





Research Article

Agricultural terraces in the Mediterranean: medieval intensification revealed by OSL profiling and dating

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The history of agricultural terraces remains poorly understood due to problems in dating their construction and use. This has hampered broader research on their significance, limiting knowledge of past agricultural practices and the long-term investment choices of rural communities. The authors apply OSL profiling and dating to the sediments associated with agricultural terraces across the Mediterranean region to date their construction and use. Results from five widely dispersed case studies reveal that although many terraces were used in the first millennium AD, the most intensive episodes of terrace-building occurred during the later Middle Ages (c. AD 1100–1600). This innovative approach provides the first large-scale evidence for both the longevity and medieval intensification of Mediterranean terraces.

Keywords: Mediterranean, landscape archaeology, agricultural terraces, OSL-PD

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Introduction

Landscapes are widely recognised as precious ecological, environmental and cultural assets, as well as key contributors to individual and social well-being (Council of Europe 2000). Their character is shaped by both natural processes and human activities over thousands of years as a result of the interplay between demographic, technological, socio-economic, cultural and environmental forces (Ellis *et al.* 2013).

Terraces are characteristic elements of landscapes in many regions around the world. They provide versatile units for arable or polycropping (with fruit or olive trees, as well as cereals), and can also be grazed if uncultivated. Agricultural and environmental research has suggested the benefits of terracing for soil management and controlling moisture levels (Grove & Rackham 2001). Terraces are highly variable, their regional development reflecting a combination of natural factors (e.g. geologies, geomorphologies and hydrological conditions) and landscape histories (e.g. ownership patterns, manuring practices, field management and crop selection) (Varotto *et al.* 2019). Terraces are also connected to the heritage values of landscape, and their scenic qualities contribute strongly to regional landscape character (Pedroli *et al.* 2013). Terraced landscapes are part of UNESCO World Heritage Sites in Africa, the Americas, Europe and Asia, and in November 2018, UNESCO added the dry-stone walling associated with terraces in Croatia, Spain and Greece to its list of Intangible Cultural Heritage.

Despite their agricultural, ecological and heritage values, the histories of terraced landscapes remain poorly understood (Bevan & Connolly 2011; Nanavati *et al.* 2016) and better knowledge of historic practices is required to underpin future policies for sustainable land-use (Denevan 1995; Krahtopoulou & Frederick 2008). This lack of understanding has hampered broader research on the histories of landscapes, limiting knowledge of how settlements operated within their wider landscapes, and of how terraces reflect the long-term investment choices made by rural communities (Ferro-Vázquez *et al.* 2017; and as illustrated by the number of terrace studies in the Mediterranean; Figure 1).

The main reason for this lack of knowledge is that terraces have proven exceptionally difficult to date using archaeological and scientific methods (Acabado 2009). Although datable artefacts are sometimes recovered during excavation (Koborov & Borisov 2013), disturbance and bioturbation frequently complicate their interpretation; more often, such artefacts are altogether absent. Retrogressive analysis as part of GIS-based landscape studies can reveal the sequential relationships between landscape features, suggesting the order in which earthworks developed. Such methods, however, only allow construction of relative chronologies, as opposed to providing absolute dates (Crow *et al.* 2011). Radiocarbon methods can be applied to buried soils, and Bayesian modelling has been used to refine the interpretation of radiocarbon results for terraces (Acabado 2009). But buried soil horizons are often missing, bulk samples tend to yield overestimates of ages due to the presence of older carbon fractions in the environment, and interpretation can also be complicated by problems of 'old wood' (Puy *et al.* 2016; Ferro-Vasquez *et al.* 2019). Luminescence dating, which can be used to determine when certain minerals were last exposed to light or were heated, has also been used to date terrace soils and constructional fills (Davidovich *et al.* 2012; Porat *et al.* 2018). Nevertheless, luminescence and radiocarbon dating both have an



Figure 1. Map of the Mediterranean, with the location of study areas presented in this article: A) Boğsak, Turkey; B) Urla, Turkey; C) Naxos, Greece; D) Catalonia, Spain; E) Galicia, Spain. Previous studies include: 1) southern Greece (Foxhall et al. 2007); 2) Kea (Whitelaw 1991); 3) Lesvos (Schaus & Spencer 1994; Kizos & Koulouri 2006); 4) Kythera and Antikythera (Krahtopoulou & Frederick 2008; Bevan et al. 2013); 5) southern France (Harfouche 2007); 6) Cyprus (Wagstaff 1992); 7) Galicia, north-west Spain (Ballesteros-Arias et al. 2009; Ferro-Vasquez et al. 2019); 8) Israel (Davidovich et al. 2012; Porat et al. 2018, 2019); 9) Jordan (Kuijt et al. 2007; Beckers et al. 2013); 10) Crete (Betancourt & Hope Simpson 1992); 11) Murcia, south-east Spain (Puy & Balbo 2013); 12) Catalonia, north-east Spain (Boixadera et al. 2016); 13) Pyrenees, France (Rendu et al. 2015); 14) Ebro Valley, Spain (Quirós-Castillo & Nicosia 2019) (figure by T. Kinnaird).

inherent limitation: the dates relate only to the specific position sampled in the soil profile. A recently developed, innovative approach for dating earthwork features and agricultural terraces represents a major advance in dealing with this problem (see Kinnaird *et al.* 2017a; Turner *et al.* 2018).

Five study areas in three countries (Spain, Greece and Turkey) (Figure 1A–E) were selected in order to test the applicability of the new methods to different climatic, topographical and geological zones. This geographical distribution represents a range of soils and sediments, from dystric cambisols in Naxos, calcareous cambisols and leptosols in Catalonia, to mollic cambisols in Galicia (Panagos *et al.* 2012; European Soil Data Centre 2020). This geographic distribution also affords the possibility of identifying regional chronologies or variations in terrace construction and use. Terraces in all five study areas were sampled as part of collaborative, international fieldwork projects focused on understanding long-term landscape history.

Methodology

Within each region, the team identified terrace systems with a range of different morphological characteristics, using GIS-based historic landscape characterisations (HLCs; Turner 2018; stage one in Figure 2). Six basic types of Mediterranean terraces—braided, step and pocket terraces, check-dams, terraced fields and false (bulldozed) terraces—have previously been identified by historical ecologists (Grove & Rackham 2001), although their form varies between and within regions. In Catalonia, for example, historic terraces in some areas lack walls entirely, whereas rubble or rough ashlar walls are normal in other places. In the Aegean, zig-zag braided terraces are most common, but terraced fields and step terraces (either straight or curving round the hillside) are also common. The terrace character types used for our HLC analyses were based on these six basic types. In each region, our work focused on the most characteristic type(s) of terrace in that area.

In this research, portable optically stimulated luminescence (OSL) equipment (Sanderson & Murphy 2010), coupled with *in situ* gamma spectrometry, was used to contextualise soil-sediment ‘luminescence stratigraphies’ on-site and in real-time, directly relating the sediment sequences with the archaeological contexts (Kinnaird *et al.* 2017a & b; Porat *et al.* 2019). This approach has two key advantages. First, constraining and characterising the chronological sequences of the soil profiles enables better informed and more effective sampling strategies. OSL profiling generates relative sediment ‘chronologies’, which allows for direct correlations between sediment units, and the means to relate discrete features across the sites. These proxy luminescence data form the basis for generating hypotheses concerning the construction and later modification of the earthworks and terraces. The luminescence profiles are used in the field to identify specific sedimentary horizons with probable archaeological significance (in particular, construction events, evidence of repair or modification), which can then be targeted for OSL dating or other geoarchaeological analyses.

Second, by combining this approach with subsequent laboratory analysis, it is possible to assess the ‘chronology’ of the whole sediment profile in a terrace, rather than having to rely on a small number of quantitative dates from arbitrarily selected points in the profile. This means that discrete soil/sediment units can sometimes be identified and related to the construction

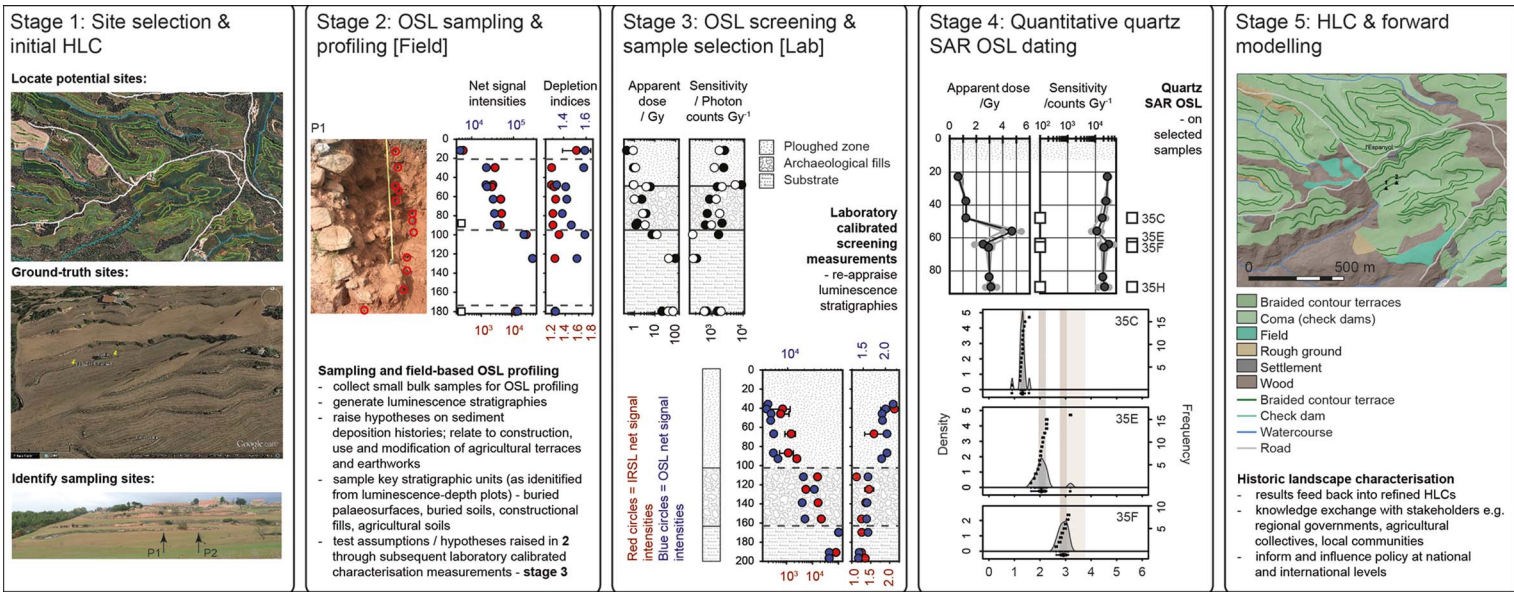


Figure 2. Stages one to five of the methodology: stage one) initial HLC and site selection; stage two) OSL field profiles used to create hypotheses about earthwork development and target soils/sediment samples for subsequent laboratory analysis; stage three) OSL laboratory screening and sample selection for dating (for details, see Figure 3); stage four) quartz SAR-OSL dating of selected samples (for details, see Figure 4); stage five) interpretation and use of results to refine HLC and landscape modelling (figure by T. Kinnaird).

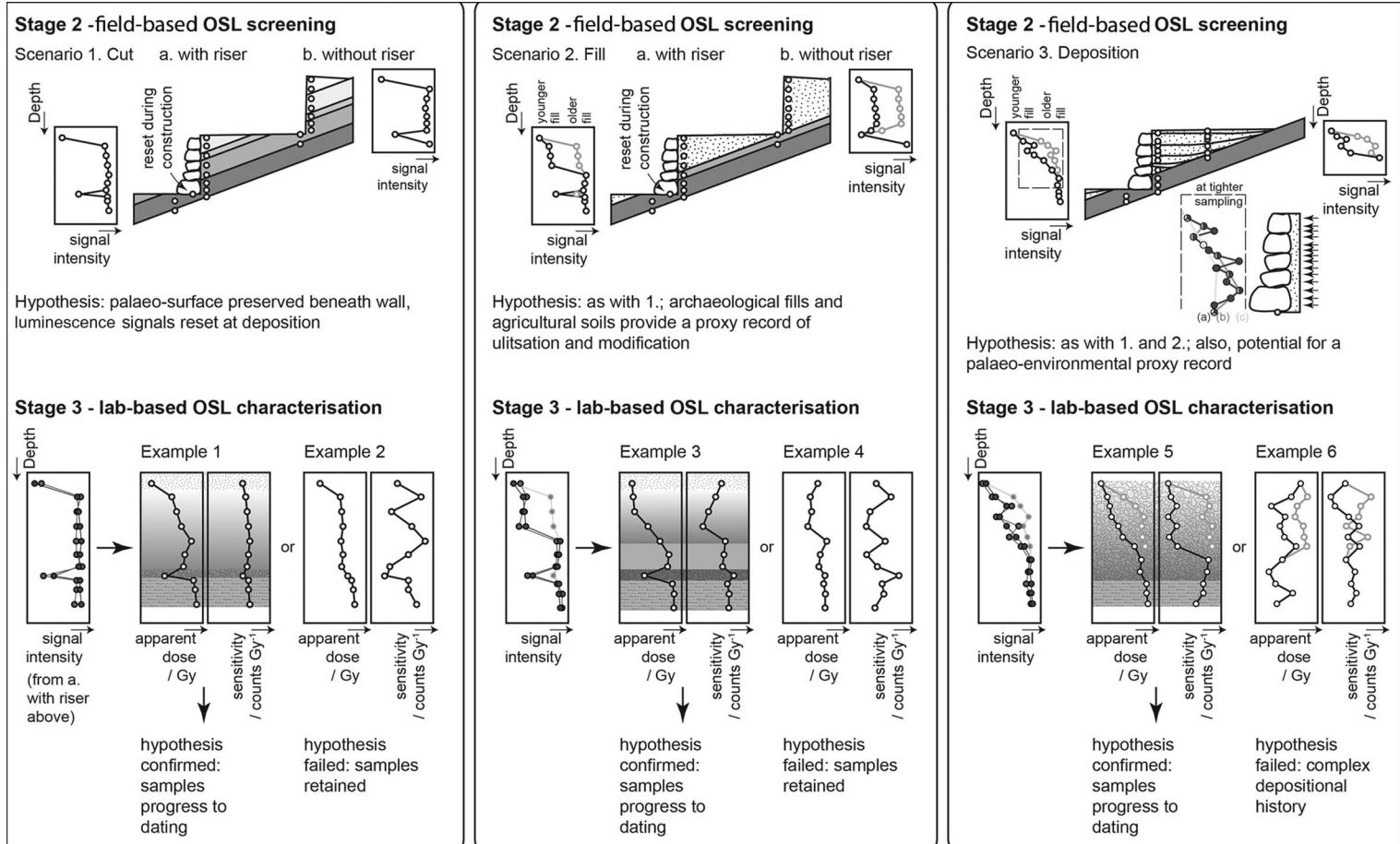


Figure 3. Hypothesis testing: progression from preliminary OSL screening in the field (stage two) to calibrated OSL characterisation in the laboratory (stage three).

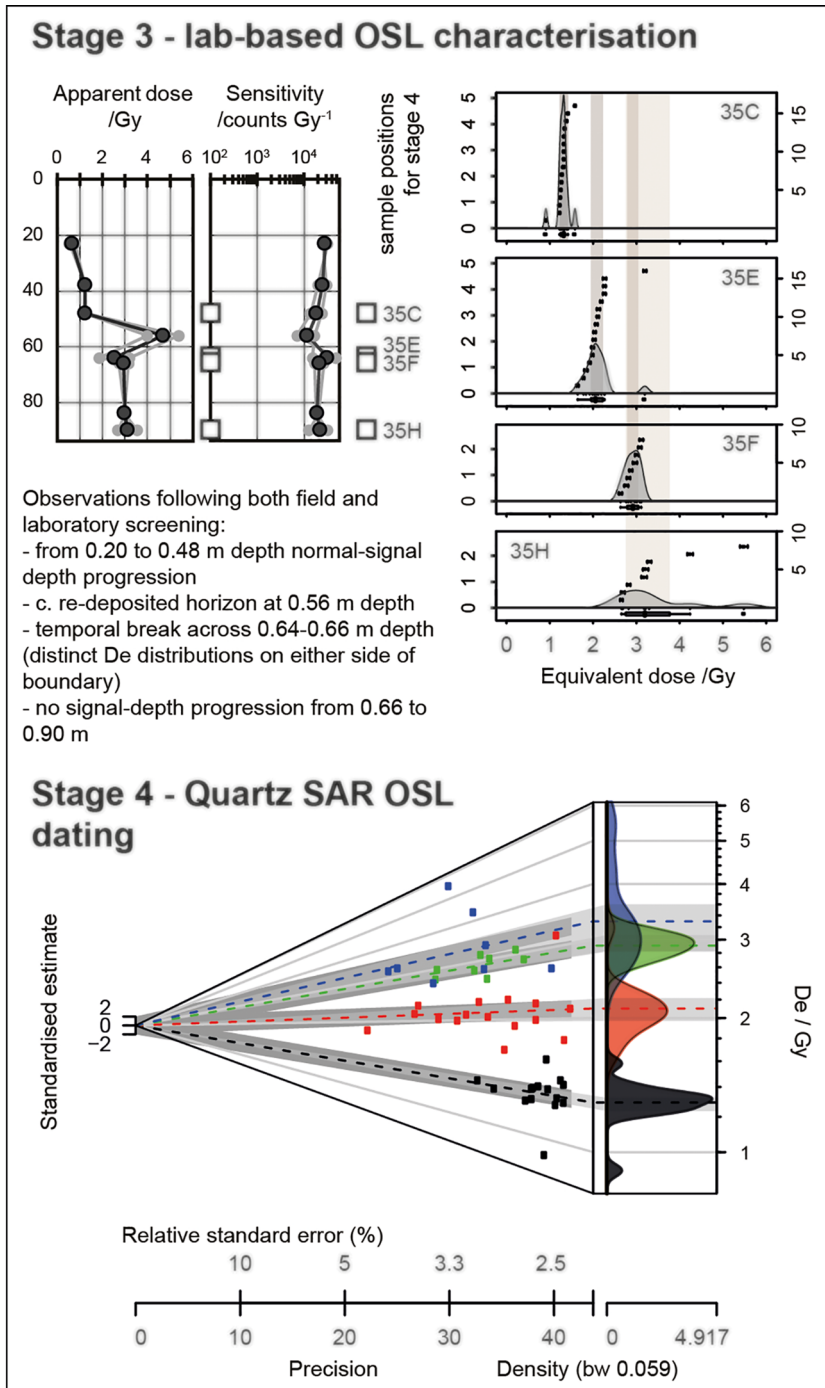


Figure 4. Progression from laboratory OSL screening and characterisation (stage three) to quantitative quartz SAR OSL dating (stage four) (figure by T. Kinnaird).

or modification of the earthwork or terrace. Our methodology for dating the construction sequences of agricultural features is summarised in [Figure 2](#), and is described in further detail in the online supplementary material (OSM).

[Figures 3–4](#) illustrate the progression from field profiling and hypothesis development (stage two in [Figure 2](#)) to OSL characterisation and screening in the laboratory (stage three), then quartz single-aliquot regenerative (SAR) OSL dating (stage four). [Figure 3](#) illustrates examples of the hypotheses raised during fieldwork, based on observations of the sedimentology, archaeology and trends in proxy luminescence data. A gradual increase in OSL and infrared stimulated luminescence (IRSL) signal intensity with depth might suggest that the sediments in the profile built up steadily over time, whereas an ‘inverted’ progression—where sediment with higher intensities overlies sediment with lower intensities—might indicate material that had previously been buried elsewhere, then subsequently re-deposited by natural or human processes. The range of intensities across these progressions may indicate the relative rates of sedimentation; sudden breaks in signal intensity may correspond to discontinuities or hiatuses in deposition. Trends in IRSL and OSL depletion indices down the profile may indicate the extent to which the luminescence signal mixes an ‘inherited’ dose built up in a previous location, while the IRSL:OSL ratios may reflect changes in mineralogy.

In the first scenario shown in [Figure 3](#) (left), the terrace has been constructed by cutting directly into the bedrock slope, with a stone wall built to retain the upper slope. Potential targets for dating may include any materials exposed to light (and therefore ‘bleached’ and ‘reset’) at the time of construction that are now beneath the wall, or any materials that subsequently filtered down the void between the wall and the bedrock cut slope. Such materials may correspond to minima in signal intensities at depth. This hypothesis is tested in stage three: if the basal sediments are marked by minima in apparent dose values, samples should be progressed to dating at stage four ([Figure 3](#): example one). If not, then the sediment was probably not sufficiently disturbed at the time of construction to reset the luminescence dating signals, and the dating samples should be retained ([Figure 3](#): example two).

Alternatively, a terrace may be constructed by cutting into the bedrock slope, raising a stone or earth retainer, and then filling the void behind the retainer with sediment. This space might be infilled at construction (scenario two; [Figure 3](#): middle), or by gradual accumulation (scenario three). Additional dating priorities would be located at the base of the anthropogenic fill (scenario two), or throughout the sediment accumulation (scenario three; [Figure 3](#): right). The field profiles are likely to provide some insights into the construction sequence. If the sediment beneath the retainer is marked by minima in signal intensities, this sediment may have been disturbed at construction. If signal intensities are inverted, or if there is no signal-depth progression, then the fill may have been deposited rapidly. If there is a signal-depth progression, then this can elucidate whether sedimentation was uniform or episodic, gradual or rapid. These hypotheses can be tested and refined in stage three. Inverted or similar apparent doses with depth through the fill might imply that the sediment was deliberately re-deposited or packed ([Figure 3](#): example three). The magnitude and range in apparent doses through the fill(s) provide a first approximation for depositional age(s): if dose rates were uniform, and sedimentological and mineralogical characteristics are relatively homogeneous, then the ratio between top and bottom provides some indication of chronology. Steps

or substantial shifts in apparent doses with depth probably indicate where there have been hiatuses in deposition, or where erosion has occurred. The reproducibility between aliquots can provide an indication of how well bleached the sediment was at deposition: good reproducibility suggests it was well bleached, poor reproducibility that it was poorly bleached (Figure 3: example five). Heterogeneous distributions of sensitivity and apparent dose through the sediment stratigraphies imply complex depositional histories, and samples should be progressed to dating with caution (Figure 3: examples four & six). An applied example of this methodology is illustrated below.

Case study: Geçirim-Kuzkuyusu, Mersin, Turkey

To illustrate the field and laboratory methods that have been applied in all five study areas, we present a case study based on one example of a terrace system in southern Turkey (Figure 1A). The fieldwork was undertaken within the framework of the Boğsak Archaeological Survey project, a multi-disciplinary and diachronic archaeological research programme that includes the documentation, study and analysis of terrestrial and submerged material remains, as well as aspects of intangible heritage (Varinlioğlu 2017). The project comprises several sub-fields, including landscape, maritime, and architectural survey, archaeometric and geoarchaeological analysis, and ethnographic and anthropological research. To date, detailed survey and recording has focused on Roman and late antique remains on the islands of Boğsak (ancient Asteria) and Dana (and the adjacent shores), which lie in the Taşucu Gulf to the west of Silifke, on Turkey's southern Mediterranean coast (Varinlioğlu 2017; Varinlioğlu *et al.* 2017). While the coastal area has seen increasing industrialisation and urbanisation in recent decades, the mountainous hinterland of Boğsak has witnessed a growing level of abandonment, as farmers and transhumant pastoralists have increasingly moved to towns and cities. Extensive field survey in this area has identified the remains of settlements, as well as agricultural and industrial facilities, dating from the Chalcolithic onwards (Mac Sweeney & Şerifoğlu 2017).

HLC analysis of Boğsak's hinterland, carried out between 2015 and 2018, has highlighted the range of landscape character types found in the region. As none of the agricultural terraces in the area had been dated archaeologically, fieldwork was undertaken at five sites to ground-truth the HLC analysis, and to date the creation and development of key terrace examples using OSL profiling and dating (OSL-PD). Fieldwork at one of these sites, located between Geçirim and Kuzkuyusu near the centre of the Boğsak study area, is presented here.

HLC analysis of the landscape surrounding a deserted settlement of unknown date identified five different types of field systems: strip fields, rectilinear fields, maquis fields, braided terraces and check dams (Figure 5). This classification was checked and verified during fieldwork in November 2016. The deserted settlement has a commanding view of the surrounding agricultural lands. To the east lie several valleys running down from a north–south ridge to the more open arable land below. The enclosed slopes are concave—steeper towards the ridge and gentler towards the valley bottom. These enclosed areas are extensively terraced, with individual 'fields' separated by stone walls every 10–20m downslope. The walls, whose age was unknown, stand 0.50–0.80m tall. The sediment sequences associated with three check dams in two adjacent valleys were examined, and samples collected for

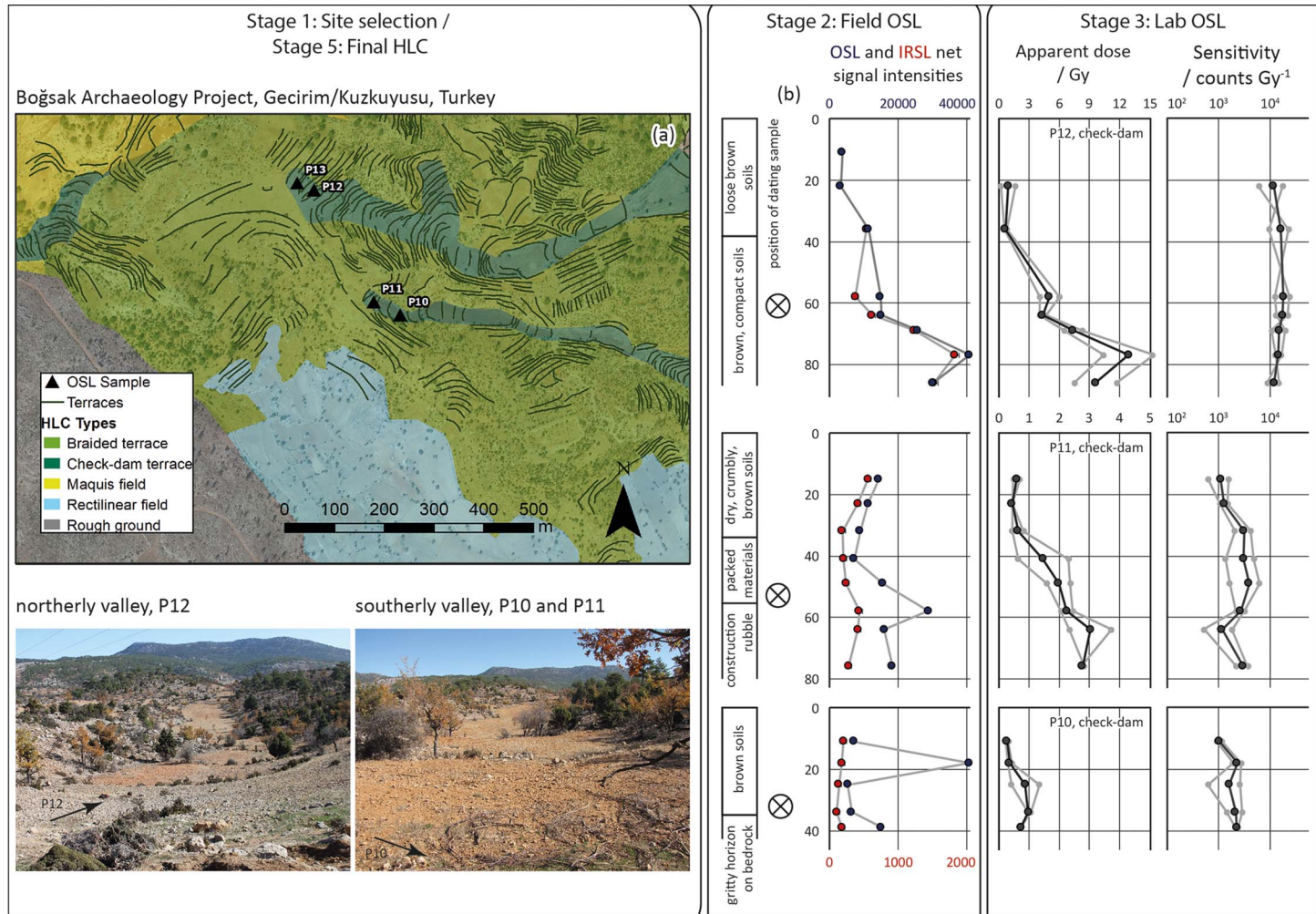


Figure 5. Case study: ancient site between Geçirim and Kuzkuyusu, with fields, check dams and terraces on slopes: a) historic landscape characterisation (HLC); b) luminescence stratigraphies (figure by T. Kinnaird).

OSL-PD, each with the aim of defining sediment chronologies and modelling the construction sequences. [Figure 5](#) shows the distribution of the terrace walls investigated, together with the luminescence stratigraphies generated for the associated sedimentary sequences.

Terraces one and two were located in the southerly valley ([Figure 5](#)). Terrace one was located low down in the valley, close to the topographic break between the steep slope and flat low-lying land. This was a check-dam, faced with a drystone wall standing 0.50m tall. The sediment profile (P10) comprised approximately 0.35m of brown agricultural soil, then a 50mm-thick C horizon, before bedrock was encountered at a depth of 0.40m. Five bulk sediment samples were taken at approximately 50mm intervals down profile for OSL profiling. This series shows that the luminescence-depth profile is inverted from the surface to approximately 0.35m deep, with maximum intensities at 0.18m; the lowest sample is characterised by low signal intensities. This was interpreted in the field as reflecting deposition from hillwash/downslope movement of soils, with the spike in intensities at 0.18m potentially reflecting a failure of soil management upslope.

Check dam two was located high in the same valley, close to the ridge above. The facing wall (0.80m tall) protected a sediment profile (P11), which comprised alternating horizons of brown silt loam and more calcitic silt loams, with the latter more rubbly in nature. These rubbly horizons were attributed in the field to the construction of the terrace. Eight bulk sediment samples were collected through this profile. Signal intensities are inverted from the surface to approximately 0.41m deep, then increase with depth through the interval 0.41–0.58m, before dropping off from 0.58m. This was interpreted in the field as reflecting deposition from hillwash, ‘packing’ during construction with mixed age materials, and disturbance or bleaching of the substrate at deposition.

The final check dam sampled, terrace three, was located towards the top of the slope, in the adjacent coombe to the north ([Figure 5](#)). Its facing wall stood 0.80m tall, and was found to be the best constructed of the three structures investigated. The sediment profile (P12) consists of approximately 0.35m of brown, agricultural soils, overlying a 0.20m cobble horizon, which, in turn, overlay a buried, brown, compact soil. Eight bulk sediment samples were collected through this profile, which extended to bedrock at a depth of 0.87m. Initial impressions were that the agricultural soil had accumulated slowly over time, that there was a short chronology to the cobble horizon and that the buried soil represented a longer and more stable accumulation.

In summary, all the profiles exhibited aggradation over time, with stratigraphic breaks indicative of changes in erosional and depositional processes. In the case of those profiles containing a buried soil, the signal intensities at the base of the sediment stratigraphies were consistent with these units having been bleached at deposition. This probably resulted from disturbance of the buried soil during construction of the terrace wall. Accordingly, samples for OSL dating were positioned at the base of the sediment stratigraphies, above the R horizon (or bedrock). It was noted during fieldwork that the magnitude and range in signal intensities recorded in these sediments implied that there was some chronology to the sequence of construction: terrace three in the northerly valley was considered likely to be the oldest and terrace one the youngest; terrace two may have been constructed sometime between the other two.

These assumptions were tested in the subsequent programme of analytical work. The magnitude and range in apparent dose estimates across the investigated sediment stratigraphies supported the chronological framework suggested above for construction (Figure 5). The trends and maxima in apparent dose estimates supported the suggestion that the lower units in each of the sediment stratigraphies were disturbed and bleached during construction. *In situ* gamma dose-rate measurements implied no dosimetric gradients or discontinuities. This justified the positioning of the dating samples at the base of the sediment stratigraphies.

The construction of the terraces in the southern valley is dated to AD 1340±50 (terrace two) and AD 1850±20 (terrace one), upslope and downslope, respectively (see the OSM). The terrace wall in the northern valley was constructed sometime after AD 430±100. Apparent ages were retrospectively determined for each profiling sample (see the OSM). Our sediment chronologies imply that deposition of the agricultural soils from 0m to a depth of approximately 0.35m (0.38m in P10, 0.32m in P11, 0.36m in P12) was synchronous across the study region (after the early nineteenth century AD), and further corroborate the construction sequence for walls one to three. The evidence for this is:

- 1) The agricultural soils in P10, P11 and P12 have similar compositions.
- 2) Sub-samples at a depth of approximately 0.35m in each profile return apparent dose estimates in the range of around 0.4–0.5 Gy.
- 3) *In situ* gamma spectrometry implies no local variations in environmental dose rate. The sediment chronologies indicate that the greatest time-depth in P11 and P12 was from 0.40m to bedrock, potentially spanning 400 and 800 years, respectively.

This case study illustrates the methods used in each of the five study regions to identify suitable sites for sampling, and subsequently to profile and analyse them in the field and the laboratory. It demonstrates that OSL profiling at the time of archaeological survey is an extremely powerful tool for the interpretation of the sedimentary stratigraphies associated with terraces and other earthwork boundaries.

Results and discussion

Table 1 summarises the spatial coverage of each of the HLCs (between approximately 20 and 600km²), the estimated total length of the terraces in each of the five study areas (>300km), and the number of terrace types identified in each area based on their morphologies.

Figures 6–7 summarise our age constraints for terrace construction and utilisation across the Mediterranean region (also tabulated in the OSM). The data are drawn from the agricultural terraces and earthworks surveyed in the five case studies, sub-divided into 16 sub-regions, examined through 52 profiles comprising approximately 528 field and 357 laboratory samples and 65 dating samples (see Table S1 in the OSM). The total dataset comprises 283 temporal constraints in the 0–2 ka range on terrace construction and utilisation: 55 sediment ages relating to terrace construction or substantial modification and 228 apparent ages calculated from the calibrated dataset (for terrace utilisation). In addition, we compiled 42 previously published radiocarbon ages. The results are presented as

Table 1. Historic landscape character types with agricultural terraces in three Mediterranean countries

Case studies	Case study area (km ²)	Area of terraces (km ²)	Types of terraces	Estimated length of terraces (km)
Turkey (Boğsak, Mersin Province and Urla, Izmir)	577.9	57.7	6	306
Greece (Naxos, Cyclades)	104.1	35.0	7	1044
Spain (western Catalonia and Galicia)	19.7	9.0	6	609

follows: first, sediment ages linked to terrace construction; second, sediment ages linked to utilisation and modification of terraces; and third, radiocarbon ages interpreted here as also representing utilisation. OSL and radiocarbon dates are binned in 125 year intervals. The horizontal axis is limited to the last 2000 years, as the majority of the OSL and radiocarbon data date construction and utilisation to this period.

Our dataset implies that terrace modification and utilisation was continuous throughout the last 2000 years, although patterns of terrace development varied. In some cases, existing systems were gradually subdivided (as in medieval Naxos), whereas in others, large-scale reorganisation took place (e.g. around the monastery at Samos, in Galicia).

Importantly, the OSL-PD sediment chronologies have produced evidence of large-scale land-use in periods for which no other evidence indicative of landscape exploitation survives. This is exemplified by our case studies at Gölcük (Silifke, Turkey) and Kastro Apalirou (Naxos, Greece), where braided terrace systems lie immediately adjacent to the remains of extensive, deserted settlements dated through archaeological survey to the fifth to ninth centuries AD. It was originally assumed that the partly abandoned terraces were likely contemporaneous with the settlements. The luminescence chronologies, however, demonstrate that the main periods of terrace construction and use at both sites were several hundred years later, between the eleventh and fourteenth centuries. This major episode of land use is otherwise entirely unattested: neither area has surviving medieval documentary records, surface finds of later medieval artefacts are relatively scarce and local conditions are not conducive for the preservation of pollen cores.

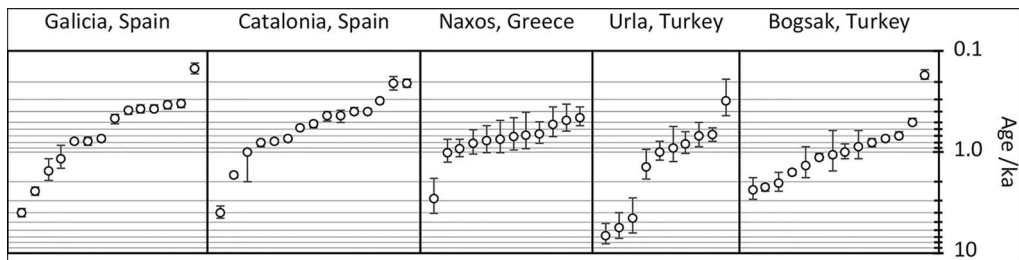


Figure 6. Individual quartz SAR-OSL depositional ages obtained for sediments associated with terrace construction in each case study (figure by T. Kinnaird).

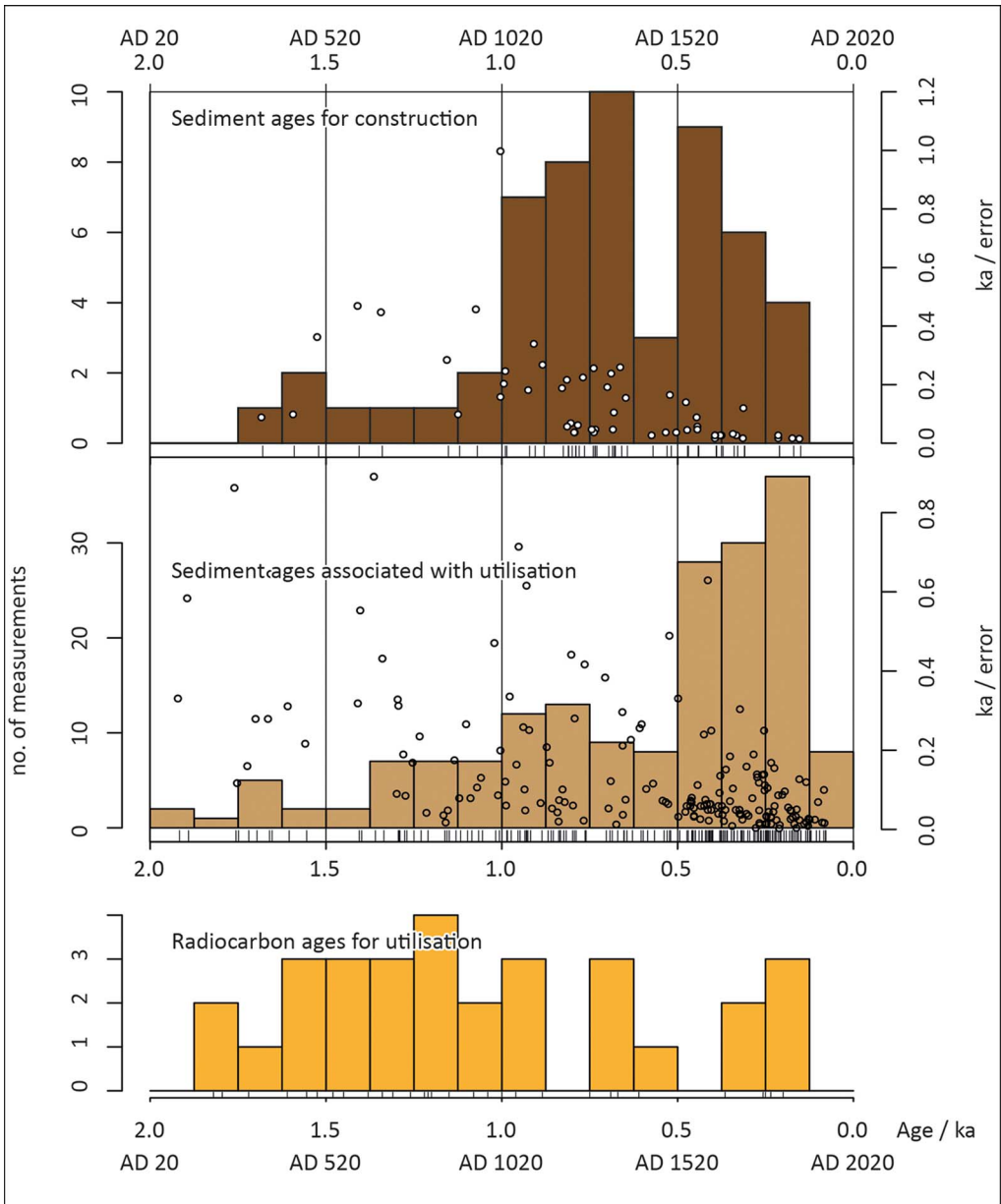


Figure 7. Quartz OSL constraints for a) construction (brown) and b) utilisation (tan) (figure by T. Kinnaird).

At certain times, terrace-building appears to have intensified, including during the mid twelfth and early sixteenth centuries AD. These trends are broadly synchronous in the five case-study areas, despite differences in terrace morphology and function. Data from climate proxies suggest that both peaks in terrace-building coincided with relatively cool periods (Xoplaki *et al.* 2018). Nevertheless, the relationships between climate and land use are not straightforward: climate models also suggest rainfall patterns across the region diverged

significantly during these periods (Finné *et al.* 2019). Agricultural change could have been stimulated by various other drivers, including political, economic and social factors (Haldon & Rosen 2018). Shifting patterns of land tenure and local autonomy, for example, could have been important in all five case-study areas (Barton 2010; Vionis 2012: 39–56). Terraces may have provided a flexible resource that enabled farmers to respond in resilient ways to different challenges.

The formation sequences of terraces, along with other archaeological earthworks, such as earth banks (Vervust *et al.* 2020), can now be reconstructed in detail using OSL-PD. The ability to create fully dated sediment profiles reduces our dependence on patchy documentary and archaeological sources, and helps us to discern and understand key periods of landscape change. It also opens the possibility to link other soil-science approaches, such as sediment micromorphology, microfossil analysis and geochemistry, providing essential, diachronic detail on shifting land-use and soil management. The ability to describe and date accurately how landscapes were exploited at different times in the past means that it will be possible to understand the effects of different practices—which practices, for example, proved sustainable over long periods and which triggered environmental degradation. Such knowledge has the potential to help landscape archaeologists provide valuable scenarios for transdisciplinary debates about future policy in areas from agriculture and water management to energy and climate change.

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Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.15184/aqy.2020.187>

References

- ACABADO, S. 2009. A Bayesian approach to dating agricultural terraces: a case from the Philippines. *Antiquity* 83: 801–14. <https://doi.org/10.1017/S0003598X00099002>
- BALLESTEROS-ARIAS, P. & F. CRIADO-BOADO. 2009. El paisaje agrario medieval en Galicia: Herramientas metodológicas, in J. Bolós & E. Vicedo (ed.) *Poblament, territori i historia rural*

- (VI Congrés sobre Sistemes Agraris, Organització Social i Poder Local): 599–612. Lleida: Institut d'Estudis Ilerdencs.
- BARTON, T. 2010. Lords, settlers and shifting frontiers in medieval Catalonia. *Journal of Medieval History* 36: 204–52.
<https://doi.org/10.1016/j.jmedhist.2010.07.002>
- BECKERS, B., B. SCHÜTT, S. TSUKAMOTO & M. FRECHEN. 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. *Journal of Archaeological Science* 40: 333–48.
<https://doi.org/10.1016/j.jas.2012.06.041>
- BETANCOURT, P. & R. HOPE SIMPSON. 1992. The agricultural system of Bronze Age Pseira. *Cretan Studies* 3: 47–54.
- BEVAN, A. & J. CONOLLY. 2011. Terraced fields and Mediterranean landscape structure: an analytical case study from Antikythera, Greece. *Ecological Modelling* 222: 1303–14.
<https://doi.org/10.1016/j.ecolmodel.2010.12.016>
- BEVAN, A., J. CONOLLY, S. COLLEDGE & A. STELLATOU. 2013. The long-term ecology of agricultural terraces and enclosed fields from Antikythera, Greece. *Human Ecology* 41: 255–72.
<https://doi.org/10.1007/s10745-012-9552-x>
- BOIXADERA, J., S. RIERA, S. VILA, I. ESTEBAN, R. ALBERT, J. LLOP & R. POCH. 2016. Buried A horizons in old bench terraces in Les Garrigues (Catalonia). *Catena* 137: 635–50.
<https://doi.org/10.1016/j.catena.2014.08.017>
- Council of Europe. 2000. European landscape convention (European Treaty Series 176). Available at:
<https://www.coe.int/en/web/conventions/full-list/-/conventions/treaty/176> (accessed 11 March 2021).
- CROW, J., S. TURNER & A.K. VIONIS. 2011. Characterizing the historic landscapes of Naxos. *Journal of Mediterranean Archaeology* 24: 111–37.
<https://doi.org/10.1558/jmea.v24i1.111>
- DAVIDOVICH, U., N. PORAT, Y. GADOT, Y. AVNI & O. LIPSCHITS. 2012. Archaeological investigations and OSL dating of terraces at Ramat Rahel, Israel. *Journal of Field Archaeology* 37: 192–208.
<https://doi.org/10.1179/0093469012Z.00000000019>
- DENEVAN, W. 1995. Prehistoric agricultural methods as models for sustainability. *Advances in Plant Pathology* 11: 21–43.
[https://doi.org/10.1016/S0736-4539\(06\)80004-8](https://doi.org/10.1016/S0736-4539(06)80004-8)
- ELLIS, E.C., J.O. KAPLAN, D.Q. FULLER, S. VAVRUS, K. KLEIN GOLDEWIJK & P.H. VERBURG. 2013. Used planet: a global history. *Proceedings of the National Academy of Sciences of the USA* 110: 7978–85.
<https://doi.org/10.1073/pnas.1217241110>
- European Soil Data Centre. 2020. European Soil Data Centre, Joint Research Centre, European Commission. Available at: esdac.jrc.ec.europa.eu (accessed 11 March 2021).
- FERRO-VÁZQUEZ, C., C. LANG, J. KAAL & D. STUMP. 2017. When is a terrace not a terrace? The importance of understanding landscape evolution in studies of terraced agriculture. *Journal of Environmental Management* 202: 500–13.
<https://doi.org/10.1016/j.jenvman.2017.01.036>
- FERRO-VASQUEZ, C., J. KAAL, F. SANTOS ARÉVALO & F. CRIADO BOADO. 2019. Molecular fingerprinting of ¹⁴C dated soil organic matter fractions from archaeological settings in NW Spain. *Radiocarbon* 61: 101–30.
<https://doi.org/10.1017/RDC.2018.62>
- FINNÉ, M., J. WOODBRIDGE, I. LABUHN & C. ROBERTS. 2019. Holocene hydro-climatic variability in the Mediterranean: a synthetic multi-proxy reconstruction. *The Holocene* 29: 847–63.
<https://doi.org/10.1177/0959683619826634>
- FOXHALL, L., M. JONES & H. FORBES. 2007. Human ecology and the classical landscape: Greek and Roman worlds, in S. Alcock & R. Osborne (ed.) *Classical archaeology*: 91–117. Oxford: Blackwell.
- GROVE, D. & O. RACKHAM. 2001. *The nature of Mediterranean Europe: an ecological history*. New Haven (CT) & London: Yale University Press.
- HALDON, J. & A. ROSEN. 2018. Society and environment in the East Mediterranean c. 300–1800 CE: problems of resilience, adaptation and transformation. Introductory essay. *Human Ecology* 46: 275–90.
<https://doi.org/10.1007/s10745-018-9972-3>
- HARFOUCHE, R. 2007. *Histoire des paysages méditerranéens terrassés: aménagements et agriculture* (British Archaeological Reports International Series 1634). Oxford: Archaeopress.
<https://doi.org/10.30861/9781407300481>
- KINNAIRD, T., J. BOLÒS, A. TURNER & S. TURNER. 2017a. Optically stimulated luminescence profiling and dating of historic agricultural

- terraces in Catalonia (Spain). *Journal of Archaeological Science* 78: 66–77.
<https://doi.org/10.1016/j.jas.2016.11.003>
- KINNAIRD, T., T.C. DAWSON, D. SANDERSON, D. HAMILTON, A. CRESSWELL & R. RENNELL. 2017b. Chronostratigraphy of an eroding complex Atlantic round house, Baile Sear, Scotland. *Journal of Coastal and Island Archaeology* 14: 46–60.
<https://doi.org/10.1080/15564894.2017.1368744>
- KIZOS, T. & M. KOULOURI. 2006. Agricultural landscape dynamics in the Mediterranean: Lesvos (Greece) case study using evidence from the last three centuries. *Environmental Science and Policy* 9: 330–42.
<https://doi.org/10.1016/j.envsci.2006.02.002>
- KOBOROV, D. & A. BORISOV. 2013. The origins of terraced field agriculture in the Caucasus: new discoveries in the Kislovodsk Basin. *Antiquity* 87: 1086–1103.
<https://doi.org/10.1017/S0003598X00049887>
- KRAHTOPOULOU, A. & C. FREDERICK. 2008. The stratigraphic implications of long-term terrace agriculture in dynamic landscapes: polycyclic terracing from Kythera Island, Greece. *Geoarchaeology* 23: 550–85.
<https://doi.org/10.1002/gea.20231>
- KUIJT, I., B. FINLAYSON & J. MACKAY. 2007. Pottery Neolithic landscape modification at Dhra'. *Antiquity* 81: 106–18.
<https://doi.org/10.1017/S0003598X00094874>
- MAC SWEENEY, N. & T.E. ŞERİFOĞLU. 2017. Never the same river twice: the Göksu Valley through the ages, in Y. Heffron, A. Stone & M. Worthington (ed.) *At the dawn of history: Near Eastern studies in honour of J.N. Postgate*. 335–54. Winona Lake (IN): Eisenbrauns.
<https://doi.org/10.5325/j.ctv1bxh3qk.27>
- NANAVATI, W., C. FRENCH, K. LANE, O. HUAMAN OROS & D. BERESFORD-JONES. 2016. Testing soil fertility of Prehispanic terraces at Viejo Sangayaico in the upper Ica catchment of south-central highland Peru. *Catena* 142: 139–52.
<https://doi.org/10.1016/j.catena.2016.03.007>
- PANAGOS P., M. VAN LIEDEKERKE, A. JONES & L. MONTANARELLA. 2012. European Soil Data Centre: response to European policy support and public data requirements. *Land Use Policy* 29: 329–38.
<https://doi.org/10.1016/j.landusepol.2011.07.003>
- PEDROLI, B., S. TAGLIASACCHI, T. VAN DER SLUIS & W. VOS. 2013. *Portus Delphini: landscape and environmental research on the Promontorio di Portofino*. Rotterdam: FERGUS-ON.
- PORAT, N., U. DAVIDOVICH, Y. AVNI, G. AVNI & Y. GADOT. 2018. Using OSL measurements to decipher soil history in archaeological terraces, Judean Highlands, Israel. *Land Degradation & Development* 29: 643–50.
<https://doi.org/10.1002/ldr.2729>
- PORAT, N., G. LÓPEZ, N. LENSKY, R. ELINSON, Y. AVNI, Y. ELGART-SHARON, G. FAERSHTEIN & Y. GADOT. 2019. Using a portable OSL reader to obtain a time scale for soil accumulation and erosion in archaeological terraces, the Judean Highlands, Israel. *Quaternary Geochronology* 49: 65–70.
<https://doi.org/10.1016/j.quageo.2018.04.001>
- PUY, A. & A. BALBO. 2013. The genesis of irrigated terraces in al-Andalus: a geoarchaeological perspective on intensive agriculture in semi-arid environments (Ricote, Murcia, Spain). *Journal of Arid Environments* 89: 45–56.
<https://doi.org/10.1016/j.jaridenv.2012.10.008>
- PUY, A., A. BALBO & O. BEBENZER. 2016. Radiocarbon dating of agrarian terraces by means of buried soils. *Radiocarbon* 58: 345–63.
<https://doi.org/10.1017/RDC.2015.21>
- QUIRÓS-CASTILLO, J. & C. NICOSIA. 2019. Reconstructing past terraced agrarian landscapes in the Ebro Valley: the deserted village of Torrentejo in the Basque Country, Spain. *Geoarchaeology* 34: 684–97.
<https://doi.org/10.1002/gea.21730>
- RENDU, C. *et al.* 2015. Reconstructing past terrace fields in the Pyrenees: insights into land management and settlement from the Bronze Age to the Early Modern era at Vilalta (1650m asl, Cerdagne, France). *Journal of Field Archaeology* 40: 461–80.
<https://doi.org/10.1179/2042458215Y.0000000002>
- SANDERSON, D. & S. MURPHY. 2010. Using simple portable OSL measurements and laboratory characterisation to help understand complex and heterogeneous sediment sequences for luminescence dating. *Quaternary Geochronology* 5: 299–305.
<https://doi.org/10.1016/j.quageo.2009.02.001>
- SCHAUS, G. & N. SPENCER. 1994. Notes on the topography of Eresos. *American Journal of*

- Archaeology* 98: 411–30.
<https://doi.org/10.2307/506437>
- TURNER, S. 2018. Historic landscape characterisation: an archaeological approach to landscape heritage, in G. Fairclough, I. Sarlov-Herlin & C. Swanwick (ed.) *Routledge handbook of landscape character assessment*: 37–50. London: Routledge.
<https://doi.org/10.4324/9781315753423-3>
- TURNER, S., J. BOLÒS & T. KINNAIRD. 2018. Changes and continuities in a Mediterranean landscape: a new interdisciplinary approach to understanding historic character in western Catalonia. *Landscape Research* 43: 922–38.
<https://doi.org/10.1080/01426397.2017.1386778>
- VARINLIOĞLU, G. 2017. ‘Built like a city’: Asteria in late antiquity, in E. Rizos (ed.) *New cities in late antiquity: documents and archaeology* (Bibliothèque de l’Antiquité Tardive 35): 247–66. Turnhout: Brepols.
- VARINLIOĞLU, G., N. KAYE, M. JONES, R. INGRAM & N. RAUH. 2017. The 2016 Dana Island survey: investigation of an island harbor in ancient Rough Cilicia by the Boğsak Archaeological Survey (BOGA). *Near Eastern Archaeology* 80: 50–59.
<https://doi.org/10.5615/neareastarch.80.1.0050>
- VAROTTO, M., L. BONARDI & P. TAROLLI (ed.). 2019. *World terraced landscapes: history, environment, quality of life*. Cham: Springer.
<https://doi.org/10.1007/978-3-319-96815-5>
- VERVUST, S., T. KINNAIRD, P. HERRING & S. TURNER. 2020. Optically stimulated luminescence profiling and dating of earthworks: the creation and development of prehistoric field boundaries at Bosigran, Cornwall. *Antiquity* 94: 420–36. <https://doi.org/10.15184/aqy.2019.138>
- VIONIS, A.K. 2012. *A Crusader, Ottoman, and early modern Aegean archaeology*. Leiden: Leiden University Press.
- WAGSTAFF, M. 1992. Agricultural terraces: the Vasilikos Valley, Cyprus, in M. Bell & J. Boardman (ed.) *Past and present soil erosion* (Oxbow Monograph 22): 155–62. Oxford: Oxbow.
- WHITELAW, T. 1991. The ethnoarchaeology of recent rural settlement and land use in northwest Keos, in J. Cherry, J. Davis & E. Mantzourani (ed.) *Landscape archaeology as long-term history: northern Keos in the Cycladic Islands*: 403–54. Los Angeles: University of California Institute of Archaeology.
- XOPLAKI, E. *et al.* 2018. Modelling climate and societal resilience in the Eastern Mediterranean in the last millennium. *Human Ecology* 46: 363–79.
<https://doi.org/10.1007/s10745-018-9995-9>