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INSIGHTS ON TOPOGRAPHY DEVELOPMENT IN THE VASILIKÓS AND DHIARIZOS VALLEYS, CYPRUS, FROM INTEGRATED OSL AND LANDSCAPE STUDIES

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ABSTRACT

Given the long history of human occupation on Cyprus, and the intensely disturbed and eroded nature of its landscape, the present-day topography has been linked to 10^{2-3} years of human settlement and land use. Luminescence dating methods provide a chronological framework to interpret landscape processes and human-environmental interactions over this timescale, and coupled with landscape studies in the Vasilikós and Dhiarizos valleys, the means to test this assumption. The first case study examines the landscape in the Vasilikós valley, populated and exploited with regard to its natural resources since the Neolithic. The second case study examines the landscape around the Chalcolithic settlement of Souskiou-*Laona* where the underlying geology, geomorphology and environment contributed to the choice of site. The luminescence chronologies reported herein suggest that modifications in the first-order catchment hydrology occurred over timescales in excess of 10^3 years. It is shown that the present-day topography in Cyprus was initiated in the latest Pliocene-Pleistocene, as a result of pronounced uplift of the island and the environmental conditions which prevailed, and that only minor modifications to this first-order topography have occurred since, with the re-working, and re-deposition of Early - Middle Pleistocene sediments over timescales of both 10^{2-3} and 10^{4-5} years.

KEYWORDS: Topography development, Geo-archaeology, Eastern Mediterranean

INTRODUCTION

The investigation of archaeological landscapes has become an intrinsic part of interpreting long-term changes in settlement and land use, especially among early agricultural societies (e.g. Mediterranean, and Cyprus specific studies, include: Gomez, 1987; Butzer, 2005; Butzer and Harris, 2007; Deckers, 2007; Dusar et al., 2011; Fall et al., 2012). The Chalcolithic period in Cyprus marks the start of basic settlement continuity, agricultural experimentation and presumed modification of the natural environment by humans (Peltenburg et al., 2006, Peltenburg 2011). Given that 5000 years have passed between then and now, it has been suggested that the Cypriot landscape has been impacted or degraded by centuries of human interactions (see discussion in Butzer and Harris, 2007). Clearly, both natural and anthropogenic processes will have contributed to the present intensely eroded and degraded Cypriot landscape of today, and potentially, that these processes have been operating over different timescales (10^{2-3} vs. 10^{4-5} years, respectively). The temporal resolution of the luminescence dating method is ideal for differentiating between these processes, and when coupled with geoarchaeological studies, provides a means to study the complex and intrinsic link between environment and people. In this manuscript, we present the results from two case studies from southwest and southern Cyprus, where both natural climatically-driven processes, and human-environmental interactions, are believed to have contributed to development of the present-day topography.

The first case study is concerned with the development of the first-order topography in the Vasilikós Valley, a prominent river valley in south central Cyprus (Fig. 1). The bedrock geology, and the Quaternary landforms, within this valley provide a long, protracted record of landscape evolution, from late-stage tectonic uplift of the island in the Late Pliocene-Early Pleistocene (Poole and Robertson, 1991; Kinnaird et al., 2011; Kinnaird and Robertson, 2012) through to the present day. This region has been populated, and exploited for its natural resources, for over 9 ka of human history; from the Acremic Neolithic, through the Chalcolithic and into the Middle and Late Bronze Age (see summary in Todd, 2004; Gomez, 1987). The study of the late Quaternary landforms within this valley provides a unique opportunity to determine the relative impact of natural, climatically-linked, and anthropogenic slope processes on topography development. At present, the poorly defined chronology for these deposits, and the poor preservation of pollen within these sediments, has prevented a detailed extended palaeo-climatic record. Thus, the study in the Vasilikós Valley examines the spatial and temporal distribution of surficial, calcareous Quaternary colluvial deposits (spread widely throughout Cyprus), to assess whether these deposits are a proxy palaeo-climatic record.

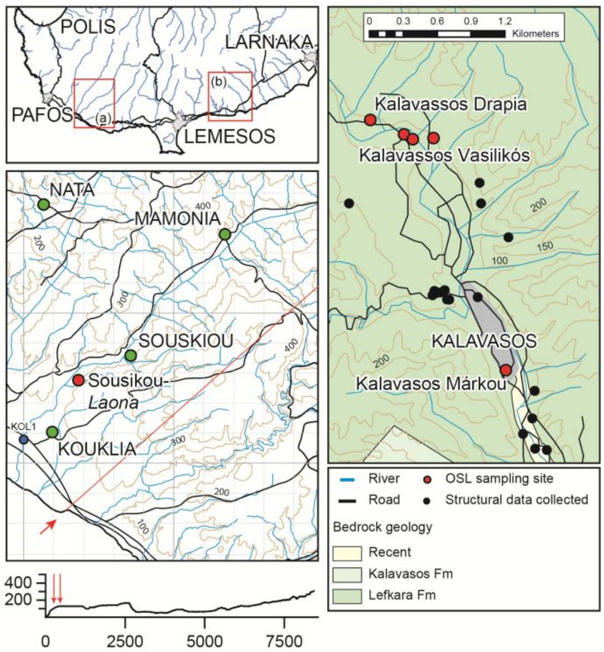

Figure 1. (a) Topographic map of the Dhiarizos valley, showing the traces of the Dhiarizos and Argakin Vathin rivers. The complex of Souskiou-*Laona* is located at the confluence of the two rivers. The cross-section, marked by the red line, shows the topography of the Vathyrkakas plateau, the elevated Oreites Forest Block, and the topographic gradient from the coast towards the Troodos Mountains; (b) Topographic and geological map of the *Vasilikós* valley. The positions of the palaeo-environmental sections studied are shown.

The second case study examines the first-order topography in the region around the Chalcolithic settlement-cemetery complex of Sousikou-*Laona*, south-west Cyprus (Fig. 1). This site is one of several Chalcolithic settlements in the Dhiarizos river valley, a natural corridor/route between the coast and the uplands/interior of the island. The Sousikou-*Laona* complex is located on an elevated spur, at the confluence of the Dhiarizos and Aragin Vathin rivers (Fig.1). Its location is clearly linked to its topographic position above the Dhiarizos river valley, with the settlement orientated to the south (located on an elevated spur), hidden on the slopes facing away from the main river channel, and the cemeteries prominently located on the crest of the ridge, at an elevated position on the Vathyrkakas plateau. In detail, the complex is dissected by a ravine, cut by the Vathyrkakas stream, which separates the settlement, on the *Laona* ridge, from the main concentration of graves to the west of the ravine. It is known that the slopes above the ravine are active, due to the excavation of buildings that would have originally extended outwards into the ravine from their present position (Peltenburg et al., 2006; Peltenburg, 2011). Thus, the second study, provides an opportunity to assess a landscape exploited/settled in Chalcolithic times, and assess the relative contributions of both natural and anthropogenic landscape processes, on the development of the present-day topography.

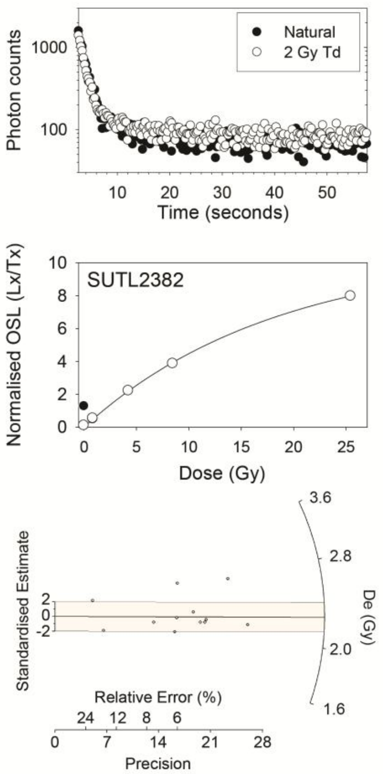

Figure 2. Representative dose response curve for sample SUTL2382, the lowermost sample from the Dhiarizos river section. The stored dose estimate for this sample, based on the weighted mean of 7 aliquots, was 2.23 ± 0.02 Gy.

Landscape evolution processes (10^{4-5} years)

The physiography of the island is dominated by two mountain masses, the Troodos and Kyrenia Mountains, and the central plain they encompass, the Mesaoria plain. Coastal lowlands, varying in width, surround the island. This topography stems largely from the Late Pliocene-Early Pleistocene (Robertson, 1977; Poole and Robertson, 1991; Kinnaird et al., 2011), when major uplift was focused on the Troodos Massif (Robertson, 1977; McCallum and Robertson, 1990), and, the geological record documents a transition from quiet open-marine Pliocene muds and silts (McCallum et al., 1993), to alluvial conglomerates and sands of the 'fanglomerate series' (Poole and Robertson, 1991; 1998).

The combination of tectonic uplift and a progressive fall in global sea-level through the late Pliocene to late Pleistocene interval caused these 'fanglomerates' to be progressively uplifted relative to sea-level and incised, as the rivers cut down to successive new base-levels. The net effect of this is that, in the present landscape, the oldest fanglomerate sediments are preserved at topographically elevated positions, with younger units occurring at progressively lower elevations. Numerous workers (Poole and Robertson, 1991; Poole, 1992; Poole and Robertson, 1998; Kinnaird et al., 2011; Kinnaird and Robertson, 2012) have recognised that the fanglomerates, and the regional erosional surfaces they overlie, provide temporal and spatial markers to interpret the late-stage uplift history of the island, and as such, a relative chronology exists for the fanglomerate series (discussed below in relation to the landscape studies at Sousikou-*Laona*).

The sediments are subdivided into four informal units, termed F0 to F4, after the erosion surface they overlie, or the erosion event they formed in response to. The progressive uplift, and subsequent incision, of the Troodos Massif and its sedimentary cover, resulted in a change in the nature of the bed-load with time: the earliest fanglomerates are dominated by Troodos material with abundant gabbro, whereas the later fanglomerates are dominated by material derived from a higher structural level in the Troodos ophiolite and its sedimentary cover.

The increase in elevation of the Troodos Massif through the late Pliocene to Mid Pleistocene, coupled with uplift in northern Cyprus (Kyrenia Range; Robertson and Woodcock, 1986; Harrison et al., 2004;), may have created local, physical barriers to the circulation of air masses in the eastern Mediterranean region, intercepting moisture, and resulting in an enhanced flux of precipitation to the region, Waters et al., 2010.

The late Pleistocene-Holocene terrestrial sediments are a proxy for palaeo-environmental change (e.g. Waters et al., 2010), with major erosional events (and associated deposits), including increased fluvial incision and mass debris mobilisation, reflecting periods of climatic down-turn, and stable periods, associated with the generation of soils, reflecting more favourable climatic conditions.

Anthropogenic processes (10^{2-3} years)

Traditionally, the island's topographic relief, in the foothills of the Troodos, and along the coastal fringe, is thought to have been heavily influenced/modified by millennia of human settlement and improvident land use (see discussion in Butzer and Harris, 2007).

In the early prehistory period, the 'Neolithic', settlements would have been localised, with restricted landscape adaption; one imagines that if there were agropastoral damage to the environment, it would have been restricted to proximal areas.

In contrast, population growth, settlement continuity and expansion in the Chalcolithic period, would have increased the demand on the environment, potentially leading to deforestation and increased agro-pastoral damage to the landscape.

The case study in the Dhiarizos valley, at the Chalcolithic settlement and cemeteries of Sousikou-*Laona*, explores this concept, through examining the relative roles of natural and anthropogenic processes on the development of topography in this region.

It has been suggested that at the time of occupation, the ravine was less intensely incised, and that easier access existed between the settlement and cemeteries on the opposite sides of the ravine; this has led archaeologists (Sewell, 2009) to suggest that human-environmental interactions led to increased landscape modification on the timescale of 10^3 years.

METHODOLOGY

Field sampling

The authors visited a number of localities within the Vasilikós and Dhiarizos valleys to assess the magnitude, and duration of Early Pleistocene - Recent erosion events, encompassing the anthropogenic period of interest.

At all localities, samples were collected for OSL dating and profiling, to provide a temporal framework to assess sediment stratigraphies, and test the concepts outlined above. Sections were cleaned for sampling, prior to describing the sediment stratigraphies, and collecting samples for OSL profiling and dating. All OSL samples were extracted under opaque black tarpaulins.

At each sampling position, in-situ gamma dose rates were measured using a using a 2x2" NaI scintillation detector connected to a Health Physics Rainbow Multichannel Analyser. In addition, 'bulk' samples of sediment were recovered for laboratory water content and dosimetry measurements.

Within the Vasilikós valley, the authors selected sections to encompass the full range of morphological types of havara deposits, at localities within the valley axis, and along its margins.

Site 1 (Kalavasos-*Márkou*, 34.7698°N, 33.2963°E) is located to the south and west of Kalavasos village, c. 150 m south of the village church. It is a slope-cut, located 30 m above the valley bottom at the first flattening of the slope toe. Site 2 (Kalvasos-*Vasilikós*, 34.7873°N, 33.2879°E) is located at a road cut c. 1 km north-northwest of the village, c. 20 m above the valley bottom.

With respect to the valley margin, this site is located at a more distal position on the fan than site 2. Site 3 (Kalavasos-*Drapia*, 34.7883°N, 33.2844°E) is located c. 200 west-northwest of site 2, a couple of metres high and dry of the main Vasilikós channel. It represents a slightly more distal, and topographically lower, part of the fan observed at the previous site (Fig. 3).

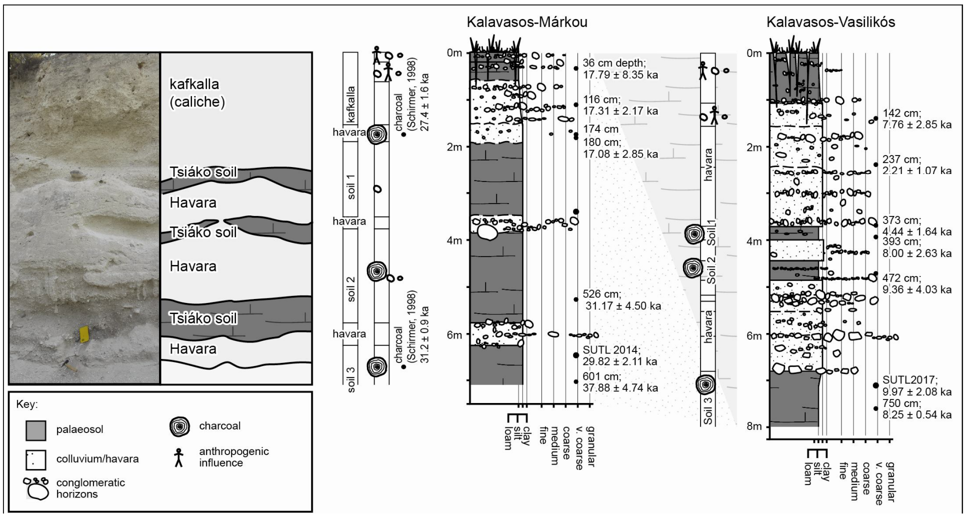

Figure 3: Quartz OSL chronologies for the Kalavasos-Vasilikós and -Márkou palaeo-environmental sections.

Geological investigations and geomorphological mapping were undertaken in the region around Souskiou-*Laona*¸ to establish a relative chronology for the landforms in the vicinity of Souskiou-*Laona* through the identification and correlation of the various erosion surfaces and channel fills. To determine the incision history of the Vathyrkakas ravine, relative to the main channel, OSL investigations were carried out at selected sections at the mouth of the Vathyrkakas fan and in the modern Dhiarizos channel. Site 1 (34.7347 °N, 32.6013°E) is a river-cut, located several metres west of the main channel, and 30 m northwest of the abandoned village of Souskiou. The Dhiarizos valley floor is covered by sands, silts, and massive, poorly sorted immature conglomerates. The conglomerates range from clast-supported in the channels, to matrix-supported units, interbedded with fine sands and silts, in the overbank units.

Clasts are dominated by lithologies derived from the Mamonia Complex (i.e. limestones and sandstones) and local bedrock (i.e. calcarenites and chalks), with subordinate coarse-grained igneous (Troodos-derived) rocks.

Two quartz SAR OSL ages have previously been reported from this section in Spencer and Sanderson (2002; Table 2). Site 2 (Vathyrkakas fan, 34.7242°N, 32.5787°E) is located at the intersection of the Vathyrkakas ravine, and the Dhiarizos channel. The sampled stratigraphy consists of clast- and matrix- supported boulder and pebble alluvial conglomerates, interbedded within poorly- to moderately-stratified, internally disorganised, matrix-supported colluvial deposits. The lithologies represented in the fan sequence are derived largely from the local bedrock, with only subordinate amounts of Mamonia and Troodos derived materials (which are reworked from the older channel deposits upstream, and from the *Laona* ridge). The third locality was within the Souskiou-*Laona* complex (34.7267°N, 32.5871°E); where, a number of sediment stratigraphies were studied, to assess the landscape processes operating on the flank of the *Laona* ridge.

LUMINESCENCE METHODOLOGY

In the Dhiarizos study, all sediment stratigraphies were first characterised with a SUERC portable OSL reader (for technical information on the portable instrumentation the reader is referred to Sanderson and Murphy, 2010). Natural luminescence signals from bulk sediment were measured using an interleaved sequence of system dark count, infra-red stimulated luminescence (IRSL) and OSL, so that dark count rates, IRSL and OSL integrated signal intensities, depletion rates, IRSL/OSL ratios, and post-stimulated phosphorescence could be evaluated. Then, for both studies, simple luminescence screening measurements (cf. Sanderson et al., 2001, 2003; Burbidge et al., 2007), were undertaken to provide a preliminary assessment of sensitivities and stored dose estimates throughout all sampled stratigraphies. In this technique, paired aliquots of 40% HF-etched quartz, and 15% HF-etched polymineral were extracted from each sediment sample, and assessed using a simplified two-step single-aliquot regenerative dose procedure. On the basis of this data, luminescence sensitivity vs. depth, and apparent dose vs. depth profiles, were generated for all sediment stratigraphies (Fig. 2). A more conventional approach was followed for all dating samples. Sample preparation and analysis was undertaken at the Scottish Universities Environmental Research Centre (SUERC) following well-established procedures (see Sanderson et al., 2001; Burbidge et al., 2007). Dose rates for the bulk sediment were quantified using high resolution gamma spectrometry (HRGS) and thick source beta counting (TSBC; Sanderson, 1988) in the laboratory, coupled with water content analysis and in-situ gamma dose rate measurements (FGS; Table 1).

Table 1. Dosimetry measurements

a. Estimated water content, based on fractional and saturated water contents, as received. Error taken as ± 5-10%

b. The cosmic ray contribution to the total dose calculated after Prescott and Hutton (1994)

c. Based on a reconciliation of the HRGS, TSBC and FGS data, combining water content corrections, and attenuating for grain size; for samples SUTL1327 and 1327, the total effective dose was obtained from reconciliation of the TSBC and FGS data. For the samples, in which HRGS and FGS yielded concordant gamma dose rate estimates, the total dose was calculated using an averaged value (e.g. SUTL1328); conversely, when discordant estimates were obtained, preferential weighting was given to the FGS measurement (e.g. SUTL2382).

Site Name	Sample no.	SUTL no.	Altitude / m	Field γ dose rate / mGya^{-1}	TSBC, dry / mGya^{-1}	HRGS, dry[a] / mGya^{-1}			W_{insitu}[b]	Cosmic[c] / mGya^{-1}	Total[d] / mGya^{-1}
						Alpha	Beta	Gamma			
Sousikou	SOA1†	1327	80	0.58 ± 0.04	0.85 ± 0.06	-	-	-	32	0.10 ± 0.01	1.22 ± 0.08
	SOA2	1328	80	0.58 ± 0.04	0.89 ± 0.04	9.25 ± 0.84	0.88 ± 0.06	0.54 ± 0.04	32	0.10 ± 0.01	1.47 ± 0.06
	SOA3†	1329	80	0.64 ± 0.05	0.75 ± 0.08	-	-	-	8	0.12 ± 0.01	1.40 ± 0.11
	SOA4	1330	80	0.64 ± 0.05	0.80 ± 0.04	10.94 ± 0.82	1.09 ± 0.06	0.68 ± 0.04	8	0.12 ± 0.01	1.52 ± 0.06
Dhiari-zos	DI01	2382	55	0.38 ± 0.03	0.82 ± 0.04	8.48 ± 0.51	0.91 ± 0.04	0.54 ± 0.03	16	0.13 ± 0.01	1.01 ± 0.08
	DI02	2383	55	0.36 ± 0.05	0.83 ± 0.04	7.00 ± 0.44	0.87 ± 0.04	0.48 ± 0.02	15	0.10 ± 0.01	0.98 ± 0.08
	DI03	2384	55	0.34 ± 0.03	0.81 ± 0.05	4.82 ± 0.36	0.68 ± 0.04	0.38 ± 0.02	15	0.08 ± 0.01	0.86 ± 0.07
Kalava-sos	Mátrou	2014	98	-	0.45 ± 0.04	1.25 ± 0.31	0.27 ± 0.03	0.14 ± 0.02	20	0.09 ± 0.01	0.68 ± 0.04
	Vasilikós	2017	110	-	1.65 ± 0.05	8.06 ± 0.68	1.46 ± 0.06	0.77 ± 0.04	20	0.09 ± 0.01	2.22 ± 0.08
	Drapia	2047	105	-	0.62 ± 0.04	2.13 ± 0.34	0.28 ± 0.04	0.16 ± 0.02	20	0.12 ± 0.01	0.78 ± 0.04

HRGS data were converted to dose rates using conversion factors derived from Aitken (1983) and Sanderson (1987). These were then reconciled with measured beta and gamma dose rates, taking into account water content. Dose rate conversion factors are periodically reviewed and it is noted here that our values are consistent with recent compilations (Liritzis et al., 2013; Aitken and Adamiec, 1998; Guérin et al., 2011).

Single aliquot regenerative procedures similar to those previously utilised in the SUERC laboratory were followed for all dating samples (e.g. Sanderson et al., 2001; 2003; 2007). Sets of 16 discs were used, grouped into subsets of four, which were preheated at temperatures of 200°C, 220°C, 240°C and 260°C for 30 s prior to readout. The readout cycle consisted of a natural measurement, followed by a nominal 1 Gy test dose, followed by a series of regenerative doses (8, 16, 24, 32 and 40 Gy) interleaved with the response to the test dose.

OSL measurements were taken for 60 seconds with the blue LEDs at 125°C. OSL data were reduced by extracting net signals from the first 2.4 s of stimulation after subtraction of integrated signals from the last 9.6 s of measurement. Natural and regenerated signals were normalised to the subsequent test-dose response, and equivalent doses evaluated both for each disc, and for groups of discs by interpolation of saturating exponential fits to the dose response curves. A representative dose response curve for the lowermost sample from the Dhiarizos river section is shown in Fig. 4. Luminescence ages were calculated using standard microdosimetric models, 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 (Table 2).

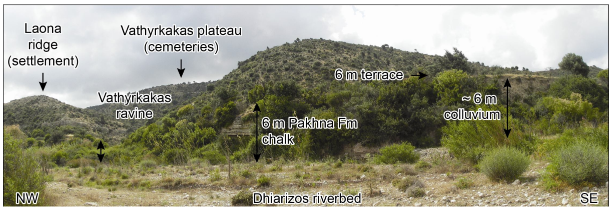

Figure 4. Photograph of the exit of the Vathyrkakas ravine, taken from a vantage position on the modern riverbed of the Dhiarizos river, illustrating the main geomorphological elements discussed in the text. Note, the relative positions of the 6 m+ fluvial terrace, and the 2 m+ knick point where the Argakin Vathin river meets the Dhiarizos river.

Table 2. Quartz SAR OSL age estimates

SUTL no.	no. of aliquots[a]	Weighted mean De / Gy	Age / ka	Calendar years	Archaeological/Geological Period
1327†	16 (16)	16.00 ± 7.91	13.11 ± 6.54	-	Late Pleistocene
1328	16 (7)	17.62 ± 2.31	12.02 ± 1.65	-	Late Pleistocene
1329†	16 (16)	5.38 ± 1.51	3.84 ± 1.12	1830 ± 1120 BC	Prehistoric Bronze Age
1330	16 (5)	2.96 ± 2.14	1.94 ± 1.41	AD 70 ± 1410	Early Roman*
2382	16 (7)	2.23 ± 0.02	2.20 ± 0.17	190 ± 170 BC	Hellenistic
2383	16 (6)	2.32 ± 0.02	2.36 ± 0.18	350 ± 180 BC	Cypro-Geometric to Archaic
2384	16 (8)	0.40 ± 0.09	0.46 ± 0.11	AD 1550 ± 110	Late Medieval, 'Venetian'
2014	16 (4)	20.22 ± 0.86	29.82 ± 2.11	-	Late Pleistocene
2017	16 (2)	22.13 ± 4.54	9.97 ± 2.08	-	Neolithic
2047	16 (2)	51.68 ± 1.59	66.40 ± 4.07	-	Late Pleistocene

To provide a preliminary chronology based on the profiling data, the dosimetry determined for the adjacent full OSL dating samples, taken from a few decimetres above or below the profiling samples, were used to calculate apparent age estimates. The close proximity of the full dating and profiling samples, and the uniformity of the dose rates justify this approach. The error on such age estimates may be large, but as the aim is to distinguish between events operating over the 10^{3-4} years and 10^{2-3} years, these are deemed acceptable.

RESULTS

Vasilikós sites

At the Márkou site, the stratigraphy is comprised of alternating layers of white-tan colluvial deposits (havara) – silty, powdery, deposits of clast-rich and clast-poor horizons, predominantly chalk, but with subordinate locally-derived lithics (e.g. calcarenites, cherts etc) – and grey-brown to brown-grey palaeosol horizons, with varying organic contents.

An anthropogenic colluvium (1.5 m thick) unconformably overlies the lower succession. Within the havara horizons, clast imbrication indicates a dominant westward direction to flow, into the axis of the valley.

The Vasilikós - Drapia sections contain similar sequences of alternating bands of havara and palaeosol horizons.

Given the fragmentary and dispersed nature of the outcrops an attempt was not made to correlate units between the sections: it is simply stated site 1 represents a proximal setting, whereas sites 2 and 3, distal settings.

The chronologies obtained for the sediment stratigraphies sampled at Márkou and Vasilikós are shown in Fig. 2. Whilst we recognise that these chronologies are based largely on apparent estimates obtained from the luminescence profiling data, with only a few quartz SAR ages, the data clearly indicate coherent internal stratigraphies. The Márkou sediments were deposited in the period 34.6 ± 1.6 to 17.2 ± 1.7 ka BP, whereas the sediments at Vasilikós are younger, spanning the period 8.4 ± 0.5 to ~ 3.3 ± 0.9 ka BP (based on weighted means of the combined quartz SAR OSL and profiling datasets). The strata in the Drapia section did not yield sufficient quartz for dating purposes. It is argued later that the sequences of inter-bedded palaeosols and havara deposits in the Vasilikós valley are sensitive archives of climate and environment change and, provide important information on local and regional environmental processes and conditions. Importantly, the data indicate that the sediment in each profile accumulated within different temporal periods: the first in the late Quaternary and the second within the anthropogene; indicating that slope processes were similar in both periods, and that in the later period, human activity in the region was not responsible for greater wastage.

Sousikou-Laona

The *Laona* ridge, and Vathyrkakas plateau, are a mature erosion surface of Early - Mid Pleistocene age (equivalent to F1; Table 1; Poole and Robertson, 1998; Kinnaird et al., 2011; located by the seaward red arrow on Fig. 1). The erosion surface forming the Vathyrkakas plateau can be traced south towards Kouklia, where it passes into an aggradation surface, on which there is an accumulation of matrix-supported boulder and pebble conglomerates (F2; Poole and Robertson, 1998).

The Vathyrkakas ravine is a narrow channel, incised into bedrock chalk and marl (Fig. 3). The base of the ravine hangs 2 m clear of the level of the Dhiarizos river bed (Fig. 3). To the southwest of the channel exit, there is a 6 m high cliff of chalk, which is capped by c. 1 m of colluvium (Fig. 3). It is possible that this 6 m+ surface is a relict terrace (of the Fanglomerate series, possibly equivalent to F3), albeit modified, and the ravine has cut down later to 2m+. The most recent incision of the Dhiarizos has removed the entire 2m+ terrace opposite the field and cut into the bedrock, but has not cut into the small 2m+ ravine exit.

Table 3. Prominent erosional surfaces, and associated sediments, in the vicinity of the Sousikou-*Laona* excavation.

Position	Location	Description	Elevation	Inferred age	References
N34°43.412′ E32°36.415′	Roadcut on the Kouklia-Archimandrita road	Marine Terrace (F0)	260 m	Late Pliocene	Poole and Robertson (1991, 1998); Poole (1992); Kinnaird (2008); Kinnaird et al. (2011)
N34°43.536′ E32°36.424′	*Laona* ridge	Fanglomerate (F1)	180 m	Latest Pliocene/Early Pleistocene	This study
N34°42.678′ E32°24.762′	Kouklia village	Fanglomerate (F1 cliff line?)	85 m	Latest Pliocene/Early Pleistocene	This study; Poole and Robertson (1991, 1998); Poole (1992)
N34°43.464′ E32°34.789′	Vathyrkakas Ravine	Fanglomerate (F2 or F3?)	variable	Mid to Late Pleistocene	This study
N34°43.464′ E32°34.789′	Mouth of Vathyrkakas Ravine	6m+ Fluvial Terrace	60 m	Mid to Late Pleistocene; earlier than the 2m+ terrace	This study
		2m+ Fluvial Terrace	54 m	Early Pleistocene; later than the 2m+ terrace	This study
N34°43.468′ E32°34.753′	Dhiarzos riverbed	Fluvial Terrace (F4)	~50 m	Modified in the Recent; see OSL results	This study; Poole and Robertson (1991, 1998); Poole (1992)

The Vathyrkakas plateau was incised by the proto-Aragin Vathin river in F2 or younger times (no later than the Mid Pleistocene), as the ravine intersects the regional F1 surface (Table 3). The proto-Aragin Vathin river must have been captured by the larger proto-Dhiarizos river between F2 and F3 times. The youngest erosional event in the vicinity of the Souskiou-*Laona* ridge is the incision of the Dhiarizos river to its present level, as the ravine essentially stands 2m+ proud of the main channel (equivalent to Poole and Robertson's F4 event). The quartz SAR OSL chronology established at site 1 provides a means to appraise the fluvial dynamics of the palaeo-Dhiarizos river: providing constraints on the flux of sediment passing through the system. Although the OSL chronology for the Sousikou section is disappointing in that errors on individual age estimates are large, reflecting wide equivalent dose distributions, the section still reveals much on our understanding of processes within the modern channel. Given the heterogeneity in equivalent dose estimates, which reflects the fact that this sediment encloses mixed age populations, the OSL data can only provide terminus post quem on the age of deposition. However, the data imply reworking of Quaternary deposits within the fluvial system, with only incomplete bleaching. Coupled with our landscape studies, this strengthens the argument that in the Quaternary deposits are being reworked and transported downstream, with only minor modification of the entrenched topography in the Holocene.

The chronology established for the sediments at the mouth of the Vathyrkakas ravine, is somewhat easier to interpret, spanning from the fourth to second century BC to the Ventian period (Table 2). The quartz OSL chronology indicates that material was being flushed through the ravine at a late stage, in response to variable climatic conditions in the Roman and Ventian periods.

Taken collectively, the evidence indicates that the Vathyrkakas ravine formed no later than the Early Pleistocene, over a prolonged period of 10^{4-5} years, with only minor modifications in the subsequent period. Saying this, it is clear that the slopes above the ravine have continued to evolve in the period 10^3 - 10^2 years (Peltenburg et al., 2006; Peltenburg, 2011), due to the positions of buildings on the eastern slope of the *Laona* ridge that would have originally extended outwards into the ravine from their present position.

Sensitivity-depth and dose-depth profiles obtained from a sedimentary stratigraphy at the most northern end of the excavation (Fig. 5), provides a preliminary chronology to evaluate the relationship between, apparently, interbedded anthropogenic and colluvial layers.

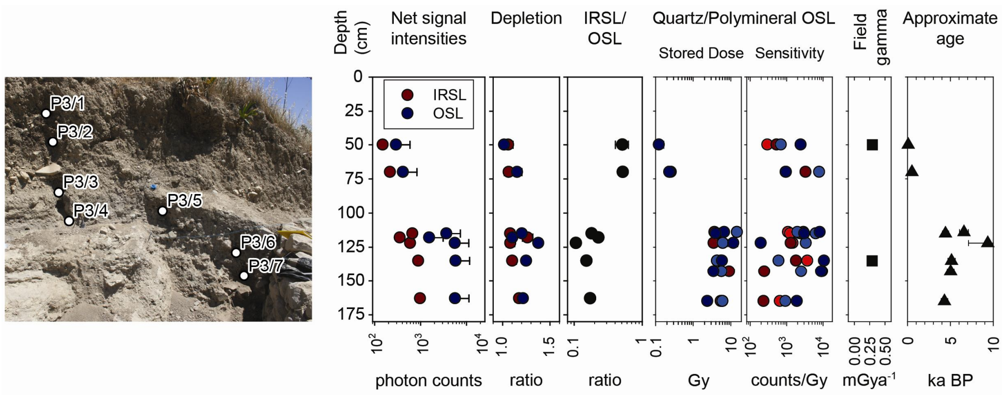

Figure 5. Net IRSL and OSL signal intensity-depth profiles, sensitivity-depth profiles and dose-depth profiles for a sediment stratigraphy examined at the Sousikou-*Laona* excavation. The profile taken at the extreme northern end of the excavation, encompasses occupational layers at the base, intercalated anthropogenic-colluvial horizons in the middle, and in the upper layers, colluvium.

The apparent synchronicity between the age of the lower colluvial units (3100 – 2300 BC), and occupation on the ridge (1st phase, 3300 - 3100 BC; 2nd phase, 2800-2700 BC; Peltenburg, 2011), lends credibility to a scenario in which human activity led to enhanced degradation of the slope. Intriguingly, quartz luminescence sensitivities increase with height, through the interbedded anthropogenic-colluvial layers (Fig. 5), which may indicate a change in quartz provenance (through aeolian processes?) with height in the sequence, or that quartz within the anthropogenic layers was modified by exogenic processes, such as heating in the use of landscape clearance, or in seasonal burning associated with agronomic activity.

DISCUSSION

The coupled landscape studies and chronological investigations in the Vasilikós and Dhiarizos valleys have clearly demonstrated that the present-day topography, and associated landforms, in each of the investigated areas, were initiated prior to the Early Pleistocene (with the first-order topography developed largely by the Mid Pleistocene), and that subsequently material has been 'cyclically' flushed through this 'inherited' drainage network, in response to variable climatic conditions over the last 10 ka BP. In previous studies, the authors (Robertson et al., 1991; Kinnaird, 2008; Kinnaird et al., 2011; Kinnaird and Robertson, 2012) have shown that the Plio-Pleistocene was a period in which the island experienced substantial uplift, entrenching the pre-Pliocene topography, and largely initiating the present fist-order topography. The emphasis of the previous studies were on constraining the rates of uplift, and discriminating between tectonic and eustatic triggers on Plio-Quaternary processes and landforms. In this earlier work, it was reasoned that the spatial and temporal distributions of the Plio-Quaternary landforms were such, that the dominant control on these deposits was tectonic uplift, and although, the impact of climatic change was considered, the temporal resolution of the dating methods employed was not sufficient for isolating and thus assessing, the climatic 'signal'.

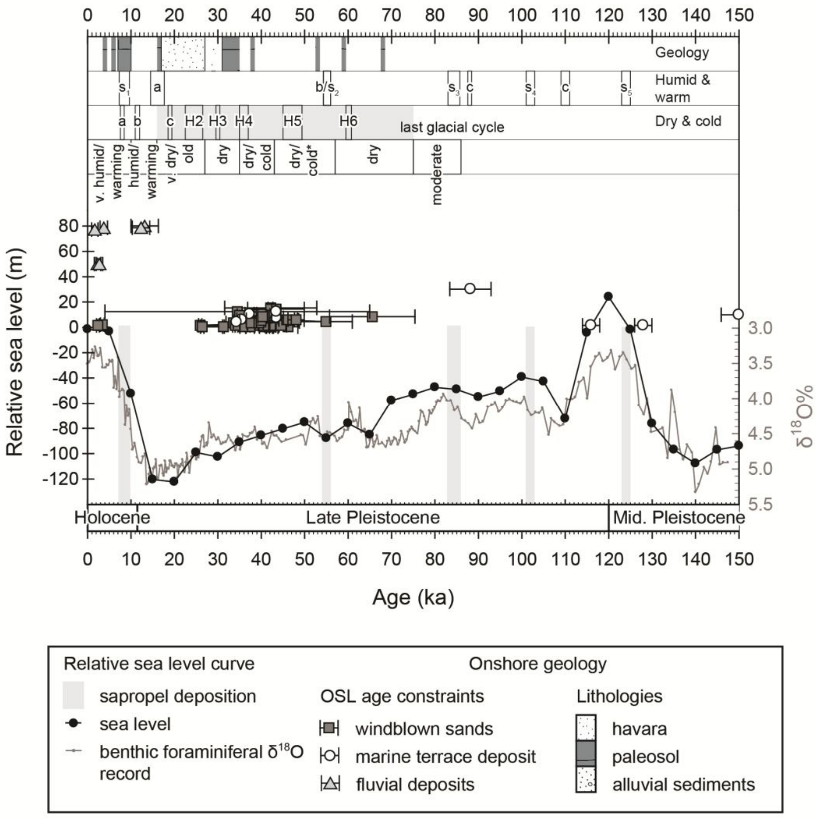

Figure 6. A compilation of the palaeo-environmental data available for the eastern Mediterrenean region, together with the eustatic sea level curve of Miller et al. (2005) and the benthic foraminiferal δ18O record from Pacific (Carnegie Ridge) core V19-V30. The preliminary chronology for terrestrial late Quaternary deposits in the Vasilikós and Dhiarizos river valleys are shown (this study, triangles), as are the published age constraints on late Quaternary littoral deposits from the coastal zone (recently reviewed in Harrison et al. 2012, squares/circles). References are as follows: sapropel chronology (labeled S1 - S5; Kroon et al. 1998, Langgut et al. 2011, Rossignol-Strick 1999), Heinrich event chronology (labelled H2 - H6; Langgut et al. 2011), palaeo-climatic reconstructions (Finné et al. 2011, Langgut et al. 2011). Abbreviations as follows: *dry & cold*: a = period of climatic deterioration marked by a reduction in pollen concentrations in marine cores (Langgut et al. 2011), b = Younger Dryas event, c = last glacial maximum; *humid & warm:* i = sapropel formation, ii = Bölling-Allerød episode, iii = known pluvial events (Langgut et al. 2011, Macklin et al. 2002)

The OSL chronologies presented in the Vasilikós and Dhiarizos valleys, provide a means to assess landscape processes operating over the timescale of 10^{4-5} and 10^{2-3} years, and therefore, discriminate between climatically driven changes in catchment hydrology, and anthropogenic-induced modifications. The Vasilikós and Dhiarizos alluvial sequences contains a proxy record of environmental conditions during the Early Pleistocene - Holocene; with a cyclic record of incision, erosion and deposition, forming a terraced landscape, and alluding to variable climatic conditions. Interestingly, the OSL constraints on the later history, albeit fragmentary in nature, indicate that river incision and aggradation was synchronously occurring throughout Cyprus, and the wider Mediterranean basin (over the last 200 ka; Fig. 6; Macklin et al., 2002). Fig. 6 is a compilation of the available palaeo-environmental information that is available for the wider eastern Mediterranean region, including information obtained from offshore marine cores (Kroon et al., 1998, Rossignol-Strick 1999, Langgut et al., 2011), archaeological and historical data (Finné et al., 2011), and ^{18}O isotope records (Orland et al., 2012). The sea-level record of Miller et al., (2005) is also shown, as the late Quaternary landforms on Cyprus are closely coupled with the interplay between sea-level change and tectonic uplift. Indeed, the lowermost fanglomerates (F4 and F3) in southern Cyprus have been correlated with littoral marine terraces formed at < 3 m and 8 -11 m respectively, dated at 116-130 ka and 185-192 ka (Poole et al., 1990).

In the Vasilikós valley, calcareous Quaternary colluvial deposits are spread widely, abutting the chalk cliffs, lining the valley margins, and mantling the valley floor. The occurrence of havara as slope debris, debris cones and as a surficial veneer attests to the different origins of havara. The bulk of the havara has a colluvial aspect, deposited during hillwash, rock fall and soil creep. These deposits must attest to wet and humid conditions, requiring extreme water-supply to form. In contrast, the palaeosols formed under more stable climatic conditions. Therefore, the havara-palaeosol successions, are a proxy for palaeo-environmental /-climatic change, and the chronologies obtained here provide, a first means of appraising early Holocene climatic fluctuations.

It has been argued previously that these deposits formed in response to specific conditions during known stadial/interstadial periods in the eastern Mediterranean, with the havara deposits deposited during periglacial conditions, and the palaeosols deposited during interstadial conditions. Schirmer (1998) reported radiocarbon ages from charcoal collected from the lower- and upper-most palaeosol horizons in the Márkou section of 32.0 ± 0.9 ka and 27.4 ± 1.6 ka, respectively (uncalibrated radiocarbon ages; middle Würmian, Fig. 3). Our extended chronology for the Vasilikós sections, suggests that the temporal duration of the havara-palaeosols successions is prolonged, extending back from the Holocene to the late Pleistocene. Intriguingly, the chronologies indicate the slope processes in both the late Quaternary, and the Anthropogene, were operating over similar timescales, and that human activity has not been responsible for greater degradation.

Our investigations in the Dhiarizos valley extend the palaeo-environmental/-climatic studies into the Anthropogene. In addition to illustrating that the present topography in this region was inherited from the Early Pleistocene, it has shown that material has been flushed through the inherited first-order topography, during wet periods, re-working and re-depositing the Early-Middle Pleistocene sediments. In the main channel, pronounced flooding, and mobilisation of sediment through the main channels, and its tributaries, dating to the Little Ice Age, largely obliterated the earlier records of alluviation. Historically, the eastern Mediterranean region experienced wetter conditions from 6000 to 5400 cal yrs BP (calibrated ^{14}C AMS ages; Finné et al., 2011), followed by a less wet period leading up to one of fully-fledged aridity from c. 4600 cal yrs BP to present (Finné et al., 2011), with occasional wetter conditions creating more benign climates at times e.g. during the Ventian and Frankish periods (1300 - 1400 AD; Deckers, 2005; Deckers, 2007).

This hypothesis is in line with previous landscape studies in the Dhiarizos watershed; Decker and co-authors (2005a,b; 2007) provide a preliminary chronology for the young alluvial fill of the Dhiarizos valley, at a number of localities within the watershed, on the basis of terminus post quem TL dating of sherds contained in a number of channel fills.

The age of the sediment in each section is thus provided by the age of the youngest archaeological shard it contains. Alluvial phases were identified in the late Roman to early Byzantine, and a second in the late Medieval - Ottoman.

CONCLUSIONS

- Although archaeological inspection might suggest that the Cyprus landscape is intensely degraded and eroded as a result of millennia of human occupation, the geological record, as indicated in the two case studies, suggests that the first-order topography as viewed today, has its origins in the Late Pliocene - Early Pleistocene.
- It is suggested that throughout the Late Pleistocene to Holocene interval sediment has been reworked, and, most recently, flushed through, an inherited drainage network, in response to variable climatic conditions in the last 10 ka.
- The temporal resolution of luminescence dating methods is ideal for differentiating between the relative impact of naturally, climatically-influenced and anthropogenic modifications of the first-order topography in the Vasilikós and Dhiarizos valleys.

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