Geomorphology of the Valdegovía valley (Basque-Cantabrian Basin, Northern Spain): an example of a sub-Mediterranean, low-mid mountainous, structurally controlled area

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ABSTRACT
A detailed geomorphological map at 1:25,000 scale is presented for the Valdegovía valley (Álava, Northern Spain), located at the central zone of the Basque-Cantabrian Basin. The map has been developed after several field surveys, with the aid of GIS techniques and high resolution digital terrain models (DTM) derived from LiDAR datasets. The high resolution LiDAR DTMs have revealed uncountable ground features and slope breaks that frequently are hidden by dense forests. Considering the tectonic control and the current sub-Mediterranean climate of the studied area, most landforms and deposits in the Valdegovía valley respond to lithostructural, gravitational, karstic, fluvial, and anthropogenic morphogenesis. We conclude that the geomorphological evolution of the Valdegovía valley has been strongly conditioned by a structural control related with two main NW-SE trending asymmetric folds.

1. Introduction

The Valdegovía valley (342 km²) is a sparsely populated rural area (4 people/km²), which extends along the border of Álava and Burgos provinces (Northern Spain). It is characterized by a low-medium mountainous physiography (elevations range from 471 m a.s.l. to 1367 m a.s.l.), defined by a NW-SE trending ranges (Bóveda–Arcamo, Peña Lisa–Olvedo, Recuenco–Peña Goea, and Anderejo–Arcena). Hydrologically, it corresponds with the Omecillo and Purón sub-watersheds, located in the NW zone of the Ebro basin (see the altimetry and location sketch in the geomorphological map). The climate is sub-Mediterranean, which explains temperate annual mean temperatures (10–12°C) and relatively high precipitation values (650–1000 mm). Several areas of this valley show great valuable scenery and environmental potential, being included into the Natural Parks of Valderejo and Montes Obarenes–San Zadornil, and also into the Natura 2000 network (e.g. Sierra de Árcena, Sobrón, Arcamo, Ebro and Omecillo).

Previous geomorphological studies in Valdegovía are scarce and fragmentary. A first research was carried out by Adán de Yarza (1885), who provided the first detailed geological data for the whole Álava province, which would in turn constitute the basis of the future geoscientific studies of this area. Later, Hazera (1968) described and delineated the main cuestas of this sector of the Basque-Cantabrian Basin. More recently González-Amuchastegui (1993), González-Amuchastegui and Serrano (2014) studied in detail the travertine deposits of the Purón river. Finally, González-Amuchastegui and Soria (2012) and Soria (2014) studied in detail the fluvial terrace system and related glacs of the Ebro river in the close Miranda Basin. Previous geomorphological maps have been developed only for the nearby areas, i.e. Tobalina valley (González-Amuchastegui & Serrano, 1996; Ortega, 1974). In order to fill this cartographic gap, we present a new geomorphological map with the aim of identifying the main landforms in the Valdegovía valley and, furthermore, understanding their morphogenetical and morphostructural framework. The applied methods and obtained results in the framework of this geomorphological map are intended to be the basis for the forthcoming geoscientific mapping of the Basque-Cantabrian Basin.

2. Geological context

Geologically the Valdegovía valley is located in the western edge of the Pyrenees, concretely close to the southern limit of the Basque-Cantabrian Basin (Figure 1). The southern limit of this basin, which
locates 20 km towards the South, is constituted by the Sierra de Cantabria-Obarenes thrust, representing the limit with the Tertiary Ebro basin (Ábalos, 2016; Gabaldón, García Portero, & Fernández Carrasco, 1991; Morales Rodríguez, 2000; Ramírez del Pozo, 1973). The study area includes from the NE to the SW the following three structural main domains (Gabaldón et al., 1991; Robles, 2014): (1) the Alava platform, (2) the Miranda-Treviño syncline, and (3) the Valderejo-Sobrón anticline. These domains are characterized by a NW-SE trending folds and faults, that have conditioned the main fluvial valleys and ridges, and the subsequent structural control (García Fernández, 2006) of the landforms in this region (e.g. García Fernández, 1981; Junquitu, 2015). It is also noticeable the salt tectonics control in the genesis and geodynamic evolution of the aforementioned main folds (e.g. Valderejo-Sobrón anticline); indeed, salt diapirs (e.g. Salinas de Rosío, Salinas de Añana) appear aligned along a N120E direction (Eguíluz & Llanos, 1988).

The Valderejo-Sobrón anticline is a N120E trending asymmetric fold, where the SW limb shows a moderate dip, whereas the NE limb is upright to vertical. This asymmetry is interpreted to be related with halokinetic
movements (pers.comm. Eguíluz, 2017). The rocky materials outcropping in the study area are varied, but principally most of rocks correspond with Mesozoic-Cenozoic carbonate rocks overlying the Keuper evaporites (Frankovic, Eguíluz, & Martínez-Torres, 2016; Ramírez del Pozo, 1973; Robles, 2014). The Jurassic sequence is constituted by marls and limestones, but only crops out in the innermost areas of the Valderejo-Sobrón antcline (1 km to the SW from the Nograro village). Unconformably onto the Jurassic limestones, the Albian-Lower Cenomanian sequences (Valmaseda formation; 1500–3000 m thick) consist of alternating sands, sandstones, and micro-conglomerates; this unit passes upwards to Cenomanian limestones, the Albian-Lower Cenomanian sequences are overlied by a carbonate sequence that but principally most of rocks correspond with Mesozoic-Cenozoic carbonate rocks overlying the Keuper evaporites (Frankovic, Eguíluz, & Martínez-Torres, 2016; Ramírez del Pozo, 1973; Robles, 2014). The Jurassic sequence is constituted by marls and limestones, but only crops out in the innermost areas of the Valderejo-Sobrón antcline (1 km to the SW from the Nograro village). Unconformably onto the Jurassic limestones, the Albian-Lower Cenomanian sequences (Valmaseda formation; 1500–3000 m thick) consist of alternating sands, sandstones, and micro-conglomerates; this unit passes upwards to Cenomanian limestones, the Albian-Lower Cenomanian sequences are overlied by a carbonate sequence that including the Gárate formation (350–400 m thick Turnonian limestones and marly limestones), the Zuazo marls (Turonian-Lower Coniacian; 200–350 m thick), the Subijana limestones (Coniacian; 350–500 m thick), the Osma marls and marly limestones (Santonian; 350–500 m thick), the Bóveda calcarenites (Upper Santonian; 100–200 m thick), and finally the Basabe marls and marly limestones (Lower Cenomanian; 100–200 m thick). The siliceous detrital sedimentation started in the Upper Campanian, and is represented by a 50–100 m thick sequence of alternating reddish sandstones and siliceous sandstones, microconglomerates and, at the top, sandy limestones. Finally, the Maastrichtian is represented by bioclastic limestones and white dolomitic limestones (a 30–40 m thick unit).

The Paleocene marine deposits (140–160 m thick unit) consist of an alternating sequence of marls and dolomites (Baceta, 1996). Tertiary continental deposits (up to 300–350 m thick) are made up of conglomerates (Pobes formation), silts, siltstones, and calcarenites. These materials appear unconformably overlying the Paleocene marine succession. Finally, the sedimentary register culminate with Miocene lacustrine–palustrine marls and white limestones (up to 200–250 m thick). The Quaternary sedimentation is mainly related with fluvial deposits (terraces of the Omecillo river) and also with gravitational and polygenetic landforms.

3. Methods

The 1:25,000 geomorphological map of the Valdegovía valley (Main Map) was implemented after several field surveys (from 2012 to 2015). Approximately a thousand observation points were logged, analysed and georeferenced with the aid of a GPS unit (Garmin GPS Map 60C) and later with a smartphone provided with an A-GPS chipset and the OruxMaps free software. A significant amount of geotagged photos was also taken with a built-in GPS camera (Sony DSC-HX400 V) in order to document landforms that were assessed in the field. The data were collected in the GIS as point shapefiles and integrated with the supplementary cartography into the same map project. This additional cartography included: (1) orthophotos of different flight programmes of Diputación Foral de Álava (2 m/pixel; 1957), and Basque Country Government (0,25 m/pixel; 2009, 2012); (2) 1:5000 topographic maps in CAD format of Diputación Foral de Álava and Basque Country Government; (3) 1:50,000 geological map of the sheets 110 (Martín, Ramírez del Pozo, & Carreras, 1977), 111 (Del Olmo, Ramírez del Pozo, & Tomás, 1977), 136 (Olivé, Aguilar, & Ramírez del Pozo, 1978), and 137 (Olivé, Ramírez del Pozo, & Riba, 1978) of the MAGNA series, edited by the Instituto Geológico y Minero de España (IGME); and finally, (4) 1:25,000 geological map of the Ente Vasco de Energía, sheets 110-II-IV/136-II (Garrote, Muñoz, Fernández, Cerezo, & Zapata, 1992a), 111-I-III (Garrote, Muñoz, Fernández, Cerezo, & Zapata, 1992b) and 117-I-III (Garrote, Muñoz, Fernández, Cerezo, & Zapata, 1992c).

The main resource utilized in order to map field-assessed landforms was a high-resolution LiDAR DTM of the Basque Country Government (1 m/pixel; 2012), which was used as well to recognize many terrain features or slope breaks that were unrecognizable – usually hidden under dense forests – in landscape scenes. Additional morphometric and morphographic data was extracted from the LiDAR DTM, including slope maps, hillshading models, topographic profiles, 3D scenes and relative elevation differences between landforms.

Mapped landforms were classified according to the geomorphological legend proposed by the IGME (Martín Serrano, Salazar, Nozal, & Suárez, 2004). Considering the marked litho-structural control in the Valdegovía valley, the IGME legend system has been assessed as the most suitable one in order to perform the map, providing specific symbols for most of the lithologies and morphogenetical systems of the mapped area. This legend has been also satisfactorily applied in other nearby areas like the Sierra de Aracil (Benito-Calvo, Tarriño, Lobo, Junguitu, & Larreina, 2010) and the Sierra de Atapuerca (Benito-Calvo & Pérez-González, 2015). With regards to the current study, some specific modifications were introduced in the IGME legend for a more detailed differentiation of both litho-structural and anthropogenic landforms.

4. Geomorphology

The geomorphological evolution of Valdegovía was initiated and mainly determined by the Alpine orogeny (Teixell, 2004), that formed the main ridges and elevations in the Basque-Cantabrian basin during the
Paleogene. The structural evolution of this area carried out the development along the southern edge of the Basque-Cantabrian basin the endorheic Ebro proto-basin (Eocene/Oligocene; Martínez-Torres, 1993, 1997). As a consequence of the opening of the endorheic Ebro Basin (Nichols, 2004) towards the Mediterranean Sea, sedimentation in the tertiary basin of Miranda-Treviño was finished (Late Pliocene; Arche, Evans, & Clavell, 2010). Alpine deformation generated NW–SE trending asymmetric folds of relatively large amplitude (8–12 km), with southern limbs dipping less (up to 40°) than northern ones (up to 90°). As a consequence of this structural configuration the main landforms of studied area correspond to a folds-model relief. According to the previously exposed relevance of the structural control of the studied area, the landform description and classification followed the main morphostructural units. These units correspond to the different limbs and axial zones of (Figure 2): (1) the Valderejo – Sobrón anticline (VSA), (2) the Miranda – Treviño syncline (MTS), and (3) the Cuartango anticline (CA).

Superimposed to the above mentioned folds-model relief, fluvial incision along the Purón and Omecillo sub-watersheds has excavated the main valleys preferentially since the Late Tertiary, when lacustrine-palustrine sedimentation in the MTS finished. Lithological contrasts in the area have also promoted the development of wide karstic (e.g. in the coniacian thick limestones units) and gravitational landforms, which are described in detail later.

Considering the geomorphological – geological features described above, seven morphogenetic systems have been defined for the Valdegovía valley: lithostructural, fluvial, gravitational, karstic, polygenetic and anthropogenic.

a. Litho-structural

The main litho-structural landforms in the Valdegovía valley correspond to a folds-model relief that is governed by the limbs of the VSA and MTS (see above). Structural slopes are widely represented landforms as they coincide with the most resistant layers of the...
carbonate sequence (upper Coniacian-Paleogene). In this litho-structural context, large structural backslopes locate along the constant and gently dipping NE limb of the MTS, coinciding with the major cuestas where Upper Santonian calcarenites crop out (Bóveda range; Figure 3A). Along the SW limb of the VSA, where coniacian limestones show moderate and constant dips, structural backslopes are represented by hogbacks and typical chevon morphologies (e.g. the Lunada hill). This is in contrast to the NE limb of the VSA, where the same limestone units lay almost vertically forming outstanding bars in the Peña Goea range. Along both limbs of the VSA, structural backslopes locally show variable dips (coinciding with hinge lines), where ojivas are the most frequent landforms. In addition, in the western periclinal ends of the VSA and CA the coniacian limestones define also near horizontal to gently dipping (up to 15°) large structural slopes (e.g. Anderejo-Recuenco and Arcamo ranges) that have been significantly karstified (see 4d section). These structural slopes appear dissected by the quaternary fluvial incision, standing out the cataclinal fluvio-karstic gorges of the Árcena (excavated by the Purón river) and Bóveda ranges. It is also remarkable the cluse of Sobrón, where the Ebro river has completely dissected (with an W-E direction) the VSA near its SE periclinal end, and thus connected the Tobalina and Miranda-Treviño tertiary basins. On the other hand, several anticlinal valleys (e.g. combe of Valderajo, Figure 3C) and derived mounts (e.g. El Cacho, la Rasilla, and La Presa hills, Figure 3C) are placed along the hinge zone of the VSA (Figure 3C), whereas synclinal hills (e.g. Medropio and Yerdos) locate along the hinge zone of the MTS (Figure 3B). Joints and faults with morphological expression are particularly relevant in the Arcamo range, with the development of typical ‘bookshelf’ structures in the most competent limestone units.

**b. Fluvial**

The most relevant fluvial landforms identified in the studied area were generated by the Omecillo, Tumeclillo, and Purón rivers, and their auxiliary streams. The Omecillo river rises in the western periclinal end of the MTS and flows subsequently (very close to the sinclinal axis; Figure 3B), excavating less competent marls and siltstones (Upper Cretaceous–Tertiary). The Quaternary fluvial dynamics has developed a terraced alluvial plain in the continental Tertiary materials. Only two levels are identified in the Omecillo watershed: (1) the floodplain (T₀), and (2) a well preserved fluvial terrace (T₁) situated 5–7 m above the T₀. The best preserved sites of T₁ are located between the Villanueva and Espejo villages. The T₁ level appears 20–25 m below the pre-Quaternary planation surfaces (e.g. the Llano–Cuestavicente glacs and the Bellojín–Tuesta glacis), post-dating these surfaces. On the other hand, the Tumecillo river is characterized by small floodplains (locally abandoned), many cataclinal stretches (e.g. the Angosto gorge), and some abandoned channels (e.g. 2 km northwards the Osma village). The Purón river rises in the NW periclinal end of the Valderejo–Sobrón anticline, flowing nearly subsequently towards the southwestern limb of this structure, and finally cross-cutting it and forming the gorges of Purón. These gorges represent the pass-way to the Tobalina valley (Burgos) and the Ebro river. Along the gorges of the Purón, several travertine terraces and tufa buildings are located (e.g. González-Amuchastegui, 1993; González-Amuchastegui et al., 2000; González-Amuchastegui & Serrano, 2007). Finally, mixed alluvial–colluvial deposits occur frequently in the cataclinal valleys and dissected areas of the glacis (Figure 4B).

**c. Gravitational**

Gravitational landforms are predominantly located at the base of steep scarps defined by the Coniacian and Upper Santonian limestone units (e.g. Subijana Formation), though locally they also appear at the base of other competent units, as the Tertiary conglomerates (Pobes Formation) and the Albiano–Conenamian sandstones (Valmaseda Formation). Colluviums are widespread all over the Valdegovía valley, but considering the provided map scale (1:25,000), only those colluvial deposits thicker than 1 m had been delineated in the geomorphological map. The thickest colluvial accumulations (up to 5 m thick) are located next to the ridges, defined by the vertical dipping Coniacian limestones (e.g. Peña Goea range; Figure 4A), and at the base of the front of the hogbacks (e.g. Árcena range). These colluvial accumulations generally appear overlying the relatively less competent Turonian–Santonian marls.

Debris flows are representave landforms in the central areas of the Valderejo–Sobrón anticline (Figure 5), being spatially associated with the detritic Valmaseda Formation (Albian–Conenamian), standing out the following two significant allochthonous accumulations: (1) Several coalescent polycyclic debris fans, 2.9 × 1.1 km in size, at the NE slopes of the Árcena range (2.5 km southwestwards from the Nogroar town), and (2) a single debris flow deposit, 1.2 × 0.4 km in size, along the northern slopes of the Costoria hill (1 km westwards from the Barrio town). These accumulations have an estimated maximum thickness of 12 m in their distal zones and are generally composed by quartz grains and angular rock fragments (up to 6 cm) embedded into a sandy, locally silty, matrix.

Finally, rock avalanches and scree are common at the base of the steepest carbonated scarps (Coniacian
Santonian limestones). Several small landslides and solifluction areas (decametric in scale) were locally developed in relation with low competent Albian – Cenomanian sands and siltstones.

d. Karstic

The western periclinal ends of the Valderejo – Sobrón and the Zuazo anticlines coincide with large structural surfaces, where the highly competent Coniacian limestones crop out. In these areas, limestone layers are near horizontal or gently dipping (up to 15°), exhibiting three main joint systems (N140E, N100E, and N70E trends). Limestone weathering and dissolution processes have been particularly incident along these fractures, standing out the Anderejo – Recuenco and Arcamo ranges, where the most significant karstic landscapes are located. Exokarstic landforms of the near horizontally limestone areas are mainly represented by sinkholes clustered in large sinkhole fields, such as in the Coronas – Lerón (1.4 × 0.5 km) and the Campullido – Anderejo (1.9 × 0.7 km) karstic platforms; in these areas, limestone pavements are also significant. It is also remarkable the Navazúa endorheic depression (1 × 0.6 km; Arcamo range), representing a paradigmatic example of a karstic-tec-tonic polje filled with thin terra rossa deposits. Whereas the karstic areas developed in the gently dipping limestone layers (7°–15°) are mainly characterized by dissolution lines (bogaz). As occurs with the large scale karstic landforms, the joint systems have controlled the genesis of karren landforms, such as orthogonal fissures (klufkarren) and clints (rinnenkarren).

e. Polygenetic

Glacis represent the most significant polygenetic landforms of the mapped area. Their development
is constrained to the intermediate zone of the Omecillo watershed, where it crosses the fold axis of the Miranda – Treviño syncline. In this structural context, sub-structural slopes have been developed coinciding with gently dipping (up to 10°) beds at the base of the nearing elevations (Olvedo – Pelistornes in the north, and Los Castros – Berbeia in the west). The main glacis are located close to the Espejo village. Among them stand out the Bellojín – Tuesta and Llano – Cuestavicente glacis, which are 3.8 × 1.6 km and 1.4 × 0.6 km in size, respectively and with relative elevations of + 30–35 m and + 50–55 m above the current Omecillo river floodplain. From a morphometric point of view, the slope values of the glacis vary from 3–5° in the upper zones to 1–2° in the most distal areas. Generally, the proximal zones of the glacis constitute depositional landforms (0.5–1.5 m thick cover), whereas the distal areas are principally erosional. Because of the quaternary fluvial incision, glacis appear significantly dissected, being divided into several disconnected planation surfaces. The relative elevation of these planation surfaces might be related to the pre-quaternary endorheic Omecillo watershed. It is also remarkable that numerous reworked diapiric clasts (ophites and dolostones) are found in the distal zone of the Bellojín-Tuesta glacis. The presence of these clasts could be related with pre-quaternary evaporitic flows derived from the nearby Salinas de Añana diapir, which is located 2.5 km to the east.

Figure 5. LiDAR-derived hillshading 3D views of some relevant gravitational landforms located along the hinge zone of the Valdereso–Sobrón anticline. (A) Coalescent debris fans (AB) deposited at the NE slopes of the Árcena range. (B) Massive debris flow (DF) located in the N slopes of the Costoria hill.
f. Anthropogenic

The valuable archaeological heritage of the Valdegovía valley comprises profuse remains from the Bronze Age to the Middle Age (Instituto Alavés de Arqueología, 1987; Llanos, 1975; Quirós, 2009), which locate in several settlements (e.g. Castros de Lastra, Medropio, Villalpún, Castros de Berbeia, Tijuenzo, etc.). In these sites, considerable small scarp and slope breaks (of metric scale) have been identified with the aid of the LiDAR DTM. These relict landforms consist of abandoned agricultural terraces, currently hidden by dense scrubs or forests. Likely other nearby rural areas (Lasanta, Ábalos, B. (2016). Geologic map of the Basque-Cantabrian Basin, Burgos-Álava, Spain. Mapa Geológico de España a escala 1:50.000. Hoja 111 Orduña). In these sites, terraced landscapes (structural and non-structural), most of which coincide with relevant archaeological sites.

The applied methodology in this geomorphological map is intended to be the basis for forthcoming geological and geomorphological maps of the Basque-Cantabrian Basin. Finally, this contribution emphasizes the geodiversity of the mapped area, and could be useful for educational and divulgative purposes for the Protected Natural Areas of the Valdegovía valley.

Software

ESRI ArcGIS 10.2, as courtesy of the Servicio de Cartografía (SGIKER) of the University of the Basque Country (UPV-EHU), was used for LiDAR DTM construction, map digitizing and layout production. QGIS 2.16 has been used in order to obtain additional morphometric data (with the QProf extension). The creation of the final PDF layout has been implemented with Inkscape 0.92. Oruxmaps outdoor-GPS software was also utilized in fieldwork stages for waypoint collecting and multi-map offline visualizing, including LiDAR DTM.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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