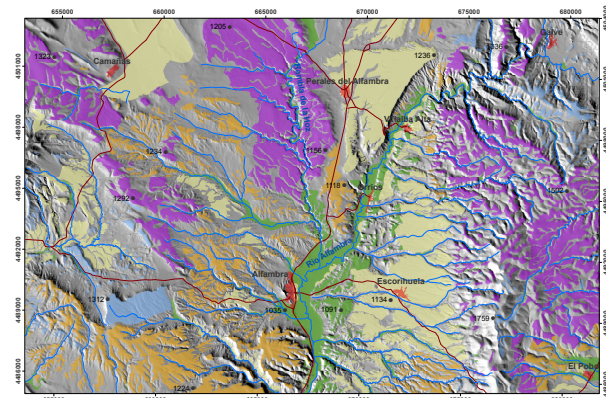


Based in Godoy et al. (1983): Mapa Geológico de España 1:50000, serie Magna. Hoja 542 (Alfambra). I.G.M.E.

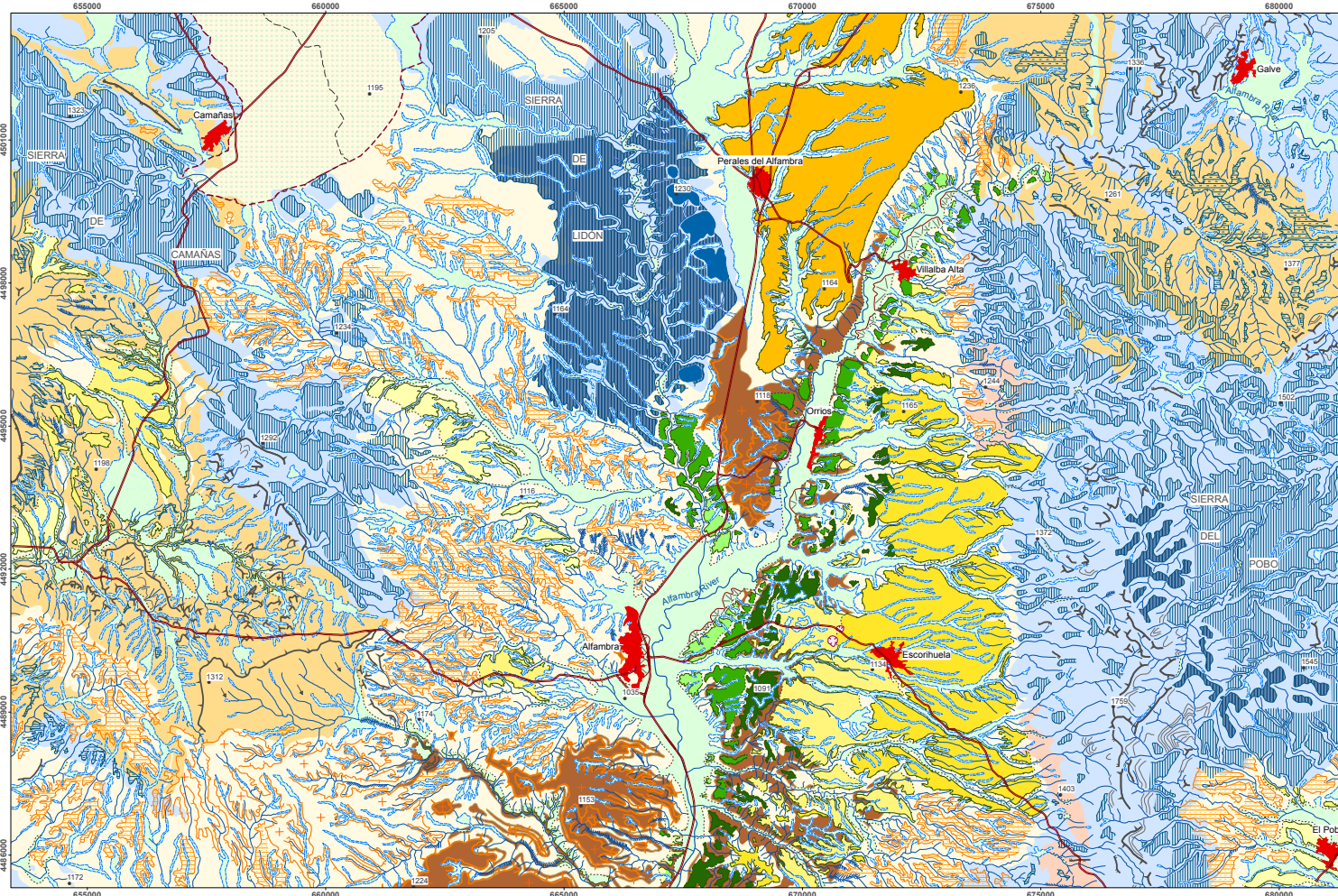
Mesozoic sandstones and clays	Holocene detrital sediments
Mesozoic marls	Plio-Quaternary and Pleistocene detrital sediments
Mesozoic limestones	Neogene gypsums and marls
Upper Triassic (Kruper) clay and gypsums	Neogene limestones
Triassic dolostones	Neogene conglomerates, sandstones, and clays
Lower Triassic (Bunt) sandstones	Paleogene conglomerates, sandstones, and clays

Legend: Localities (red star), Roads (red line), Scale: 0 1 5 kilometers.

GEOMORPHOLOGICAL UNITS



Legend: Pediments, alluvial fans, and infill valleys; Fluvial terraces; Mesozoic and Paleogene structural reliefs; Neogene structural reliefs; Erosion surfaces; 1234 Altitudes; Fluvial network; Localities; Roads; Scale: 0 1 5 kilometers.



GEOLOGICAL BEDROCK

- Neogene limestones, marls, and gypsums
- Neogene conglomerates, sandstones, and clays
- Paleogene limestones, marls, and detrital materials
- Cretaceous-Jurassic limestones, marls, sandstones, and clays
- Triassic clays, gypsums, dolostones, and sandstones

STRUCTURAL RELIEFS

- Cuesta reliefs
- Chevrons
- Hogbacks
- Mesozoic-Paleogene reliefs
- Structural platforms in Neogene (mesas)
- Neogene reliefs

KARSTIC MORPHOLOGIES

- Alluvial dolines
- Polje outline
- Polje infills

EROSION SURFACES

- Intra-Miocene erosion surface
- Middle-Upper Pliocene main erosion surface
- Residual reliefs
- Scarps of the erosion surfaces

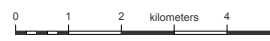
FLUVIAL NETWORK

- Main river (Alfambra River)
- Incised fluvial network
- Flat bottom valleys

PLIO-QUATERNARY AND QUATERNARY ACCUMULATIONS

- Pediment, alluvial fan, and infill valleys**
- Plio-Quaternary pediment
 - Pleistocene pediments (Qp1)
 - Pleistocene pediments (Qp2)
 - Pleistocene pediments (Qp3)
 - Alluvial fans
- Fluvial terraces**
- Pleistocene fluvial terraces (Q1)
 - Pleistocene fluvial terraces (Q2)
 - Pleistocene fluvial terraces (Q3)
 - Floodplains and infilled valleys
- Others**
- Scarpmnts in pediments and terraces
 - Internal limits of the deposits

- Localities
- Roads
- Altitudes



COORDINATE SYSTEM
 Hoja 542 (Alfambra), Mapa Topográfico Nacional 1:50000, Instituto Geográfico Nacional (IGN)
 ETRS_1989_UTM_Zone_30N
 Projection: Transverse Mercator
 Geographic Coordinate System: GCS_ETRS_1989
 Datum: D_ETRS:1989
 Linear Unit: Meter
 Angular Unit: Degree
 Latitude of Origin: Greenwich Meridian