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The genesis of irrigated terraces in al-Andalus. A geoarchaeological perspective on intensive agriculture in semi-arid environments (Ricote, Murcia, Spain)

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ABSTRACT

Irrigated terraces in the Iberian Peninsula are associated with al-Andalus; the name with which the region was known following the migration of Arabic–Berber tribes across the Strait of Gibraltar, starting from 711 AD. Several of these agricultural areas have remained in use in the west Mediterranean to the present day. Historical texts usually refer to later extensions of the original Andalusi irrigated terrace fields, yet little is known about their foundation period. In this study we examined the micromorphology and undertook physico-chemical analyses and radiocarbon dating of a buried soil found in Ricote (Murcia, Spain) to provide relevant information to understand the initial stages of terrace building within al-Andalus. Results of our study show that: (1) Andalusi peasants selected a saline Hipercalcic Calcisol developed on colluvial materials on which to build the first irrigated terraces, (2) The soil was probably cleared of bushes by fire prior to terrace construction, (3) The shifting of sediments implied in the building of terraces seems to have entailed the inversion of the original soil stratigraphy, (4) Radiocarbon dating of submillimetric fragments of charred wood embedded in the top horizon of the buried Hipercalcic Calcisol (2σ 647–778 AD) suggests the original irrigated terraces of Ricote were built shortly after the arrival of Arabic and Berber tribes in the Iberian Peninsula.

1. Introduction

Terracing is a common agricultural strategy that is attested worldwide. The construction of agricultural terraces involves the shifting of sediments along a slope to obtain a staircase sequence of flattened parcels with deep agricultural soils capable of adequate moisture retention (Treacy and Denevan, 1994). Terrace fields can therefore be defined as constructed fields. Although this definition encompasses all agricultural land, terrace fields demand more labour than most (Torró, 2007) and have a greater impact in terms of anthropogenic transformations of the slope gradient and connected physiographical and ecological processes. Terraces are never built in isolation: each terrace represents a portion of a larger, complex system (Barceló et al., 1998; Torró, 2007). Terrace systems are consistently built from the bottom of the slope upwards, as lower terraces support those constructed above. For the same reason, terraces built at the base of the slope are generally bigger that those lying above. This was noticed in the 16th and 17th centuries by Inca Garcilaso de la Vega (1609), whose general observations of Inca terrace-building apply to most terraced areas.

Slight variations within this general procedure may apply, as multiple factors affect terrace construction, e.g. the characteristics of the chosen environment or the aims of the builders. For example, hydromorphic soils must be drained before terracing to prevent landslides and protect the stability of the system in case of heavy precipitation. Likewise, rocks are usually removed from stony soils before terrace construction begins. Wild plants are also removed, and different types of vegetation imply the use of different weeding procedures (Cooter, 1978). Topographical conditions determine the shape of terraces. In general, the construction of terrace walls is more difficult on steep slopes, while the flattening of the terrace surface is more problematic when gentle slopes are involved (Treacy and Denevan, 1994). Terrace walls tend to be built with local stones. However, earth banks, to which plant cover may be added to increase stability, are also common (Veeck et al., 1995). Soil and sediment added to new-built terraces may proceed from the same slope or from deposits found elsewhere. Terraces built with imported soils and sediments have been identified previously in Peru (Keeley, 1985), Yemen (Wilkinson, 2006) and Israel (Ackerman et al., 2005). The type of crop that will be cultivated on a given terrace may also condition its shape (e.g. exposure, surface topography) and composition (e.g. due to the necessity of adding allochthonous soils and sediments) (Hudson, 1992).

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Building procedures become more complex when the construction of irrigated terraces is involved, as they require previous design to ensure correct articulation between (1) location of the water source, (2) topography of the catchment, (3) network of channels and (4) cultivation area (Barceló, 1989). Gravity is the main constrain in the design of hydraulic systems, as it allows water to flow. Slopes must be calculated and the layout of channels and terraces carefully planned. Due to gravity, hydraulic systems tend to have rigid and easily recognisable boundaries. In order to maintain the efficiency of the original system, later transformations must be undertaken with close reference to the initial design. In this sense, the original design of any given hydraulic system strongly determines the nature and scope of potential future alterations. This implies that the original irrigated terraces and later additions or modifications remain discernible through time, unless the original system is completely obliterated to allow the construction of a brand new one (Barceló, 1989).

The construction of irrigated terraces in the Iberian Peninsula (henceforth referred to as al-Andalus) was a preferential agrarian option following the arrival of Arabic–Berber tribes in 711 AD. Hydraulic systems were accompanied with the introduction of exotic plants such as artichoke, cucumber, lemon, orange and sugar cane, to name but a few (Watson, 1983). The spread of hydraulic systems and related plant species across the Mediterranean was defined by Glick (1991) as a large scale propagation of oriental landscapes, and by Watson (1983) as an agricultural revolution. Historically, the expansion and propagation of Andalusi hydraulic systems in the Iberian Peninsula was boosted by the feudal conquest of al-Andalus between the 11th century and 1495 AD. Feudal lords modified, altered and extended Andalusi irrigated fields. Many of them remain active in the present day, and some, such as those in Murcia and Valencia, are still recognised among the biggest and most productive agricultural areas in Europe (Acosta et al., 2011). These hydraulic systems, known in Spain as *huertas*, have functioned persistently over the past millennia through contrasting climatic phases, including the Medieval Climatic Anomaly (MCA) and the Little Ice Age (LIA) (Morellón et al., 2011; Moreno et al., 2011). This makes them extremely interesting in terms of understanding pre-industrial agriculture technology in semi-arid environments. Apart from the inherent historical and archaeological value, the study of al-Andalus irrigated terraces is most relevant for the development of present-day sustainable agricultural strategies. In these terms, a number of key factors remain largely unknown, including (1) the characteristics of the pre-existing environments over which the irrigated terraces were built, (2) the timing of their construction and (3) their construction process. In this paper, such questions are approached through the geoarchaeological study of the Andalusi irrigated terraces of Ricote (Murcia, Spain). The aim is to stress the importance that the introduction of irrigated agricultural systems have had in the making of some of the most emblematic Mediterranean landscapes.

1.1. Ricote: physiography, history and archaeology

Ricote is one of the eight villages found in the Ricote Valley, in the southeast of the Iberian Peninsula (Fig. 1a). The regional climate is semi-arid with strong seasonality. Average summer and winter temperatures are 31–34 °C and 1–5 °C respectively. Annual rainfall oscillates between 200 and 350 mm, and evapotranspiration between 750 and 900 mm (López Bermúdez, 1973). The low precipitation regime, the sharp seasonal differences in rainfall and the high evapotranspiration rate create conditions of aridity comparable to those found in wide regions of North Africa. In some of the villages annual average temperature (which varies from 12.7 to 17.7 °C) can be over 4 °C above the Spanish average (13 °C) (Pantaleón Cano et al., 2003).

The village of Ricote currently houses 1450 inhabitants. It is located in a *hoya*, a pot-shaped plain surrounded by mountains. Irrigated terraces extend over approximately 120 ha; they climb from the lowest elevation in the *hoya* (235 m asl) up the surrounding slopes (375 m asl). Lemon trees are the main produce presently cultivated within those terraces. Mountains surrounding the Ricote irrigated fields are essentially limestone and Keuper marls, with minor outcrops of polygenic sandstone and gypsum. Quaternary colluvial and silty-clay sediments detached from the hillsides have resulted in Haplic (Calcaric) Fluvisols and Haplic Calcisols in the flattest and lowest reaches of the *hoya*. To the west, Triassic calcareous marlstones support Lithic Leptosols and Haplic Gypsisols. To the south, the same geological substratum led to the formation of Haplic (Calcaric) Regosols and Haplic Calcisols (FAO, 2006; Puy, 2012).

The earliest textual mention of Ricote dates back to 896 AD. In his *Muqtabis* (literally 'the one who takes the candle from another', a sort of annals), Ibn Hayyān narrates the military campaign launched by the Emir against a group of insurgents that sought refuge in the fortification of *al-Sujūr,* the current castle of Ricote (Lévi-Provençal, 1953). The presence of Andalusi kitchenware distributed throughout the complex suggests that the structure was permanently inhabited (Eiroa Rodríguez, personal communication). Two centuries later, al-Bakrī mentioned the *alquería* of *Riqūt* (Carmona, 2005). *Alquería* was a term referring to a residential complex occupied by a reduced number of inhabitants and the associated agricultural areas. The main settlement was probably located in Cabezo del Algezar, to the north of the present day village. The hilltop has yielded pottery dated to the 11th century (Manzano Martínez, 2002). The presence of at least one Andalusi settlement in the 9th century suggests this as the latest plausible period for the creation of the original hydraulic system (Puy, 2012) (Fig. 1b).

The relative chronology of the successive extensions composing the hydraulic system of Ricote was determined previous to the present work following the principles of hydraulic archaeology (Kirchner and Navarro, 1993). The method is based on systematic field survey, morphological analysis of the relationship between channel network and irrigated terraces and the study of written records. In the case of Ricote, written records are preserved in the Órdenes Militares (Archivo Histórico Nacional de Madrid, AHN) and in the Protocolos (Archivo Histórico Provincial de Murcia, AHPM), and cover the 15th–19th centuries. The data obtained showed that most additions made to the current extension of the hydraulic system (120 ha) were in two main steps. The first major enlargement (c. 50 ha) was undertaken between the feudal conquest (1243 AD) and the end of the 15th century. The second was completed before 1613 AD, leading to a total extension of c. 118 ha. A final minor addition (c. 2 ha) took place in the 18th century, when the hydraulic system reached its present extension (Fig. 1c). Written records are not available for the foundational period of the hydraulic system at Ricote. Results presented here help filling this documentary gap, contributing to the understanding of the construction of the original irrigated area that covered a surface of 1.9 ha (Puy, 2012).

2. Materials and methods: the geoarchaeological approach

A trench was opened by mechanical means in one of the terraces within the original Andalusi irrigated area (Fig. 1c, d). The trench, dug perpendicular to the retaining wall, was restricted to 6 m^2 to avoid disturbance of the planted lemon trees.

The maximum depth reached was 280 cm below the surface. Bedrock was not reached. The exposed stratigraphy included two

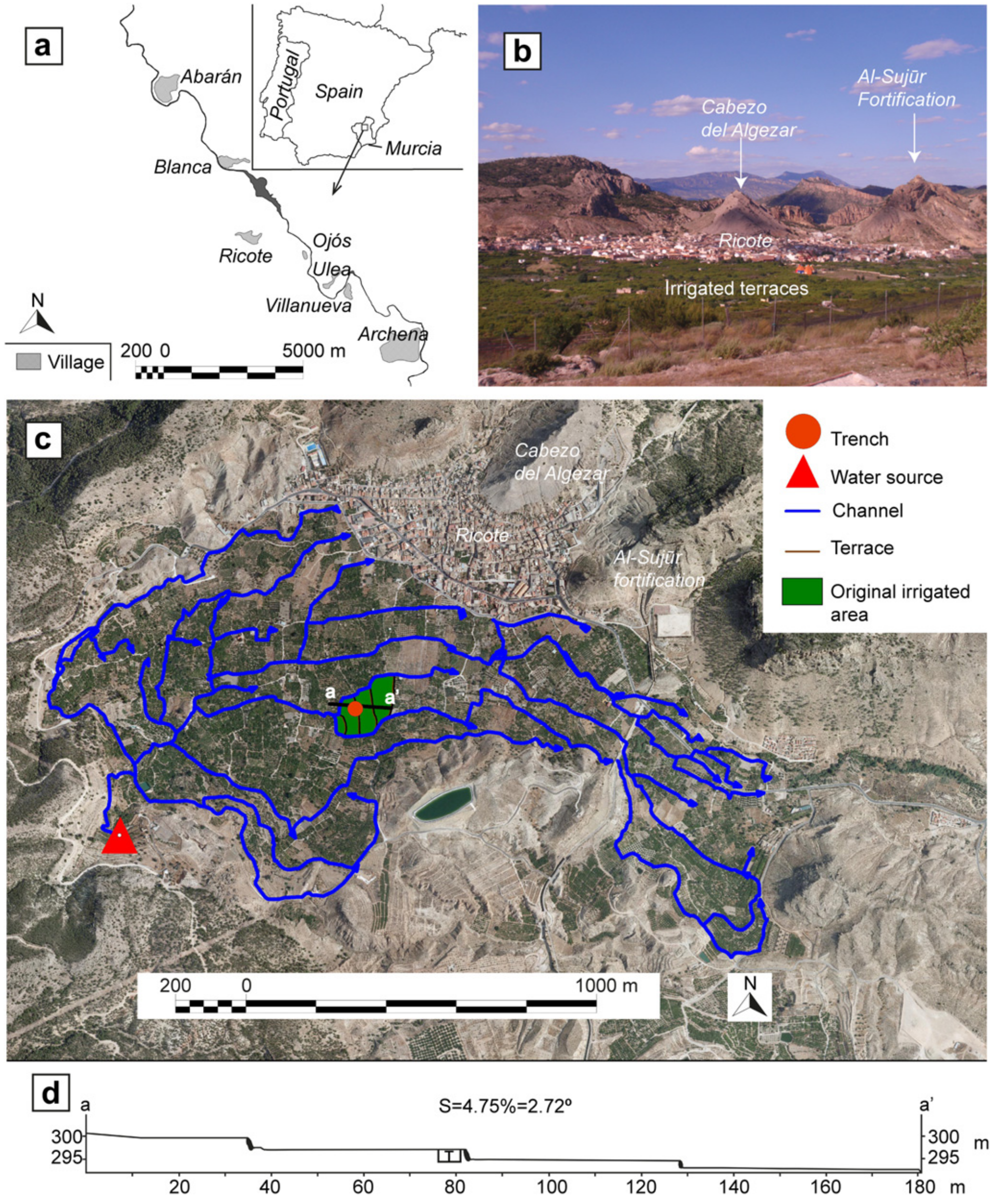

Fig. 1. Location of Ricote. a) The Ricote Valley (Murcia, Spain). b) Picture of the village of Ricote and its irrigated terraces. The Cabezo del Algezar and Ricote fortress are hidden behind the village. c) Plan of the hydraulic system showing the main channels of the huerta, the location of the trench and the original Andalusi irrigated terraces. d) Section of the irrigated terraces nearby sampled terrace (T).

levels: (1) the terrace fill and (2) the original slope soil buried under the terrace fill. They were recorded and drawn following Hodgson's (1976) criteria. Both levels were sampled with Kubiena boxes, 20 cm long, for the production of thin sections for micromorphological analysis. Loose samples were extracted before thin section production from the Kubiena boxes in the laboratory at 2 cm intervals for pH, Electrical Conductivity (EC), Loss On Ignition (LOI), Magnetic Susceptibility (Mag Sus) and Particle Size Distribution (PSD) analyses (Brothwell and Pollard, 2001; Heiri et al., 2001; Syvitski, 1991). Two horizons were identified in the buried soil – Ab and Bbk – and each of these were sampled to determine soluble cations and anions and Sodium Adsorption Ratio (SAR) (Porta Casanellas et al., 1986). Charcoal fragments were extracted from the topmost level of the original slope soil to obtain a *post quem* date for the construction of the terrace (Fig. 2).

pH and EC measurements were carried out by dipping a pH/EC tester Hanna 98310® in a solution containing 1/3 sediment and 2/3 deionised water. LOI values were determined after heating sediment samples in a muffle furnace at 105 °C, 400 °C, 480 °C and 950 °C (six hours per cycle) to obtain proxy estimates of moisture, organic matter, coal, carbonate and silicate contents. Total Organic Carbon (TOC) was calculated as the sum of LOI_{400} and LOI_{480} cycles. Mag Sus was measured on 10 cm^3 sediment samples dried at 105 °C overnight using a MS2 Bartington Magnetic Susceptibility® tester. PSD was done on 10 g sediment samples after pre-treatment in a 40 ml 4.4% sodium pyrophosphate solution heated at 90 °C for three hours. Grain sizes between 0.02 μm and 2000 μm were measured with a laser particle sizer Malvern Mastersizer 2000®. Following protocols of the Soils and Sediment Laboratory, Department of Geography, University of Cambridge, particles between 0.021 μm and 1.95 μm were defined as clay, between 1.96 μm and 62.5 μm as silt, and between 62.6 μm and 2000 μm as sand. With the exception of LOI (not replicable), the mean of three measurements was used to determine final values. Finally, soluble cations

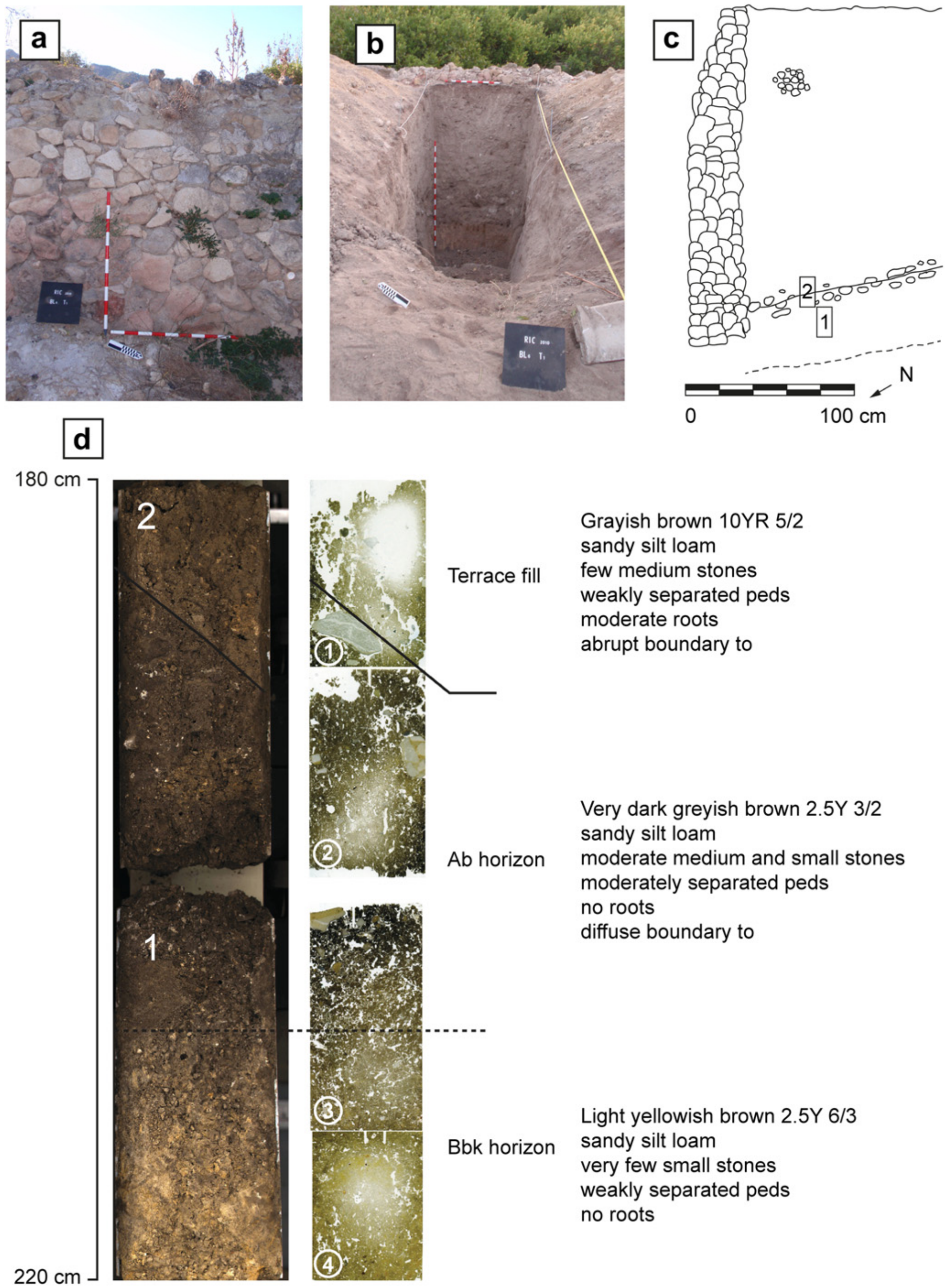

Fig. 2. The terrace and sampling strategy. a) Detail of the terrace wall fabric. b) Trenching. c) Stratigraphy of the terrace. Complete stratigraphic sequence including the fill and the original slope soil. d) Correspondence between undisturbed soil samples and thin sections along with macromorphological description.

and anions and SAR were determined on a soil extract sample obtained after saturating 300 g of sediment with deionized water following the procedures described by Porta Casanellas et al. (1986).

After subsampling, undisturbed soil samples were left to dry at room temperature for six weeks before impregnation with a mixture of 1800 ml resin, 200 ml acetone and 10 ml Methyl Ethyl Ketone (MEKP). Impregnated samples were left to dry for a further six weeks. Two 5 mm sections were cut from each hardened block with a diamond saw. For each sample, one section was kept as archive, the other was mounted on a 3 mm thick glass plate, thinned down to 30 μm with a BROT® polisher and hand-polishing and slip-covered with a 0.2 mm thick glass. Micromorphological description was carried out with a Leitz® Laborlux 12 Pol microscope following guidelines given in Stoops (2003) and interpretation of the micromorphological features was based on Stoops et al. (2010).

Radiocarbon dating was performed at Beta Analytics on a collection of sub-millimetric fragments of charred wood. Fragments were extracted from the bulk sediment after optical examination using steel tools and a magnifying glass. Taxa identification was not viable. The numerous charred wood fragments used for dating are assumed to represent the soil organic matter Mean Residence Time (MRT) (Hetier et al., 1983), independent of the specific taxa composing the sample. Radiocarbon ages were calibrated to cal years BP (present is 1950) and years BC/AD using Calib 6.1 (Reymer et al., 2009).

3. Results and discussion

The soil buried under the terrace fill seems to have had an original inclination of 4.75%. It may be characterised as a saline Hipercalcic Calcisol (FAO, 2006) developed on colluvial material, as defined by its high carbonate content (71.57–65.4%), EC values (above 4000 μS/cm) and gypsum and calcium carbonate impregnative pedofeatures, along with the fluctuating percentages of clay, silt and sand. The main ions comprising soluble salts are Ca^{2+}, Mg^{2+} and sulphates, and their high values agree with the presence of Keuper (Triassic) marls in the lithology of the Ricote Valley. The highest Mag Sus values were recorded at the bottom of the terrace fill (15 SI) and at the top of the Ab horizon (43.9 SI), where the highest carbon and TOC concentrations were also derived from LOI. We relate the recorded peaks in Mag Sus and TOC to fire exposure, possibly due to intentional burning of the vegetation on the original slope prior to terrace building. Sub-millimetric charred remains extracted from the top horizon of the buried Hipercalcic Calcisol (Ab) provide a median probability age of 706 AD (2σ 647–778 AD), suggesting the construction of the original cluster of terraces at Ricote was undertaken by some of the first Arabic–Berber tribes entering the Iberian Peninsula (711 AD). Results from bulk analyses are presented in Table 1. Soluble cations and anions and SAR are shown in Table 2. Micromorphological description is summarised in Table 3. Ages obtained from radiocarbon dating are shown in Table 4.

3.1. Before the terrace: poor slope soils and semi-arid climate

Due to rapid burial, soils preserved under agricultural terraces are good indicators of past environmental conditions (French and Whitelaw, 1999; Krahtopoulou and Frederick, 2008). They inform on the factors that have contributed to their formation: topography, climate, vegetation, geological substrate and time, as well as human action (French, 2003).

The original soil was intercepted at the bottom of the trench, indicating that the original inclination in this portion of the slope was probably in the order of 4.75%. The exposed retaining wall, built of locally available stone cemented with a mixture of lime and smaller clasts, was 117 m long and 1.85 m tall. The terrace had a total area of 0.5 ha. The original level found immediately below the terrace fill had every feature required for identification as a buried soil (Fedoroff et al., 2010): (1) Indicators of biological activity including passage features and channels (c. 50 μm–150 μm length), as well as snail shells. (2) Pedogenic microstructure and pedogenic b-fabric, mainly microsparitic crystals, a common feature in calcareous soils with a high calcium carbonate content. Micritic crystallitic b-fabric in the form of calcite crystal precipitates within the clayey micromass. Pores are filled with clay-size pedogenic carbonate crystals (Durand et al., 2010). Undisturbed pedofeatures include lenticular gypsum infillings and calcium carbonate impregnative pedofeatures. (3) Moderately to highly separated peds and moderately to well developed pedality can be detected few centimetres below a poorly structured Ab horizon.

The buried soil may be defined as a saline Hipercalcic Calcisol (FAO, 2006), poorly developed under arid climatic conditions. Results from SAR (2.2 and 2.3 meq/l for the Ab and Bbk horizons

Table 1
Data obtained from bulk samples analyses. In 'layer', 1 refers to the terrace fill and 2 to the original slope soil.

Number	Layer	pH	EC (μS/cm)	Loss on ignition (by mass)					MagSus (SI)	Particle size distribution		
				% Organic matter (loss at 400 °C)	% Coal (loss at 480 °C)	% Total organic carbon (% organic matter + % coal)	% $CaCO_3$ (loss at 950 °C)	% Silicate residue		% Clay	% Silt	% Sand
1	1	–	–	2.62	1.328	3.948	68.481	28.899	13.3	15.034	61.212	23.754
2	1	10.14	2418	2.46	0.674	3.134	68.116	29.424	12.2	9.349	71.408	19.243
3	1	10.32	2193	2.576	0.733	3.309	66.91	30.514	11.1	4.938	50.638	44.425
4	1	10.12	3129	2.593	0.747	3.34	65.405	32.001	9.4	6.285	72.913	20.802
5	1	–	–	2.603	1.175	3.778	67.471	29.926	15.1	14.653	66.215	19.132
6	2	–	–	2.613	1.265	3.878	65.918	31.469	12	15.232	62.021	22.747
7	2	–	–	2.471	1.222	3.693	70.634	26.895	11.3	11.952	52.169	35.88
8	2	10.1	3075	2.515	0.706	3.221	66.359	31.126	7.8	4.592	56.638	38.77
9	2	10	4412	2.51	0.411	2.921	66.24	31.249	7.1	4.19	50.381	45.429
10	2	10.2	2576	2.532	0.766	3.298	67.353	30.115	43.9	8.584	69.116	22.3
11	2	10.23	2375	2.438	0.561	2.999	67.082	30.48	9.1	5.843	49.199	44.958
12	2	10.12	1889	2.282	0.626	2.908	68.643	29.075	8.2	5.851	55.99	38.159
13	2	10.1	1902	2.256	0.624	2.88	70.318	27.426	5	7.009	63.856	29.136
14	2	9.81	4814	1.434	0.728	2.162	66.842	31.723	4.4	7.443	47.292	45.265
15	2	9.98	4588	2.369	0.769	3.138	65.911	31.72	8	9.391	67.329	23.28
16	2	9.86	2876	2.413	0.78	3.193	66.865	30.722	7.2	9.773	69.532	20.695
17	2	10.05	3932	2.176	0.699	2.875	67.144	30.68	5.3	6.915	44.812	48.273
18	2	9.93	3131	1.988	0.656	2.644	68.912	29.1	3.9	6.146	44.295	49.559
19	2	9.98	3626	1.253	0.742	1.995	70.875	27.872	3.9	12.361	56.66	30.979
20	2	9.96	2774	2.675	0.745	3.42	71.025	26.3	3.4	10.283	50.494	39.223
35	2	10.28	3193	1.161	0.684	1.845	71.086	27.753	3.8	16.676	75.632	7.692
21	2	9.99	3240	1.695	0.583	2.278	71.573	26.732	3.7	12.272	66.434	21.293
22	2	9.68	2766	1.851	0.745	2.596	71.09	27.059	3.3	11.18	45.944	42.876

Table 2
Results from soluble cations and anions and Sodium Adsorption Ratio (SAR).

Horizon	Depth (cm)	EC (μS/cm)	Nitrates (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Na^+ (meq/l)	Mg^{2+} (meq/l)	Chlorides (meq/l)	Sulphates (meq/l)	Sodium adsorption ratio (meq/l)
Ab	183–208	4100	1.0	1.6	27.8	9.8	13.6	8.0	39.6	2.2
Bbk	208–220	3860	0.3	1.0	27.8	10.3	11.6	5.6	42.2	2.3

Table 3
Micromorphological description of thin sections.

Thin section number	Horizon	Depth of horizons (cm)	Microstructure	Groundmass	Micromass	Pedofeatures				Observations
						$CaCO_3$ impregnative pedofeatures	Calcitic nodules	Gypsic features	Iron nodules	
1	Terrace fill	0–183 0–190	Vughy microstructure	Open porphyric, c/f$_{62\ \mu m}$ ratio: 17/7. Subrounded and subangular smooth-edged quartz grains. Few fine gravel and few very coarse sand grains.	Grayish brown, crystallitic calcitic b-fabric	**	**	**	*	Very few lenticular, mamillate and blocky charred plant material of less than 300 µm on the lowest part of microfacie. Few snail shells.
	Ab	183–208 190–208	Vughy microstructure	Open porphyric, c/f$_{62\ \mu m}$ ratio: 4/1. Subrounded and subangular smooth-edged quartz grains. Few fine gravel and few very coarse sand grains.	Very dark grayish brown, crystallitic calcitic b-fabric	**	**	**	–	Calcific pendant of two different laminae underneath bioclast wackestone. Few snail shells. Very few organic matter; mostly highly humified and silty sized. Very few charred plant material of less than 200 µm length.
2	Ab		Two microstructures: vughy and granular microstructure	Double space porphyric, c/f$_{62\ \mu m}$ ratio: 4/1. Subrounded and subangular smooth-edged quartz grains. Few fine gravel and few very coarse sand grains.	Very dark brown, crystallitic calcitic b-fabric	***	***	**	*	Very few organic matter, highly humified and silty sized. Few snail shells.
3	Ab		Granular microstructure	Equal enaulic, c/f$_{62\ \mu m}$ ratio: 4/1. Subrounded and subangular smooth-edged quartz grains. Common fine gravel and few very coarse sand grains.	Very dark brown, crystallitic calcitic b-fabric	***	***	*	*	Very few organic matter, highly humified and silty sized. Few snail shells.
	Bbk	208-	Vugy microstructure	Open porphyric, c/f$_{62\ \mu m}$ ratio: 4/1. Subrounded and subangular smooth-edged quartz grains. Very few fine gravel and very coarse sand grains.	Light yellowish brown, crystallitic calcitic b-fabric	***	***	*	*	Seldom organic matter, highly humified and silty sized. No snail shells
4	Bbk		Vughy microstructure	Open porphyric, c/f$_{62\ \mu m}$ ratio: 3/1. Subrounded and subangular smooth-edged quartz grains. No fine gravel, very few very coarse sand grains	Light yellowish brown, crystallitic calcitic b-fabric	***	***	*	–	No organic matter. No snail shells

* = very few; ** = few; *** = common.

Table 4
Results from radiocarbon dating.

Lab. nr.	Sample level and depth	$^{13}C/^{12}C$ ratio	^{14}C age	1 Sigma BP	2 Sigmas BP	1 Sigma AD	2 Sigmas AD	Median BP	Median AD
Beta-292733	Charred wood in upper part of Ab horizon (196 cm–206 cm)	−23.2	1310 ± 40 BP	1238–1289 (0.72)	1172–1303	661–712 (0.72) 746–767 (0.28)	647–778	1245	706

respectively) suggest that the high pH of the soil (9.68–10.28) may be related to weathering of the geological substratum rather than presence of sodium. Both the pH and the water-soluble ions show that rainfall was insufficient to filter and wash away the cations liberated by the erosion of the geological substratum, mainly Ca^{2+} and Mg^{2+}. Brady and Weil (2008) have demonstrated that alkaline environments only allow for limited biodiversity in terms of viable wild plant taxa, mostly due to the low presence of elements such as zinc, copper, iron or manganese. In the case of Ricote, this possibility is suggested by the content of organic material found in the buried soil (1.16–2.67%). Similarly low contents in organic matter are typical of soils in the Murcia region and in shrub-covered soils near Cabo de Gata (Almería), one of the most arid regions of Europe (Aranda and Oyonarte, 2005). However, the lack of plant remains observed in thin sections suggest that the prevailing alkaline conditions may also be responsible for their poor preservation (French, 2003).

A calcitic pendant was identified within the lower part of a coarse clast in the Ab horizon. The pendant shows two distinct layers: dark (inner) and grey (outer). Calcitic pendants are the result of an evolutionary mineralogical sequence involving different types of calcitic crystallisations. They are good indicators of arid and calcareous environments (Durand et al., 2010). In our case, darkness in the inner layer is likely to have derived from a higher concentration of organic material and mineral impurities in the soil (Courty et al., 1994); its formation requiring humid conditions. Conversely, light colours, as in the outer layer, generally derive from poorer edaphic conditions in dry climates.

While the majority of the analysed samples give EC values significantly lower than 4000 μS/cm, the Ab (4412 μS/cm) and Bbk (4814 μS/cm) horizons provide values in excess of 4000 μS/cm, usually found in saline soils (Tanji, 2002). Moderate soil salinization may derive from the combination of high temperatures and scarce precipitation. Soil salinization may take place naturally when soluble salts from the geological substratum rise to the surface by capillary transport due to evapotranspiration. In our case, the main ions comprising soluble salts are Ca^{2+}, Mg^{2+} (which in high amounts tend to increase the pH of the soil; Ortiz Silla, personal communication), and sulphates (Table 2). This concurs with the presence of Keuper Marls in the lithology of the Valley of Ricote, made of clay-minerals, dolomite (calcium magnesium carbonate) and gypsum, the latter turning into sulphates after solubilizing in water. Lenticular gypsum crystals are also common in the buried soil of Ricote, as well as coatings and incomplete and loose continuous infillings (Fig. 3).

The presence of subrounded and subangular gravel-sized clasts and very coarse sand grains within the Ab horizon, combined with fluctuating values in sand and silt percentages, suggests a cyclic colluvial origin for the poorly sorted soils originally found in the lower reaches of the Ricote *hoya*. Frequent colluvial events are characteristic of Mediterranean regions with seasonally concentrated precipitations.

Overall, features observed in the buried soil at Ricote tend to develop in high temperature alkaline environments (Poch et al., 2010) with strong seasonality. Regional climatic records show that semi-arid conditions have prevailed in the southeast of the Iberian Peninsula since the Miocene, and that they were particularly severe in the Roman period (Carrión et al., 2010). The analysis of the buried soil at Ricote suggests that semi-arid environmental conditions also prevailed at the time of the first Andalusi migration.

Soils developed in areas of colluvial accumulation, such as those found in the lower reaches of the Ricote *hoya*, were considered ideal for sowing by the 12th–13th century agronomist Ibn al-‘Awwām (Bolens, 1974). It is within this portion of the Ricote Valley that Andalusi settlers built the first irrigated terraces (Puy, 2012). They converted the original poor soil (shallow, coarse, poor in organic material and nutrients, dry and saline) into an artificially irrigated soil that had the potential to offer higher yields per surface unit.

3.2. Land clearance and terrace building: implementing soil potential

The highest Mag Sus values were recorded within the lower layer of the terrace fill and the Ab horizon (15.1 and 43.9 SI respectively) (Table 1). In general, four main factors may contribute to increase the magnetism of sediments: the presence of iron, the effects of pedogenesis, the presence of magnetic minerals and the effects of fire (Goldberg and Macphail, 2006; Heller and Evans, 1995; Tite and Mullins, 1971; Torrent et al., 2010).

In arid environments plants often suffer from iron deficiency (Chen and Barak, 1982), and indeed, microscopic observation of the groundmass in Ricote thin sections indicates iron content <5% throughout the sample. Higher magnetic readings do not correspond with higher iron concentrations in thin section. Similarly, the magnetic signal recorded does not seem to be related to the presence of magnetic minerals, as the correlation coefficient between magnetic susceptibility and mineral residues found in samples after LOI_{950} is negligible ($r^2 = 0.05$). Of all variables, the most closely related to magnetic susceptibility is Total Organic Carbon (TOC), which reflects the total amount of organic material and coal ($r^2 = 0.186$) (Fig. 4). Tendency between TOC and magnetic susceptibility shows two outliers (43.9 SI and 3.4 SI). The correlation coefficient between magnetic susceptibility and TOC increases to $r^2 = 0.62$ if the highest value (43.9 SI) is excluded and to $r^2 = 0.75$ if the lowest (3.4 SI) is also excluded.

Magnetic susceptibility in organic materials increases through burning. In the analysed buried soil, high Mag Sus values concur with the highest coal concentrations after LOI (Fig. 5). It may be derived that the recorded peaks in Mag Sus are related with exposure to fire. The effects of burning, however, are difficult to see in thin section. Following Canti (2003), burnt vegetation is detected in thin section by the presence of microcrystalline calcium-carbonate aggregates (10–30 μm), burnt soil carbonates, elongated silica structures, vesicular glassy slags and very fine crystalline material with high birefringence. Such features are difficult to observe in Ricote thin sections as they are distorted by the high incidence of calcium carbonate, the presence of crystallitic calcitic b-fabric in the micromass and the high pH of the soil, which tends to dilute silica (Piperno, 2006).

Our current results do not provide univocal evidence of anthropogenic fire clearance at Ricote prior to terrace construction. However, the peak in charcoal concentration within the Ab horizon

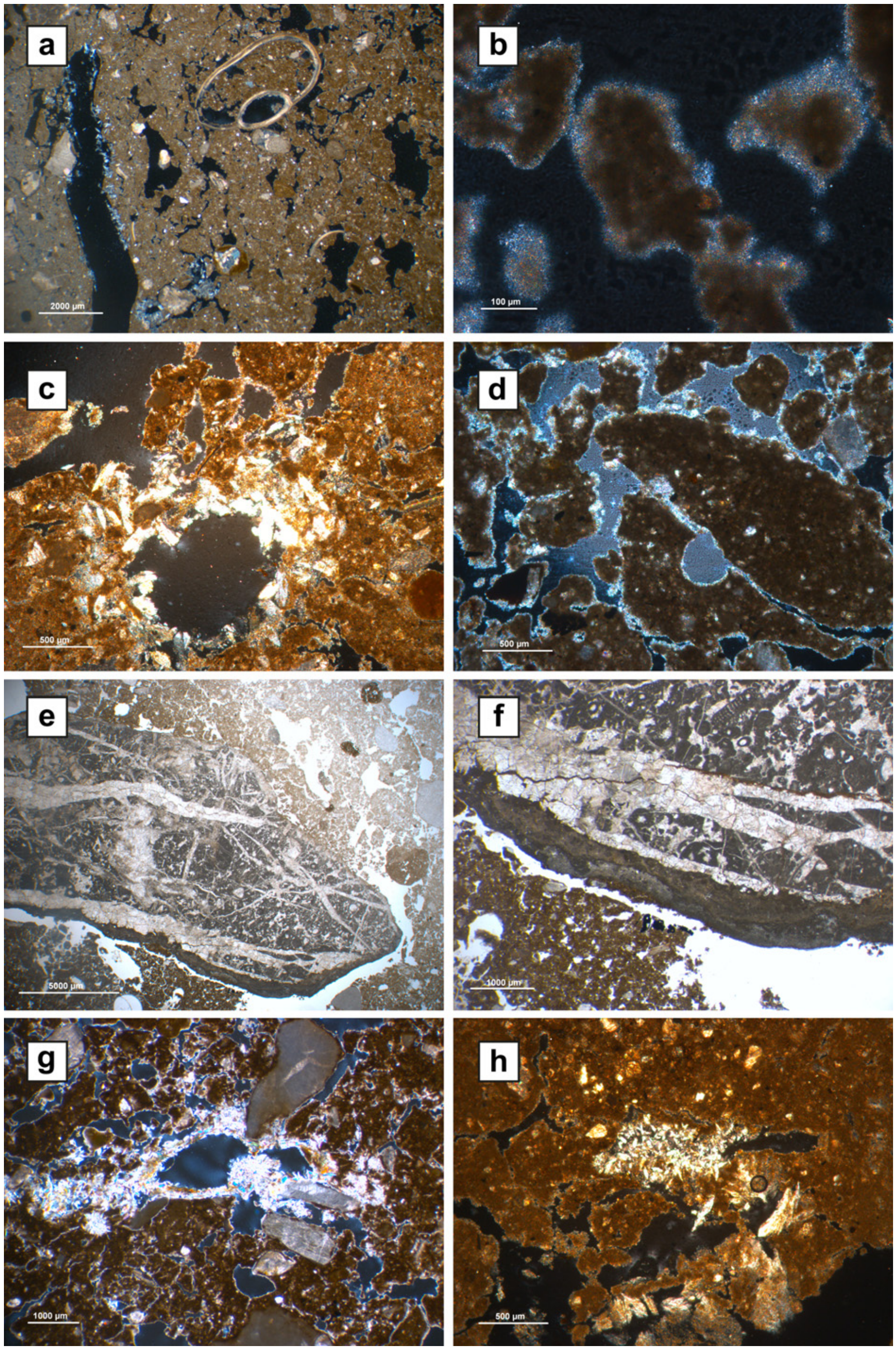

Fig. 3. Main micromorphological features identified in thin section. Photographies under XPL (Cross Polarized Light) and PPL (Plane Polarized Light). a) Evidence of biological activity. Snail shells and channels (XPL). b) Micritic coatings around peds (XPL). c) Lenticular gypsum crystals coating a void (XPL). d) Granular microstructure (XPL). e) Clast with pendant (PPL). f) Detail of the pendant with the two laminae (PPL). g) Gypsum coating of void in Ab horizon (XPL). h) Loose continuous infilling of void in Bbk horizon (XPL). Note change of colour in the groundmass between Ab and Bbk horizons due to the larger proportion of clay in the latter. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and in the lower portion of the terrace fill is remarkable. This concentration of charcoal was derived from LOI analysis and confirmed by the thin section. We believe that average charcoal contents within the rest of the studied profile are likely due to recurrent, accidental bush fires. The high concentration of charcoal recorded, also coinciding with the darker hue of the Ab horizon, seems to indicate that the charcoal was buried shortly after being produced. As the burial of the original soil is anthropogenic, we conclude that the origin of the fire was also most likely to be anthropogenic. The sum of these considerations, within the historical framework of the arrival of Arab and Berber tribes in the Iberian Peninsula, makes in our view for a strong argument in favour of anthropogenic burning prior to terrace building.

Moreover, intentional burning has previously been attested to as a clearance strategy commonly used prior to terrace construction (Alcaraz, 1999; Bal et al., 2010), especially indicated in bushy areas, where the subsoil is full of thick and twisting roots (Cooter, 1978). Once the area has been cleared, a terrace-retaining wall is built and

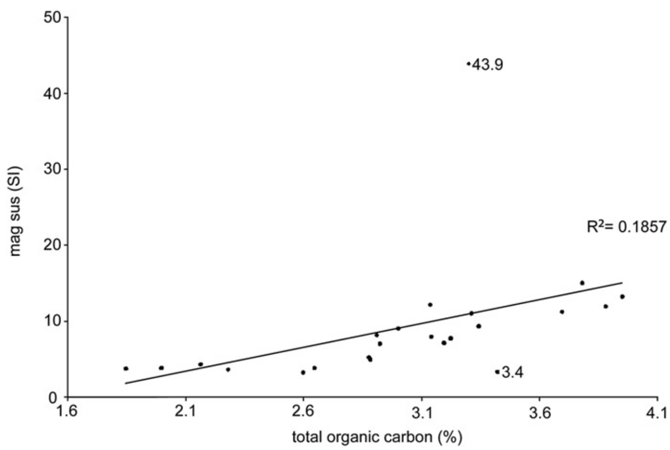

Fig. 4. Dispersion graph showing the correlation coefficient between magnetic susceptibility and TOC.

sediment shifted to obtain a flattened sowing area. At Ricote, the retaining wall was built within a foundation trench dug into the A horizon of the original slope soil. The absence of an explicit horizonation within the terrace fill indicates that stones were laid and sediment shifted from the slope in a single stage. This is a different technique from that followed for the construction of check dams and cross-channel terraces, where sediment naturally accumulates against the built terrace wall (Denevan, 2001).

The filling of an artificial terrace using local soil and sediment may be done in two different ways. (1) Inverting the soil stratigraphy, that is, dumping excavated soil horizons in inverse order; topsoil at the bottom of the fill, covered with B–C horizons (Frederick and Krahtopoulou, 2000). (2) Conserving the soil horizonation, that is, separating the topsoil after excavation, dumping the B–C horizons first, and topping them with the original topsoil (Hudson, 1992). Evidence from Ricote suggests that the first option was chosen, the highest carbon concentrations and magnetic readings coinciding with the Ab horizon and the bottom of the terrace fill. A lower magnetic signal and the absence of soil aggregates, reasonably a consequence of the shifting process, are the only elements differentiating the bottom of the terrace fill from the original slope soil.

Morphologically, foundation terraces at Ricote confirm previously observed patterns, with single terraces covering between 0.1 and 0.7 ha with an overall extension of the original irrigated area over 1.9 ha (Puy, 2012). Most foundation terrace clusters in al-Andalus observed to date extended over less than 2 ha (Sitjes, 2006). Likewise, single terraces were generally broad to obtain large cultivation areas with small retaining walls (Barceló et al., 1998; Torró, 2007). Such trends are derived from a corpus of more than 200 Andalusi hydraulic systems studied over the past 30

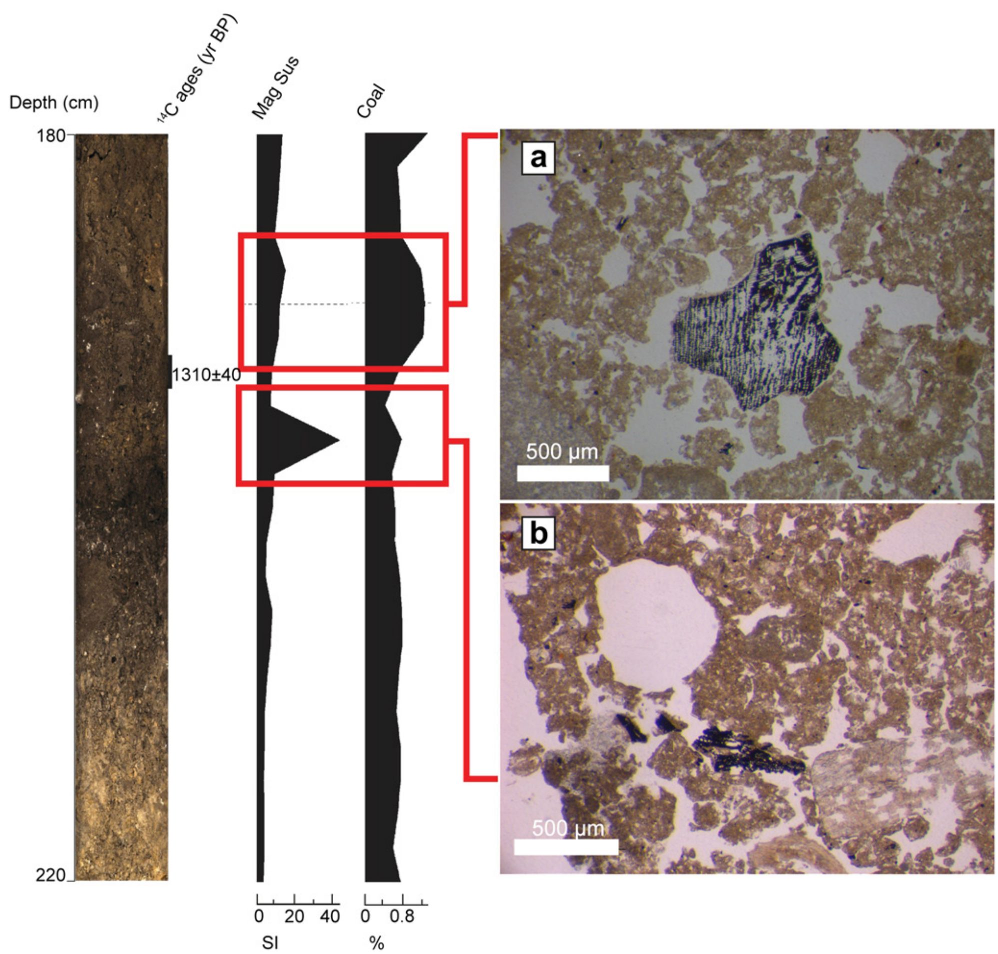

Fig. 5. Correlation between magnetic signal and coal content. Photographs under PPL (Plane Polarized Light). a) Charred fragment in the lowest level of the terrace fill. b) Charred wood fragment in Ab horizon.

years in Catalonia, Valencia, the Balearic Islands (e.g. Barceló and Retamero, 2005; Guinot, 2005; Kirchner, 1997), and to a less extent in Andalucía (Barceló et al., 1998; Sitjes, 2006).

In sum, the original slope soil at Ricote was likely cleared with fire prior to terracing. Foundations for the retaining wall were then built cutting into the original topsoil. Broad terraces were built over an area of approximately 2 ha. The terrace fill was obtained locally, probably dumping the topsoil first and topping it with the Bk horizon.

3.3. Dating terraces: the genesis of Ricote hydraulic system

The dating of agricultural terraces is a widely debated issue. An array of relative and absolute dating approaches has been followed. Some base their chronology on construction techniques used in retaining walls. Others assess the age of the terrace based on the age of what is found on its top, including trees, buildings, and scatters of pottery and archaeological structures. Lichen analysis and cosmogenic isotope analysis of the stones used for the walls have also been attempted (Borejsza et al., 2008; Frederick and Krahtopoulou, 2000; Rackham and Moody, 1996; Riera Mora and Palet Martinez, 2008; Torró, 2007). Optically Stimulated Luminescence (OSL) dating has been successfully applied to date late Holocene sediments in the absence of preserved organic matter (Avni et al., 2012; Roberts et al., 2001). However, the use of OSL dating in recent historical contexts implies higher degrees of uncertainty than radiocarbon dating. Thus far, when viable, radiocarbon dating has proven the most satisfactory method in Holocene contexts to obtain absolute dating from organic matter embedded in soils buried under terrace fills (Ballesteros et al., 2006; Bruins and van der Plicht, 2004; Harfouche, 2006).

Soils are open systems since organic matter contained in a given soil accumulates through time. Once a soil is isolated by burial, the input of organic matter ceases (Martin and Johnson, 1995). The radiocarbon age estimation for the burial of a given soil therefore relies on the concept of Mean Residence Time (MRT), that is the average age of all organic matter contained in the soil, virtually including a mixture of woody taxa living on it before burial (Hetier et al., 1983). Charred remains extracted from the surface of the buried soil at Ricote reflect the soil organic matter MRT, providing the oldest possible date for the construction of the terrace. The median probability age obtained from the organic material contained in the upper part of the Ab horizon is 706 AD (2 σ 647–778 AD), which immediately pre-dates the historically documented arrival of Arabic–Berber tribes to the Iberian Peninsula (711 AD) and the earliest recorded presence of peasant groups in the region (896 AD). This date makes Ricote one of the earliest attested examples of Andalusi irrigated terraces within the Iberian Peninsula.

The obtained date reflects the foundation of the hydraulic system at Ricote, a unit from which constituent elements cannot be dissociated (Ron, 1966). The initial cluster of terraces at Ricote was built at the same time as the associated channels and water catchment infrastructures. The distinction between original and later terrace clusters was made at Ricote based on the principles of hydraulic archaeology (Kirchner and Navarro, 1993; for the application of this methodology in Ricote, see; Puy, 2012). Further dating of successive extensions of the initial cluster will help define the chronology of the different stages of cluster terrace building, and understand in detail how the current Ricote terrace system evolved from its initial configuration.

Evidence from Ricote suggests that the original hydraulic system was built shortly after the arrival of Arabic and Berber tribes from North Africa. The pre-existing environment was radically transformed. Based on agrarian technology developed in North Africa, Andalusi peasant groups introduced intensive agriculture of exotic taxa in different ecological niches of the Iberian Peninsula, from the alluvial plains of Valencia and Tortosa (Catalonia) to the mountain slopes of Casarabonela (Málaga) and ravines and valley floors of the Balearic Islands (Guinot, 2005; Kirchner, 1997; Retamero, 2011; Virgili, 2010). The newly arrived tribes seem to have possessed a full knowledge of the means necessary to introduce intensive irrigated agriculture into the marked regionality characterising the Mediterranean landscape, in terms of topographical (Horden and Purcell, 2000) and edaphic heterogeneity (Yaalon, 1997). Future work will have to determine whether construction techniques similar to those observed in the Valley of Ricote were used for all Andalusi irrigated terrace systems or whether variants existed that were adapted to the specific environments characterising different portions of the Iberian Peninsula. Likewise, more terraces and terrace systems will need to be studied and dated in order to adequately assess the scope and pace of the expansion of irrigated agriculture in the Iberian Peninsula. Andalusi written records are scarce (Guichard, 2001) and references to irrigated spaces before the 10th century almost non-existent. Archaeological and historical evidence, however, suggests that in some regions this kind of agriculture may have spread very quickly after the arrival of Arab-Berber tribes. For example, the successful adaptation of a type of Syrian pomegranate is documented in Casarabonela, Málaga, as early as 780 AD (Martínez Enamorado, 2003).

To our knowledge, Ricote is the first case study of integrated AMS dating and geoarchaeological analysis of an Andalusi irrigated terrace. At this stage we do not have the possibility to comparatively evaluate the broader significance of our results in these terms. In our opinion, considering the overall coherence of our results, this approach should be extended to other areas of al-Andalus. The identification, dating and analysis of more pre-Andalusi soils and Andalusi terrace-building strategies will allow a better understanding of the way these tribes and clans contributed to the construction of large portions of the Western Mediterranean landscape, transforming low-production regions into places suitable for the introduction and maintenance of intensive cultivation that are still in use today.

4. Conclusions

The foundational cluster of Ricote irrigated terraces is one of the earliest of its kind attested within the Iberian Peninsula. The Ricote hydraulic system was probably built at the beginning of the 8th century, in coincidence with the first migrations of Arab–Berber tribes across the Gibraltar Strait. This date also allows contextualizing the beginning of the agrarian tool complex associated with the management of hydraulic systems. This includes water catchment management, canalization and terrace building, as well as growing of a broad range of exotic produces and the development of specific agricultural practices. Irrigation allows simultaneous farming of crops with different requirements and growth rhythms. The peasant has to carry out multiple works simultaneously to satisfy the needs of different plant taxa. Channel network maintenance and plant tending mean a considerable amount of labour per surface unit. This translates into an intensive agrarian system that minimizes risk and uncertainty and allows obtaining multiple harvests within a year.

The initial cluster in Ricote was made of broad terraces supported by 1–2 m high retaining walls. It has been suggested that Andalusi peasants avoided the construction of narrow terraces (Torró, 2007) to gain as much cultivable space as possible thus building the smallest possible retaining walls (Barceló et al., 1998). Nevertheless, the construction of broad terraces involves the shifting of considerable volumes of soil and sediment (Hudson, 1995). In these terms, the Andalusi terrace building technique used at Ricote implies a quick and intense transformation of the pre-existing environment. The terrain was likely cleared of vegetation with fire, and local soils were used to fill the terraces, possibly inverting the original horizonation.

The early stages of Andalusi migration into the Iberian Peninsula seem strictly related to the appearance of irrigated agricultural terrace systems, one of the most emblematic anthropogenic trademarks of the west Mediterranean landscape. Andalusi people selected the most convenient areas to convert the originally poor soils into soils that could support intensive cultivation. In this way they set the foundations for the establishment of some of the longer-lasting agricultural strategies in southern Europe. As a result, the largest irrigated terrace systems presently in use within the Iberian Peninsula are still among the most productive in semi-arid areas. They preserve a strong dependency from the original Andalusi plan and pre-industrial technology in spite of numerous later additions and extensions, presenting a topic case of sustainable agriculture integrating past and present technology and know-how.

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