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# PAST AND PRESENT GEOMORPHOLOGICAL HAZARD AND CULTURAL HERITAGE LOSS IN EL CASTELLAR CASTLE SCARP (CENTRAL EBRO BASIN, SPAIN)

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**ABSTRACT.** The ruins of the Medieval castle and village of El Castellar are located on an abrupt 1.2-km-long scarp of Miocene gypsums, in the central sector of the Ebro depression. The Medieval remains of the main El Castellar castle are perched on a 100 m cliff on the Ebro River. Considering the historical and geoarchaeological relevance of El Castellar settlement, this investigation aimed to study the geomorphological hazards and paleoenvironmental context of the site during and after the settlement and its later evolution, including its current state. To afford this objective the geomorphological context was determined analyzing the dynamics of each scarp sector. Geomorphological data suggest that in Medieval times its constructions were favored by the Medieval Climatic Anomaly (MCA) environmental conditions. During that times, the Ebro River was located in a centered position on its floodplain, and lateral alluvial fans protected the scarp from basal erosion. Later, during the Little Ice Age (LIA), great climatic flows and recurrent floods changed the river dynamics and promoted the river channel movement against the scarp, destabilizing its foot and generating large landslides and rockfalls, thus promoting its retreat. The village buildings and castle at the top of the scarp were seriously damaged. For several reasons, the area is not easily accessible, but it still contains a relevant archaeological heritage that deserves to be studied and preserved.

## *Riesgos geomorfológicos pasados y presentes y pérdidas de patrimonio cultural en el escarpe del castillo de El Castellar (Cuenca Central del Ebro, España)*

**RESUMEN**. Las ruinas del castillo medieval y villa de El Castellar se sitúan sobre un abrupto escarpe de yesos del Mioceno de 1,2 km de longitud, en el sector central de la Depresión del Ebro. Los restos medievales del castillo principal de El Castellar se alzan sobre un acantilado de 100 m sobre el río Ebro. Teniendo en cuenta la relevancia histórica y geoarqueológica del poblamiento de El Castellar, esta investigación tiene como objetivo estudiar los peligros geomorfológicos y el contexto paleoambiental del yacimiento durante y después del poblamiento y su evolución posterior, incluyendo su estado actual. Para lograr este objetivo se determinó el contexto geomorfológico analizando la dinámica de cada sector del escarpe. Los datos geomorfológicos sugieren que en Época Medieval sus construcciones se vieron favorecidas por las condiciones ambientales de la Anomalía Climática Medieval (ACM). En esa época, el río Ebro estaba situado en una posición centrada en su llanura de inundación, y los abanicos aluviales laterales protegían el escarpe de la erosión basal. Posteriormente, durante la Pequeña Edad del Hielo (LIA), grandes caudales y recurrentes inundaciones cambiaron la dinámica del río y promovieron el movimiento del cauce contra el escarpe, desestabilizando su pie y generando grandes derrumbes y desprendimientos, favoreciendo así su retroceso. Los edificios del pueblo y el castillo en la parte superior del escarpe sufrieron graves daños. Por varias razones, la zona no es de fácil acceso, pero aún contiene un importante patrimonio arqueológico que merece ser estudiado y preservado.

**Keywords:** MCA, LIA, slope dynamics, fluvial dynamics, geoarchaeology.

**Palabras clave:** Anomalía Climática Medieval, Pequeña Edad del Hielo, dinámica de laderas, dinámica fluvial, geoarqueología.

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## 1. Introduction

After fulfilling their military functions, many Medieval castles were not adapted to new roles, and were, therefore, gradually degraded by different natural or anthropic erosive processes (Gutiérrez-Carrillo *et al.,* 2020). The conservation of these patrimonial remains in rural areas must be supported by good arguments about their value and significance, and sometimes they can bring economic opportunities to local communities (Grimwade and Carter, 2000). Besides, the study of the surrounding landscapes, together with the historical and heritage importance of the sites, heightens visitors' expectations to learn about the area. These studies should be carried out by interdisciplinary teams because they require a deep understanding, documentation, and interpretation, as pointed out by the Xi'an Declaration (ICOMOS, 2005) for the conservation of heritage structures. The use of new technologies and the geomorphological study of the hazards affecting the structures and landscapes bring new perspectives to meet these goals (Canuti *et al.,* 2000; Gutiérrez-Carrillo *et al.,* 2020; Lazzari and Gioia, 2017; Uplekar, 2019; Versaci *et al.,* 2020).

The ruins of the Medieval castle and village of El Castellar are located on an abrupt 1.2-km-long scarp of Miocene gypsums, in the central sector of the Ebro depression (Fig. 1). This relief is part of a continuous 70-km-long scarp located at the north of Zaragoza city (Peña-Monné *et al.,* 2021). The Medieval remains of the main El Castellar castle are perched on a cliff of more than 100 m high over the Ebro River, being one of the most impressive landscapes of the Ebro depression (Fig. 2a).

The main scarp is the southernmost relief close to the Ebro River that had great strategic importance throughout the Middle Ages, constituting an offensive spearhead in the Aragonese conquest of the taifa city of *Saraqusta* (Zaragoza). Although El Castellar and other castles and towers may have been erected under the Islamic domain, the absence of archaeological studies does not allow us to support this hypothesis in all cases. Already in times of feudal rule, a fortified line of territorial control was consolidated, taking advantage of the escarpment on the Ebro. From NW to SE, this line includes the castles of Pola (or Pla), Santa Inés, and El Castellar, the Candespina tower, and the castles of Alfocea, Miranda, and Juslibol (Fig. 1). These castles and tower were gradually abandoned for different reasons, such as the scarp retreat, the loss of their strategic function, bad communication, social conflicts, among others. At present, they are severely damaged. Despite their historical importance, none of them were excavated. Only Juslibol was deeply geoarchaeologically studied (Peña-Monné *et al.,* 2014), and guidelines were proposed for its subsequent excavation, which was never conducted. Besides, a geoarchaeological and paleoenvironmental reconstruction was made in the surroundings of Miranda castle (Peña Monné, 1996), but without further interventions.

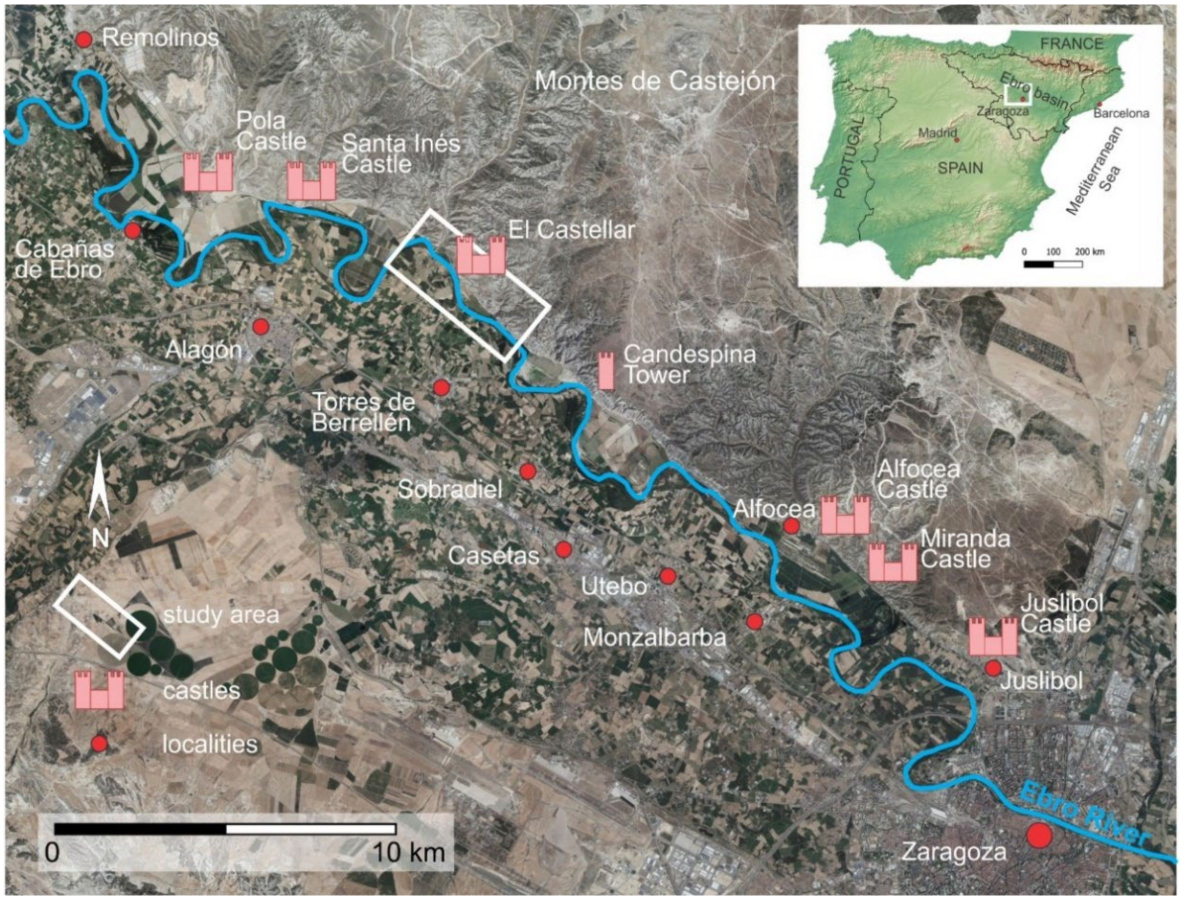


*Figure 1. Location of the study area in the central sector of the Ebro basin showing the line of Medieval castles on the gypsum scarp to the north of Ebro River.*

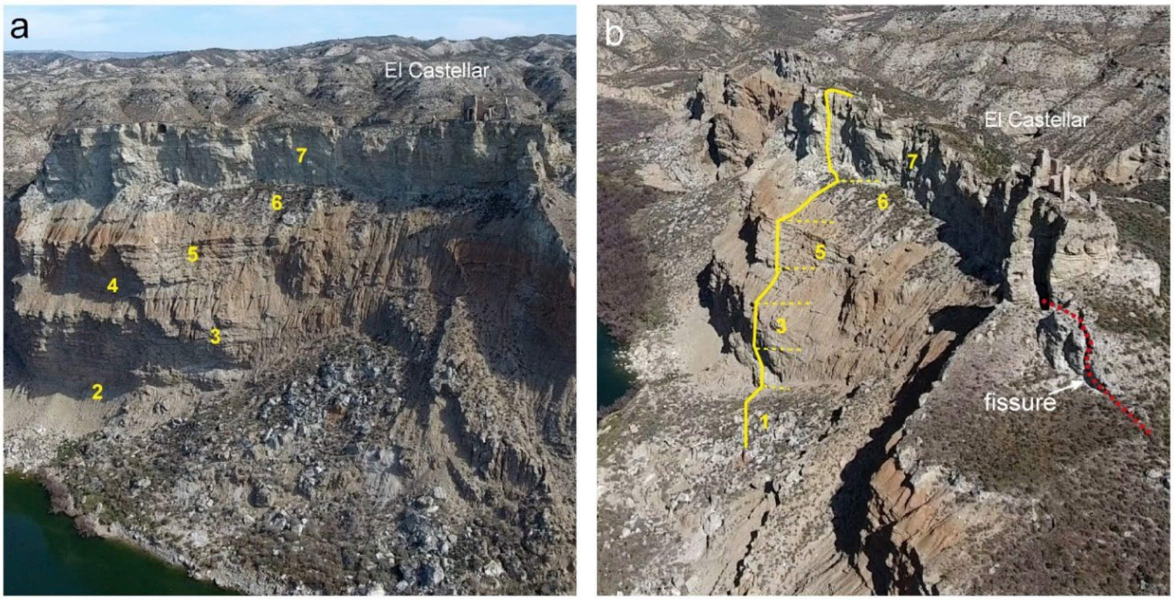


*Figure 2. Aerial views of the central sector of El Castellar scarp showing the stratified units of the Zaragoza Fm (see explanation in the text).*

Considering the historical and geoarchaeological relevance of El Castellar settlement, this study aimed to establish the geomorphological and paleoenvironmental context of the site during and after the settlement and its later evolution, and to assess its current state. The scarp retreat process and derived hazards were analyzed in terms of the Ebro River dynamics mainly during the Medieval Ages and the Little Ice Age (LIA). Besides, an evolutionary reconstruction was performed based on antique maps and documentation, together with different paleoenvironmental records (slope deposits, karstic depressions, and tributary infilled valleys).

### *1.1. Geological and geomorphological settings*

The scarp of El Castellar is part of the central sector of the Ebro Depression, formed as a southern foreland basin of the Pyrenees Ranges. From the Upper Eocene, the basin had an endorheic arrangement up to its opening to the Mediterranean during the Upper Miocene (Urgeles *et al.,* 2010). When the basin closed to the Mediterranean, the surrounding mountain ranges, especially the Pyrenees, contributed a large amount of sediment to fill the basin, forming large alluvial fans. The thick detritic accumulations of its margins changed to evaporitic formations on the distal sectors (Fm Zaragoza) and limestones (Fm Alcubierre) (Quirantes, 1978). The beginning of the exorheism produced the erosion of these deposits during the establishment of the fluvial network of the Ebro River, creating the present geomorphological landscape.

The gypsums of the Zaragoza Fm (Quirantes, 1978) are the main component of the Ebro scarp. They derive from the anhydrite, halite, and glauberite deposits (Gil Martín *et al.,* 1991; Salvany *et al.,* 2007). They are also interstratified with marls, clays, and sands. In the evaporitic unit, the limestones overlap, thickening towards the north (Montes de Castejón). The scarp of El Castellar sector is composed of the interbedded sequences of gypsums and lutites of the Zaragoza Fm, Middle Aragonian in age (Middle Miocene). This lithological cyclicality is the result of changes in the lacustrine environment where they sedimented (Gil Martín et al., 1991). Figures 2a and 2b show the lateral and frontal view of the stratigraphic sequence of El Castellar scarp. On the top, where El Castellar's defensive sector was built, the upper alabaster gypsums are severely fractured (7). Under this cover, the lutite layers (6, 4, 2) show erosive entrances alternating with more resistant levels of gypsum (5, 3, 1, the last one normally covered by the slope debris).

The main scarp shows an abrupt vertical front, sometimes overhanged, on the Ebro River channel. Its arrangement is almost rectilinear, sometimes interpreted as a result of tectonic influence (Van Zuidam, 1976; Ibáñez and Mensua, 1976; Pellicer *et al.,* 1984). Some authors have also related it to subsidence processes (Gutiérrez, 1998; Benito *et al.,* 2000). However, other authors hold that it is the result of the lateral fluvial erosion of the Ebro River meanders (Peña Monné, 1996; Guerrero and Gutiérrez, 2017; Peña-Monné *et al.,* 2021). Its detailed morphology stemmed from the activity of the slope processes triggered by the strong gradient, the fractures, and the lithology, as well as the basal erosion produced by the river. Thus, accumulations due to rockfalls, landslides, and rock-topple were described by several authors, such as Pellicer *et al.* (1984), Pellicer and Echeverría (1989), Gutiérrez *et al.* (1994), Constante (2009), and Lizaga *et al.* (2016).

The gypsum and limestone surface is affected by karstic depressions, studied by Van Zuidam (1976), Gutiérrez *et al.* (1985), and Constante (2009). They are flat valleys with imprecise edges, identifiable due to the presence of denser and more permanent vegetation than that of the surrounding areas. Many of them are poljes developed on gypsum captured by the stream network forming their headwaters in many cases. Over one of these poljes is located the Virgen del Castellar hermitage, also affected by the scarp retreat.

Along the gypsum scarp several ravines coming from the Montes de Castejón and the scarpment itself flow to the Ebro River (Peña-Monné *et al.,* 2021). In the study area highlights Val de la Virgen stream. This stream has a basin of 79 km$^2$, and its main channel is 19 km long and one of the few streams crossing the gypsum scarp. It is a torrential stream with a 2.6% gradient, and at present, it forms a small alluvial fan at its confluence with the Ebro River. In the middle and lower sections of Val de la Virgen stream, there are three stepped aggradation levels, which were formed during the Upper Pleistocene and the Holocene (Constante, 2009; Constante *et al.,* 2010). In the confluence with the Ebro River, alluvial fans were formed. At present, is only possible to find the Medieval stage fan, over which the La Magdalena hermitage was built, and the younger stage was formed during the late LIA ($18^{th}$-$19^{th}$ centuries).

Currently, this sector of the Ebro valley is characterized by semiarid environmental conditions typical of its continental Mediterranean climate. Average annual rainfalls reach 314 mm in Zaragoza, with equinoctial maximums and almost dry summers; the annual average temperature is 14.6ºC, ranging from 6.4ºC in January and 24.3ºC in July (Cuadrat, 2004). As a consequence, the water deficit is very high (around 1900 mm/year). This circumstance, together with the gypsum abundance and intense human impact on the vegetation cover, gives the scarp a truly arid appearance, with only gipsophilic species adapted to eptosol and gypsisol-type soils. Only on the floor of the wetter tributary streams are there abundant trees, such as those of the genus *Tamarix*.

## *1.2. The Medieval El Castellar site*

El Castellar scarp sector shows remains of Bronze, Iron, Iberian, and Roman occupations (Pérez Casas, 1987, 1990; Burillo, 1991; Pina Polo y Pérez Casas, 1998). However, El Castellar Medieval castle and village are the most remarkable archaeological remains. Their foundation, by the name of *Supra Cesaraugusta*, is documented in a 1091 diploma stamped by King Sancho Ramírez, giving population rights to a group of settlers and allowing the development of agricultural and sailing activities, along with the use of firewood. The owners of these rights also received a charter of legal freedom and exemption from manorial charges (Lacarra, 1985). In this epoch, El Castellar controlled a vast land bordering with Pola, Zuera, Castejón de Valdejasa, Tauste, Villanueva de Gállego, Alfocea, Alagón, and Sobradiel territories (Laliena Corbera and Iranzo Muñío, 2016).

The location of El Castellar village and castle was strategic not only due to its defensive capacity but also as a collecting point of the *paria* (tax charged to rural Muslim communities in the region) (Lacarra, 1985). This despoiled the taifa state of vital resources for the maintenance of the troops. Besides, it was the most advanced outpost, together with the Juslibol castle, for the siege of the Muslim city of Saraqusta, conquered in 1181 by Alfonso I "El Batallador" (The Fighter). By the mid-$15^{th}$ century, the fight between the Jiménez Cerdán, lords of El Castellar, and the city of Zaragoza had worsened and one of the city judges was murdered. This led to a raid in 1466 devastating several places in the surroundings of Torres de Berrellén, belonging to El Castellar. Although some researchers argue that the village and castle of El Castellar were destroyed, according to contemporary documentation this was not the case (Zurita, 1562-1580). However, in 1572, after a century of decline, El Castellar was depopulated. The subsequent degradation process, especially due to the main scarp erosive retreat, resulted in the present landscape.

In 1910, the San Gregorio National Training Centre was created (Tornero, 1999) in the area where El Castellar ruins are located, making it difficult to access the area and conduct archaeological research, although the area contains remains of great heritage interest (Fig. 3a). The ruins of the castle-palace lie on the highest area of the village, surrounded by defensive masonry towers (Figs. 3b, 3c) and a magnificent gateway built with brick and alabaster remains (Fig. 3d). To the south, a high precipice towards the Ebro River shows the unstable remains of the castle (Fig. 3e). The lowest part of the castle, on the northern slope, retains part of the wall. Also, on the scarp, there is part of a large cistern, named Doña Urraca Cave (Fig. 3f). The NE end of El Castellar (Fig. 3a) shows some walls of La Magdalena hermitage with a bay window and lobed arches (Fig. 3g). The cemetery was located in this area, and it was affected by the lateral erosion of the Ebro River and some graves are visible. Besides, a complex network of burial galleries excavated in the alluvial fan of Val de La Virgen is still preserved.


*Figure 3. a) Panoramic view of the northern and central areas of El Castellar scarp with remaining Medieval constructions; b) Northern façade of the main castle viewed from the lower wall; c) and d) remains of the defensive towers on the sides of the castle entrance and detail of the gateway; e) southern face of the main castle open to the scarp over the Ebro River; f) cistern (Doña Urraca Cave) hanging over the scarp; g) remains of La Magdalena hermitage.*

## 2. Methodology

First, a geomorphological map was made using 2014 and 2020 satellite images from Google Earth. They were complemented with 1956-1957 aerial photographs at a 1:32,000 scale (American Flight Series B, Army Map Service, USA), and aerial photographs of the National Flight from 1997 at a 1:40,000 scale. All images were digitized and georeferenced using QGIS v.3.14 to create a geographic information system. De Rodolphe (1746) and Coello (1853) historical maps were also georeferenced and introduced into the system to reconstruct the Ebro channel location over time since the LIA. Georeferentiation was made identifying a minimum of 20 homologous points applying a polynomial 1 transformation obtaining an error of about (X, Y) ≈ 5 m.

In order to improve field knowledge, an intensive field survey has been performed by stages since 2010 with permissions obtained from the military authorities. Besides, there are sectors only accessible through the Ebro River, which required using inflatable boats, to reach areas like the slope deposits at the foot of El Castellar scarp.

Historical documentation related to *Supra Cesaraugusta*-El Castellar were analyzed, from its foundation in 1091 to its depopulation, to relate the geomorphological evolution and the Medieval human occupation of the scarp.

## 3. Results

El Castellar scarp is NW-SE oriented and it extends 1.2 km between the outlet of Val de la Virgen ravine and Mina Real sector (Fig. 4a), at 280-290 m a.s.l. Its shape is not completely rectilinear, showing a soft convexity in its central sector (Fig. 4a), where the main castle of El Castellar is located at the top of the scarp. There are also two inbounds, one at Val de la Virgen ravine in the north and another on the scarp of Virgen del Castellar hermitage in the south (Fig. 4a). As shown in section I-I' (Fig. 4b), there is a strong topographic dissymmetry between the scarp front and the northern slope. The scarp is almost vertical and rises over 100 m above the Ebro River. It is the front of a tilted gypsum block limited towards the north by a fault. However, towards the NE, El Castellar has a smoother slope connecting the abrupt upper sector with the Barranco Conejero ravine (Fig. 4b). The top of the scarp shows four higher structural shoulders where the defensive remains of El Castellar are located, separated by smooth depressions, some of which were probably defensive moats.

In the northern sector of the study area, the Ebro River flows against the scarp section located at the west of Val de la Virgen valley and Peña Palomera hill, deviating towards the south, to return towards the scarp in the central sector, where El Castellar castle and village are located (Fig. 4a); then, the Ebro River flows separated from the scarp again in the southern sector, at the confluence with the Jalón River. This arrangement of the river concentrates all its hydraulic energy during floods in the central bulge. However, during the LIA, the river circulated fully attached to the escarpment along its entire length (Peña-Monné *et al.,* 2021), as shown on the De Rodolphe map (1746) (Figs. 4c, 5a). As a consequence, the entire scarp section was subject to intensive erosive activity during the $18^{th}$ century, in coincidence with a phase of high flows of the Ebro River. From 1850, the river channel gradually separated from most of the scarp (Fig. 5b), as shown by Coello's map (1853), until its current position (Fig. 5c). However, the strong step previously created by lateral river erosion left a highly unstable arrangement manifesting as mass movements such as landslides and rockfalls.

In the northern sector, a large alluvial fan was formed by Val de la Virgen stream during Medieval times (Fig. 6a). This fan was later eroded by the Ebro River meander developed towards the alluvial fan during the LIA, according to De Rodolphe's map (1746). During El Castellar occupation period, this sector of the alluvial fan was the cemetery around La Magdalena hermitage. The old alluvial fan profile shows burials on the upper 2 m of the silty deposit. Especially remarkable is the presence of large cists cut by the river, hanging on the alluvial fan profile (Figs. 6b, 6c) and next to the rocky outcrop on the right side of Val de la Virgen stream (Figs. 6b, 6d). Other tombs were identified on the surface of the alluvial fan, and burial galleries were excavated in the silts, as pointed out by Gascón (2007).

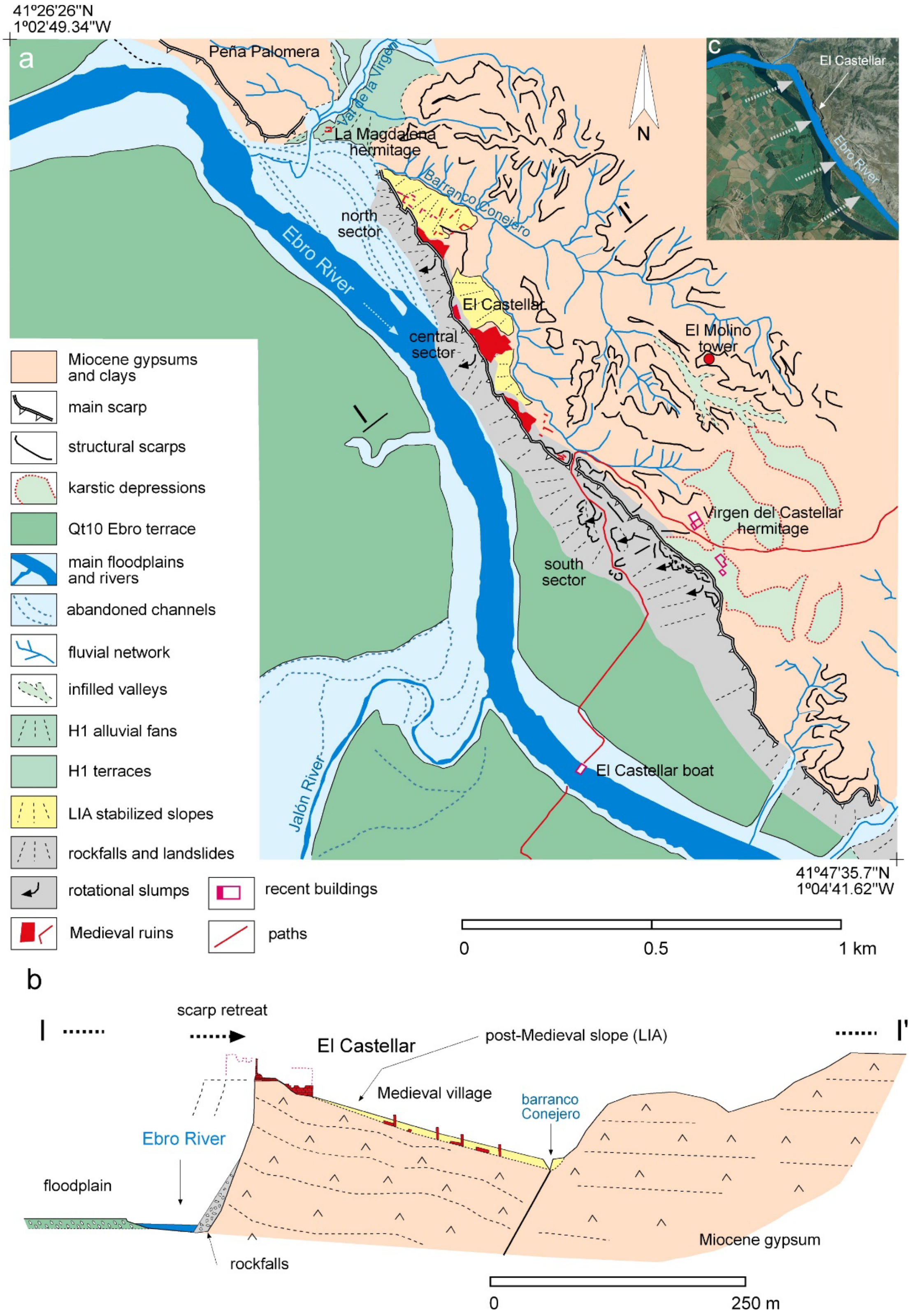


*Figure 4. a) Geomorphological map of El Castellar scarp. Cross section I-I' is indicated; location of the main Medieval remains and the three sectors identified; b) cross section I-I' showing the morphological dissymmetry of El Castellar relief; c) reconstruction of the Ebro River position during the LIA from the De Rodolphe (1746) map.*

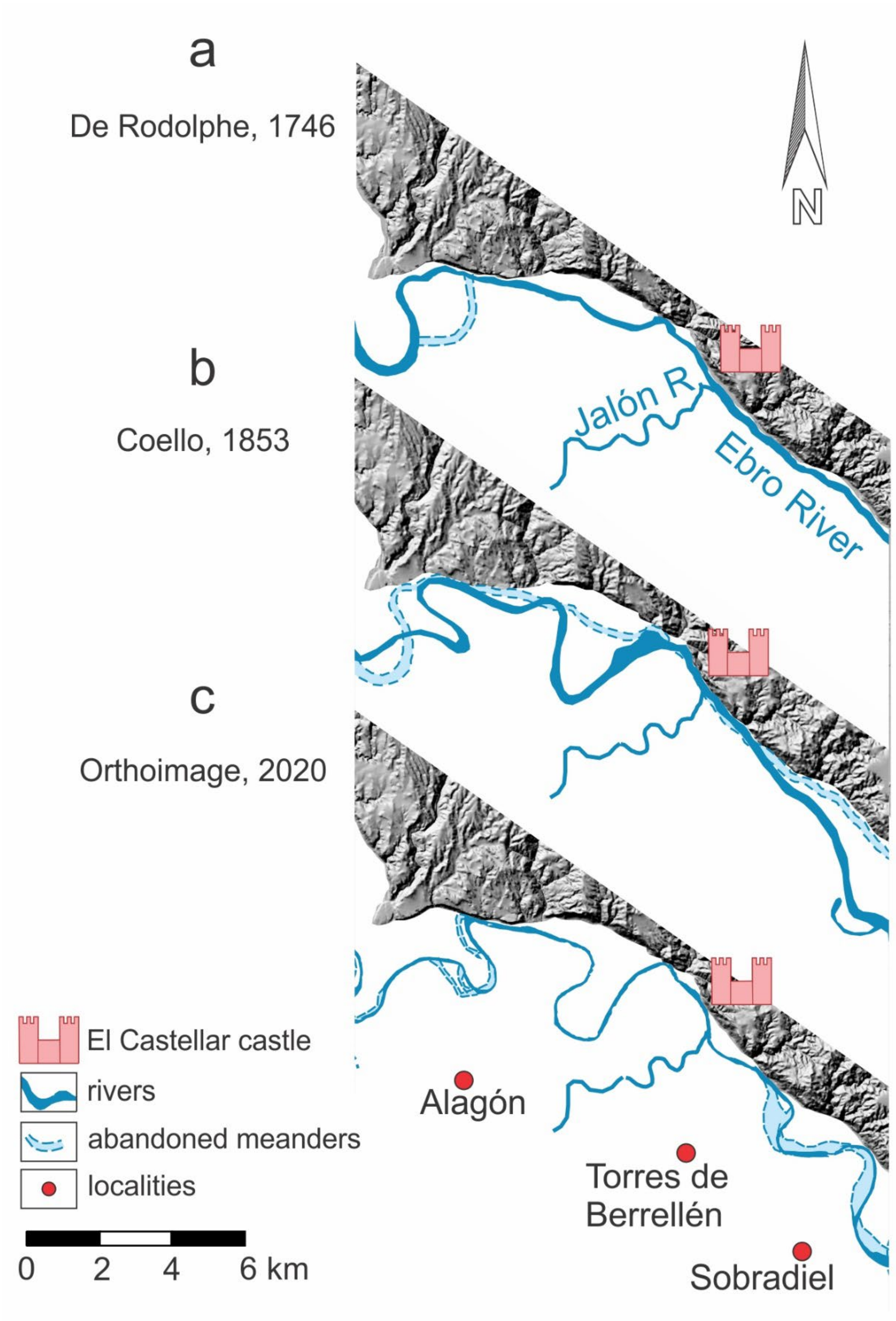


*Figure 5. Evolutionary schemes of the Ebro River channel in El Castellar sector; a) in the De Rodolphe (1746) map; b) from the Coello (1853) map; c) location of the Ebro River in 2020.*

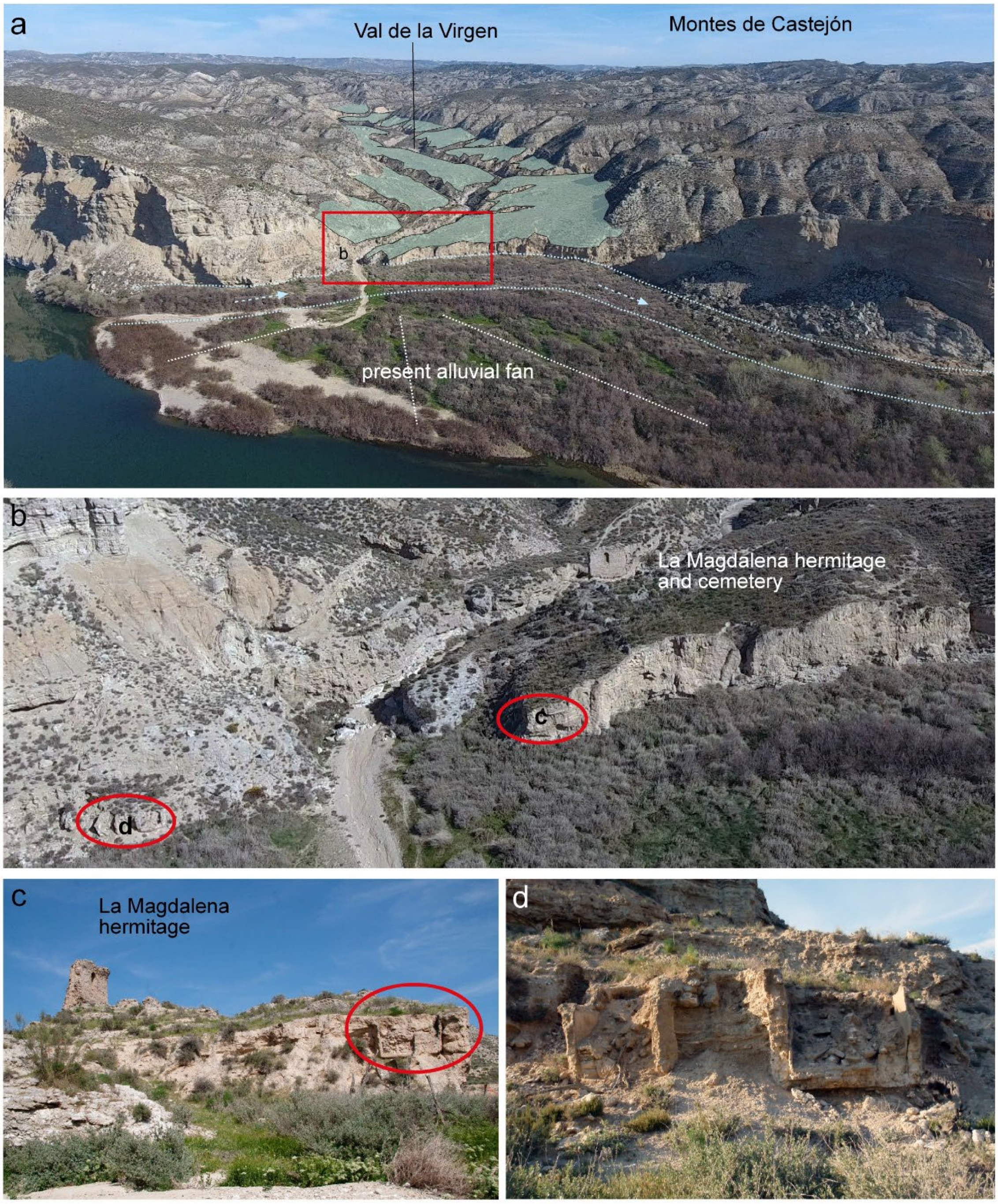


*Figure 6. Alluvial accumulations of Val de la Virgen stream and geoarchaeology: a) general view of the present alluvial fan and its H1 Holocene fill (green color) (red square indicating the position in Fig. 6b; dash line indicating Ebro River in late LIA stages) ; b) front profile of the H1 level of the alluvial fan where the cemetery and La Magdalena hermitage are located (red squares with next photo positions); c) profile of the alluvial fan and graves cut by the Ebro River meanders; d) graves included in the profile close to Ebro River.*

Towards the east of Val de la Virgen stream, the meander of the Ebro River extended up to the Barranco Conejero ravine outlet and flowed against the north limit of El Castellar scarp. This promoted the collapse of many defensive structures located in that sector (Fig. 7a). At present, some wall remains are located on the edge of the precipice (Fig. 7b). The old slope and one of the defensive moats of this sector are visible in the new scarp (Fig. 7a). It is possible to find debris cones due to rockfalls and landslides coming from the upper cornice, as shown on the right of Figure 7c.

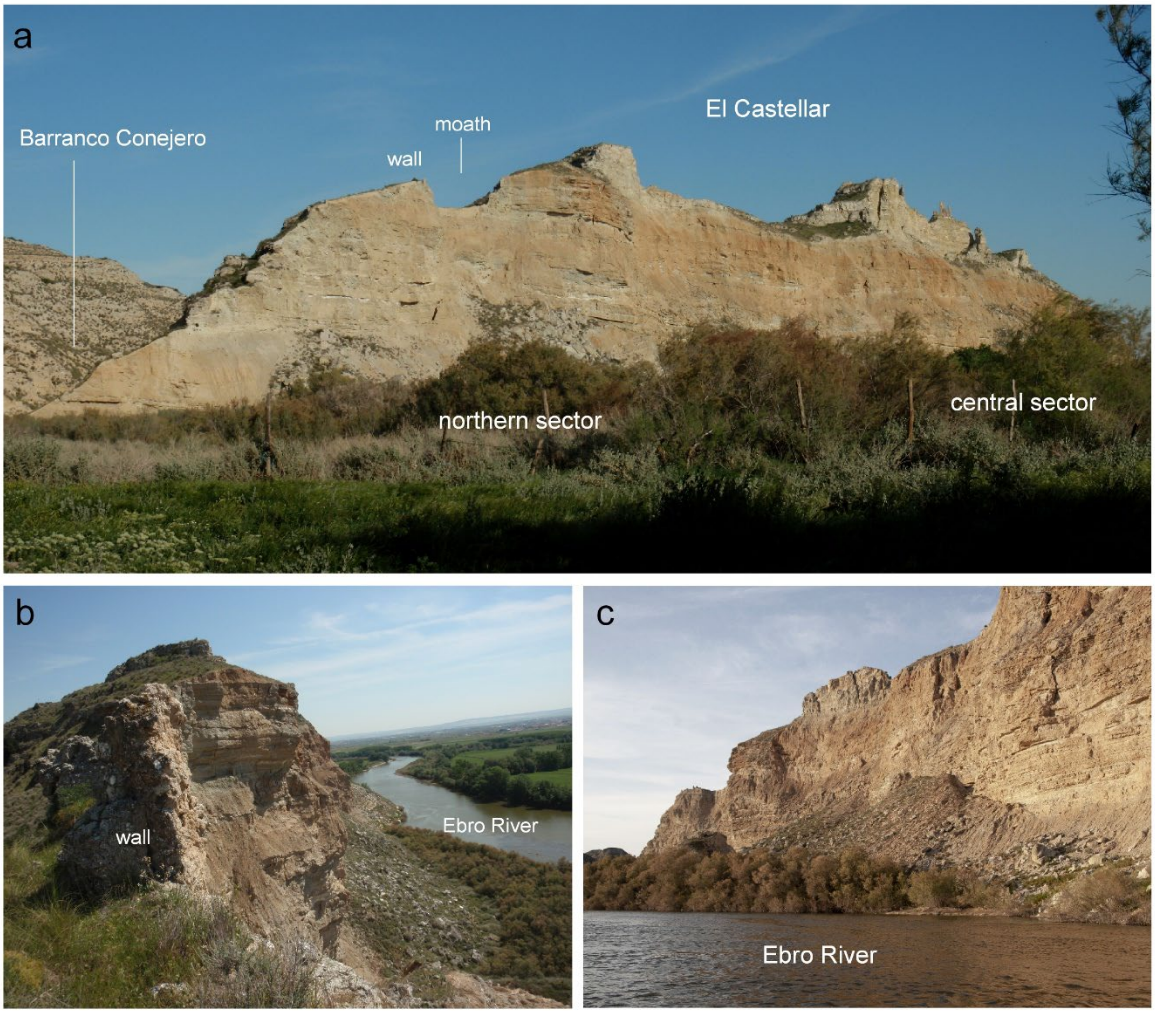


*Figure 7. Northern sector of El Castellar scarp: a) the abrupt front with alabaster gypsum on top due to the activity of slope processes; hanging upper slopes and one of the defensive moats; b) building remains on the scarp border; c) accumulations at the scarp foot caused by rockfalls and landslides.*

The central sector remains active with erosive dynamics, despite the large accumulations of blocks that protect the scarp from the direct influence of the river flow (Fig. 8a). The top of the scarp forms a vertical cliff where many fractures were identified (Fig. 8a). Laterally, the scarp is bordered by small scarps isolating a little mesa where the upper buildings of the main castle are located. These lateral depressions served as the natural moats of the castle and they show large fills of sediments from the collapse of the old constructions, especially thick (more than 6 m) on the southern side. Some monolithic pinnacles from the scarp front are undergoing a collapse process, showing large open fissures on both sides (Fig. 8a).

The scarp front has a narrow shoulder corresponding to an old slope, preserved in several sectors. We named it Stage 1 as it is the first record of slope development (Fig. 8a). However, these slope remains contain building debris, potsherds, etc, coming from the castle. Thus, it is possible to assume that there was a large landslide phase before Stage 1, which gave rise to the development of the upper scarp, but no deposits remain from that stage (named Stage 0 in Fig. 8bA). Stage 0 might involve a large loss of the castle surface due to the scarp retreat, which later served as a starting point for the development of the Stage 1 slope (Fig. 8bB, 8c, 8d).

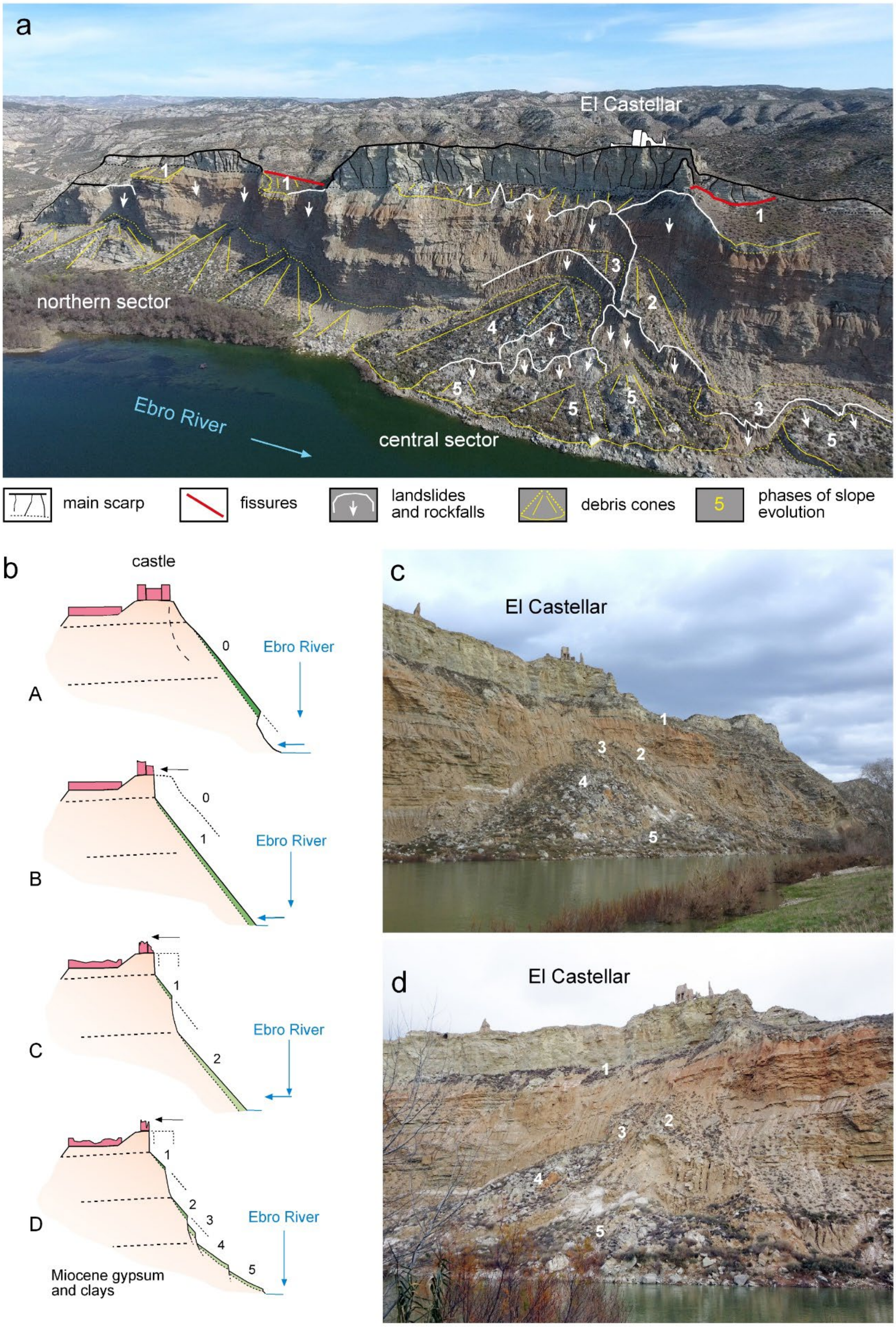


*Figure 8. Central sector of El Castellar scarp: a) interpretation of the main geomorphological components of the scarp. Numbers indicate the evolutionary stages of each slope located at the foot of the main castle; b) evolutionary scheme –without scale– of the scarp retreat and slope formation; c) and d) two images of the accumulation stages of the slopes.*

Subsequently, the massive landslides and rockfalls affected the deposits of Stage 1 in successive phases, forming the steps of Stage 2 (Fig. 8bC, 8c, 8d). Later, Stage 2 was eroded and Stage 3 developed. Finally, the last stages (4 and 5) were developed by successive landslides of previous accumulations, whose scars are visible (Fig. 8bD, 8c, 8d). These landslides are triggered by the clayey layers interbedded in the substrate that sometimes emerges in the sliding planes. The complete landslide formed a large fan entering the Ebro floodplain protecting the scarp foot, temporally impeding its retreat.

The southern sector begins in the southernmost sector of the Medieval village, with occupations on small flat structural surfaces on the slope and the northern valley floor close to the current Virgen del Castellar hermitage (Fig. 4a). The landslides, with large rocky masses, are located on the slope of the scarp front, in the sector where the old pathway ascended. At present, the path trace has been partially modified.

The floor of the karstic depression of Virgen del Castellar hermitage is filled with 1-3 m of gypsy silts. It is 112 m above the Ebro River channel (Fig. 9a) and 300 m wide in the hanging front. It is affected by multiple rotational landslides dropping towards the river side forming a chaotic mass of blocks (Fig. 9a). The displaced blocks currently visible near the scarp top (Fig. 9b) belong to recent slides, showing compressive fissures parallel to the scarp (Fig. 9c), maintaining its unstable characteristics.

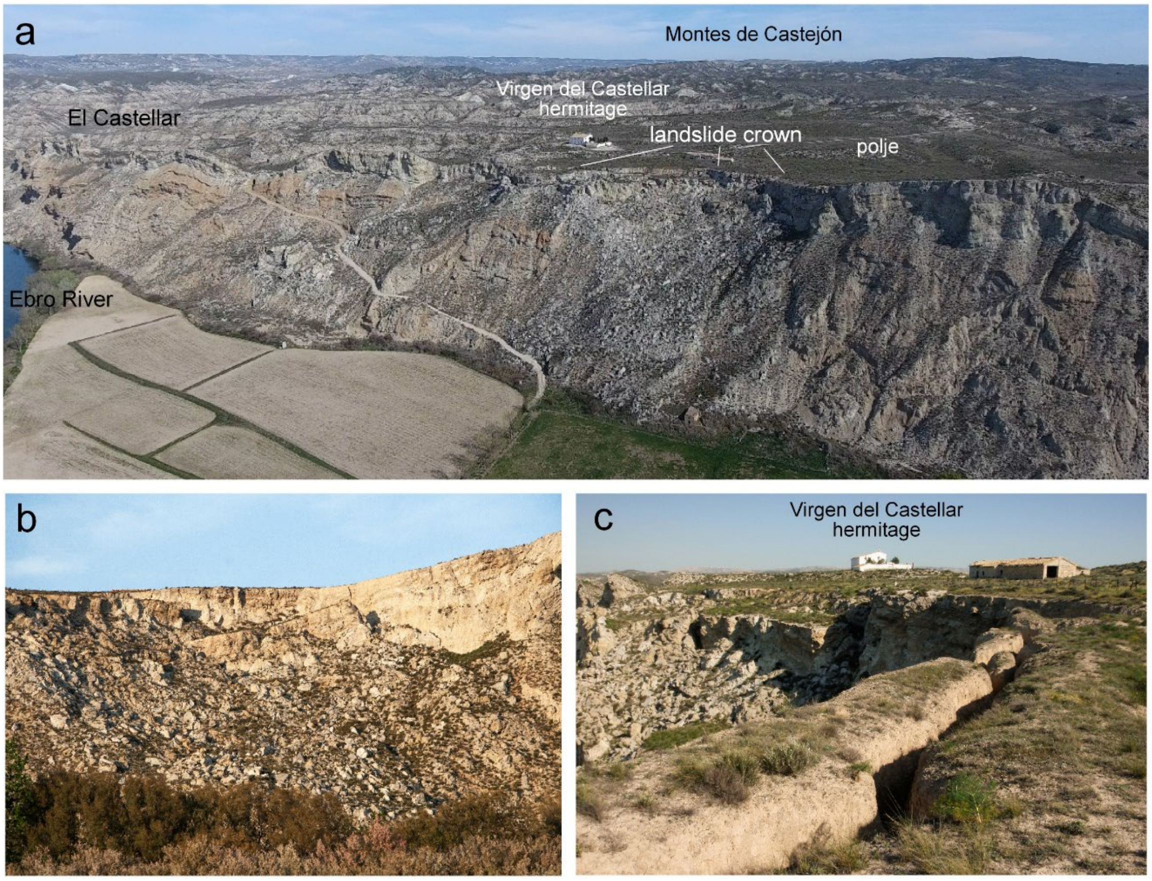


*Figure 9. Southern sector of El Castellar scarp: a) general view of the scarp with large displaced blocks, together with the ascending path; to the right, hanging polje of Virgen de El Castellar hermitage with its front affected by landslides; b) blocks recently displaced in the front of the hanging polje; c) fissures in the upper scarp corresponding to the polje fills.*

While the scarp front is subjected to heavy erosion, the slopes descending along the Barranco Conejero ravine show remarkable and uniform regularization covering the entire area (Fig. 10a), except for the hard gypsum strata. These slopes protect from erosion the remains of buildings that formed the lower and middle sectors of El Castellar village. The scarp retreat in the northern sector reached the regularized slope (Fig. 10b), showing the content of the deposit. Many archaeological remains can be found in the sediment, mainly building fragments with masonry, bones, and Medieval potsherds (Fig. 10c). The later incision of the Barranco Conejero ravine cut the floor valley and slope accumulations by more than 4 m in depth (Fig. 10d) exposing abundant ceramic potsherds from the urban times (Fig. 10e).

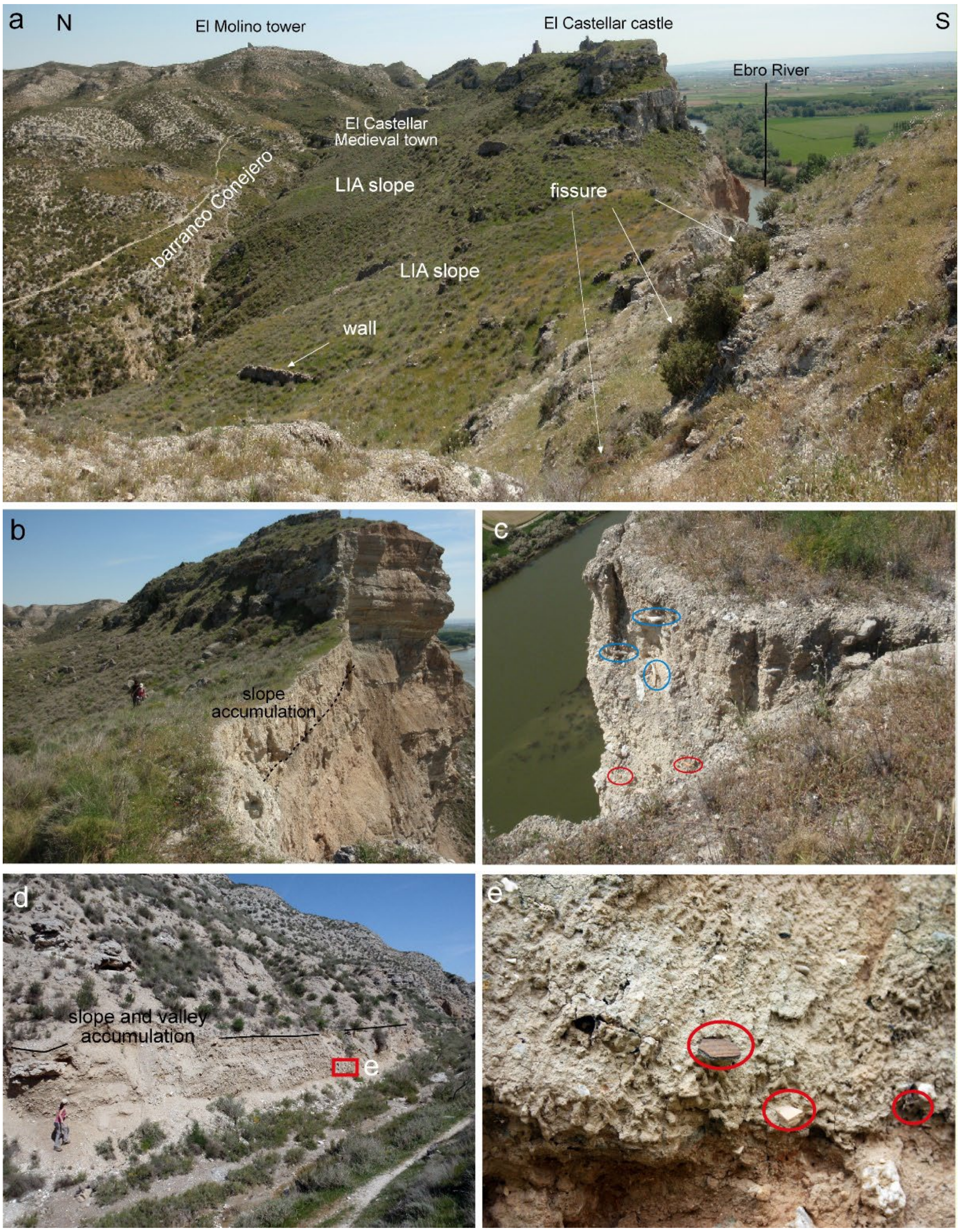


*Figure 10. Regularized northern slopes of El Castellar: a) general view of the main geomorphological features and Medieval remains; b) slope of sector A retreating by erosion; c) inner detail of the deposit: bones (blue) and potsherds (red); d) profile of the LIA slope and valley fill from the Barranco Conejero ravine; e) detail of previous profile (Fig. 10.d) with ceramic potsherds (red).*

This north-facing slope accumulation is still regular due to its orientation, favoring plant cover by humidity availability. Besides, the absence of cattle grazing inside the military ground favors the good vegetation cover, protecting soil and landforms from erosion. The age of this slope is clearly post-Medieval, even later than the abandonment of the village during the 16th century.

## 4. Discussion

The Medieval frontier castles on the Ebro gypsum scarp in the north of Zaragoza were built to fulfill the military needs of those times. Once the castles lost their strategic role, none of them remained active for long. Only two of them gave rise to the development of present-day villages: Alfocea and Juslibol, although their castles were abandoned. In both cases, their locations were not favorable, especially that of Juslibol, located on an Ebro River terrace highly deformed by the karstification of the underlying gypsum. As a result, in little more than one century, some walls collapsed (Peña-Monné et al., 2014). El Castellar was occupied until the 16th century. Perhaps the instability of the surface on which it was built conditioned its survival but socio-economic factors also constrained it. There are no documented records of large mass movements, suggesting that the first stages of the scarp retreat must have occurred after the 16$^{th}$ century.

There are many records of residual deposits of alluvial fans of tributaries of the Ebro River that converge at the scarp foot (Constante, 2009; Constante *et al.,* 2009, 2010). These fans were formed from at least the Chalcolitic with successive overlapping of deposits of Bronze, Roman and Medieval ages (Peña-Monné *et al.,* 2021). This long sedimentary sequence shows a continued evolution uninterrupted by the erosion produced by the Ebro River. This means that the river channel was located in a centered position on its floodplain, or near the right bank (Peña-Monné *et al.,* 2021). Although there are some records of large floods during the Middle Ages, it seems that its energy was centered on positions away from the scarp, since the alluvial fans were active then. Other smaller tributaries, in a hanging position today due to the scarp retreat, allowed us to infer their alluvial fans' longitudinal profiles and estimate that during the Late Roman Epoch, the Ebro River was almost 400 m away from the scarp (Peña-Monné *et al.,* 2021). These data show that during the Middle Ages the scarp was stable with the Ebro River far from it. Then, the upper area was suitable as a position for a defensive settlement. In addition, the alluvial fans and fluvial terraces were large enough to perform agricultural activities on the left bank of the Ebro River, together with extensive grazing and woodland exploitation in the northern sector. With this land extension at the scarp foot, the pathways between El Castellar and Zaragoza were possible, and they were complemented by boat crossing, still in use in some places. This scenario was favored by the environmental conditions of the Medieval Climatic Anomaly (MCA), allowing El Castellar village to grow, reaching a large extension, as inferred from the surface corresponding to the old urban area (Fig. 4).

In contrast to this favorable situation, an important change affected El Castellar during the 16$^{th}$ century, during the LIA climax, and continued up to the mid-19$^{th}$ century (Wanner *et al.,* 2011). Two colder stages are recognized in the Iberian Peninsula from dendroclimatic and geomorphological studies: the first one between 1620 and 1715 in coincidence with the Late Maunder Minimum; and the second one between 1760 and 1800 (Oliva *et al.,* 2018), related to the Dalton Minimum (Tejedor *et al.,* 2017). Also, the lacustrine records (Morellón *et al.,* 2012, González-Sampériz *et al.,* 2017) and glacial advances (Serrano and Martín-Moreno, 2018) coincided with the dates of these cold events. Large floods on the Iberian rivers occurred due to rains and snowmelt during the LIA. The periods 1730-1760 and 1780-1810 were established as those with the highest concentration of floods by Benito *et al.* (1996, 2003). In the European context, Bloschl *et al.* (2020) distinguish three stages with large floods for the Iberian Peninsula: 1590-1640, 1750-1800, and 1840-1880. In the Ebro River, the first data from a gauge station are from 1891, but there are flow estimations for a few large floods known from historical records (Balasch *et al.,* 2019) with a maximum of 5560 $m^3 s^{-1}$ in 1643. These values are higher than those of the instrumental era (1891-present), when the strongest flood occurred in 1961 with 4130 $m^3 s^{-1}$ (López Bustos, 1972; Ollero *et al.,* 2021). Besides, the number of extraordinary floods of the Ebro River was high during the LIA as shown in the Conde de Sástago's description (1796): Between 1778 and 1790, during the construction of the Canal Imperial de Aragón, 59 floods were recorded, delaying the construction works.

These large flows displaced the Ebro River channel from the central sector of its floodplain towards the left bank side. In this scenario, the channel gradually reached the scarp as depicted on De Rodolphe's map (1746). Towards the middle of the 18th century, the river flowed against the scarp along 14 km between Casas de Pola and Alfocea. This movement produced deep processes at the scarp foot and the Medieval castles on its top. First, it eroded the alluvial fans developed by Ebro River left bank tributaries inside its floodplain, still active in Medieval times. These fans were important as agricultural areas, and as a means of communication in addition to protecting the scarp. A large meander of the Ebro River developed, eroding deep inside the Val de la Virgen alluvial fan and reaching the old cemetery in the valley. Many tombs disappeared and others remained hanging on the alluvial fan scarp next to La Magdalena hermitage (Fig. 6).

In the northern sector of El Castellar gypsum scarp, many of the constructions collapsed due to the retreat, although some walls remain at the top (Fig. 7b). This retreat reaches the slope at the back of the scarp (Fig. 7c), forming a rocky slope with a high gradient (Figs. 2a, 2b, 7a). In the central sector of El Castellar scarp, we believe that the first large landslide (Stage 0) may have occurred in the early LIA (16th-17th centuries), and the retreat process continued in the late LIA (18th and first half of 19th century) including at least Stages 1 to 3. Stages 4 and 5 are more recent and only retouched the larger landslides with small slides in the lower part of the deposits accumulated at the scarp foot (Fig. 8b). A theoretical reconstruction of the main castle proposed by Establés Elduque (1991) indicates a loss of one-third of the castle, although we believe that the percentage is higher.

In the southern sector, the landslides affected the scarp in the polje where the old Virgen del Castellar church was located. This church collapsed in 1840 due to a large landslide (Fig. 9). This event is included in a record of the priest of Torres de Berrellén, contemporary to the mass movement. In this document, he mentions that the Ebro River channel was blocked (Gascón, 2007). The current hermitage is located away from the scarp (Fig. 9). De Rodolphe's map (1746) shows an image of the highest river activity, which was constant until the 19th century, as shown on Coello's map (1853), when the river separated from the scarp (Peña-Monné *et al.,* 2021). This movement affected mainly the southern sector because in the northern and central sectors the river is still close to the scarp, although not reaching it due to the accumulations at its foot.

According to these dynamics in the scarp evolution, the Medieval buildings of El Castellar were deeply affected, especially the most remarkable buildings located on top of the scarp. This is the case of the main castle, where only a part of two towers, the main gate, and a part of a cistern remain, among other walls (Figs. 3b, 3c). Behind the main gate, only a narrow space in the inner enclosure of the main castle remains. In 1807, Coche (1807) delivered a sermon in El Castellar church about "the ruinous rubble that surrounds us", vividly depicting the situation 200 years ago.

Despite the destruction, the archaeological remains on the northern slope, where most of El Castellar village is located, are better preserved than those at the top. Its conservation was favored by the vegetation cover on the slope, developed during the LIA, which prevented erosive processes (Fig. 10). The incision of some streams in the southern area reveals the presence of walls of many houses under the slope deposit.

The lithology and structure of the scarp hinder conservation efforts to stop the scarp retreat in the areas where the most important buildings are located, as shown in several images (Figs. 3d, 3e, 7b, 8). At present, the fluvial dynamics is limited not only by the debris at the scarp foot but also by the diminished flows controlled by present climatic conditions and fluvial regulations by dam constructions. However, the gradients still favor gypsum rockfalls from the upper scarp. In addition, the monoliths are almost separated from the scarp and new landslides may occur from the two large open fissures highlighted in Figure 8a.

It is possible to restore some buildings in the upper area, especially the East façade facing NE of the main castle, with its notable gateway. Moreover, despite its historical importance, it is very difficult to visit the place due to accessibility and security problems, as mentioned above. Perhaps the best option would be to move the castle gateway to another area of El Castellar, like the NE slope, where the lower sector of the castle is preserved, or to Val de la Virgen area, next to the cemetery and La Magdalena hermitage, where a musealization of the entire area could be performed. In any case, both areas deserve a detailed archaeological study in order to know El Castellar history in depth.

## 5. Conclusions

El Castellar village and castle were the most important sectors on the defensive line of Zaragoza city during Medieval times. Their remains are located on an abrupt scarp, as well as on the north-facing slope and the alluvial fan of Val de la Virgen stream, but they have not been studied from an archaeological point of view.

At present, the area shows a ruinous appearance with high collapse risk and complicated accessibility. In the past, the paleogeographical and paleoenvironmental conditions of the Medieval Climatic Anomaly propitiated a large human settlement in this area of the scarp. The main favorable factor was its position far away from the lateral movements of the Ebro River meanders. Wide alluvial fans extended at the scarp foot and the slopes were more stable, allowing the constructions of secure pathways at the scarp foot.

From the 16th-17th century, the Ebro River notably changed its hydrological characteristics due to the colder and wetter environmental conditions of the Little Ice Age. The flood events were more frequent and, at times, more severe. The Ebro River moved towards the scarp foot, triggering basal erosion processes with landslides and rockfalls. These processes seriously deteriorated the fortification on the top, which collapsed several centuries after the population abandoned the area.

After this period of highest erosive activity, from the mid 19th century and especially during the 20th century, the fluvial dynamics diminished and the debris accumulations at the scarp foot facilitated some stabilization, although the risk of collapse persists at the top of the scarp. The possibility of interventions to avoid larger heritage loss is limited for the main castle, but archaeological excavations in the old village are possible considering that large areas are still preserved in the northern slope and the alluvial fan of Val de la Virgen.

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