# WATER AND DEFENSE SYSTEMS IN ELS VILARS FORTRESS (ARBECA, CATALONIA, SPAIN): A MULTIPROXY APPROACH

Power architecture, poliorcetics, moat, well, water resources, hydrography, hydrology, micromorphology, soil science

**Emili Junyent*** **Rosa Maria Poch**** **Carles Balasch****

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*La Forteresse des Vilars se distingue par sa fortification complexe et sa défense active face au risque de siège ou blocus du IVe siècle av. J.-C. Le système inondable des fossés assurait l'approvisionnement et la gestion de l'eau, renforçait la défense et déployait la magnificence de l'architecture du pouvoir. Les ressources hydriques potentielles du bassin d'écoulement de l'Aixaragall – le torrent qui l'alimentait- sont analysées dans leur contexte paléoclimatique; sont également étudiées les relations entre l'ancien cours d'eau, les fossés et le puits du point de vue de l'hydrologie, ainsi que les conditions de fonctionnement du fossé à partir de l'étude hydraulique de l'environnement et de la micromorphologie des sédiments accumulés dans le fossé.*
Architecture du pouvoir, poliorcétique, fossés, puits, ressources hydriques, hydrographie, hydrologie, micromorphologie, pédologie

## 1. INTRODUCTION

The fortress of Els Vilars is located near Arbeca, in Les Garrigues county (fig. 1). It was built in the mid-8th century BCE and abandoned in the late-4th century BCE, according to radiocarbon dating. It is considered to be a unique enclosure in the context of the early Iron Age of the Iberian peninsula and Europe, due to the

* Grup d'Investigació Prehistòrica. Departament d'Història. Universitat de Lleida. Pl. Víctor Siurana, 1, 25003, Lleida, Catalonia. ejunyent@historia.udl.cat
** Departament de Medi Ambient i Ciències del Sòl. Universitat de Lleida. Av. Rovira Roure 191, 25198 Lleida, Catalonia. rosa.poch@macs.udl.cat, cbalasch@macs.udl.cat

exceptional characteristics and size of the moat and defenses (towered walls, *chevaux de frise*, fortified access, central well) that occupied over 80% of the built area (Alonso/Junyent/López 2010). Also notable is the choice of a valley bottom for the fortress location. It was continuously occupied for more than four centuries and has been object of a research project since the 1980s, making it an important settlement for the understanding of the processes that led to the segmentary societies of the northern Ebro valley, through the leadership and appearance of aristocracies, from the archaic Iberian pre-Roman state societies.

The fortress attained its maximum splendour and complexity at the end of the 5th century BCE when the structures were in place, for receiving water from a neighbouring stream in order to feed the moat and cen-

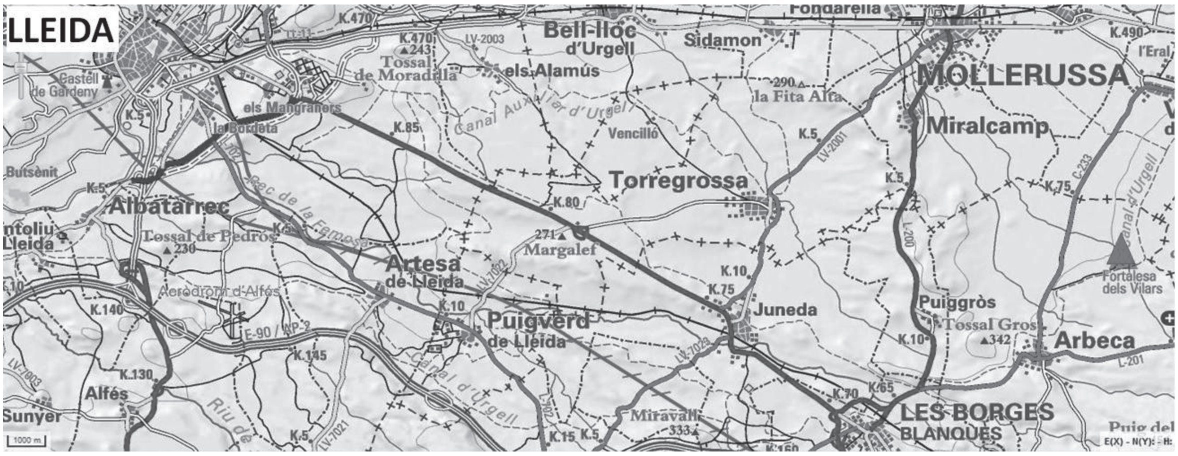



**Figure 1.** Location of Els Vilars Fortress (red triangle).



tral well, and the external defenses had been integrated into the same system. This moat is one of the most interesting elements, characterized by its considerable size (18 m wide and 4-5 m deep) and by its complex structure (connection with the stream through surface runoff, inner pools and ditches, stone-lined walls, probable connection with the inner well through subsurface flow).

The village was abandoned around 300 BCE, as deduced from the black-varnished pottery found in the late epochs, and from the scarce but significant presence of pieces of imported luxury tableware of Attican origin that have been dated to Agora of Athens. The radiocarbon dating of the moat and well sediments are consistent with this date. There is no evidence of a traumatic or violent event to explain the abandonment: the site was not destroyed but rather simply abandoned. It is possible that exhaustion of the nearby fields, or a drought period made a change of location advisable. One thing is certain, however: the wall, the moat and the defenses – the settlement's reason for existing – became an insurmountable obstacle to the normal urban development of an Ilergetian village, which required wider streets, more complex and spacious houses and an increased diversity in the use of space given the new social and productive needs. Eventually the size and complexity of the defense systems became a hinderance to development, becoming impossible to absorb as the town evolved.

Such defense structures, including a moat, are not known in similar Iberian fortresses. Understanding the dynamics of the flooding regime is extremely relevant given the aridity of the environment (390 mm rainfall y-1), and also because it modifies the present knowledge of the Iberian poliorcetics[1] and the past environmental conditions of the area.

## 2. PHYSICAL SETTING

### A. CLIMATE

The present-day climate of the southern part of Lleida, using data from Les Borges Blanques station, is characterized by a mean annual temperature of 14.6°C, July and August being the warmest months with average temperatures of 24°C and 32°C respectively. Autumn is warmer than the spring, usually January is the coldest

1.- The art of conducting and resisting sieges month followed by December and February (Porta *et al.* 1983). The frost-free period according to Emberger is from 25th April to 26th October, and there is total risk of frost according to Papadakis from 18th November until 22th March. The soil temperature regime, according to SSS (1999) is thermic.

Total annual rainfall for different climatic stations in the area are in Table 1. It ranges between 370 and 560 mm, and its distribution throughout the year is irregular, with two marked minima, one in winter and one in summer. Equally important to the total precipitation with regard to water availability to plants, is the precipitation intensity, inferred from the number of days of rain. For the stations Albagés, Vilosell, Juneda and Omellons, the average rainy days per month does not exceed 10, and during July and August is less than 5.5 days (Porta *et al*. 1983). These rain events are not very useful for soil recharge as they have high runoff coefficients with little infiltration. This is the reason why the soil moisture regime according to Soil Survey Staff (1999) is aridic in soils with low water holding capacity (AWHC <50 mm), while the remainder (AWHC >50 mm) is xeric[2] (Jarauta, 1989). The area is therefore a transitional zone between desert and the Mediterranean pedoclimate, depending on the water holding capacity of the soil.

The annual water deficit of these soils is illustrated by the values of potential evapotranspiration in Table 1, which are more than twice the values of precipitation.

The present-day dry conditions, however, do not reflect the climate at the time of occupation of Els Vilars. According to Alonso (1999) from anthracological and palaeovegetation studies, the climate was more humid, with a predominance of large patches of forest of oaks, the clearance of which would have been due rather to landuse purposes than weather conditions. Presumably the soil moisture regime would have been xeric in all cases, ie, able to sustain rainfed agriculture for part of the year. In this sense, the most favourable soil for agriculture in an environment with limited water would be that with largest AWHC: non-stony and non-saline.

**Table 1.** Average annual rainfall and PET (Thornthwaite method) for the climatic stations south of Lleida (correlative period of 1968-80).

| Station | Annual precipitation (mm) | Annual PET (mm) |
|---|---|---|
| Omellons | 406.9 | 797.7 |
| Juneda | 411.1 | 812.3 |
| Les Borges Blanques | 440.5 | 805.9 |
| Albages | 468.8 | 789.5 |
| Vilosell | 557.4 | 733.5 |
| Utxesa | 427.9 | 851.1 |
| Serós | 369.0 | 810.8 |
| Lleida | 398.4 | 840.2 |



Initial stable isotope analyses of wood charcoal showed two main phases of increased water availability (1500-900 BCE; 300 BCE to 300 CE) alternating with drier periods (Ferrio *et al*. 2007). Further studies with a larger dataset confirmed a wetter climate than the present-day, by an increase of 10 to 25% of the present annual rainfall (fig. 2) during the occupation (800-300 BCE) of Els Vilars (Voltas *et al.* 2008; Aguilera *et al*. 2011). This would mean an annual rainfall of 440-500 mm.

The autumn precipitation (September to December) was estimated from charcoal C isotopes by Aguilera *et al*. (2009). The data for Els Vilars show an average 44% increase from 159 mm at present to 229±35 mm in the period 580-390 BCE. The data also suggest that the annual rainfall distribution in this period differed by having a more humid autumn than the present (fig. 2).

2.- Soil moisture regime with a period during the year where plants can take water from the soil.

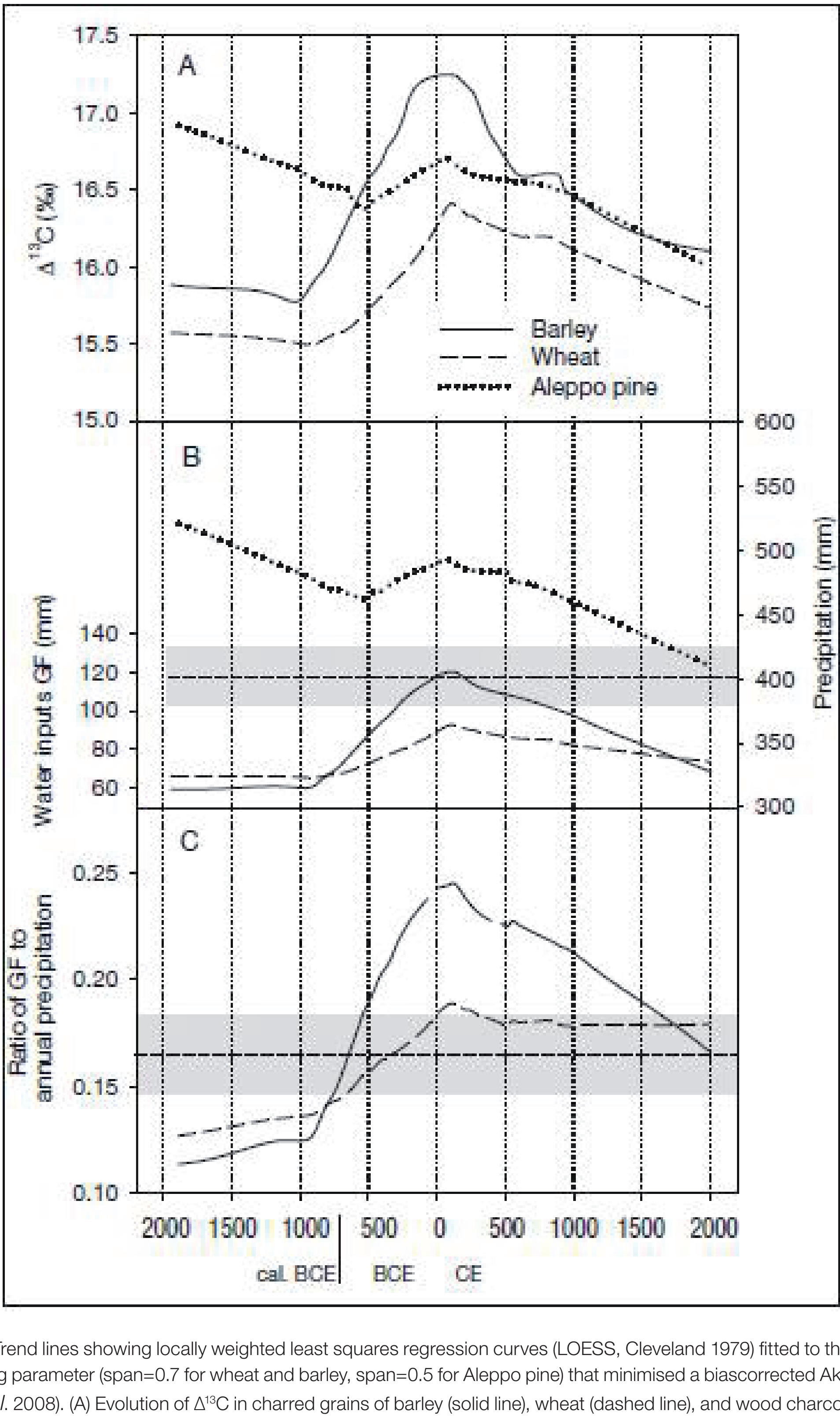
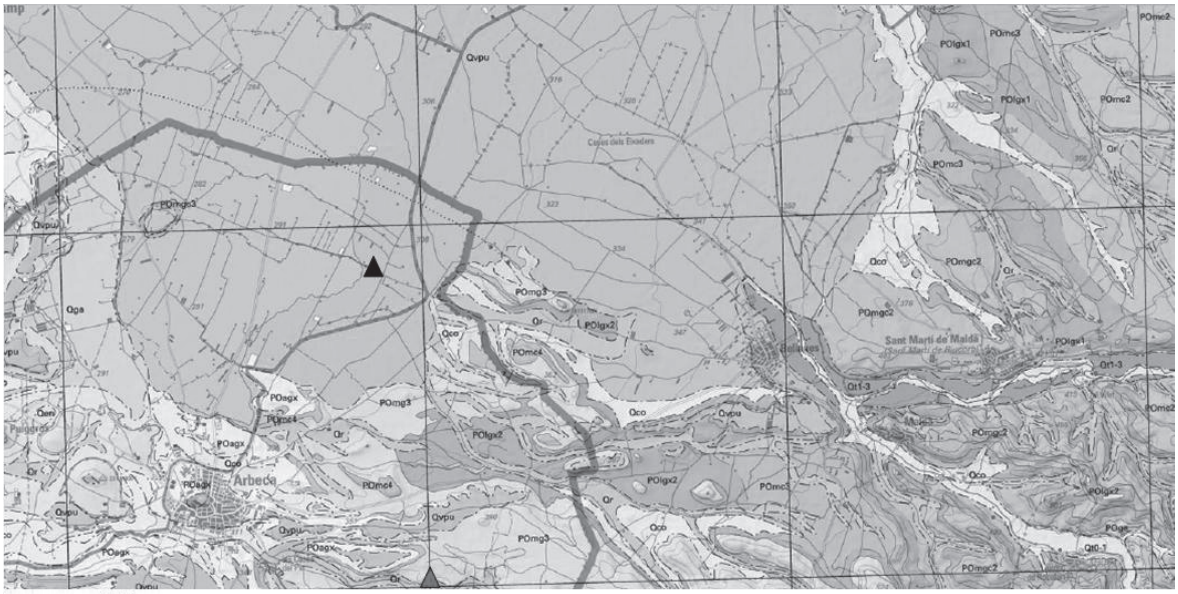



**Figure 2.** Trend lines showing locally weighted least squares regression curves (LOESS, Cleveland 1979) fitted to the data using a smoothing parameter (span=0.7 for wheat and barley, span=0.5 for Aleppo pine) that minimised a biascorrected Akaike statistic (Voltas *et al*. 2008). (A) Evolution of $\Delta^{13}C$ in charred grains of barley (solid line), wheat (dashed line), and wood charcoal of Aleppo pine (dotted line) from archaeological sites from the Mid-Ebro Basin (NE Spain) over the last four millennia. (B) Estimated water inputs (left y-axis) during grain filling of barley (solid line) and wheat (dashed line), and estimated annual rainfall (right y-axis) from Aleppo pine (dotted line). The horizontal dashed line and darkened area indicate the current average annual rainfall for the city of Lleida city ±2SE. Drawn from original data in Ferrio et al. 2006. (C) Estimated ratio of rainfall during grain filling to annual rainfall using barley (solid line) or wheat (dashed line) as indicators of grain filling rainfall. The horizontal dashed line and darkened area indicate the current average ratio for Lleida ±2SE.

## B. GEOLOGY, GEOMORPHOLOGY AND HYDROLOGY

The settlement of Els Vilars of Arbeca (304 m asl) is located about 4 km north-east of the village of Arbeca, on the southern bank of the Urgell plain. This plain is a large landscape unit of alluvial origin, partly covered by several coalescent alluvial fans of El Corb River flowing from the east (Ramírez 1998). The largest one occupies the central part and the eastern margin of the plain with its apex in Belianes. The south-western part of this fan coalesces with a smaller fan fed by the episodic Aixaragall stream. (fig. 3). The fortress of Els Vilars is situated on this zone of coalescence on the right bank of the Aixaragall-fed smaller cone.




Squares of 5 km.

▲ Els Vilars ▲ x 330,000; y 4,600,000

Qco Colluvial deposits. Clays with angular dispersed gravels. Holocene.

Qr Deposits of the present-day river and torrent beds. Holocene.

Qt0-1 Present-day riverbed, common flood plain and lowest terrace (0-2 m). Recent Holocene.

Qga Accumulation Glacis. Clays and gravels. Pleistocene-Holocene.

Qt1-3 Gravels and lutites. Pleistocene-Holocene.

Qvpu Gravels with lutitic matrix and sand lenses. Pleistocene.

POagx Red lutites with sandstone intercalations. Oligocene.

POlgx2 Lutites with intercalations of sanstones and calcilutites. Catian.

POmc3 Micritic limestones with intercalations of grey marls and carbonatic silts. Catian.

POmc4 Marls and clays with limestone intercalations. Catian.

POmg3 Marls and clays with intercalations of sandstones and sandy limestones. Catian.

POmgc3 Lutites with intercalations of sandstones and conglomerates. Catian.

POmc2 Marls with limestone intercalations. Rupelian-Catian.

POmgc2 Clays, silts and fine-grained sanstones with intercalations of conglomerates, sandstones and limestones. Rupelian.

**Figure 3**. Geological Map Les Garrigues 1:50,000. Institut Geològic de Catalunya. www.igc.cat.

During the Holocene the geomorphological dynamics have been fairly constant: El Corb alluvial fan has been growing in extent due to the sedimentary contributions of large floods. The distributary channels flowed across the highest parts, from there bringing water loaded with silt and gravel to depressed areas and enlarging the deposit. The water courses have been migrating across a very gently inclined surface (regular topographic gradient 0.0089) which allows sudden changes in the direction of the courses. The added sediment, usually in the most distal or external areas, involves the expansion of the entire unit, which progrades north and north-west. In the areas of contact between fans, lateral overlap of the units can occur, creating endorrheic conditions, ponding and stagnant flood waters.

The small cone located at the exit of the Aixaragall channel occupies a triangular area bounded roughly by the towns of Arbeca, Miralcamp and La Pleta hill (353 m), an area of about 14 km$^2$. However, the catchment area of the Aixaragall has a drainage area of 20.65 km$^2$, which seems wholly insufficient for the development of such a large cone. It seems likely that part of it was formed by materials brought by the neighbouring Corb River, which later deviated its course (Calvet 1980; Gallart/Calvet/Clotet 1984). The Aixaragall was responsible for the erosion of a slight depression in a WNW-ESE direction just north of Els Vilars. At present, although this depression has almost disappeared due to subsequent flooding and levelling works for irrigation/drainage, it still forms the catchment area responsible for the episodic floods of the Aixaragall basin. Research on flooding regimes of the Urgell plain suggests that these extraordinary floods – an important sediment supply – occur once each hundred years (Piquer 1986; Costa/ Cots 1992; Lanaspa 2002).



The relief of the plain around Els Vilars during its occupation was very similar, if not identical, to what we can see today. The slopes and valley bottoms of rivers and streams in the area have not substantially changed, due to the low intensity of erosion during a geologically short period, such as the last 2,500 years. However, the flat alluvial fan where the fortress is found did not have the same stability. In this area there has been an increase in positive relief due to the accretion of sediments associated with flooding during heavy rainfall. This accretion led to a thickness increase of about 1 m in the alluvial accumulated materials during that period.

The flow of the Aixaragall is the responsible for the sediment supply that formed the alluvial fan where Els Vilars settlement is located. the stream flows through subsurface flow to the alluvial fan. At present, when this subsurface water crosses the Urgell irrigation canal (east of Els Vilars) by being conducted through an artificial drainage under the canal. Already in the irrigated area, it flows westwards along an open, partly piped drainage channel just to the north of Els Vilars.

The hydrographic network of the distributary channels on the cone at the time of settlement is unknown, although it is likely to have been different from the present-day. However, the position of the apex of the cone would have been very similar to the present one. Paleoflood episodes originating from this point were able to fill the plain with water and sediment, giving rise to deposits with highly variable thickness and grain size. In this sense, the irregularities of the original topography may have had some impact on the thickness of the aquifer gravel draining the cone.

## C. SOILS AND PALEO-LANDUSE

The available information on soils of the area is compiled in the 1:25 000 maps of the Soil Map of Catalonia. Map units are arranged in strips along an approximately EW direction determined by the drainage conditions and materials of the Aixaragall basin (fig. 4). The characteristics of the units are summarized in Table 2. Imperfectly drained soils (as the Linyola unit) occur along the axis of the stream until it enters the cone, where the better drainage conditions allow the developent of well-drained, non-saline, deep soils of the Comelles series. The higher positions are occupied by the Seana and Bellvís series: soils formed on calcium carbonate-cemented gravels that form Bkm horizons. The difference between the two series would be the depth at which the horizon is cemented, with Seana being the shallowest.

Saline soils are found on the eastern side of the cone, probably in old endorrheic areas between different coarse deposits. These soils are slightly to moderately saline under the present climate.

Considering that the soil and geomorphological features of the Els Vilars environment have not substantially changed over the past 3000 years, it is possible to do an exercise of land evaluation (FAO 1976), taking into account the most likely landuses around the fortress. This would produce an approximate picture of the past landuse pattern, and ultimately lead to a justification of the location of the fortress. It is limited by the lack of knowledge about the farming systems (system of planting equipment, tillage practices and fertilization) and of the precise distribution of soils and climate characteristics at the time. Nevertheless, the most important limitations to the use of agricultural land met by the settlers were salinity and hydromorphism (Linyola, Bellcaire and Romeu series), and low water holding capacity, shallowness and stoniness (Seana, Bellvís, Pedrís and Alcanó series). The village is located in the alluvial fan, next to, but not in the stream axis, in a position not greatly affected by flooding. The best soils are found along the stream axis.

The most likely landuses in the area of Els Vilars were established by Alonso (1999):

*Winter cereals*

Consisted of short cycle rainfed wheat or barley, spread by hand, using ploughs, alternating fallow and crops every 2 years, with an estimated production of 420 to 840 l/ha. Tillage operations must have consisted of weeding with hoe or plough, ploughing, stubble burning, and possibly fertilization with manure and / or ashes. The tillage should have not been more than about 15 cm deep.

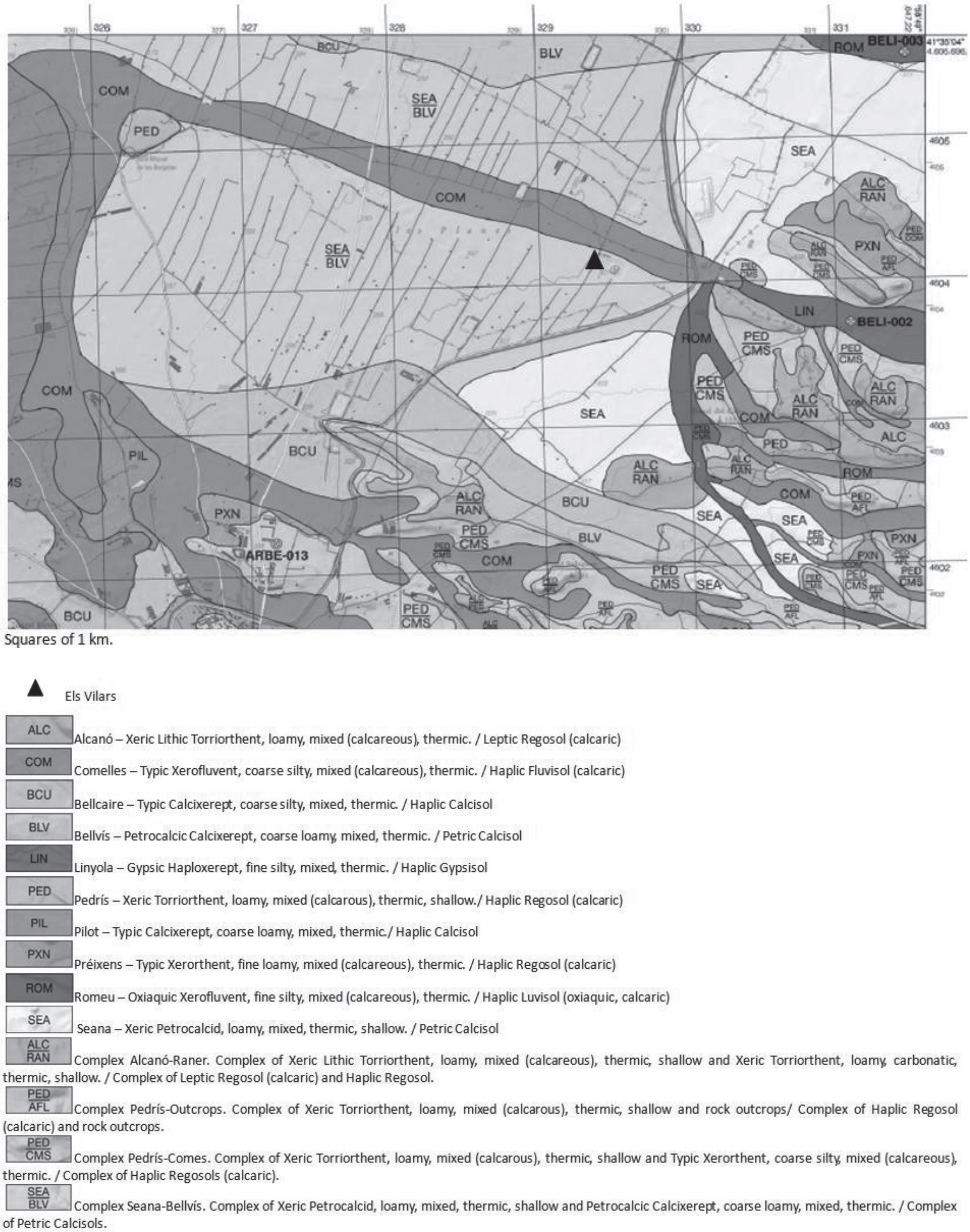



**Figure 4.** Soil distribution around Els Vilars. Soil Map of Catalonia 1: 25,000, Institut Geològic de Catalunya. Sheet: Les Borges Blanques.

**Table 2.** Main characteristics of the soils surrounding Els Vilars relevant for landuse.

| Soil Series | Texture | Depth | Drainage | Coarse elements | Salinity | AWHC* | Accumulations |
|---|---|---|---|---|---|---|---|
| Alcanó | Medium to moder-ately fine | Shallow | Well drained | Variable | Absent | Very low | None |
| Belianes | Medium | Very deep | Well drained | Very few | Absent | High | None |
| Bellcaire | Medium to moder-ately fine | Deep | Well drained | None | Slightly saline | Very high | Carbonate nodules in depth |
| Bellvís | Medium | Medium | Well drained | Very fre-quent | Absent | Low | Bkm at moderate depth |
| Comelles | Medium | Very deep | Well drained | Few | Absent | Very high | None |
| Linyola | Medium | Very deep | moderate, mot-tles at 60 cm | Few | Slightly saline | Very high | Vermiform gypsum (5-10%) |
| Pedrís | Medium | Shallow | Well drained | Variable | Absent to very slighty saline | Low | None |
| Pilot | Medium | Moderately deep | Well drained | None | Absent | High | Carbonate nodules in depth |
| Préixens | Medium | Deep | Well drained | Variable | Absent | High | None |
| Romeu | Moder-ately fine | Very deep | Well drained (100-150 cm water table) | None | Slightly saline | Very high | None |
| Seana | Medium | Shallow | Well drained | Frequent | Absent | Very low | Bkm at shallow depth |

* AWHC: available water holding capacity



*Horticulture*
These are more intensive spring crops (millet, maize, emmer wheat, lentils, beans), planted in clumps using hoes or sticks. Cultivation was probably deeper than in winter cereals (20 cm?). Farming operations, as with cereals, were weeding, fertilization and burning. Due to the time-consuming operations and tillage intensity, these crops should not have been very far from the village.
*Pastures*
They were probably located in marginal lands, where soil degradation by salinization, erosion or hydromorphism did not allow the attainment of acceptable yields.
*Riparian woodland*
These riparian forests were located on the banks of streams and in areas with groundwater flowing near the surface. The only anthropogenic activities must have been collecting firewood and other products.
*Forests: oak and maquis*
The natural forest, more or less cleared, occupied land with more limited water availability and tillage possibilities.

These landuse scenarios allow us to make a first attemp at a landuse map, displayed in fig. 5. Although the landscape is dominated by open oak forest and maquia, the location of Els Vilars has – at a relatively short distance – all soil requirements for the practised landuses, together with surface water availability. It appears, therefore, that the proximity of quality soil and available water were favourable factors for the location of the fortress.

## 3. STRUCTURE OF THE SITE: ELS VILARS PHASES

The combination of stratigraphic observations, the knowledge of urban and defense developments, the study of archaeological materials and calibrated radiocarbon dating allows the recognition of the building sequence and dates of the following phases (fig. 6) in Els Vilars:

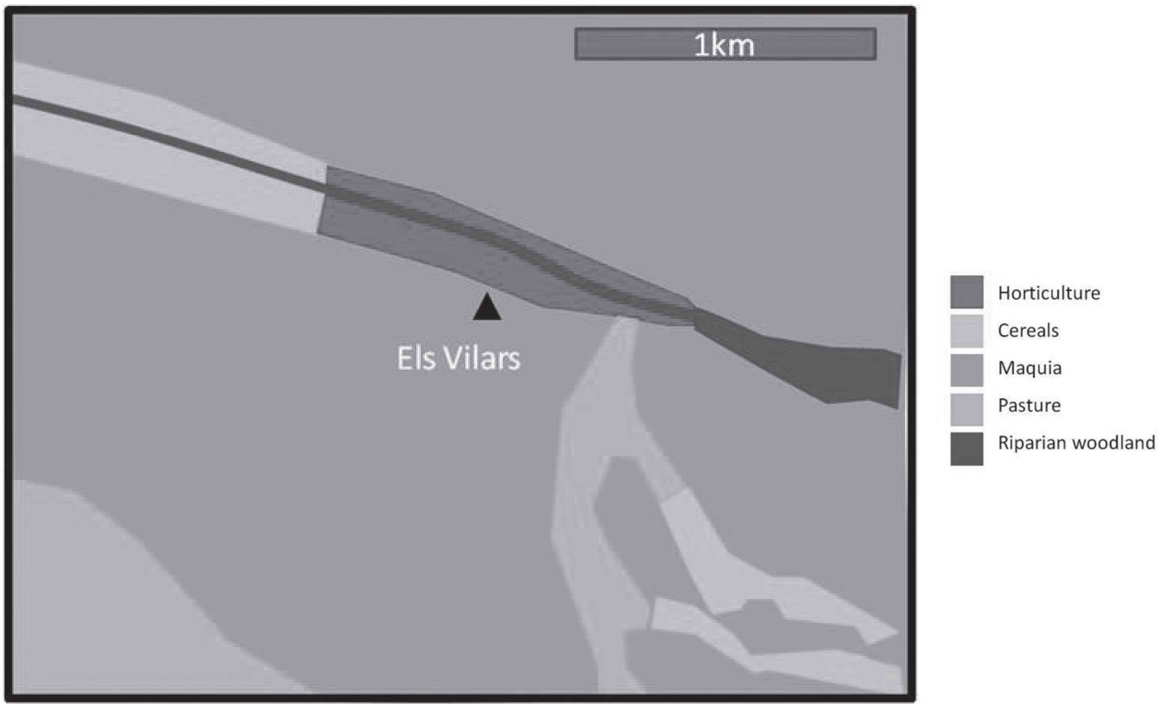



**Figure 5.** Possible landscape around Els Vilars, given the soil distribution and the past landuse scenarios.



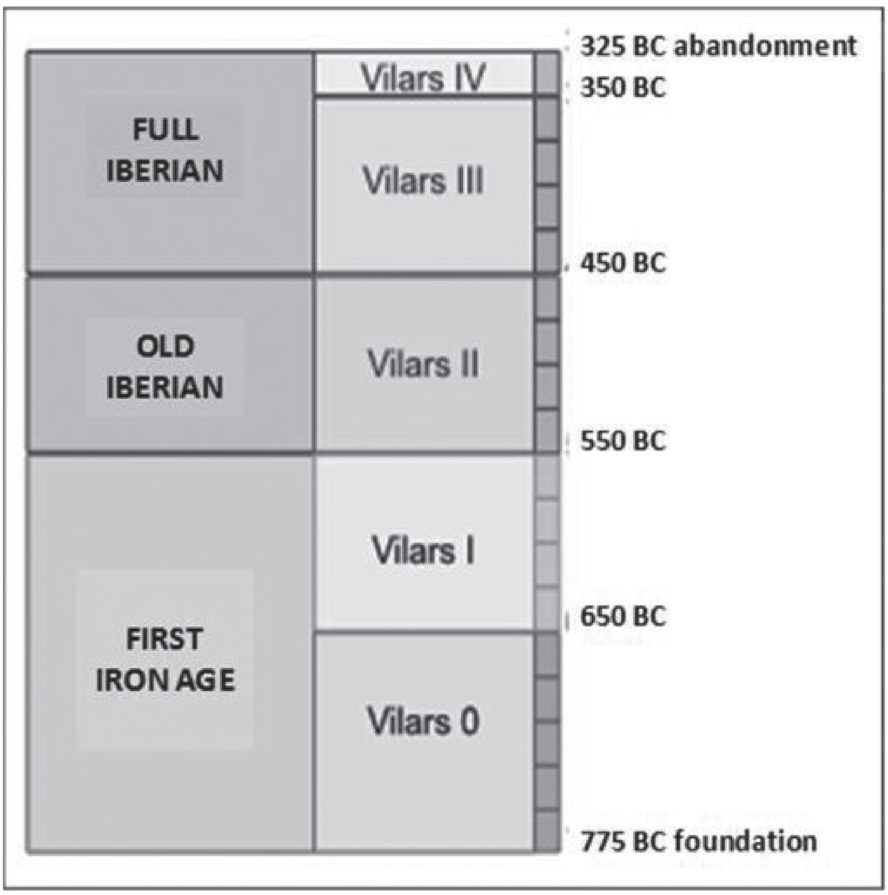



**Figure 6.** Chronology of the five phases of Vilars.

Vilars 0 (750/725-650/625 BCE). First Iron Age. Foundational phase. Wall with twelve towers and two gateways that opened to the east and west, the latter was closed very soon during this phase (Junyent *et al*. 2009, 307-333). The urban perimeter was arranged with a ring street around the central space, which, in general, was maintained until the last occupation. There is no evidence of a presumed central pond before the well of the the Full Iberian Epoch (Vilars III-IV).

Vilars I (650/625-550/525 BCE). First Iron Age. The walls and towers were strengthened by adding the third stone lining, and the *Cheval-de-frise*[3] constructed.

Vilars II (550/525-450 BCE). Old Iberian Epoch. The northern gateway was opened and the first moat excavated, destroying part of the *Cheval-de-frise*. The new gateway, suitably fortified, became the main entrance. The subsequent evolution of the moat destroyed or obscured some features of the initial construction. The inner wall was lined with stone only along the northern section – related to the gateway –, while the rest of the sections appeared as a bare slope constructed by excavation of the substrate with occasional reinforcements of overlapping stones stuck close to the walls. (Junyent/ Moya 2011, 93-120). The worship site with an Oriental fireplace belongs to this phase (GIP 2005, 651-667).

Vilars III-IV (450-300 BCE). Full Iberian Epoch. The knowledge of these phases inside the enclosure is very poor and limited to the space preserved in the central enclosure. The opening for the eastern tower-door seems to continue at an upper level, acting as communication from the inside with the space outside the walls but protected by the moat. The defensive system reached its maximum development during this period. The great moat around the fortress finally replaced the *Cheval-de-frise* and the stones which had been introduced vertically at the foot of the wall were buried – sometimes reused – due to the building of the wall escarpment. Another advanced moat protected the fortified entrance ramp to the north gate and, inside, the well guaranteed the water supply. All together it formed a complex hydraulic system fed by the water of the old course of the Aixaragall river (figs. 7 and 8).




**Figure 7.** Structure of Els Vilars.

3.- Field of embedded standing stones intended to make access difficult.




**Figure 8.** Aerial view of Els Vilars (to the E), with the approximate waterway of the Aixaragall channel. Solid arrows: present artificial drainage of the Aixaragall. Dashed arrows: apparent old path of the Aixaragall.

## 4. THE DEFENSIVE STRUCTURES OF ELS VILARS

### 4.1. THE WALLS AND THE DOORS

The wall with its towers reached a width of almost 6 meters. Except for more complex areas near the main gate, it is formed by four walls that were successively added. The first wall was built with stone, while the second one was made with a mixed stone foundation and elevation of adobe bricks. They were later joined by a third and a fourth stone lining, both during the old phases, although the latter already at the beginning of the Old Iberian period. The stone blocks, large and medium-sized and uncut, were joined using mud. A conservative estimation allows us to establish the height between four and five meters, not taking into account the walkway and wooden parapets at the top. During the Old Iberian Epoch, twelve regularly distributed solid towers were built, as well as an empty tower protecting the north gate and used as a guard tower. At the base of the towers were hollows into which large slabs were wedged that contributed to their stability. In order to prevent these from being absorbed by the widening of the curtain wall, they were lined by one and two walls, even three in the case of large solid tower that protected the north gate, where the use of sundried mud bricks was also documented (GIP 2003, 242-243; Alonso/Junyent/López 2010, 19-20).

Extensive information about the gates of the fortress has been published (Junyent *et al.* 2009, 307-334). In the beginning of the early Iron Age (Vilars 0), there were two gateways aligned on an east-west axis. The west gate, flanked by massive stone towers and crossed by a culvert, was abandoned early during this phase. Inside the enclosure, during Vilars I, the space leading to the door was occupied by a house, while outside the walls the growth of the towers absorbed one of the side towers, while the other became a larger tower which occupied the site of the old gate. The main entrance, the only one existing during Vilars I, was actually a gatetower opening to the east. There was a frontal doorway, with a corridor 1.5 m wide that crossed a massive tower with a rectangular base 6 x 5 m leading to the rear doorway, where two hinge holes can still be seen corresponding to two different periods of use. The enemy, in maximum sized groups of two or three people able to gain entrance, would have been caught literally in this mousetrap and could have been eliminated through the openings on the corridor. At the beginning of the Old Iberian period (Vilars II), the north gate was built, intended to be the definitive main entrance of the fortress until the end. The process was different to the one followed for the west gate: the wall was perforated to open the new gateway, seeking the protection of a large tower to the right, and it was properly fortified. The new structure was projected forward: an empty tower was built to the left (to the right viewed from the attacking side) and to the right, a massive bastion was joined to the tower. The result is a frontal doorway flanked by two towers, followed by a long and narrow corridor. The enemy – after first having had to pass the advanced defenses and the fortified ramp – would then have been forced to run a dozen meters under the defender fire, and would be cornered in the last section at the second doorway, subject to attack from above with spears from the upper walkway through arrowslits to the inner arch.

Although the three fortified gates of the fortress are different, they share two basic features: they are flanked by towers, and they are narrow enough both to facilitate defense and to prevent attack in groups. This feature was meant as a deterring strategy within a conception of passive defense. This situation changed later on with the building of the fortified ramp (Junyent/López/Moya 2009, 325-329).



## 4.2. THE "CHEVAUX-DE-FRISE"

This advanced defense system, meaning "Frisian horses" (*piedras hincadas* in Spanish), consists of an area around a fortification or in front of the zone that has to be defended, that was embedded with vertically orientated stones in order to hinder the access or movement of both cavalry and infantry. Besides its military functionality, its added symbolic and scenic value to the architecture of power is important. The *chevaux-de-frise* are presumably inspired by Central European fences (Harbison 1971, 195-225). There are fields scattered in Ireland, Wales, Scotland and the Iberian Peninsula. They are frequent in Celtic Hispania and exceptional in the Iberian world (Pech Maho, Sigean, France). They show a large chronological and cultural diversity, from the Bronze age to Republican-Roman period (Alonso *et al.* (Eds.) 2003; GIP 2003, 233-274; Alonso/Junyent/López 2010, 20-23; Berrocal-Rangel 2004, 27-98; Berrocal-Rangel/Moret 2007b, 15-33). The *chevaux-de-frise* of Els Vilars was built and functioned during the 7th and part of 6th centuries BCE. The building of the moat resulted in their destruction, but the internal construction of the escarpment buried and protected the upright stones located next to wall foot. In fact, with variants, these systems, intended to hinder the enemy, have been continuously used from the Alesia siege by Caesar (52 BCE: *Cippi, Lilia, Stimuli*) until the Second World War, as it is the case of the "Dragon's teeth" of the Siegfried line (1938), or the "Atlantic Wall" at the Normandy coast (1944) (Quesada 2003, 69-100).

## 4.3. THE FORTIFIED ACCESS TO THE NORTH GATE

According to aerial photography and geophysical evidence, the old river fed the moat system and allowed water to reach the central well. Defense and water management, military architecture and scenery of power are embodied in the northern access. A wide ramp defined by side walls and defended by transverse moats from wall to wall and most likely a counterguard, crossed the two moats and made it possible to access the narrow corridor that penetrated the wall between the bastion and the towers, and finally reach the gate (Junyent/Moya/Tartera 2009, 307-333).

## 4.4. THE WELL

The central well-cistern of Els Vilars differs from the traditional cistern used for rainwater collection and storage. It is exceptional in the Iberian context due to its structural and building features, width, depth and access, and especially its preservation. Cisterns partly or completely lined with stone were already familiar to the communities of the Bronze Age Group of the Segre-Cinca II (1250-950 BCE, Regal de Pídola (Sant Esteve de Llitera) and Safranals (Fraga)), as well as to the communities of the First Iron Age or Group of Segre-Cinca IV (775-550 BCE, Záforas and Cabezo de Monleón and the recent finding of La Codera (Alcolea de Cinca)) . Later on, all the Ilergetian settlements, as well as the rest of the Iberian people, had their own cistern: i.e. Sant Antoni (Calaceit), Pilaret de Santa Quitèria (Fraga), Roques de Sant Formatge (Seròs), Gebut (Soses), Tossal de les Tenalles (Sidamon), Estinclells (Verdú). In fact, it seems to have been the traditional water supply system from the Chalcolithic in all areas of the SE Iberian Peninsula, eastern and northern Andalusia and peninsular East (i.e. Fuente Álamo, El Oficio, Castellón Alto, Peñalosa, Bastida de Totana, Illeta dels Banyets). It would last during the entire Iibero-Roman period in settlements like El Palao (Alcañiz). These cisterns, covered or not, were where rainwater was collected and stored. As Pierre Guérin observed at Castellet de Bernabé (Llíria), they were often located in an elevated position, leading to the conclusion that they did not in these cases collect street-level running water, but instead water from nearby roofs. Whether the drinkability would have been ensured by supply, piping, sedimentation or filtration systems is still unknown (Guérin 2003, 248-249). The cisterns do not seem to have been the only way to solve the water needs, since in some places such as Roques de Sant Formatge, they had been converted into landfills while the settlements were still inhabited.

Despite water being a fundamental resource. the scarcity of information available about water supply in Iberian communities is surprising. Until recently, the capture, storage, management or use of water resources has not been the subject of research. Recent studies and the present document show, very clearly, a changing trend (Agusta-Boularot 2004, 177-225; De Prado 2008, 185-200; Egea 2010, 119-138; Oliach 2010, 263-281). The discoveries of wells at la Ciutadella de les Toixoneres (Calafell) and at Can Xercavins (Rubí) expanded the initial knowledge on the ability of the Iberians to exploit groundwater resources, and helped understand the well of Els Vilars and its relationship with the moat. These structures demonstrate the considerable ability of its inhabitants to conceive and manage a highly complex hydraulic system. It should not be surprising considering the power of some Bronze Age communities, as evidenced by the fortified well La Motilla del Azuer (Tablas de Daimiel) where the well had been dug 20 m deep to obtain water.

The Els Vilars well-cistern however, has some particularities. It was built at the beginining of the 4th century BCE according to stratigraphic interpretations, Attica imports in the access ramp consisting of red figures and black varnish, and the *terminus post quem*[4] that shows a small fragment of a Saint-Valentin ceramic in a wall pre-dating the construction. The well is oval in shape, 6 by 7 m diameter, with a thick, almost vertical stone cladding lining the walls and an access ramp with steps at the bottom end leading to the water level. At present, it reaches a maximum elevation of about 5 meters, which represents approximately 7 m deep with respect to the hypothetical soil level (not preserved) inside the enclosure. The first results of the soil analyses conducted by R. Julià (CSIC), S. Riera (UB) and A. Currás (UB) revealed the absence of coprophilous fungi (which are indicators of decomposition of organic matter), and the absence of diatoms and ostracods, (which are algal and salinity indicators). Our hypothesis therefore supposes that there was neither sewage nor street runoff in the well-cistern. We do not have data for this date – 4th century BCE – but the urban layout of the first phase, Vilars 0 and I, shows that the water collected by roofs to the ring street was expelled to the outside by the west gate through a sewer (Junyent/López Moya/Tartera 2009, 311-315). Water renewal and filtration would have avoided anoxia and pollution problems in the well-cistern, since it appears clean, without pathogens and drinkable. These considerations and the evidence that the narrow access ramp was not suitable for animals, suggests that the well water was intended for human consumption (Alonso/Junyent/López 2010, 32-35; Currás *et al*. 2010; Junyent *et al.* 2011, 159-161; Junyent/Moya 2011, 112-114). It seems logical to suppose that the well opening was covered, protected from light to prevent eutrophication. Nevertheless, there is no evidence of any cover; and also the large size of the opening would have been a problem to cover.

## 4.5. THE MOAT

The excavations carried out between 2007 and 2010 revealed the large moat and an access ramp to the north gate, and also discovered a newer advanced moat, presumably related to the defense of the older, inner one and the water supply system through a channel from the torrent of Aixaragall. Regarding the large moat, the most recent publications (Junyent *et al.* 2011, 153-184; Junyent/Moya 2011, 93-120) have completely reversed earlier interpretations (GIP 2003, 244).

During the Old Iberian period (Vilars II) at end of the 6th or beginning of the 5th century BCE, the fortress underwent major changes: the northern gate was opened and a first moat built, leading to the destruction of *chevaux-de-frise*. Little is known about the moat of Vilars II because its remains were destroyed or covered by the construction of the larger moat during the Full Iberian period (Vilars III). Nothing is known about the back escarpment, in particular its width. We know, however, that the inner scarp was formed by bare land cuts in most of the sections, reinforced occasionally by retaining walls. East of the access ramp the appearance of a section more than 7 m long, carefully built and with a foundation ditch, allows us to think that the escarpment of Vilars II was only lined with stone on both sides of the northern gate. This wall, with a maximum width of 1.65 m and more than 1 m high, was buried by the building of the upper escarpment of the moat of Vilars III-IV above it, in front of the lower escarpment.

During Vilars III (450/425-350 BCE) and Vilars IV (350-300 BCE) the fortifications of the northern entrance were strengthened, the system of flooded moats renovated and the central well-cistern built. In contrast to the scarce remains of the moat of the Old Iberian period, the magnitude and characteristics of the Full Iberian moat are fully understood. It gave the fortress its maximum



4.- TPQ, the earliest time the event may have happened

complexity, and continued to function until occupation of the fortress ended. The construction and maintenance of such a work would have expanded over time, requiring constant adjustments and maintenance tasks. These were demonstrated by the detailed study of the escarpments and the location of water entrance in the north-east sector, which was closed later on by the bottom wall of the counterscarp (Junyent/Moya 2011, 109-110). In general, the large moat can be classified as a flooded moat with a bucket section, much wider than it is deep, dug into the Oligocene clay substrate of the alluvial plain (Mora-Figueroa 1996, 113-115). The width varied between 13 and 25 m and the depth between –4.60 and –5.80 m below the zero point, which coincides approximately with the current surface level of the present day fields (i.e. one meter above the surrounding surface the old fortress). The moat bottom was flat at the north-east, east, south-east and south sides, while in western sectors a longitudinal spine on the middle part created a double (duplex) moat (figs. 7 and 8). This sector was transversally divided into at least two major ponds where the maximum depth of the moat was achieved. The function of these ponds is unknown. Bearing in mind that they are at the south-west and west sides (in the shade of the walls and towers), that they are the deepest sections of the moat, and that they reach a level similar to the well bottom, we can think that they retained water during drought periods. The inner scarp, fully lined with stone along about 470 linear m of wall, has the appearance of a false double-tiered terrace, the upper one defined by a powerful wall built with a foundation trench and the lower one consisting of a sloping stone lining with an irregular thickness cut into the bare earth. The outer escarpment is formed by the land slope with a reinforced base by a wall with very variable characteristics which are the result of different remakes.
The moat of the Arbeca fortress is unique in the Iberian world, due to its features (floodability, dimensions and lined escarpments, double moat and ponds, relationships with the well...), to the fact of having been fully excavated and to the quality of the obtained information. The moats, virtually unknown until a few years ago and hardly considered in the military Iberian architecture, are now presented as a characteristic element of the defense of Iberian oppida[5], except in cases where the topography makes them clearly useless (Junyent/Moya 2011, 117; Junyent *et al.* 2011, 164-165). The international meeting *Les defenses exteriors i la poliorcètica mediterrània preromana: els fossats, segles VIII a III a.n.e.,* Lleida-Arbeca 2010, sets the inflexion point for their recognition in the Iberian poliorcetics (Junyent/López/Mastria (eds.) 2011, 89-295).



5. POWER ARCHITECTURE AND POLIORCETICS

The identification of the unique and exceptional features of the fortress determine their interpretation. Its setting, conceived from the beginning as a power center, reflects the will of a preconceived and modulated design, free from the topographic constraints of the hill tops and exhibited with the pride on the plain. During four centuries it underwent modifications, always stressing the scenic features and the symbolic values inherent to the power architecture, and always dimensioning defense structures beyond the strict functional and military needs. These defense structures occupied over 80% of the built area. Moreover, the increasing complexity and construction of the central well are indicators of other types of changes.
The old fortress (Vilars 0, I and II, between the 8th and 5th centuries BCE) reflects a concept of passive defense in a context of "heroic war" where the defensive capability surpasses the offensive one. In this concept imposing walls deter the enemy from attacking, and fighting takes place away from the walls, either in singular or in open field clashes, In the 4th century BCE, the situation appears to have changed. The construction of the central well to ensure the water supply clearly shows the perception of the threat of siege, and the construction of the moat system and in particular the fortified access ramp to the northern gate, reflect the idea of active defense. The concept of an organized defense was introduced in steps, along with the compartmentalization of the defense space, which also made counterattack possible.
The narrowness of the door and the corridor before it, combined with the width of the access ramp crossing the moat, was a brilliant solution: it allowed monumentalizing the entrance without weakening the gate, and it allowed the possibility of a sudden exit in order to counterattack from the access ramp, which would also have acted as a counter-wall or barbican (Junyent 2009; Junyent 2010, 305-309; Junyent *et al.* 2009, 326-329; Junyent/Moya 2011, 114-117). These features considered together obliges us to rethink the supposed simplicity of the Iberian fortifications (Quesada 2009, 112-130; 2010, 179; Junyent 2010, 308) and to agree that Els Vilars was designed anticipating the possibility of a siege or blockade (Quesada 2007: 75-98; Alonso/Junyent/López 2010, Junyent/Moya 2011, 115-117). Defense and water management, architecture and military scenery find their maximum expression in the system of moats, the central well and the northern gate (Junyent/Moya 2011, 93-120; Junyent *et al.* 2011, 1172-176).

5.- Large defended Iron Age to early Roman settlements.

## 6. THE MOAT: MORPHOLOGY AND ANALYSES OF THE SEDIMENTS

### 6.1. MORPHOLOGY AND MICROMORPHOLOGY OF THE SEDIMENTS

The sediment filling the moat is grouped into two major stratigraphic packages. From the bottom upwards, a few levels of gray and green clay were formed under anaerobic conditions due to the permanent flooded conditions. Over these first strata lie oxidized strata of clay, sand and gravels accumulated over the centuries, due to abandonment, erosion of the slopes and contributions from river floods (fig. 9).

All the studied levels on the shallower side of the duplex moat (fig. 9) are characterized by a lack of organic or anthropic components, by a lack of sorting (particle-size uniformity) and a lack of stratification. The sediments on the deeper side of the duplex moat show a fine stratification with sorted strata of submillimeter size, corresponding to frequent (monthly, seasonal) low-energy flooding events. The characteristics of the flooding regime of the rest of the moat can be deduced from the relation between the redoximorphic features and the pores of the sediments. The deepest sediments, in contact with the excavated substrate, show a grey groundmass without iron oxides, corresponding to a reduced (gley) material. The oxidation mottles correspond to iron quasi-coatings around pores, formed during the few drying events in the moat when air entered the macropores. Another interesting feature is the presence of mouldic voids with pseudomorphs after lenticular gypsum as individual crystals or as crystals rosettes, that would correspond to leaching of gypsum formed once in the sediments (fig. 10) . The shape of the pores correspond to gypsum formed in saturated or near-saturated conditions (Poch *et al.* 2010; Poch/Balasch/Junyent 2010). While the presence of gypsum in the catchment area is enough to justify the formation of the crystals by dissolution and reprecipitation, the lenticular mouldic voids have been attributed in other environments to the leaching of gypsum formed by

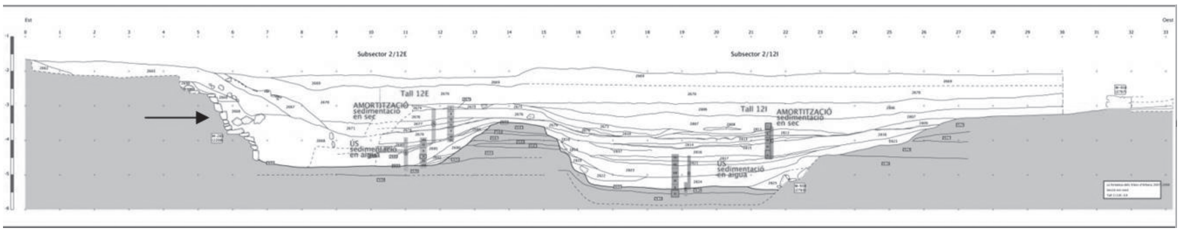



**Figure 9.** Scheme of the N section of the moat (S-N). Note the spine in the middle dividing the moat into two depressions. The blue line indicates the change from reduced to oxidized sediments. The black arrow indicates the level of the white carbonate precipitates that would correspond to the water level during the period of flooding.

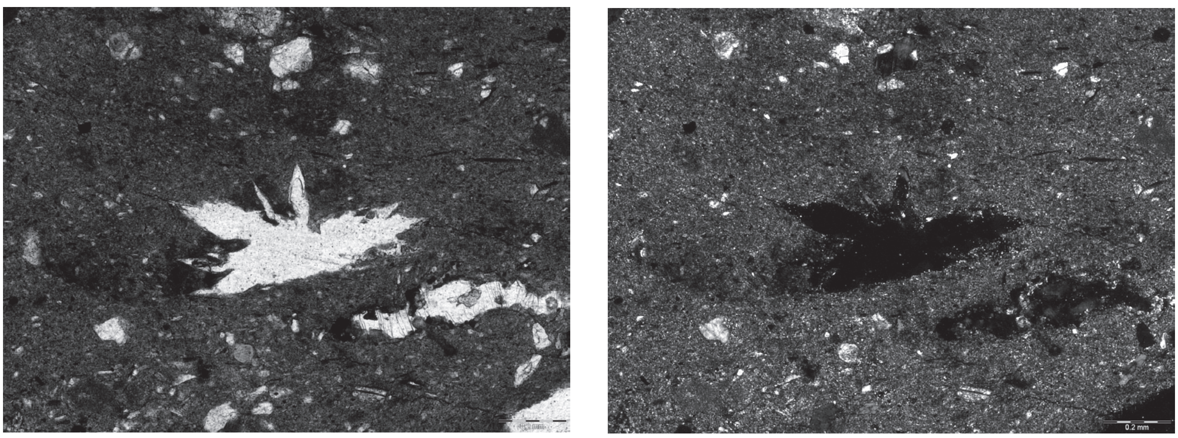


**Figure 10.** Mouldic voids after lenticular gypsum, and Fe-hypocoatings in the reduced sediment. The bar is 0.2 mm. PPL and XPL.

oxidation of sulphidic sediments (with pyrite), and with a calcium source nearby (Poch *et al*. 2009). Some Fe-nodules in organic remains could correspond to pseudomorphs after pyrite (fig. 11). All these features are indicators of nearly-permanent flooding conditions. The most recent sediments are brownish, oxidized, and in spite of the presence of some redoximorphic features, they correspond to imperfectly drained materials without a complete reduction (i.e. pseudogley). They would correspond to faster rates of sedimentation, without free water, where restructuring processes would have taken place giving a pedal appearence to the sediments.

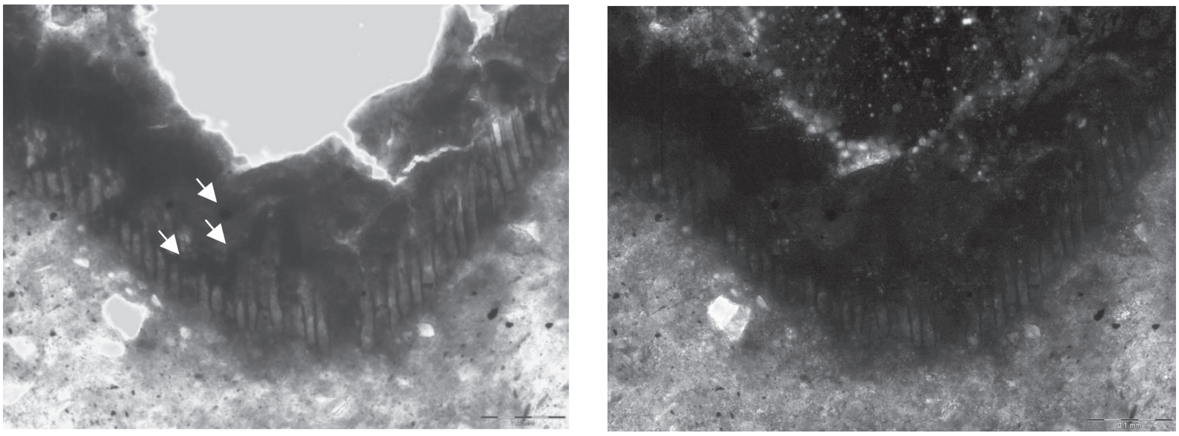


**Figure 11.** Iron micronodules (arrows), probably pseudomorphs after pyrite, associated with a ferruginized root section. The bar is 0.1 mm. PPL and XPL.



6.2. MICROMORPHOLOGY OF THE LEVEL CARBONATE ACCUMULATIONS

Whitish coatings formed by calcium carbonate cover part of the stone face of the inner moat lining, on the northern side, with a thickness of 10 to 20 cm (fig. 12). They follow a completely horizontal line that coincides with the foot of the ramp that leads to the well at 3.16 to 3.32 m under the zero level (i.e. probably the upper waterlevel of the well at its maximum). They are mixed with blackish iron and manganese coatings. The micromorphology of the carbonate coatings (0.5 to 2 mm thick) consists of micrite or elongated sparite, perpendicular to the stone face, very similar to the carbonate pendents of calcic or petrocalcic horizons of the area (fig. 13). These accumulations in soils are caused by the precipitation of calcite at the wetting front (boundary between humid and dry conditions), and can be due either to downward (from leached horizons) or upward (from a watertable) movement of water. In the environment of the settlement it would be similar to the latter process, i.e. a water surface at a certain height that would evaporate and where calcite would precipitate on a width corresponding to the oscillation interval of the water level. A capillary rise is impossible through the large macropores between the wall stones. The presence of iron oxides mixed with the calcite in the perched positions of the wall (well drained at present) also suggests a saturated water level to this height during a long period of time. In contrast, temporary or oscillating water levels would have resulted in thinner accumulations of carbonates on the whole wall and the iron oxides would have been almost absent.

**Figure 12.** White line on the internal scarpment of the moat (N side) corresponding to $CaCO_3$ precipitation. The thickness of the white line is about 20 cm.

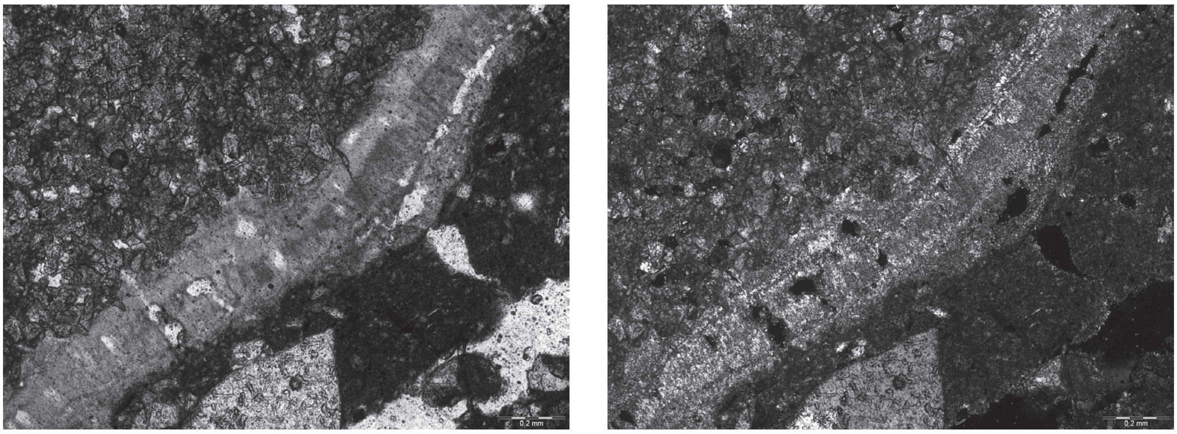


**Figure 13.** Calcite coatings, made of sparite crystals perpendicular to the sandstone of the internal moat scarpment (upper left). The bar is 0.2 mm. PPL and XPL.

Badia *et al.* (2009) found calcite accumulation rates of 0.066 mm/ky (11–64 ky) in the terraces of the Segre river (near the study area). Considering a thickness of 0.3 mm (maximum thickness measured in thin sections), the period of formation would be 4500 years in a pedogenic environment. However, if we assume a free water level, the conditions would be more similar to a wet environment and it would be more suitable to use the rates of Pustoyoytov (2003) that showed growth rates higher than 1 mm/ky under the semi-humid conditions of west Germany, in which case the formation could have take place in less than 300 years.

## 7. WATER RESOURCES AND WATER USE IN THE SYSTEM MOAT/WELL/VILLAGE

At this point, the main questions arising are: was the drainage area of Aixaragall river large enough to feed the moat system? How did the well/cistern function? Where did the water came from? Is there any relationship between the moat and the well/cistern?

### 7.1. ESTIMATION OF THE WATER SUPPLY BY THE AIXARAGALL DRAINAGE SYSTEM AND THE MOAT WATER STORAGE

The annual contribution of Aixaragall water resources has been calculated by two different techniques: (1) direct stream flow measurements during 2011 (annual average flow of 3.56 l / s with an annual precipitation $P_{2011}$ = 302.6 mm), and (2) indirect estimation by a water resources distribute model grid (1 x 1 m grid, SIMPA-CEDEX) applied to the basin for 60 years (average annual flow of 10.36 l / s with P = 428.1 mm). The average annual contribution obtained with both techniques are respectively 112,000 $m^3$ and 325,000 $m^3$. The difference between the two methods is due to the fact that the volumetric year (2011) was one of the driest in the record period. Moreover, according to the model and the current climate, there is a high irregularity of the monthly water supply, since 70% of the months had a negligible to no water contribution.

The annual water demand in Els Vilars, considering about 150 inhabitants and including provision for cattle, has been roughly estimated as 440 $m^3$/year. In the situation of full moat, an amount of about 11,800 $m^3$ per year is also needed, considering a fixed water level of 1.5 m from the bottom of the moat and including the annual losses by evaporation and deep infiltration. The sum of both amounts is approximately 12,250 $m^3$. If new findings confirm the existence of an additional half outer-moat (which would nevertheless be smaller than the present moat with the present knowledge), it would be necessary to add a third amount.

The well located in the middle of the fortress has an approximate capacity of 160 $m^3$, when filled to a height of 5 m of water from the well bottom.

Two hypotheses for the operation of the water system of Els Vilars can be proposed: a) the moat was filled by surface water from the Aixaragall stream or b) the moat was filled by subsurface water stored in the aquifer of the Oligocene lutites and sandstones. A third hypothesis, considering the possibility of the Aixaragall detritic aquifer contributing to the filling of the moat has to be discarded due to the inadequate thickness of its alluvial-fan gravels.

a) Looking at the contributions of the stream and the demands of the system it can be concluded that the water supply to the fortress and the moat would have been guaranteed from the Aixaragall stream runoff, supplying about 10 times water than necessary. The base level of the current stream (now piped) is very close to the elevation of the present topographic surface. The base level at the time of the settlement, however, was 1.5 m below the present ground surface (elevation –3.10 m at the zero site level) according to pottery finds at the bottom of paleocanals connected with the moat bottom. Therefore, it is above or at the same level as the highest moat water-level, which is the same as the level of calcite precipitation on the inner moat scarpment, the base of the stairs of the well or the height of the reduced moat sediment layers. Therefore, this geometry would hydraulically allow for the diversion of water from the stream to the moat. Reinforcing this hypothesis is the fact that the estimated annual rainfall for the period of operation would have been about 25% higher than the present according to paleoclimatic studies in the area (Voltas *et al*., 2008; Aguilera *et al.,* 2011), and therefore the available water resources would have been higher than the ones reported. The geophysical survey of neighbouring fields between Els Vilars and the old Aixaragall course (Sala/Garcia/Tamba 2009) also support the idea of a surface supply of water from l'Aixaragall.

b) A contribution of groundwater through Oligocene sediments is unlikely given the low permeability of the materials (of the order of 10-4 m / day, i.e. 3.6 cm/year). The water flow would be too slow and insufficient to fill the moat for practical purposes. However, the fact that these rocks are almost on the surface has led to the alteration and breaking down of the outcropping section and the development of discontinuities that could be used for water flow, but always at its surface. This explains for example, the seepage of water present in the bottom of the moat and inside the well, above the artificial drain built in 2007, which flows from the lateral flow of irrigation surplus infiltrating neighbouring fields. The electrical conductivities of the waters of the artificial drain reach values of 2,000 µS/cm (at 25°C)[6]. This value is lower than the salt content of the Aixaragall waters (3,600 µS/cm at 25ºC)[6], indicating a different origin that can only explained by irrigation waters. If the water of the moat and well came from an Oligocene aquifer they would be highly mineralized, its salinity being of the same order or higher than the salinity of the Aixaragall and much higher that the salinity of the irrigation waters.

### 7.2. FUNCTIONAL RELATIONS BETWEEN THE MOAT AND THE WELL-CISTERN.

The structure and position of the materials in cross section (fig. 14) is such that the Oligocene impervious materials are acting as an aquitard. It is therefore unlikely that these materials could have fed the well and acted as the main water supply for the fortress. At present the Oligocene is water-saturated in its upper section due to the drastic landuse changes brought about by irrigation over more than that last 100 years; but this situation is unlikely to have occurred in the past. The coarse, alluvial fan materials of the Aixaragall river are covering this aquitard, but as it has been explained in previous sections, the extent of these materials is not enough to form an aquifer that could supply water in sufficient amounts to the well. Nevertheless, if the hypothesis of the surface water feeding the moat is correct, the water level would have reached these gravels, percolated through them and fed the well. The height of the gravels (3.7 to 3.3/3.1 m below zero level) is lower than the carbonate level (3.16 to 3.32 m below zero level), therefore water could have percolated radially from the moat to the well through a water layer about 0.4-0.6 m thick (fig. 15). The carbonate level is also approximately equal to the depth of the reduced sediments in the moat (–3.3 m) and to the depth of the lowest level of the stairs leading to the well (–3.25 m), and somewhat lower than the old baselevel of the Aixaragall water course (–3.1 m); thus we can consider this level as the permanent water level of the moat and well.

The well was then fed laterally over the bottom, and would act as cistern during conditions of low water levels in the moat, since it would retain water below the gravel level on the aquitard. This fact explains the large diameter of this structure, rare in wells ss. The lack of information about the structure of the roofs, and about the full characteristics of a previous –smaller– cistern before the excavation of the moat makes impossible to consider the possibility of any water supply from above, although the roofs of the inner ring were probably shedding water to it during the first stages of its construction.

This system would have ensured a clean water supply to the well even in siege situations, that is estimated in four months. The fact that the well was deepened at the same time that the moat was built supports this idea.

## 8. CONCLUSIONS

— To avoid water eutrophycation in the moat and thus in the well it is necessary to maintain a continuous flow of water in and out in order to refresh the stored water. Although the northern part of the settlement has not yet been excavated, RADAR surveys revealed the existence of channel structures leading



6.- Measures taken at March 2012, one week after beginning of irrigation.

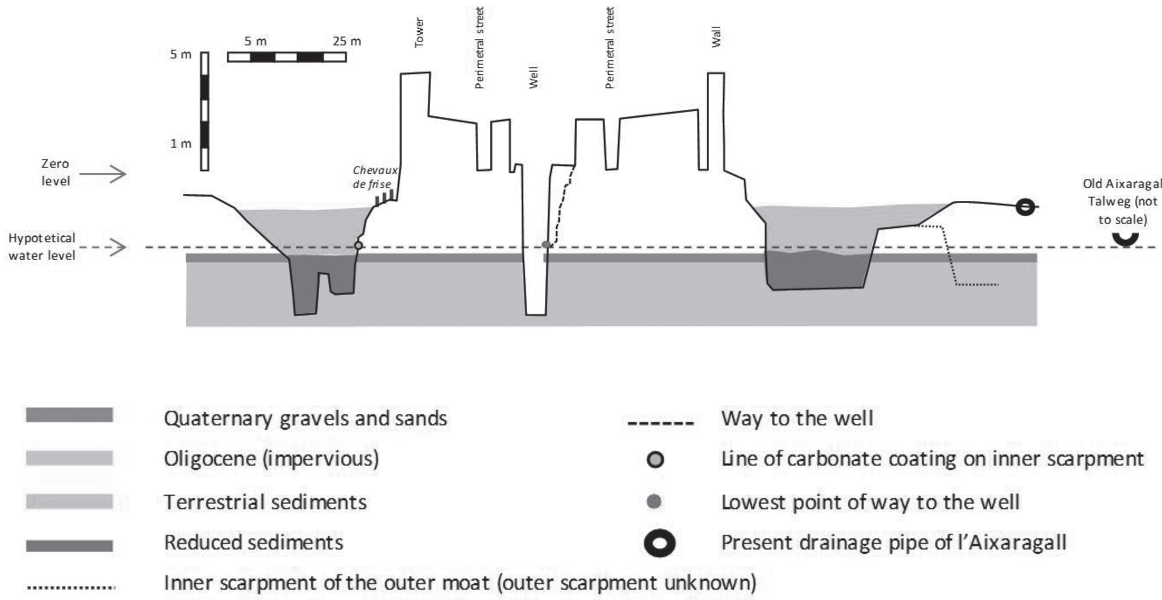



**Figure 14.** Present SW-NE section of the fortress and the moat.

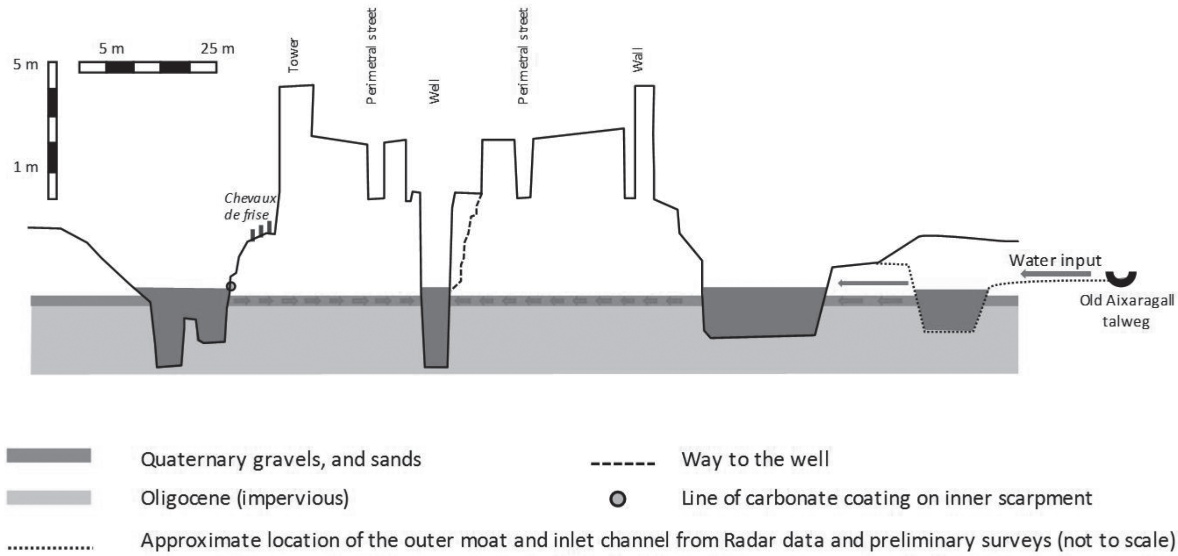



**Figure 15.** Hypothesis of hydrologic relations of the system river / moat / well through a SW-NE section. The water enters the moat by surface flow, fills up the outer and inner moat, percolates through the Quaternary gravels over the impervious Oligocene, and enters the well by seepage.



to the Aixaragall stream near the north gate, which could have supplied water to the moat. More research is needed to completely explain the functioning of the moat system in relation to the Aixaragall.

— The moat water demand represents, in volume, 25 times the water needs of the village. Therefore, the initiative to build the moat represented a great leap forward in the planning and use of resources, which could only have been achieved with guarantees of water availability.

— In case of a discontinued water supply from the stream, the water storage in the well would have

lasted at least 4 months. In case of siege, it could allow long resistence periods.
- The losses by evaporation and seepage into the trench represent half of the water demand (52%) needing to be supplied to the moat in order to maintain a stable level.
- The deep infiltration losses are only 5% of the total losses of the moat. This may explain the absence of waterproof structures, as lining of the lateral scarpments.
- The abandonment of the fortress could have been caused by several reasons, as epidemics, loss of geopolitical interest, but also may have climatic reasons (drought at the end of the 3rd century BC) or even hydrological, as a high flood silting the moat that would cause the loss of singularity of the fortress. Any of these hypotheses need further research.

## ACKNOWLEDGEMENTS

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## REFERENCES

AGUILERA, M., FERRIO, J.P., PÉREZ, G., ARAUS, J.L., VOLTAS, J. (online) 2011, Holocene changes in precipitation seasonality in the western Mediterranean Basin: a multi-species approach using $\Delta^{13}C$ of archaeobotanical remains, *Journal of Quaternary Science* DOI: 10.1002/jqs.1533.

AGUILERA, M., ESPINAR, C., FERRIO, J.P., PÉREZ, G., VOLTAS, J. 2009, A map of autumn precipitation for the third millennium BP in the eastern Iberian Peninsula from charcoal carbon isotopes, *Journal of Geochemical Exploration* 102, 157-165.

AGUSTA-BOULAROT, S. 2004, Maîtrise de l'eau et installations hydrauliques en Gaule du Sud IVe-IIe s. av. J.-C. , *in* Agusta-Boulerot A., Lafon, X. (eds.). *Des Ibères aux Vénètes. Phénomenès protourbains et urbains de l'Espagne à l'Italie du Nord (IVe-IIe s. av. J.-C.* Actes du colloque international tenu a l'Ècole Française de Rome les 10-12 juin 1999 (*Coll. de l'EFR* 328), Rome, 177-225.

ALONSO, N. 1999, *De la llavor a la farina. Els processos agrícoles protohistòrics a la Catalunya Occidental. Monographies d'Archéologie Méditerranéenne* 4. Publ de l'UMR 154 du CNRS. Lattes.

ALONSO, N., JUNYENT, E., LAFUENTE, Á., LÓPEZ, J. B. (coords.) 2003, *Chevaux-de-frise i fortificació en la primera edat del ferro europea,* (Reunió Internacional. Lleida, 27-29 de març de 2003), Universitat de Lleida i Consell Comarcal del Segrià. Lleida.

ALONSO, N., JUNYENT, E. I LÓPEZ, J. B. 2010, *Arbeca, La Fortalesa dels Vilars*, Guies del Museu d'Arqueologia de Catalunya, Generalitat de Catalunya, Barcelona.

BADIA, D., MARTÍ, C., PALACIO, E., SANCHO, C., POCH, R.M. 2009, Soil evolution over the Quaternary period in a semiarid climate (Segre river terraces, northeast Spain), *Catena* 77, 165–174.

BERROCAL-RANGEL, L. 2004, La defensa de la comunidad. Sobre las funciones emblemáticas de las murallas protohistóricas en la Península Ibéric, *Gladius*, XXIV, 27-98.

BERROCAL-RANGEL, L., MORET, P. (eds.) 2007a, *Paisajes fortificados de la Edad del Hierro. Las murallas protohistóricas de la Meseta y la vertiente atlántica en su contexto europeo* (Coloquio celebrado en la Casa de Velázquez, Octubre de 2006), Real Academia de la Historia, Casa de Velázquez, Madrid.

BERROCAL-RANGEL, L., MORET, P. 2007b, La fortificaciones protohistóricas de la Hispania céltica. Cuestiones a debate, *in* Berrocal-Rangel, L. i Moret, P. (eds.), *Paisajes fortificados de la Edad del Hierro. Las murallas protohistóricas de la Meseta y la vertiente atlántica en su contexto europeo*, (Coloquio celebrado en la Casa de Velázquez, Octubre de 2006). Real Academia de la Historia, Casa de Velázquez, Madrid, 15-33.

CALVET, J. 1980, *Relaciones entre la evolución geomorfológica cuaternaria de la Depresión Central Catalana (Segarra y Pla d'Urgell) y del Valle del Segre*, Fundació Juan March, Madrid, inèdit.

COSTA, C., COTS, L. 1992, *Estudio hidrogeoquímico del acuífero aluvial del Urgell*. Treball monogràfic XXVI Curs Internacional de Postgrau en Hidrologia Subterrània, Barcelona, inèdit.

CURRÁS, A., ZAMORA, L., ALONSO, N., JULIÀ, R., JUNYENT, E., LÓPEZ, J. B., RIERA, S., MARQUÉS, M. A., MEZQUITA, F., ARMENGOL, J. 2010, Landscape Evolution During the Last 3000 Years in a Semi-Arid Region (the Urgell Plain, Ebro Basin, NE Spain): Integration of Anthropogenic and Natural Sedimentary Records, *1st Landscape Archaeology Conference: LAC2010*, Institute for Geo- and Bioarchaeology (IGBA), Research Institute for the Heritage and History of Cultural Landscape and Urban Environment (CLUE) and the Cultural Heritage Agency (RCE) of the Netherlands at the VU University Amsterdam, 26th to 28th January 2010.

DE PRADO, G. 2008, La gestió de l'aigua a l'*oppidum* del Puig de Sant Andreu (Ullastret), *Cypsela* 18, 185-200.

EGEA, A. 2010, La cultura del agua en época ibérica: una visión de conjunto, *Lucentum* XXIX, 119-138.
FAO 1976. *Framework for Land Evaluation*. *FAO Soils Bulletin* 32, Roma.
FERRIO, J.P., ALONSO, N., LÓPEZ, J.B., ARAUS, J.L., VOLTAS, J., 2006, Carbon isotope composition of fossil charcoal reveals aridity changes in the NW Mediterranean Basin, *Global Change Biology* 12, 1-14.
FERRIO, J.P., VOLTAS, J., ALONSO, N., ARAUS, J.L. 2007, Reconstruction of climate and crop conditions in the past based on the carbon isotope signature of archaeobotanical remains, *in* Dawson, T. and Siegwolf, R. (eds.), *Stable Isotopes as Indicators of Ecological Change*, Academic Press, 319-332.
GALLART, F., CALVET, J., CLOTET, N. 1984, Observaciones geomorfológicas del Pla d'Urgell, posible influencia de deformaciones neotectónicas recientes en el origen de esta depresión, *Acta Geol. Hisp*. 19 (2), 75-80.
GRUP D'INVESTIGACIÓ PREHISTÒRICA (N. ALONSO, A. COLET, M. GENÉ, X. GÓMEZ, E. JUNYENT, A. LAFUENTE, J.B. LÓPEZ, A. MOYA, E. TARTERA, A. VIDAL) 2003, Caballos y hierro. El campo frisio y la fortaleza de Els Vilars d'Arbeca (Lleida, España), siglos VII-IV ane, *in* Alonso, N., Junyent, E., Lafuente, A., López, J.B. (eds.), *'Chevaux-de-frise' i fortificació en la primera edat del ferro europea*, Universitat de Lleida, Lleida, 233-274.
GRUP D'INVESTIGACIÓ PREHISTÒRICA 2005, Dos hogares orientalizantes de la fortaleza de Els Vilars (Arbeca, Lleida), *in* Celestino, S., Jiménez, J. (Eds.), Actas del III Simposio Internacional de Arqueología de Mérida (2 vols.), *Protohistoria del Mediterráneo Occidental: El Periodo Orientalizante* (Mérida, 5-8 de mayo de 2003), *Anejos de Archivo Español de Arqueología* XXXV, Mérida, 651-667.
GUÉRIN, P. 2003, *El Castellet de Bernabé y el horizonte ibérico pleno edetano*, SIP Serie de Trabajos Varios, núm. 101, Diputación Provincial de Valencia, Valencia.
HARBISON, P. 1971. Wooden and stone Chevaux de Frise in Central and Western Europe, *Proceedings of the Prehistoric Society*, XXXVII, 195-225.
HERRERO, C., BOIXADERA, J., DANÉS, R., VILLAR, J.M. 1993, *Mapa de Sòls de Catalunya* 1:25000, DG Producció i Indústries Agroalimentàries – ICC.
JARAUTA, E. 1989, *Modelos matemáticos del régimen de humedad de los suelos*, Tesi Doctoral, ETSEI- UPC. Lleida-Barcelona.
JUNYENT, E. 2009, El fossat, les defenses de la fortalesa dels Vilars d'Arbeca (segles V-IV a. de la n. e.) i la guerra ibèrica, *Patrimoni arqueològic i arquitectònic a les terres de Lleida*, Departament de Cultura i Mitjans de Comunicació, Generalitat de Catalunya, Publicació digital, Dl: L59-2010.
JUNYENT, E. 2010, Ressenya a Fernando Quesada, *Armas de la antigua Iberia. De Tartesos a Numancia, Esfera de los Libros, Madrid*, *Revista d'Arqueologia de Ponent* 20, 305-309.
JUNYENT, E., LÓPEZ, J.B., MASTRIA, F. (eds.) 2011, *Les defenses exteriors i la poliorcètica mediterrània preromana: els fossats, segles VIII a III a.n.e.*., Dossier, *Revista d'Arqueologia de Ponent* 21, 91-295.
JUNYENT, E., LÓPEZ, J. B., MOYA, A., TARTERA, E. 2009, L'accés fortificat i les portes en el sistema defensiu de la fortalesa dels Vilars (Arbeca, les Garrigues), *Revista d'Arqueologia de Ponent* 19, 307-334.
JUNYENT, E., POCH, R. M., C. BALASCH, C., SALA, R. 2011, La Fortalesa de l'aigua. Els fossats i el pou dels Vilars d'Arbeca: primeres lectures, *Tribuna d'Arqueologia 2009-2010*, Departament de Cultura i Mitjans de Comunicació. Generalitat de Catalunya, Barcelona, 153-184.
JUNYENT, E., MOYA, A. 2011, Els fossats de la Fortalesa dels Vilars d'Arbeca (Catalunya, Espanya), *Revista d'Arqueologia de Ponent* 21, 93-120.
JUNYENT, E., PÉREZ, A. 2003. *L'antiguitat, d'Iltirta a Ilerda*, a *Història de Lleida*, vol. 1, Pagès Editors, Lleida.
LANASPA, F. 2002, *Calibración y puesta a punto de un modelo de flujo de agua subterránea en los conos aluviales de la zona regable de los canales de Urgell (Lleida) y seguimiento de algunos parámetros de calidad de la misma*, Projecte Final de Carrera, Escola Tècnica Superior d'Enginyeria Agrària de Lleida, inèdit, 154 p.
MORA-FIGUEROA, L. DE 1996, *Glosario de Arquitectura Defensiva Medieval*. Universidad de Cádiz (*Bibliothecae castellarium* 1), Cadis.
OLIACH, M. 2010, Cisternes protohistòriques de la Plana Occidental catalana. Aspectes morfològics i utilitaris, *Cypsela* 18, 263-281.
PIQUER, J.J. 1986, Història i cultura de la Vall del Corb, *in* Boleda, R., Duch, J., Gelabert, D., Vallverdú, J., *La vall del Corb*, Pub. del l'Institut d'Estudis Ilerdencs, Lleida, 78-136.
POCH R. M., THOMAS B. P., FITZPATRICK R. W., MERRY R. H. 2009, Micromorphological evidence for mineral weathering pathways in a coastal acid sulfate soil sequence with Mediterranean-type climate, South Australia, *Australian Journal of Soil Research* 47, 403-422.
POCH, R.M., BALASCH, C., JUNYENT, E. 2010, Micromorphological evidences for ponding regimes and water management of the moat of the Iberian site of Els Vilars (Catalonia), Abstract book of the *International Working Meeting in Archaeological Soil Micromorphology (17th-21st of may 2010. Brno, Czech Republic)*, Edited by Lenka Lisa, Prague, 29-31.
POCH, R.M., ARTIEDA, O., HERRERO, J., VERBA-LEVEDEBA, M. 2010, Gypsic Features, in Stoops, Marcelino, Mees (eds.), *Interpretation of micromorphological features of soils and regoliths*, Elsevier, in press.

PORTA, J., JULIÀ, R. I COL. 1983, *Els sòls de Catalunya. Àrea Meridional de Lleida*, Departament d'Agricultura, Ramaderia i Pesca, Generalitat de Catalunya.

PUSTOVOYTOV, K. 2003, Growth rates of pedogenic carbonate coatings on coarse elements, *Quaternary International* 106–107, 131–140.

QUESADA, F. 2003, De los fosos de Troya a la línea Sigfrido. Las 'piedras hincadas' en el contexto de la historia de las fortificaciones, *in* Alonso, N., Junyent, E., Lafuente, A., López, J.B. (coords.) *Chevaux-de-frise i fortificació en la primera edat del ferro europea (Reunió Internacional. Lleida, 27-29 de març de 2003)*, Univesitat de Lleida / Consell Comarcal del Segrià, Lleida, 69-100.

QUESADA, F. 2007, Asedio, sitio, asalto... Aspectos prácticos de poliorcética en la Iberia prerromana, *in* Berrocal-Rangel, L., Moret, P. (eds.) *Paisajes fortificados de la Edad del Hierro. Las murallas protohistóricas de la Meseta y la vertiente atlántica en su contexto europeo (Coloquio celebrado en la Casa de Velázquez, Octubre de 2006)*, Real Academia de la Historia i Casa de Velázquez, Madrid, 75-98.

QUESADA, F. 2009, La guerra en la Cultura Ibérica, *in* Almagro M. (coord.) Prehistoria y Antigüedad, *in* Hugo O'Odonnell (dir.), *Historia Militar de España*, Ministerio de defensa, Laberinto, Madrid, 112-130.

RAMÍREZ, J.I. 1998, *Mapa Geomorfológico*, *in* Barnola, A. Robador, A. (eds.), *Mapa Geológico de España a escala 1:50.000*, Hoja nº 389 Tàrrega, Instituto Tecnológico Geominero de España, Madrid, 58.

SALA, R., GARCIA, E., TAMBA, R. 2009, *Prospección geofísica multi-sistema per a la descripció de restes arqueològiques al jaciment dels Vilars, Arbeca. Informe d'intervenció*, SOT Prospecció Arqueològica, Barcelona, Inèdit.

SSS - Soil Survey Staff 1999, *Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys*, 2nd edition. Agricultural Handbook 436, Natural Resources Conservation Service, USDA, Washington DC, USA, 869.

VOLTAS, J., FERRIO J.P., ALONSO, N., ARAUS, J.L. 2008, Stable carbon isotopes in archaeobotanical remains and palaeoclimate, *Contributions to Science* 4 (1), 21-31.