A Neolithic palaeo-catena for the Xagħra Upper Coralline Limestone plateau of Gozo, Malta, and its implications for past soil development and land use

Charles French* (1), Sean Taylor (1), Rowan McLaughlin (2), Alan Cresswell (3), Tim Kinnaird (3, 4), David Sanderson (3), Simon Stoddart (1) and Caroline Malone (2)

(1) Department of Archaeology, University of Cambridge, Cambridge, CB2 3DZ, England
(2) Department of Archaeology, Queens University Belfast, Northern Ireland
(3) Scottish Universities Environmental Research Centre, East Kilbride, Scotland
(4) School of Earth and Environmental Sciences, University of St Andrews, Scotland

ABSTRACT

Geoarchaeological survey on the island of Gozo combined with test excavations and new chronometric dating of two Neolithic temple sites at Santa Verna and Ġgantija on the Xagħra plateau have revealed well preserved buried soils which tell a new story of soil development and change for the early-mid-Holocene period. Micromorphological analysis has suggested that the earlier Neolithic climax soil type was a thick, well-developed, humic and clay-enriched argillic brown Mediterranean soil. With human intervention on the Xagħra Upper Coralline Limestone plateau from at least the early 4th millennium BC, the trajectory of soil development quickly changed. Radical soil change was marked by the removal of scrub woodland, then consequent poorer organic status and soil thinning, and rubefication and calcification, no doubt exacerbated by Neolithic agricultural activities and a more general longer-term aridification trend. The beginnings of this transitional brown to red Mediterranean soil change process has been observed at Santa Verna temple by the early 4th millennium BC, and appears to be much further advanced by the time of the latter use of Ġgantija temple in the early-mid-3rd millennium BC. There is also evidence of attempts at amending these deteriorating soils during this period and into the 2nd millennium BC, a practice which probably underpinned the viability of later Neolithic agricultural society in the Maltese Islands. The changes observed ultimately resulted in the creation of the thin, xeric, red Mediterranean soils on the Coralline Limestone mesa plateaux which are typical of much of Gozo and Malta today.

Keywords: micromorphology, brown/red Mediterranean soils, argillic, calcification, rubefication, Ġgantija and Santa Verna temples

** Corresponding author: caif2@cam.ac.uk*

1. Introduction

Soil degradation and erosion in the islands of Malta and Gozo is regularly observed as a compelling and prevalent problem today and one that possibly has its origins in earlier prehistoric times (Blouet, 1997; Grima, 2004, 2008; Lang, 1960; Malone et al., 2009; Vella, 2003). Moreover, these islands appear to share many of the same soil characteristics and history of a continual struggle against aridification, dewatering and the intensification of agriculture associated with the creation of extensive terraced landscapes, just as occurred in many other parts of the southern Mediterranean area (Brandt and Thornes, 1996; Carroll et al., 2012; Sadori et al., 2013). As a corollary the development of the typical red Mediterranean soils or *terra rosa* on limestone substrates of this region (Bridges 1978; Kemp, 1986; Lang, 1960; van Andel et al., 1990; Yaalon, 1997) will also be investigated.

The geoarchaeological and palaeosol study reported on in this paper formed part of the ERC-funded *FRAGSUS* project (*Fragility and sustainability in restricted island environments: adaptation, cultural change and collapse in prehistory)* which is investigating fragility and sustainability in the Maltese islands during the fourth and third millennia BC under the direction of Professor Caroline Malone (Queen's University, Belfast) (www.qub.ac.uk/sites/FRAGSUS/). This enabled a new opportunity to elucidate the Holocene soil history of the island of Gozo and its associations with prehistoric land-use, especially the impacts of the first Neolithic farmers, and provide new land-use data with which to compare to other long-term records of soil processes and development in the southern Mediterranean region. Geoarchaeological survey, test excavations and soil sampling, and new radiocarbon and optically stimulated luminescence (OSL) dating all concentrated on the history of soil development of the Upper Coralline Limestone plateau of Xagħra and the associated Ramla and Marsalforn valleys in north-central Gozo (Fig. 1). In particular, new buried soil data has emerged from recent archaeological investigations of two Neolithic 'temple' sites, Santa Verna (Fig. 2) and Ġgantija (Fig. 4), as well as from several construction sites in the modern town of Xagħra on the same plateau and associated hand augering surveys around these sites and across the Ramla and Marsalforn valleys (Figs. 1, 8 and 11). This research project has provided a good glimpse into the changing soil and land-use history of the island of Gozo during the earlier-mid-Holocene period, and how it is reflected in the Maltese landscape of today.

2. Research goals

It has always been assumed that the seasonally dry and hot Mediterranean climate made the Maltese landscape quite marginal in agricultural terms (Schembri, 1997). As a consequence, it has also been presumed that terracing was adopted extensively from prehistoric times in Malta and Gozo to conserve soils and moisture, and create a better landscape for subsistence based agriculture (Sagona, 2015). Like many other parts of the Mediterranean, this landscape is believed to have been prone to deforestation, drought and soil erosion, combined with intensive human activity, and that this has been the case since Neolithic times (Bevan and Conolly, 2013; Brandt and Thornes, 1996; Djamali et al., 2013; Grima, 2008; Grove and Rackham, 2003; Hughes, 2011). The research reported on here aimed to examine these assumptions and test them using geoarchaeological approaches, both on- and off-site (French, 2015). This paper sets out the first detailed geoarchaeological and micromorphological study of two significant Neolithic palaeosol contexts from beneath the Santa Verna and Ġgantija Neolithic temple sites and the associated Marsalforn and Ramla valleys to either side of the Xagħra plateau on which these temple sites are situated on the island of Gozo.

The main objectives of the geoarchaeological work were to:
1) investigate the pre-Neolithic temple buried soil record on the Xagħra plateau;
2) create a well dated palaeo-catena model for the earlier-mid-Holocene land-use sequence of Gozo, ultimately for comparison with the adjacent larger island of Malta; and
3) establish if there is any correlation between observed soil properties and the activities of prehistoric people, especially the impacts of early agriculture and terracing, and/or long-term climate change.

3. Methodology

New test excavations at the Santa Verna and Ġgantija temple sites (Figs. 1-5) by the *FRAGSUS* project have revealed old land surfaces beneath mixed soil and/or cultural deposits with well preserved *in situ* palaeosols. These profiles were first discovered during relatively small-scale excavations by Evans in 1954 at Ġgantija (Evans 1971, 180-181) and Trump in 1961 at Santa Verna (Trump 1966, 19-20). These programmes of work were directed towards establishing a chronology for prehistoric developments on the islands, and the significance of the palaeosols was largely passed over at the time. In 2014 and 2015 a renewed programme of archaeological work was undertaken at these two sites, which were then extensively sampled for micromorphological, physical and multi-element geo-chemical analyses (Tables 1, 3 and 4). This was accompanied by a radiocarbon dating programme carried out on charred plant remains by the 14CHRONO Laboratory of Queen's University, Belfast, with the dates calibrated using the IntCal13 dataset (Reimer et al., 2013), and a limited selection of quartz optically stimulated luminescence (OSL), single aliquot regenerative sequence determinations from several terrace and valley fill profiles were provided by SUERC, University of Glasgow (Cresswell et al., 2017) (Table 2) based on the methodology of Wintle and Murray (2006) and Sanderson and Murphy (2010), with corrections made for the depth of overburden using the method of Prescott and Hutton (1994).

In total, 42 soil blocks from ten key soil profiles (Table 1) were prepared for thin section analysis (after Murphy, 1986; Courty et al., 1989) and described using the accepted terminology of Bullock et al. (1985), Stoops (2003) and Stoops et al. (2010) (Table 5). The micromorphological analysis will be the main focus of this paper. In addition, a suite of basic physical parameters (pH, loss-on-ignition and magnetic susceptibility) (Table 3) and multi-element ICP-AES analyses (Table 4) were carried out a series of small bulk samples (40) taken in conjunction with the micromorphological block samples (Avery and Bascomb, 1974; Clark, 1996, 99-117; French, 2015; Holliday and Gartner, 2007; Wilson et al., 2008). pH measurements were determined using a 10g to 25 ml ratio of <2mm air-dried soil to distilled water with an Hanna HI8314 pH metre. Determining loss-on-ignition followed the protocol of the Department of Geography, University of Cambridge, to record the percentages of calcium and carbon in the soil (www.geog.cam.ac.uk/facilities/laboratories/techniques/psd.html). For loss-on-ignition (*ibid.*), weighed sub-samples were heated to 105˚C for 6 hours to measure water content, then heated to 400 ˚C for 6 hours to measure carbohydrate content, then to 480 ˚C for 6 hours to measure total organic matter content, and finally heated to 950 ˚C for 6 hours to measure CO_2 content lost from $CaCO_3$ within the sediment

(Bengtsson and Ennell, 1986). The calcium carbonate content can then be calculated by stoichiometry (Boreham et al., 2011). A Malvern Mastersizer was used for the particle size analysis (Table 3) using the same Geography facilities at Cambridge. For magnetic susceptibility measurements a Bartington MS2B metre was used, giving mass specific calculations of magnetic susceptibility for weighed, $10cm^3$ subsamples (English Heritage, 2004, 27). Multi-element analyses using the 35-element aqua regis ICP-AES method were conducted at the ALS Global laboratory in Seville (www.alsglobal.com), and the elements exhibiting greater than trace amounts and/or are generally considered to be enhanced by human activities (cf. Wilson et al., 2008; Fleisher and Sulas, 2015) are tabulated in Table 4.

4. The study area and research context

4.1 The geology of Gozo

The hard rock sequence of Malta and Gozo comprises Lower Coralline Limestone at its base, which is succeeded by the Globigerina Limestone, Blue Clay and Greensand formations, with the Upper Coralline Limestone at the top (Oil Exploration Directorate, 1993; Pedley et al., 1976, 2002) (Fig. 1). Generally Gozo has a more varied geology than Malta, with many outcrops of Blue Clay, especially occurring in the valleys, and table-top plateau or mesas of weathered and eroded Upper Coralline Limestone. These formations essentially lie horizontally, but are displaced at intervals by faults, which form the river valleys and coastlines, and in turn control the weathering and erosion of the exposed rock layers. The homogeneous Globigerina Limestone varies in thickness from *ca*. 20-200m and is separated into three units (lower, middle and upper) by metre-thick conglomerates inbetween.

4.2 Santa Verna

The Late Neolithic temple now known as Santa Verna is situated on the southwestern side of Xagħra town, on rising ground near the edge of an Upper Coralline Limestone plateau, overlooking much of the island (Figs. 1-3). The temple itself consists of numerous megalithic blocks in the shape of two cruciform shaped interior spaces with a huge surrounding megalithic wall (Sagona 2015, 74ff) (Fig. 2). The hand auger survey on the Upper Coralline Limestone plateau around the temple (13 boreholes) revealed less than 50cm of reddish brown, fine sandy silt loam topsoil to the north of the temple, present in small-holder arable fields. To the south, this was even thinner with increasingly extensive patches of bare rock with open scrub pasture, mainly used for bird hunting today. East of the temple and dipping into the Weid Gunen Inrik valley, the soil profiles in the auger survey deepened quickly to as much as 100cm with some B horizon survival consisting of a well-structured, reddish brown silt loam to silty clay loam, before thinning again eastwards to *ca*. 10-45cm of modern ploughsoil, the area all being used for small-holder arable fields today.

Previous archaeological work reported by Ashby et al. (1913) and Trump (1966) at Santa Verna revealed *in situ* buried soils sealed beneath a series of temple floors and other deposits, although they were not studied using any archaeological science techniques. These strata were radiocarbon dated for the first time as part of the 2015 excavation, demonstrating that the megalithic 'temple' structure is among the earliest stone monuments found in the central Mediterranean, its construction beginning in the early 4th millennium BC, perhaps prior to the construction of the nearby well-known Ġgantija temple (Table 2). The megalithic structure was significantly later at about 3800 cal BC than the *in situ* soils, which were associated with the earliest phase of agriculture in Gozo/Malta in the mid-late 6th millennium BC, according to three radiocarbon dates on charred plant remains (5500 to 5320 cal BC, UBA-31042, 6412±44BP; 5290 to 5000 cal BC, UBA-31043, 6181±40BP; 5300 to 5070 cal BC, UBA-31044, 6239±37BP; all at 2-sigma) (T.R. McClaughlin, pers. comm.). The sequence of temple construction was particularly well exemplified in Trench E, as well as in the re-excavated sondages of Ashby and Trump (Fig. 3). The base of the Ashby Sondage revealed a well preserved, *ca*. 45cm thick palaeosol. This was comprised of a *ca*. 15cm thick organic Ah silt loam horizon over a reddish brown silt loam B horizon of about 30cm in thickness. A similar occurrence was also revealed in the Trump Cut 55 about 3m to the north and in the trial trench (B) which was cut some 30m to the northeast of the temple site. All four of these buried soil profile exposures were sampled for soil micromorphological analysis, physical characterisation and multi-element analyses (Tables 3 and 4).

4.3 Ġgantija temple and surroundings

The upper part of the Xagħra plateau comprises three natural terrace steps in the Upper Coralline Limestone rising over a slope height of about 30 metres. Ġgantija temple is located on the middle of these three terraces, approximately 1km west of Santa Verna (Figs. 1 and 4), and adjacent to a probable former fault line with a freshwater spring (Sagona 2015, 79; Ruffell et al., in press.). Although indicators of activity from virtually every phase of prehistory can be found in this locality, the recently excavated outer parts of the Ġgantija temple date to about 2500-2350 cal BC (Table 2), which in the Maltese Islands is known as the Tarxien period (Sagona, 2015, 67ff).

Ġgantija temple is much better-preserved above ground than Santa Verna and comprises two adjoining five-roomed apsidal buildings made from massive Coralline Limestone blocks, beginning about 3700 BC and re-worked through various phases to about 2350 BC (Evans 1971; T.R. McClaughlin, pers. comm.) (Fig. 4; Table 2). The temple sits upon level ground, which has in recent years been further built-up and retained by a stone wall. Augering survey around the southern fringe of the site just outside this retaining platform wall (Fig. 1) mainly produced thin soils with no signs of buried soils or deep agricultural terrace fills, except in one location. This was a small walled triangular field in the southwestern corner of the Ġgantija platform, where a well preserved buried soil was found about 50-70cm beneath the modern ground surface. In 2014 and 2015 there was the opportunity to excavate sizable test pits on either side of the present day platform: one to the southwest (TP1), and a larger unit to the southeast, where a former shop and more recently a WC building for visitors to the site had been recently demolished (WC Trench) (Figs. 4 and 5). Both trenches were excavated to the upper surface of the Upper Coralline Limestone bedrock.

Test Pit 1 on the southern side of the temple revealed two large, upright, sub-rectangular limestone blocks which may be *in situ* and several more smaller blocks just below the ploughsoil surface which may be part of temple collapse (Figs. 4 and 5). Beneath, there was *ca*. 80cm of heavily rooted, greyish brown silt loam with a mixture of limestone gravel pebbles and abundant artefacts. This horizon is indicative of an agricultural terrace soil but which contains artefactual material contemporary with the later Neolithic use of the temple (C. Malone, pers. comm.). The base of this terrace soil gave an imprecise OSL date of 760+/-920 BC (Table 2; 2.78+/-0.92 years/ka), but most probably is indicative of a later prehistoric age. Then there was a clear contact with an *in situ* buried soil, ranging between *ca*. 80 and 130cm in depth. This soil comprised three horizons: an upper dark brown silt loam (at 80-90cm), a brown silt (90-120cm), a dark reddish brown fine sandy/silt loam (120-125/130cm), all developed on the weathered Upper Coralline Limestone bedrock (at 125/130+cm) (Fig. 5). This profile was sampled for physical, micromorphological and geochemical analyses, and OSL profiling and dating.

Abundant artefacts, primarily Neolithic pottery sherds with some bone and lithics continued to be present down-profile to the base of this soil. Their abundance certainly suggests considerable use of this area immediately outside the temple during the Tarxien or late Neolithic period (*ca*. 2500-2350 BC), and corroborates the surface information from the Cambridge Gozo survey for later Neolithic occupation in the vicinity (Boyle, 2014; Malone et al., 2009). The OSL dates provide corroboration of this *in situ* early Holocene soil which was forming from at least 8770+/-680 BC, with its upper surface buried after 1140+/-250 BC (Table 2; 10.79+/-0.68 and 3.16+/-0.25 years/ka).

In the WC Trench on the eastern side of the temple, a similar but more complicated sequence was revealed (Figs. 4 and 5). Beneath terrace soil make-up, stone-wall collapse and perhaps the construction of a stepped stone entranceway ramp to the temple, there was a well preserved sequence of midden deposits overlying an intact and complete buried soil sequence. A new radiocarbon date of 2580-2300 cal BC (3962+/-50 BP; UBA-33707) from wood charcoal recovered from the *in situ* soil beneath the stone ramp is indicative of the mid-later-3rd millennium BC, equating with the associated late Neolithic pottery of the Tarxien period (Sagona, 2015, 67ff) (Table 2).

The buried soil in WC Trench was *ca*. 35-45cm in thickness and consists of a lower, reddish brown silty clay loam B horizon with an organic silt loam A horizon above (Fig. 5). The incorporation of the artefact assemblage throughout the profile, albeit with much lesser quantities recovered in the lower half of the profile, suggests that it has undergone considerable anthropogenic additions and soil faunal mixing in the past. Above this soil there is a series of discontinuous lenses of calcitic ash, fine pea-grit gravel and humified/charcoal rich ‘soot’ over a thickness of about 10cm (contexts 1004, 1042, 1041 and 1040) which are indicative of a series of thin dumps or accumulations of settlement-derived debris on it. These in turn are overlain by two major phases of silt loam soil accumulation (contexts 1016 and 1015) which contain very large quantities of Tarxien-period pottery and bone. A wide area of large, collapsed and broken limestone blocks then seals this soil/midden sequence from further disturbance, which could be related to later Neolithic and subsequent modifications of the temple site. This profile sequence was sampled for physical, micromorphological and multi-element analyses (Table 1).

4.4 Xagħra town

As several new houses were under construction in Xagħra town with deep basement areas being excavated into the top of the Upper Coralline Limestone plateau whilst fieldwork was underway, there was the opportunistic chance of observing some relatively well preserved buried soil profiles in the modern town (Figs. 1 and 7). In three instances, there were thick (*ca*. 35-80cm), strongly reddened and structurally well-developed soils observed, all developed directly on the limestone bedrock and also in vertical weathering fissures into this bedrock. These soils were spot sampled for comparative micromorphological analysis.

4.5 The Ramla and Marsalforn valleys augering survey

A combination of hand augering and recording exposed valley profiles, followed up by targeted sampling for physical, micromorphological and geochemical analyses, and OSL profiling (Cresswell et al., 2017) and dating (Table 1) provided potential linkages between the soil changes observed on the Upper Coralline Limestone Xagħra plateau and the associated Marsalforn and Ramla valleys. Several borehole transects (56 boreholes) were made from the Ġgantija Neolithic temple site southeast/northeastwards across the Ramla valley, and from Santa Verna temple north across the Xagħra plateau and westwards across the Marsalforn valley (20 boreholes) (Fig. 1).

The upper part and mid/lower slopes of the Ramla valley are dominated by grey silty clay loam soils up to *ca*. 1.2m in thickness on the Blue Clay geology. These are essentially single horizon ploughsoils, often part saturated and gleyed below a depth of *ca*. 50-60cm. As the valley opens out and shallows towards the sea to the north, flat lower plateau tongues of land emerge on Globigerina Limestone. These have a very characteristic calcitic, fine sandy/silt loam soil developed on them, almost like a loessic soil, generally <50-60cm in thickness. This area is dominated by terrace agriculture and spring-heads and modern ponds, with historical evidence to suggest that the terrace field system has been in existence since at least the mid-16th century AD (Blouet, 1963; Wettinger, 1981, 2011).

To the west in the Marsalforn valley, there were ubiquitous terraces, regularly composed of thick (1-4m) silty clay hillwash accumulations, often with hints of possible standstill horizons present. An erosion cut profile in the middle Marsalforn valley, opposite Ta'Manea in Weid ir-Rigu (Profile 627; N 36 03.472/ E 014 14.946) was cut back and sampled for physical, multi-element and micromorphological analyses and OSL profiling/dating (Fig. 9). This profile comprised *ca*. 3.7m of rubbly fine sandy/silt loam which was interrupted by two incipient buried soil horizons at *ca*. 1.75-2.10 and 2.70-2.85m down-profile. A series of 10 small bulk samples were taken for OSL profiling from 1.75-3.25m, and three OSL tube samples at 1.75, 2.65 and 3.2m down-profile. OSL profiling suggested that this profile represented an age-related gradual accumulation of hillwash-type sediment (Cresswell et al., 2017). OSL dating suggests that this profile was aggrading from about 1500 BC throughout later prehistoric times (Table 2; 3.58+/-0.24 to 2.78+/-0.92 years/ka).

To the southeast-northeast in the Ramla valley, an erosion cut profile in the lower Ramla valley about 200m inland from Ramla Bay (Profile 627; N 36 03.442/E 014 17.045) was cut back and sampled for physical, soil micromorphological and multi-element analyses and OSL profiling and dating (Fig. 9). This profile is comprised of a series of alternating horizons of calcitic silt loam and coarse sand/pebble horizons, with the whole profile generally fining upwards, over a depth of *ca*. 1.4m. A series of 11 small bulk samples were taken from the finer silt loam horizons and three tubes taken for OSL dating at 15, 62 and 103cm down-profile. The latter sample loci were also sampled for micromorphological analysis. OSL profiling suggested that aggradation had occurred over time with at least two clear breaks, suggesting palaeo-surfaces of some kind at *ca*. 46cm and 115cm, potentially indicative of changes in erosion processes from alternating fast/slow to a much slower aggradational dynamic

(Cresswell et al., 2017). The profiles indicate the parts of the sedimentary sequence which are likely to have been re-deposited without the luminescence signals being re-set at deposition. Moreover, the ratio of net signal intensities between the upper (those not affected by recent soil turnover) and lower units, implies that the temporal range represented by these units may be relatively short. OSL dating suggests that this valley floor fill sequence is ostensibly of the late 19th and early 20th centuries (Table 2; 0.17+/-0.01 years/ka).

5. Results

The results described below will concentrate on the physical and elemental characterisation and micromorphological analysis of the buried soils encountered at the Santa Verna and Ġgantija Neolithic temple sites, as well as those sampled on three modern construction sites in Xagħra town, and two valley fill profiles to the west and east in the associated Marsalforn and Ramla valleys respectively.

5.1 Physical and elemental characterisation of the buried soils (Tables 3 and 4)

pH values at Ġgantija were all alkaline (ranging from 7.3 to 8.2) (Table 3). The total organic matter content is a reasonable *ca*. 3.5-5.3% in the buried soils, better than the modern topsoil at *ca*. 3.4%, with a range of values in the archaeological deposits above the buried soils of *ca*. 2.1-3.2% (Table 3). There is a significant calcium carbonate component throughout, ranging in frequency from *ca*. 33-78% (Table 3), a feature which is reflected in the ubiquitous micrite component visible in thin section (see below). In terms of the particle size analysis, the silt (*ca*. 17-80%) and quartz sand (*ca*. 5-78%) fractions generally predominate, with reasonable amounts of clay, increasing with depth in the buried soil in Test Pit 1 (5.44-14.21%), but very low proportions of clay (<0.5%) in the buried soil in the WC Trench (Table 3). In particular the terrace soil in Test Pit 1 has a very high silt content (82.36%) as does the context 1004 horizon that accumulated on the upper surface of the buried soil in the WC Trench (80.11%) (Table 3; Fig. 5), possibly indicative of dry, open soils and wind-blow effects.

Most of the multi-element values were low and/or unremarkable, although phosphorus (P) was however very enhanced in every horizon, especially in the buried soil in Test

Pit 1, as were the calcium (Ca) and strontium values (Sr) (Table 4). Phosphorus values in Test Pit 1 ranged from 2200 ppm at the base of the soil to >10,000 ppm in the upper 20cm of this soil. Strontium values were also relatively enhanced ranging from *ca*. 172-380ppm (Table 4). The enhancement of these two elements suggests large additions of organic material and household refuse to the soil (Entwistle et al., 1998; Holliday and Gartner, 2007; Wilson et al., 2008), coincident with the substantial quantities of fragmentary animal bone and Tarxien-period pottery recovered during the excavation. Similarly in the WC Trench, the buried soil and especially the multiple horizons of accumulating soil and archaeological debris above gave very high P values, ranging from 5010 to >10000ppm along with enhanced strontium values (*ca*. 238-322ppm) (Table 4). Likewise the magnetic susceptibility values were either very enhanced or low (Table 3), especially in the horizons dominated by archaeological material that had built-up on the buried soil. This suite of high values probably reflects the amount of organic and fire-related settlement debris contained within these deposits (Allen and Macphail, 1987; Clark, 1996, 109ff; Fassbinder, 2016, 502). Calcium and calcium carbonate values were also very high (Tables 3 and 4), which complements the enhanced phosphorus and strontium values to indicate the strong influence of midden-type refuse and hearth rake-out (Entwistle et al., 1998), but may equally reflect weathering and solution from the overlying limestone blocks of the collapsed temple structure above and the large amounts of secondary calcium carbonate observed in the micromorphological analysis of the buried soils at Ġgantija.

At Santa Verna, pH values from the buried soils are very alkaline (ranging from 8.5-8.92) and the magnetic susceptibility values were generally low, except for the lower fill of the pit in Trump Cut 55 (sample 3/4) (Table 3). This probably also reflects the amount of organic and fire-related settlement debris contained within this fill deposit. The total organic matter content is a reasonable *ca*. 4.1-6.5% in the buried soils, better than the modern topsoil at *ca*. 3.4% (Table 3). There is a strong calcium carbonate component throughout, ranging from *ca*. 8-64% (Table 3), but this is generally lower than the values observed in the Ggantija soil sequence, especially in the base of the buried soil. The particle size analysis results indicate that the buried soils tend to be dominated by the silt fraction (*ca*. 46-76%) but with a strong but variable quartz sand component (*ca*. 10-52%), with the clay fraction ranging between *ca*. 5 and 15% (Table 3). The higher clay component in the buried soils as compared to those at Ggantija is reflected in the well organised clay fraction observed in thin section in the basal horizon of the buried soil (see below).

In the multi-element analysis, the upper parts of the soil profiles were notably all moderately to highly enhanced with phosphorus and strontium values (Table 4). Phosphorus values varied from 900 to >10000ppm, with the Trench E profile (6850ppm at base to 9250ppm) and lower pit fill in Trump Cut 55 (>10000ppm) very enhanced, with relatively enhanced strontium values varying between 53 and 361 ppm. These elements suggest that the upper horizon of the soils and the earthen temple floors were receiving substantial amounts of organic settlement waste material prior to burial (Entwistle et al., 1998; Wilson et al., 2008). Although calcium values were often of a similar range to those at Ġgantija, the range of values in the pre-temple buried soils (in the Ashby Sondage and Trump Cut 55) were much less (ranging from 1.4-8.4% with higher and lower values in the upper and lower samples, respectively) (Table 4).

5.2 Soil micromorphology of the buried soils at Santa Verna (Table 5; Fig. 3)

From the borehole transect and Trench B to the north/northeast of the Santa Verna temple site (Figs. 1 and 2), there was an extensive area of well preserved buried soil of variable thickness present beneath *ca*. 40cm of gravelly fine sandy silt loam ploughsoil. In all other directions surrounding the temple, the auger survey revealed that the land surface is either severely denuded with large areas of bare exposed areas of Upper Coralline Limestone present, or in places supporting a thin (<15cm thick), single horizon turf over a micritic, fine sandy silt loam A horizon directly on the limestone bedrock.

The buried soil revealed in Trench B outside of the temple exhibited three horizons in thin section (Figs. 3 and 6). The uppermost horizon (sample 1/1) was a pellety to aggregated, strongly reddened, gravelly silty clay (Fig. 6a). There is a dust of very fine organic matter/charcoal as well as about 10-20% micrite (or silt-sized calcium carbonate), and common sesquioxide nodules throughout the groundmass. The middle horizon (sample 1/2) was completely dominated by micritic calcium carbonate with *ca.* 30% as small aggregates of the same reddish brown silty clay fabric present in upper sample. There was a similar dust of very fine organic matter/charcoal throughout. The lowermost horizon (samples 1/3 and 1/4) was composed of a weak to moderately developed, small blocky, dusty (or silty) clay loam with very abundant, moderately birefringent, pure to dusty clay in speckles and striae throughout the groundmass (Fig. 6b).

The aggregated or excremental and reddened fabric of the uppermost buried soil horizon suggests that it is the lower A horizon of a very disturbed soil that has been subject to much physical mixing, bioturbation, oxidation, illuviation and rubefication processes. In particular, the presence of common micritic calcium carbonate suggests considerable evapo-transpiration leading to the secondary formation of micritic calcium carbonate. The calcium carbonate component is derived from the weathering and dissolution of the calcareous limestone parent material which is not completely leached out of the profile due to the low moisture regime, a feature which is widely characteristic of soils in semi-arid climates (Durand et al., 2010; Yaalon, 1983). Importantly, its presence implies that it was probably a dry, open and de-vegetated former topsoil.

The middle horizon of the buried soil in Trench B is dominated by abundant secondary calcium carbonate and silty clay soil aggregates. This suggests severe physical and soil faunal mixing leading to considerable aeration and oxidation. This horizon is essentially acting as a depleted, calcified and replaced, eluvial upper B or Eb horizon, but with the A horizon silty clay fabric aggregates suggestive of physical mixing processes at work.

The lowermost horizon of the same buried soil is dominated by translocated, striated pure to dusty clay indicative of an argillic or Bt horizon of a well-developed brown Mediterranean soil (Bridges, 1978, 69; Fedoroff, 1997). There are also a few discontinuous linings of the voids with micrite, indicating secondary calcification processes in this soil. The whole profile, and especially the lowermost horizon, is also becoming very reddened or rubified. This process involves iron compounds which are produced from the weathering of minerals including iron oxides and hydroxides precipitating as poorly crystalline ferrihydrites or haematite, which then coat the silt/sand grains and clays (Lindbo et al., 2010; Yaalon, 1997). This feature is associated with alternate periods of wetting/eluviation/leaching and long summer droughts

(Bridges, 1978, 33; Duchaufour, 1982; Catt, 1990; Clark, 1996, 100; Lelong and Souchier, 1982; Lindbo et al., 2010; Stoops and Marcelino, 2010).

The sesquioxide nodules in the upper horizon of this soil (Fig. 6a) have probably formed through cheluviation as organo-metallic compounds associated with humic material from the root complex combining with strong iron staining (and aluminium, magnesium and silica) and moving down-profile through eluviation under weakly acidic and/or redoximorphic conditions (Wilson and Righi, 2010). The biodegradational processes may be caused by a number of factors such as cool and humid climatic conditions, seasonal sub-surface groundwater, acid producing vegetation, quartz-rich and base cation depleted parent materials, or a combination of two or more of these factors (*ibid*.). Although one would not expect some of these conditions to necessarily exist on the limestone bedrock here, nonetheless the pollen analysis of the Santa Verna (and Ggantija) palaeosol suggests a damp, scrubby steppe habitat of pine, juniper, *Erica* and ferns, as well as the presence of aquatic organisms and particularly phytoplankton in the buried soil points to the presence of standing water bodies and an acidic flora in the immediate vicinity (C.O. Hunt, pers. comm.). These conditions may well have been conducive to creating these sesquioxide nodules in the former lower A horizon of the Santa Verna palaeosol.

In the main excavations within the temple, a series of samples were taken from the *ca*. 15 to 60cm in thick buried soils present beneath Neolithic earthen floors within the temple complex in Trench E (Profile 4), the Ashby Sondage (Profile 2) and Trump Cut 55 (Profile 3) (Fig. 3). In Trench E just inside the main surviving arc of upright megaliths, the buried soil (sample 4/3) was composed of a pellety to small aggregated, reddish brown silty clay loam with common, birefringent, pure to dusty clay striations throughout the groundmass, as well as common very fine organic/charred punctuations and common sesquioxide nodules and rare occurrences of very small burnt bone fragments. This points to a very disturbed and bioturbated, reddened and clay enriched B horizon soil, essentially similar in structure and fabric to that observed outside the temple in Trench B. No upper, organic Ah horizon was present, probably suggesting truncation associated with the act of temple construction. .

Five meters further north in the Ashby Sondage (Profile 2) (Ashby et al., 1913), an earthen floor and limestone rubble horizon sealed a *ca*. 45cm thick *in situ* buried soil composed of two horizons (Fig. 3). The upper horizon (*ca.* 15cm thick; sample 2/1) was an heterogeneous, pellety mixture of mainly micritic calcium carbonate with abundant fine to very fine charcoal fragments and fine aggregates of orangey brown silty clay, with the occasional pot and bone fragment present. The lower horizon (20cm thick; samples 2/2 and 2/3) was predominantly composed of a striated, birefringent silty clay with strong reddening and only minor (<5%) micritc calcium carbonate present. This horizon exhibited an irregular small blocky structure defined by fine channels, and contained a fine organic/charcoal dust throughout. These features suggest that this is probably the base of a calcitic lower A horizon mixed with fine anthropogenic debris over the relatively undisturbed clay-enriched and well developed argillic Bt horizon of a buried soil, essentially similar to the other pre-temple buried soils.

In the adjacent Trump Cut 55 (Profile 3), there was a well preserved buried soil (samples 3/1 and 3/2) about 55cm thick present beneath a hard-packed earthen floor (Fig. 3). In contrast to the soil present in the Ashby Sondage (Profile 2), this buried soil exhibited a blocky to columnar blocky with a micro-aggregated microstructure, but exhibited a similar silty clay fabric strongly reddened with iron oxides and hydroxides with a dust of organic matter and very fine charcoal throughout. With depth this soil became denser and more clay enriched with a well-developed striated to reticulate and birefringent, pure to dusty clay groundmass, just as in the base of the buried soil in Trench B. Although these reddened clays could simply be relict in origin (Davidson, 1980; Fedoroff, 1997) and the result of the long-term weathering of the limestone bedrock material (Catt, 1990), the well organised, reticulate, gold to reddish-yellow, pure to dusty clay aspect of the groundmass is more indicative of an illuvial clay-enriched Bt or argillic horizon developed in the base of an *in situ* buried soil (Bullock and Murphy, 1979; Fedoroff, 1968, 1997; Kuhn et al., 2010). This argillic soil is the most well-developed of all the buried soil profiles observed in pre-Neolithic contexts at Santa Verna and Ġgantija.

It is clear that Profiles 2 and 3 have not suffered as severe disruption, mixing and calcification as the other buried soils encountered here and at nearby Ġgantija (see below). Significantly, this soil is indicative of an earlier, well-developed and less disturbed soil type, more akin to a brown argillic Mediterranean soil associated with more moist and well vegetated conditions (Bridges, 1978, 68-9). Nonetheless, this soil is just beginning to be disturbed and opened up, as testified to by the minor but increasing secondary calcium carbonate formation and the fine organic and micro-charcoal dust throughout its fabric. This soil type change from a well structured and clay enriched argillic brown soil (or orthic luvisol) to a calcitic reddish brown to red Mediterranean soil (chromic luvisol) (Bridges, 1978, 68-9) would appear to be beginning just prior to the construction of the temple at Santa Verna (from *ca*. 3800 cal BC), a process that was interrupted by this soil being sealed by the sequence of temple floors above.

5.3 Soil micromorphology of the buried soils at Ġgantija (Table 4; Figs. 5 and 6)

In Test Pit 1 on the southern side of Ġgantija temple, a series of five contiguous blocks were taken through the *ca*. 36-65cm thick buried soil beneath *ca*. 80cm of later terrace deposits (Figs. 1 and 5). There were two horizons evident. The basal two-thirds of the buried soil (samples 23 and 24) is a calcitic, fine sandy/silty clay loam with a weakly developed blocky structure and a pellety to small aggregated micro-structure (Fig. 6c). Fine organic matter, charcoal and shell are commonly present throughout, as are minor occurrences of bone fragments. There is a generally moderate reddening with iron oxides and hydroxides throughout the dusty or silty clay groundmass, as well as aggregates of strongly iron stained clay. There are few if any illuvial clay or dusty clay coatings in the voids or of the grains and/or clay striae in the groundmass, rather non-birefringent dusty clay is only present as the groundmass. In addition, there are some partial to complete infills of the voids with micritic to amorphous calcium carbonate and very fine organic matter punctuations (Fig. 6c), which is becoming increasingly prevalent towards the upper part of the buried soil.

The upper one-third of the buried soil (samples 25 and 26) is becoming more dominated by micritic calcium carbonate, humic brown staining, other abundant fragments of bone, organic matter and fine charcoal, with included aggregates of herbivore dung and red clay soil. In particular, sample 26 is a very dark brown, humic and amorphous sesquioxide stained, very fine sandy clay loam soil with common interconnected vughs between an aggregated structure (Fig. 6d).

The *ca*. 80cm of terrace soil above (samples 27 and 28) is a pellety to aggregated sandy loam with about 20% fine gravel-size limestone rubble throughout. It also contains minor micrite and <20% dusty clay in the groundmass, with minor amounts of fine charcoal, bone and shell fragments. There is weak to moderate reddening of the groundmass with iron oxides and hydroxides. The soil fabric becomes increasingly humic and stained dark brown up-profile.

Both the terrace soil and the palaeosol beneath essentially exhibit similar soil fabrics, although the terrace make-up is more humic, aggregated and very artefact-rich with common fine bone and charcoal fragments. These features suggest the incorporation and comminution of organic midden waste in this terrace soil. The buried soil beneath exhibits two horizons: an upper, aggregated, very dark brown humic organic Ah horizon, and a B horizon below composed of a mixture of fine sandy clay loam and micritic calcium carbonate. Micrite is common throughout the groundmass, and especially lining and filling in the voids. There is a slight increase in dusty or silty clay content with depth, and an associated better small blocky structural development. Pot/bone/charcoal fragments decline in presence with depth, but are always present. Thus, it appears that there is a complete Ah/Bw profile of a cambisol type of palaeosol present (after Bridges, 1978, 58), although it is not well-developed and its upper half is considerably mixed.

This palaeosol has undergone some pedogenesis, but there is little evidence of clay illuviation. Instead it is characterised by the predominant secondary formation of calcium carbonate and rubefication with iron oxides and hydroxides, as well as the incorporation of fine anthropogenic debris (mainly fine charcoal and bone fragments) through soil mixing processes by the soil fauna. Thus this soil has changed from being a relatively stable and structured soil to one that is more open and disturbed such that its development was interrupted and it became increasingly affected by drying out, evapotranspiration and secondary rubefication and calcification.

The ubiquitious fine to coarse artefact inclusions are indicative of deliberate anthropogenic inputs to this soil and considerable soil mixing processes at work. These actions added organic status and friability to this soil, effectively creating an ‘amended soil' more suitable for agricultural use (Simpson, 1998; Simpson et al., 2006). This suggests the deliberate creation of a thickened, enhanced soil adjacent to the southwestern part of Ġgantija temple by the mid-2nd millennium BC if not earlier. There is a similar occurrence recorded in the WC Trench, but possibly earlier and of mid-3rd millennium BC date (see below).

The buried soil (samples 3/3, 3/6, 3/7 and 3/8) exposed in the base of the WC Trench profile on the east side of Ġgantija temple (Figs. 4 and 5) is a pellety to finely aggregated, micritic, fine sandy clay loam (Fig. 6f) with an even mix of fine gravel-sized limestone pebbles (<1.5cm). The groundmass is dominated by interconnected vughs and non-birefringent dusty clay, with moderate staining with iron oxides and hydroxides, and a sizeable silt component. There is also a common presence of very fine organic/charcoal punctuations throughout. Moving up-profile, this soil becomes more humic with increasing amounts of included very fine anthropogenic debris (Fig. 6e).

Immediately above the apparent upper contact of the buried soil there was a *ca*. 4cm thick horizon of calcitic fine sand, then *ca*. 6cm of a calcitic sandy loam soil, then *ca*. 4.5cm of calcitic fine sand above, a fine limestone gravel horizon *ca*. 4cm thick (contexts 1004, 1040-42), and finally two overlying thick (*ca*. 45cm) soil horizons (contexts 1016 and 1015) (Fig. 5). All of these horizons contained abundant Tarxien or later Neolithic pottery sherds (Sagona, 2015, 67), and animal bone fragments, as well as up to 20% fine limestone gravel and 10-20% fine organic and charcoal punctuations. This alternating soil/fine gravel repeated sequence is suggestive of a cumulative stop/start build-up of soil with dumped anthropogenic debris interrupted by thin coarser weathered surfaces with possibly some localised rainsplash erosion contributing. It is suggestive of an open, accumulating ground surface, probably associated with the large upright Coralline stones located immediately to the north of this sample sequence.

Thus the buried soil In the WC Trench is a very bioturbated, organic Ah over a poorly developed weathered, moderately rubified, Bw horizon. This soil has been much affected by soil faunal mixing processes and the ubiquitous formation of secondary calcium carbonate throughout. The ubiquitous silt component also suggests a considerable wind-blown component, probably from fine, dry unconsolidated soil surfaces in the vicinity (Yaalon and Ganor, 1973). Subsequently the buried Ah horizon has been deliberately built up in several episodes of deposition through the addition of a similar soil material containing abundant pottery, bone and organic matter. As was evident in the TP1 sequence, the multiple overlying horizons present above the buried soil in the WC Trench suggest the deliberate thickening and enhancement of the underlying soil with settlement-related refuse, possibly as an early form of soil amendment and perhaps even an early form of terracing. All indications are that this occurred within the later Neolithic period of the mid-later 3rd millennium BC.

5.5 Soil micromorphology from construction sites in Xagħra town (Table 5; Fig. 7)

The palaeosols observed in several construction site localities on the top of the Coralline Limestone plateau occupied by the town of Xagħra exhibited two distinct alkaline horizons (Fig. 7, left; Table 3). The lower horizon was a deep purplish red, silty clay loam, and the upper horizon was an orangey red, more fine calcitic, silty clay loam. In thin section in the lower horizon, strongly amorphous sesquioxide impregnated dusty clay predominates, with only about 15% very fine quartz sand present in addition. The clay component is speckled to striated, weakly reticulate striated in places, with moderate to strong birefringence (Fig. 7, lower right) and has a considerable very fine organic/charcoal component present throughout, well worked into the groundmass. The upper horizon is more vughy, contains a greater very fine to fine quartz sand component and minor micritic content, and exhibits some very fine organic/charcoal punctuations (Fig. 7, upper right).

These strongly reddened soils are characterised by a well-developed blocky ped structure, organised illuvial clays and silty clays with depth, a great degree of reddening with secondary iron oxides and hydroxides (rubefication), and lesser amounts of included limestone pebbles and fragments with depth. Although these soils are becoming slightly more organic and vughy up-profile, no *in situ* organic Ah horizons were observed in any location; these have probably been truncated and removed by house building in the last century and more recently. Nonetheless, there is a very fine to fine included organic component throughout these soils, which is suggestive of the long-term incorporation of organic material, especially carbonised and fine humified organic material.

Although these palaeosols are undated, they have been sealed by buildings above for at least a century. They appear to be characteristic red Mediterranean soils (‘terra rosa’ or Chromic Luvisols or Ultisols) (Bridges, 1978, 68; Soil Survey Staff, 1999; WRB, 2014). They feature an A/B1/B2/C set of horizons, with strong weathering, clay eluviation and illuviation, and abundant secondary iron oxide/hydroxide formation, probably predominantly haematite (Fe_2O_3) (Duchaufour, 1982; Lelong and Souchier, 1982), much of which could be related to the long-term weathering of the limestone bedrock beneath (Catt, 1990). There is also the illuvial deposition of pure clay and/or sometimes calcium carbonate in the lower argillic horizon (B2 or argillic Bt). Although these soils may be of much greater antiquity than the Holocene (Catt, 1990; Kemp, 1986), the environmental factors which are thought to be important for the development of this soil type include strong seasonal variation with rainfall during the winter and spring months (<650mm) and xeric conditions during the summers (Bridges, 1978, 68; Yaalon, 1997), conditions which prevail in the Maltese Islands.

5.6 Physical, multi-element, soil micromorphological analyses of the Marsalforn and Ramla valley fill sequences (Figs. 1, 8, 9 and 11; Tables 3, 4 and 6)

The three samples taken from the upper (175-210cm) and lower (270-310cm) incipient soils within the colluvial profile at the Marsalforn valley profile 626 (Fig. 8) were all very alkaline with a low total organic content (*ca*. 1.6-2.2%) and very high calcium component (Table 3) as well as relatively enhanced phosphorus and strontium values (Table 4). The high calcium content is corroborated by the silt-sized micritic calcium carbonate so dominant in the thin sections of the same contexts, and the moderately enhanced phosphorus and strontium components would indicate the receipt of midden-type refuse and hearth rake-out material (Entwistle et al., 1998), as does the moderately enhanced magnetic susceptibility values, especially in the basal colluvial soil horizon. These features could be seen as an attempt to increase the fertility of these soil surfaces in the past, which is also reflected in the fine included anthropogenic debris visible in thin section.

Soil micromorphological analysis of the same three samples revealed highly micritic, shell-rich, fine sandy loams throughout with the sand-size component being almost entirely composed of sub-rounded Coralline Limestone material (Fig. 9a; Table 6). This sand-size material occasionally exhibits micro-laminations (Fig. 9b), but consistently exhibits a sub-angular to columnar blocky ped structure of greater and lesser expression. The consistently high silt content observed in the particle size analysis (*ca*. 58-65%) and very high calcium carbonate content of *ca*. 75-80% (Table 3) undoubtedly reflects the predominant micrite component. There is a general absence of anthropogenic inclusions, even very fine charcoal. This heterogeneous mix of fine calcitic soil and limestone rubble fabrics indicate that these 'soils' are of colluvial/hillwash origin, possibly interrupted by colluvial fan deposition where the limestone rubble content increases markedly, but the subsequent structural formation generally implies some longer-term stability of these horizons and weak pedogenesis (Macphail, 1992).

The multi-element results of the three spot samples taken from the alluvial fills in the Ramla valley profile reveal a similar story of elemental enhancement to that described for the Marsalforn valley (Table 4). The fill deposits were all alkaline but with quite low magnetic susceptibility enhancement (Table 3), high calcium carbonate (*ca*. 55-64%) and silt component (*ca*. 60-79%) (Table 3), and moderately enhanced phosphorus values (Table 4). This may reflect activities in the immediate catchment, but is harder to ascribe to *in situ* rather than derived evidence of human activity.

The Ramla Profile 627 sequence revealed at least four pale grey, calcareous 'soil' horizons alternating with fine to coarse pebbly horizons (Fig. 8; Table 6). The physical and soil micromorphological analyses of these grey 'soil' horizons (at 4-13, 13-15, 26-28 and 60-90cm) indicated that they are composed of relatively organic, very micritic, fine sandy/silty clay loam soil (Table 3) with greater/lesser amounts of included very fine limestone gravel. They exhibit evident bioturbation and some weak secondary ped formation. There were minor amounts of silt and clay, very fine charcoal and organic matter fragments present, and the occasional silt or silty clay crust (Fig. 9c). There was also the very occasional void infill or aggregate of a very fine sandy clay loam with a reticulate striated silty clay component reminiscent of argillic (or Bt) horizon material (Fig. 9d), incorporated in this profile. The lowermost horizon (627/3; 100-140cm) is a dense but aggregated, calcitic, shelly sand with indications of fine laminations is situated directly on the Globigerina Limestone bedrock. The laminar aspect of this profile suggests the stop/start aspect of its accumulation, with the coarse limestone rubble units (at least three) indicative of episodic phases of alluvial fan type of deposition, and the finer units inbetween indicative of fine soil erosion from the catchment and overbank deposition in the valley bottom (Goldberg and Macphail, 2006, 77ff).

6. Discussion (Table 7)

Previous interpretations of the landscape of prehistoric Malta drew on a particular view of the modern landscape with the Neolithic monuments dominating and overlooking lowland valleys and the ubiquitous terracing being of at least Bronze Age origin (Blouet, 1997; Grima, 2004, 2008; Sagona, 2015). Essentially this landscape comprised flat-topped limestone mesas with a highly denuded 'garrigue' srubby grassland vegetation and shallow eroded remnants of earlier red soils with large areas of exposed bedrock (Fig.10) overlooking clay dominated, gentle valleys with extensive agricultural terrace systems (Fig. 11). Springs emanated from just below the Upper Coralline Limestone plateau zone at the upper contact with the Blue Clay geology, leading to lateral flush wet zones down-slope as well as modern cisterns and small reservoirs being built to enhance water capture of these natural wet zones. Across variable degrees of slope into the valleys below, there are extensive exposed areas of grey silty clay on Blue Clay geology across the mid-upper slopes, situated at the geological boundary between the Upper Coralline and Globigerina Limestones, such as in the Ramla valley. These clay slope areas are now highly terraced and commonly used for arable cereal crops today as they are relatively moisture and nutrient retentive, even if they are fine grained 'heavy' soils which are difficult to turn with a plough. Hillwash deposits tend to be relatively thin on these lower slopes, and their erosive potential is largely controlled by terracing. In the lower parts of many valleys such as in the lower Ramla and Marsalforn valleys, the limestone bedrock (of both Upper Coralline and Globigerina) outcrops in a series of low steps or inset plateaux which are all farmed today, usually with wheat and barley crops and vines. The valley bottoms have a varied geomorphology, but are often narrow and meandering, often scoured out and cut into the Globigerina Limestone bedrock through water action, and/or infilled in their lower reaches with combinations of eroded coarse to fine hillwash material derived from the soils and geology upslope over depths of *ca*. 2-4m.

As a consequence of the combined archaeological, chronological, geoarchaeological and micromorphological studies conducted as part of the *FRAGSUS* project, the interpretation of the relationship between soils and the prehistoric landscape must now take into account the new evidence of former well-developed soils that have survived in well-defined locations associated with several Neolithic temples on Gozo. These well developed soils of the past were not in the distant gaze of the major monuments, but directly associated with and adjacent to those monuments.

This new evidence is derived from the completely different 'brown to red' Mediterranean transitional soil type uncovered at Santa Verna in a pre-3800 cal BC context. This buried soil at Santa Verna is thick (up to 65cm) and exhibited much better development and horizon characteristics than any found elsewhere on the Xagħra plateau and in the associated valley systems. It is also much better preserved than is the case at the nearby temple site of Ġgantija, and much less affected by the secondary formation of micritic calcium carbonate. Two horizons are visible, a more reddish to purply brown lower horizon and a slightly browner but still reddish brown upper horizon. This palaeosol or red brown Mediterranean soil (or Orthic Luvisol or Ultisol) was probably formed under a well vegetated and moister pedo-climatic regime in the earlier Holocene (Fedoroff, 1997; Yaalon, 1997). It is characterised first by the weathering of the limestone substrate and then by clay illuviation down-profile creating a clay enriched lower Bt or argillic horizon. In all the buried soil profiles there is also a considerable component of aeolian dust, contributing to the ubiquitously high silt component of these soils, a feature that is widespread across the Mediterranean region (Yaalon and Ganor, 1973). Strong reddening or rubefication of the Xagħra palaeosols probably occurred hand-in-hand with the process of clay illuviation (Fedoroff, 1997; Yaalon, 1997) and rapid bio-degradation of organic material, as well as increasing calcification with time. These latter processes are probably associated with the removal and disturbance of the vegetative cover and a marked, lengthy dry season (Goldberg and Macphail, 2006, 70; Gvirtzman and Wieder, 2001; Yaalon, 1997). It is the very eroded, disturbed and highly weathered thin base of this type of soil which is now commonly found on and around the margins of the limestone plateaux of Gozo, such as at Xagħra.

Where it survives the pellety crumb or bioturbated/excremental structure of the buried upper soil horizon is indicative of a mollic or mull humic horizon (Gerasimova and Lebedeva-Verba, 2010, 354; Goldberg and Macphail, 2006, 65). In addition, the upper parts of all the buried soil profiles analysed contained significantly enhanced phosphorus values and abundant micro-charcoal. Both inside and outside the Santa Verna temple, the transition from this lower A horizon to the B horizon is marked by a very mixed fabric of pellety/aggregated silty clay and varying admixtures of micritic calcium carbonate, which can more or less predominate. This is essentially acting as a depleted and oxidised, calcium carbonate dominated eluvial Eb horizon. Below this, and especially in the Ashby and Trump Sondages within the interior of the temple, there is *ca*. 20-40cm of a clay-enriched Bt horizon present. This is primarily composed of a silty clay with pure to slightly dusty clays evident and greater/lesser degrees of striation and micro-lamination, and a small blocky to columnar ped structure. This is indicative of a stable, well drained and organised, illuvial, clay-enriched or argillic Bt horizon (Bullock and Murphy, 1979; Fedoroff, 1968, 1997; Kuhn et al., 2010, 233ff). This type of clay-enriched, argillic brown soil no longer appears to exist elsewhere in present day Malta and Gozo.

The buried soils discovered to either side of the present-day platform on the southern and eastern sides of Ġgantija temple dated to pre-*ca*. 2500 cal BC revealed another variation in the soil story on the Xagħra plateau (Figs. 4 and 5; Table 2). These soils exhibit clear signs of fines (of silt and clay) illuviation and depletion, abundant secondary formation of calcium carbonate and to a lesser extent reddening with iron oxides/hydroxides. This suggests that these soils also formed initially under more moist, better vegetated and organic, nutrient-rich conditions, unlike the present day pedo-climatic regime of dry Mediterranean with rapid bio-degradation, seasonal rains and a marked and lengthy dry season (Fedoroff, 1997; Yaalon, 1997). This evidence suggests that there had also been a clay-enriched earlier Holocene soil developed at Ġgantija similar to that which was observed beneath the nearby Santa Verna temple, but it had already undergone more sustained anthropogenic influence and disturbance in terms of opening up its vegetated surface, and consequently greater humification and evapo-transpiration processes. Both these Ġgantija profiles appear to be a 'half-way' soil-type in development terms between a brown and a red Mediterranean soil, with the Ġgantija soil formation sequence more altered as a result of a longer period of continuing human use and disturbance, in contrast to the Santa Verna palaeosol which was buried about 1000-1300 years earlier.

Thus the former presence of a well developed brown Mediterranean soil with a thick clay-enriched argillic Bt horizon present at both temple sites prior to the 4^{th} millennium BC on the Coralline Limestone of the Xagħra plateau is therefore of great significance. Importantly OSL determinations at Ġgantija temple suggests that this soil was forming from at least the earlier Holocene. A similar soil type was also present in a very thick exposure (up to 80cm) near the base of a 10m sediment core extracted from the Xemxija basin in northern Malta, dated from *ca*. 7500-7200 cal BC (8334+/-46 BP; UBA-29347) at its base by AMS radiocarbon assay (Table 2). Thus it is possible that similar brown, clay-enriched or argillic soils were once more widespread in the Maltese Islands, and indeed the wider Mediterranean region (Yaalon, 1997). Moreover, these soils with their distinctive argillic horizons most probably developed under conditions of slightly greater moisture and vegetative cover in the earlier Holocene (Fedoroff, 1997; Yaalon, 1997). These soils then probably underwent processes of organic depletion, physical mixing, weathering and erosion down-slope when farming was introduced from the 6th millennium BC, with subsequent intensification of these processes coupled with aridification from the earlier 4th millennium BC onwards.

In addition at both sites, there was the remarkable incorporation of abundant fine midden-like materials into and on top of the buried soil, especially at Ġgantija and to a lesser extent at Santa Verna. These particularly included later Neolithic Tarxien-period pottery, humified organic matter, and fine fragments of charcoal and animal bone. The very high phosphorus and relatively high strontium values may also suggest the addition of organic refuse to these soils. These features of probable soil management and amendment would have enhanced soil fertility and stability. This finding gives an important insight into how the people who lived in Gozo during the later Neolithic period managed to sustain their rich and complex lifeways – as abundantly demonstrated by the elaborate traditions of burial and art in the nearby and contemporary Brochtorff Xagħra Circle (Malone et al., 2009).

Current and previous palynological studies of sediment cores taken from Malta and Gozo suggest that woodland was either absent or relatively sparse and scrubby for much of the prehistoric period with only some relicts of the natural early Holocene southern Mediterranean pine/juniper scrubland present (Carroll et al., 2012) (Table 7). But by the time that the Santa Verna temple was being built in the early 4th millennium BC, these trees and scrub were fast disappearing and soils were being cultivated for wheat and barley as early as *ca*. 5700 cal BC (M. Farrell, L. Coyle-McClung and C.O. Hunt, pers. comms.). This evidence serves to corroborate the story of the pre-temple buried soils at both Santa Verna and Ġgantija, which exhibit characteristics of a process of permanent changes to the environment – a moist, scrubby landscape changing to a managed agricultural landscape associated with mainly dry, open and erosive soil conditions.

The human exploitation of these transitional brown to red soils during the Late Neolithic period was followed by drier climatic conditions probably from the late 3rd millennium and certainly from the 2nd millennium BC onwards (Carroll et al., 2012; Magny et al., 2011; Morris, 2002; Sadori et al., 2013). It is the xeric moisture regime of strong seasonal winter/summer rainfall contrasting with winter rainfall in excess of evapotranspiration versus a lengthy period of the drying out of the root zone in the soil over the summer months which defines the climatic constraints on soil formation in Malta and elsewhere in the Mediterranean region (Yaalon, 1997). In combination with human use of the mesa plateau and the coincident removal of vegetation, there were the associated processes of soil moisture loss, de-stabilisation and humic and fines depletion. Consequently, a number of significant secondary soil processes then took precedence, predominantly the biodegradation of the humic components and the common formation of silt-sized calcium carbonate, as well as clay and iron movement and their redeposition down-profile leading to strong soil reddening. These combined processes resulted in the development of thin, organic depleted, highly iron impregnated xeric soils which were becoming increasingly dominated by secondary calcium carbonate formation (Aguilar, 1983). These secondary processes changed the earlier Holocene soil type and moisture-vegetation balance once and for all. In addition, recent palynological work on Malta suggests coincident disruption of the landscape as marked by a gradual decline in the scrub and tree vegetation, which became more pronounced from *ca*. 4000 BC on and especially from *ca*. 2300 cal BC, and perhaps even the relative 'abandonment' of arable agriculture in the late 3rd millennium BC with an associated greater emphasis on pastoral activities (Carroll et al., 2012; Djamali et al., 2013).

Thus it is suggested that the soil development catena observed between Santa Verna and Ġgantija over the 4th to mid-3rd millennia BC is tracing a major soil developmental change associated with use and disruption of this landscape that is occurring just before and during the construction and use of these two temples. The thin, single horizon, calcitic, silt-rich, red Mediterranean soils with low base status that are now so typical of the mesa plateau began to became the norm on the Coralline Limestone geology of Gozo from at least the later 3rd millennium BC. Associated and subsequent over-use for arable and grazing led to gradual and continuing denudation, depletion, rubefication and xerification, coincident with the establishment of an impoverished garrique flora, resulting in the ubiquitous thin red xeric soils and denuded plateau areas as they are today (Fig. 10). Indeed, this could have been both a stimulus to and a driver of terrace construction in the adjacent valley systems as well as leading to a greater emphasis on pastoral agriculture.

During the last four millennia, agriculture in combination with the seasonally very dry Mediterranean climate has kept these red, xeric, fine soils ubiquitously present on the higher/upper parts of the Gozo landscape, ostensibly associated with the Upper Coralline Limestone. These 'terra rosa' red soils became thinner and more mono-horizonal, less moisture retentive and less fertile with time, unless subject to continual amendment with household waste and domestic livestock manure, and/or managed land-use involving mixed pasture, fruit/olive tree and arable use. From at least the late Neolithic period, soil erosion associated with human use also became a factor in causing slope erosion and valley fill processes in many parts of Mediterranean Europe (Dusar et al., 2011; Garcia-Ruiz and Lana-Renault, 2011). This certainly became a major feature of the Maltese landscape in the Bronze Age from the beginning of the 2nd millennium BC, if not earlier. This is well corroborated by the evidence from the Marsalforn valley where considerable volumes of hillwash are gradually on the move from at least the mid-2nd millennium BC, and in the Xemxija core with a further 5.7m of stop/start soil alluvial aggradation with eroded calcitic soil material occurring throughout later prehistoric times from at least *ca*. 2198-1985 cal BC (3704+/-29 BP; UBA-28265) (Table 2).

From the wider geoarchaeological survey of the Gozitan valleys conducted by the *FRAGSUS* project, most valley slope hillwash deposits on the Blue Clay geology are slight and the thick valley fill aggradational deposits on limestone geology tend to concentrate in the terrace systems and valley bases or just inland from the coast. This implies that the slopes of the valleys on Blue Clay geology were relatively quite stable with calcitic vertisols (Lang, 1960; Vella, 2003). The intractability of these clay and silt dominated soils meant that they were best avoided for arable agriculture until the arrival of metal-shod, mould-board ploughs, which did not occur until the Roman period (Margaritis and Jones, 2008). Consequently, it is suggested that the Blue Clay slope areas are more likely to have remained as scrub woodland and/or natural grassland for limited grazing for most of prehistoric times. There are also numerous springs emanating from the upper and lower contacts of the clay with the limestone geology which would have provided natural water sources and wet areas for reed and sedge growth (as they still do today), all suitable as roofing, building and clothing materials for example. Thus, the exploitation of the Blue Clay valley landscapes may have been relatively limited and/or in some balance (Carroll et al., 2012), contrasting with the limestone catchment valleys which were more erosion prone with much thicker hillwash accumulations, now extensively terraced, with an unknown volume of eroded soil potentially washed out to sea in high rainfall events (Mayes, 2001).

Major landscape modifications of the some valleys on Gozo appear to have occurred from the later medieval period onwards. For example, the Blue Clay slopes of the Ramla valley become more systematically exploited in the mid-16th century by the crusader Order of St John and again in the mid-19th century with two sets of superimposed systems of field boundaries and sinuous ownership boundaries located on the slopes (Alberti et al., 2017; Blouet, 1997; Carroll et al., 2012; Grima, 2008; Wettinger, 2011) (Fig. 11). This extensification and intensification of landscape development may well have been associated with pressure on land to enable more sustainable arable agriculture to support the island population, but was also dependent on the use of better plough machinery and importantly reliable water sources from the natural spring lines in each valley.

Since the 1960s, there has been continuing transformation of the Gozitan landscape with widespread clearance and uptake of arable land in the valleys and slope areas and expanding town-scapes on the limestone plateau (Vella, 2003). There has been soil removal and re-deposition on the plateaux as well as deliberate amendment of the thin red soils around the mesa margins using silty clay soil taken from the mid-/upper slope areas of the Blue Clay geology. For example, this occurred in the olive grove fields on the eastern side of Ġgantija temple in 1961 and 1985. At the same time, the mesa plateaux have become more and more occupied by urban development, especially since the 1980s, perhaps as a corollary of the poor state of soil development and survival. Today, although the landscape is relatively stable, heavy rainfall events still cause intensive periods of surface water flooding and soil run-off into the sea.

7. Conclusions

Geoarchaeological fieldwork and a suite of physical, multi-element and micromorphologocal analyses focusing on the Neolithic temple sites located on the Xagħra plateau and the associated Marsalforn and Ramla valleys on the island of Gozo have suggested a new model of soil development for the early-mid-Holocene. Thick, moist, well-developed and vegetated argillic brown soils (or orthic luvisols) with a considerable wind-blown silt component existed on the Coralline Limestone plateau areas of the island from at least the 9th-5th millennia BC that subsequently underwent major soil change. The palaeosol records revealed in the micromorphological analyses clearly show the combined effects of the impact of Neolithic farming communities on the soil/landscape system from at least the early 4th millennium BC and increasingly over time the seasonally very dry climatic regime. The well developed brown soils then gradually changed to thinner, drier and more calcitic red Mediterranean soils (or chromic luvisols), equating with Lang's (1960) 'terra soils' and 'xerorendzinas'. Despite this type of soil's naturally low base status, associated with rapid biodegradation of the near surface organic matter, a degree of agricultural productivity may well have been maintained though the enhancement of the soil's organic content with the deposition of household derived organic and artefactual waste. This significant soil management feature appears to have had its beginnings in the mid-later 3rd millennium BC, at least at Ġgantija and probably also at Santa Verna. This deliberate soil enhancement may well have underpinned the viability of later Neolithic agricultural society in the Maltese Islands.

This new model of soil change in later Neolithic times in Gozo suggests that seminal models of the setting of monuments now need to be reassessed as we can no longer rely on modern soil distribution as a guide to the nature of past landscapes. Importantly with time, the system of prehistoric soil improvement came under inevitable strain. A combination of devegetation, sustained human use and a wider coincident aridifying trend led to the formation of either dry, organic poor, red Mediterranean 'terra rosa' soils and/or thin, organic-poor, calcitic soils associated with open xeric landscapes. This set of processes was in-train from the mid-late 3rd millennium BC onwards, probably making successful arable farming very difficult on the Coralline Limestone plateaux. Soil erosion in some limestone geology valleys such as Marsalforn was well underway by the mid-late 2nd millennium BC, equating with strong evidence for a period of maximum erosion from *ca*. 1350-550 cal BC observed in several deep valley cores made by the *FRAGSUS* team elsewhere in Malta (www.qub.ac.uk/sites/FRAGSUS/). It was probably not until the 16th century AD and later that the clay vertisol valley landscapes witnessed much exploitation for arable agriculture in any intensive way, leading to later erosion and aggradation in the lower valleys such as the Ramla in more recent times.

Acknowledgements

This research was undertaken as part of the Advanced Grant 323727, FP7 "Ideas" Specific Programme, European Research Council, *FRAGSUS: Fragility and sustainability in restricted island environments: Adaptation, cultural change and collapse in prehistory*, led by the Principal Investigator Professor Caroline Malone on behalf of the extended research team. We are indebted to the ERC for its financial support. We would like to thank all at Heritage Malta, the Ġgantija visitor's centre, the National Museum and the University of Malta for their friendly and useful assistance throughout. In particular, we would like to thank Daphne Caruana, George Azzopardi, Dr Anthony Pace, Nathaniel Cutajar, Ella Samut-Tagliaferro, Dr Nick Vella, Dr Reuben Grima, Joanne Mallia, George Said-Zammit, Mevrick Spiteri, Katya Stroud and Sharon Sultana. We also thank the Queen's University Belfast radiocarbon and

SUERC University of Glasgow OSL dating teams, Dr Tonko Rajkovaca of the McBurney Laboratory, University of Cambridge, for making the thin section slides, the ALS Global laboratory in Seville, Spain, for processing the multi-element ICP-AES analyses, and Dr Rowan McClaughlin and David Redhouse for providing several illustrations.

References

Aguilar, J., Guardiola, J.L., Barahona, E., Dorronsoro, C., Santos, F., 1983. Clay illuviation in calcareous soils, in: Bullock, P., Murphy, C.P. (Eds.), Soil Micromorphology. A.B. Academic, Berkhamsted, pp. 541-550.

Alberti, G., Grima, R., Vella, N.C., 2018. The use of geographical information system and 1860s cadastral data to model agricultural suitability before heavy mechanization. A case study from Malta. Plos One 13, 2, 1-28, e0192039.

Allen, M.J., Macphail, R.I., 1987. Micromorphology and magnetic susceptibility studies: their combined role in interpreting archaeological soils and sediments, in: Fedoroff, N., Bresson, L.M., Courty, M.A. (Eds.), Soil Micromorphology. Paris: Plaisir, pp. 669-676.

Ashby, T., Bradley, R.N., Peet, T.E., Tagliaferro, N., 1913. Excavations in 1908-11 in various megalithic buildings in Malta and Gozo. Papers of the British School at Rome, 6, 1-126.

Avery, B.W., Bascomb, C.L., (Eds.), 1974. Soil Survey Laboratory Methods. Soil Survey Technical Monograph No. 6, Harpendon.

Bengtsson, L., Enell, M., 1986. Chemical analysis. In Berglund, B.E. (Ed.) Handbook of Holocene palaeoecology and palaeohydrology. Chichester: John Wiley, pp. 323-451.

Bevan, A., Conolly, J., 2013. Mediterranean Islands, Fragile Communities and Persistent Landscapes. Cambridge University Press, Cambridge.

Blouet, B., 1963. The changing landscape of Malta during the rule of the Order of St John of Jerusalem 1530-1798. University of Hull.

Blouet, B., 1997. The Story of Malta, sixth ed. Progress Press, Malta.

Boreham, S., Conneller, C., Milner, N., Taylor, B., Needham, A., Boreham, J., Rolfe, C.J., 2011. Geochemical indicators of preservation status and site deterioration at Star Carr. Journal of Archaeological Science 38, 2833-2857.

Boyle, S., 2014. The social and physical environment of early Gozo – a study of settlement and change. Unpublished Ph.D. thesis, Queen's University Belfast.

Brandt, C.J., Thornes, J.B., 1996. Mediterranean desertification and land-use. John Wiley & Sons Ltd., London.

Bridges, E.M., 1978. World Soils, second ed. Longman, London.

Bullock, P., Murphy, C.P., 1979. Evolution of a palaeo-argillic brown earth (Paleudalf) from Oxfordshire, England. Geoderma 22, 225-252.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T., 1985. Handbook for Soil Thin Section Description. Waine Research, Wolverhampton.

Catt, J.A., 1990. Paleopedology manual. Quaternary International 6, 1-95.

Carroll, F.A., Hunt, C.O., Schembri, P.J., Bonanno, A., 2012. Holocene climate change, vegetation history and human impact in the Central Mediterranean: evidence from the Maltese Islands. Quaternary Science Reviews 52, 24-40.

Clark, A., 1996. Seeing beneath the Soil: prospecting methods in archaeology (2nd edition). Routledge, London.

Courty, M-A., Goldberg, P., Macphail, R.I., 1989. Soils and micromorphology in archaeology. Cambridge University Press, Cambridge.

Cresswell, A.J., Sanderson, D.C.W., Kinnaird, T.C., French, C. 2017. 'Luminescence analysis and dating of sediments from valley fills and archaeological sites on Gozo and Malta.' Unpublished report, July, 2017. SUERC, East Kilbride.

Davidson, D.A., 1980. Erosion in Greece during the first and second millennia BC, in: Cullingford, R.A., Davidson, D.A., Lewin, J. (Eds.), Timescales in Geomorphology. New York, Wiley and Sons, pp. 143-158.

Djamali, M., Gambin, B., Marriner, N., Andieu-Ponel, V., Gambin, T., Gandouin, E., Lanfranco, S., Medail, F., Paron, D., Ponel, P., Morhange, C., 2013. Vegetation dynamics during the early to mid-Holocene transition in NW Malta, human impact versus climate forcing. Vegetation History and Archaeobotany 22, 367-380.

Duchaufour, P., 1982. Pedology. Allen and Unwin, London.

Durand, N., Monger, H.C., Canti, M.G., 2010. Calcium carbonate features, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of micromorphological features of soils and regoliths. Amsterdam: Elsevier, pp. 149-194.

Dusar, B., Verstraeten, G., Notebaert, B., Bakker, J., 2011. Holocene environmental change and its impact on sediment dynamics in the eastern Mediterranean. Earth-Science Reviews 108, 137-157.

English Heritage, 2004. Geoarchaeology: Using earth sciences to understand the archaeological record. Swindon: English Heritage.

Entwistle, J.A., Abrahams, P.W., Dodgshon, R.A., 1998. Multi-element analysis of soils from Scottish historical sites, interpreting land-use history through physical and chemical analysis of soil. Journal of Archaeological Science 25, 53-68.

Evans, J.D., 1971. The prehistoric antiquities of the Maltese islands, London: Athlone Press.

Fassbinder, J.W.E., 2016. Magnetometry for archaeology, in: Gilbert, A.S. (Ed.), Encyclopedia of Geoarchaeology. Dordrecht: Springer, pp. 499-514.

Fedoroff, N., 1968. Genese et morphologie des sols a horizon b textural en France atlantique. Science du Sol 1, 29-65.

Fedoroff, N., 1997. Clay illuviation in Red Mediterranean soils. Catena 28, 171-189.

Fleisher, J., Sulas, F., 2015. Deciphering public spaces in urban contexts: Geophysical survey, multi-element analysis, and artefact distributions at the 15th-16th-century AD Swahili settlement of Songa Mnana, Tanzania. Journal of Archaeological Science 55, 55-70.

French, C., 2015. A handbook of geoarchaeological approaches to landscapes and settlement sites. Oxford: Oxbow.

Garcia-Ruiz, J.M., Lana-Renault, N., 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region – A review. Agriculture, Ecosystems and Environment 140, 317-338.

Gerasimova, M., Lebedeva-Verba, M., 2010. Topsoils - Mollic, takyric and yermic horizons, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of Micromorphological features of Soils and Regoliths. Elsevier, Amsterdam, pp. 351-368.

Goldberg, P., Macphail, R.I., 2006. Practical and Theoretical Geoarchaeology. Blackwells Scientific, Oxford.

Grima, R. 2004. The landscape context of megalithic architecture. In Cilia, D. (ed.) Malta Before History. Malta: Miranda, 327-45.

Grima, R., 2008. The Making of Malta. Midsea Books, Malta.

Gvirtzman, G., Wieder, M., 2001 Climate of the last 53,000 years in the eastern Mediterranean, based on soil-sequence stratigraphy in the coastal plain of Israel Quaternary Science Reviews 20, 1827-1849.

Grove, A.T., Rackham, O., 2003. The nature of Mediterranean Europe: an ecological history. Yale University Press, New Haven.

Holliday, V., Gartner, W., 2007. Methods of P analysis in archaeology. Journal of Archaeological Science 34, 301-333.

Hughes, J.D., 2011. Ancient deforestation revisited. Journal of History of Biology 44, 43-57.

Kemp, R., 1986. Pre-Flandrian Quaternary soils and pedogenic processes in Britain, in: Wright, V.P. (Ed.), Paleosols: Their Recognition and Interpretation. Princeton University Press, Princeton, pp. 242-262.

Kuhn, P., Aguilar, J., Miedema, R., 2010. Textural features and related horizons, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of micromorphological features of soils and regoliths. Elsevier, Amsterdam, pp. 217-250.

Lang, D.M., 1960. Soils of Malta and Gozo. Colonial Office, Colonial Research Studies Report No. 29. H.M.S.O., London.

Lelong, R., Souchier, B., 1982. Ecological significance of the weathering complex: relative and importance of general and local factors, in: Bonneau, M., Souchier, B. (Eds.), Constituents and Properties of Soils. Academic Press, London, pp. 82-108.

Lindbo, D.L., Stolt, M.H., Vepraskas, M.J., 2010. Redoximorphic features, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of micromorphological features of soils and regoliths. Elsevier, Amsterdam, pp. 129-147.

Macphail, R.I., 1992. Soil micromorphological evidence of ancient soil erosion. In Bell, M., Boardman, J. (Eds.), Past and Present Soil Erosion. Oxbow Monograph 22, Oxford, pp. 197-215.

Goldberg, P., Macphail, R.I., 2006. Practical and Theortetical Geoarchaeology. Oxford: Blackwell Scientific.

Magny, M., Vanniere, B., Calo, C., Millet, L., Leroux, A., Peyron, O., Zanchetta, G., La Mantia, T., Tinner, W., 2011. Holocene hydrological changes in south-western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews 30, 2459-2475.

Malone, C., Stoddart, S., Bonanno, A., Trump, D. (Eds.), 2009. Mortuary Customs in Prehistoric Malta: Excavations at the Brochtorff Circle at Xagħra (1987-94). McDonald Institute for Archaeological Research, Cambridge.

Margaritis, E., Jones, M.K., 2008. Greek and Roman Agriculture, in: Oleson, J.P. (Ed.), The Oxford Handbook of Engineering and Technology in the Classical World. Oxford University Press, Oxford, pp. 158–174.

Mayes, J. 2001. Rainfall variability in the Maltese Islands: changes, causes and consequences. Geography 167, 121-130.

Morris, M.W., 2002. Soil Science and Archaeology: Three Test Cases from Minoan Crete. The Institute for Aegean Prehistory Academic Press, Philadelphia.

Murphy, C.P., 1986. Thin section preparation of soils and sediments. A.B. Academic, Berkhamsted.

Oil Exploration Directorate, 1993. Geological Map of the Maltese Islands. Sheet 1 – Malta – Scale 1:25,000. Malta: Office of the Prime Minister.

Pedley, H., House, M., Waugh, B., 1976. The geology of Malta and Gozo. Proceedings of the Geologists' Association 87, 325-341.

Pedley, H.M., Clark, M.H., Galea, P., 2002. Limestone Isles in a Crystal Sea: The Geology of the Maltese Islands. Publishers Enterprises Group Ltd., San Gwann.

Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: Large depths and long-term variations. Radiation Measurements 23, 497-500.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T.J., Hoffman, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and marine13 radiocarbon age calibration curves 0-50,000 years cal BP. Radiocarbon 55 (4), 1869-1887.

Ruffell, A., Hunt, C.O., McLaughlin, R., Malone, C., Schembri, P., French, C., Grima, R., Stoddart, S.K.S. 2018. Water and Cosmology in the Prehistoric Maltese World Fault Control on the Hydrogeology of Ġgantija, Gozo (Maltese Islands). Journal of Archaeological Science: Reports 1432.

Sadori, L., Ortu, E., Peyron, O., Zanchetta, G., Vanniere, B., Desmet, M., Magny, M., 2013. The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy). Climate Past 9, 1969-1984.

Sagona, C., 2015. The Archaeology of Malta: From the Neolithic through the Roman period. Cambridge University Press, Cambridge.

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

Schembri, P.J., 1997. The Maltese Islands: climate, vegetation and landscape. GeoJournal 41, 1-11.

Simpson, I.A., 1998. Early land management at Tofts Ness, Sanday, Orkney: the evidence of thin section micromorphology, in: Mills, C.M. and Coles, G. (Eds.), *Life on the Edge. Human Settlement and Marginality*, Oxbow Monograph 100, pp. 91-98. Oxbow, Oxford.

Simpson, I.A., Guttman, E.B., Shepherd, A., 2006. Characterising midden in Neolithic settlement construction: an assessment from Skara Bare, Orkney. *Geoarchaeology* 21, 221-235.

Soil Survey Staff, 1999. Soil Taxonomy. U.S. Department of Agriculture, Agriculture Handbook 436. Department of Agriculture, Washington, D.C.

Stoops, G., 2003. Guidelines for analysis and description of soil and regolith thin sections. Soil Science Society of America, Inc., Madison, Wisconsin.

Stoops, G., Marcelino, V., 2010. Lateritic and bauxitic materials, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of Micromorphological features of Soils and Regoliths. Elsevier, Amsterdam, pp. 329-350.

Stoops, G., Marcelino, V., Mees, F. (Eds.), 2010. Interpretation of Micromorphological features of Soils and Regoliths. Elsevier, Amsterdam.

Trump, D.H., 1966. Skorba. Society of Antiquaries, London.

van Andel, T.H., Zangger, E., Demitrack, A., 1990. Land use and soil erosion in prehistoric Greece. Journal of Field Archaeology 17, 379-396.

Vella, S.J., 2003. Soil Survey and Soil Mapping in the Maltese Islands: the 2003 Position, in: Jones, R., Houšková, B., Bullock, P., Montanarella, L. (Eds.), Soil Resources of Europe, European Soil Bureau, Research Report No. 9. European Office for Official Publications of the European Communities, Luxembourg, pp. 235-244.

Wettinger, G., 1981. Agriculture in Malta in the Late Middle Ages, in: Buhaguar, M. (Ed.), Proceedings of History Week. Malta: The Historical Society, Malta, pp. 1-48.

Wettinger, G., 2011. Malta in the high Middle Ages. Melita Historica (Malta) 15 (4), 367-390.

Wilson, C.A., Davidson, D.A., Malcolm, S., Cresser, M., 2008. Multi-element soil analysis: an assessment of its potential as an aid to archaeological interpretation. Journal of Archaeological Science 35, 412-424.

Wilson, M.A., Righi, D., 2010. Spodic materials, in: Stoops, G., Marcelino, V., Mees, F. (Eds.), Interpretation of micromorphological features of soils and regoliths. Elsevier, Amsterdam, pp. 251-273.

Wintle, A.G., Murray, A.S., 2006. A review of quartz stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols. Radiation Measurements 41, 369-391.

W.R.B., 2014. World Reference Base for Soil Resources. World Soil Resources Report No. 106. F.A.O., Rome.

www.alsglobal.com (see ME-41 ICP)

www.geog.cam.ac.uk/facilities/laboratories/techniques/psd.html

www.qub.ac.uk/sites/FRAGSUS/

Yaalon, D.H., 1983. Climate, time and soil development, in: Wilding, L.P., Smeck, N.E., Hall, G.P. (Eds.), Pedogenesis and Soil Taxonomy. I. Concepts and Interactions. Elsevier, Amsterdam, pp. 233-251.

Yaalon, D.H., 1997. Soils in the Mediterranean region: what makes them different? Catena 28, 157-169.

Yaalon, D.H, Ganor, E., 1973. The influence of dust on soils during the Quaternary. Soil Science 116, 146-155.

List of Figures

1. Location map of the test excavation/sample sites and geoarchaeological survey areas on Gozo and Malta, with the geology and elevations, based on LiDAR last return data (December 2012), supplied by the former Malta Environment and Planning Authority, with world coastlines plotted using public domain data from www.naturalearthdata.com, and geology plotted after Lang (1960) (T.R. McLaughlin)

2. Plan of Santa Verna temple and the locations of the test trenches (T.R. McLaughlin) (left) with a view of upstanding temple megaliths behind Trench E (upper right) and the terra rossa soil below terrace deposits in Trench B outside the temple (lower right) (C. French)

3. Santa Verna excavation trench profiles all with sample locations marked: upper left: the off-site Trench B buried red soil below terrace deposits ; lower left: the Trump Cut 55 profile with pit fill and associated buried soil; upper right: Trench E profile showing a series of thin earthen floors with limestone rubble inbetween and buried soil below; lower right: the Ashby Sondage profile with the buried soil at its base

4. Plan of Ġgantija temple and locations of Test Pit 1 and the WC Trench excavations (T.R. McLaughlin) (left), with as-dug views of the WC Trench (upper right) and TP1 (lower right) (C French)

5. Ġgantija Test Pit 1 on the southwest side of Ġgantija temple (above), and the east-west section of the Ġgantija WC Trench on the southeast side of the temple (below)

6. Soil photomicrographs from Santa Verna and Ġgantija (C. French):
a) Photomicrograph of pellety, micritc silty clay with sesquioxide nodules (sn), Santa Verna, Trench B, sample 1/1 (frame width = 4.5mm; cross polarized light)
b) Photomicrograph of striated clay-dusty clay (sc) groundmass with micritic calcium carbonate void linings, Santa Verna, Trench B, sample 1/3 (frame width = 4.5mm; cross polarized light)
c) Photomicrograph of the calcitic void fill (cv) in fine sandy clay loam, base of buried soil, Ġgantija Test Pit 1, sample 23 (frame width = 4.5mm; cross polarized light)
d) Photomicrograph of the aggregated, very dark brown, humic and amorphous sesquioxide stained very fine sandy clay loam soil with common interconnected vughs, Ġgantija Test Pit 1, base of terrace soil, sample 26 (frame width = 4.5mm; cross polarized light)
e) Photomicrograph of the aggregated, humic calcitic sandy loam soil with calcitic ash (ca) and bone (b) fragments, base of buried soil, Ġgantija WC Trench sample 3/8 (frame width = 4.5mm; plane polarized light);

f) Photomicrograph of the aggregated calcitic sandy/silty clay loam soil, base of buried soil, Ġgantija WC Trench, sample 3/8 (frame width = 4.5mm; cross polarized light)

7. Xagħra town: left: a typical 'terra rossa' soil sequence at construction site 2; upper right: photomicrograph of the blocky silty clay groundmass with very fine included organic matter/charcoal punctuations in the upper horizon of the palaeosol, sample 5, quarry (frame width = 4.5mm; plane polarized light); lower right: photomicrograph of the reticulate striated clay in the lower horizon of the palaeosol, sample 5, quarry (frame width = 4.5mm; cross polarized light) (C. French)

8. The Marsalforn (Pr 626) (left) and Ramla (Pr 627) (right) valley fill sequences, with the micromorphology samples and OSL profiling/dating loci marked (scale = 2m) (C. French)

9. Ramla and Marsalforn valley profiles soil photomicrographs (C. French):
a. Photomicrograph of dense calcitic, shelly sand with included fine charcoal (vfc), Marsalforn Pr 627, sample 1 (frame width = 4.5mm; cross polarized light)
b. Photomicrograph of dense but aggregated, calcitic, shelly sand with fine laminar aspect, Marsalforn Pr 627, sample 3 (frame width = 4.5mm; cross polarized light)
c. Photomicrograph of calcitic, shelly sand with fine silt crusts (sc), Ramla Pr 626, sample 3 (frame width = 4.5mm; cross polarized light)
d. Photomicrograph of silty clay aggregate (sca) in the calcitic, shelly sand, Ramla Pr 626, sample 1 (frame width = 4.5mm; cross polarized light)

10. Scrub woodland on an abandoned terrace system and garrigue plateau land on the north coast of Gozo (C. French)

11. Terracing within land parcels (defined by modern sinuous lanes) on the Blue Clay slopes of the Ramla valley probably established by the Order of St John in the 16th century AD (C. French)

List of Tables

6. Summary of the micromorphological features from the Marsalforn and Ramla valley fill profiles

7. Major phases of landscape development for the Marsalforn-Xagħra-Ramla area of Gozo during the Holocene