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

3
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12
13
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 Xaghra 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 Xaghra 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

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41 **1. Introduction**

42

43 Soil degradation and erosion in the islands of Malta and Gozo is regularly observed as
44 a compelling and prevalent problem today and one that possibly has its origins in earlier
45 prehistoric times (Blouet, 1997; Grima, 2004, 2008; Lang, 1960; Malone et al., 2009;
46 Vella, 2003). Moreover, these islands appear to share many of the same soil
47 characteristics and history of a continual struggle against aridification, dewatering and
48 the intensification of agriculture associated with the creation of extensive terraced
49 landscapes, just as occurred in many other parts of the southern Mediterranean area
50 (Brandt and Thornes, 1996; Carroll et al., 2012; Sadori et al., 2013). As a corollary the
51 development of the typical red Mediterranean soils or *terra rosa* on limestone substrates
52 of this region (Bridges 1978; Kemp, 1986; Lang, 1960; van Andel et al., 1990; Yaalon,
53 1997) will also be investigated.

54

55 The geoarchaeological and palaeosol study reported on in this paper formed part of the
56 ERC-funded *FRAGSUS* project (*Fragility and sustainability in restricted island*
57 *environments: adaptation, cultural change and collapse in prehistory*) which is
58 investigating fragility and sustainability in the Maltese islands during the fourth and
59 third millennia BC under the direction of Professor Caroline Malone (Queen's
60 University, Belfast) (www.qub.ac.uk/sites/FRAGSUS/). This enabled a new
61 opportunity to elucidate the Holocene soil history of the island of Gozo and its
62 associations with prehistoric land-use, especially the impacts of the first Neolithic
63 farmers, and provide new land-use data with which to compare to other long-term
64 records of soil processes and development in the southern Mediterranean region.
65 Geoarchaeological survey, test excavations and soil sampling, and new radiocarbon and
66 optically stimulated luminescence (OSL) dating all concentrated on the history of soil
67 development of the Upper Coralline Limestone plateau of Xagħra and the associated
68 Ramla and Marsalforn valleys in north-central Gozo (Fig. 1). In particular, new buried
69 soil data has emerged from recent archaeological investigations of two Neolithic
70 'temple' sites, Santa Verna (Fig. 2) and Ġgantija (Fig. 4), as well as from several
71 construction sites in the modern town of Xagħra on the same plateau and associated
72 hand augering surveys around these sites and across the Ramla and Marsalforn valleys
73 (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**

78

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 CO₂ content lost from CaCO₃ 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, 10cm³ 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 Xaghra 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

176 on the Upper Coralline Limestone plateau around the temple (13 boreholes) revealed
177 less than 50cm of reddish brown, fine sandy silt loam topsoil to the north of the temple,
178 present in small-holder arable fields. To the south, this was even thinner with
179 increasingly extensive patches of bare rock with open scrub pasture, mainly used for
180 bird hunting today. East of the temple and dipping into the Weid Gunen Inrik valley,
181 the soil profiles in the auger survey deepened quickly to as much as 100cm with some
182 B horizon survival consisting of a well-structured, reddish brown silt loam to silty clay
183 loam, before thinning again eastwards to *ca.* 10-45cm of modern ploughsoil, the area
184 all being used for small-holder arable fields today.

185

186 Previous archaeological work reported by Ashby et al. (1913) and Trump (1966) at
187 Santa Verna revealed *in situ* buried soils sealed beneath a series of temple floors and
188 other deposits, although they were not studied using any archaeological science
189 techniques. These strata were radiocarbon dated for the first time as part of the 2015
190 excavation, demonstrating that the megalithic ‘temple’ structure is among the earliest
191 stone monuments found in the central Mediterranean, its construction beginning in the
192 early 4th millennium BC, perhaps prior to the construction of the nearby well-known
193 Ġgantija temple (Table 2). The megalithic structure was significantly later at about
194 3800 cal BC than the *in situ* soils, which were associated with the earliest phase of
195 agriculture in Gozo/Malta in the mid-late 6th millennium BC, according to three
196 radiocarbon dates on charred plant remains (5500 to 5320 cal BC, UBA-31042,
197 6412±44BP; 5290 to 5000 cal BC, UBA-31043, 6181±40BP; 5300 to 5070 cal BC,
198 UBA-31044, 6239±37BP; all at 2-sigma) (T.R. McClaughlin, pers. comm.). The
199 sequence of temple construction was particularly well exemplified in Trench E, as well
200 as in the re-excavated sondages of Ashby and Trump (Fig. 3). The base of the Ashby
201 Sondage revealed a well preserved, *ca.* 45cm thick palaeosol. This was comprised of a
202 *ca.* 15cm thick organic Ah silt loam horizon over a reddish brown silt loam B horizon
203 of about 30cm in thickness. A similar occurrence was also revealed in the Trump Cut
204 55 about 3m to the north and in the trial trench (B) which was cut some 30m to the
205 northeast of the temple site. All four of these buried soil profile exposures were sampled
206 for soil micromorphological analysis, physical characterisation and multi-element
207 analyses (Tables 3 and 4).

208

209 *4.3 Ġgantija temple and surroundings*

210

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

219

220 Ġgantija temple is much better-preserved above ground than Santa Verna and
221 comprises two adjoining five-roomed apsidal buildings made from massive Coralline
222 Limestone blocks, beginning about 3700 BC and re-worked through various phases to
223 about 2350 BC (Evans 1971; T.R. McClaughlin, pers. comm.) (Fig. 4; Table 2). The
224 temple sits upon level ground, which has in recent years been further built-up and
225 retained by a stone wall. Augering survey around the southern fringe of the site just
226 outside this retaining platform wall (Fig. 1) mainly produced thin soils with no signs of
227 buried soils or deep agricultural terrace fills, except in one location. This was a small
228 walled triangular field in the southwestern corner of the Ġgantija platform, where a well
229 preserved buried soil was found about 50-70cm beneath the modern ground surface. In
230 2014 and 2015 there was the opportunity to excavate sizable test pits on either side of
231 the present day platform: one to the southwest (TP1), and a larger unit to the southeast,
232 where a former shop and more recently a WC building for visitors to the site had been
233 recently demolished (WC Trench) (Figs. 4 and 5). Both trenches were excavated to the
234 upper surface of the Upper Coralline Limestone bedrock.

235

236 Test Pit 1 on the southern side of the temple revealed two large, upright, sub-rectangular
237 limestone blocks which may be *in situ* and several more smaller blocks just below the
238 ploughsoil surface which may be part of temple collapse (Figs. 4 and 5). Beneath, there
239 was *ca.* 80cm of heavily rooted, greyish brown silt loam with a mixture of limestone
240 gravel pebbles and abundant artefacts. This horizon is indicative of an agricultural
241 terrace soil but which contains artefactual material contemporary with the later
242 Neolithic use of the temple (C. Malone, pers. comm.). The base of this terrace soil gave
243 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

312 *ca.* 50-60cm. As the valley opens out and shallows towards the sea to the north, flat
313 lower plateau tongues of land emerge on Globigerina Limestone. These have a very
314 characteristic calcitic, fine sandy/silt loam soil developed on them, almost like a loessic
315 soil, generally <50-60cm in thickness. This area is dominated by terrace agriculture and
316 spring-heads and modern ponds, with historical evidence to suggest that the terrace
317 field system has been in existence since at least the mid-16th century AD (Blouet, 1963;
318 Wettinger, 1981, 2011).

319

320 To the west in the Marsalforn valley, there were ubiquitous terraces, regularly
321 composed of thick (1-4m) silty clay hillwash accumulations, often with hints of
322 possible standstill horizons present. An erosion cut profile in the middle Marsalforn
323 valley, opposite Ta'Manea in Weid ir-Rigu (Profile 627; N 36 03.472/ E 014 14.946)
324 was cut back and sampled for physical, multi-element and micromorphological
325 analyses and OSL profiling/dating (Fig. 9). This profile comprised *ca.* 3.7m of rubbly
326 fine sandy/silt loam which was interrupted by two incipient buried soil horizons at *ca.*
327 1.75-2.10 and 2.70-2.85m down-profile. A series of 10 small bulk samples were taken
328 for OSL profiling from 1.75-3.25m, and three OSL tube samples at 1.75, 2.65 and 3.2m
329 down-profile. OSL profiling suggested that this profile represented an age-related
330 gradual accumulation of hillwash-type sediment (Cresswell et al., 2017). OSL dating
331 suggests that this profile was aggrading from about 1500 BC throughout later
332 prehistoric times (Table 2; 3.58+/-0.24 to 2.78+/-0.92 years/ka).

333

334 To the southeast-northeast in the Ramla valley, an erosion cut profile in the lower
335 Ramla valley about 200m inland from Ramla Bay (Profile 627; N 36 03.442/E 014
336 17.045) was cut back and sampled for physical, soil micromorphological and multi-
337 element analyses and OSL profiling and dating (Fig. 9). This profile is comprised of a
338 series of alternating horizons of calcitic silt loam and coarse sand/pebble horizons, with
339 the whole profile generally fining upwards, over a depth of *ca.* 1.4m. A series of 11
340 small bulk samples were taken from the finer silt loam horizons and three tubes taken
341 for OSL dating at 15, 62 and 103cm down-profile. The latter sample loci were also
342 sampled for micromorphological analysis. OSL profiling suggested that aggradation
343 had occurred over time with at least two clear breaks, suggesting palaeo-surfaces of
344 some kind at *ca.* 46cm and 115cm, potentially indicative of changes in erosion
345 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

380 Pit 1, as were the calcium (Ca) and strontium values (Sr) (Table 4). Phosphorus values
381 in Test Pit 1 ranged from 2200 ppm at the base of the soil to >10,000 ppm in the upper
382 20cm of this soil. Strontium values were also relatively enhanced ranging from *ca.* 172-
383 380ppm (Table 4). The enhancement of these two elements suggests large additions of
384 organic material and household refuse to the soil (Entwistle et al., 1998; Holliday and
385 Gartner, 2007; Wilson et al., 2008), coincident with the substantial quantities of
386 fragmentary animal bone and Tarxien-period pottery recovered during the excavation.
387 Similarly in the WC Trench, the buried soil and especially the multiple horizons of
388 accumulating soil and archaeological debris above gave very high P values, ranging
389 from 5010 to >10000ppm along with enhanced strontium values (*ca.* 238-322ppm)
390 (Table 4). Likewise the magnetic susceptibility values were either very enhanced or
391 low (Table 3), especially in the horizons dominated by archaeological material that had
392 built-up on the buried soil. This suite of high values probably reflects the amount of
393 organic and fire-related settlement debris contained within these deposits (Allen and
394 Macphail, 1987; Clark, 1996, 109ff; Fassbinder, 2016, 502). Calcium and calcium
395 carbonate values were also very high (Tables 3 and 4), which complements the
396 enhanced phosphorus and strontium values to indicate the strong influence of midden-
397 type refuse and hearth rake-out (Entwistle et al., 1998), but may equally reflect
398 weathering and solution from the overlying limestone blocks of the collapsed temple
399 structure above and the large amounts of secondary calcium carbonate observed in the
400 micromorphological analysis of the buried soils at Ġgantija.

401

402 At Santa Verna, pH values from the buried soils are very alkaline (ranging from 8.5-
403 8.92) and the magnetic susceptibility values were generally low, except for the lower
404 fill of the pit in Trump Cut 55 (sample 3/4) (Table 3). This probably also reflects the
405 amount of organic and fire-related settlement debris contained within this fill deposit.
406 The total organic matter content is a reasonable *ca.* 4.1-6.5% in the buried soils, better
407 than the modern topsoil at *ca.* 3.4% (Table 3). There is a strong calcium carbonate
408 component throughout, ranging from *ca.* 8-64% (Table 3), but this is generally lower
409 than the values observed in the Ġgantija soil sequence, especially in the base of the
410 buried soil. The particle size analysis results indicate that the buried soils tend to be
411 dominated by the silt fraction (*ca.* 46-76%) but with a strong but variable quartz sand
412 component (*ca.* 10-52%), with the clay fraction ranging between *ca.* 5 and 15% (Table
413 3). The higher clay component in the buried soils as compared to those at Ġgantija 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).

452

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.

464

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.

470

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%) micritic 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 ubiquitous 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

616 soil' more suitable for agricultural use (Simpson, 1998; Simpson et al., 2006). This
617 suggests the deliberate creation of a thickened, enhanced soil adjacent to the
618 southwestern part of Ġgantija temple by the mid-2nd millennium BC if not earlier. There
619 is a similar occurrence recorded in the WC Trench, but possibly earlier and of mid-3rd
620 millennium BC date (see below).

621

622 The buried soil (samples 3/3, 3/6, 3/7 and 3/8) exposed in the base of the WC Trench
623 profile on the east side of Ġgantija temple (Figs. 4 and 5) is a pellety to finely
624 aggregated, micritic, fine sandy clay loam (Fig. 6f) with an even mix of fine gravel-
625 sized limestone pebbles (<1.5cm). The groundmass is dominated by interconnected
626 vughs and non-birefringent dusty clay, with moderate staining with iron oxides and
627 hydroxides, and a sizeable silt component. There is also a common presence of very
628 fine organic/charcoal punctuations throughout. Moving up-profile, this soil becomes
629 more humic with increasing amounts of included very fine anthropogenic debris (Fig.
630 6e).

631

632 Immediately above the apparent upper contact of the buried soil there was a *ca.* 4cm
633 thick horizon of calcitic fine sand, then *ca.* 6cm of a calcitic sandy loam soil, then *ca.*
634 4.5cm of calcitic fine sand above, a fine limestone gravel horizon *ca.* 4cm thick
635 (contexts 1004, 1040-42), and finally two overlying thick (*ca.* 45cm) soil horizons
636 (contexts 1016 and 1015) (Fig. 5). All of these horizons contained abundant Tarxien or
637 later Neolithic pottery sherds (Sagona, 2015, 67), and animal bone fragments, as well
638 as up to 20% fine limestone gravel and 10-20% fine organic and charcoal punctuations.
639 This alternating soil/fine gravel repeated sequence is suggestive of a cumulative
640 stop/start build-up of soil with dumped anthropogenic debris interrupted by thin coarser
641 weathered surfaces with possibly some localised rainsplash erosion contributing. It is
642 suggestive of an open, accumulating ground surface, probably associated with the large
643 upright Coralline stones located immediately to the north of this sample sequence.

644

645 Thus the buried soil In the WC Trench is a very bioturbated, organic Ah over a poorly
646 developed weathered, moderately rubified, Bw horizon. This soil has been much
647 affected by soil faunal mixing processes and the ubiquitous formation of secondary
648 calcium carbonate throughout. The ubiquitous silt component also suggests a
649 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 Xaghra 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 Xaghra 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’ scrubby 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 become 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 garrigue 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 horizontal, 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.

987

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

1000 **7. Conclusions**

1001

1002 Geoarchaeological fieldwork and a suite of physical, multi-element and
1003 micromorphological 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

1021 soil enhancement may well have underpinned the viability of later Neolithic
1022 agricultural society in the Maltese Islands.

1023

1024 This new model of soil change in later Neolithic times in Gozo suggests that seminal
1025 models of the setting of monuments now need to be reassessed as we can no longer rely
1026 on modern soil distribution as a guide to the nature of past landscapes. Importantly with
1027 time, the system of prehistoric soil improvement came under inevitable strain. A
1028 combination of devegetation, sustained human use and a wider coincident aridifying
1029 trend led to the formation of either dry, organic poor, red Mediterranean ‘terra rosa’
1030 soils and/or thin, organic-poor, calcitic soils associated with open xeric landscapes. This
1031 set of processes was in-train from the mid-late 3rd millennium BC onwards, probably
1032 making successful arable farming very difficult on the Coralline Limestone plateaux.
1033 Soil erosion in some limestone geology valleys such as Marsalforn was well underway
1034 by the mid-late 2nd millennium BC, equating with strong evidence for a period of
1035 maximum erosion from *ca.* 1350-550 cal BC observed in several deep valley cores
1036 made by the *FRAGSUS* team elsewhere in Malta (www.qub.ac.uk/sites/FRAGSUS/).
1037 It was probably not until the 16th century AD and later that the clay vertisol valley
1038 landscapes witnessed much exploitation for arable agriculture in any intensive way,
1039 leading to later erosion and aggradation in the lower valleys such as the Ramla in more
1040 recent times.

1041

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