Journal of Archaeological Science 78 (2017) 66–77

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Optically-stimulated luminescence profiling and dating of historic agricultural terraces in Catalonia (Spain)

Tim Kinnaird [a, *], Jordi Bolòs [b], Alex Turner [c], Sam Turner [c]

[a] Scottish Universities Environmental Research Centre (SUERC), East Kilbride, UK
[b] Department of History, University of Lleida, Lleida, Spain
[c] McCord Centre for Landscape, School of History, Classics and Archaeology, Newcastle University, UK

ARTICLE INFO

Article history:
Received 12 September 2016
Received in revised form
8 November 2016
Accepted 9 November 2016

ABSTRACT

Dating agricultural terraces is a notoriously difficult problem for archaeologists. The frequent occurrence of residual material in terrace soils and the potential for post-depositional disturbance mean that conventional artefactual and lab-based dating methods often provide unreliable dates. In this paper we present a new technique using luminescence field profiling coupled with OSL dating to produce complete (relative) sequences of dates for sedimentary stratigraphies associated with agricultural terraces and earthworks. The method is demonstrated through a series of case-studies in western Catalonia, Spain, in which we reconstruct the formation sequence of earthwork features from the Middle Ages through to the present day. OSL profiling at the time of archaeological survey and excavation permitted spatially and temporally resolved sediment 'chronologies' to be generated, and provides the means to interpret the environmental and cultural archives contained in each. The case-studies presented here show that luminescence approaches are a valuable tool to reconstruct landscape histories.

1. Introduction

Farming communities have created terraced landscapes all over the world to produce diverse crops and to provide level grazing for livestock. In dry land agriculture the benefits of terraces include the redistribution of sediment to create soils with improved root penetration and better water retention. Terraces are often connected to what people consider 'traditional' forms of work and agriculture, and together with the fact that terraced landscapes are frequently considered 'scenic' they contribute to how we perceive local and regional landscape character (Pedroli et al., 2013). Terraces are therefore widely regarded as important elements of landscape heritage for both environmental and cultural reasons. Much previous research on terrace systems has been carried out by specialists in environmental and agricultural disciplines (e.g. Cots-Folch et al., 2009; García-Ruiz, 2010; García-Ruiz et al., 2010; Bevan and Conolly, 2011).

Given these considerations it is all the more surprising that the histories of terraced landscapes are poorly understood. There are two key problems relating to the chronological development of most terraces systems: first, to know when they were originally established; and second, to understand how they developed over time. In this paper we present the results of a pilot study designed to address these questions by using field- and laboratory-based luminescence profiling to establish detailed stratigraphies of the entirety of the exposed terrace profile, coupled with the dating of the associated sediments by optically-stimulated luminescence (OSL).

Our case-studies are located on four different terrace systems in western Catalonia (Spain), where we worked in the framework of the *Canvis i continuïtats* research programme led by the University of Lleida (Fig. 1a). The overall aim of this project is to develop new approaches to studying historic landscapes by combining documentary research, retrogressive map analysis, historic landscape characterisation and scientific approaches to dating landscape features (Bolòs, 2014).

Catalonia preserves some of the most useful documentary sources in medieval Europe for understanding the exploitation and organisation of the medieval landscape from the 9th century AD onwards (Bolòs, 2004). In contrast to many parts of the Mediterranean, these detailed records enable the accurate identification of many historic field systems on steep slopes which are terraced today (Bolòs, 2004: 327-8; Torró, 2007). This strongly suggests that

* Corresponding author.
E-mail address: timothy.kinnaird@glasgow.ac.uk (T. Kinnaird).

http://dx.doi.org/10.1016/j.jas.2016.11.003

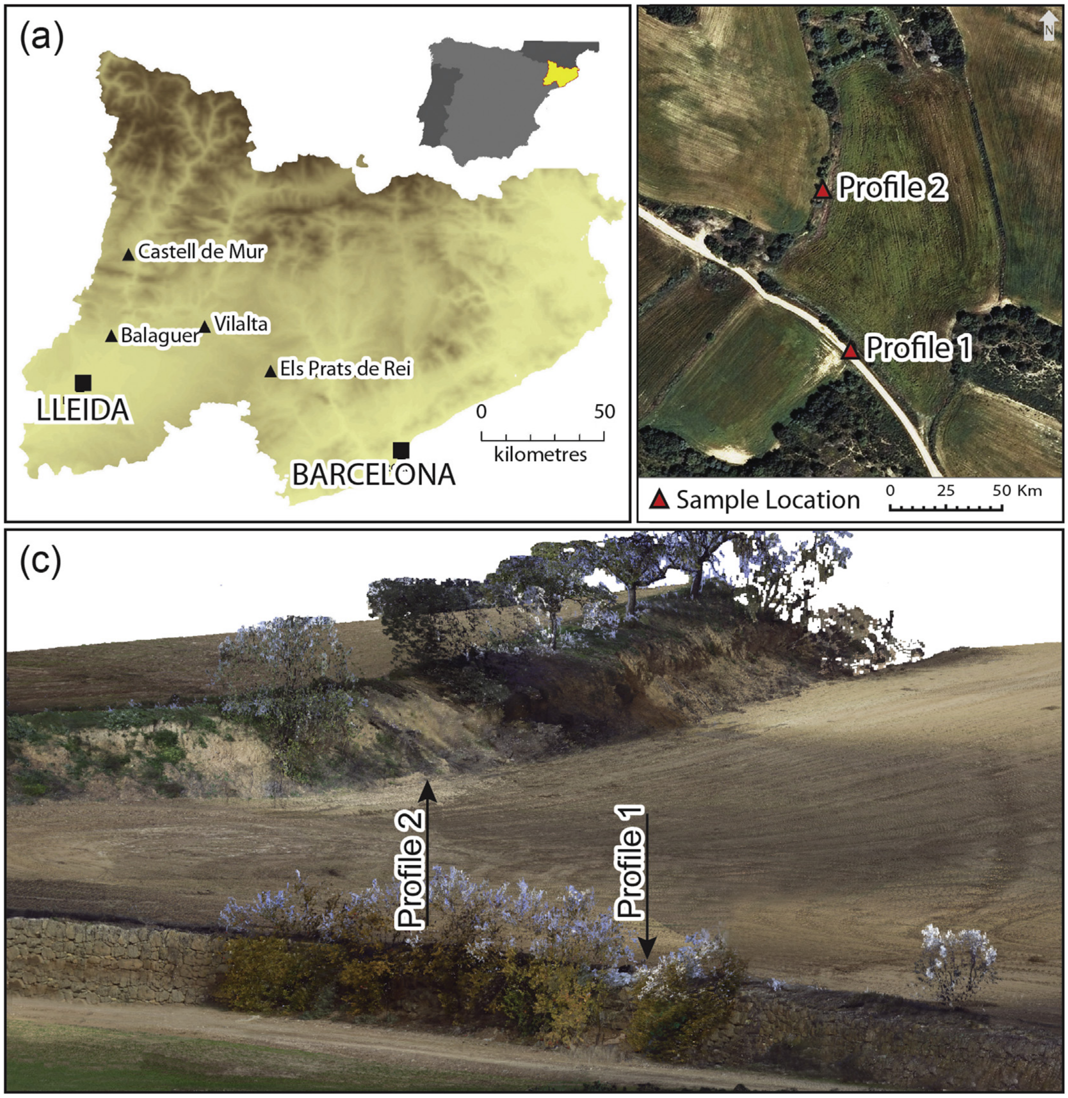

Fig. 1. (a) Location map, (b) GoogleEarth image of the Balaguer field system, showing the positions of the two profiles, and (c) representative 3-D model of any one study area; this image shows the Balaguer field system, from a perspective looking at the check-dam in the foreground (see Fig. 2a) and the earthen bank in the background.

various terrace systems have existed from at least *c.* AD 1000. The Catalan landscape also exhibits a range of terrace types including check-dams, terraced fields, step terraces, braided terraces and irrigated terraces (for basic terrace typology see Grove and Rackham, 2001: 108). For these reasons it provides a good region to test methods for dating terraces. Four areas were selected for investigation (Fig. 1a): the first concerns the field systems 2.5 km NW of the town of Balaguer, a region of low-lying and undulating topography, with both check dams and stepped contour terraces with stone walls (Grove and Rackham, 2001: 108) (Figs. 1b and 2a). The second area investigated, located 350m W of the village of Vilalta is in an area of similar relief, but instead characterised by a straight stepped terrace landscape, with prominent walls built of squared stones, which strike linearly across the landscape. Site 3 is located 2.8 km SE of Els Prats de Rei. Here, the terraces form a braided terrace landscape, with individual terraces aligned sub-parallel to the valley axis, which step progressively up/down slope along switchbacks which delineate the terrace ends (Fig. 2b). The fourth area investigated was at the Castel de Mur, in a region of much more pronounced relief with steep bedrock slopes with both stepped and braided terraces (Fig. 2c), and additionally include features related to an irrigation system.

2. Approaches to dating terraced landscapes in the Mediterranean

Despite being widespread features in today's Mediterranean landscape, mention of terraces is frequently absent from ancient or medieval texts. The reasons for this omission are uncertain: it could be that terraces were so commonplace they were considered unremarkable, yet some scholars of classical Greece have gone as far to argue that they did not exist in Antiquity (e.g. Foxhall, 1996; Foxhall et al., 2007). There is also a perception that since terraces are continually repaired and rebuilt through history, detailed studies would prove unproductive (e.g. Lee, 2001). The assumption that features which are still in use are likely to be of low value for understanding ancient patterns has significantly hampered archaeological knowledge of Mediterranean landscapes: for example, the archaeological potential of field boundaries is rarely considered, even when they are major earthwork features that

Fig. 2. Representative photos of the terraces and sediment stratigraphies examined: (a) the Balaguer check dam (see Fig. 4); (b) the braided terrace network at Els Prats de Rei; (c) a stepped terrace at the Castell de Mur.

might have long histories. A brief review of recent studies helps to highlight some problems associated with the archaeological methods applied to date these features.

Retrogressive analysis has proven a practical technique for identifying ancient terrace systems, and to underpin historic character analysis of case-studies in Turkey, Greece and Italy (Crow et al., 2011; Turner and Crow, 2010; Pietrobono and Turner, 2010). This method examines the stratigraphic relationships between landscape features to interpret the order in which they developed. Such relationships can be identified during field survey, as for pre-18th-century terraces on Crete, Kea and Lesbos in the Aegean (Whitelaw, 1991: 405-10; Schaus and Spencer, 1994; Rackham and Moody, 1996: 86; Kizos and Koulouri, 2006). Other studies have capitalised on GIS to integrate and analyse newly available aerial photographic and satellite data over large areas, e.g. Byzantine and/or medieval features on Kythera (Bevan et al., 2003). The key problem with such studies is that they tend to lack chronological precision because the stratigraphic sequences on which they rely are relative rather than absolute. Comparatively few landscape features have securely known dates of origin (examples might include specific Roman roads or frontiers like the Anastasian Wall in the hinterland of Istanbul: Crow and Turner, 2009). This problem means that even where direct stratigraphic relationships can be detected, episodes of change and development can often be constrained only loosely in chronological terms. Added to this, many previous studies have only been able to suggest dates for ancient terrace systems by association with or proximity to ancient buildings or other structures, rather than by direct stratigraphic relationships (e.g. on Crete: Price and Nixon, 2005: 672-3).

Direct intervention through archaeological excavation could provide a way to address these issues, but unfortunately there are still notable challenges (Frederick and Krahtopoulou, 2000; Walsh, 2014). Besides the prohibitively high cost of large digging campaigns, there are significant issues relating to the recovery and dating of samples from terrace soils. Research on terrace excavations around the Mediterranean was reviewed by Harfouche (2007), who outlined a methodology for dating terraces by excavation, with particular reference to southern France in the late Iron Age and Roman period. Excavators have been able to suggest dates for terraces based on archaeological finds stratified in their sediments, e.g. terraces near Salamanca (Spain) dated by Maria Ruiz del Árbol (2005) to the Roman period. There are, however, a number of problems with dating agricultural soils using artefacts, since farming practices and other taphonomic processes often lead to significant post-depositional disturbances which are notoriously hard to detect. It is also hard to be sure whether finds (usually ceramics) have been discovered in their primary context (and therefore relatively close to their date of production), or whether they have been re-deposited in terrace soils at a later date. In some exceptional cases excavators have been reasonably confident about the validity of ceramic dating, for example in the Kislovodsk basin of the Causcasus where very large volumes of ceramics were recovered from boreholes and targeted excavations (Koborov and Borisov, 2013). Such examples are rare: it is more common to find either small numbers of abraded finds or nothing at all. In practical terms, the value of artefacts for terrace dating is usually constrained by factors such as the chronological precision of regional ceramic typologies and the ease of identification. Furthermore, such methods only provide information about periods when artefacts were used and deposited in terrace soils. They can tell us little about periods when the use of ceramics or other finds was not widespread or when changes in farming practices (e.g. manuring: Jones, 2011) meant they were not deposited. As a result, even if a sequence of dates based on finds can be generated, it will inevitably only be partial at best.

Scientific approaches to sediments hold out the possibility of more accurate characterisation in terms of both dating and structure, but can suffer from similar problems to artefactual dating. The key dating techniques applied to obtain direct dates from terrace soils have been radiocarbon, tephrochronology and OSL. All have helped to confirm that terraces existed in many different parts of southern Europe and the Mediterranean in historic and prehistoric periods. Conventional radiocarbon and AMS dates for sediments can be achieved using either discrete fragments (e.g. charcoal) or bulk soil samples (for examples in Spain and Greece see Ballesteros-Arias and Boado Criado, 2009; Bevan et al., 2012). However, radiocarbon samples can suffer from similar taphonomic problems to artefact-based dates, with the added difficulty that sediments can derive from natural events that are unrelated to (and usually more ancient than) the terrace formation (Koborov and Borisov, 2013: 1094). Although bulk samples may help overcome the problem of residuality, they also give less precision because they reflect a mean date for organic carbon in the material sampled (Bevan et al., 2012: 269). Tephrochronology may have some potential for untangling the complexities of such sediments in Mediterranean terraces, but is equally affected by post-depositional mixing (both up and down working), and the method has only been applied on a few occasions (e.g. Bronze Age terraces on Pseira, Crete: Betancourt and Hope Simpson, 1992).

OSL has been used successfully to date terraces from prehistoric and historic periods in Jordan, Israel, Greece and Spain ranging in date from prehistory to recent times and including different types of terraces such as check-dams and irrigated systems (Davidovich et al., 2012; Beckers et al., 2013; Bevan et al., 2012; Puy and Balbo, 2013; Gadot et al., 2016). It is clear that many terrace systems have been reorganised or rebuilt on several occasions, leading both to the realignment of terrace walls and the re-deposition and mixing of sediments in new contexts (Krahtopoulou and Frederick, 2008). Perhaps the most significant problem in practical terms is that in the case of both OSL and radiocarbon dating, each sample can only yield a date that relates to a specific part of the sediment profile: for reasons of time and cost this means that the interpretation of terrace profiles often relies on just one or two quantitative age estimates/dates. The methods used to date terraces up to now have all relied on specific objects (or individual dates) in a soil profile. Since objects or soils might be re-deposited from their original context or move after deposition in the terrace, there are significant uncertainties about the reliability of the resulting dates.

2.1. A new methodology for dating terraced landscapes

In this paper we propose a new methodology for dating agricultural terraces and earthworks, and apply these methods to the case-studies in western Catalonia. Our approach combines archaeological survey with sampling for luminescence profiling and OSL. It allows luminescence stratigraphies to be generated in real-time and related directly to sediments and artefact distributions in the field in order to facilitate archaeological observations and interpretations. This enables the development of informed sampling strategies which can be targeted towards dating priorities and objectives. This approach can overcome some of the limitations of the alternative dating methods which rely on one or two dates from a section, as the soil/sediment stratigraphies are profiled in their entirety.

The field-based luminescence measurements presented in the paper were made with a SUERC portable OSL reader to record both infra-red stimulated luminescence (IRSL) and OSL from bulk sediments (Table S1; Sanderson and Murphy, 2010). IRSL and OSL net signal intensities, depletion indices and their IRSL:OSL ratios were calculated as per Kinnaird et al. (2011, 2015). IRSL and OSL intensities within a section might be expected to respond to a combination of (a) the *in situ* growth of luminescence after deposition, (b) luminescence sensitivity (the amount of light per unit dose – in turn linked to mineralogical origin, grain size, clast content, and other bulk properties including colour), (c) local dose rates and (d) initial bleaching and inherited luminescence from prior cycles of environmental irradiation (Sanderson and Murphy, 2010). Moreover, the depletion index, which represents the proportion of signal released in the first half of the stimulation cycle relative to the second half, is an indicator of sample transparency coupled to information about whether the samples contain an inherited or single cycle signal.

Prior to fieldwork, we had postulated on the luminescence-depth profiles which might be observed in the sediment stratigraphies associated with these built and engineered structures (Fig. 3). In a scenario in which the terrace is directly cut into the bedrock slope (Fig. 3-1), the potential targets for dating may include any material preserved beneath the stone riser (TPQ for construction), and any material which filtered down the void between the riser and bedrock cut slope (TAQ). The worked surface at the base of the structure may have been reset at deposition, in which case, this would clearly be seen in the luminescence profile (as indicated by the minima in intensities at depth). Alternatively, if the terraces were constructed by partially cutting into the bedrock slope, constructing a stone riser or earthen retainer, then filling the

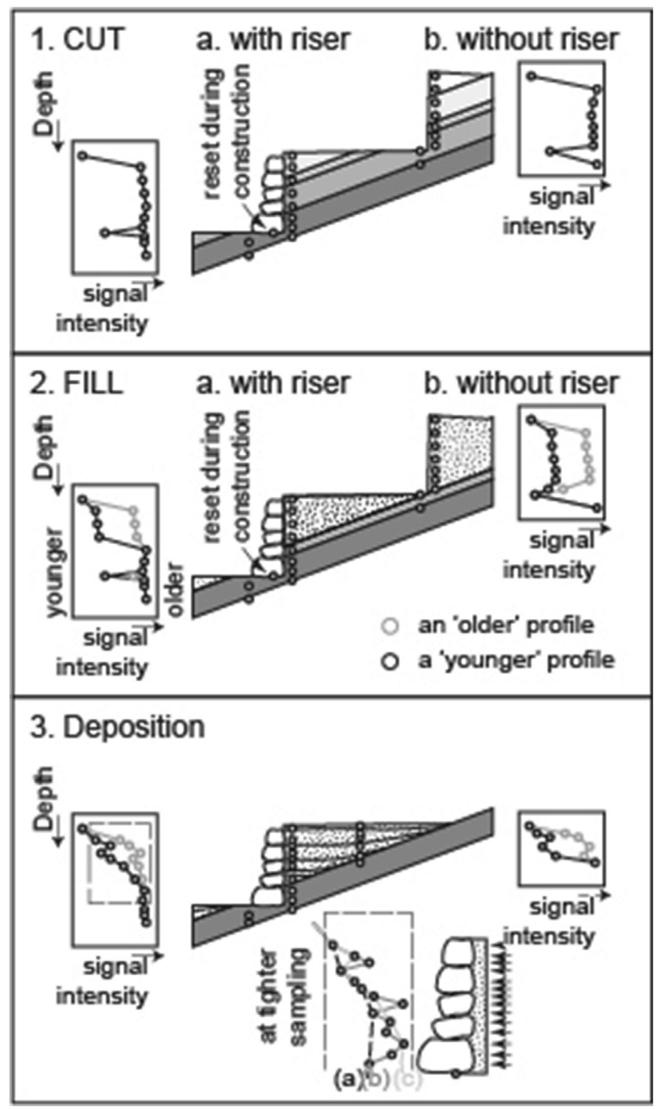

Fig. 3. Hypothetical luminescence-depth profiles for sediment stratigraphies associated with the construction of agricultural terraces: 1) CUT, modern materials, archaeological fills and substrate readily distinguishable; preservation of dating targets poor to non-existent; 2) FILL, modern materials, archaeological fills and substrate potentially distinguishable - depending on the characteristics of the fill; preservation of dating targets is likely; 3) DEPOSITION, modern materials, archaeological fills and substrate potentially distinguishable - depending on the rate of sedimentation; preservation of dating targets is likely.

void behind (Fig. 3-2), an additional dating objective would be the base of the anthropogenic fill (illustrated by the step in intensities at depth). In a third scenario, where the bedrock slope was cleared to form a stable platform for the riser (as above), but following construction of the retainer, sedimentation was left to natural processes (as in a check-dam; Fig. 3-3), then the number of dating objectives increase (sedimentation rates may be recorded in the luminescence-depth profiles, with shallow signal-depth progressions suggesting slow deposition, and conversely steep signal-depth progressions suggesting rapid deposition).

3. The case studies

In the following sections, we first describe the sediment stratigraphies relative to the OSL sampling and the dating objectives/priorities, before commenting on the luminescence stratigraphies, and the implications for more formal dating. These are described in detail, as it was the combined approach of archaeological investigation coupled with field-based luminescence profiling, which led to the successful sampling campaigns and subsequent dating of these features. We go on to describe the progression to laboratory analysis, first preliminary luminescence screening and characterisation, and subsequently more conventional quantitative quartz OSL dating.

3.1. Sampling and preliminary OSL investigations

The first task at each site was to identify the most suitable terrace(s) for survey. Each of the terraced field systems were walked, the most promising candidates noted, and then a judgement made on: (a) how representative the terrace was within its wider landscape context; (b) whether the terrace showed signs of any historical or modern disturbance; (c) how disruptive sampling would be to the present land-use; and (d) the ease of access to the studied section and to the associated sediments. Having selected the most promising terraces for further investigation, small test-trenches were opened to expose the sediment stratigraphies associated with each, which were immediately protected under temporary dark cover. At each excavation, the sediment stratigraphies were described and logged, then small quantities of sediment, weighing 5–10 g, were removed at regular intervals (with tighter resolution sampling around key stratigraphic units) for immediate interrogation with the SUERC portable OSL reader (Sanderson and Murphy, 2010). The most promising horizons were sampled for subsequent laboratory analysis. For this, the sections were subjected to further cleaning under dark cover, and then small copper and larger stainless steel tubes driven into the cleaned faces, for profiling and dating, respectively. In situ gamma spectrometry (FGS) measurements were taken at each of the dating positions with a Rainbows Multichannel Analyser coupled with a 2 $\times$ 2" NaI probe (Table S3).

In parallel, the investigated sections were scanned using a phased-based Faro Focus $\times$330D laser scanner (Fig. 1c) to document the archaeological excavations, and also locate and contextualise each terrace in the wider historic landscape. Multiple scans were taken at each site with an average resolution of 24 million points per scan and registered, using Faro Scene 5.5 into a single point cloud to provide a metrically correct record. In total, 38 scans containing 950 million points were obtained across the four locations. The profiles derived from the laser scans were used in conjunction with photographs to record the vertical position of each sample (Fig. 4).

3.1.1. Case study 1, Balaguer

The first study examined the bounding features of a representative field, in the context of a landscape with contour terraces, check dams and terraced fields in the region of Balaguer (Figs. 1b and c, 2a and 4). The features examined here were a stone-faced terraced wall, approximately 1.5 m tall, forming a check-dam at the southern limit of a cultivated field; and an earthen bank, which delineates the western limit of the same field (Figs. 2a and 4). At each, the modern soils were sampled to define the trends associated with current farming practices, and the lower anthropogenic and natural fills to define the environmental history and early soil formations. Thus, signal intensities and stratigraphic trends associated with the former were identified and isolated from the latter. Assuming that in both profiles the lower fills are in their original setting, then the lowest preserved soil in each provides a *terminus ante quem* for construction (Figs. 3 and 4), and the upper fills provide some temporal constraints on the later history of the site. The sediment stratigraphy associated with the terrace wall consisted of a lower and upper sequence of anthropogenic fills (P1/19-10; Fig. 4), separated by a prominent stone horizon at c. 80 cm (P1/10–12). The profile continued into the modern mound/soil which delineated the present ploughed field (P1/9-8). In contrast, the earthen bank was found to enclose a lower sequence of clayey loams (P2/13-12), strata enclosing a prominent cobble horizon at depth (c. 90 cm; P2/11-10), an overlying sequence of clayey loams (P2/9-3), and materials associated with the present ploughed soil (P2/2-1). The modern ploughed soils were characterised by IRSL and OSL signal intensities on the order of $1–2 \times 10^3$ and $1.5–2.5 \times 10^4$ photon counts, respectively. Progressing down through both sections, through the archaeological fills, IRSL and OSL signal intensities increase (across one order of magnitude), implying a normal age-depth progression. In both profiles, the strata enclosing the coarser fills, between 77 and 85 cm depth in profile 1 and 87–117 cm depth in profile 2, show a substantial increase in net signal intensities through these horizons (implying re-deposited materials poorly zeroed at deposition), before returning to signal levels in trend with the normal age-depth progression.

Given the common stratigraphic/sedimentological attributes and the similar luminescence profiles, this implies that the two features are temporally as well as spatially linked. Dating samples were strategically positioned throughout the sediment sequences to test this hypothesis.

3.1.2. Case study 2, Vilalta

The investigations at Vilalta concentrated on a single terraced feature, a distinctive stone-clad wall, several metres high forming a prominent boundary between two adjacent fields. The sediments associated with this terrace were examined through four profiles (P3 to P6; Fig. 5), spanning a total section c. 6 m wide and c. 2 m tall, separated into two sub-sections by a surviving central pillar of retained wall. The profiles cut adjacent strata, including the modern ploughed soil (P3/1–2, P4/1–2, P5/1 and P6/1–2), an upper fill of clayey loams (P3/3, P4/3, P5/2–3 and P6/3–4), and a lower sequence of packed materials (P3/4, P4/4, P5/4 and P6/5–8). The latter profile was extended in depth relative to the others, permitting access to strata adjacent to the foundations of the terrace wall. Profiling sample P6/9 was positioned directly in front of and adjacent to the lowest stone in the position of this test-pit. In profiles 3 and 4, a 20–30 cm deep zone of soils, marked by plough marks, is characterised by IRSL and OSL signal intensities on the order of 10^2 - 10^3 and $1–9 \times 10^4$ photon counts, respectively. The equivalent zone in profiles 5 and 6 are characterised by IRSL and OSL intensities an order of magnitude larger; if the soils are subject to similar environmental dose rates, and share similar luminescence sensitivities, then this may suggest that ploughing has penetrated to a greater depth in the latter profiles. Irrespective of

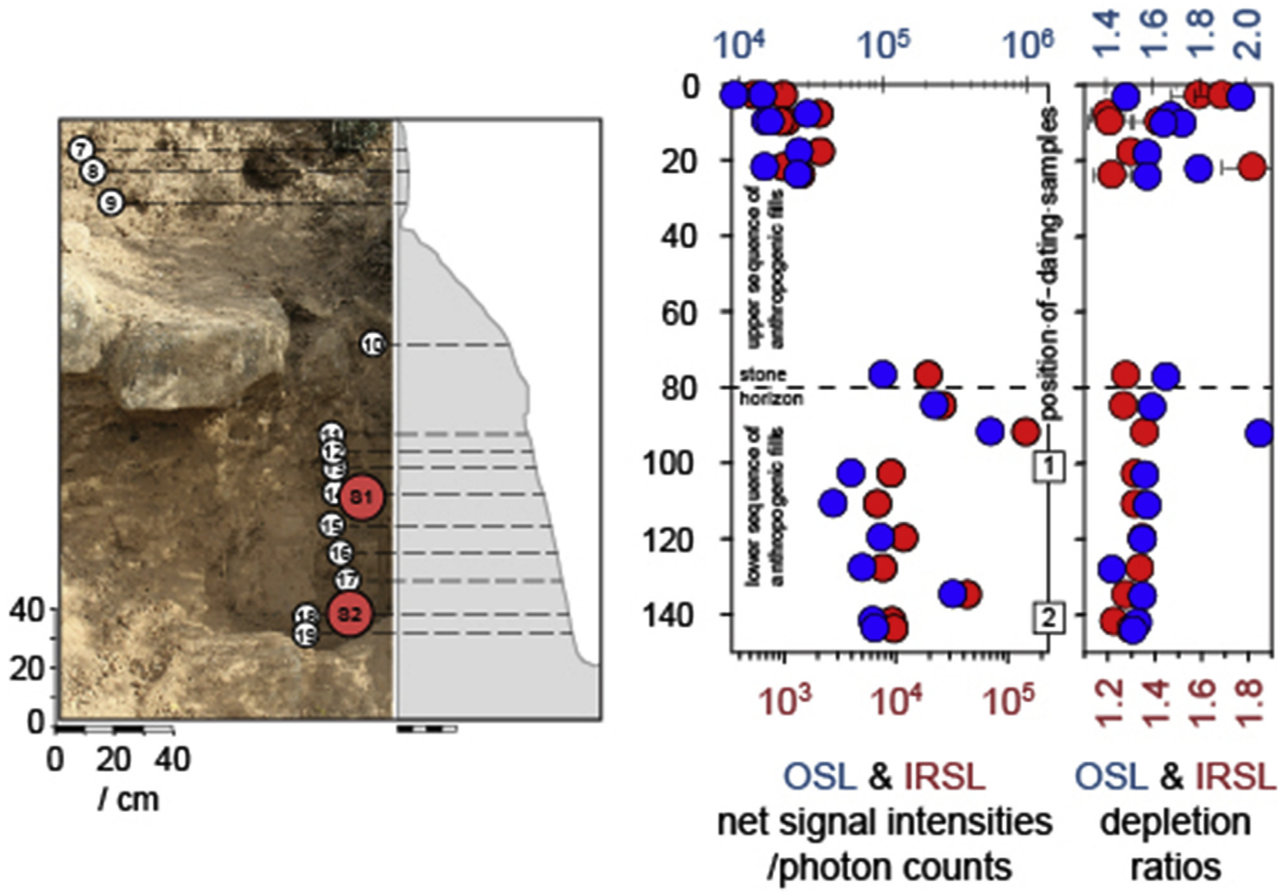

Fig. 4. (left) Photograph of the sediment stratigraphy preserved behind the Balaguer check dam (profile 1) and topographic profile produced from laser scanning, and (right) luminescence-depth profiles for these sediments. For interpretation please see text.

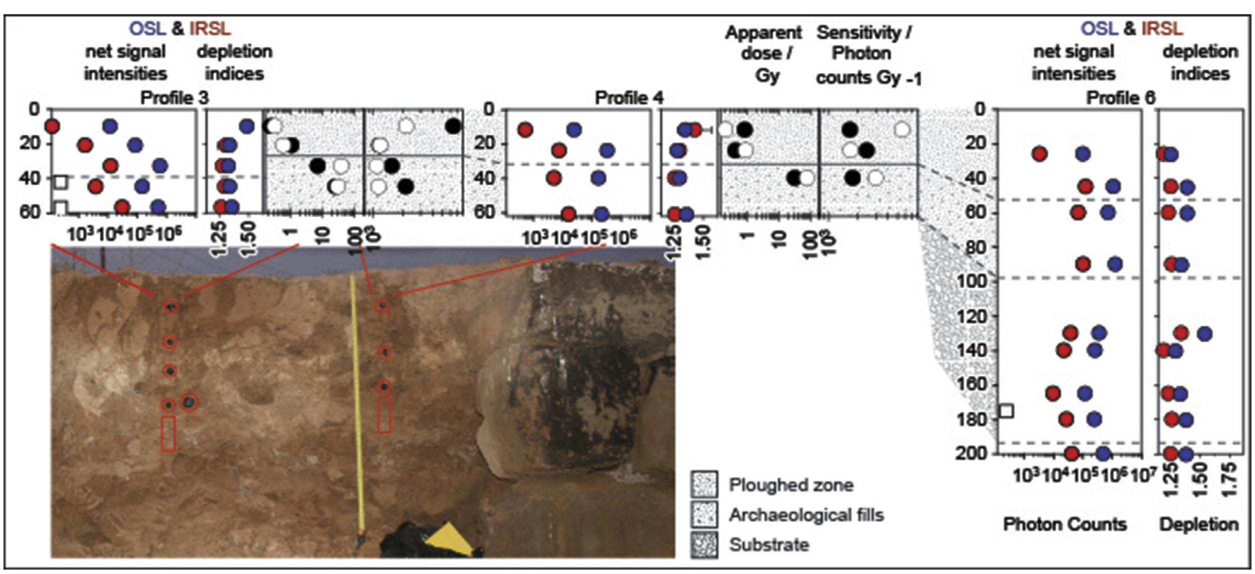

Fig. 5. Luminescence vs depth profiles for the sediment stratigraphies examined at Vilalta.

the studied profile, the base of the ploughed horizon appears to be marked by a positive spike in signal intensities (to 10^3 - 10^4 in IRSL photon counts and 3–6 $\times$ 10^5 OSL photon counts in profiles 3 and 4, and 10^5 IRSL photon counts and 10^6 OSL photon counts in profile 6). Further down section, luminescence signals increase systematically with depth, through the finer loamy fills into the packed materials, consistent with a normal age-depth progression. On this basis, the dating targets were identified as the units at the top of the packed materials (reset during construction; Fig. 3), and the base of the clayey loams (TAQ; Fig. 3).

3.1.3. Case study 3, Els Prats de Rei

The investigations within a braided terrace system at Els Prats de Rei examined a single agricultural terrace which was aligned ENE-WSW along the axis of the valley and extended c. 140 m. One profile was located towards its north-eastern limit near to the switch-back which terminates this feature (P7; Fig. 2b); a second profile was examined half way along its length (P8). The first profile cuts through c. 70 cm of modern materials (P7/1–5; Fig. 6), before passing into c. 70 cm of packed archaeological materials (P7/6–10), first characterised by clayey loams, then clast-supported breccias, before encountering materials associated with the foundations at depth (>160 cm; P7/11). The profile then shifts laterally, in front of the retaining wall, into sediment associated with historic and modern slumps (P7/12–14). Along strike, 10 profiling samples were taken through the modern fills (P8/1), the upper fill of brown, clayey loams (P8/2–6), the lower fill of packed materials (P8/7), and substrate (P8/8–10). Net signal intensities as obtained in the modern soil are comparable in both sections, 2×10^2-10^3 photon counts following IRSL, and up to 3.5×10^6 photon counts following OSL (Fig. 6). Progressing down through the sections, through the finer, loamy fills, signal intensities systematically increase (over a dynamic range of two in P8, and a dynamic range of five in P7), consistent with a normal age-depth progression. In P8, the profile then cuts into the substrate, characterised by net signal intensities an order of magnitude larger than those observed in the overlying fills (10^4 vs 10^3 photon counts in IRSL, and 10^5 vs 10^4 photon counts in OSL). In P7, the profile continues down section, through coarser packed materials, into the fills associated with the foundations of the wall. Interestingly, the samples taken from the lower sequence of fills (P7/11–13), return signal intensities partway between the substrate-derived signals, and those obtained from the overlying fills, implying some mixing of materials between units. Dating samples were positioned at the base of the lower fill to provide a *terminus ante quem* for the period of construction, and immediately beneath the foundations of the retaining wall to provide a *terminus post quem* for the period of construction (Fig. 3).

3.1.4. Case study 4, Castell de Mur

The precipitous slopes surrounding Castell de Mur are extensively terraced, with both stepped and braided terrace features, including some structures related to a complex irrigation system. For the purposes of this preliminary investigation, 3 terraces were selected for further analysis: the first two relate to a stepped terrace system c. 200m W of the western boundary wall of the castle; the third, a prominent contour terrace c. 150 m SE of the castle (Fig. 2c). 30 profiling and 4 dating samples explore the sediment stratigraphies associated with the stepped terrace system. Terrace 1 (sampled in P9; Fig. 7), located topographically beneath terrace 2 (P10), is associated with the full sequence of modern and archaeological fills (P9/1–9 and P10/1–6) and packed materials (P9/10–14 and P10/7–12). In addition, profiling samples P9/15–17, enclose the humic soils which have infiltrated between the retaining wall and the archaeological fills and packed materials. Profiling samples P10/11–13 encompass the strata adjacent to and beneath the foundation stones. The lower parts of these profiles should define the period of construction of these terraces, and the upper parts, the early site formation processes immediately after construction. With regard to the latter, it will be important to determine the rate of sedimentation, as this will elucidate whether these materials were packed or deposited naturally, and enable estimation of soil-mixing processes and rates. Further temporal constraints on sedimentation and a *terminus ante quem* for construction are provided by the dating samples positioned in the upper and lower fills (OSL11-13 and OSL14, respectively). A set of 3 profiling samples and a single dating sample define the sediment stratigraphy associated with a contour terrace, c. 150 m SE of the castle (Fig. 2c). The packed materials at the base of this terrace included a ceramic sherd characteristic of 16th-17th pottery.

IRSL net signal intensities were extremely low, with very few (<20%) of the samples yielding measurable IRSL signals (Fig. 7). Fortuitously, OSL net signal intensities are a magnitude larger, and register variations in intensities over a dynamic range of 10^3 photon counts, revealing complex depositional sequences. For P9, which encompasses the sediment associated with the lower of the stepped terraces, the luminescence proxy data suggests at least three units (as defined on their luminescence characteristics): an upper unit, representing the ploughed horizon, characterised by an inversion in OSL signal intensities; a middle unit, of packed fine materials, characterised by a normal progression in luminescence signals with depth from 3.2×10^3 to 8.5×10^3 photon counts; and a lower unit of coarser, packed materials, similarly characterised by a normal signal-depth progression, from 3.9×10^3 to 1.9×10^4 photon counts. Profiling samples P9/17–19 enclose the sediment which had infiltrated the void between the stone-facing and fill of the terrace; as such, this sediment should be younger than the archaeological fills, and it is notable that these materials yielded lower signal intensities than those obtained from the adjacent sediments. Similarly, P10, which explored the luminescence

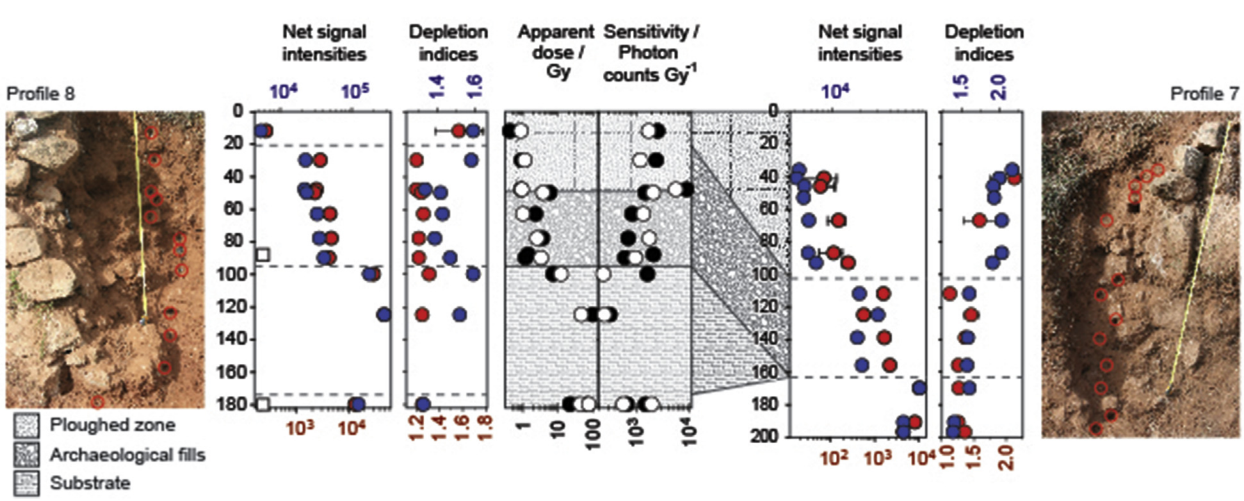

Fig. 6. Luminescence vs depth profiles for the sediment stratigraphies examined at Els Prats de Rei.

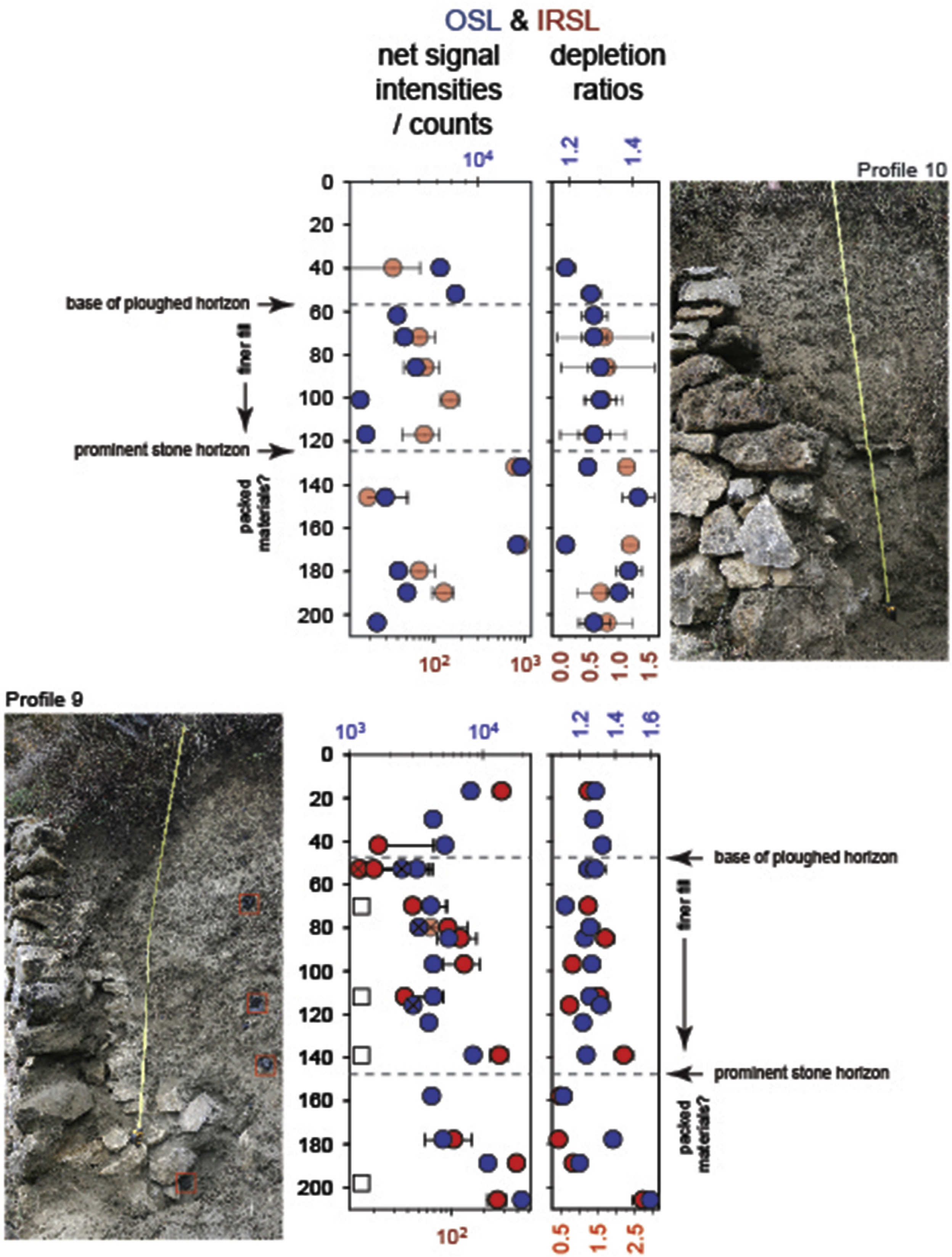

Fig. 7. Luminescence vs depth profiles for the sediment stratigraphies examined at the Castel de Mur.

properties of the sediment associated with the upper of the sample terraces, suggested a three-unit model of accumulation with the modern ploughed horizon, the upper finer fill, and the lower coarser, stony packed fill all represented. Profile 10 then continued down into strata associated with the foundations of the wall, with P10/11–12, enclosing sediment adjacent to, and behind these foundations, and P10/13, the sediment immediately in front of the wall. The upper and lower fills, and materials associated with the foundations, all yield very similar intensities of 4.7×10^3, 4.8×10^3 and 4.8×10^3 photon counts respectively, which is consistent with these materials being deposited as one. Intriguingly, signal intensities are (in general) lower throughout this profile than those recorded in the lower stratigraphy, which is consistent with the lower terrace being constructed first, and the upper retaining wall being built later in the history of the site.

3.2. Laboratory analysis

Informed by this field profiling, our investigations progressed to the laboratory: first, to preliminary luminescence screening and characterisation, and subsequently to conventional quantitative quartz OSL dating using laboratory protocols previously utilised in the SUERC luminescence laboratories (Burbidge et al., 2007; Ghilardi et al., 2015; Kinnaird et al., 2015). Full details of the laboratory protocols are provided in the supplementary data files.

In brief, quartz and polymineral separates were prepared from all samples, then paired aliquots from each were subjected to a modified 2-step Single Aliquot Regenerative dose (SAR) protocol, incorporating both IRSL and OSL measurements (Table S2; laboratory profiling, cf. Burbidge et al., 2007; Kinnaird et al., 2015). This allows for (a) a preliminary assessment of sensitivity distributions, (b) a first indication of the magnitude and range of quartz OSL and feldspar IRSL stored dose estimates (a proxy for age, when the dose rate estimates to these materials are known), and (c) an observation on paired reproducibility, which may relate to zeroing of the luminescence signals at deposition. Dose rate estimates to these sediments were assessed using a combination of FGS, high resolution gamma spectrometry (HRGS; Table S3) and thick source beta counting (TSBC; Table S3), reconciled with each other, water contents and micro-dosimetry of the model (Table S3).

The materials selected for quartz SAR OSL analysis were subjected to further mineral separation procedures using acid washes and density separation to further concentrate the quartz (Ghilardi et al., 2015). Equivalent doses were determined by OSL from 8 to 16 aliquots of quartz per sample (depending on quartz yields) using a single-aliquot-regenerative (SAR) dose OSL approach (Table S4). For one site, Balaguer, the quartz OSL sediment chronologies were augmented by a series of feldspar singe-aliquot-regeneration-additive (SARA) dose IRSL analyses (Kinnaird et al., 2015; Table S5). Dose estimates were obtained using an adapted SARA protocol, incorporating long overnight preheats before first measurement, with the aim of mitigating short-term fading effects. Luminescence ages were determined by dividing the equivalent stored dose by the dose rate, with uncertainties that combined measurement and fitting errors from the SAR analysis, all dose rate evaluation uncertainties, and allowance for the calibration uncertainties of the sources and reference materials. Given the temporal and spatial constraints on the sediment stratigraphies from field profiling, and the close proximity of the dating positions to these samples, apparent ages were retrospectively determined for each set of paired aliquots obtained from the initial laboratory screening by combining the dose rates estimated for each position (Table S4; cf. Muñoz-Salinas et al., 2014). We acknowledge that these estimates are relative, but in general these estimates do corroborate the OSL sediment ages, yielding internally coherent chronologies.

The quantitative and semi-quantitative OSL sediment ages are now considered on a site by site and section by section basis.

3.2.1. Case study 1, Balaguer

Notably, the maxima and trends in the stored dose – depth profiles reproduce those observed in the field profiles, strengthening the preliminary hypothesis that the two sediment stratigraphies examined at Balaguer share similar depositional histories. The archaeological fills at the base of the stone check-dam are characterised by stored dose values in the range 1.6 to 0.7 Gy (with the exception of the strata between 120 and 128 cm, which carry residuals in excess of c. 30 Gy, Table S2). The dating sample, positioned in the lowest preserved soil/fill within this sequence, provide *terminus ante quem* for the construction of this wall - AD 1630 ± 20 (0.39 ± 0.02 ka; SUTL2744; Table S4). The equivalent feldspar IRSL SARA ages obtained for these units support a late 16th century – early 17th century AD date for construction (Table S5). The apparent ages determined for each of the profiling samples augment this sediment chronology, spanning from AD 1510 ± 60 (2737H; Figs. S4–1) to 1650 ± 40 (2737A; Figs. S4–1). It is important to note that these sediment ages are all from positions beneath the re-deposited horizon at 80 cm. The stored dose estimates obtained for the sediments within the earthen bank are as informative, showing a progression with depth, from 0.1 Gy (near to the surface) to 1.7 Gy at the base, passing through at least one re-deposited horizon at 87 cm (also observed in the field profiles). Following field profiling, it was suggested that this horizon related to stabilisation of the bank and thus construction. Indeed, the dating samples positioned either side of this unit, yielded sediment ages of AD 1490 ± 40 (TAQ; 0.53 ± 0.04 ka; SUTL2745) and AD 1290 ± 50 (TPQ; 0.73 ± 0.05 ka; SUTL2746), consistent with the chronology for the built structure.

The sediment chronologies therefore imply that the two features are temporally, as well as spatially linked, and suggest that terracing was a feature of this landscape since the 16th-17th centuries AD.

3.2.2. Case study 2, Vilalta

The luminescence stratigraphies for the sediment accumulations at Vilalta obtained from field profiling suggested a rather uniform depositional history, and again this was corroborated by subsequent laboratory analysis. The basal units, characterised by a coarse-grained fill, return stored dose estimates in excess of 25 Gy; a transitional layer, with heterogeneous stored dose estimates between >25 Gy and 7 Gy, implying some mixing of substrate-derived and archaeological-age materials; and the archaeological fills, characterised by stored dose values in the range 1.1 to 0.3 Gy (Fig. 5; Table S2), corresponding to individual sediment ages spanning from the early 12th to mid to late 17th century. More formal constraints on the period of construction of this terraced feature, are a *terminus post quem* provided by the quartz OSL SAR age of AD 1230 ± 40 (0.79 ± 0.04 ka; SUTL2750) determined for the strata adjacent to the foundations of the wall, and a *terminus ante quem* by the quartz OSL SAR age of AD 1200 ± 60 (0.81 ± 0.0 k ka; SUTL2748), as determined by the lowest preserved fill/soil in the sequence.

3.2.3. Case study 3, Els Prats de Rei

For the most part, the stored dose - depth profiles reproduce the apparent trends and maxima in the field profiling dataset, further justifying the coupled OSL profiling and dating approach. The basal units (P8/8–10; Fig. 6; Table S2) returned stored dose values in excess of 10 Gy, indicating a clear distinction between the substrate (and substrate-derived materials) from the archaeological fills above. Further up the section, the archaeological fills are characterised by stored dose values in the range 1–5 Gy, with a slight decrease in stored dose values with height (P8/4–7), consistent with the hypothesis raised following field profiling that these materials were deposited rapidly or contain re-deposited materials of similar age. In contrast, the profiling samples enclosing the upper soils (P8/1–3; Fig. 6; Table S2) yielded lower stored dose values, typically sub-Gy, supportive of the postulated age discontinuity (albeit that the boundary between the two units is re-defined, see Fig. 6). The constraint on the period of construction is a *terminus ante quem* provided by the quartz OSL SAR age of AD 1440 ± 30 (0.57 ± 0.03 ka; SUTL2751) which was obtained from the lowest preserved soil in the sampled sediments. Unfortunately, a sample positioned beneath the wall in strata associated with the foundations, which had been collected to provide a *terminus post quem* for construction, yielded natural luminescence signals in excess of the saturation signals for the regenerative dose curves. The minimum age estimate for this unit is in excess of 19.5 ka (SUTL2752). For the upper part of the sediment stratigraphy, the apparent ages determined from the profiling samples augment the sediment OSL chronology, spanning the mid 17th to mid 18th centuries AD; in the lower part of the profile, mixing between substrate-derived materials and the archaeological fills resulted in elevated stored dose estimates and therefore over-estimations in apparent age.

3.2.4. Case study 4, Castell del Mur

Above, it was noted that the sediment stratigraphies at Castell del Mur were characterised by extremely low IRSL intensities, and weak, but measurable OSL intensities. Notably, this trend was reproduced in the laboratory, such that all subsequent efforts were concentrated on the full dating samples. A constraint on the construction of the stepped terraces 200 m W of the castle, is a *terminus ante quem* provided by the sediment OSL age of AD 1570 ± 50 (0.44 ± 0.05 ka; SUTL2756), obtained from the lowest preserved fill. A later period of modification and re-use of the terrace in the early 19th century AD, is constrained by the quartz OSL SAR ages obtained for the strata enclosing the prominent stone horizon at 140 cm depth, AD 1810 ± 15 (0.21 ± 0.02 ka; SUTL2754) and AD 1805 ± 30 (0.21 ± 0.03 ka; SUTL2755).

Further east, the contour terrace c. 150 m SE of the castle has a date of construction in the early 18th century AD, as evidenced by the sediment age obtained for the foundation fill, AD 1710 ± 20 (0.31 ± 0.02 ka; SUTL2757). Intriguingly, had the ratios of net signal intensities been examined between the sediment stratigraphies sampled at both sites, then the same relative chronology would have been produced.

4. Discussion

We have shown that the combination of OSL profiling and dating can elucidate the methods of construction, and later modifications, of a variety of morphological and structural forms of agricultural terrace. Each of the key findings are reiterated here, such that the insights gained can inform future initiatives to date similar features in other terraced landscapes. OSL profiling at the time of archaeological survey and excavation permitted spatially and temporally resolved sediment 'chronologies' to be generated, allowing for direct correlations between sedimentary units, and the means to relate discrete features on site. This proxy luminescence data formed the basis for generating hypotheses concerning the methods of construction and later modifications of these terraces. In detail, several common observations warrant further discussion. The first to note, on the premise that the luminescence profiles represent the dosimetric histories of the constituent sediments, is that stratigraphic progressions and breaks/shifts in signal intensities do document changes in depositional process and setting. For example, the base of the modern ploughed horizon is clearly delineated in all profiles, marked by a step from signal intensities outside the normal age-depth progression to those in line. The stratigraphic shifts in signal levels at depth delineate sedimentological and stratigraphic breaks in the sequences, and therefore breaks in deposition, which relate to 'events' in the history of the site i.e. initial clearing, construction, changing environmental conditions, a switch in land-use or farming practices. The stratigraphic depth trends in the luminescence data are also informative (constrained by the aforementioned boundaries), which identify the units which show normal-age depth progressions, and those which are inverted, providing the means to distinguish those which accumulated by natural processes, and those which were re-deposited or intentionally repacked. Furthermore, the changes in slope and the dynamic ranges over which these occur, relate to the rate of sedimentation, providing the first relative temporal frameworks to interpret the sedimentary profiles. Also of interest are variations in the depletion indices and IRSL:OSL ratios with depth. For example, it was commonly observed that the modern and upper anthropogenic fills (post-construction sediments) were characterised by higher depletion indices than those obtained for the lower fills (potentially emplaced at construction) and substrate (potentially modified at construction). Higher depletion indices may indicate the better bleached materials, so it was significant for dating purposes that the field profiles revealed that a dating priority was the base of the anthropogenic fills. Furthermore, the modern soils were generally characterised by lower IRSL:OSL ratios than those obtained for the archaeological fills beneath. This may be an indication of a lower feldspar to quartz ratio in the modern materials, and it is suggested here that this is perhaps indicative of different environmental origins, such as a higher experience of oxidative weathering in comparison with the archaeological fills. Real-time profiling therefore provides a wealth of temporal (and spatial) constraints to interpret the cultural and environmental archives in each of the associated sedimentary stratigraphies.

Moreover, these luminescence-depth profiles provide a means to contextualise the sediment stratigraphies such that the sediment ages are not isolated, and instead relate to the entirety of the profiles under examination. For a number of the dating samples the equivalent dose distributions were heterogeneous (Table S4), implying that for these samples the sediment enclosed mixed-age materials, reflecting variable bleaching at deposition or post-depositional mixing processes. The field profiles provide some measure of control on this, providing the context to interpret equivalent dose distributions on a sample by sample basis, and the means to resolve and model different dose populations, throughout the sediment stratigraphies. Furthermore, as associated sediment ages can be spatially (as well as temporally) linked, this approach justifies the combination of conventional and Bayesian statistical approaches to assimilate ages, and provide tighter chronological controls on the age of the agricultural terraces (Table S6).

This methodology has, for the first time, provided the sediment chronologies to interpret the formation sequences of earthwork features in western Catalonia, dating discrete features in four locations to the early to late 13th century AD (*Vilalta,* and potentially *Balaguer*), the early to late 15th century AD (*Balaguer* and *El Prats de Rel*), and the mid 17th century AD (*Castell de Mur*, and potentially *Balaguer*). Table S6 lists weighted mean combinations for our best estimate on the periods of construction for each of these features, based on the whole stratified dating sets, and for various subsets of the dating and profiling samples. It is notable that in any of these combinations, our temporal constraints on the periods of construction do not change; however, this approach highlights synchronicity in cultural activity and environmental conditions across each of the case-studies.

5. Conclusions

Archaeologists' attention often remains focussed on identifying specific and spatially defined ancient 'sites', rather than thinking more generally in terms of the wider history of the landscape. In part, this has been because it has been difficult to date the observable stages in the life of archaeological features like terraces or field boundary banks from their origins to the present day. The case-studies of terraces used in this project show that new methods can identify the formation sequence of earthwork features from the Middle Ages through to the present day in Catalonia.

OSL dating combined with luminescence field profiling has considerable potential to help understand the historic development of terraces and indeed other types of field systems. Instead of relying on single dates provided by archaeological finds or lab methods, field profiling enables the creation of a complete (relatively) dated sequence for all the sediments associated with a feature. The method has outstanding potential to deepen our understanding of the chronology of terrace systems across the Mediterranean and around the world. In fruitful combination with other geoarchaeological techniques such as micromorphology, soil chemistry and tephra, analysis of pollen, plant remains and biomarkers, it could provide an effective means to create highly detailed histories of land use. As such, it would contribute significantly to a revolution in our understanding of past landscapes.

Acknowledgements

The authors gratefully acknowledge funding for this research from the Ministerio de Economía y Competitividad of Spain (MINECO HAR2012-35022). The authors were assisted in the field by Joan Lluis, Anna Perera, Natalia Salazar and Marta Sancho, and in the laboratory by David Sanderson, and we thank them all for their support and insights

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2016.11.003.

References

Ballesteros-Arias, P., Criado-Boado, F., 2009. El paisaje agrario medieval en Galicia. Herramientas metodológicas. In: Bolós, J., Vicedo, E. (Eds.), Poblament, territori i historia rural. VI Congrés sobre Sistemes Agraris, Organització Social i Poder Local. Institut d'Estudis Ilerdencs, Lleida, pp. 599–612.

Beckers, B., Schütt, B., Tsumkamoto, S., Frechen, M., 2013. Age determination of Petra's engineered landscape: optically stimulated luminescence (OSL) and radiocarbon ages of runoff terrace systems in the Eastern Highlands of Jordan. J. Archaeol. Sci. 40 (1), 333–348.

Betancourt, P., Hope Simpson, R., 1992. The agricultural system of Bronze age Pseira. Cretan Stud. 3, 47–54.

Bolòs, J., 2004. Els Orígens Medievals del Paisatge Català. L'arqueologia del paisatge com a font per a conèixer la història de Catalunya. Institut d'estudis Catalans, Barcelona.

Bolòs, J., 2014. L'arqueologia del paisatge de la Catalunya medieval. Butlletí la Soc. Catalana d'Estudis Històrics 25, 101–170.

Bevan, A., Frederick, C.D., Krahtopoulou, A., 2003. A digital Mediterranean countryside: GIS approaches to the spatial structure of the post-Medieval landscape on Kythera (Greece). Archeol. Calcolatori 14, 217–236.

Bevan, A., Conolly, J., 2011. Terraced fields and Mediterranean landscape structure: an analytical case study from Antikythera, Greece. Ecol. Model. 222 (7), 1303–1314.

Bevan, A., Conolly, J., Colledge, S., Stellatou, A., 2012. The long-term ecology of agricultural terraces and enclosed fields from Antikythera, Greece. Hum. Ecol. 41 (2), 255–272.

Burbidge, C.I., Sanderson, D.C.W., Housley, R.A., Allsworth, J.P., 2007. Survey of Palaeolithic sites by luminescence profiling, a case study from Eastern Europe. Quat. Geochronol. 2, 296–302.

Cots-Folch, R., Martínez-Casasnovas, J.A., Ramos, M.C., 2009. Agricultural trajectories in a Mediterranean mountain region (Priorat, NE Spain) as a consequence of EU vineyard conservation plans. Land Degrad. Dev. 20 (1), 1–13.

Crow, J., Turner, S., 2009. Silivri and the Thracian hinterland of Istanbul: an historic landscape. Anatol. Stud. 59, 167–181.

Crow, J., Turner, S., Vionis, A.K., 2011. Characterizing the historic landscapes of Naxos. J. Mediterr. Archaeol. 24 (1), 111–137.

Davidovich, U., Porat, N., Gadot, Y., Avni, Y., Lipschits, O., 2012. Archaeological investigations and OSL dating of terraces at Ramat Rahel, Israel. J. Field Archaeol. 37 (3), 192–208.

Foxhall, L., 1996. Feeling the earth move: cultivation techniques on steep slopes in Classical Antiquity. In: Shipley, G., Salmon, J. (Eds.), Human Landscapes in Classical Antiquity: Environment and Culture. Routledge, London, pp. 44–67.

Foxhall, L., Jones, M., Forbes, H., 2007. Human ecology and the classical landscape: Greek and Roman worlds. In: Alcock, S., Osborne, R. (Eds.), Classical Archaeology. Blackwell, Oxford, pp. 91–117.

Frederick, C., Krahtopoulou, A., 2000. Deconstructing agricultural terraces; examining the influence of construction method on stratigraphy, dating and archaeological visibility. In: Halstead, P., Frederick, C. (Eds.), Landscape and Landuse in Postglacial Greece. Sheffield Academic Press, Sheffield, pp. 79–94.

Gadot, Y., Davidvich, U., Anvi, G., Anvi, Y., Piasetzky, M., Faershtein, G., Golan, D., Porat, N., 2016. The formation of a Mediterranean terraced landscape: Mount Eitan, Judean Highlands, Israel. J. Archaeol. Sci. Rep. 6, 397–417.

García-Ruiz, J.M., 2010. The effects of land uses on soil erosion in Spain: a review. Catena 81, 1–11.

García-Ruiz, J.M., Lana-Renault, N., Beguería, S., Lasanta, T., Regüés, D., Nadal-Romero, E., Serrano-Muela, P., López-Moreno, J.I., Alvera, B., Martí-Bono, C., Alatorre, L.C., 2010. From plot to regional scales: interactions of slope and catchment hydrological and geomorphic processes in the Spanish Pyrenees. Geomorphology 120, 248–257.

Ghilardi, M., Sanderson, D.C.W., Kinnaird, T.C., Bicket, A., Balossino, S., Parisot, J.-C., Hermitte, D., Guibal, F., Fleury, J.T., 2015. Dating the Bridge at Avignon (South France) and reconstructing the Rhone river fluvial palaeo-landscape in provence from medieval to modern times. J. Archaeol. Sci. Rep. 4, 336–354.

Grove, D., Rackham, O., 2001. The Nature of Mediterranean Europe. An Ecological History. Yale University Press, New Haven and London.

Harfouche, R., 2007. Histoire des paysages méditerranéens terrassés: aménagements et agriculture. British Archaeological Reports International Series 1634. Archaeopress, Oxford.

Jones, R. (Ed.), 2011. Manure Matters. Historical, Archaeological and Ethnographical Perspectives. Ashgate, Aldershot.

Kinnaird, T.C., Sanderson, D.C.W., Woodward, N.L., 2011. Applying luminescence methods to geoarchaeology: a case study from Stronsay, Orkney. Earth Environ. Sci. Trans. R. Soc. Edinb. 102 (03), 191–200.

Kinnaird, T.C., Sanderson, D.C.W., Bigelow, G., 2015. Feldspar SARA IRSL dating of very low dose rate Aeolian sediments from Sandwick South, Unst, Shetland. Quat. Geochronol.

Kizos, T., Koulouri, M., 2006. Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. Environ. Sci. Policy 9, 330–342.

Koborov, D., Borisov, A., 2013. The origins of terraced field agriculture in the Caucasus: new discoveries in the Kislovodsk basin. Antiquity 87, 1086–1103.

Krahtopoulou, A., Frederick, C., 2008. The stratigraphic implications of long-term terrace agriculture in dynamic landscapes: polycyclic terracing from Kythera Island, Greece. Geoarchaeology 23, 550–585.

Lee, W., 2001. Pylos regional archaeological project, part IV. Change and the human landscape in a modern Greek village in Messenia. Hesperia 70, 49–98.

Muñoz-Salinas, E., Bishop, P., Sanderson, D.C.W., Kinnaird, T.C., 2014. Using OSL to assess hypotheses related to the impacts of land-use change with the early nineteenth century arrival of Europeans in south-eastern Australia: an exploratory case study from Grabben Gullen Creek, New South Wales. Earth Surf. Process. Landforms 39, 1576–1586.

Pedroli, B., Tagliasacchi, S., van der Sluis, T., Vos, W., 2013. Portus Delphini. Landscape and environmental research on the Promontorio di Portofino. FERGUSON, Rotterdam.

Pietrobono, S., Turner, S., 2010. Comparing methods in European context: historic landscape characterisation and new perspectives for research in Italy. Archeol. Postmedievale 14, 111–133.

Price, S., Nixon, L., 2005. Ancient Greek agricultural terraces: evidence from texts and archaeological survey. Am. J. Archaeol. 109, 665–694.

Puy, A., Balbo, A., 2013. The genesis of irrigated terraces in al-Andalus. A geo-archaeological perspective on intensive agriculture in semi-arid environments (Ricote, Murcia, Spain). J. Arid Environ. 89, 45–56.

Rackham, O., Moody, J., 1996. The Making of the Cretan Landscape. Manchester University Press, Manchester.

Ruiz del Árbol, M., 2005. La arqueología de los espacios cultivados. Terrazas y explotación agraria romana en un área de montaña: la Sierra de Francia (Salamanca). Anejos de Archivo Español de Arqueología, Madrid.

Sanderson, D.C.W., Murphy, S., 2010. Using simple portable OSL measurements and laboratory characterisation to help understand complex and heterogeneous sediment sequences for luminescence dating. Quat. Geochronol. 5, 299–305.

Schaus, G., Spencer, N., 1994. Notes on the topography of Eresos. Am. J. Archaeol. 98 (3), 411–430.

Torró, S., 2007. Terrasses irrigades a les muntanyes valencianes: les

traonsformacions de la colonització Cristiana. In: Bolòs, J. (Ed.), Esudiar i getionar el paisatge historic medieval. Territori i Societat a l'Edad Mitjana. Universitat de Lleida, Lleida, pp. 81–143.
Turner, S., Crow, J., 2010. Unlocking historic landscapes in the Eastern Mediterranean: two pilot studies using historic landscape characterisation. Antiquity 84, 216–219.
Walsh, K., 2014. The Archaeology of Mediterranean Landscapes. Human-Environment Interaction from the Neolithic to the Roman Period. Cambridge University Press, Cambridge.
Whitelaw, T., 1991. The ethnoarchaeology of recent rural settlement and land use in northwest Keos. In: Cherry, J., Davis, J., Mantzourani, E. (Eds.), Landscape Archaeology as Long-term History: Northern Keos in the Cycladic Islands. University of California Institute of Archaeology, Los Angeles, pp. 403–454.