A neolithic palaeo-catena for the Xaghra upper corraline limestone plateau it implications for past soil development and land use

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1 **A Neolithic palaeo-catena for the Xagħra Upper Coralline Limestone plateau of**
2 **Gozo, Malta, and its implications for past soil development and land use**
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14 *ABSTRACT*
15

16 Geoarchaeological survey on the island of Gozo combined with test excavations and

17 new chronometric dating of two Neolithic temple sites at Santa Verna and Ġgantija on

18 the Xagħra plateau have revealed well preserved buried soils which tell a new story of

19 soil development and change for the early-mid-Holocene period. Micromorphological

20 analysis has suggested that the earlier Neolithic climax soil type was a thick, well-

21 developed, humic and clay-enriched argillic brown Mediterranean soil. With human

22 intervention on the Xagħra Upper Coralline Limestone plateau from at least the early

23 4th millennium BC, the trajectory of soil development quickly changed. Radical soil

24 change was marked by the removal of scrub woodland, then consequent poorer organic

25 status and soil thinning, and rubefication and calcification, no doubt exacerbated by

26 Neolithic agricultural activities and a more general longer-term aridification trend. The

27 beginnings of this transitional brown to red Mediterranean soil change process has been

28 observed at Santa Verna temple by the early 4th millennium BC, and appears to be much

29 further advanced by the time of the latter use of Ġgantija temple in the early-mid-3rd

30 millennium BC. There is also evidence of attempts at amending these deteriorating soils

31 during this period and into the 2nd millennium BC, a practice which probably

32 underpinned the viability of later Neolithic agricultural society in the Maltese Islands.

33 The changes observed ultimately resulted in the creation of the thin, xeric, red

34 Mediterranean soils on the Coralline Limestone mesa plateaux which are typical of

35 much of Gozo and Malta today.

36

37 *Keywords:* micromorphology, brown/red Mediterranean soils, argillic, calcification,
38 rubefication, Ġgantija and Santa Verna temples
39

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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

74 soil and land-use history of the island of Gozo during the earlier-mid-Holocene period,
75 and how it is reflected in the Maltese landscape of today.

76

77 **2. Research goals**

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79 It has always been assumed that the seasonally dry and hot Mediterranean climate made
80 the Maltese landscape quite marginal in agricultural terms (Schembri, 1997). As a
81 consequence, it has also been presumed that terracing was adopted extensively from
82 prehistoric times in Malta and Gozo to conserve soils and moisture, and create a better
83 landscape for subsistence based agriculture (Sagona, 2015). Like many other parts of
84 the Mediterranean, this landscape is believed to have been prone to deforestation,
85 drought and soil erosion, combined with intensive human activity, and that this has
86 been the case since Neolithic times (Bevan and Conolly, 2013; Brandt and Thornes,
87 1996; Djamali et al., 2013; Grima, 2008; Grove and Rackham, 2003; Hughes, 2011).
88 The research reported on here aimed to examine these assumptions and test them using
89 geoarchaeological approaches, both on- and off-site (French, 2015). This paper sets out
90 the first detailed geoarchaeological and micromorphological study of two significant
91 Neolithic palaeosol contexts from beneath the Santa Verna and Ġgantija Neolithic
92 temple sites and the associated Marsalforn and Ramla valleys to either side of the
93 Xagħra plateau on which these temple sites are situated on the island of Gozo.

94

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

103

104 **3. Methodology**

105

106 New test excavations at the Santa Verna and Ġgantija temple sites (Figs. 1-5) by the
107 *FRAGSUS* project have revealed old land surfaces beneath mixed soil and/or cultural

108   deposits with well preserved *in situ* palaeosols. These profiles were first discovered

109   during relatively small-scale excavations by Evans in 1954 at Ġgantija (Evans 1971,

110   180-181) and Trump in 1961 at Santa Verna (Trump 1966, 19-20). These programmes

111   of work were directed towards establishing a chronology for prehistoric developments

112   on the islands, and the significance of the palaeosols was largely passed over at the

113   time. In 2014 and 2015 a renewed programme of archaeological work was undertaken

114   at these two sites, which were then extensively sampled for micromorphological,

115   physical and multi-element geo-chemical analyses (Tables 1, 3 and 4). This was

116   accompanied by a radiocarbon dating programme carried out on charred plant remains

117   by the 14CHRONO Laboratory of Queen's University, Belfast, with the dates

118   calibrated using the IntCal13 dataset (Reimer et al., 2013), and a limited selection of

119   quartz optically stimulated luminescence (OSL), single aliquot regenerative sequence

120   determinations from several terrace and valley fill profiles were provided by SUERC,

121   University of Glasgow (Cresswell et al., 2017) (Table 2) based on the methodology of

122   Wintle and Murray (2006) and Sanderson and Murphy (2010), with corrections made

123   for the depth of overburden using the method of Prescott and Hutton (1994).

124

125   In total, 42 soil blocks from ten key soil profiles (Table 1) were prepared for thin section

126   analysis (after Murphy, 1986; Courty et al., 1989) and described using the accepted

127   terminology of Bullock et al. (1985), Stoops (2003) and Stoops et al. (2010) (Table 5).

128   The micromorphological analysis will be the main focus of this paper. In addition, a

129   suite of basic physical parameters (pH, loss-on-ignition and magnetic susceptibility)

130   (Table 3) and multi-element ICP-AES analyses (Table 4) were carried out a series of

131   small bulk samples (40) taken in conjunction with the micromorphological block

132   samples (Avery and Bascomb, 1974; Clark, 1996, 99-117; French, 2015; Holliday and

133   Gartner, 2007; Wilson et al., 2008). pH measurements were determined using a 10g to

134   25 ml ratio of <2mm air-dried soil to distilled water with an Hanna HI8314 pH metre.

135   Determining loss-on-ignition followed the protocol of the Department of Geography,

136   University of Cambridge, to record the percentages of calcium and carbon in the soil

137   (www.geog.cam.ac.uk/facilities/laboratories/techniques/psd.html).   For   loss-on-

138   ignition (*ibid*.), weighed sub-samples were heated to 105˚C for 6 hours to measure

139   water content, then heated to 400 ˚C for 6 hours to measure carbohydrate content, then

140   to 480 ˚C for 6 hours to measure total organic matter content, and finally heated to 950

141   ˚C for 6 hours to measure CO_2 content lost from $CaCO_3$ within the sediment

142 (Bengtsson and Ennell, 1986). The calcium carbonate content can then be calculated

143 by stoichiometry (Boreham et al., 2011). A Malvern Mastersizer was used for the

144 particle size analysis (Table 3) using the same Geography facilities at Cambridge. For

145 magnetic susceptibility measurements a Bartington MS2B metre was used, giving mass

146 specific calculations of magnetic susceptibility for weighed, $10cm^3$ subsamples

147 (English Heritage, 2004, 27). Multi-element analyses using the 35-element aqua regis

148 ICP-AES method were conducted at the ALS Global laboratory in Seville

149 (www.alsglobal.com), and the elements exhibiting greater than trace amounts and/or

150 are generally considered to be enhanced by human activities (cf. Wilson et al., 2008;

151 Fleisher and Sulas, 2015) are tabulated in Table 4.

152

153 **4. The study area and research context**

154

155 *4.1 The geology of Gozo*

156

157 The hard rock sequence of Malta and Gozo comprises Lower Coralline Limestone at

158 its base, which is succeeded by the Globigerina Limestone, Blue Clay and Greensand

159 formations, with the Upper Coralline Limestone at the top (Oil Exploration Directorate,

160 1993; Pedley et al., 1976, 2002) (Fig. 1). Generally Gozo has a more varied geology

161 than Malta, with many outcrops of Blue Clay, especially occurring in the valleys, and

162 table-top plateau or mesas of weathered and eroded Upper Coralline Limestone. These

163 formations essentially lie horizontally, but are displaced at intervals by faults, which

164 form the river valleys and coastlines, and in turn control the weathering and erosion of

165 the exposed rock layers. The homogeneous Globigerina Limestone varies in thickness

166 from *ca*. 20-200m and is separated into three units (lower, middle and upper) by metre-

167 thick conglomerates inbetween.

168

169 *4.2 Santa Verna*

170

171 The Late Neolithic temple now known as Santa Verna is situated on the southwestern

172 side of Xagħra town, on rising ground near the edge of an Upper Coralline Limestone

173 plateau, overlooking much of the island (Figs. 1-3). The temple itself consists of

174 numerous megalithic blocks in the shape of two cruciform shaped interior spaces with

175 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

6

210

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

244   probably is indicative of a later prehistoric age. Then there was a clear contact with an

245   *in situ* buried soil, ranging between *ca*. 80 and 130cm in depth. This soil comprised

246   three horizons: an upper dark brown silt loam (at 80-90cm), a brown silt (90-120cm), a

247   dark reddish brown fine sandy/silt loam (120-125/130cm), all developed on the

248   weathered Upper Coralline Limestone bedrock (at 125/130+cm) (Fig. 5). This profile

249   was sampled for physical, micromorphological and geochemical analyses, and OSL

250   profiling and dating.

251

252   Abundant artefacts, primarily Neolithic pottery sherds with some bone and lithics

253   continued to be present down-profile to the base of this soil. Their abundance certainly

254   suggests considerable use of this area immediately outside the temple during the

255   Tarxien or late Neolithic period (*ca.* 2500-2350 BC), and corroborates the surface

256   information from the Cambridge Gozo survey for later Neolithic occupation in the

257   vicinity (Boyle, 2014; Malone et al., 2009). The OSL dates provide corroboration of

258   this *in situ* early Holocene soil which was forming from at least 8770+/-680 BC, with

259   its upper surface buried after 1140+/-250 BC (Table 2; 10.79+/-0.68 and 3.16+/-0.25

260   years/ka).

261

262   In the WC Trench on the eastern side of the temple, a similar but more complicated

263   sequence was revealed (Figs. 4 and 5). Beneath terrace soil make-up, stone-wall

264   collapse and perhaps the construction of a stepped stone entranceway ramp to the

265   temple, there was a well preserved sequence of midden deposits overlying an intact and

266   complete buried soil sequence. A new radiocarbon date of 2580-2300 cal BC (3962+/-

267   50 BP; UBA-33707) from wood charcoal recovered from the *in situ* soil beneath the

268   stone ramp is indicative of the mid-later-3rd millennium BC, equating with the

269   associated late Neolithic pottery of the Tarxien period (Sagona, 2015, 67ff) (Table 2).

270

271   The buried soil in WC Trench was *ca*. 35-45cm in thickness and consists of a lower,

272   reddish brown silty clay loam B horizon with an organic silt loam A horizon above

273   (Fig. 5). The incorporation of the artefact assemblage throughout the profile, albeit with

274   much lesser quantities recovered in the lower half of the profile, suggests that it has

275   undergone considerable anthropogenic additions and soil faunal mixing in the past.

276   Above this soil there is a series of discontinuous lenses of calcitic ash, fine pea-grit

277   gravel and humified/charcoal rich 'soot' over a thickness of about 10cm (contexts 1004,

278 1042, 1041 and 1040) which are indicative of a series of thin dumps or accumulations

279 of settlement-derived debris on it. These in turn are overlain by two major phases of

280 silt loam soil accumulation (contexts 1016 and 1015) which contain very large

281 quantities of Tarxien-period pottery and bone. A wide area of large, collapsed and

282 broken limestone blocks then seals this soil/midden sequence from further disturbance,

283 which could be related to later Neolithic and subsequent modifications of the temple

284 site. This profile sequence was sampled for physical, micromorphological and multi-

285 element analyses (Table 1).

286

287 *4.4 Xagħra town*

288

289 As several new houses were under construction in Xagħra town with deep basement

290 areas being excavated into the top of the Upper Coralline Limestone plateau whilst

291 fieldwork was underway, there was the opportunistic chance of observing some

292 relatively well preserved buried soil profiles in the modern town (Figs. 1 and 7). In

293 three instances, there were thick (*ca*. 35-80cm), strongly reddened and structurally well-

294 developed soils observed, all developed directly on the limestone bedrock and also in

295 vertical weathering fissures into this bedrock. These soils were spot sampled for

296 comparative micromorphological analysis.

297

298 *4.5 The Ramla and Marsalforn valleys augering survey*

299

300 A combination of hand augering and recording exposed valley profiles, followed up by

301 targeted sampling for physical, micromorphological and geochemical analyses, and

302 OSL profiling (Cresswell et al., 2017) and dating (Table 1) provided potential linkages

303 between the soil changes observed on the Upper Coralline Limestone Xagħra plateau

304 and the associated Marsalforn and Ramla valleys. Several borehole transects (56

305 boreholes) were made from the Ġgantija Neolithic temple site southeast/northeastwards

306 across the Ramla valley, and from Santa Verna temple north across the Xagħra plateau

307 and westwards across the Marsalforn valley (20 boreholes) (Fig. 1).

308

309 The upper part and mid/lower slopes of the Ramla valley are dominated by grey silty

310 clay loam soils up to *ca*. 1.2m in thickness on the Blue Clay geology. These are

311 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

346 (Cresswell et al., 2017). The profiles indicate the parts of the sedimentary sequence

347 which are likely to have been re-deposited without the luminescence signals being re-

348 set at deposition. Moreover, the ratio of net signal intensities between the upper (those

349 not affected by recent soil turnover) and lower units, implies that the temporal range

350 represented by these units may be relatively short. OSL dating suggests that this valley

351 floor fill sequence is ostensibly of the late 19th and early 20th centuries (Table 2; 0.17+/-

352 0.01 years/ka).

353

354 **5. Results**

355

356 The results described below will concentrate on the physical and elemental

357 characterisation and micromorphological analysis of the buried soils encountered at the

358 Santa Verna and Ġgantija Neolithic temple sites, as well as those sampled on three

359 modern construction sites in Xagħra town, and two valley fill profiles to the west and

360 east in the associated Marsalforn and Ramla valleys respectively.

361

362 *5.1 Physical and elemental characterisation of the buried soils* (Tables 3 and 4)

363

364 pH values at Ġgantija were all alkaline (ranging from 7.3 to 8.2) (Table 3). The total

365 organic matter content is a reasonable *ca*. 3.5-5.3% in the buried soils, better than the

366 modern topsoil at *ca*. 3.4%, with a range of values in the archaeological deposits above

367 the buried soils of *ca*. 2.1-3.2% (Table 3). There is a significant calcium carbonate

368 component throughout, ranging in frequency from *ca*. 33-78% (Table 3), a feature

369 which is reflected in the ubiquitous micrite component visible in thin section (see

370 below). In terms of the particle size analysis, the silt (*ca*. 17-80%) and quartz sand (*ca*.

371 5-78%) fractions generally predominate, with reasonable amounts of clay, increasing

372 with depth in the buried soil in Test Pit 1 (5.44-14.21%), but very low proportions of

373 clay (<0.5%) in the buried soil in the WC Trench (Table 3). In particular the terrace soil

374 in Test Pit 1 has a very high silt content (82.36%) as does the context 1004 horizon that

375 accumulated on the upper surface of the buried soil in the WC Trench (80.11%) (Table

376 3; Fig. 5), possibly indicative of dry, open soils and wind-blow effects.

377

378 Most of the multi-element values were low and/or unremarkable, although phosphorus

379 (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

414 reflected in the well organised clay fraction observed in thin section in the basal horizon
415 of the buried soil (see below).

416

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

428

429 *5.2 Soil micromorphology of the buried soils at Santa Verna* (Table 5; Fig. 3)

430

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

439

440 The buried soil revealed in Trench B outside of the temple exhibited three horizons in
441 thin section (Figs. 3 and 6). The uppermost horizon (sample 1/1) was a pellety to
442 aggregated, strongly reddened, gravelly silty clay (Fig. 6a). There is a dust of very fine
443 organic matter/charcoal as well as about 10-20% micrite (or silt-sized calcium
444 carbonate), and common sesquioxide nodules throughout the groundmass. The middle
445 horizon (sample 1/2) was completely dominated by micritic calcium carbonate with *ca*.
446 30% as small aggregates of the same reddish brown silty clay fabric present in upper
447 sample. There was a similar dust of very fine organic matter/charcoal throughout. The

448 lowermost horizon (samples 1/3 and 1/4) was composed of a weak to moderately
449 developed, small blocky, dusty (or silty) clay loam with very abundant, moderately
450 birefringent, pure to dusty clay in speckles and striae throughout the groundmass (Fig.
451 6b).

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

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

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

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

483

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

500

501 In the main excavations within the temple, a series of samples were taken from the *ca*.
502 15 to 60cm in thick buried soils present beneath Neolithic earthen floors within the
503 temple complex in Trench E (Profile 4), the Ashby Sondage (Profile 2) and Trump Cut
504 55 (Profile 3) (Fig. 3). In Trench E just inside the main surviving arc of upright
505 megaliths, the buried soil (sample 4/3) was composed of a pellety to small aggregated,
506 reddish brown silty clay loam with common, birefringent, pure to dusty clay striations
507 throughout the groundmass, as well as common very fine organic/charred punctuations
508 and common sesquioxide nodules and rare occurrences of very small burnt bone
509 fragments. This points to a very disturbed and bioturbated, reddened and clay enriched
510 B horizon soil, essentially similar in structure and fabric to that observed outside the
511 temple in Trench B. No upper, organic Ah horizon was present, probably suggesting
512 truncation associated with the act of temple construction. .

513

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

527

528 In the adjacent Trump Cut 55 (Profile 3), there was a well preserved buried soil
529 (samples 3/1 and 3/2) about 55cm thick present beneath a hard-packed earthen floor
530 (Fig. 3). In contrast to the soil present in the Ashby Sondage (Profile 2), this buried
531 soil exhibited a blocky to columnar blocky with a micro-aggregated microstructure, but
532 exhibited a similar silty clay fabric strongly reddened with iron oxides and hydroxides
533 with a dust of organic matter and very fine charcoal throughout. With depth this soil
534 became denser and more clay enriched with a well-developed striated to reticulate and
535 birefringent, pure to dusty clay groundmass, just as in the base of the buried soil in
536 Trench B. Although these reddened clays could simply be relict in origin (Davidson,
537 1980; Fedoroff, 1997) and the result of the long-term weathering of the limestone
538 bedrock material (Catt, 1990), the well organised, reticulate, gold to reddish-yellow,
539 pure to dusty clay aspect of the groundmass is more indicative of an illuvial clay-
540 enriched Bt or argillic horizon developed in the base of an *in situ* buried soil (Bullock
541 and Murphy, 1979; Fedoroff, 1968, 1997; Kuhn et al., 2010). This argillic soil is the
542 most well-developed of all the buried soil profiles observed in pre-Neolithic contexts
543 at Santa Verna and Ġgantija.

544

545 It is clear that Profiles 2 and 3 have not suffered as severe disruption, mixing and
546 calcification as the other buried soils encountered here and at nearby Ġgantija (see
547 below). Significantly, this soil is indicative of an earlier, well-developed and less

548   disturbed soil type, more akin to a brown argillic Mediterranean soil associated with

549   more moist and well vegetated conditions (Bridges, 1978, 68-9). Nonetheless, this soil

550   is just beginning to be disturbed and opened up, as testified to by the minor but

551   increasing secondary calcium carbonate formation and the fine organic and micro-

552   charcoal dust throughout its fabric. This soil type change from a well structured and

553   clay enriched argillic brown soil (or orthic luvisol) to a calcitic reddish brown to red

554   Mediterranean soil (chromic luvisol) (Bridges, 1978, 68-9) would appear to be

555   beginning just prior to the construction of the temple at Santa Verna (from *ca*. 3800 cal

556   BC), a process that was interrupted by this soil being sealed by the sequence of temple

557   floors above.

558

559   *5.3 Soil micromorphology of the buried soils at Ġgantija* (Table 4; Figs. 5 and 6)

560

561   In Test Pit 1 on the southern side of Ġgantija temple, a series of five contiguous blocks

562   were taken through the *ca*. 36-65cm thick buried soil beneath *ca*. 80cm of later terrace

563   deposits (Figs. 1 and 5). There were two horizons evident. The basal two-thirds of the

564   buried soil (samples 23 and 24) is a calcitic, fine sandy/silty clay loam with a weakly

565   developed blocky structure and a pellety to small aggregated micro-structure (Fig. 6c).

566   Fine organic matter, charcoal and shell are commonly present throughout, as are minor

567   occurrences of bone fragments. There is a generally moderate reddening with iron

568   oxides and hydroxides throughout the dusty or silty clay groundmass, as well as

569   aggregates of strongly iron stained clay. There are few if any illuvial clay or dusty clay

570   coatings in the voids or of the grains and/or clay striae in the groundmass, rather non-

571   birefringent dusty clay is only present as the groundmass. In addition, there are some

572   partial to complete infills of the voids with micritic to amorphous calcium carbonate

573   and very fine organic matter punctuations (Fig. 6c), which is becoming increasingly

574   prevalent towards the upper part of the buried soil.

575

576   The upper one-third of the buried soil (samples 25 and 26) is becoming more dominated

577   by micritic calcium carbonate, humic brown staining, other abundant fragments of

578   bone, organic matter and fine charcoal, with included aggregates of herbivore dung and

579   red clay soil. In particular, sample 26 is a very dark brown, humic and amorphous

580   sesquioxide stained, very fine sandy clay loam soil with common interconnected vughs

581   between an aggregated structure (Fig. 6d).

582

583 The *ca*. 80cm of terrace soil above (samples 27 and 28) is a pellety to aggregated sandy

584 loam with about 20% fine gravel-size limestone rubble throughout. It also contains

585 minor micrite and <20% dusty clay in the groundmass, with minor amounts of fine

586 charcoal, bone and shell fragments. There is weak to moderate reddening of the

587 groundmass with iron oxides and hydroxides. The soil fabric becomes increasingly

588 humic and stained dark brown up-profile.

589

590 Both the terrace soil and the palaeosol beneath essentially exhibit similar soil fabrics,

591 although the terrace make-up is more humic, aggregated and very artefact-rich with

592 common fine bone and charcoal fragments. These features suggest the incorporation

593 and comminution of organic midden waste in this terrace soil. The buried soil beneath

594 exhibits two horizons: an upper, aggregated, very dark brown humic organic Ah

595 horizon, and a B horizon below composed of a mixture of fine sandy clay loam and

596 micritic calcium carbonate. Micrite is common throughout the groundmass, and

597 especially lining and filling in the voids. There is a slight increase in dusty or silty clay

598 content with depth, and an associated better small blocky structural development.

599 Pot/bone/charcoal fragments decline in presence with depth, but are always present.

600 Thus, it appears that there is a complete Ah/Bw profile of a cambisol type of palaeosol

601 present (after Bridges, 1978, 58), although it is not well-developed and its upper half is

602 considerably mixed.

603

604 This palaeosol has undergone some pedogenesis, but there is little evidence of clay

605 illuviation. Instead it is characterised by the predominant secondary formation of

606 calcium carbonate and rubefication with iron oxides and hydroxides, as well as the

607 incorporation of fine anthropogenic debris (mainly fine charcoal and bone fragments)

608 through soil mixing processes by the soil fauna. Thus this soil has changed from being

609 a relatively stable and structured soil to one that is more open and disturbed such that

610 its development was interrupted and it became increasingly affected by drying out,

611 evapotranspiration and secondary rubefication and calcification.

612

613 The ubiquitious fine to coarse artefact inclusions are indicative of deliberate

614 anthropogenic inputs to this soil and considerable soil mixing processes at work. These

615 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

650   surfaces in the vicinity (Yaalon and Ganor, 1973). Subsequently the buried Ah horizon

651   has been deliberately built up in several episodes of deposition through the addition of

652   a similar soil material containing abundant pottery, bone and organic matter. As was

653   evident in the TP1 sequence, the multiple overlying horizons present above the buried

654   soil in the WC Trench suggest the deliberate thickening and enhancement of the

655   underlying soil with settlement-related refuse, possibly as an early form of soil

656   amendment and perhaps even an early form of terracing. All indications are that this

657   occurred within the later Neolithic period of the mid-later 3rd millennium BC.

658

659   *5.5 Soil micromorphology from construction sites in Xagħra town* (Table 5; Fig. 7)

660

661   The palaeosols observed in several construction site localities on the top of the

662   Coralline Limestone plateau occupied by the town of Xagħra exhibited two distinct

663   alkaline horizons (Fig. 7, left; Table 3). The lower horizon was a deep purplish red,

664   silty clay loam, and the upper horizon was an orangey red, more fine calcitic, silty clay

665   loam. In thin section in the lower horizon, strongly amorphous sesquioxide impregnated

666   dusty clay predominates, with only about 15% very fine quartz sand present in addition.

667   The clay component is speckled to striated, weakly reticulate striated in places, with

668   moderate to strong birefringence (Fig. 7, lower right) and has a considerable very fine

669   organic/charcoal component present throughout, well worked into the groundmass. The

670   upper horizon is more vughy, contains a greater very fine to fine quartz sand component

671   and minor micritic content, and exhibits some very fine organic/charcoal punctuations

672   (Fig. 7, upper right).

673

674   These strongly reddened soils are characterised by a well-developed blocky ped

675   structure, organised illuvial clays and silty clays with depth, a great degree of reddening

676   with secondary iron oxides and hydroxides (rubefication), and lesser amounts of

677   included limestone pebbles and fragments with depth. Although these soils are

678   becoming slightly more organic and vughy up-profile, no *in situ* organic Ah horizons

679   were observed in any location; these have probably been truncated and removed by

680   house building in the last century and more recently. Nonetheless, there is a very fine

681   to fine included organic component throughout these soils, which is suggestive of the

682   long-term incorporation of organic material, especially carbonised and fine humified

683   organic material.

684

685 Although these palaeosols are undated, they have been sealed by buildings above for at

686 least a century. They appear to be characteristic red Mediterranean soils ('terra rosa' or

687 Chromic Luvisols or Ultisols) (Bridges, 1978, 68; Soil Survey Staff, 1999; WRB,

688 2014). They feature an A/B1/B2/C set of horizons, with strong weathering, clay

689 eluviation and illuviation, and abundant secondary iron oxide/hydroxide formation,

690 probably predominantly haematite (Fe_2O_3) (Duchaufour, 1982; Lelong and Souchier,

691 1982), much of which could be related to the long-term weathering of the limestone

692 bedrock beneath (Catt, 1990). There is also the illuvial deposition of pure clay and/or

693 sometimes calcium carbonate in the lower argillic horizon (B2 or argillic Bt). Although

694 these soils may be of much greater antiquity than the Holocene (Catt, 1990; Kemp,

695 1986), the environmental factors which are thought to be important for the development

696 of this soil type include strong seasonal variation with rainfall during the winter and

697 spring months (<650mm) and xeric conditions during the summers (Bridges, 1978, 68;

698 Yaalon, 1997), conditions which prevail in the Maltese Islands.

699

700 *5.6 Physical, multi-element, soil micromorphological analyses of the Marsalforn and*

701 *Ramla valley fill sequences* (Figs. 1, 8, 9 and 11; Tables 3, 4 and 6)

702

703 The three samples taken from the upper (175-210cm) and lower (270-310cm) incipient

704 soils within the colluvial profile at the Marsalforn valley profile 626 (Fig. 8) were all

705 very alkaline with a low total organic content (*ca.* 1.6-2.2%) and very high calcium

706 component (Table 3) as well as relatively enhanced phosphorus and strontium values

707 (Table 4). The high calcium content is corroborated by the silt-sized micritic calcium

708 carbonate so dominant in the thin sections of the same contexts, and the moderately

709 enhanced phosphorus and strontium components would indicate the receipt of midden-

710 type refuse and hearth rake-out material (Entwistle et al., 1998), as does the moderately

711 enhanced magnetic susceptibility values, especially in the basal colluvial soil horizon.

712 These features could be seen as an attempt to increase the fertility of these soil surfaces

713 in the past, which is also reflected in the fine included anthropogenic debris visible in

714 thin section.

715

716 Soil micromorphological analysis of the same three samples revealed highly micritic,
717 shell-rich, fine sandy loams throughout with the sand-size component being almost
718 entirely composed of sub-rounded Coralline Limestone material (Fig. 9a; Table 6). This
719 sand-size material occasionally exhibits micro-laminations (Fig. 9b), but consistently
720 exhibits a sub-angular to columnar blocky ped structure of greater and lesser
721 expression. The consistently high silt content observed in the particle size analysis (*ca*.
722 58-65%) and very high calcium carbonate content of *ca*. 75-80% (Table 3) undoubtedly
723 reflects the predominant micrite component. There is a general absence of
724 anthropogenic inclusions, even very fine charcoal. This heterogeneous mix of fine
725 calcitic soil and limestone rubble fabrics indicate that these 'soils' are of
726 colluvial/hillwash origin, possibly interrupted by colluvial fan deposition where the
727 limestone rubble content increases markedly, but the subsequent structural formation
728 generally implies some longer-term stability of these horizons and weak pedogenesis
729 (Macphail, 1992).

730

731 The multi-element results of the three spot samples taken from the alluvial fills in the
732 Ramla valley profile reveal a similar story of elemental enhancement to that described
733 for the Marsalforn valley (Table 4). The fill deposits were all alkaline but with quite
734 low magnetic susceptibility enhancement (Table 3), high calcium carbonate (*ca*. 55-
735 64%) and silt component (*ca*. 60-79%) (Table 3), and moderately enhanced phosphorus
736 values (Table 4). This may reflect activities in the immediate catchment, but is harder
737 to ascribe to *in situ* rather than derived evidence of human activity.

738

739 The Ramla Profile 627 sequence revealed at least four pale grey, calcareous 'soil'
740 horizons alternating with fine to coarse pebbly horizons (Fig. 8; Table 6). The physical
741 and soil micromorphological analyses of these grey 'soil' horizons (at 4-13, 13-15, 26-
742 28 and 60-90cm) indicated that they are composed of relatively organic, very micritic,
743 fine sandy/silty clay loam soil (Table 3) with greater/lesser amounts of included very
744 fine limestone gravel. They exhibit evident bioturbation and some weak secondary ped
745 formation. There were minor amounts of silt and clay, very fine charcoal and organic
746 matter fragments present, and the occasional silt or silty clay crust (Fig. 9c). There was
747 also the very occasional void infill or aggregate of a very fine sandy clay loam with a
748 reticulate striated silty clay component reminiscent of argillic (or Bt) horizon material
749 (Fig. 9d), incorporated in this profile. The lowermost horizon (627/3; 100-140cm) is a

750 dense but aggregated, calcitic, shelly sand with indications of fine laminations is
751 situated directly on the Globigerina Limestone bedrock. The laminar aspect of this
752 profile suggests the stop/start aspect of its accumulation, with the coarse limestone
753 rubble units (at least three) indicative of episodic phases of alluvial fan type of
754 deposition, and the finer units inbetween indicative of fine soil erosion from the
755 catchment and overbank deposition in the valley bottom (Goldberg and Macphail,
756 2006, 77ff).

757

758 **6. Discussion** (Table 7)

759

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

784 reaches with combinations of eroded coarse to fine hillwash material derived from the

785 soils and geology upslope over depths of *ca*. 2-4m.

786

787 As a consequence of the combined archaeological, chronological, geoarchaeological

788 and micromorphological studies conducted as part of the *FRAGSUS* project, the

789 interpretation of the relationship between soils and the prehistoric landscape must now

790 take into account the new evidence of former well-developed soils that have survived

791 in well-defined locations associated with several Neolithic temples on Gozo. These well

792 developed soils of the past were not in the distant gaze of the major monuments, but

793 directly associated with and adjacent to those monuments.

794

795 This new evidence is derived from the completely different 'brown to red'

796 Mediterranean transitional soil type uncovered at Santa Verna in a pre-3800 cal BC

797 context. This buried soil at Santa Verna is thick (up to 65cm) and exhibited much better

798 development and horizon characteristics than any found elsewhere on the Xagħra

799 plateau and in the associated valley systems. It is also much better preserved than is the

800 case at the nearby temple site of Ġgantija, and much less affected by the secondary

801 formation of micritic calcium carbonate. Two horizons are visible, a more reddish to

802 purply brown lower horizon and a slightly browner but still reddish brown upper

803 horizon. This palaeosol or red brown Mediterranean soil (or Orthic Luvisol or Ultisol)

804 was probably formed under a well vegetated and moister pedo-climatic regime in the

805 earlier Holocene (Fedoroff, 1997; Yaalon, 1997). It is characterised first by the

806 weathering of the limestone substrate and then by clay illuviation down-profile creating

807 a clay enriched lower Bt or argillic horizon. In all the buried soil profiles there is also a

808 considerable component of aeolian dust, contributing to the ubiquitously high silt

809 component of these soils, a feature that is widespread across the Mediterranean region

810 (Yaalon and Ganor, 1973). Strong reddening or rubefication of the Xagħra palaeosols

811 probably occurred hand-in-hand with the process of clay illuviation (Fedoroff, 1997;

812 Yaalon, 1997) and rapid bio-degradation of organic material, as well as increasing

813 calcification with time. These latter processes are probably associated with the removal

814 and disturbance of the vegetative cover and a marked, lengthy dry season (Goldberg

815 and Macphail, 2006, 70; Gvirtzman and Wieder, 2001; Yaalon, 1997). It is the very

816 eroded, disturbed and highly weathered thin base of this type of soil which is now

817 commonly found on and around the margins of the limestone plateaux of Gozo, such

818 as at Xagħra.

819

820 Where it survives the pellety crumb or bioturbated/excremental structure of the buried

821 upper soil horizon is indicative of a mollic or mull humic horizon (Gerasimova and

822 Lebedeva-Verba, 2010, 354; Goldberg and Macphail, 2006, 65). In addition, the upper

823 parts of all the buried soil profiles analysed contained significantly enhanced

824 phosphorus values and abundant micro-charcoal. Both inside and outside the Santa

825 Verna temple, the transition from this lower A horizon to the B horizon is marked by a

826 very mixed fabric of pellety/aggregated silty clay and varying admixtures of micritic

827 calcium carbonate, which can more or less predominate. This is essentially acting as a

828 depleted and oxidised, calcium carbonate dominated eluvial Eb horizon. Below this,

829 and especially in the Ashby and Trump Sondages within the interior of the temple, there

830 is *ca*. 20-40cm of a clay-enriched Bt horizon present. This is primarily composed of a

831 silty clay with pure to slightly dusty clays evident and greater/lesser degrees of striation

832 and micro-lamination, and a small blocky to columnar ped structure. This is indicative

833 of a stable, well drained and organised, illuvial, clay-enriched or argillic Bt horizon

834 (Bullock and Murphy, 1979; Fedoroff, 1968, 1997; Kuhn et al., 2010, 233ff). This type

835 of clay-enriched, argillic brown soil no longer appears to exist elsewhere in present day

836 Malta and Gozo.

837

838 The buried soils discovered to either side of the present-day platform on the southern

839 and eastern sides of Ġgantija temple dated to pre-*ca*. 2500 cal BC revealed another

840 variation in the soil story on the Xagħra plateau (Figs. 4 and 5; Table 2). These soils

841 exhibit clear signs of fines (of silt and clay) illuviation and depletion, abundant

842 secondary formation of calcium carbonate and to a lesser extent reddening with iron

843 oxides/hydroxides. This suggests that these soils also formed initially under more

844 moist, better vegetated and organic, nutrient-rich conditions, unlike the present day

845 pedo-climatic regime of dry Mediterranean with rapid bio-degradation, seasonal rains

846 and a marked and lengthy dry season (Fedoroff, 1997; Yaalon, 1997). This evidence

847 suggests that there had also been a clay-enriched earlier Holocene soil developed at

848 Ġgantija similar to that which was observed beneath the nearby Santa Verna temple,

849 but it had already undergone more sustained anthropogenic influence and disturbance

850 in terms of opening up its vegetated surface, and consequently greater humification and

851   evapo-transpiration processes. Both these Ġgantija profiles appear to be a 'half-way'

852   soil-type in development terms between a brown and a red Mediterranean soil, with the

853   Ġgantija soil formation sequence more altered as a result of a longer period of

854   continuing human use and disturbance, in contrast to the Santa Verna palaeosol which

855   was buried about 1000-1300 years earlier.

856

857   Thus the former presence of a well developed brown Mediterranean soil with a thick

858   clay-enriched argillic Bt horizon present at both temple sites prior to the 4th millennium

859   BC on the Coralline Limestone of the Xagħra plateau is therefore of great significance.

860   Importantly OSL determinations at Ġgantija temple suggests that this soil was forming

861   from at least the earlier Holocene. A similar soil type was also present in a very thick

862   exposure (up to 80cm) near the base of a 10m sediment core extracted from the Xemxija

863   basin in northern Malta, dated from *ca*. 7500-7200 cal BC (8334+/-46 BP; UBA-29347)

864   at its base by AMS radiocarbon assay (Table 2). Thus it is possible that similar brown,

865   clay-enriched or argillic soils were once more widespread in the Maltese Islands, and

866   indeed the wider Mediterranean region (Yaalon, 1997). Moreover, these soils with their

867   distinctive argillic horizons most probably developed under conditions of slightly

868   greater moisture and vegetative cover in the earlier Holocene (Fedoroff, 1997; Yaalon,

869   1997). These soils then probably underwent processes of organic depletion, physical

870   mixing, weathering and erosion down-slope when farming was introduced from the 6th

871   millennium BC, with subsequent intensification of these processes coupled with

872   aridification from the earlier 4th millennium BC onwards.

873

874   In addition at both sites, there was the remarkable incorporation of abundant fine

875   midden-like materials into and on top of the buried soil, especially at Ġgantija and to a

876   lesser extent at Santa Verna. These particularly included later Neolithic Tarxien-period

877   pottery, humified organic matter, and fine fragments of charcoal and animal bone. The

878   very high phosphorus and relatively high strontium values may also suggest the

879   addition of organic refuse to these soils. These features of probable soil management

880   and amendment would have enhanced soil fertility and stability. This finding gives an

881   important insight into how the people who lived in Gozo during the later Neolithic

882   period managed to sustain their rich and complex lifeways – as abundantly

883   demonstrated by the elaborate traditions of burial and art in the nearby and

884   contemporary Brochtorff Xagħra Circle (Malone et al., 2009).

885

886 Current and previous palynological studies of sediment cores taken from Malta and

887 Gozo suggest that woodland was either absent or relatively sparse and scrubby for much

888 of the prehistoric period with only some relicts of the natural early Holocene southern

889 Mediterranean pine/juniper scrubland present (Carroll et al., 2012) (Table 7). But by

890 the time that the Santa Verna temple was being built in the early 4th millennium BC,

891 these trees and scrub were fast disappearing and soils were being cultivated for wheat

892 and barley as early as *ca*. 5700 cal BC (M. Farrell, L. Coyle-McClung and C.O. Hunt,

893 pers. comms.). This evidence serves to corroborate the story of the pre-temple buried

894 soils at both Santa Verna and Ġgantija, which exhibit characteristics of a process of

895 permanent changes to the environment – a moist, scrubby landscape changing to a

896 managed agricultural landscape associated with mainly dry, open and erosive soil

897 conditions.

898

899 The human exploitation of these transitional brown to red soils during the Late

900 Neolithic period was followed by drier climatic conditions probably from the late 3rd

901 millennium and certainly from the 2nd millennium BC onwards (Carroll et al., 2012;

902 Magny et al., 2011; Morris, 2002; Sadori et al., 2013). It is the xeric moisture regime

903 of strong seasonal winter/summer rainfall contrasting with winter rainfall in excess of

904 evapotranspiration versus a lengthy period of the drying out of the root zone in the soil

905 over the summer months which defines the climatic constraints on soil formation in

906 Malta and elsewhere in the Mediterranean region (Yaalon, 1997). In combination with

907 human use of the mesa plateau and the coincident removal of vegetation, there were the

908 associated processes of soil moisture loss, de-stabilisation and humic and fines

909 depletion. Consequently, a number of significant secondary soil processes then took

910 precedence, predominantly the biodegradation of the humic components and the

911 common formation of silt-sized calcium carbonate, as well as clay and iron movement

912 and their redeposition down-profile leading to strong soil reddening. These combined

913 processes resulted in the development of thin, organic depleted, highly iron

914 impregnated xeric soils which were becoming increasingly dominated by secondary

915 calcium carbonate formation (Aguilar, 1983). These secondary processes changed the

916 earlier Holocene soil type and moisture-vegetation balance once and for all. In addition,

917 recent palynological work on Malta suggests coincident disruption of the landscape as

918 marked by a gradual decline in the scrub and tree vegetation, which became more

919 pronounced from *ca*. 4000 BC on and especially from *ca*. 2300 cal BC, and perhaps
920 even the relative 'abandonment' of arable agriculture in the late 3rd millennium BC
921 with an associated greater emphasis on pastoral activities (Carroll et al., 2012; Djamali
922 et al., 2013).

923

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

937

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

953   throughout later prehistoric times from at least *ca*. 2198-1985 cal BC (3704+/-29 BP;

954   UBA-28265) (Table 2).

955

956   From the wider geoarchaeological survey of the Gozitan valleys conducted by the

957   *FRAGSUS* project, most valley slope hillwash deposits on the Blue Clay geology are

958   slight and the thick valley fill aggradational deposits on limestone geology tend to

959   concentrate in the terrace systems and valley bases or just inland from the coast. This

960   implies that the slopes of the valleys on Blue Clay geology were relatively quite stable

961   with calcitic vertisols (Lang, 1960; Vella, 2003). The intractability of these clay and

962   silt dominated soils meant that they were best avoided for arable agriculture until the

963   arrival of metal-shod, mould-board ploughs, which did not occur until the Roman

964   period (Margaritis and Jones, 2008). Consequently, it is suggested that the Blue Clay

965   slope areas are more likely to have remained as scrub woodland and/or natural

966   grassland for limited grazing for most of prehistoric times. There are also numerous

967   springs emanating from the upper and lower contacts of the clay with the limestone

968   geology which would have provided natural water sources and wet areas for reed and

969   sedge growth (as they still do today), all suitable as roofing, building and clothing

970   materials for example. Thus, the exploitation of the Blue Clay valley landscapes may

971   have been relatively limited and/or in some balance (Carroll et al., 2012), contrasting

972   with the limestone catchment valleys which were more erosion prone with much thicker

973   hillwash accumulations, now extensively terraced, with an unknown volume of eroded

974   soil potentially washed out to sea in high rainfall events (Mayes, 2001).

975

976   Major landscape modifications of the some valleys on Gozo appear to have occurred

977   from the later medieval period onwards. For example, the Blue Clay slopes of the

978   Ramla valley become more systematically exploited in the mid-16th century by the

979   crusader Order of St John and again in the mid-19th century with two sets of

980   superimposed systems of field boundaries and sinuous ownership boundaries located

981   on the slopes (Alberti et al., 2017; Blouet, 1997; Carroll et al., 2012; Grima, 2008;

982   Wettinger, 2011) (Fig. 11). This extensification and intensification of landscape

983   development may well have been associated with pressure on land to enable more

984   sustainable arable agriculture to support the island population, but was also dependent

985   on the use of better plough machinery and importantly reliable water sources from the

986   natural spring lines in each valley.

988   Since the 1960s, there has been continuing transformation of the Gozitan landscape

989   with widespread clearance and uptake of arable land in the valleys and slope areas and

990   expanding town-scapes on the limestone plateau (Vella, 2003). There has been soil

991   removal and re-deposition on the plateaux as well as deliberate amendment of the thin

992   red soils around the mesa margins using silty clay soil taken from the mid-/upper slope

993   areas of the Blue Clay geology. For example, this occurred in the olive grove fields on

994   the eastern side of Ġgantija temple in 1961 and 1985. At the same time, the mesa

995   plateaux have become more and more occupied by urban development, especially since

996   the 1980s, perhaps as a corollary of the poor state of soil development and survival.

997   Today, although the landscape is relatively stable, heavy rainfall events still cause

998   intensive periods of surface water flooding and soil run-off into the sea.

999

7. Conclusions

1001

1002   Geoarchaeological fieldwork and a suite of physical, multi-element and

1003   micromorphologocal analyses focusing on the Neolithic temple sites located on the

1004   Xagħra plateau and the associated Marsalforn and Ramla valleys on the island of Gozo

1005   have suggested a new model of soil development for the early-mid-Holocene. Thick,

1006   moist, well-developed and vegetated argillic brown soils (or orthic luvisols) with a

1007   considerable wind-blown silt component existed on the Coralline Limestone plateau

1008   areas of the island from at least the 9th-5th millennia BC that subsequently underwent

1009   major soil change. The palaeosol records revealed in the micromorphological analyses

1010   clearly show the combined effects of the impact of Neolithic farming communities on

1011   the soil/landscape system from at least the early 4th millennium BC and increasingly

1012   over time the seasonally very dry climatic regime. The well developed brown soils then

1013   gradually changed to thinner, drier and more calcitic red Mediterranean soils (or

1014   chromic luvisols), equating with Lang's (1960) 'terra soils' and 'xerorendzinas'.

1015   Despite this type of soil's naturally low base status, associated with rapid

1016   biodegradation of the near surface organic matter, a degree of agricultural productivity

1017   may well have been maintained though the enhancement of the soil's organic content

1018   with the deposition of household derived organic and artefactual waste. This significant

1019   soil management feature appears to have had its beginnings in the mid-later 3rd

1020   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

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